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Design Principles High-speed Maglev System (MSB)

Information

Introduction

Technical systems are developed, realised, approved and operated on the basis of generally accepted codes of engineering practice. There is no self-contained body of rules for high-speed maglev systems. We have therefore compiled a set of generally applicable guidelines for a high-speed maglev system that have been derived from development, testing, approval and operation.

Project-neutral design principles have been drafted for high-speed maglev systems and their individual subsystems. The "Eisenbahn-Bundesamt" (EBA - German Federal Railway Authority) proposes to apply this documentation as "engineering rules" in the sense of Section 3 Paragraph 1 of the "Magnetschwebebahn-Bau- und Betriebsordnung" (MbBO - Maglev Construction and Operation Regulations).

Scope

This documentation applies to maglev systems in the Federal Republic of Germany in accordance with the "Allgemeines Magnetschwebebahngesetz" (AMbG - General Maglev System Act).

Structure of the Documentation

Similar to a basic standard, this documentation lays down the generally accepted technical and operational requirements for a high-speed maglev railway system that are project-neutral. These requirements constitute the principles for the design, planning, realisation and operation of high-speed maglev projects. Reference is also made to existing engineering rules that apply to high-speed maglev systems.

The regulations according to DIN 820 have been applied by analogy in the preparation of this documentation. The degree to which the requirements are binding has been defined by reference to DIN 820, Part 2, E, and has been taken into consideration when formulating the individual requirements.

The documentation comprises the MSB design principles listed in the table below.

Complete System

Doc.No.

50630	Complete System (GS)	
67536	GS – Annex 1	Abbreviations and Definitions
67539	GS – Annex 2	Statutes, Regulations, Standards and Directives
67285	GS – Annex 3	Environmental Conditions
69061	GS – Annex 4	Rules for Operation (Train Operation and Maintenance)
72963	GS – Annex 5	Noise

Vehicle

Doc.No.

67698	Vehicle Part I	General Requirements
67694	Vehicle Part II	Design
67650	Vehicle Part III	Kinematic Gauge
73388	Vehicle Part IV	Levitation/Guidance System
73389	Vehicle Part V	Brake System

Drive and energy supply

Doc.No.

50998	Drive and energy supply

Operation Control System

Doc.No.

53328	Operation Control System

Guideway

Doc.No.		
57284	Guideway Part I	Primary Requirements
57288	Guideway Part II	Design
41727	Guideway Part III	Geometry
60640	Guideway Part IV	Alignment
60641	Guideway Part V	Surveying
63842	Guideway Part VI	Maintenance

Table: MSB Design Principles

Copyright

Status of the Procedure

The acceptance of the documentation by the various individual Technical Committees on 15.02.2007 completes the process of national agreement.

Procedure for the Provision of Information pursuant to Directive 98/34/EC

The requirements of Directive 98/34 are complied with on completion of the process of national agreement.

Publication by the Federal Railway Authority

The Federal Railway Authority publishes the documentation in its capacity as management of the high-speed maglev system technical committees. The technical committees alone are responsible for the content of the documentation.

Equivalence Clause

Vehicles and operating plant from other Member States of the European Community or Turkey or from an EFTA State that is a party to the EEA Agreement are also permitted provided the same level of traffic safety as contained in the high-speed maglev system design principles is guaranteed.

Note

The obligations laid down in Directive 98/34/EC of the European Parliament and of the Council of 22 June 1998 laying down a procedure for the provision of information in the field of technical standards and regulations and of rules on Information Society services (OJ L 204 Page 37), as amended by Directive 98/48/EC of the European Parliament and of the Council of 20 July 1998 (OJ L 217 Page 18), have been complied with.

Revision status of the complete document

Revised 20.06.2007

High-speed Maglev System Design Principles Complete System

Distribution

This document has been released for publication by the Technical Committee "Complete System".

Change history

Release date: 15.02.2007; white paper, Technical Committee "Complete System"

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General

Purpose of the document, scope

This documents lays down the technical and operational minimum requirements for a high-speed maglev rail system (MSB system) that are project-neutral. These requirements constitute the basis for the design, planning, realisation and operation of high-speed maglev projects. Reference is also made to existing standards and directives that apply to high-speed maglev systems.
These design principles apply to a high-speed maglev system according to the General Maglev System Act /AMbG/.

High-speed Maglev System Design Principles

This document forms part of a documentation for high-speed maglev systems consisting of multiple design principles. The document tree is shown in Figure 1. These high-level "complete system" design principles and their annexes apply uniformly for the whole documentation.
The documentation consists of the existing

- High-speed Maglev System Design Principles Complete System, Doc. No.: 50630, /MSB AG-GESAMTSYS/, with annexes:
  - Annex 1: Abbreviations and Definitions, Doc. No.: 67536, /MSB AG-ABK&DEF/
  - Annex 2: Statutes, Regulations, Standards and Directives, Doc. No.: 67539, /MSB AG-NORM&RILI/
  - Annex 3: Environmental Conditions, Doc. No.: 67285, /MSB AG-UMWELT/
  - Annex 4: Rules for Operation (Train Operation and Maintenance), Doc. No.: 69061, /MSB AG-BTR/
  - Annex 5: Noise, Doc. No.: 72963, /MSB AG-SCHALL/

as well as the jointly applicable low-level documents:

- High-speed Maglev System Design Principles Vehicle, Part I: General Requirements, Doc. No.: 67698, /MSB AG-FZ GEN/
- High-speed Maglev System Design Principles Vehicle, Part II: Dimensioning, Doc. No.: 67694, /MSB AG-FZ BEM/
- High-speed Maglev System Design Principles Vehicle, Part III: Kinematic Gauge, Doc. No.: 67650, /MSB AG-FZ KIN/

- High-speed Maglev System Design Principles Vehicle, Part IV: Support/Guidance System, Doc. No.: 73388, /MSB AG-FZ TRAFÜ/
- High-speed Maglev System Design Principles Vehicle, Part V: Brake System, Doc. No.: 73389, /MSB AG-FZ BREMS/
- High-speed Maglev System Design Principles Drive and Power Supply, Doc. No.: 50998, /MSB AG-ANT/
- High-speed Maglev System Design Principles Operation Control System, Doc. No.: 53328, /MSB AG-BLT/
- High-speed Maglev System Design Principles Guideway, Part I: High-level Requirements, Doc No.: 57284, /MSB AG-FW ÜBG/
- High-speed Maglev System Design Principles Guideway, Part II: Dimensioning, Doc. No.: 57288, /MSB AG-FW BEM/
- High-speed Maglev System Design Principles Guideway, Part III: Geometry, Doc. No.: 41727, /MSB AG-FW GEO/
- High-speed Maglev System Design Principles Guideway, Part IV: Track Alignment, Doc. No.: 60640, /MSB AG-FW TRAS/
- High-speed Maglev System Design Principles Guideway, Part V: Surveying, Doc. No.: 60641, /MSB AG-FW VERM/
- High-speed Maglev System Design Principles Guideway, Part VI: Maintenance, Doc. No.: 63842, /MSB AG-FW IH/

Abbreviations and definitions

The abbreviations and definitions given in /MSB AG-ABK&DEF/ apply.

Statutes, regulations, standards and directives

The normative documents listed in /MSB AG-NORM&RILI/ contain requirements that form part of the High-speed Maglev System Design Principles by cross reference in the High-speed Maglev System Design Principles. Where normative documents in /MSB AG-NORM&RILI/ are dated, subsequent changes or revisions of these publications do not apply. With undated references, the latest version of the normative document that is referred to applies.
The version of the standards and directives to be observed in an MSB project must be decided bindingly on a project-specific basis.

Identification and binding value of requirements

The requirements of /DIN 820/ were essentially applied in the preparation of this document.

In the following chapters and the annexes of this document

- Requirements are shown in normal font
- Explanations, guide values and examples are shown in *italics*

The degree to which the requirements are binding has been defined by reference to /DIN 820/, Part 2, Annex G, and has been taken into consideration when formulating the individual requirements.

System Characteristics

The coordinate system, direction of travel and assignment between reference points, phase windings and exciter poles are shown in Figure 3*,* Figure 4 *and* Figure 5.

Function

The high-speed maglev system must be constructed as a track-guided transport system for passenger and/or goods traffic, and must have the following characteristics:

- Noncontact support/guidance function by controlled electromagnets (electromagnetic levitation technology, EMS), Chapter 0,
- Noncontact drive and brake function by synchronous long-stator linear drive, transformation of the controlled traction power at stationary plants, Chapter 0,
- Noncontact on-board energy supply of the MSB vehicles above a project-specifically defined speed at which the on-board power demand is fully covered, Chapter 0,
- Fully technically and automatically controlled train operation, Chapter 0,
- Guideway elevated or at grade, Chapter 0.

The geometry of the guideway and the geometry of the devices that support and guide the vehicles must be harmonised with one another such that track guidance is guaranteed at the respective permitted speeds and with the alignment parameters, even when utilising the permissible tolerances of the components.
The forces that occur at the interface between the guideway and the devices for supporting, guiding, driving and braking in the vehicles, must be safely absorbed and transmitted, including in case of failure.

Transport

Speed

The vehicle maximum speed, guideway maximum speed and tunnel maximum speed must be defined project-specifically. (see Chapter 0).
Typical values for vehicle and guideway maximum speeds:

- *long-haul traffic 400-500 km/h*
- *airport link 300-400 km/h.*

The journey maximum speed must be derived from the vehicle maximum speed, the guideway maximum speed and the tunnel maximum speed.
The design of the MSB vehicle must be based on the vehicle maximum speed.
The design of the guideway must be based on the guideway maximum speed.
The technical maximum speed can be defined project-specifically.

Journeys in the speed range above the journey maximum speed and up to the technical maximum speed may be carried out using reserves in dimensioning only after testing and approval in each separate case.
During the design stage, the site-dependent nominal speed that is required for train operations shall be calculated having regard to operational and economic aspects, and realised by the system configuration.
For the definitions and relationships of the speed relative to each other, see also /MSB AG-ABK&DEF/, Chapter 5.

Acceleration

Section 13, (5) /MbBO/ must be taken into consideration.
This requirement is met as follows:
The start-up and brake-related acceleration of a vehicle must not exceed 1.5 m/s².
Exceptional influences shall be allowed for according to the requirements of Chapter 0.
The mean and maximum drive acceleration should be defined project-specifically and according to site, and having regard to operational and economic aspects.
The operationally usable brake retardation is limited by the braking capacity of the Safe Brake, by the train resistance and by the maximum running profile monitored by the OCS.
For requirements relating to acceleration in the y and z direction, see Chapter 0.

Track alignment

Section 13, (1) and Section 13, (7) /MbBO/ must be taken into consideration.

Alignment data

Section 13, (2); Section 13, (3); Section 13, (4) und Section 13, (6) /MbBO/ must be taken into consideration.
The following values should also be adhered to:

	Values	**Criterion**
Platform area		**Scheduled stop**
Transverse inclination *	≤ 3.0 °	Wheelchair users, risk of falling when boarding and alighting
Linear inclination	≤ 5 ‰	
Service stopping place for operational stopping		**Unscheduled stop**, e.g. in case of operational or technical faults
Transverse inclination	≤ 6 °	Wheelchair users, risk of falling
Linear inclination	≤ 100 ‰ according to proof of the holding function	Holding function
Other service stops		**Unscheduled infrequent stop**, essentially for technical faults
Transverse inclination	≤ 12°	
Linear inclination	≤ 100 ‰ according to proof of the holding function	Holding function
Evacuation stops		**Unscheduled infrequent stop**, in emergencies
Transverse inclination **)	≤ 6 °	Possibility of evacuation
Linear inclination **)	≤ 5 ‰	
Open stretch, outside stops		**Unscheduled stop in exceptional and very rare failure situations**
Transverse inclination	≤ 12 ° up to 16 ° in special cases	Usability for alignment
Linear inclination	≤ 100 ‰	Usability for alignment

**) /MbBO/ Section 13 (3) limits the permissible transverse inclination in the stationary train in the platform area to 3.4 °. The max. permitted transverse inclination of 3.0 ° for the alignment is derived from this.*
***) Figures apply to the platform or walkway area within evacuation stops; the figures for other service stop apply outside these areas*

Table 1: Alignment data for maglev stops

Characteristic	Area	Criterion for maximum value
Warping	≤ 0.10°/m, in special cases up to 0.15°/m *)	Kinematics of the MSB vehicle
Lateral and vertical jerk		
• basically	≤ 0.5 m/s³	Comfort
• as an exception e.g. in station proximity	≤ 1 m/s³	Comfort
• on points at junction	≤ 2 m/s³	Comfort
Omnidirectional jerk (not at points)	≤ 1 m/s³	Comfort

*) Transverse inclination > 12 ° and warping > 0.10 °/m only at constraints of the alignment after testing and approval in each case.

Table 2: General alignment data

The following values must also be adhered to as minimum radius in cases where horizontal radii and vertical radii are superimposed:

$$\frac{1}{R_{x,z}} = \left| \frac{\cos\alpha}{R_V} - \frac{\sin\alpha * \cos^2\beta}{R_H} \right|$$

β Linear inclination, positive on an incline, negative on a decline
α Transverse inclination, positive on a right-hand bend, negative on a left-hand bend (in the direction of ascending kilometre markers)
R_H Horizontal radius
R_V Vertical radius, positive on a crown, negative in a trough

α' [°/m]	0	0,01	0,02	0,03	0,04	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,12	0,13	0,14	0,15
$R_{x,z\ min}$ [m]	530	550	590	630	670	710	770	830	900	990	1.100	1.230	1.410	1.640	1.950	2.430

Table 3: Dependence $R_{xz\ min}$ on warping α'

Allowing for the $R_{x,z}$ criterion there is a minimum vertical radius R_{Vmin} with transverse inclination α of the guideway and horizontal radius R_H according to the following table:

R_{Vmin} [m] when	R_H=350	R_H=400	R_H=500	R_H=600	R_H=700	R_H=800	R_H=1.000	R_H=2.000
α = 0°	±1300	±1020	±780	±670	±620	±580	±530	±530
α = 4°	-1760/ 1040	-1230/ 860	-870/ 700	-730/ 620	-650/ 580	-610/ 550	-550/ 530	-540/ 530
α = 8°	-2590/ 840	-1530/ 740	-970/ 630	-780/ 580	-690/ 530	-630/ 530	-570/ 530	-550/ 530
α = 12°	-4710/ 700	-1980/ 640	-1090/ 570	-840/ 530	-720/ 530	-660/ 530	-580/ 530	-550/ 530
α = 16°(*)	-21900/ 600	-2740/ 560	-1230/ 530	-900/ 530	-760/ 530	-680/ 530	-590/ 530	-550/ 530

(*) Approval by the responsible supervisory authority is required in individual cases

Table 4: Overview of minimum vertical radii R_{Vmin} and horizontal radii R_H

Transitional bends must be constructed as follows in sectors for passenger traffic:

- horizontal: sinusoids
- points in junction position: clothoids (approximately)

In sectors with no passenger traffic, other transitional bends can be defined, e.g. for points in maintenance plants.

- vertical: clothoids

Requirements for low-frequency acceleration changes through a succession of alignment elements are contained in /MSB AG-FW TRAS/.

The requirements of the long stator linear drive in regard to the length in the three-dimensional curve must be taken into consideration when aligning the route and defining the support intervals.

Requirements of the synchronous long stator linear drive are determined, for example, by the pole centres.

The coordinate system and sub-sectors of the alignment, as well as the spatial layout of the long stator winding, are shown schematically in Fig. 4 and Fig. 5.

The alignment requirements are detailed further in /MSB AG-FW TRAS/. The sequence of alignment elements (curves, crowns, troughs) is described.

Dimensioning limiting accelerations

The free lateral acceleration (lateral to the guideway table) must not exceed the following values:

- Standard guideway 1.5 m/s²
- Points 2.0 m/s².

The free dynamic normal acceleration (normal to the guideway table) must not exceed the following values:

- Crown 0.6 m/s²
- Trough 1.2 m/s².

The lateral and vertical accelerations to be achieved in normal operation from aspects of comfort should be defined project-specifically.

Clearance gauge and line cross-section

The typical cross section must be defined project-specifically. Aspects of maintenance and safety must be taken into consideration as well as the clearance gauge according to /MbBO/.

Clearance, track centres

For the clearance gauges of the single and double track guideway, refer to /MSB AG-FW TRAS/.

The values according to Table 5 must be achieved.

	Abb.	Unit [km/h]	Design speed v_e ≤ 300	≤ 300*)	300 < v_e ≤ 400	400 < v_e ≤ 500
Track centres	S	[m]	4.40	4.50	4.80	5.10
Width of the line cross-section**)	b	[m]	10.10	10.20	10.50	11.40

*) for special conditions: 10° < α or
5° < α ≤ 10° and RH ≤ 3,500 m

**) Figures for α = 0°. The values given allow for the clearance conditions for curve radii and guideway transverse inclination with the above limits, i.e. no increase in track centres on curves.

Table 5: Speed-dependent track centres

System structure

Section 2, (2) and Section 2, (3) /MbBO/ must be taken into consideration.
Within the scope of these design principles, the MSB system is divided into the following sub-systems contrary to the designation in the /MbBO/ (see Figure 2*):*

- *MSB vehicle*
- *Drive and energy supply*
- *Operation Control System*
- *Guideway*
- *Other operating plant*
- *Special vehicle.*

Availability

The complete system must have the following characteristics in order to achieve a high degree of availability:

- a guideway dimensioned to be operationally stable, no permanent geometry or surface alterations of the guideway beams as a result of defined operational and environmental impacts, adjustable guideway beam position to offset plastic soil deformations,
- realisation of the operationally necessary active functions to be extensively modular, with autonomous, redundant modules,
- continuation of schedule operation following isolated faults in any desired mobile or static module,
- extensively status-oriented maintenance based on automatic failure disclosure with electrical/electronic modules,
- automated detection of significant changes in position of the guideway functional surface and largely automated initiation of maintenance actions,
- maintenance work carried out with the least possible impact on train operations.

The quantitative requirements for the system availability should be defined project-specifically.
The system availability should be measured in every project.
A fault tree analysis can be used for this purpose, for example.
The system must be designed so that:

- train operations according to Chapter 0 are assured,
- the required availability is achieved by high module reliability or by redundancy or both,

- MSB vehicles do not have to stop between two stations because of individual technical faults,
- in case of an availability-relevant fault the train can still be moved to the maintenance facility.

It must be remembered that MSB vehicles cannot be towed away.

Reliability

Failure performance/failure frequency of active modules

In case of failure of an operationally relevant active module

- a redundant module must assume the function,
- there must be automatic failure disclosure,
- an automatic test and reactivation while maintaining the safe condition during and after reactivation must take place as soon as the cause of the failure is no longer present.

The MTBF times must be determined for operationally relevant active modules.

Failure performance/failure frequency of structural and cladding components

Structural parts of vehicle and guideway as well as vehicle cover panels must be sustainable, stable and fit for purpose.
The resulting requirements for construction/choice of materials and proofs are contained in the "Design Principles Vehicle/Guideway".
The influences to be allowed for in the design are given in /MSB AG-FZ BEM/ and /MSB AG-FW BEM/.

Maintainability

Requirements for maintainability are contained in the Design Principles for the various individual subsystems. Basic requirements are listed below.

Requirements for modules and cabling

So far as is economically meaningful, the service life of electrical and mechanical modules should be designed for the expected useful life of the respective subsystem.
Modules whose service life is less than the expected useful life of the subsystems should be easy to access and replace.
Modifications or rework should not be necessary when replacing modules.
Testing and adjustment after module replacement should be avoided so far as possible by the appropriate design of the modules (e.g. self-calibration, self-test etc.).
Opportunities for assembly and installation errors should be eliminated so far as possible by design. For plug-and-socket connections that carry safety-relevant signals, appropriate technical measures (e.g. slot coding) should be taken to ensure that they can only be connected to their assigned location / device / module.

Modules, cables and lines must be identified clearly, uniquely and systematically. A module's designation must clearly identify its version and, if applicable, the software release.
A systematic identification must be used for the installation position of modules.
It must be possible for failures to be disclosed by automatic diagnostic devices and / or by scheduled planned inspections.

Inspectability of modules

Modules that must be inspected according to a maintenance schedule must be accessible for inspection.

Maintenance

Section 8(1) Section 8(2) and Section 8(3) of the /MbBO/ must be observed.
Requirements for operating rules (train operations and maintenance) are defined in /MSB AG-BTR/.
Maintenance must conform to /DIN 31051/.
The integration of maintenance into operations, and the dovetailing of maintenance with train operations must be defined project-specifically.
A project-specific maintenance concept must be created.

Basic approach

The specified maintenance actions must have an instruction manual for their execution which includes test reports /checklists for documenting the results.
The maintenance of the subsystems must be integrated in the maintenance of the complete system, and a Maintenance Manual (MM) must be created for this purpose.
The MSB subsystems may be divided up into suitable subject or topic units in which standardised maintenance procedures can then be carried out.
The effectiveness and appropriateness of the measures must be regularly reviewed on the basis of the documented results.
Suitable information systems must be put in place for this purpose, and for the purpose of supporting the maintenance management.
The maintenance must be subject to quality management comparable with /DIN EN ISO 9000/.

Repairs

A repair should be performed by the replacement of modules or on the basis of the smallest replaceable units that must be defined project-specifically.
Each module or smallest replaceable unit must be replaceable and testable in itself.
The lifecycle of replaced / repaired modules / smallest replaceable units must be clearly and traceably documented together with a description of the fault, particulars of the cause of the fault and the repair (or replacement by a new part as applicable).

Useful life

The useful lives of subsystems and components must be defined project-specifically.

The complete system must fulfil the specified requirements during the useful life when used according to specification (train operations and maintenance).

Rating of parts and modules

Mechanical/structural parts/modules must be rated and proven

- according to the criteria of stability / load withstand capability and
- fitness for purpose

on the basis of

- the maximum influences arising out of operation and environment according to /MSB AG-UMWELT/ and
- the parameter range and failure behaviour specified in this document.

The dimensioning action combinations and loads are defined in /MSB AG-FZ BEM/ und /MSB AG-FW BEM/.
The influences from operation and the environment on the basis of which the service strength and predicted service life of parts and modules is determined are defined in /MSB AG-FZ BEM/ and /MSB AG-FW BEM/.
The limiting values that apply to all subsystems and on which the design must be based should be taken from Chapter 0.

Safety

Safety concept

Project-specific safety requirements

Section 23, (1) and Section 23, (2) /MbBO/ must be observed.
Guidance for design is given in the official justification for Section 23 /MbBO/.
A project-specific safety concept must be created based on /EN 50126/.
The safety concept must analyse and assess the project-specific risks on the basis of the safety-relevant requirements and characteristics of the MSB system specified in the Design Principles (see Figure 1), and must define risk-reducing measures (technical, structural, operational and organisational).
The safety concept must define project-specific safety objectives and a risk acceptance criterion.
The project-specific risk analysis and assessment can be carried out as part of a risk analysis according to /EN 50126/.
Information on methods will be found in /prEN 50126-2/ and /prR009-004/.
The risk-reducing measures can be described in an action catalogue or action list.
The requirements for the rescue concept, in particular procedures, decision criteria and responsibilities, must be defined in the safety concept project-specifically.
The risk analysis, risk list, action catalogue and rescue concept can form part of the project-specific safety concept.

The risk analysis, risk list, action catalogue and rescue concept must be harmonised with each other project-specifically.
Compliance with the maximum permissible number of persons in the MSB vehicle must be described in the safety concept.
The residual risk should not exceed the defined risk acceptance criterion.

Project-neutral safety requirements

The requirements listed in the following sections represent separate requirements for individual risk aspects that are not the preserve of project-specific safety requirements.
They shall not be a substitute for the systematic and project-specific analysis and assessment of all risks.
The safety requirements for the functions must be derived from the risk analysis.
Safety-relevant functions must be demonstrated according to the CENELEC standards (/ DIN EN 50126/, / DIN EN 50128/ and /DIN EN 50129/).
The components and modules which are used to perform these functions must be demonstrated according to the product-specific standards (e.g. parent standard /DIN EN 61508-1/).
Other requirements for safety-relevant functions are described in

- *Chapter 0 and in the Design Principles for the subsystems, see* Figure 1 *and*
- *Chapter 0 for the protection of train operations.*

Protection of persons

Construction characteristics

- *for fire safety are described in Chapter 0,*
- *for the protection of persons in the MSB vehicle are described in /MSB AG-FZ GEN/,*
- *for the protection of persons on the platform are described in Chapter 0 .*

The protective effect against a risk to persons from electrostatic discharge from the outer skin of the MSB vehicle according to /MbBO/ Section 17, (4) must be demonstrated.
Specific measures for the occupational safety of the maintenance personnel must be defined project-specifically.
For operations carried out within the danger area of the guideway (from the special vehicle or independently of it), e.g. maintenance or vegetation control, protection for the persons concerned must be defined project-specifically. The danger area must be defined project-specifically.
Work carried out within the danger area of the guideway must be signalled in such a way that train movements that may put the persons affected at risk are made impossible. The route section that is affected must be closed before work commences and may not be signalled clear until work is complete. This line clear detection is a precondition for the issue of a clearance for the corresponding route section.

If train operations with MSB vehicles are to take place while the work is in progress, it must be possible for the person responsible for the work to close route sections by means of technical devices and signal them clear again.
A collective fall protection must be provided for work on the guideway.
Further safety measures for the protection of persons can be defined project-specifically.

Fire safety

Project-specific fire safety concepts must be defined.
Fire alarms must be signalled at the operation centre.
Requirements for the transmission of fire alarms must be derived from the project-specific safety concept.
The fire safety concept may infer restrictions on the carriage of baggage and goods.

Fire safety in the vehicle

The technical fire safety requirements for MSB vehicles are described in /MSB AG-FZ GEN/.

The technical fire safety requirements for the devices of the OCS in the MSB vehicle must be defined project-specifically having regard to the fire safety concept of the vehicle.
Fire safety requirements for special vehicles must be defined project-specifically.

Fire safety in installations

The design of tunnels must taken into account the fire safety requirements according to /EBA-RL MSB Tunnel/.
The design of stations must taken into account the fire safety requirements according to /EBA-Lf MSB Station/.
The need for and design of fire safety concepts for other installations must be decided project-specifically.

Collisions

Collision avoidance

A collision between vehicles must be reliably prevented (guide value for probability of occurrence as per SIL 4 according to /DIN EN 61508-1/).
Passing a danger point must be reliably prevented (guide value for probability of occurrence as per SIL 4 according to /DIN EN 61508-1/).
Clearance violations due to the failure of a guideway module must be prevented in order to avoid collisions.
Failures in magnetic control loops that can lead to contact between magnets and stator or lateral guide rail with excessive force transference into the structure of the MSB vehicle and guideway must be prevented.
The guideway must be dimensioned having regard to the effects of local probable earthquake intensity according to /MSB AG-UMWELT/.

Protective structures and devices must be provided according to the safety concept having regard to /EN 1317/ and the /RPS/.
The following principles must be applied:

- for traffic routes under the MSB guideway:
  Supports, guideway beam bearers etc. must be dimensioned to allow for impact by road vehicles (see /MSB AG-FW BEM/).
  The guideway must be provided with a collision barrier on the basis of a risk analysis,
- for traffic routes above the MSB guideway:
  Protection must be provided against the falling of vehicles and objects onto the guideway on the basis of a risk analysis.
- for traffic routes parallel to the guideway:
  A collision barrier for the supports of the elevated guideway and at-grade guideway must be provided on the basis of a risk analysis.

The following organisation and operational measures must be provided:

- special forest maintenance along the route of the high-speed maglev system so that the MSB clearance gauge according to /MbBO/ remains free, even from falling trees etc.,
- measures for winter operations according to Chapter 0,
- other project-specific measures to be define in the safety concept (see Chapter 0).

Collision behaviour

The following representative collision cases must be considered:

- 15 kg stone on slide rail,
- 50 kg round stone in centre of guideway table or beside the guideway beam level with the levitation magnets of the MSB vehicle,
- Tree (length 18 m, trunk diameter at point of impact 20 cm), lying at 45° on the elevated guideway or horizontally across the at-grade guideway table,
- 75 kg hydrobody on the guideway table.

The maximum speed to be defined project-specifically must be taken into consideration.
For these representative collisions, accelerations in the passenger compartment must be limited to the extent that the risk remains at least tolerable (assessment criterion: Head Injury Criterion (HIC)).
For these representative collisions, accelerations must not result in a danger to the track guidance or the stability of the guideway.
For these representative collisions, deformations of the passenger cell must be limited to the extent that persons are not trapped in the passenger compartment.
The penetration strength of the car body cell in a head-on collision with an obstacle must be designed according to the penetration strength for windows (against a standard projectile, mass 1kg, impact velocity 600 km/h) according to /UIC 651/.

The way in which the above collision cases are diagnosed and the follow-up measures that must be taken must be decided on a project-specific basis.

Departure from the guideway

Unintended vehicle departure from the guideway must be prevented.
Departure from the guideway is conceivable at guideway ends or at open ends of track-switching devices.
For this purpose, the following must be defined project-specifically:

- Danger points before guideway ends and
- Danger points before the open ends of track-switching devices.

Unscheduled stop

The unscheduled stop of a train outside the platform area of stations must occur either within a defined section of track adjacent to the platform area or at a service stopping place.
The unscheduled stop of an MSB vehicle outside a stopping place may therefore only occur when there is a simultaneous coincidence of certain fault conditions and other failures. Situations arising from this must be allowed for in the safety concept.
Example: If while accelerating immediately after an unscheduled stop at a service stopping place the energy supply to the drive fails before the speed needed to reach the next stopping place is attained.

Track sections adjacent to the platform area of stations

Track sections adjacent to the platform area of stations must have the characteristics of a service stopping place (see Chapter 0) and should be equipped throughout with external on-board energy supply. These areas may be interrupted by individual short sections in which

- the permitted linear or transverse inclination for service stopping places according to Chapter 0 is exceeded, or
- the evacuation of an MSB vehicle is possible with difficulty only, e.g. where the train crosses traffic routes.

An unscheduled stop should be made outside such sections.
Guide value for the length of line sections adjacent to the platform: 1 to 2 km.

Service stopping places (BHPL)

Service stopping places must be designed project-specifically.
The project-specific design must observe the following principles:

- There must always be one service stopping place that can be reached under the controlled use of the kinetic energy of the MSB vehicle.
- To reach a service stopping place, driving, braking and levitation profiles must be defined which allow for locally specified conditions.

- The braking profiles must be achievable by both the long stator drive and the Safe Brake at least for all of the service stopping places where a stop for operational reasons is to be expected.
  Braking profiles to other service stopping places may be designed so that they are achieved with the Safe Brake but not by the long stator drive.
- Monitoring by the OCS against passing a danger point must be realised with a failure probability that must be derived project-specifically.
  The probability of failure as per SIL 4 according to /DIN EN 61508-1/ is a guide value.
- Monitoring by the OCS for reaching a reachability point must be realised with a failure probability that must be derived project-specifically.
  The probability of failure as per SIL 3 according to /DIN EN 61508-1/ is a guide value.

The permitted probabilities of occurrence for passing a danger point and for not reaching a reachability point must be defined on the basis of the project-specific risk analysis (Chapter 0).
A service stopping place is determined by a reachability and a danger point.
In case of an impending violation of the braking and levitation profiles *there is a safe drive shutdown. The MSB vehicle slows under controlled conditions with the Safe Brake to the current BHPL.*
Service stopping places at which a stop for operational reasons is expected should be equipped with al external on-board energy supply.
On line sections with an exceptionally long and steep gradient, a service stopping place must be provided at the start of the gradient section.
Provision must be made to ensure that in the event of reverse hover to the service stopping place at the start of the gradient section, this line section is protected by the OCS.
Guide value for the probability of failure as per SIL 4 according to /DIN EN 61508-1/.
According to /MSB AG-BLT/, in the event of an automatic train stop in such a gradient section (e.g. 5 % over 10 km), the passed service stopping place at the start of the gradient section can be approached.
Guide value for the minimum length of service stopping places: train length + 350 m.
Requirements for alignment at service stopping places according to Chapter 0.
Construction and equipment according to Chapter 0.

Drive malfunctions

Consideration must be given to the following in conjunction with drive malfunctions:

- synchronous fault currents with significant residence times and an effect that generates shearing force, in regard to forces and accelerations in the x-direction, and
- synchronous fault currents with significant residence times and an effect that weakens or strengthens the field of the levitation magnet.

The fault current strength must not result in

- a force that is unacceptable for the design of the MSB vehicle and guideway, or
- an unacceptable acceleration (with a violation of limiting running profiles or a risk to persons in the vehicle).

The fault current strength must be monitored and limited for this purpose.

Effect that generates shearing force:

- **Faulty drive force**

The faulty drive force must be limited so that the force in the x-direction used as the basis to design the MSB vehicle and guideway (as per the "Exceptional Effects", see Chapter 0, No. 7. (2)) is exceeded by no more than a probability of occurrence according to SIL 4 (guideline).
Stability of the guideway and design of the MSB vehicle, classification according to /DIN EN 61508-1/.

- **Faulty drive acceleration**

The faulty positive drive acceleration in the direction of travel must be limited so that the maximum acceleration on which the maximum running profile is based is exceeded by no more than the probability of occurrence specified for it by the OCS.
The limitation of the probability of occurrence for the event "passing the danger point" (see Chapter 0) applies. The faulty drive acceleration must be allowed for pro rata. Rating is according to /DIN EN 61508-1/.
The faulty negative drive acceleration (deceleration) in the direction of travel must be limited so that the maximum acceleration on which the minimum running profile is based is exceeded by no more than a probability of occurrence specified for it by the OCS.
The limitation of the probability of occurrence for the event "not reaching the reachability point" (see Chapter 0) applies. The faulty drive acceleration must be allowed for pro rata.

Effect that weakens or strengthens the field of the levitation magnet:

A faulty drive current with an effect that weakens the field of the levitation magnet on one motor / guideway side may occur.
Stability of the guideway and design of the MSB vehicle, rating in regard to the probability of failure according to /DIN EN 61508-1/, one-sided setting-down is considered as a special load case.
A faulty drive current with an effect that weakens the field of the levitation magnet on both motor / guideway sides may occur at most with a probability of occurrence according to SIL 4 (guideline).
A faulty drive current with an effect that strengthens the field of the levitation magnet must be limited so that the resulting force in the x-direction on which the design of MSB vehicle and guideway is based (as per the "Exceptional Effects", see Chapter 0, No. 7) is exceeded by no more than a probability of occurrence according to SIL 4 (guideline).
Stability of the guideway and design of the MSB vehicle, classification according to /DIN EN 61508-1/.

Earth fault detection and shutdown:

The earth fault detection and shutdown must be implemented with a project-specifically defined availability.

No direct faulty force effect occurs in this case.

Rescue concept

The requirements for rescue must be defined in a project-specific rescue concept.
The rescue concept must be part of the project-specific safety concept.
The rescue concept gives particular consideration to the safety of persons in the event of a fire in the MSB vehicle.
The rescue concept should be based on the self-rescue principle.
External rescue measures must be additionally included.
The rescue concept must describe the sequence of a time-critical evacuation under the project-specific conditions and the interaction of all safety measures (technical, structural, operational and organisational) for the case of evacuation.
Based on the requirements of the rescue concept, the risk analysis (see Chapter 0) assesses whether the residual risk is acceptable for the case of evacuation.

Proof of safety

Proof of system safety according to Section 4 (2) /MbBO/ must be provided project-specifically as proof of safety on the basis of /DIN EN 50129/.

Environment

Effects from the environment

The modules and subsystems of the MSB system must be rated and qualified on the basis of the data of the primary environment /MSB AG-UMWELT/.
If environmental data beyond the primary environment data must be considered in a project area, then these must be covered by a special design.
If the specified environmental data are likely to be exceeded, then operations must be restricted or stopped by project-specific operating regulations.

Wind

The impact of side wind, including gusting (as per /MSB AG-UMWELT/) and traversing areas sheltered from the wind, must be offset by the electromagnetic guidance system.
Where exceptional side wind gusts are overlaid, the electromagnetic guidance system may be temporarily assisted by the mechanical lateral guidance without this affecting the train operations.
Following winds and head winds must be allowed for when designing the stopping distances and distances from stopping places.

Winter

Installations and vehicles must be designed so that danger to third parties from snow, water or ice is avoided.

When aligning the at-grade guideway, the gradient height must be defined project-specifically taking account of the anticipated climatic effects (e.g. build-up of snow).
The guideway table must be constructed so that rain and melt water can run off unimpeded.
The magnetic support, guidance and drive function must not be affected by icing according to /MSB AG-UMWELT/ of MSB vehicle and guideway.
The operation and stopping distance of the Safe Brake according to Chapter 0 must allow for icing of the guideway unless this is prevented by, for example, design measures.
Winter service measures must be defined project-specifically.
Rescue equipment must be included in the winter service.

Electromagnetic interference

The immunity of the MSB system from electromagnetic interference from outside must conform to the requirements of /DIN EN 50121/.
Lightning protection must conform to /DIN V VDE V 0185-3/.

Effects on the environment

Noise

The /MSB-LSchV/ applies.
The method for determining the correction factors DFz and DFb is described in Annex 5 to the Design Principles Complete System.

Magnetic, electric and electromagnetic interference

Standards /DIN EN 50121-2/, /DIN EN 50121-5/ and /26th BImSchV/ must be applied.

Travelling comfort

Comfort requirements should be defined project-specifically.

Comfort-relevant aspects of alignment

Requirements for acceleration and jolt are given in Chapter 0.
Requirements regarding low-frequency changes in acceleration and jolts from a succession of alignment elements are given in /MSB AG-FW TRAS/, Chapter 6.2.

Comfort-relevant vibration (rms values)

Acceleration should achieve the following guide values for the rms values:
0.2 m/s^2 in x, y and z direction on 95 % of all evaluation sections
(with rating filter as per /ISO 2631, ORE B 153/, evaluation sections 5 s or 500 m each).

Pressure fluctuations in tunnels

Based on the maximum pressure load in tunnels given in Chapter 6.1.1.3.3., the pressure seal-tightness and compressive rigidity of the MSB vehicle should be designed so that the comfort requirements are complied with.
The permitted pressure fluctuations acting on passengers in the MSB vehicle must be defined project-specifically.
Guide value for the maximum change in pressure in the passenger compartment in tunnels
500 Pa in 1 s
800 Pa in 3 s
1000 Pa in 10 s.
For the aerodynamic requirements arising out of the design of the vehicle, refer to Chapter 0.
For the building requirements for tunnels, refer to Chapter 0.

System concept/design

Subsystems

MSB Vehicle

Structure
The structure of the MSB vehicle is shown in Figure 9.

Vehicle boundary
Proof of kinematic boundary line according to /MSB AG-FZ KIN/.

Car body
Section 18(1) and Section 18(3) /MbBO/ must be taken into consideration.
For pressure stresses on the car body, refer to Chapter 0.

Functions

Support and guide
Section19 /MbBO/ must be taken into consideration. This requirement must be met as follows:
Structure/Function
The magnetic drivetrain must transmit the support/guidance/drive forces to the guideway as area loads.
The MSB vehicles have a magnetic drivetrain which extends over the entire length of the vehicle and consists of a series of levitation chassis and levitation/guide magnets.
Section 17(4) and Section 20(1) /MbBO/ must be taken into consideration. These requirements must be met as follows.
Requirements for the mechanical support function:

- The support skid must realise the function of the mechanical support and of the holding brake of the set-down, stationary MSB vehicle in areas where stationary vehicles must be secured against inadvertent movement.
- The support skids must be able to bring the MSB vehicle to a stop below the set-down speed.
- Upon the failure of the two support control circuits on a levitation frame, the support skids must assume the support function while travelling.
- The sliding behaviour between the slide rail and the support skid must be matched so that the static and dynamic loads on which the design of the guideway and the MSB vehicle are based are complied with.

- The failure of the magnetic support function in one support control circuit must be detected and must initiate an automatic system response with the aim of limiting the sliding distance to a project-specifically defined dimension.

See Figure 10*: Braking characteristic of safe brake for an MSB vehicle section.*
Guide value for the sliding distance of a levitation frame set down on support skids: 100 to 200 km
Requirements for the mechanical guide function:

- Upon the failure of both guide control circuits on a levitation frame, the mechanical guide function must be provided by the sliding of mechanical guide elements on lateral guide rails.
- The sliding behaviour between the lateral guide rail and the mechanical guide element must be matched so that the static and dynamic loads on which the design of the guideway and the MSB vehicle are based are complied with.

Safe Brake

Functional characteristics

The braking capability of the MSB vehicle must be available to comply with the maximum running profile monitored by the OCS.
If a Safe Brake is used with a different operating principle than the drive, then it must be ensured that the Safe Brake function is not unacceptably affected (e.g. by the drive).
A fault or a failure that occurs within the devices that trigger the brake system must generate at least the same braking effect as an operational triggering.
The maximum value of the braking force must be compatible with the design loads for the guideway and the MSB vehicle.
The safely attainable minimum value of the braking force must be matched to the running profiles under unfavourable conditions (e.g. a strong following wind) that are monitored for safety-technical purposes.
The vehicle's own Safe Brake must be designed so that the MSB vehicle is able to autonomously execute a braking manoeuvre to a stopping place with the OCS devices that are built into it.
For specific projects, the Safe Brake can be supplemented by the braking effect of shading coils when designing the Safe Brake profile, see also /MSB AG-ANT/, Chapter 5.3.
Exceeding the braking force assumed in the design loads must be prevented. If this cannot be achieved by the design, then the prevention of a simultaneous action of the braking force of the long stator drive and the vehicle's own Safe Brake by the operation control system with a probability of occurrence of SIL 4 (guide value) must be proven (see Chapter 0*)*.
A set-down MSB vehicle must not be influenced by the long-stator drive.
This is achieved by the excitation for the long-stator drive being absent in the set-down condition.
The function of the holding brake must be proven for line sections in which MSB vehicles must be secured against inadvertent movement.

MbBO Section 13(2) states that a linear inclination of 5 ‰ must not be exceeded in these sections. Exceptions from this requirement are permissible in individual cases on special grounds provided safety is demonstrated in another way.
The holding brake function must be proven if, in special cases, stationary MSB vehicles in sections with a linear inclination > 5 ‰ must be secured against inadvertent movement.
The Safe Brake function must be capable of executing an automatic stop according to /MSB AG-BLT/.

On-board energy supply

The on-board energy supply function must be monitored (see Chapter 0).
It must be ensured that sufficient on-board power is available to carry out a journey including a stop with the Safe Brake.

Configuration parameters

Section 3(3); Section 17(1); Section 17(6), Section 18(2) and Section 21(1) /MbBO/ must be taken into consideration.
For requirements for fire safety in the MSB vehicle, see Chapter 0.

Vehicle configuration

Section 20, (2) /MbBO/ must be taken into consideration. This requirement must be met as follows.
The MSB vehicles must be made up of vehicle sections that are self-contained in regard to the support and guide function, brake device, on-board energy supply and car body.
The system size of vehicle sections of an MSB vehicle must be 24.768 m.
(levitation magnet occupancy length, see also Chapter 0, No. 6.1.1. (3)).
The length dimensions of MSB vehicle end sections may differ from this.
An MSB vehicle must have two end sections.
An MSB vehicle may also have up to 8 centre sections.
The number of sections is decided project-specifically based on the transport task (e.g. traffic volume).
The individual sections must be freely configurable as part of the vehicle design for passenger and goods transport.
Daily variations in traffic volume can be operationally addressed by using MSB vehicles with more or fewer centre sections and/or by changing the schedule.
The capacity of the MSB vehicles can be increased by adding centre sections to meet the long-term growth the demand for transport.
An MSB vehicle is referred to as a train when it is equipped with, and operationally controlled and protected by, OCS devices (see /MSB AG-ABK&DEF/).
Dimensions of MSB vehicle sections are shown by way of example:

- *End/centre section for passenger transport long-haul:* Figure 6
- *End/centre section for passenger transport airport link:* Figure 7 and Figure 8
- *Car body and support/guide system:* Figure 9

Running resistance

For a definition of running resistance, see /MSB AG-NORM&RILI/.
The running resistance is made up of the following components:

- Aerodynamics,
- Magnetisation,
- On-board power generation.

The local downslope force must be taken into consideration in addition to the running resistance when defining running profiles and determining levitation and braking distances.
Guide values for the running resistance for MSB vehicles with 2 to 10 sections at 0 to 400 km/h and its components: Figure 11
The running resistance must be project-specifically defined and allowed for in the design (see Figure 11):
Total running resistance:
$F_W = F_A + F_M + F_B$

Aerodynamics:
$F_A = 2.8\ \text{kN} * (v/[m/s])^2 * (0.53 * N/2 + 0.30) * 10^{-3}$
Aerodynamic increases in running resistance through tunnels must be additionally allowed for on a project-specific basis.
The aerodynamics component is largely proportional to v^2 but it also includes a small component proportional to v to allow for the air removal for ventilation and air conditioning. This component proportional to v can be taken as contained in the component proportional to v^2.

Magnetisation:
$F_M = N * (0.1\ \text{kN} * (v/[m/s])^{0.5} + 0.02\ \text{kN} * (v/[m/s])^{0.7})$
applies when using the recommended material for the lateral guide rails according to Chapter 0.

On-board power generation:

$F_B = 0$	for 0 to 20 km/h
$F_B = N * 7.3\ \text{kN}$	for 20 to 70 km/h
$F_B = N * (146\ \text{kN} / v/[m/s] - 0.2\ \text{kN})$	for 70 to 500 km/h

where
v - velocity of MSB vehicle
N - number of vehicle sections

for steady-state operation

- without a supply from an external on-board energy supply (when operating with external on-board energy supply up to 100 km/h, $F_B = 0$),

- without recharging of the on-board batteries,
- without wind influence, and
- for mean ambient temperature in moderate climate (as per /MSB AG-UMWELT/) with a corresponding air conditioning rating.

Aerodynamics

The aerodynamic loading resulting from oncoming traffic and in tunnels must be allowed for as per /EN 14067-2/ and /EN 14067-3/.
The vehicle must be designed to allow for the maximum permissible pressure difference (internal/external) in tunnels and the pressure effect from oncoming traffic.
The pressure difference (internal/external) in tunnels is determined by the change in external pressure that depends on the tunnel length and cross-section, and the delayed change in internal pressure. The change in internal pressure is determined by the pressure seal-tightness and compressive rigidity of the car body. The tunnel cross-section, the comfort requirements and the vehicle characteristics must therefore be coordinated. See also 0 and 0.
The maximum pressure difference (internal/external) may not exceed 5,500 Pa (limit).
The maximum value of the pressure difference (internal/external) that occurs in tunnels must be determined project-specifically.
The pressure effect with an oncoming train on open track is shown in Figure 12.
The pressure effect on static equipment along the guideway on open track when a vehicle passes by is also shown in Figure 12.

Drive and energy supply

The Drive and Energy Supply subsystem must supply other subsystems of the MSB system with the necessary energy, and propel MSB vehicles according to the requirements of the operation control system.
The Drive and Energy Supply subsystem must observe the following interfaces with other subsystems:

- Guideway (stator of the synchronous long-stator motor, track-switching devices, reference locations),
- MSB vehicles (levitation magnet as the exciter of the synchronous long-stator motor, absolute and relative position information, external on-board energy supply),
- Operation control system (running requirements, safe drive shutdown),
- Other MSB system components (auxiliary energy supply).

Structure

Depending on location, the Drive and Energy Supply subsystem must consist of the following components:

- Central devices for **operating and observing** and for **diagnosis**,
- **Energy supply** (structure Figure 13) with

    - **Devices in substations** for auxiliary and traction energy supply, if necessary also for the external on-board energy supply and
    - **Trackside devices** for the auxiliary energy supply of the trackside devices of the MSB system and, if necessary, the external on-board energy supply,
- **Drive** (Figure 14) with
    - **Devices in substations** for transforming the electrical energy and for regulating/controlling, and
    - **Drive circuit** along the guideway to distribute the electrical energy along the guideway and for control, comprising of circuit cables, switch points and stator sections.

Functions

At central **control stations** it must be possible to observe the status of the complete subsystem and operators must be able to carry out the necessary operating actions. Manual operating actions must not be necessary during undisturbed scheduled operation.
The **energy supply** must include the subfunctions of energy matching and distribution, auxiliary energy supply, external on-board energy infeed, traction energy supply, power factor correction and control energy supply.
The **energy matching and distribution** must (where necessary) match the voltage level provided at the interface with the public mains to the mains design used in the drive, and distribute it to the functional units of the energy supply described below.
The **auxiliary energy supply** must supply the drive regulation/control system, the OCS, the points and any other components of the MSB system with the energy required in each case. The energy supply must be uninterruptible for selected components.
The **external on-board energy infeed** must provide energy according to the power demand of the MSB vehicles at locations to be defined. It must transform the energy according to the construction of the external on-board energy supply and feed it to the guideway-side components.
The **traction energy supply** must supply the drive with the energy needed for traction.
If necessary, the **power factor correction** must ensure compliance with the required connection conditions at the interface with the public energy supply grid.
The **control energy supply** must monitor all energy supply devices and in case of a fault initiate protection responses and if necessary automatic redundancy changeovers. It must also check switching actions entered at the operator terminal for plausibility with the existing interlock conditions and initiate the necessary switching actions.
The **drive** must fulfil the following subfunctions according to Figure 15:
The converters must transform the provided energy according to the vehicle location, the vehicle speed and the required acceleration.
The transformers must be constructed so that the brake energy can be fed back into the public grid.
The line must be divided up into **drive sectors** in which an MSB vehicle can be driven according to OCS requirements.

The components of the drive circuit are assigned to a drive sector at any given point in time. The drive sectors usually coincide with the safety areas of the operation control system.
Within the drive sectors, the electrical traction power must be converted to mechanical power in synchronous long-stator motors.
The excitation is generated by the levitation magnets installed on the MSB vehicle.
The **drive regulation/control system** must coordinate all operations that are drive sector-wide and overarching:

- Creating and cancelling drive units and synchronising neighbouring drive units until the vehicle guidance is passed from one drive unit to the next,
- Coordinating the use of the converters, stator sections and redundancies,
- Controlling the operating modes for all drive devices as a function of their status and the current OCS input.

The **vehicle guidance system** must guide an MSB vehicle over a drive circuit according to the running profile input by the OCS, allowing for the comfort conditions. The following must be provided for this:

- Communication with the operating control system to receive the inputs for destination, direction of travel and speed,
- Communication with the MSB vehicle to receive the relative and absolute position information,
- Calculation of target braking speeds,
- Distance and speed control,
- Phase regulating (determining the vehicle position relative to the long stator).

The **circuit controller** must coordinate the control and monitoring of the various controlgear of the drive circuit as a function of stator section change procedures, vehicle position and speed, with the following functions:

- Generating control signals for on/off switching of the stator section switches and circuit switches,
- Monitoring switch messages,
- Circuit cable and long stator protection.

The **current regulation system** must regulate the stator current by frequency, amount and phase angle, with:

- Determining the rotor voltage induced by the MSB vehicle in the long stator,
- Translating the inputs of vehicle guidance and drive control into manipulated variables for the converter regulation/control system.

The **converter regulation/control system** must control and regulate all the components of a converter according to the inputs of the current controller and drive controller, with:

- Actual-value capture on the grid and motor side and in the converter power circuit,

- Controlling and monitoring the converter power circuit,
- Controlling and monitoring the assigned peripheral components such as control-gear, transformers and cooling system.

Configuration parameters

The following boundary conditions / parameters for the drive configuration must be derived from system-specific, project-specific or operational requirements:
General:

- The complete line must be divided up into drive sectors in line with operational requirements.
- Junctions may be located inside or on the edge of a drive sector.
- To meet the availability requirements, the stator sections on the two guideway sides must be assigned to independent motor systems and should normally be spatially offset.

Interface with the operation control system (drive shutdown):

- The drive must provide shutdown devices for the safe drive shutdown.

The safe drive shutdown is triggered by the OCS.

- The drive should ensure that in the event of a drive shutdown in a drive sector, the effect on other drive sectors is confined to a loss of redundancy or to a power reduction.

Operations:

- Project-specifically defined drive failure combinations must be taken into consideration when designing the stopping places.

Motor parameters:

The following motor parameters must be defined project-specifically:

- Ohmic resistance per unit length,
- Inductance per unit length,
- Capacitance per unit length,
- Motor constant,
- Magnetizing and leakage inductance,
- Maximum permissible conductor temperature and temperature response,
- Rotor voltage.

For motor characteristic data see Chapter 0, Annex: No. 8.

The characteristics of the safety devices and of the long-stator winding must be matched to ensure a reliable safety function.
The following measures must be provided to reduce the connection guideway:

- Partial winding of one or more stator sections with resulting change in motor data,

- Temporary or permanent interconnection of one or more stator sections or parts of stator sections on both sides at the neutral point (short-circuit).

Operation Control System

Section 15(3) and Section 15(4) /MbBO/ must be taken into consideration. These requirements must be executed according to /MSB AG-BLT/.

Structure

The operation control system must provide the components for securing, monitoring and controlling the train operations.
The operation control system must connect the subsystems of the high-speed maglev system functionally into a complete system that is ready for operation.
The neighbouring subsystems and operative levels of the OCS are (see Figure 16*):*

- *Station master,*
- *Guideway and stations (incl. track-switching devices and reference points for positioning)*
- *Vehicle (all MSB vehicles and project-dependently technically secured special vehicles),*
- *Drive and energy supply (substations with drive units),*
- *Maintenance.*

The components of the operation control system may be mobile (e.g. backup computer for a vehicle) or fixed (e.g. backup computer for a guideway section).
The fixed components can be subdivided into central components and decentral components. The configuration must be made as part of project planning according to the operator's requirements.

Functions

The operation control system must provide the following functions:

- Journey sequence control,
- Guideway protection,
- Running profile monitoring,
- Vehicle protection,
- Drive shutdown,
- Secure positioning,
- Data transmission.

The **journey sequence control function** must provide the following subfunctions:

- Operating and display function (displaying the current status of the guideway and of all vehicles known to the OCS, processing operator inputs),
- Generating journey requirements (from operator actions and automatically from journey schedules),
- Guideway setting (setting of moving guideway elements),
- Generating and transmitting control data for vehicles.

The **vehicle protection** function must monitor and control the status of the vehicles. In the MSB vehicle for example it must handle lifting, lowering, monitoring the on-board energy supply function and triggering the Safe Brake via the vehicle controller.

The **guideway protection** function must implement the setting and monitoring of routes according to the guideway parameters including the moving guideway elements. The occupancy monitoring and route cancellation function must take into account information about the vehicle movements.

The **Safe Positioning** function must determine the current position and the speed of the vehicle on the basis of the defined reference points and the relative position referenced to it. This information must provide the Safe Positioning of the running profile monitoring (see also Chapter 0).

The **running profile monitoring** function must calculate the permitted running profile from vehicle and guideway data. The running profile monitoring function must monitor this profile by means of the vehicle's safe positioning information. The running profile monitoring function must report a violation of the profile to the drive shutdown and to the vehicle protection system.

The **drive shutdown** must shut down the drive so that the action of the Safe Brake is not excessively affected by the drive.

If the maximum running profile is violated, the safe vehicle brake must also be applied.

If the minimum running profile is violated, driveless flattening out takes place after the drive shutdown.

The **data transmission** function must ensure the interchange of the following data/information between the subsystems of the high-speed maglev system and within the operation control system:

- Backup data,
- Drive data,
- Diagnostic data,
- Passenger emergency call,
- Fire alarm,
- Operational voice transmission.

Configuration parameters

The following minimum boundary conditions and/or parameters for the configuration of the operation control system must be derived from the system-specific, project-specific or operational requirements:

- The whole route must be divided up into drive sectors based on operational requirements and the drive design.
- Guideway parameters:
  - Track plan (element chain),
  - Danger points,
  - Track-switching devices,
  - Guideway linear inclination,
  - Positioning accuracy, point-based if necessary (position of the reference points),
  - Stopping places (location, length, target points, door release for MSB vehicles),
  - Automatic stop to the stopping place or as an immediate stop,
  - Point-based speeds,
  - Point-based drive configuration,
  - Point-based faulty drive acceleration,
  - Point-based permitted overlay of drive and Safe Brake.
- Vehicle parameters:
  - Characteristic curves for Safe Brake and driveless levitation of MSB vehicles,
  - Vehicle-based speed limits,
  - Vehicle length,
  - Setdown speed of MSB vehicles.
- Other parameters so far as can be OCS-controlled:
  - Sections with external on-board energy supply,
  - Platform door release.

Guideway

Structure

Section 12, (1), Section 12, (2) and Section 12, (3) and Section 14 /MbBO/ must be taken into consideration.
The guideway is part of the installations and is divided into:

- Guideway superstructures,
- Guideway substructures,
- Track-switching devices,
- Special structures,
- Route peripherals,
- Guideway equipment.

The boundary lines and clearances defined in Figure 22 should be adhered to, but they may be adapted depending on design and subject to project-specific review.
The maintenance of the guideway should be carried out from the guideway beam. This rule may be disregarded, especially for the repair of guideway substructures.
Guideway beams and items of equipment may only be operated in an application project after qualification.
Before they are used as standard designs in an application project, guideway beams and items of equipment must also be trialled under boundary conditions that are as near to the application as possible.
The effects of individual modules of the guideway on each other, especially under the dynamic loading of vehicles and environmental impacts, must be allowed for depending on the design.
The modules of the guideway must be clearly defined in a project-specific schedule of structures.
The schedule of structures must provide the following minimum information:

- Alignment parameters (three-dimensional chainage, transverse tile, linear inclination, horizontal radius, vertical radius, guideway coordinates, guideway elevation, ground level elevation),
- Support number,
- Beam number and length,
- Special structures,
- Longitudinal and crossing infrastructure (incl. headroom),
- Stator pack layout (indicating the gap),
- Location and coding of the position reference strips,

- Sections with external on-board energy supply,
- Stopping places,
- Position and layout of the motor winding relative to the stator pack layout,
- Cable routing on the substructures.

Other requirements for the guideway are defined in Design Principles Guideway Parts I to VI.
The requirements described in it apply to all modules installed directly on the guideway or in the immediate vicinity of the route.

Functions

The loads that result from operations and the environment and which act on the guideway must be defined project-specifically.
The guideway must withstand these loads and transmit them into the subsoil.
The loads resulting from the drive and vehicle are transmitted to the guideway through the functional planes of the guideway beam.
The structures of the guideway and of its mount-on parts should be designed to be fault-tolerant, fault-disclosing and/or redundant.
The guideway beams must accept the guideway-side modules of the MSB-specific guideway equipment.
The constructions must be designed such that, under the simultaneous influence of the guide-way's dead weight and the loads from operations and the environment, the functional planes display at most deviations from the requirements of the three-dimensional curve according to /MSB-FW GEO/ and /MSB-FW BEM/.

Configuration parameters

Guideway superstructures

The guideway superstructures form the running tracks of the guideway.
The guideway superstructures must accept the guideway equipment (according to Chapter 0).
The guideway superstructures must take down the acting loads into the guideway substructures (through the bearers if necessary).
MSB routes should be planned with the following standard guideway types; other types may be used for specific projects:

- Guideway type I: Single/multiple bay beam with system lengths of > 16 m (guide value: 24.768 m),
- Guideway type II: Single/multiple bay beam with system lengths of ≤ 16 m (guide value: 12.384 m),
- Guideway type III: Multiple bay slabs with system lengths of 6 m, for example (guide value: 6.192 m).

Guideway types I and II are normally supported discretely on supports with individual footings. The bearing forces of guideway type III are normally transferred to the subsoil through strip footings.
The definition of the respective guideway type and system lengths must be project-specific. Contrary to the above guide values for system lengths, beams with a shorter system length may be used:

To compensate for the radial displacement of the system axes with the dual-track guideway or at alignment constraints, guideway superstructures can be used on the track on the inside of the bend whose system length in a grid of 86 mm can be shortened by up to 4*86 mm.

With longer system lengths (approx. > 31 m) either special beams or primary support structures with a standard guideway mounted on top will have to be used.

The following "construction methods" must be used for the guideway superstructures:

- *Concrete beam/slab with integrated (concrete) cantilever arms,*
- *Steel beam/slab with integrated (steel) cantilever arms,*
- *Hybrid beam/slab as concrete beam/slabs with attached steel modules to take the guideway equipment,*
- *Concrete slab on steel beams or steel plate on concrete beams.*

A distinction is made between at-grade and elevated guideways according to the position of the gradient to the ground level elevation (guideway elevation).

Elevated guideway

Guideways with a guideway elevation of between 3.5 m and 20 m (> 20 m in special cases) are referred to as elevated guideways.
The elevated guideway (see Figure 19*) is usually constructed in beam design with discrete substructures as:*

- *Single-bay beams constrained at one end,*
- *Dual-bay beams constrained on the centre support.*

At-grade guideway

Guideways with a guideway elevation of up to 3.5 m (minimum height in special cases: 1.25 m) are referred to as at-grade guideways.
The at-grade guideway can be constructed with the following methods:

- *slab construction with continuous substructures (see* Figure 20*),*
- *beam construction with discrete substructures as per the elevated guideway.*

Guideway substructures

The guideway substructures must

- transmit the loads from the guideway superstructures into the subsoil, and
- allow the attachment of supply lines to the guideway equipment.

The guideway substructures comprise

- guideway foundation,
- guideway supports,
- other guideway substructures (including mass-spring system).

The deviations of the guideway support points in the x-direction due to the elastic deformation of the substructures must be limited to the following values:

- 10 mm due to changeable effects,
- 20 mm due to exceptional effects.

Track-switching devices

The requirements of /MbBO/, Section 12, (2) must be respected.
Track-switching devices must enable the MSB vehicles and special vehicles to change from one running track to another.
*A general distinction is made between track-switching devices that require no journey break (points) (*see Figure 25*) and track-switching devices that require a journey break (turntables and traversers).*
Track-switching devices must be provided with equipment that locks the end position reached after the track-switching operation and secure it from inadvertent adjustment.
The end position and end position locking are monitored for safety by the OCS.
The end position of the track-switching device must be maintained irrespective of failures of the control system, monitoring or energy supply.
The failure of an individual electrical, electronic or electromechanical module in actuating and locking devices, control system, monitoring and/or power supply must have no effect on the adjustment function.
The track-switching may only be adjusted

- at the request of the OCS or
- under a special operating instruction, with personnel responsibility.

The following constraints must be defined project-specifically:

- Adjustment frequencies,
- Required adjustment times,
- MTBF and
- required electrical power.

Special structures

Tunnels
Planning and execution must be project-specific.
Tunnels must meet the following requirements:

- Receive the guideway,
- Receive the line peripherals,
- Requirements of the project-specific safety concept,
- Comply with the defined clearances and boundary lines.

The tunnel must be constructed so that the compressive stress of the MSB vehicle according to Chapter 0 is not exceeded.
The tunnel should be constructed so that the changes in pressure to be defined project-specifically acting on the passenger inside the MSB vehicle according to Chapter 0 are not exceeded.
The construction of the complete tunnel structure must take account of the following project-specific factors:

- tunnel length, number of tracks and vehicle length,
- spatial requirements that go beyond the clearance (e.g. line peripherals),
- vibration transmissions,
- tunnel boom effects,
- waste heat emissions (e.g. cables),
- any existing exhaust emissions from special vehicles.

The planning and construction of the complete tunnel structure must also be based on the relevant regulations for tunnel structures.
Compliance with the geometrical requirements for the guideway must be separately demonstrated for the transition between the guideway resting on the tunnel invert and the adjacent guideway supported directly off the subsoil.
Primary structures
Planning and execution must be project-specific.
Compliance with the geometrical requirements for the guideway must be separately demonstrated for the transition between the guideway resting on the primary structure and the adjacent guideway supported directly off the subsoil. A transitional structure must be provided if necessary.
The long-stator in the transitional structure should be executed without a drive function.
The positioning function must be separately demonstrated for the area of the transitional structure.

Route peripherals

The route peripherals comprise the following modules:

- functionally necessary small structures that are needed close to the guideway route (e.g. radio masts, sectioning points),
- project-specific structures that are necessary locally, positioned close to the route (e.g. noise barriers, sight screens).

Excessive effects of route peripheral installations on the system must be avoided. Planning and execution must be project-specific.

Guideway equipment

The guideway equipment is divided into:

- MSB-specific guideway equipment (including the appropriate fasteners) with
  - long-stator with stator pack and long-stator winding,
  - slide rail,
  - lateral guide rail,
  - guideway-side positioning modules,
  - guideway-side modules of the external on-board energy supply,
- design-specific guideway equipment with
  - beam supports,
  - beam gap covers,
  - earthing and lightning protection,
- and other built-ons, with
  - temporary and/or project-specific built-ons, including fasteners, and
  - rigs for maintenance on the guideway.

Stator pack

The stator packs with their underside form the stator plane and must meet the following requirements:

- Carry the magnetic flow generated by the levitation magnets, withstanding and transmitting the forces generated by the magnetic flow (levitation forces),
- Withstand and transmit the acceleration and braking forces from the motor winding (drive forces),
- Form the reference surface (stator plane) for measuring the air gap between stator pack and levitation magnet,

- Form the reference surface for the guideway inspection,
- Form the tooth/slot sequence for positioning,
- Form the tooth/slot geometry for flow modulation for the inductive energy transmission to the MSB vehicle (on-board energy supply).

The steel sheet grade should fulfil M 800-50 A as per /EN 10106/, alternative project-specific decisions may be taken following functional testing.
The tooth/slot geometry must conform to the system grid of 86 mm.
The stator pack pitch must be 1032 mm, based on the three-dimensional curve.
The dimensions defined in /MSB AG-FW GEO/ for offsets, gaps and the angle-change criterion of the stator plane must be achieved in the assembled unstressed condition at reference temperature.

Long-stator winding

The thrust forces from the drive and the other forces (e.g. dead weight, from dynamic excitation) must be transmitted to the stator packs through the fastening of the long-stator winding in the slots of the stator pack.
The long-stator winding must be constructed as a 3-phase winding (see Figure 24 and Figure 5).
The nominal length of a winding period must be 516 mm corresponding to the wavelength of the magnetic moving field (6 tooth/slot periods).
The guide value for the cable length of a single conductor is 2.35m per linear metre of guideway.
The following requirements must be achieved:

- the electrical data and properties of the motor winding according to Chapter 0 Drive,
- the requirements for long-stator protection as per /MSB AG-ANT/ ,
- connection of the winding earth to the earth of the guideways as per /MSB AG-FW ÜBG/,
- the connection of the motor winding must be made at suitable points (e.g. at supports) allowing for the clearances as per Figure 22 and /MSB AG-FW ÜBG/,
- Temperature and load-related min. and max. gaps in the stator plane must be allowed for when laying the motor winding.

The motor section ends should be laid on guideway beam ends.

Slide rails / slide plane
The slide plane can be an integral part of the guideway beam or be constructed as a slide rail. The slide plane must meet the following requirements:

- withstand the effects introduced by special vehicles while allowing for effects from the environment,
- allow for the arising static and dynamic forces while withstanding the effects from the environment at the support skid/slide plane interface,
- withstand a maximum linear force of 250 kN per MSB vehicle section and transmit it to the guideway beam,
- the linear force between the skid of the MSB vehicle and the slide plane of the guideway that is due to static friction must, given the project-specifically defined environmental conditions and linear inclinations, be greater than the pro rata downhill force and the wind force in the x-direction (see Chapter 0) in areas in which the vehicles must be secured against inadvertent movement.
- the dimensions defined in /MSB AG-FW GEO/ for offsets, gaps and the angle-change criterion of the slide rail must be achieved in the assembled unstressed condition at reference temperature,
- satisfy the defined min. and max. values for the gaps and offsets under live load, both in the planning phase and after the completion of the guideway, with project-specific proof,
- be executed at equidistant spacing parallel to the three-dimensional curve.

The slide rails should be constructed along the length of the beam.

Lateral guide rails/lateral guide plane
The lateral guide rails form with their surface the lateral guide plane, and must meet the following requirements:

- meet the requirements of a reaction rail for the guide magnets and the brake magnet,
- withstand all static and dynamic effects from operations and the environment at the guide magnet/lateral guide plane interface brake magnet/lateral guide plane interface,
- withstand the effects introduced from special vehicles,
- must meet the dimensions defined in /MSB AG-FW GEO/ for offsets, gaps and the angle-change criterion of the lateral guide plane in the assembled unstressed condition at reference temperature.

The lateral guide rails should be executed along the length of the beam and at equidistant spacing to the three-dimensional curve.
The lateral guide rails should be made from special steel with an electrical conductivity reduced by a factor of 3 compared with S235 (ST37-2), or equivalent material. The system de-

sign should allow for a change of brake characteristics and running resistance for an alternative choice of material.

Guideway-side modules of the on-board energy supply of MSB vehicles

The guideway-side modules of the on-board energy supply transmit electrical energy to the vehicle-side modules of the external on-board energy supply in the low speed range, and must be defined project-specifically.

Guideway-side positioning modules,

The guideway-side modules of the positioning system act as reference points. Requirements for their arrangement along the guideway must be defined project-specifically.

Beam support

The beam support must facilitate an adjustment to compensate for plastic subsoil deformation. The beam support must ensure the take-down of all forces from the guideway beams.

Beam gap covers

Gaps between consecutive guideway beams must be closed if they

- can be larger than 20 mm and
- are in route sections with a maximum section speed of more than 150km/h.

Earthing and lightning protection

To protect persons and to protect against the effects of electrostatic discharge as well as in regard to electromagnetic compatibility (EMV), the electrical effects of

- lightning strike,
- differences in potential and
- earth currents and residual currents

of the vehicles and of all modules of the guideway must be taken into consideration when designing an earthing and lightning protection system for the guideway.

A project-specific earthing and lightning protection concept must be created for this purpose.

Other built-ons

Other built-ons on the guideway (due for example to the qualification of new modules, measurements or project-specific requirements) must be designed so that

- under the project-specific environmental conditions they reliably withstand all loads specified for them during the project-specifically defined service life, and
- have no unwanted effects on the system.

Boundary lines and dimensions for fixed internals and vehicles

The following boundary lines must be complied with when designing the guideway modules:

- Boundary line for the kinematic space requirement of the vehicle,
- Clearance for maintenance systems (e.g. vehicle wash),
- boundary line for fixed installations,
- boundary lines for station platforms and platform doors.

The position of the individual elements of the guideway equipment in relation to the three-dimensional curve, and the installation spaces available for the equipment are shown in Figure 22.
The space available between the installation spaces and the boundary lines may be used for local incoming and outgoing lines and as assembly space. The use must be defined project-specifically to avoid multiple occupancies of this space.

Tolerances, deviations of position

The position (Y, Z position) of the functional surfaces and the installation spaces defined for them must be achieved as indicated in Figure 22.
All particulars of the guideway geometry relate to the functional planes in the installed, painted condition (mechanical dimensions, not electrically effective dimensions).
The defined dimensions apply to the unloaded condition (guideway without live load and under its own dead weight only) at project-specifically defined reference temperature.
The maximum and minimum gaps must also be achieved having regard to the thermal linear expansion of the guideway, the elastic deformation of the substructures under the effect of load, and the assembly tolerances.
The geometrical requirements and tolerances of the functional planes are defined in the /MSB AG-FW GEO/.

Other operating plant

The layout of structures near to the route and of the other operating plants must be defined project-specifically.
Consideration must be given to the system requirements in regard to:

- Clearance,
- Boundary lines,
- Aerodynamic influences,
- Influences on the MSB radio system,
- Dimensioning,
- Maintenance and
- other project-specific requirements.

Stations

Section 3(3); Section 15(1) to Section 15(6) /MbBO/ must be taken into consideration. These requirements must be met as follows:

Stations

Stations must be designed for a project-specifically defined pass-through speed that may not exceed the local maximum line speed.
Requirements for weather protection must be defined project-specifically.
Equipping with glazed doors and walls must be carried out according to /DIN EN ISO 12543/ with safety glass.
Lighting, lightning protection/fire protection, floorcoverings, entrances/exits and access for rescue services must be defined project-specifically and based on local regulations.
The guideway within the stations (platforms and adjacent line sections according to Chapter 5.4.4) should be equipped with external on-board energy supply.
The clearances and gaps between vehicle and platform must be defined project-specifically based on the vehicle boundary of MSB vehicles.
The construction/equipment of the stations must be project-specific.

Platform doors

Platform doors are used to prevent hazards to persons while boarding and alighting and from passing trains in automatic train operations (analogous with Section 31(5) BOStrab).
It must be ensured irrespective of the train movements that

- Persons cannot enter the clearance area of the moving train or fall or jump onto the guideway from the platform,
- Objects cannot enter the clearance area of the train from the platform, and
- Persons on the platform cannot be put at risk by the effects of passing trains.

The positioning accuracy, the width and the distance of the outer doors of MSB vehicles and the configuration of the platform doors must be coordinated project-specifically in such a way that during a stop and with the vehicle and platform doors open, a defined clear passage width is available with a defined probability.
This will avoid hazards to passengers while boarding and alighting due to the passage width being too narrow. The Safe Positioning, control engineering relevant positioning or independent positioning means of the platform door system can be used as positioning equipment.
The design of the platform doors must ensure that automatic departure from the secured end position without release by the safety device is not possible.
It should be possible to temporarily set up local operation (e.g. for maintenance work).
Guideway reserving and local operation must be mutually exclusive.
At the platform door system it must be possible to manually lock malfunctioning platform doors, secure them from movement and take them out of technical control and monitoring.
This bypasses the actuation and monitoring of the platform door that is affected.
The signalling of the secured end position (closed, locked and secured from opening) may not be bypassed until the door has been manually locked in the closed position.
Platform doors that have been manually locked and secured against movement may only be released for movement under personnel responsibility.

Platform doors must have emergency unlocking devices that must be operable on the guideway side by passengers and allow the train to be evacuated irrespective of the positioning of the MSB vehicle.

Substations

Substations must be planned and constructed project-specifically.

Operations centre

Operations centres must be planned and constructed project-specifically.

Stopping places

Service stopping places

The layout and equipment of the service stopping places is carried out project-specifically having regard to the requirements in Chapter 0.
Service stopping places must guarantee that passengers and personnel are able to alight in the event of malfunctions.
Alighting is normally assisted by alighting aids carried in the MSB vehicle.
For other requirements see Chapter 0.

Maintenance installations

The maintenance installations are divided into:

- central maintenance installations,
- decentral maintenance installations and
- bases for special vehicles.

The maintenance installations must be designed project-specifically.

Special vehicle

Special vehicles can be driven by their own power.
The technical equipment which special vehicles must have must be defined project-specifically.
The work that is to be done with the special vehicles must be taken into consideration (e.g. maintenance operations).
Trailers of special vehicles which will be deployed independently of those special vehicles must conform to the regulations for special vehicles.
The following applies to the safety of special vehicles:

- Where the operations programme provides for simultaneous train operations with MSB vehicles and special vehicles, special vehicles must be incorporated into the technical safety system.
  In this case, special vehicles should contain technical devices for detecting the vehicle position and for controlling/monitoring the vehicle brakes (service and parking brake) and the vehicle's drive.

- If no simultaneous operation with MSB vehicles and special vehicles are to take place, this must be ensured by appropriate measures.

There is no simultaneous operation of MSB vehicles and special vehicles when all special vehicles are at their intended park positions or are in isolated route sections during the operation of MSB vehicles, or when all MSB vehicles are at intended park positions during operations with special vehicles.

This does not affect exemptions, e.g. for the commissioning phase, for unscheduled maintenance or in conjunction with the rescue concept.

Special vehicles are guided by technical devices. These must be designed so that a tipping of the vehicle from the guideway (even if transversely inclined) is prevented.

The introduced loads from special vehicles must not generate stresses that become decisive for the rating of the guideway.

The mechanical properties of the special vehicle including existing attachments to fulfil their intended purpose (e.g. work platforms, cranes, snow plough) must in regard to

- Geometry (dimensions of car body and chassis, e.g. gauge width),
- Weight and weight distribution,

be matched to the design limits given in /MSB AG-FW BEM/ for position-dependent and time-dependent acceleration effects and clearance requirements as per /MSB AG-FW GEO/.

Interfaces and cross-subsystem functions

Loads and effects

Criteria for designing the structure of vehicle and guideway:

a) The nature and extent of relevant effects (constant, variable and exceptional) must be known.

b) The relevant effects must be known in terms of their frequency of occurrence (assumptions are permitted).

c) The effect combinations and resulting loads on the modules must be known.

d) Loads from effect combinations with a probability of occurrence less than SIL 4 (according to /DIN EN 61508-1/) need not be allowed for in the design.

e) A risk assessment according to EN 50126 should be carried out for hazard cases due to effect combinations according to d).

Statistical data and empirical values from the field service of comparable systems/modules/materials can be used when determining the probability of occurrence according to d).

Vehicle weight

The weight of the MSB vehicles must be defined according to Annex 0, Point 4.3.

The following load conditions must be allowed for to Annex 0 :

- *Unladen weight (without payload),*
- *Mean vehicle weight (e.g. 80% of permissible load capacity) for passenger vehicles,*

- *Permissible vehicle weight (100% permissible load capacity for passenger and goods vehicles),*
- *Maximum vehicle weight (e.g. exceptional operating situations such as evacuation to adjacent sections of passenger vehicles).*

Load capacity is defined as:

- *The weight of passengers with baggage (passenger vehicles),*
- *The weight of the payload (goods vehicles).*

The frequencies of occurrence of the load conditions must be defined project-specifically.
The load conditions to be taken into consideration in the design may be defined differently on the basis of the frequencies of occurrence.
Effects:
On the basis of the project-specifically defined vehicle weights and constraints such as

- permissible accelerations in the x, y and z direction,
- operational and maximum travelling speeds,
- environmental conditions (e.g. side wind, temperatures)
- permissible operating situations,

the effect variables to be applied at the force-transmitting vehicle/guideway interfaces must be determined having regard to the requirements in /MSB AG-FW BEM/ and /MSB AG-ANT/.
The drive current must be limited so that the maximum permissible force according to Chapter 0 No. 7. (1) is not exceeded.
The drive current must be limited so that the maximum permissible acceleration/deceleration according to Section 13(5), /MbBO/ is not exceeded.
The limitation of the drive current in case of a malfunction is dealt with in Chapter 0.

Effect conditions	Frequency of occurrence
A: System condition without failures or faults of modules.	Frequent variable effects
B: System condition with failures or faults of modules.	Rare and extremely rare variable effects

Table 6: Definition of effect conditions A / B

The following effects must be observed.

Interface	Effect conditions A	Effect conditions B
Levitation magnet / long stator	Forces in z-direction from - Vehicle's dead weight - Load capacity allowing for additional mass forces resulting from - the speed and	Increased levitation magnet force of adjacent levitation magnets on failure of the levitation magnet control circuit Increased forces due to drive faults

Interface	Effect conditions A	Effect conditions B
	- the line route (radii, transverse and linear inclination) Effects on the vehicle (esp. aerodynamics) Forces in x-direction from the long-stator drive Effects on the levitation field from drive currents (value and duration must be defined project-specifically)	Increased payload weight in exceptional operating situations
Guide magnet / lateral guide rail	Forces in y-direction with transversely inclined guideway from - vehicle dead weight - load capacity allowing for additional mass forces resulting from - the speed and - the line route (radii, transverse and linear inclination) Aerodynamic effects on the vehicle	Increased guide magnet force of adjacent guide magnets on failure of the guide magnet control circuit Mechanical guide function on failure of two adjacent guide magnet control circuits
Support skid / slide rail	Forces in x, y and z-direction from - vehicle dead weight - load capacity allowing for the guideway position (radii, transverse and linear inclination) and coefficient of friction in x and y-direction.	Mechanical levitation function on failure of two adjacent levitation magnet control circuits Setting down of the MSB vehicle at v > 0 km/h due to drive faults
Vehicle brake / lateral guide rail		Mechanical and/or magnetic forces in x and y-direction when braking with the Safe Brake

Table 7: Effects at the vehicle/guideway interfaces

The dimensioning effects must be defined on the basis of /MSB AG-FZ BEM/ and /MSB AG-FW BEM/ and documented in a project-specific specification.

Positioning

Purpose and structure

Positioning is a facility for determining the position and speed of technically protected vehicles.
The main function "positioning" is divided up into devices and functions within the subsystems Vehicle (if the vehicles are technically protected), Guideway, Operation Control System and Drive Figure 18*).*

Functional requirements

The requirements for positioning (equipment for detecting position and speed information) must be defined by all subsystems.
Devices for detecting the position and speed information are referred to as "control system-relevant positioning" (see Figure 18*).*
There must be fixed components for ascertaining reference points and relative points.
The detection of position and speed information of technically protected vehicles is achieved by scanning features of the guideway, e.g. position reference points installed on the guideway (position reference strips, LRL) and the stator packs (slot / tooth periodicity).
The guideway-side position information must be captured by vehicle-side devices and further processed:

- The following information must be provided for the drive (see also /MSB AG-ANT/):
  - Vehicle location,
  - Vehicle position signal (rotor angle),
  - Vehicle identifier.
- The following information must be provided for the "Safe Positioning" function of the operation control system (see /MSB AG-BLT/):
  - Vehicle location,
  - Vehicle speed,
  - Direction of travel.
- Position information must also be provided for diagnostic purposes.

The accuracy, up-to-dateness and backup procedures on the transmission paths of all position information must be defined project-specifically and, if necessary, dependent on position and speed.
The coordinate system (chainage points/kilometre markers) and its relation to the vehicle must be defined project-specifically allowing for the vehicle length.
Other requirements for the interfaces between the participating subsystems must be defined project-specifically.
The reference points along the line and in the approach to

- Stations,
- Stopping places,
- Parking places and
- Track-switching devices

must be defined project-specifically.

Constructional requirements

Installation positions of the vehicle-side devices (e.g. sensors for scanning the slot/tooth periodicity of the long stator and the reference point information, also electronic evaluator modules) must be defined project-specifically.
The following particular factors should be considered for the vehicle-side devices:

- the space required by the guideway-side components (see Figure 22) allowing for dynamic movements of the moving vehicle,
- the environmental conditions and mechanical requirements according to /MSB AG-UMWELT/, /EN 50125-1/ and /EN 61373/.

Details of the requirements for the guideway-side devices will be found in /MSB AG-FW ÜBG/.
Other requirements for the interfaces between the participating subsystems must be defined project-specifically.

Verification

Safety requirements for the positioning system including responsibilities for verification must be defined project-specifically in interface documents.
Their compliance must be proven across all subsystems for the complete functionality.
Typical requirements are:

- *Diversity and independence in both the detection and processing of the data,*
- *Fault disclosure (permissible failure disclosure time, system responses),*
- *Safety of isolated failures.*

Operation

Difference between Operation and Modes

Definition of Operation

"Operation" is the totality of all measures used to carry passengers and goods (/MbBO/, Section 2).
This comprises the provision of the complete MSB system as well as the preparation and execution of journeys (train operations) and the performance of maintenance work.

Requirements for operation must also be laid down in the Operation Manual to be produced by the MSB contractor (/MbBO/, Section 24). Project-specific consideration must be given to the characteristics of the MSB system and the operational/organisational framework conditions of the MSB contractor and relevant statutory requirements.
Building or maintenance work (including associated journeys) can take place simultaneously during train operations. Project-specific arrangements must be laid down for this.
Project-specific special arrangements must be made and, if necessary, additional safety measures put in place for journeys for the first-time putting into service of the system and for demonstration journeys during the commissioning phase.
Requirements for rules for operation (train operations and maintenance) should be taken from /MSB AG-BTR /.

Definition of Modes

"Modes" are defined and clearly delimited types of train operation which differ in their technical and nontechnical measures for the execution of journeys.

Modes are vehicle-related, i.e. a mode is set for each vehicle participating in the train operation.
The train operation must be carried out in one of the following two modes:

- **"Normal operation"**:
  Journeys under complete technical safety,
- **"Departure from normal operation":**
  Journeys not under complete technical safety
  Complete technical safety of the guideway should be present for train operations with MSB vehicles conducted in the "Departure from normal operation" mode. The OCS functions of journey sequence control, guideway securing, running profile monitoring, drive shutdown and Safe Positioning should not be impaired. It is permissible for the monitoring of safety-relevant vehicle-side status signals (monitored by the OCS 'vehicle securing' function) to be not fully available.
  This mode may be necessary for transfer journeys to a maintenance installation, for example.
  Project-specific decisions must be taken regarding the operational arrangements to be applied to carry out journeys in the "Departure from normal operation" mode.

For special vehicles, the constraints on train operations must be decided project-specifically depending on their technical equipment.
Exceptions such as the securing of train operations within maintenance facilities must be defined project-specifically.
For the simultaneous operation of MSB vehicles and special vehicles, see Chapter 0.

Principles for the application of the modes

Train operations with passengers with MSB vehicles must be carried out in the normal operation mode as a matter of principle. Exceptions are only permitted in malfunctions and emergencies that must be defined separately.
For train operations in the "Departure from normal operation" mode, the measures for the non-technical monitoring of the vehicle status must be defined in the rules for operation.
The simultaneous operation of vehicles in different modes must be regulated project-specifically.

Operational functions and procedures

Journey inputs and operations monitoring

Manual and automatically generated journey inputs must be possible for journeys in the modes according to Chapter 0.
The train operation personnel must be able to carry out monitoring and controlling tasks.
Train operation personnel must be able to change modes.
For other requirements, see /MSB AG-BLT/.

Departure from a station in normal operation

Securing the MSB vehicle outer doors: See /MSB AG-BLT/, Chapter 6.3.3.5.
Securing the platform doors: See /MSB AG-BLT/, Chapter 6.3.2.7.
Optical and acoustic signals for passengers that signal the time to departure should be provided at the stations.

Approach to a station in normal operation

MSB vehicles must approach stations accurately and set down automatically.
Securing the MSB vehicle outer doors: See /MSB AG-BLT/, Chapter 6.3.3.5.
Securing the platform doors: See /MSB AG-BLT/, Chapter 6.3.2.7.
Passing through stations with locked platform doors must be possible; the maximum passing speed must be defined project-specifically.

Activating and deactivating of MSB vehicles

Treatment of the Safe Brake (brake test): See /MSB AG-BLT/, Chapter 6.3.3.2.
Control / monitoring on-board energy supply: See /MSB AG-BLT/, Chapter 6.3.3.3.
A direct-acting deactivation and shutdown of on-board electrical systems for a particular reason that is done without a technical consent check must be regulated as a project-specific, operational special measure (operation under personnel responsibility).
From vehicles that are parked while activated,

- the status of the fire alarms should still be transmitted and
- diagnostic data should be transmitted and incorporated into operational dispatching.

Processing automatic stops of MSB vehicles

Treatment of automatic stops is dealt with in /MSB AG-BLT/, including in Chapters 6.3.3.7 ("Automatic Stop") and 6.3.4 ("Running Profile Monitoring").
Forced braking should normally be carried out by the drive.
Cases that require immediate activation of the Safe Brake are given in /MSB AG-BLT/.
The sequence of an automatic stop with the Safe Brake is described in /MSB AG-BLT/, Chapter 6.3.3.4, its cancellation is described in /MSB AG-BLT/, Chapter 6.3.3.7.

Constraints for moving the special vehicles

It must be possible to operate special vehicles outside the environmental conditions defined in /MSB AG-UMWELT/ (e.g. for winter service operations). The limits to be observed must be defined project-specifically.
If the special vehicles cannot travel the whole MSB guideway because of their design, then appropriate restrictions and exclusions must be laid down project-specifically.
Further requirements for the treatment of special vehicles in operating procedures are given in /MSB AG-BTR /.

Quality management

The requirements of standard /DIN EN ISO 9001/ must be fulfilled in all phases of planning, execution and operation of the MSB system by introducing and maintaining a quality management system.
/DIN EN ISO 9004/ also provides additional guidance for improving the effectiveness and efficiency of the quality management system to be put in place.
A project-specific quality management plan must be produced for each subsystem.

Figures

Document tree

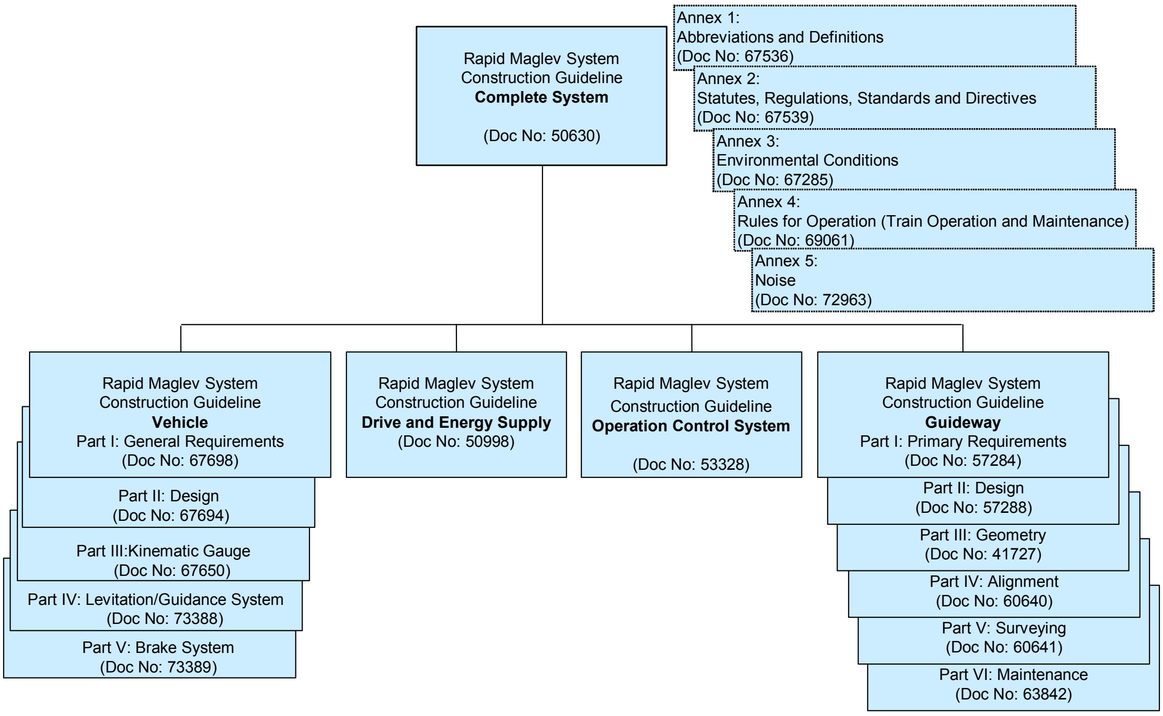
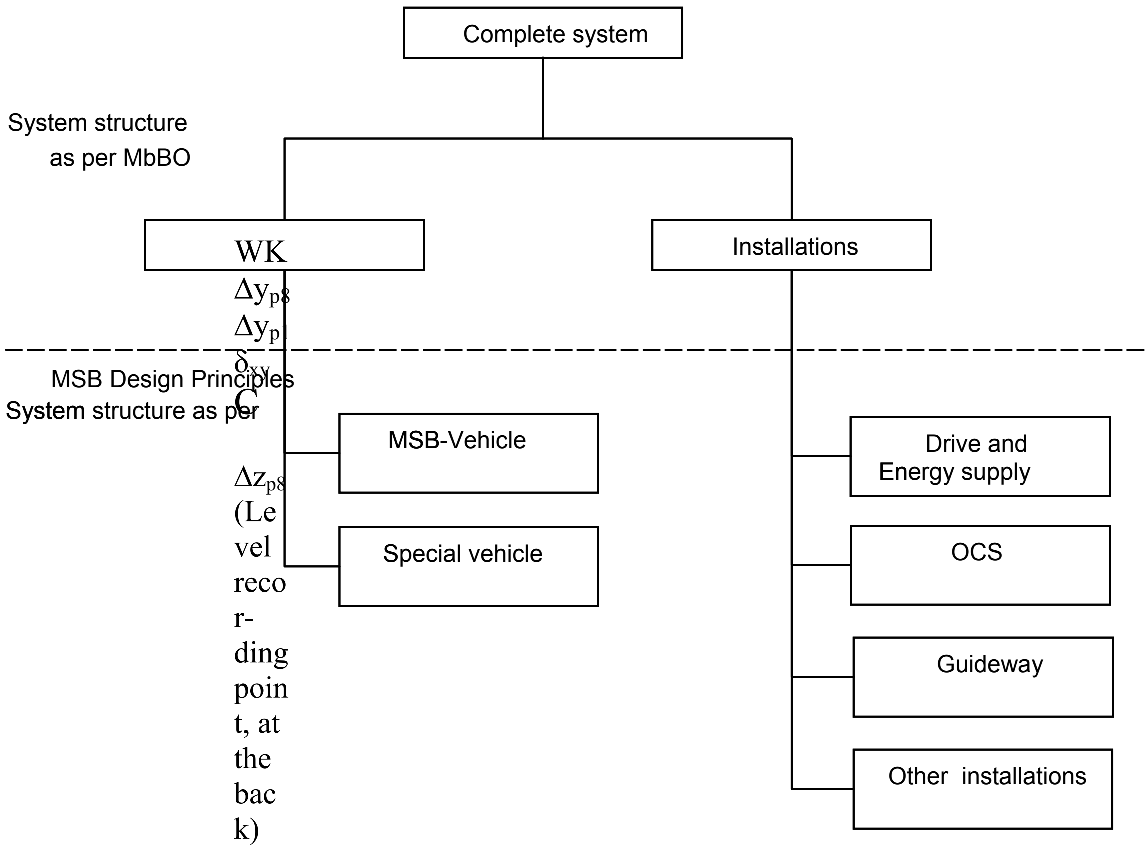


Figure 1: Document tree High-speed Maglev System Design Principles

System structure and system of coordinates



WK
Δy_{p8}
Δy_{p1}
δ_{xy}
C
Δz_{p8} (Level recor-ding point, at the back)
Δz_{p1} (Level recor-ding point, at the front)
γ_{xz}
η_{0yz}
α
η_{yz}
Centre of rota-tion
C
Stator sur-face
Lateral gui-de rail
Slid

Figure 2: System structure

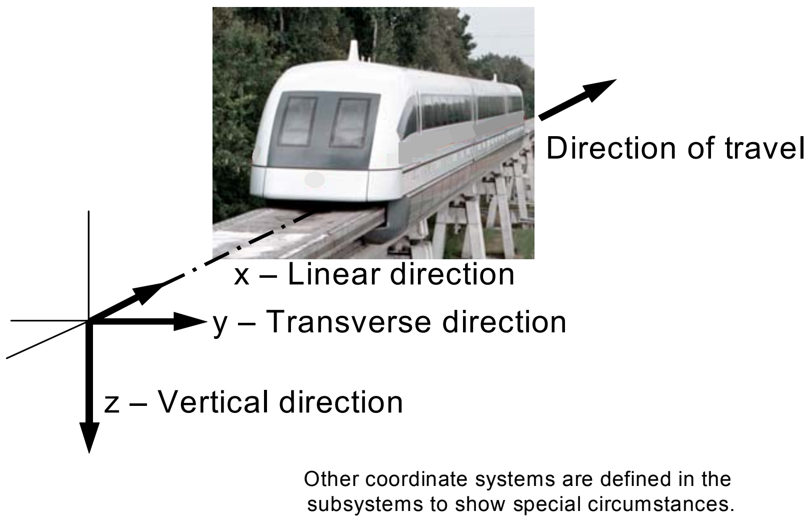


Figure 3: System of coordinates

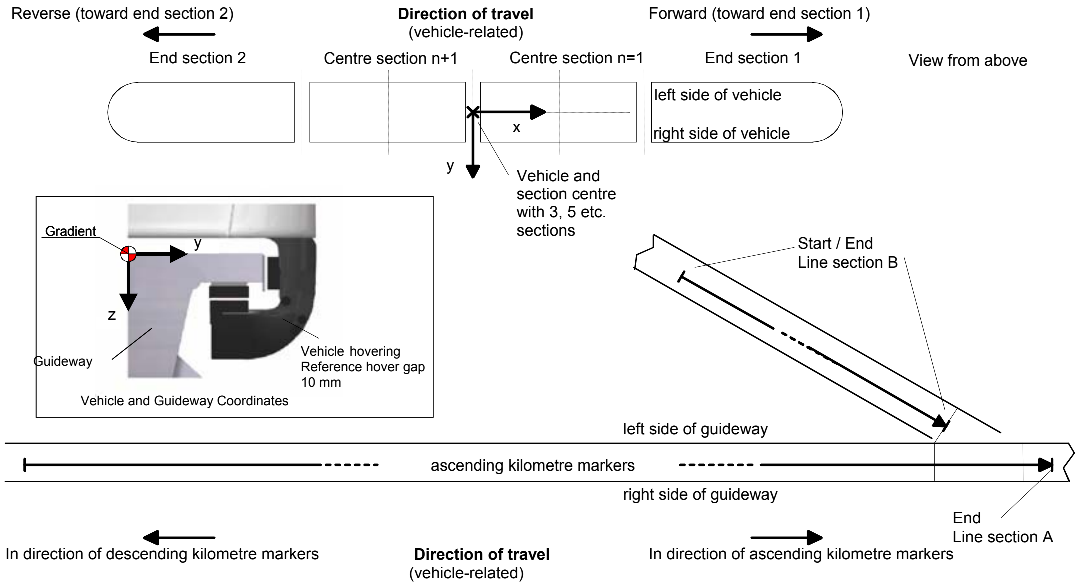


Figure 4: System of coordinates and direction of travel

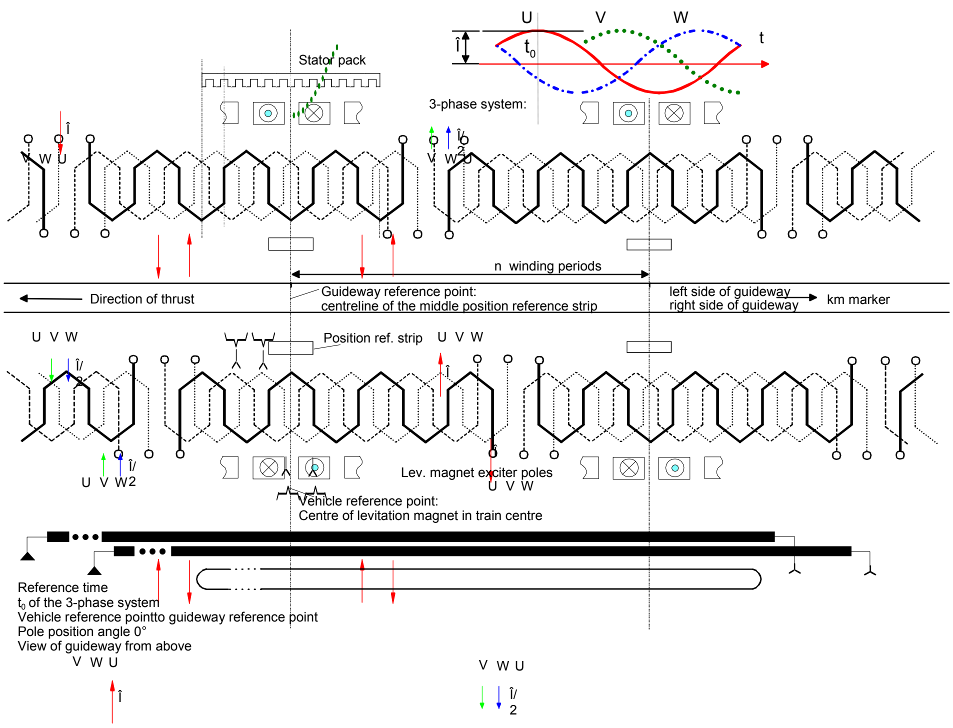


Figure 5: Layout of winding legs, reference position, exciter poles

MSB vehicle sections for passenger transport

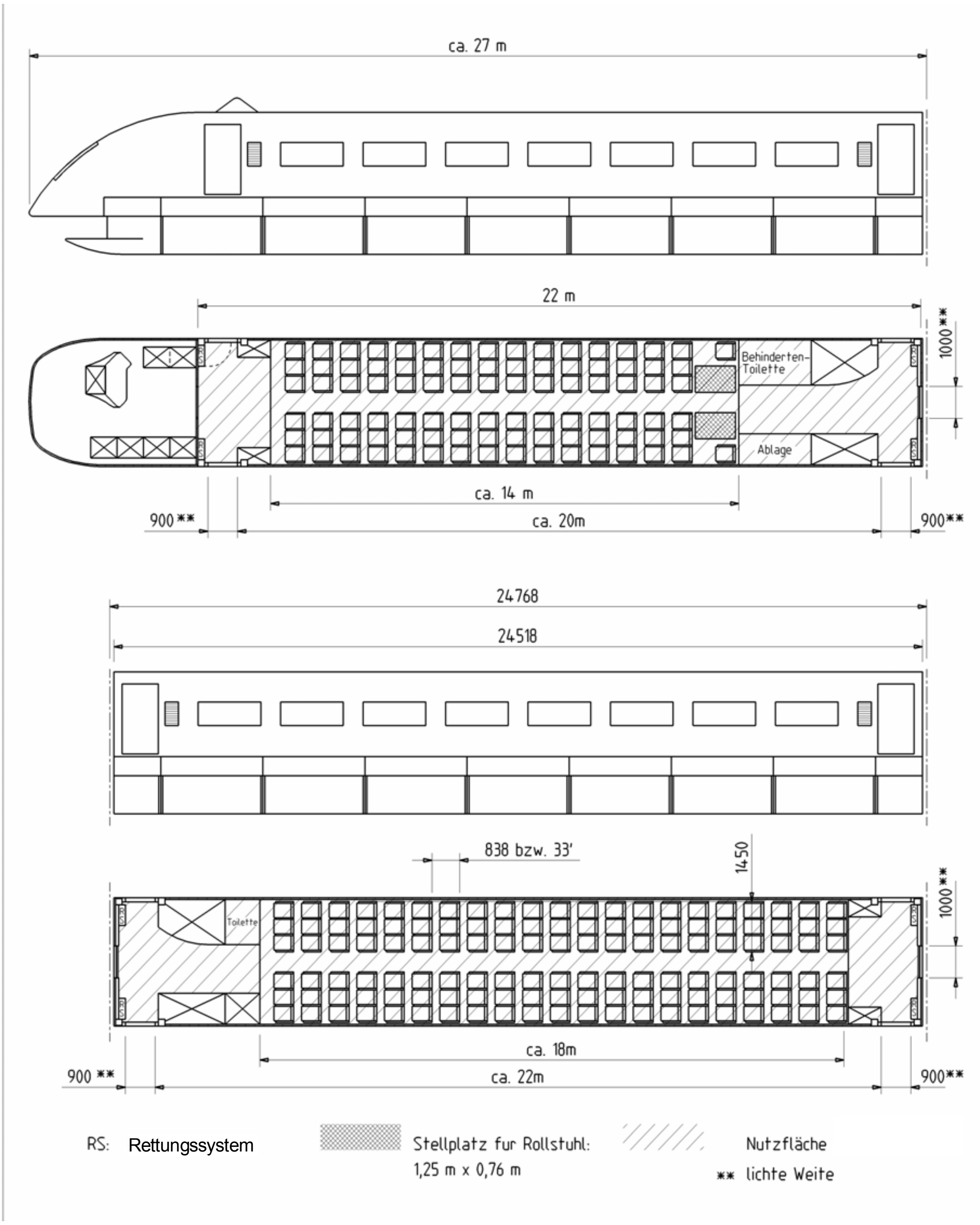


Figure 6: Vehicle sections for passenger transport long-haul (example)

Behindertentoilette	Disabled toilet
Ablage	Storage
bzw.	or
Rettungssystem	Rescue system
Stellplatz für Rollstuhl	Place for wheelchair
Nutzfläche	Useful surface area
lichte Weite	Clear width

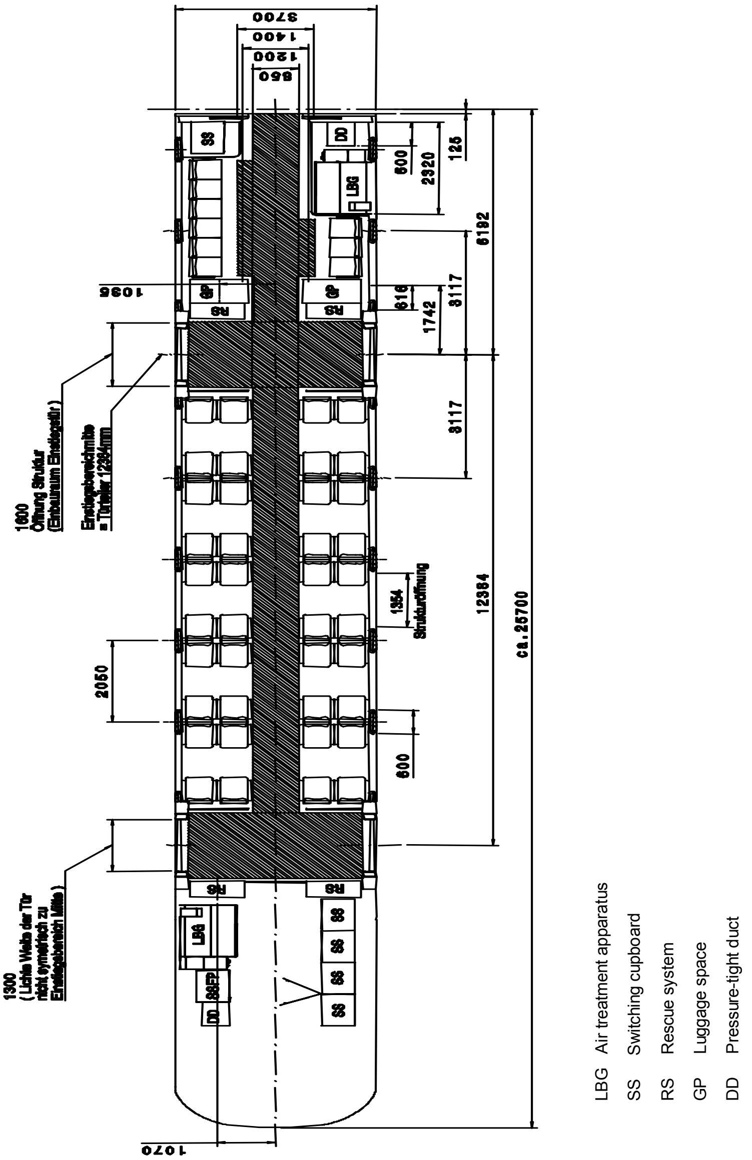


Figure 7: Vehicle end sections for passenger transport airport link (example)

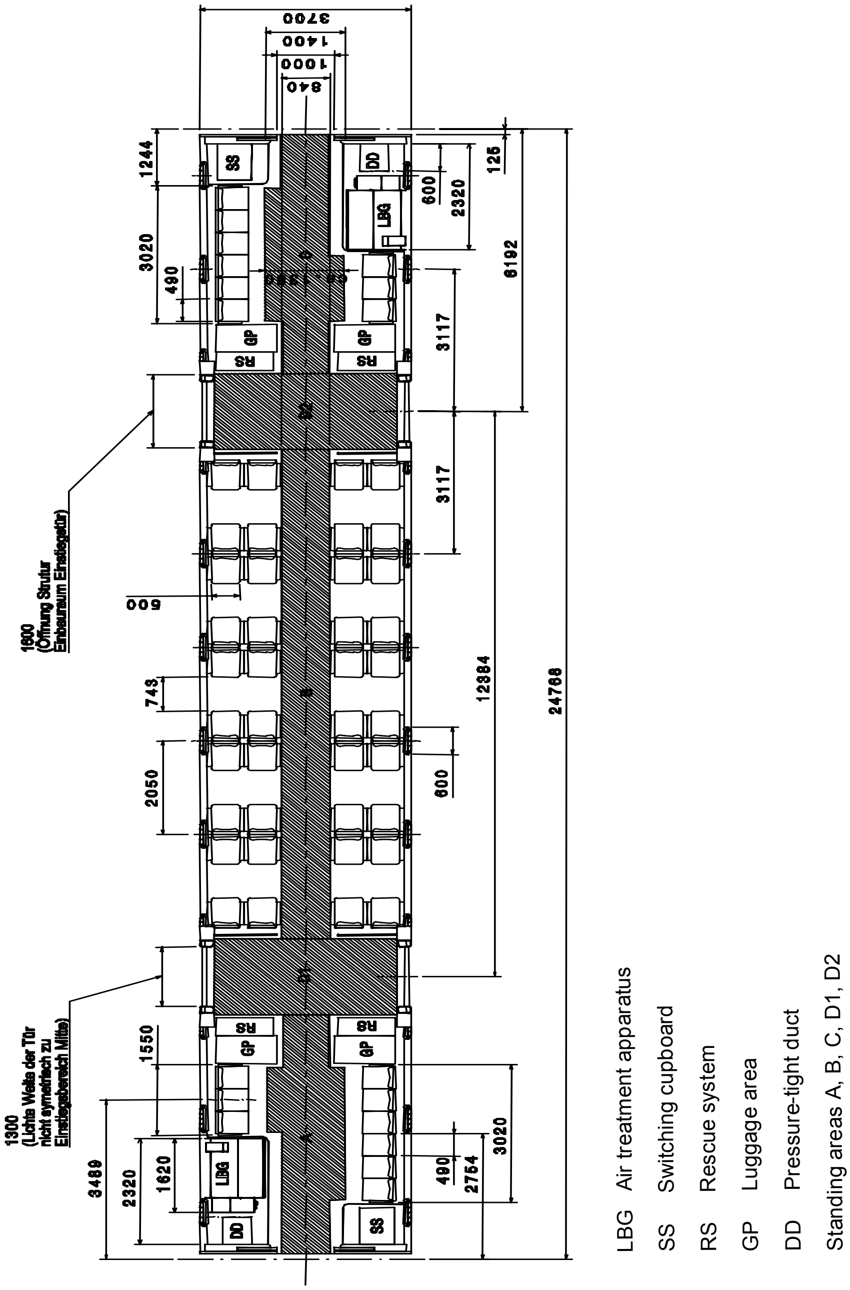


Figure 8: Vehicle centre sections for passenger transport airport link (example)

Levitation / guide system

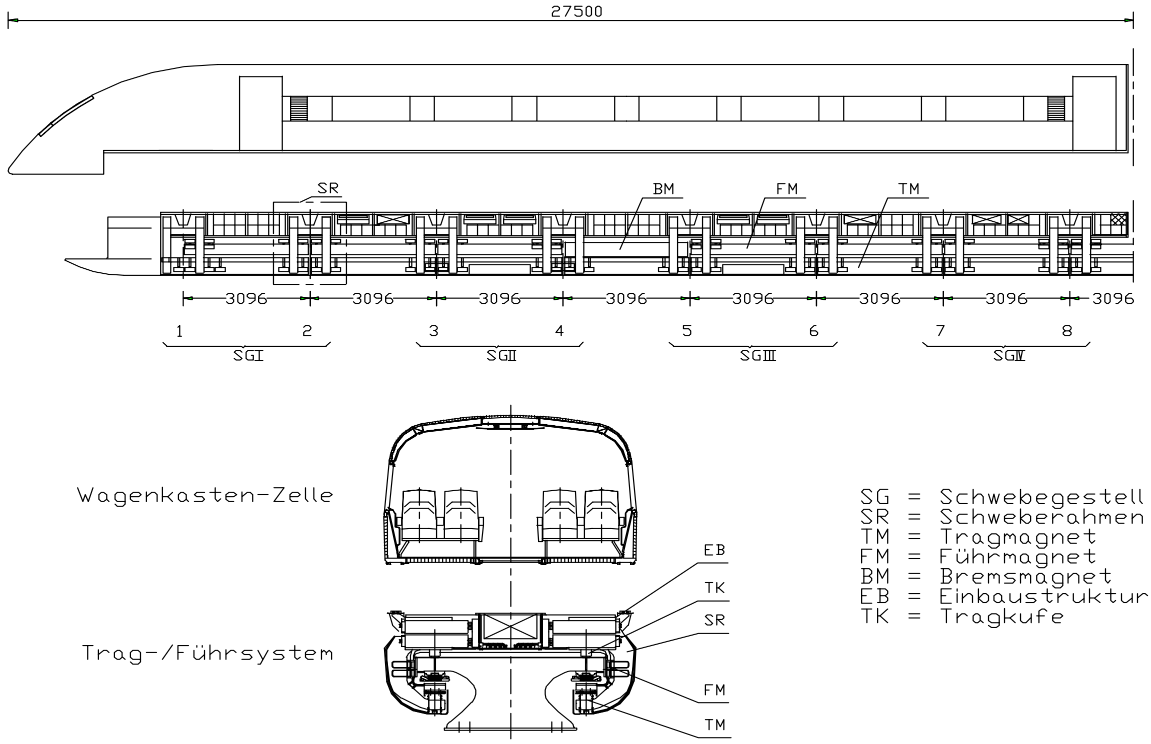


Figure 9: Levitation/guide system (example)

Wagenkasten-Zelle	Body cell
Trag-/Führsystem	Support/guidance system
Schwebegestell	Levitation chassis
Schweberahmen	Levitation frame
Tragmagnet	Support magnet
Führmagnet	Guidance magnet
Bremsmagnet	Braking magnet
Einbaustruktur	Mounting structure
Tragkufe	Support skid

Braking curve Safe Brake

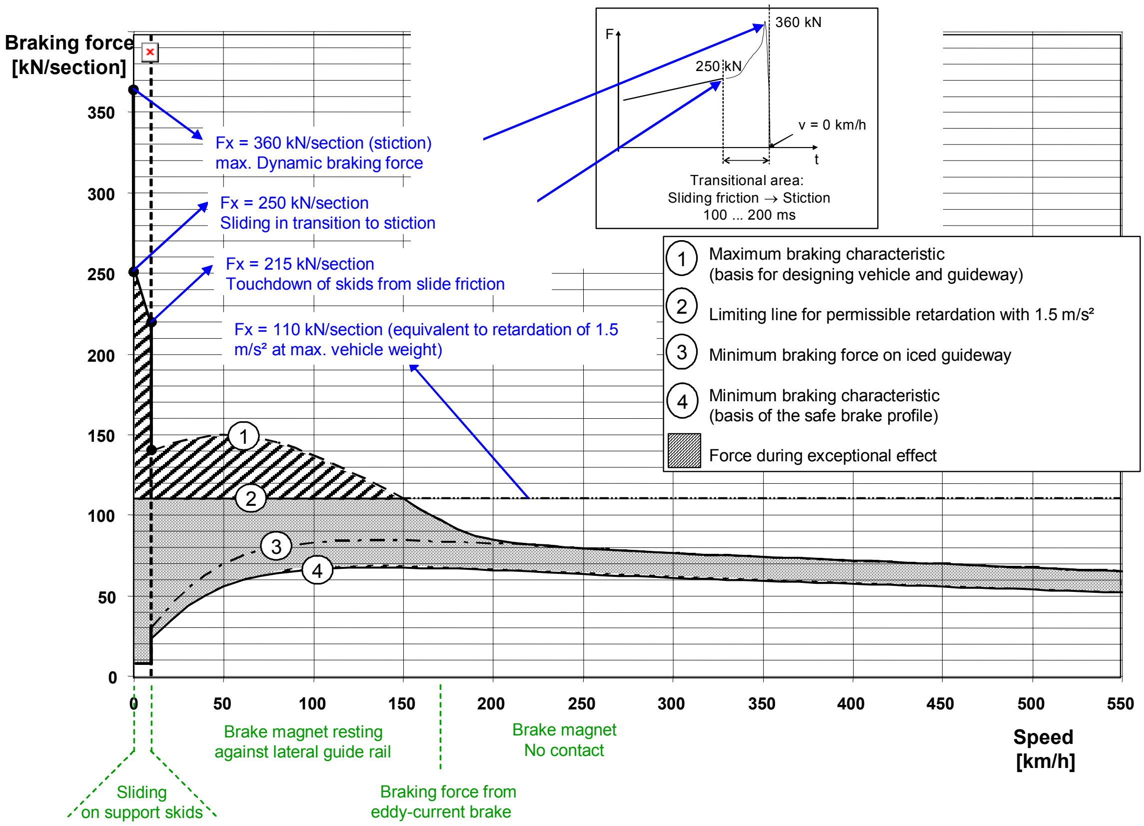
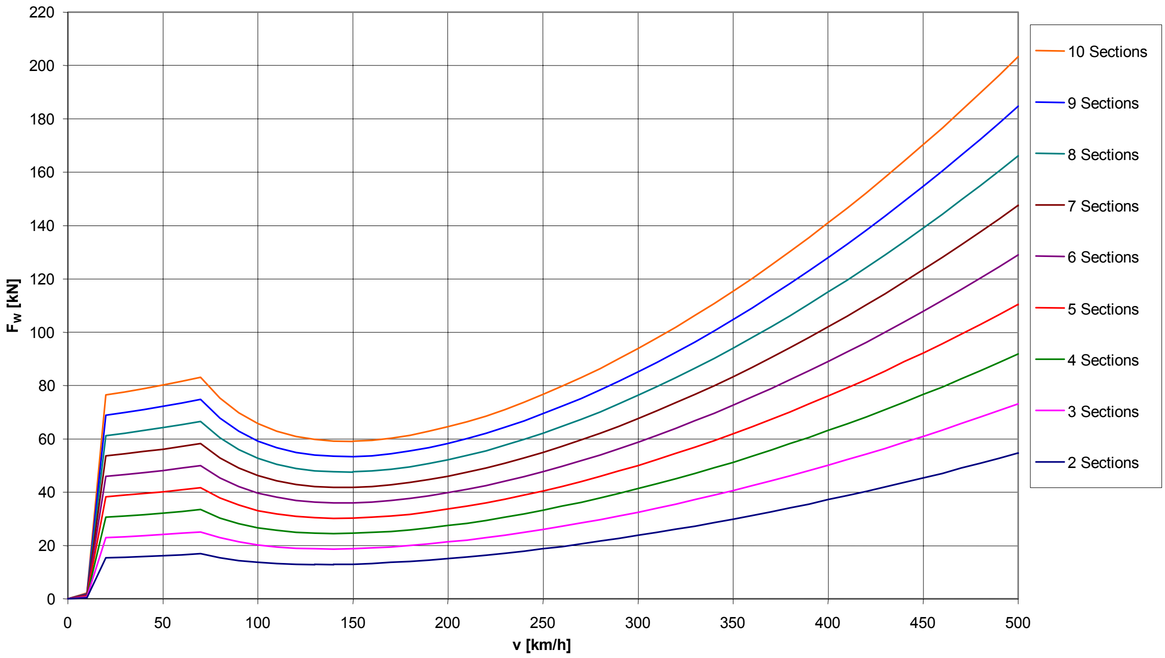


Figure 10: Braking characteristic of safe brake for an MSB vehicle section.

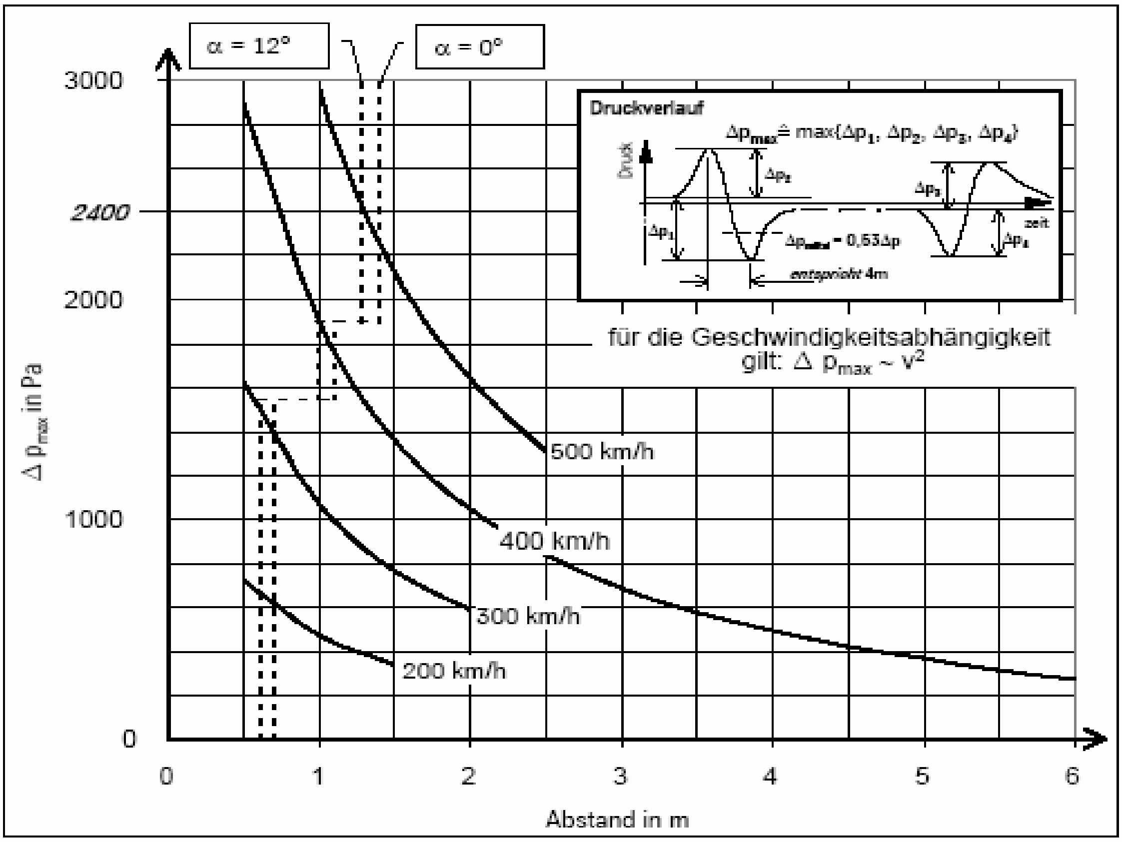
Running resistance



For explanation see Chapter 0

Figure 11: Running resistance (airport link - planning status 2006)

Pressure effect (outside tunnels)



Druckeinwirkung auf ebenen Flächen parallel zur Fahrtrichtung, ortsfest oder parallel bewegt.

- - - - - Abstand der Fahrzeug-Seitenwände bei Zugbegegnung:

$D_m = S \cdot \cos(\alpha) - B_{WK\text{-}A}$ mit S-Spurmittenabstand gem. Tab. 5
α - Querneigung
$B_{WK\text{-}A}$ – Äußere Wagenkastenbreite gemäß Anhang Nr. 4.2 (4)

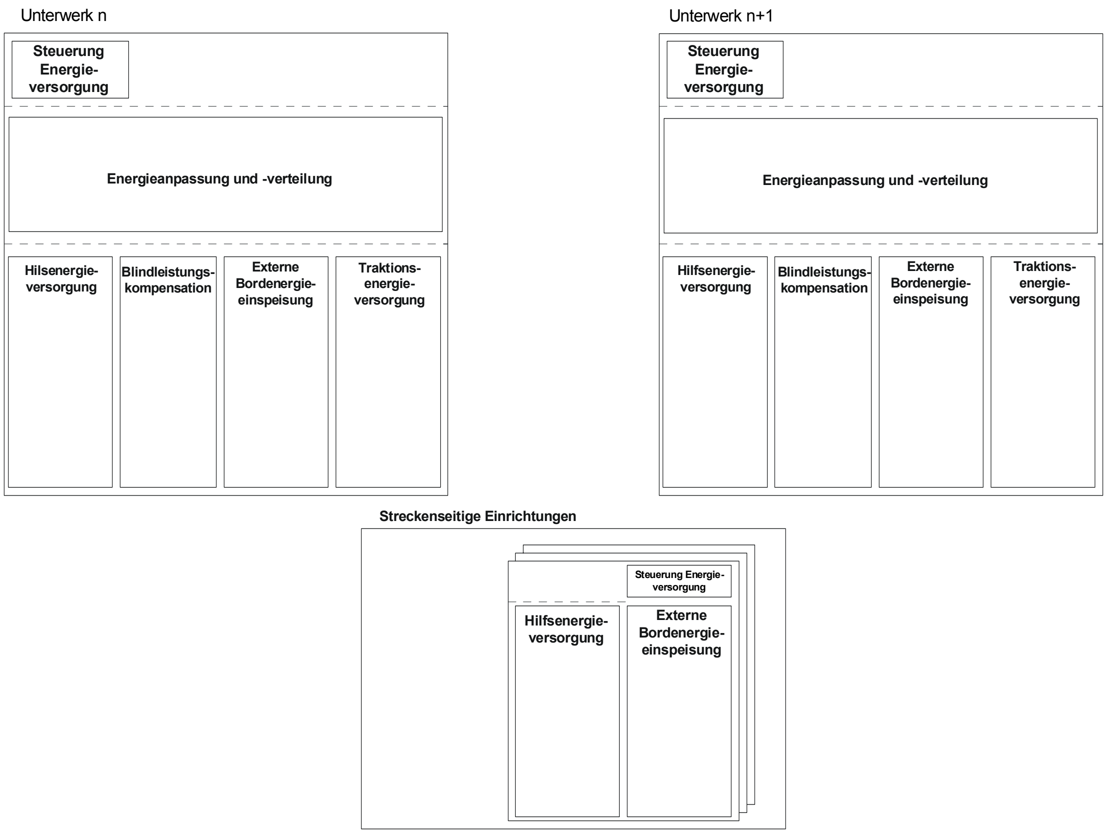
Fahrwegquerneigung	α / °	0			12		
Spurmittenabstand	S / m	4,4	4,8	5,1	4,4	4,8	5,1
Abstand der Fahrzeugseitenwände bei Zugbegegnung	D_m / m	0,70	1,10	1,40	0,60	1,00	1,29

Figure 12: Pressure effect from a passing MSB vehicle (outside tunnels)
(airport link - planning status 2006)

Druckverlauf	Pressure curve
für die Geschwindigkeitsabhängigkeit gilt	the following applies to the velocity function
Abstand in m	Distance in m

Druckeinwirkung auf ebenen Flächen…	Pressure effect on even surfaces parallel to direction of travel, fixed or moving in parallel
Abstand der Fahrzeug-Seitenwände…	Distance between vehicle side walls when trains meet
Spurmittenabstand gem. Tab. 5	Track centres according to Table 5
Querneigung	Incline
Äußere Wagenkastenbreite…	External body width according to Annex 4.2 (4)
Fahrwegquerneigung	Guideway incline

Structure of the energy supply



Unterwerk	Substructure
Steuerung Energie-versorgung	Control of energy supply

Energieanpassung und -verteilung	Energy adaption and distribution
Hilfsenergieversorgung	Auxiliary energy supply
Blindleistungskompensation	Reactive power compensation
Externe Bordenergie-einspeisung	External onboard energy supply
Traktions-energie-versorgung	Traction energy supply
Streckenseitige Einrichtungen	Track-side equipment

Figure 13: Structure of the energy supply (example)

Structure and functions of the drive

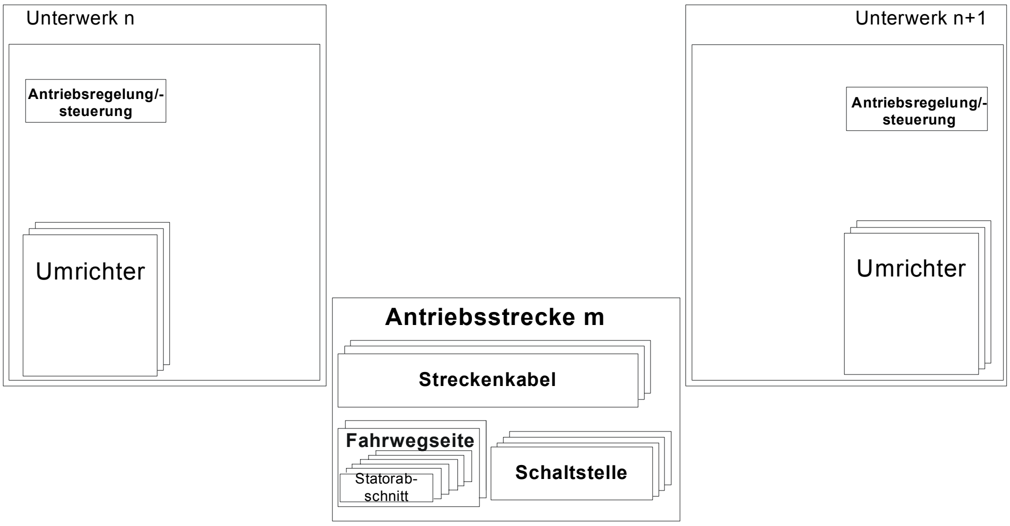
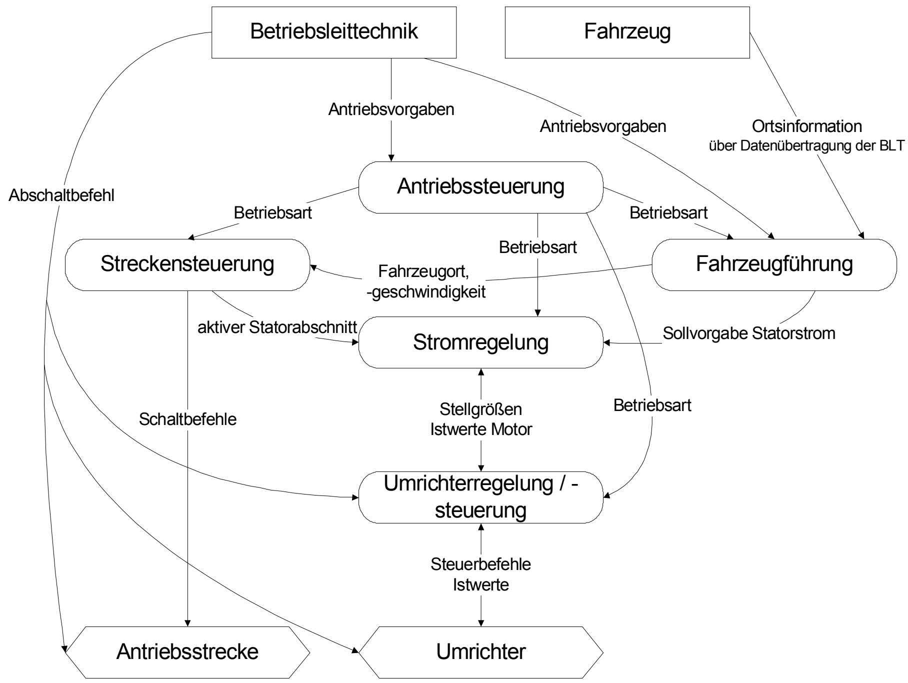


Figure 14: Structure of the drive (example)

Unterwerk	Substructure
Antriebsregelung/-steuerung	Propulsion system regulation/control
Umrichter	Converter
Antriebsstrecke	Drive section

Streckenkabel	Section cable
Fahrwegseite	Guideway side
Statorabschnitt	Stator section
Schaltstelle	Switching point



Drive functions are shown in oval boxes and external components in rectangular boxes.
Figure 15: Functions of the drive

Betriebsleittechnik	Operational control system (BLT)
Fahrzeug	Vehicle
Antriebsvorgaben	Propulsion system settings
Ortsinformation über Datenübertragung der BLT	Location information regarding data transmission from BLT
Abschaltbefehl	Shutdown command
Betriebsart	Type of operation
Antriebssteuerung	Propulsion system control

Streckensteuerung	Section control
Fahrzeugart, -geschwindigkeit	Vehicle type, speed
Fahrzeugführung	Vehicle guidance
aktiver Statorabschnitt	active stator section
Stromregelung	power control
Sollvorgabe Statorstrom	Desired settings for stator power
Stellgrößen Istwerte Motor	Variables for actual values for motor
Schaltbefehle	Switching commands
Umrichterregelung/-steuerung	Convertor regulation/control
Steuerbefehle Istwerte	Control commands actual values
Antriebsstrecke	Propulsion system section
Umrichter	Covnertor

Structure and functions of the operation control system

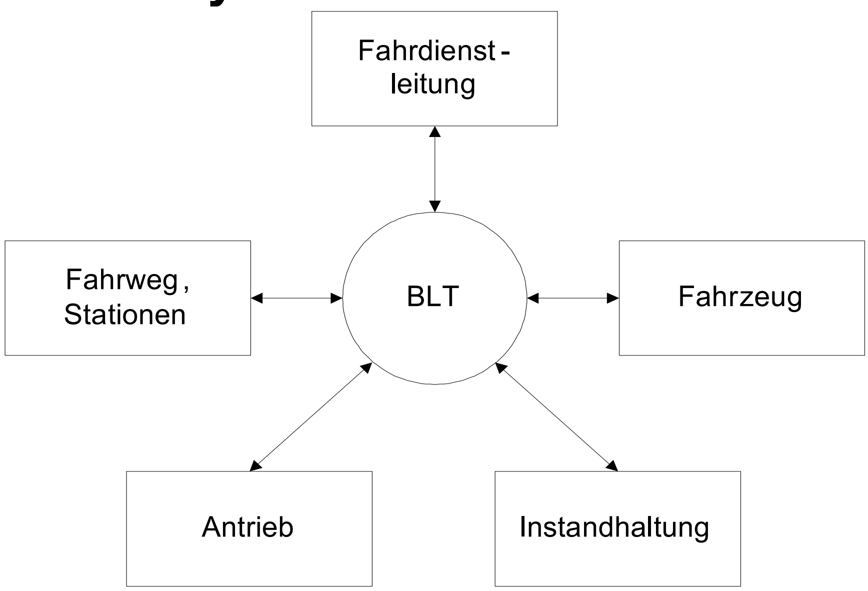
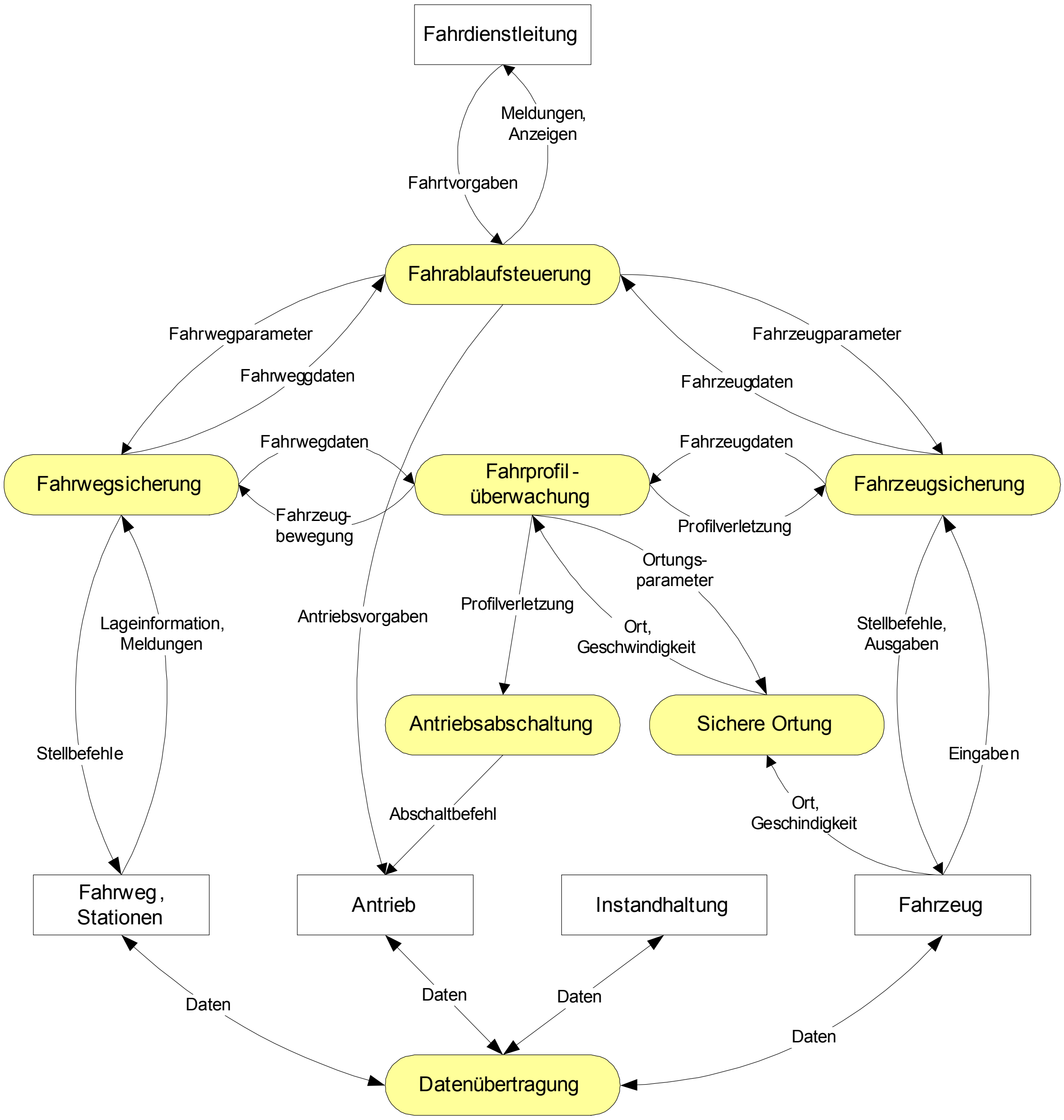


Figure 16: Placement and interfaces of the OCS

Fahrdienstleitung	Traffic controller
Fahrweg, Stationen	Guideway, stations
Fahrzeug	Vehicle
Antrieb	Propulsion system
Instandhaltung	Maintenance



OCS functions are shown in oval boxes and external components in rectangular boxes.

Figure 17: OCS functions and data flows

Fahrdienstleitung	Traffic controller
Meldungen, anzeigen	Messages, displays
Fahrtvorgaben	Trip settings
Fahrablaufsteurerung	Trip progress control

Fahrwegparameter	Guideway parameters
Fahrzeugparameter	Vehicle parameters
Fahrwegdaten	Guideway data
Fahrzeugdaten	Vehicle data
Fahrwegsicherung	Guideway protection
Fahrprofilüberwachung	Driving profile monitoring
Fahrzeugsicherung	Vehicle protection
Fahrzeugbewegung	Vehicle movement
Profilverletzung	Profile violation
Ortungsparameter	Location parameters
Lageinformationen, Meldungen	Position information, messages
Antriebsvorgaben	Propulsion system settings
Ort, Geschwindigkeit	Location, speed
Stellbefehle, Ausgaben	Actuator commands and output
Antriebsabschaltung	Propulsion system shutdown
Sichere Ortung	Safe location
Stellbefehle	Actuator commands
Eingaben	Inputs
Abschaltbefehl	Shutdown command
Ort, Geschwindigkeit	Location, speed
Fahrweg, Stationen	Guideway, stations
Antrieb	Propulsion system
Instandhaltung	Maintenance
Fahrzeug	Vehicle
Daten	Data
Datenübertragung	Data transmission

Structure of the positioning

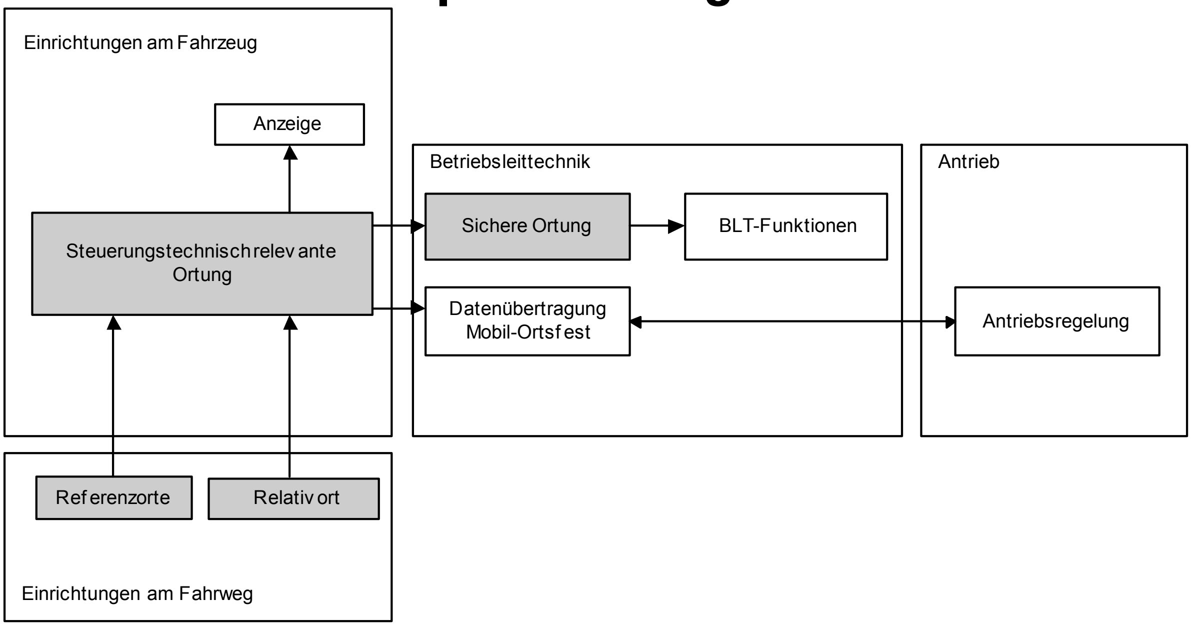


Figure 18: Structure of the positioning (example)

Einrichtungen am Fahrzeug	Equipment on vehicle
Anzeige	Display
Betriebsleittechnik	Operational control system (BLT)
Antrieb	Propulsion system
Sichere Ortung	Safe location
BLT-Funktionen	BLT functions
Steuerungstechnisch relevante Ortung	Location that is relevant to the controls
Datenübertragung Mobil-Ortsfest	Transmission of data between mobile and fixed locations
Antriebsregelung	Regulation of propulsion system
Referenzorte	Reference locations
Relativort	Relative location
Einrichtungen am Fahrweg	Equipment on guideway

Elevated guideway

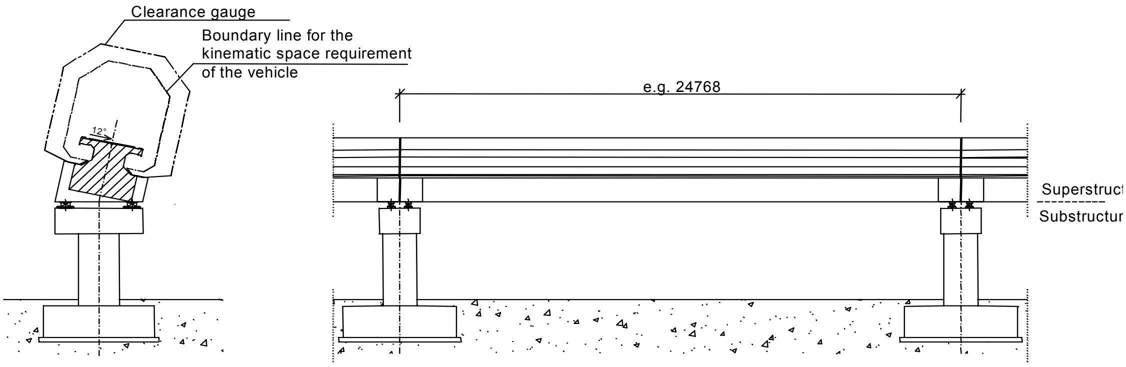


Figure 19: Elevated guideway (example)

At-grade guideway

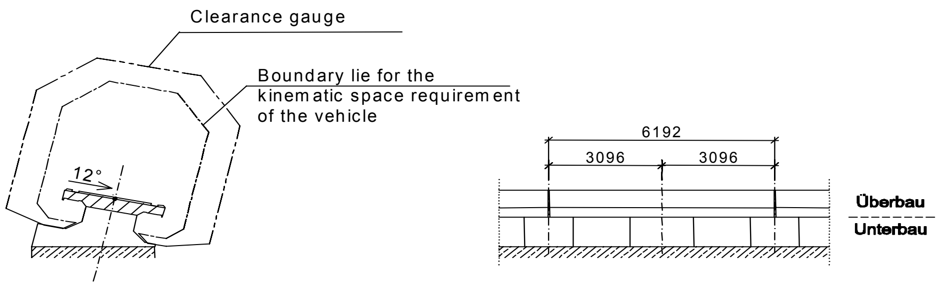


Figure 20: At-grade guideway (example)

Beam dimension

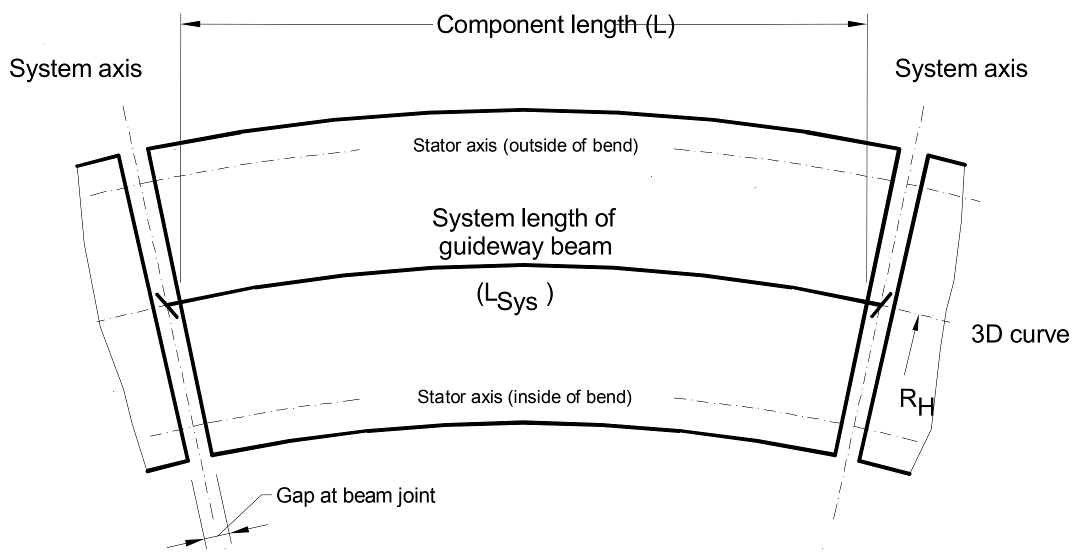
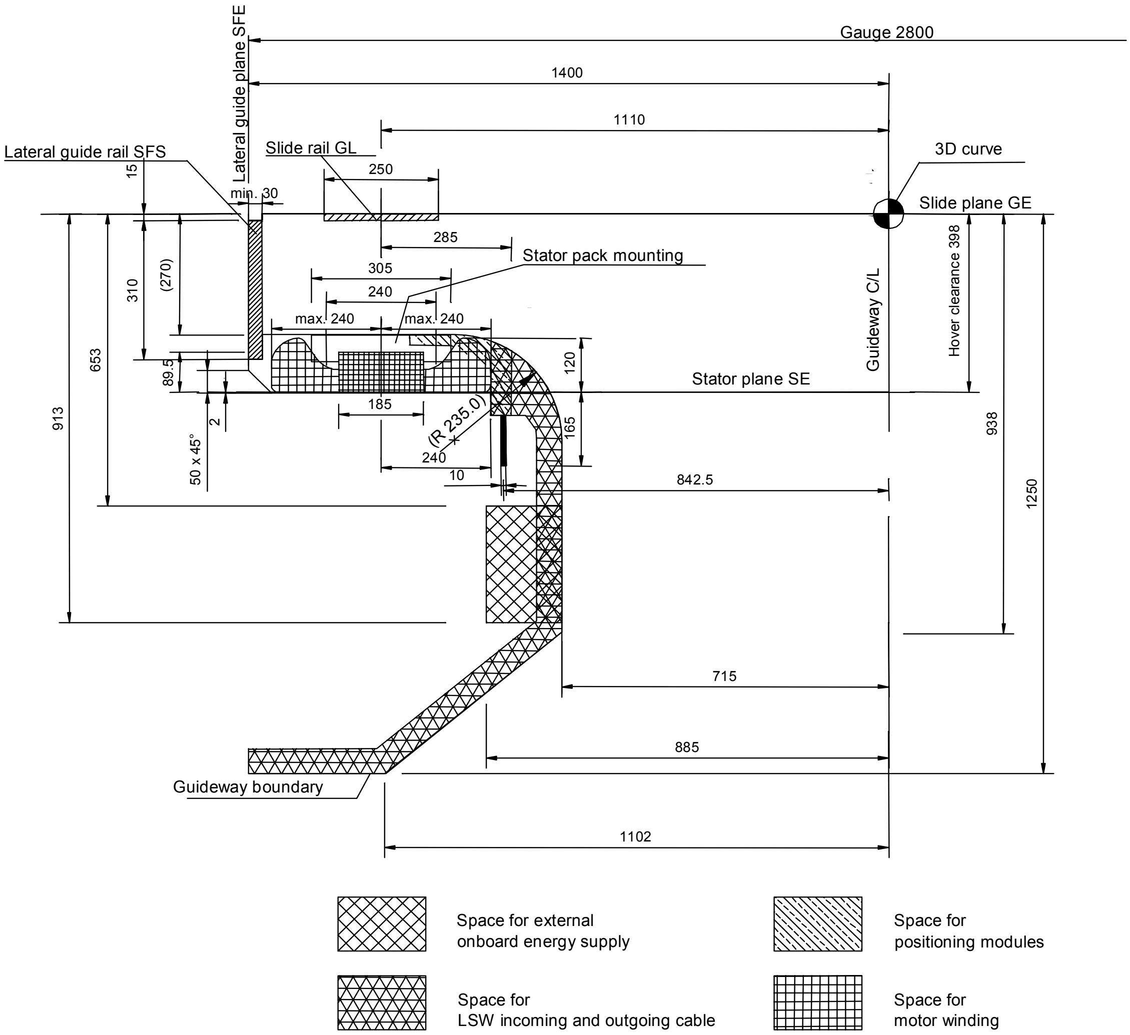


Figure 21: Beam dimension - Relationship between component length and system length

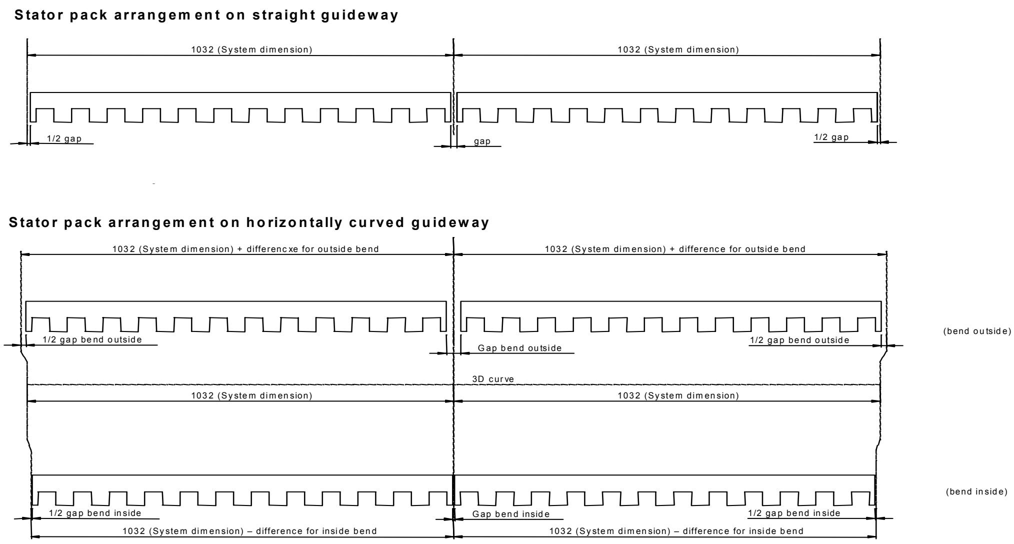
Guideway equipment and functional planes



( ) Figures in brackets are design-specific

Figure 22: Functional elements, functional planes and installation spaces on the guideway, dimensions (nominal)

Stator pack arrangement



The lengths of the individual stator pack types must be defined project-specifically.

Figure 23: Stator pack arrangement (example)

Long-stator winding

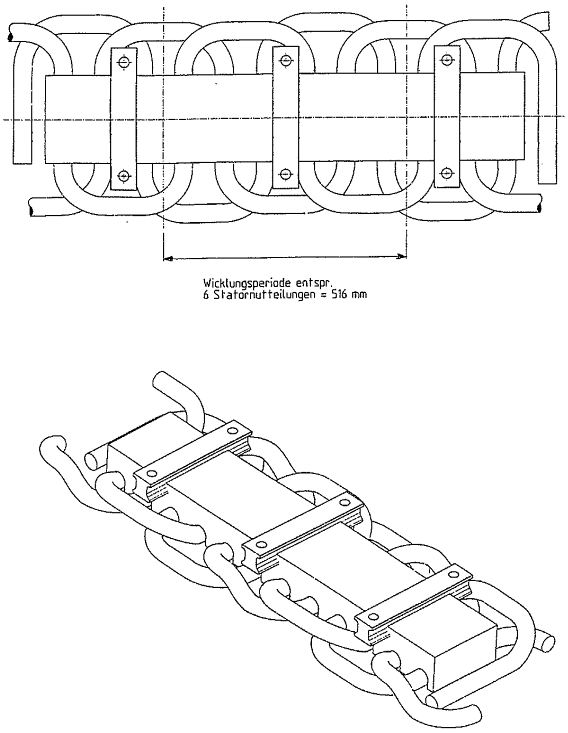


Figure 24: Long-stator winding (example)

Wicklungsperiode entspr. 6 Statornutteilungen = Winding period corresponding to 6 stator slot pitches

Track-switching devices

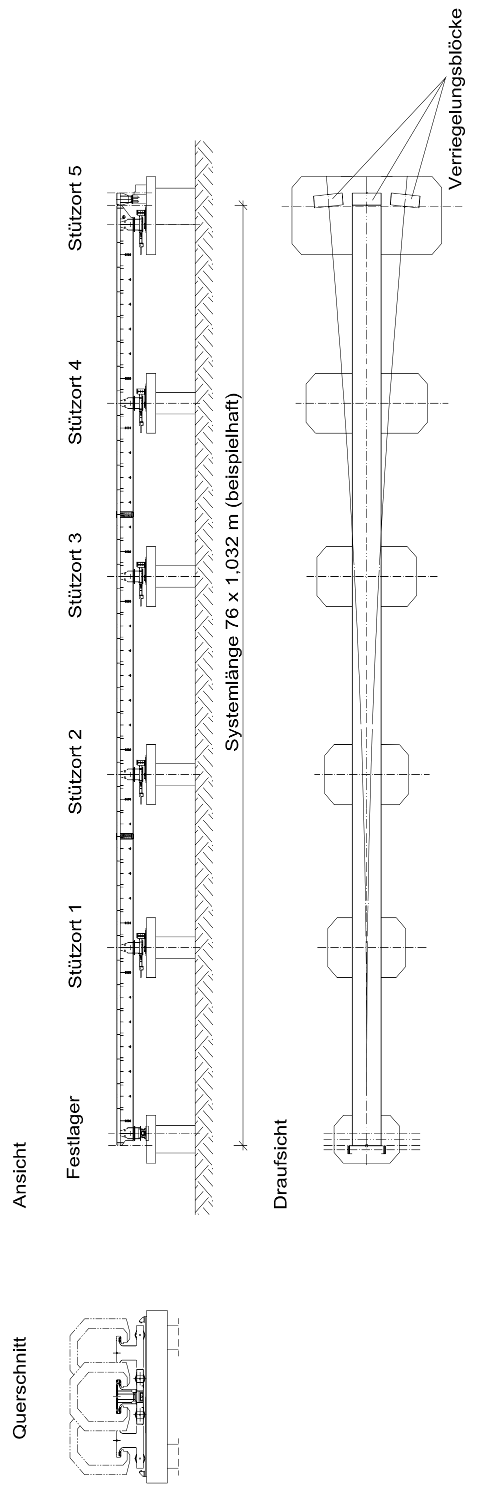


Figure 25: Point (example)

Querschnitt	Cross-section
Ansicht	Front view
Festlager	Fixed bearing
Stützort	Support point
Systemlänge (beispielhaft)	System length (example)
Draufsicht	Plan view
Verriegelungsblöcke	Locking blocks

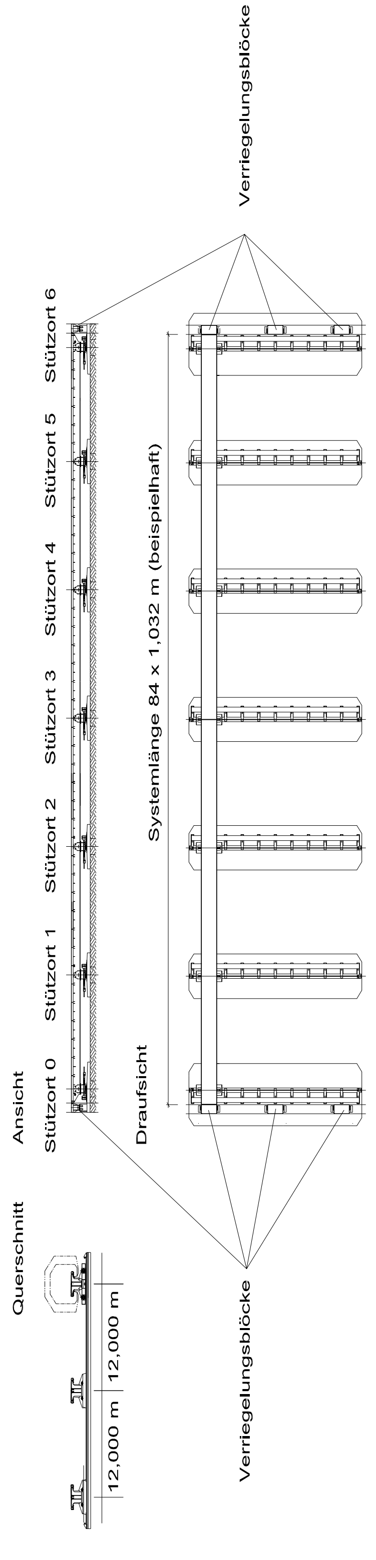

Verriegelungsblöcke
Stützort 6
Stützort 5
Stützort 4
Stützort 3
Stützort 2
Stützort 1
Stützort 0
Ansicht
Systemlänge 84 × 1,032 m (beispielhaft)
Draufsicht
Querschnitt
12,000 m
12,000 m
Verriegelungsblöcke

Figure 26: Traverser (example)

Querschnitt	Cross-section
Ansicht	Front view
Stützort	Support point
Systemlänge (beispielhaft)	System length (example)
Draufsicht	Plan view
Verriegelungsblöcke	Locking blocks

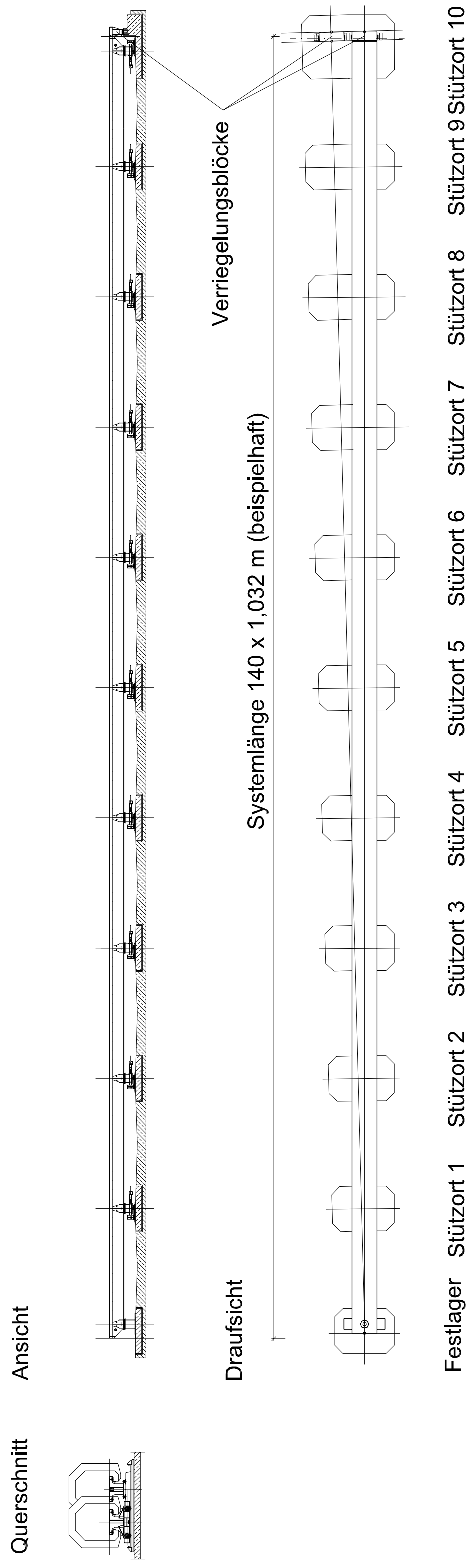

Querschnitt
Ansicht
Draufsicht
Verriegelungsblöcke
Systemlänge 140 x 1,032 m (beispielhaft)
Festlager
Stützort 1
Stützort 2
Stützort 3
Stützort 4
Stützort 5
Stützort 6
Stützort 7
Stützort 8
Stützort 9
Stützort 10

Figure 27: Turntable (example)

Querschnitt	Cross-section
Ansicht	Front view
Festlager	Fixed bearing
Stützort	Support point
Systemlänge (beispielhaft)	System length (example)
Draufsicht	Plan view
Verriegelungsblöcke	Locking blocks

Protective structures

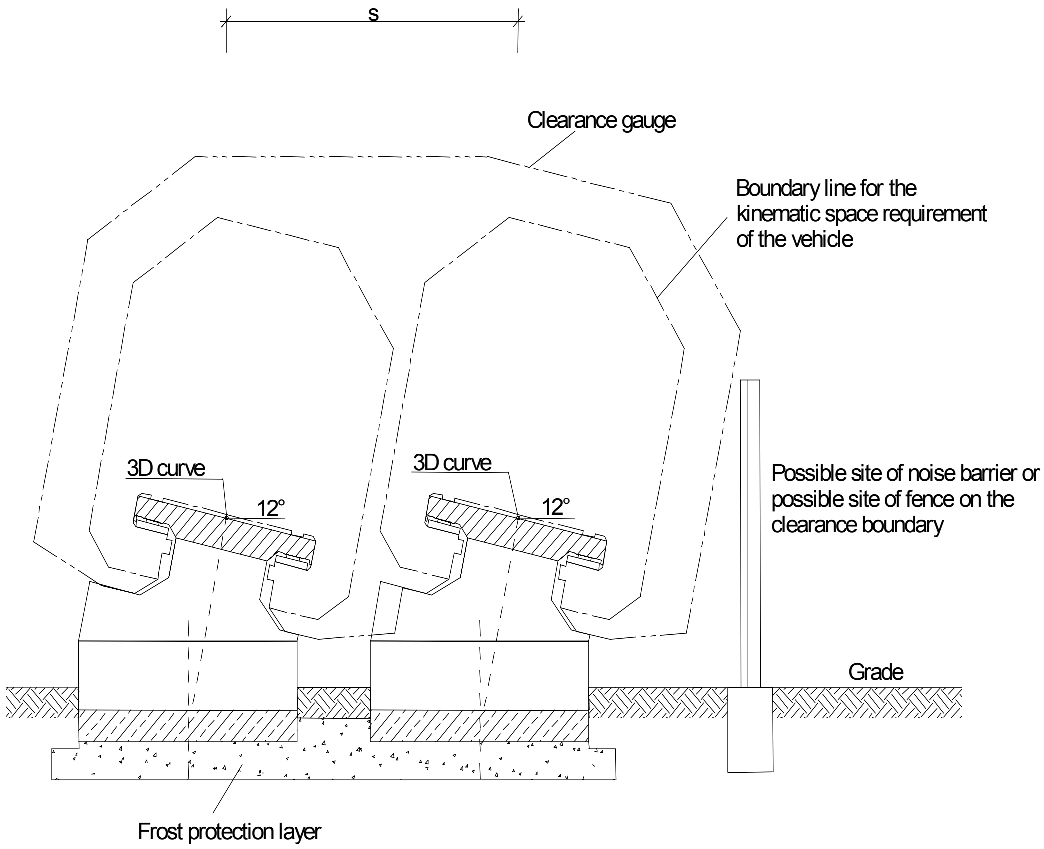


Figure 28: Noise barrier and fence on at-grade guideway (example)

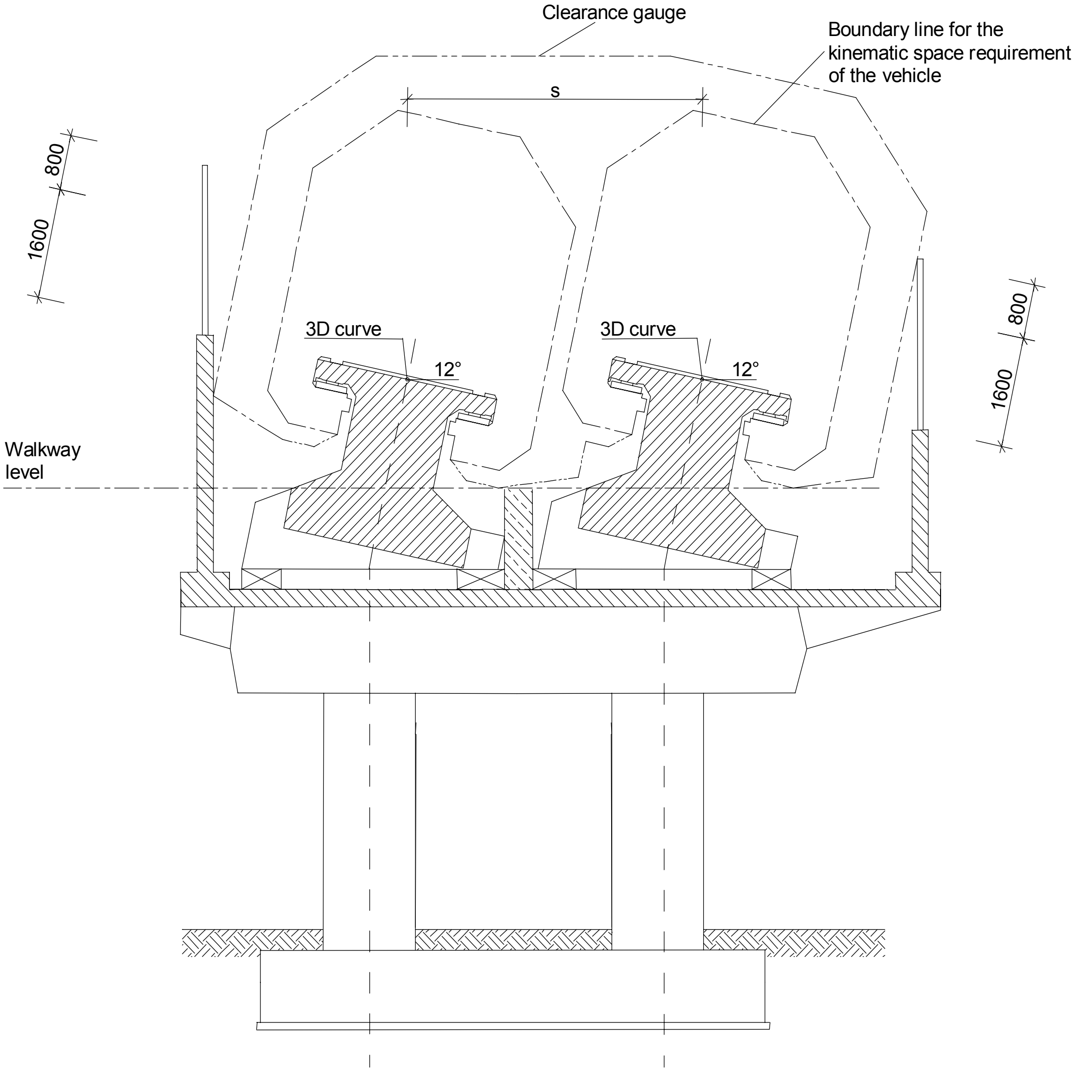


Figure 29: Noise barrier on elevated guideway (example)

Route peripherals

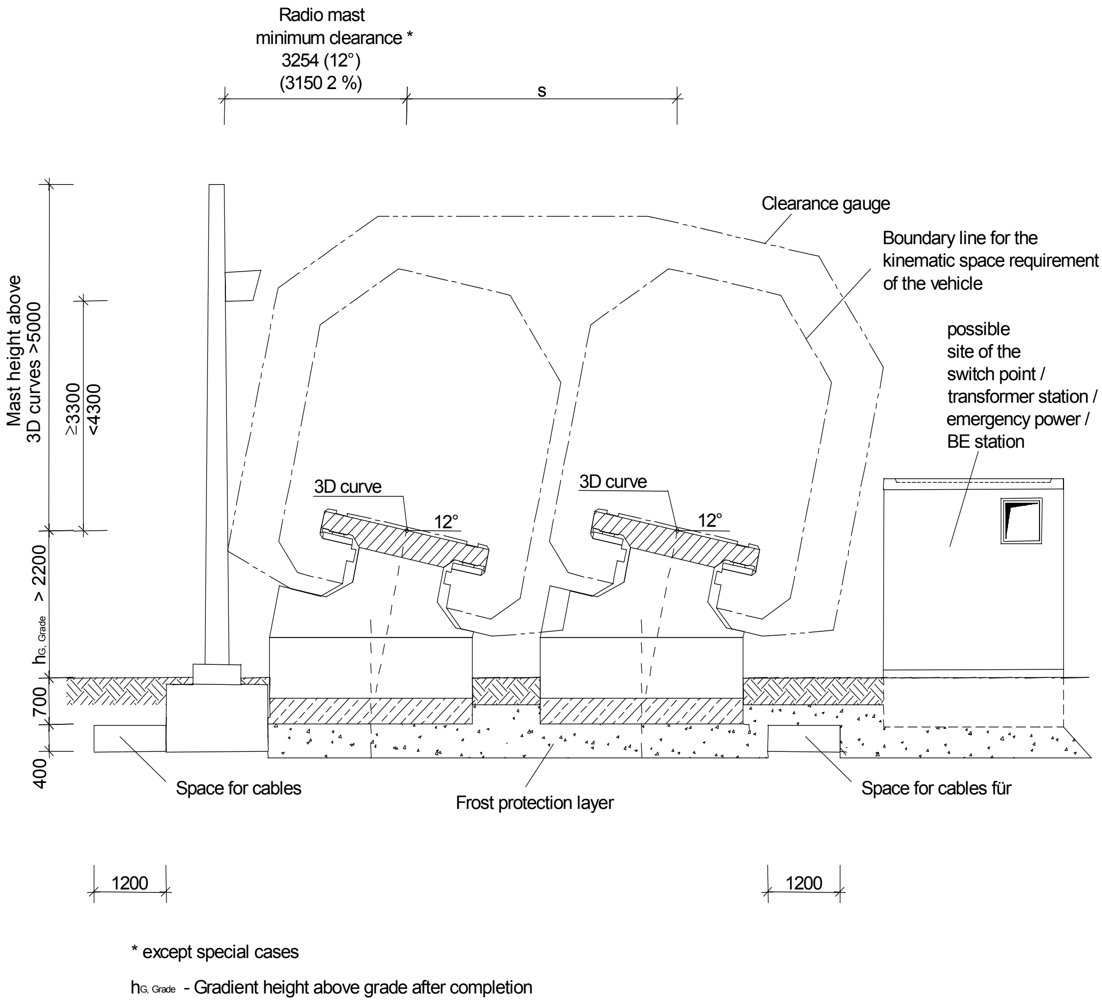
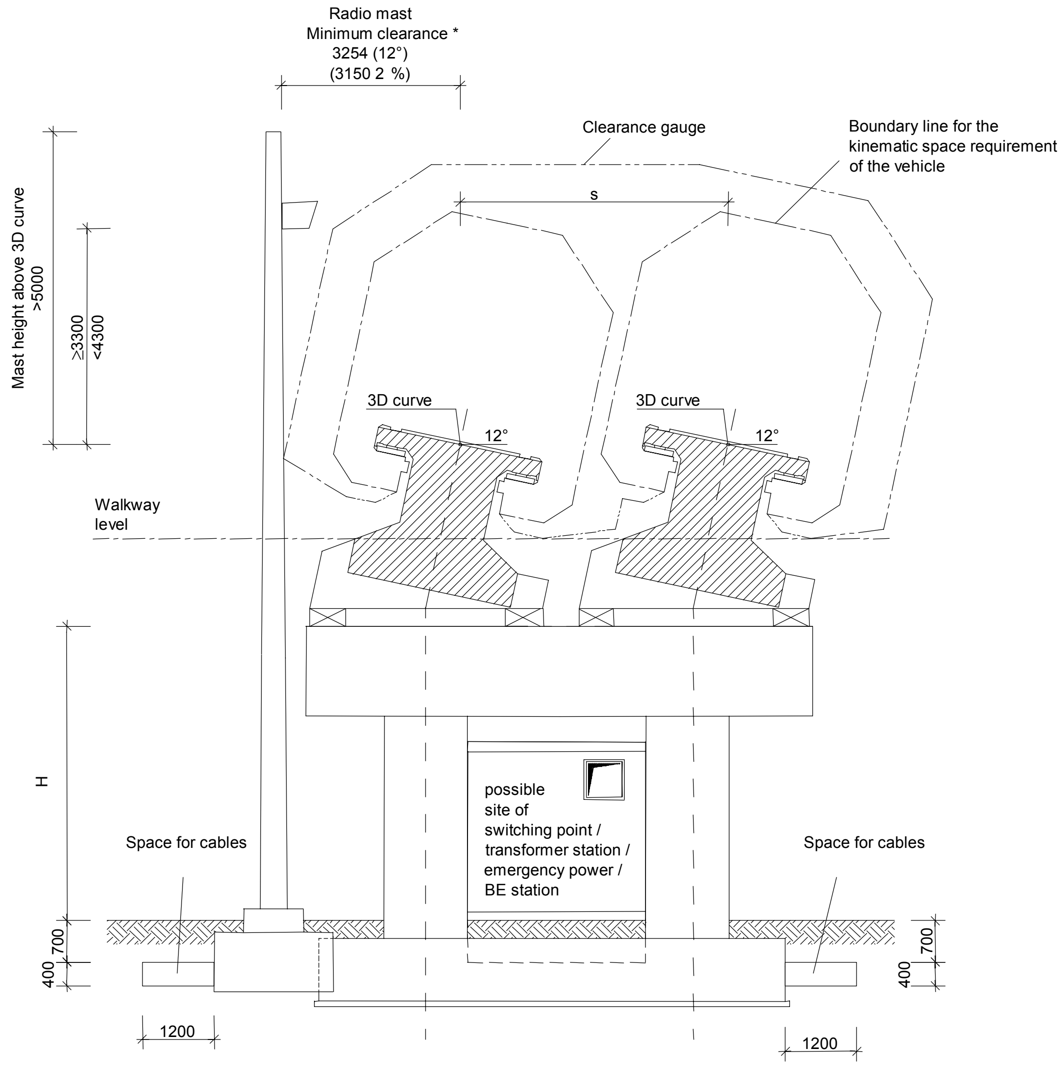


Figure 30: Route peripherals with at-grade guideway (example)



* except special cases

H – Headroom as per requirements for overpass of railway or road

Figure 31: Route peripherals with elevated guideway (example)

Annex: High-speed Maglev System Data

The system data defined below are required in order to design subsystems and modules of the MSB. The system data that are identified in this Annex as "system parameters" apply to all projects. The project-specific or product-specific data (not specially identified here as "system parameters") must be confirmed project-specifically by application of the Design Principles, or defined differently. The definitions must be allowed for in the verification process.

No.	Name	Symbol	System parameter	Value	Unit	Explanation
1.	**Transport / operational parameters**					
1.1.	**Speed**					
(1)	Maximum vehicle speed	$v_{Fz,max}$		500	km/h	Constant speed derived from the permissible continuous loads for the vehicle.
(2)	Vehicle speed limit	$v_{Fz,limit}$		-	km/h	Constant speed derived from the permissible vehicle loads (special load cases). To be defined project-specifically based on incident analyses.
(3)	Maximum guideway speed	$v_{Fw,max}(x)$		≤ 500	km/h	Position-dependent profile of the permissible speed for an aligned route derived from the strength of the guideway.
(4)	Guideway speed limit	$v_{Fw,limit}(x)$		-	km/h	Position-dependent profile of the permissible speed for an aligned route derived from the strength of the guideway under exceptional effects. To be defined project-specifically based on incident analyses.
1.2.	**Schedule**					
(1)	Signal headway			-	min	Project-specific decision
2.	**Track alignment**					
2.1.	**Horizontal radius**					
(1)	Minimum horizontal radius	$R_{H\,min}$	x	350	m	
2.2.	**Limits of transverse inclination**					
(1)	- in platform area	$\alpha_{max\,(BS)}$	x	3	°	*) /MBbO Section 13 (3) limits the permissible transverse inclination in the stationary train in the platform area to 3.4 °. The max. permitted transverse inclination of 3.0 ° for line routing is derived from this.
(2)	- at service stopping places for operationally related stop	$\alpha_{max\,(HP\_2)}$		6	°	Comfort guide value as per project-specific definition
(3)	- at other service stopping places	$\alpha_{max\,(HP\_1)}$	x	12	°	

(4)	- outside stopping places	$\alpha_{max\ (ST)}$	x	12 16	°	MbBO Section 13, (3) MbBO Section 13, (3) for approval in individual cases
(5)	Desired transverse inclination to drain the top of the guideway beam	$\alpha_{min\ (ST)}$		≥ 1.15	°	equivalent to 2%
2.3.	**Vertical radius**					
(1)	Minimum vertical radius	$R_{V\ min}$	x	530	m	
2.4.	**Limits of linear inclination**					
(1)	- in platform area	$s_{max\ (BS)}$ (β)	x	5	‰	MbBO Section 13, (2)
(2)	- in areas in which standing vehicles must be secured from inadvertent movement	$s_{max\ (BE)}$ (β)	x	5	‰	MbBO Section 13, (2), exception permitted as per MbBO Section 5, (1)
(3)	- at stopping places	$s_{max\ (HP)}$ (β)		≤ 100	‰	Defined project-specifically according to proof of the hold function
(4)	- outside stopping places	$s_{max\ (ST)}$ (β)	x	100	‰	
2.5.	**Limits of guideway warp**					
(1)	Limits of guideway warp	$\Delta\alpha_{max\ (ST)}$	x	0.10	°/m	up to 0.15°/m in special cases combination of transverse inclination over 12° and warp over 0.1°/m only after verification in individual cases.
2.6.	**Overlaying of alignment elements**					
(1)	$R_{x,z}$ criterion	$R_{x,z\ min}$	x	fx,z($\Delta\alpha$)	m	
(2)	$R_{x,y}$ criterion	$R_{x,y\ min}$	x	fx,y($\Delta\alpha$)	m	
2.7.	**Other alignment parameters**					
(1)	Track centres	S_M	x	≥ 4,400	mm	according to MbBO, speed-dependent
(2)	Clearance gauge	–	x	-	mm	according to MbBO
3.	**Accelerations, jolts, vibration and pressures**					
3.1.	**Acceleration**					
3.1.1.	**Linear acceleration (x-direction)**					
(1)	Maximum value of drive acceleration	$a_{x,max,accelerate}$	x	≤ 1.5	m/s²	MbBO Section 13, (5)
(2)	Maximum value of brake acceleration	$a_{x,max,brake}$	x	≥ -1.5	m/s²	MbBO Section 13, (5)
3.1.2.	**Unbalanced (free) lateral acceleration (y-direction)**					
(1)	Line	$a_{y,max}$	x	≤ 1.5	m/s²	to outside of bend, MbBO Section 13, (4)
(2)	Track-switching device	$a_{y,max,SWE}$	x	≤ 2.0	m/s²	to outside of bend, MbBO Section 13, (4)
3.1.3.	**Normal acceleration (z-direction)**					
(1)	Trough	$a_{z,max}$		≤ 1.2	m/s²	MbBO Section 13, (6), may be exceeded in individual cases (variable effects)
(2)	Crown	$a_{z,min}$		≥ -0.6	m/s²	
3.2.	**Jolt**					
(1)	Lateral pressure	$\dot{a}_{y,max}$		0.5	m/s³	Comfort criterion, for city entrances at constraints: up to 1.0 m/s³ in individual cases
(2)	Lateral jolt, point at junction	$\dot{a}_{y,max,SWE}$		2.0	m/s³	Comfort criterion
(3)	Vertical jolt	$\dot{a}_{z,max}$		0.5	m/s³	Comfort criterion, in individual cases at constraints: up to 1.0 m/s³

4.	**MSB Vehicle**					
4.1.	**Vehicle configuration**					
(1)	Number of vehicle sections	N_{Sekt}		2 … 10	no.	
(2)	Useful area per vehicle section	A_{Nutz}		-	m²	Project-specific decision
(3)	Seats per vehicle section	N_{Sitz}		-	-	
(4)	Standing places per vehicle section	N_{Steh}		-	-	
(5)	Payload per vehicle section	NL		-	kg	
4.2.	**Vehicle geometry**					Airport link - planning status 2006
(1)	Geometrical length, end section	L_{ES}		approx. 25	m	□
(2)	Geometrical length, centre section (system length vehicle section)	L_{MS}	x	24.768	m	see also No. 6.1.1. (3): Levitation magnet occupancy length, centre section
(3)	Geometrical length of vehicle	L_{Fzg}			m	$L_{FZG}=2*L_{ES}+(N_{Sekt}-2)*L_{MS}$
(4)	Exterior width of car body	B_{WK-A}	x	3.7	m	
(5)	Height of car body over gradient (excl. antenna)	H_{WK-Grd}		approx. 3.3	m	Vehicle set down, to be defined project-specifically
(6)	Height of top of floor above gradient	$H_{FOK-Grd}$		approx. 0.93	m	Vehicle set down, to be defined project-specifically
(7)	Height of vehicle (incl. antenna) over gradient	$H_{Fzg-Grd}$		approx. 3.8	m	Vehicle set down, to be defined project-specifically
(8)	Ext. height car body over top of floor	H_{WK-FOK}		approx. 2.4	m	to be defined project-specifically
(9)	Height of gradient over bottom of vehicle	$H_{Grd-Fzg.UK}$		approx. 0.9	m	Vehicle set down, to be defined project-specifically
(10)	Overall height of vehicle (excl. antenna)	$H_{Fzg.Ges}$		approx. 4.2	m	to be defined project-specifically
4.3.	**Vehicle weights**					The line loads given below are the basis for the guideway design. A tolerance of +/- 5% of the line loads is permissible on the vehicle side.
(1)	Dead weight of a vehicle section	M_{EG}		≥	kg	The vehicle dead weight may not be less than the value equivalent to a line load of 19 kN/m averaged over the system length of a vehicle section.
(2)	Mean weight of a vehicle section	M_{MG}		≤	kg	The mean vehicle weight is equivalent to a mean line load of 26 kN/m averaged over the system length of a vehicle section.
(3)	Permissible weight of a vehicle section	M_{ZG}		≤	kg	The permissible vehicle weight may not exceed the value equivalent to a line load of 29 kN/m averaged over the system length of a vehicle section.
(4)	Maximum weight of a vehicle section	M_{XG}		≤	kg	The maximum vehicle weight may not exceed the value equivalent to a line load of 31 kN/m averaged over the system length of a vehicle section.
5.	**Guideway**					
5.1.	**Guideway configuration**					
5.1.1.	**Basic dimensions**					

(1)	Stator pack system length	$L_{SP,Sys}$	x	1,032	mm	see also Fig. 23 /MSB AG-GESAMTSYS/, Chapter 8.16
5.1.2.	**Standard beam lengths**					
(1)	Standard guideway type I	$L_{Sys,Typ\ I}$		> 16	m	Usually supported discretely on individual footings. To be defined project-specifically.
(2)	Standard guideway type II	$L_{Sys,Type\ II}$		≤16	m	Usually supported discretely on individual footings. To be defined project-specifically.
(3)	Standard guideway type III	$L_{Sys,Typ\ III}$		approx. 6	m	Usually supported discretely on strip footings. To be defined project-specifically.
5.2.	**Guideway geometry**					
(1)	Gauge (distance between lateral guide planes)	S_{SFE}	x	2,800	mm	
(2)	Guideway hover clearance slide plane/stator plane	$T_{ZM,GLE-SE}$	x	398	mm	
5.3.	**Deviations of position of the functional planes**					
5.3.1.	**Tolerance guideway hover clearance**					
(1)	Guideway hover clearance in beam bay	ΔT_{ZM}		+3 / -5	mm	
(2)	Relative difference in hover clearances at beam joint			± 0.4	mm	
5.3.2.	**Gauge width tolerance**					
(1)	Gauge width in beam bay	max ΔS		± 2	mm	
(2)	Relative gauge difference at beam joint			± 1	mm	
5.4.	**Guideway superstructure deformation**					
5.4.1.	**in x-direction due to traffic**					
(1)	at beam joint			10 20	mm	periodical with autom. braking
5.4.2.	**in z-direction due to traffic**					
(1)	Single-bay beam	max $f_{z,Fzg}$	x	$L_{St}/4{,}000$	mm	with static effect at permissible vehicle weight
(2)	Dual-bay beam		x	$L_{St}/4{,}800$	mm	with static effect at permissible vehicle weight
(3)	Guideway plates					The construction must be assessed in individual cases.
5.4.3.	**in y-direction due to traffic**					
(1)	Single-bay beam	max $f_{y,Fzg}$	x	$L_{St}/15{,}000$	mm	with static effect at permissible vehicle weight and ay,max
(2)	Dual-bay beam		x	$L_{St}/18{,}000$	mm	with static effect at permissible vehicle weight and ay,max
(3)	Guideway plates					The construction must be assessed in individual cases.
5.5.	**Track-switching devices**					
(1)	Turnaround time of a 2-way point from end position to end position			30	s	Typical value
6.	**Geometry of the vehicle/guideway interfaces**					
6.1.	**Levitation magnet / long stator**					

6.1.1.	**Levitation magnet**					
(1)	Levitation magnet system length (standard length magnet)	$L_{sys,TM}$	x	3,096	mm	
(2)	Levitation magnet centres in y-direction	$e_{y,TM}$	x	2,220	mm	
(3)	Levitation magnet occupancy length centre section	$L_{TM-B,MS}$	x	24,768	mm	
(4)	Levitation magnet occupancy length end section	$L_{TM-B,ES}$		23,753	mm	no system dimension, may vary project-specifically
6.1.2	**Long stator**					
(1)	Lang stator centres in y-direction	$e_{y,SP}$	x	2220	mm	Nom. dim.
(2)	Width of stator pack (geometrical)	$b_{y,SP}$		≥ 185	mm	Typical embodiment: 185 mm, to be defined project-specifically
(3)	Pole centres	$e_{x,pole\ centres}$	x	258	mm	Nom. dim., 3-phase motor winding
(4)	Slot pitch (centres of the motor winding cable)	$e_{x,slot\ pitch}$	x	86	mm	Nom. dim.
6.2.	**Guide magnet - lateral guide rail**					
6.2.1.	**Guide magnet**					
(1)	Guide magnet system length	$L_{sys,FM}$	x	3,096	mm	
6.2.2.	**Lateral guide rail**					
(1)	Lateral guide rail height	h_{SFS}	x	310	mm	
(2)	Lateral guide rail thickness	d_{SFS}		≥ 30	mm	30 mm, Typical embodiment, to be defined project-specifically
6.3.	**Brake magnet - lateral guide rail**					
(1)	Brake magnet centres in x-direction	$e_{x,BM}$		24,768	mm	Guide value, different dimensions may be defined project-specifically.
6.4.	**Support skid / slide plane**					
6.4.1	**Support skid**					
(1)	Support skid length	$L_{x,TK}$		740	mm	Guide value, different dimensions may be defined project-specifically.
(2)	Support skid width	$b_{y,TK}$		110	mm	Guide value, different dimensions may be defined project-specifically.
(3)	Skid centres in x-direction	$e_{x,TK}$		3,096	mm	
(4)	Skid centres in y-direction	$e_{y,TK}$	x	2,220	mm	
6.4.2	**Slide plane**					
(1)	Slide plane / slide rail width	min $b_{y,GL}$		≥ 150	mm	
7.	**Effects at the vehicle/guideway interfaces in x-direction**					
(1)	Variable effects with drive/brakes	max stat p_x		4.8	kN/m	Local maximum; mean over a vehicle section 4.4 kN/m for a centre section of length 24.768 m. Drive current is limited so that the maximum permissible force is not exceeded.
(2)	Exceptional effects (symmetrical)	max p_x		10.0	kN/m	Equivalent to approx. 250 kN/vehicle section for a centre section of length 24.768 m

(3)	Exceptional effects (asymmetrical)	max px r,l		5.5 or 2.0	kN/m	Equivalent to a maximum total force of 185 kN/vehicle section for a centre section of length 24.768 m and a maximum uneven distribution of 0.73 : 0.27 between the two guideway/vehicle sides
8.	**Drive**					
8.1.	**Motor geometry**					
	see Levitation magnet and Long stator			-		
8.2.	**Motor constants**					
(1)	Shear force constant per centre section	$c_{M,MS}$		-	N/A	Correlated quantity equation: $c_{M,MS}$ = 43.0 * √(m_{MS}[t] / 64.5 t) with m_{MS} - actual weight of centre section. Values may vary at very high and very low temperatures due to the expansion of long MSB vehicles.
(2)	Shear force constant per end section	$c_{M,ES}$		-	N/A	Correlated quantity equation: $c_{M,ES}$ = 41.3 * √(m_{ES}[t] / 62.0 t) with m_{ES} - actual weight of end section. Values may vary at very high and very low temperatures due to the expansion of long MSB vehicles.
(3)	Induced motor voltage per vehicle section long side	u_p		-	V	Equivalent to 1/6 * c_M * speed
(4)	Conductor cross-section	A_S		300	mm	Guide value for aluminium conductor
(5)	Conductor resistance	R_S		0.23	Ω	Guide value per km stator length at 20°C and 0-30 Hz
(6)	Resistance/temp. coefficient	θ_{St}		0.004	1/°C	Guide value factor is: (1+θ_{St}*(temperature-20°C))
(7)	Resistance/frequency coefficient	f_{St}		0.004	s	Guide value factor is: (1+f_{St}*(frequency-30Hz))
(8)	Leakage inductance	L_S		2.6	mH	Guide value per km stator length without vehicle
(9)	Vehicle magnetizing inductance	L_h		0.1	mH	Guide value per section and side incl. L_S
(10)	Earth capacitance	C_S		1	uF	Guide value per km stator length
(11)	Length factor moving field line/long stator	[illegible]		2.35		Guide value
(12)	Max. conductor temperature	T_{Lmax}		70	°C	Guide value for service life reasons, technically 90°C
(13)	Thermal time constant	τ_{Stat}		1...5	h	Guide value
(14)	Nom. voltage	U_{Nenn}		10...20	kV	Guide value interlinked fundamental component rms
8.3.	**Motor interconnection**					
(1)	Motor section length	ds		1,200	m	Guide value, individually between approx. 0.5 and 3 km
(2)	Motor section offset	vers		300	m	Guide value, individually between 0 and ds/2
9.	**Operation Control System**					
9.1	**Safe positioning**					

(1)	Positional information tolerance, static			2	m	Typical value. The value must be determined project-specifically.
(2)	Speed information tolerance			5	km/h	Typical value. The value must be determined project-specifically.
9.2	**Vehicle-related speeds**					
(1)	Setdown speed			5	km/h	Typical value. The value must be determined project-specifically.
9.3	**Deceleration and running times**					
(1)	Max. drive shutdown time			2.3	s	Guide value for the shutdown time of the drive and braking energy for a safety-relevant shutdown reason by the OCS
10.	**Aerodynamics**					
10.1.	**Pressure during vehicle passage**					
(1)	Max. pressure amplitude on the vehicle sides		x	2,400	Pa	
(2)	Pressure amplitude on structures on the guideway			-	Pa	dependent on clearance and vehicle speed
(3)	Pressure load on guideway table and vehicle underfloor	□	x	-7.6 to 15.2	kN/m^2	
10.2.	**Pressure in tunnel**					
(1)	Design pressure for tunnel design			5,500	Pa	Differential pressure vehicle interior/exterior
(2)	Design pressure for vehicle design			6,000	Pa	Differential pressure vehicle interior/exterior

High-speed Maglev System Design Principles

Complete System Annex 1 Abbreviations and definitions

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List of contents

List of illustrations

General

Purpose of the document, scope

This document contains abbreviations and definitions for high-speed maglev systems.
These design principles apply to a high-speed maglev system according to the General Maglev System Act /AMbG/.

High-speed Maglev System Design Principles

This document is an annex to the Design Principles Complete System and so forms part of a documentation for high-speed maglev systems consisting of several design principles. The document tree is shown in Figure 1 /MSB AG-GESAMTSYS/.
The high-level "complete system" design principles and their annexes apply uniformly for the whole documentation:

- High-speed Maglev System Design Principles Complete System, Doc. No.: 50630, /MSB AG-GESAMTSYS/
  - Annex 1: Abbreviations and Definitions, Doc. No.: 67536, /MSB AG-ABK&DEF/
  - Annex 2: Statutes, Regulations, Standards and Directives, Doc. No.: 67539, /MSB AG-NORM&RILI/
  - Annex 3: Environmental Conditions, Doc. No.: 67285, /MSB AG-UMWELT/
  - Annex 4: Rules for Operation and Maintenance, Doc. No.: 69061, /MSB AG-BTR/
  - Annex 5: Noise, Doc. No.: 72963, /MSB AG-SCHALL/

Abbreviations and definitions

Abbreviations and definitions are listed in this document.
Further specific abbreviations and definitions may be defined in the lower-level design principles.

Statutes, regulations, standards and directives

The normative documents listed in /MSB AG-NORM&RILI/ contain requirements that form part of the High-speed Maglev System Design Principles by cross reference in the High-speed Maglev System Design Principles. Where normative documents in /MSB AG-NORM&RILI/ are dated, subsequent changes or revisions of these publications do not apply. With undated references, the latest version of the normative document that is referred to applies.

The version of the standards and directives to be observed in an MSB project must be decided bindingly on a project-specific basis.

Identification and binding value of requirements

The requirements of /DIN 820/ were essentially applied in the preparation of this document. In the following chapters and the annexes of this document

- Requirements are shown in normal font
- Explanations, guide values and examples are shown in *italics*

The degree to which the requirements are binding has been defined by reference to /DIN 820-2/ Annex G, and has been taken into consideration when formulating the individual requirements.

Overviews

The following terms and definitions must be used for the High-speed Maglev System Design Principles.

The terms and definitions are summarised alphabetically below in Chapters 0 and 0.

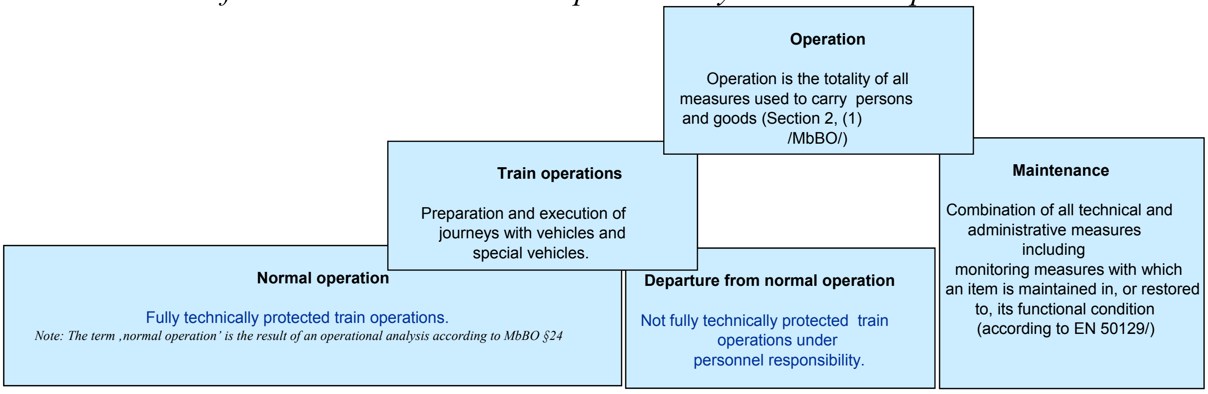

Figure 32: Chart of Operation, Modes

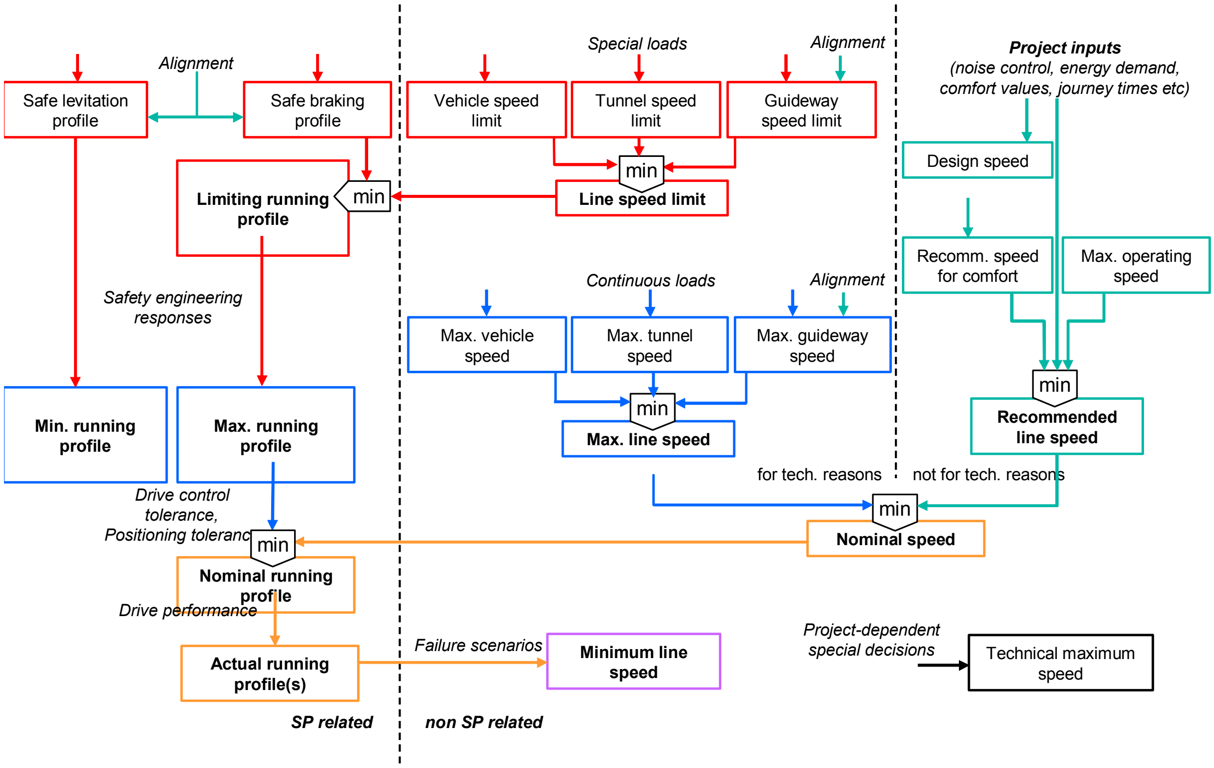

Figure 33: Chart of Speed Terms

Notes on the "Chart of Speed Terms":

The speed terms are divided up into:

- *stopping place-related speeds ("profiles") for the approach to stopping places, and*
- *non stopping place-related speeds ("speeds")*

Only profiles are directly monitored by the safety systems.

Stopping place-related:
The alignment and various system characteristics determine the safe levitation profile and the safe braking profile.
The minimum and maximum running profiles of the stopping place are obtained by forming the minimum value with the line speed limit (leads to the limiting running profile) and allowing for the safety-technical reactions. These profiles are monitored by the OCS to ensure safe compliance with the safe levitation profile / braking profile and/or the limiting running profile. The nominal running profile which should be run by the drive is obtained after deducting drive control tolerances and positioning tolerances and allowing for the nominal speed. The profile which the drive actually runs because of its efficiency is known as the actual profile. A minimum line speed which can still be run in operation and that is independent of stopping places also arises from defined failure scenarios of the drive.

Not stopping place-related:
The defined special loads and the alignment determine the corresponding speed limits for vehicle, tunnel and guideway. The minimum of these three components is referred to as the line speed limit. This limit must never be exceeded and so forms part of the limiting running profile.
The defined continuous loads for vehicle, tunnel and guideway determine the corresponding maximum speeds. The minimum of the three components it the maximum line speed. This represents the restriction on the nominal speed for technical reasons. There is also the recommended line speed as a further limitation on the nominal speed. This consists of comfort-related and possibly other non safety-related project inputs. The nominal speed forms part of the nominal running profile (see above).

In addition to all other speeds there is the technical maximum speed which, on a project-specific basis, is the maximum speed that may be run under defined special conditions, e.g. for individual journeys for verification purposes.

Abbreviations

Abbreviation	Definition
$\bar{p}$	averaged, static line load
α	Guideway transverse inclination
α	Ellipsoidal azimuth at the zero point (P_0) of the inclined conform projection (MKS)
α'	Change in transverse inclination of guideway (superelevation angle)
β	Guideway linear inclination (incline +, decline -) of the three-dimensional guideway axis
Δ	Delta, difference
δ or δ_{xy}	Yaw angle (rotation about the z-axis)
$\Delta\alpha$	Angular deviation of the y-z-plane, change in guideway transverse inclination (guideway warp)
$\Delta\alpha_{max}$	Maximum permissible guideway warp
$\Delta\alpha_y$	Difference in the unbalanced lateral acceleration from sinusoid or clothoid end and beginning
$\Delta\alpha_z$	Difference in the normal acceleration of clothoid end and beginning
$\Delta\lambda$	Ellipsoidal linear difference relative to P_0
$\Delta\varphi$	Ellipsoidal width difference relative to P_0
ΔT	Linear temperature difference
δ_{0xy}	Static yaw angle due to load asymmetry
ΔF_{pz}	Deviation of z-oscillation force from nominal load
Δf_y	Force-dependent static y-downward deflection of the chassis structure with excited guide magnet and deviation from nominal load
Δf_z	Force-dependent static downward / upward deflection with deviations from the nominal load
Δf_{zG}	Force-dependent static downward / upward deflection of the chassis structure with deviations from the nominal load
Δf_{zTK}	Static deflection of the support skid with vehicle setdown
Δf_{zTM}	Force-dependent static downward / upward deflection of the levitation magnet link with deviations from the nominal load
ΔP	Wear to guide magnet pole strip
Δs	Dynamic gap deviation, air gap levitation/guidance
Δs_1	Gap difference at guide magnet centre on bends
Δs_2	Gap difference at guide magnet end on bends
ΔT_0	Linear temperature difference between top and bottom of beam at which nominal precamber /MSB AG-FW GEO/ occurs in the unstressed condition
ΔT_M	Linear temperature difference
$\Delta T_{M,y}$	Linear temperature difference in y-direction

Abbreviation	Definition
$\Delta T_{M,z}$	Linear temperature difference in z-direction
ΔT_N	Total variation in constant temperature component
$\Delta T_{re/li}$	Temperature difference of the right and left side
ΔV_{TK}	Support slid lining wear
ΔW_y	y-construction tolerances, guideway gauge
ΔW_z	z-construction tolerances, guideway hover clearance
$\Delta x_{A,E}$	Dimension for the distance from system axis to beam beginning and end
Δy	y-construction tolerances, vehicle gauge
Δy_i	y-offset, levitation frame i
Δz	z-construction tolerances, vehicle hover clearance
Δz_i	z-offset, levitation frame i
η	Angle of articulation
η or η_{yz}	Roll angle (rotation about x axis)
η_{0yz}	Static roll angle due to load asymmetry
$\eta_{yz\alpha'}$	Roll angle of car body from guideway superelevation
η_{yzFy}	Roll angle of car body from mass force and side wind
γ	Factor of safety, partial factor of safety
γ bzw. γ_{xz}	Pitch angle (rotation about y axis)
γ_{0xz}	Static pitch angle due to load asymmetry
γ_A	Partial factor of safety for exceptional effects
γ_G	Partial factor of safety for continuous effects
γ_Q	Partial factor of safety for variable effects
λ	Ellipsoidal length
λ	Wavelength of vehicle-side excitations or effects
λ_0	Ellipsoidal length of the projection zero point
μ	Weight per unit area of the guideway beam
μ	Coefficient of friction
μ_H	Coefficient of friction for the holding brake function
$\mu_{H\ min}$	Minimum coefficient of friction for the holding brake function on an iced guideway
φ	Dynamic superelevation factor, vibration coefficient
φ	Ellipsoidal width
φ_0	Ellipsoidal width of the projection zero point
ψ	Combination factor
ψ_0	Combination factors for variable effects
ψ_1	Combination factors for frequent effects (/1/week)
$\psi_{1'}$	Combination factors for non frequent effects (1/year)
ψ_2	Combination factors for quasi-continuous effects
$\rho°$	Symbol rho, factor for converting the unit radian to degree [°]

Abbreviation	Definition
τ	Points angle tau
ϑ	Tangential torsion at beam joints
a	Acceleration, deceleration
a	In the MKS: lateral distance from the geodetic line projected true-to-length
a	Outside track
A	Clothoid parameter
A	Start
A	Area
A	Lift
A	Load cases of exceptional effects
$a_{(t)}$	Acceleration amplitude at time t
ABE	Drive sector
a_{eff} or a_{RMS}	Root-mean-square of acceleration
a_i	Acceleration in x ,y ,z direction (i=x,y,z)
$a_{i\ max}$	Maximum acceleration in x ,y ,z direction (i=x,y,z) (S-loads)
$a_{i\ mitt}$	Mean operational acceleration in x ,y ,z direction (i=x,y,z) (A-loads)
AL	Starting strip
AW	Lift from wind effects
a_x	Drive and braking acceleration
$a_{x\ max}$	Permitted maximum value for the drive and braking acceleration
a_y	Unbalanced free y-lateral acceleration (on bends)
$a_{y\ max}$	Permissible maximum value for the unbalanced free lateral acceleration
a_z	Normal acceleration (g + trough/crown run)
$a_{z\ max}$	Permissible maximum value for normal acceleration
B, b	Width (general)
b_G	Maximum lateral distance of a passenger from the three-dimensional curve (centre of the outside seat in each case)
Bg	Component, global
BHPL	Service stopping place
Bl	Component, local
OCS	Operation Control System
BM	Braking magnet
BSK	Fire safety concept
BZ	Operations centre
c	Spring constant
$c_{\eta WK}$	Roll rigidity of car body, relative to pendulum
CAD	Computer Aided Design
c_{piE}	Rigidity of the z-setdown spring i, relative to the pendulum axis
c_{ZF}	Rigidity of y-auxiliary spring

Abbreviation	Definition
d	Distance of guide magnet gap sensors
D	Damping factor, Lehr's damping factor
D	Permissible conflict between outward and return path of geometrical levelling
D	Pressure
DIN	Deutsches Institut für Normung (German Standards Institute)
DSV	Three-step method
dyn	dynamic
e	Distances in general, centres
E	End
E	Elastic modulus
E	Outcomes of effects (deformation, <stress resultants, stresses, bearing forces)
EBA	Eisenbahn-Bundesamt (German Federal Railway Authority)
EFT	Single-bay beam
EG	Load case designation for vehicle tare weight
EI	Flexural strength
elas	elastic
E_m	Mean actual value of a line observation
EMF	Electromagnetic fields
EMS	Electromagnetic levitation
EMC	Electromagnetic compatibility
EN	European Standard
EP	End pole of the levitation magnets
ES	End section
ESD	Electrostatic discharge
EVU	Energy utility company
f	Frequency; deformation
F	Force
F_A	Aerodynamic running resistance
FA	Vehicle exterior,
F_B	Running resistance from on-board energy generation
F_{Brems}	Braking force of the vehicle through the effect of vehicle-side brakes
FEM	Finite Element Method
F_G	Total braking force of the vehicle
F_H	Holding brake force
FI	Vehicle interior,
F_{Kz1}	z-coupling force, section coupling end section 1 to centre section
F_{Kz2}	z-coupling force, section coupling end section 2 to centre section
F_M	Running resistance from magnetisation of stator and lateral guide rail
FM	Guide magnet

Abbreviation	Definition
FMEA	Failure Mode & Effect Analysis
FMT	Section of guide magnet assigned to a guidance control circuit = partial magnet
F_{mWKy}	y-inertial force of car body (superelevation deficit)
F_{mWKz}	z-inertial force of car body
F_{p1z}	z-oscillation force, tail levitation frame, end section
F_{piy}	y-oscillation force, levitation frame i
F_{piz}	z-oscillation force levitation frame i
F_{pzLFi}	z-oscillation force air suspension circuit i
F_W	Running resistance of the vehicle
FW	Guideway
$F_{x,Schub}$	Drive force installed in the guideway
F_{xTM}	x-force at the levitation magnet link
F_{yFM}	y-force at the guide magnet link
F_{yFM0}	Guide magnet preload
F_{ySW}	Side wind force on end section E, centre section M
F_{yWK}	y-forces car body end section E, centre section M
f_z	z-offsets
$f_{z,Fzg}$	Deformation of guideway in z-direction by the maglev vehicle
$f_{z,Fzg,max}$	Maximum deformation of guideway in z-direction by the maglev vehicle
F_{ZFiy}	y-force at y-aux. spring levitation frame i
Fzg	Vehicle
F_{zTM}	z-force at the levitation magnet link
F_{zWK}	z-forces car body end section E, centre section M
g	Normal case acceleration (acceleration due to gravity
G	Weight
G	Load cases continuous effects
G	Shear modulus
GA_v	Shearing rigidity
ges, Ges	total
GL	Slide rail
GLE, GE	Slide plane
GLM	Slide rail centres
GPS	Global Positioning System
H	horizontal
H, h	Height (general)
HG	Load case name for increased vehicle weight
$h_{G,Gelände}$	Gradient height above grade after completion
HIC	Head Injury Criterion
H_L	Northing in the national system

Abbreviation	Definition
HP	Main pole of the levitation magnets
i	Inside track
I	Moment of inertia
i, j	Integer control variable
IH	Maintenance
ILT	Infrastructure control system
INKREFA	Incremental Vehicle Location System
K	Curvature, reciprocal of radius
K	Crown
k	Factor, coefficient
Kw	Shortwave deviation
l	left, left-hand
L	Length (general)
LA	Long-stator centreline
Lb	Clear width
L_e	Total length of an alignment element
L_{ES}	Vehicle length, end section
L_{FM}	Magnet length, guide magnet
L_{FM-B}	Guide magnet occupancy length of the vehicle
L_{Fw}	Length, bay width from support centres
L_i	Beam segment length
L_K	Length of clothoid
$L_{K\ min}$	Minimum length of clothoid
L_M	System length of a module in x-direction
L_{MS}	Vehicle length, centre section
LP	Length of the element up to point P
l_p	Pendulum length
LPZ	Lighting Protection Zone as per /DIN EN 62305-1/
LRL	Location reference lug
LS	Length of sinusoid
$L_{S\ min}$	Minimum length of sinusoid
L_{St}	Guideway beam spans (centres between bearing axes, usually a multiple of 1.032 m and relative to the centres of the support axes in the 3D curve)
L_{Sys}	System length of the beam
$L_{Tangente}$	Tangential length
L_{TM}	Levitation magnet length
L_{TM-B}	Levitation magnet occupancy length of the vehicle
Lv	Length distortion as scale difference
Lw	Long-wave deviation
m	Masse

Abbreviation	Definition
m	Linear effects due to torsion
M	Moment (general)
M	Modular construction
max	maximum
m_b	Set-down component of the vehicle mass
MbBO	Magnetschwebebahn-Bau- und Betriebsordnung (Maglev Construction and Operation Regulations)
MDT	Mean Down Time
MFE	Mechanical guidance element, e.g. guide magnet strips or startup strips
MG	Load case designation for mean vehicle weight
min	minimum
MKS	Maglev coordinate system
MRE	Magnet control unit
MREB	Magnet control unit, braking
MREF	Magnet control unit, guidance
MRET	Magnet control unit, levitation
MRK	Magnet control circuit comprising of the control circuit elements: magnet, magnet control unit and if necessary the gap measuring unit
MS	Centre section
MSB	Magnetic levitation railway, high-speed maglev system
m_{Sekt}	Total weight of a vehicle section (with or without payload)
MSF	Scale factor of the projection distortion
MSH	Special magnetic steel from the 'Heinrichshütte' (special magnetic steel with good magnetic properties)
M_T	Car body rolling moment
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
m_{WK}	Mass of car body
n	Number, general
n	Number of sections
N	Number of bays of a beam
NBT	Normal operation
NGK	Inclination change criterion [mm/m]
NL	Payload
NLÜ	Payload excess
NT	Slot arm
o	top
OG	Upper chord, top of guideway
OK	Top, top edge
P	Maximum pole strip wear
P	Any desired point on the alignment element

Abbreviation	Definition
P_0	Zero point for the MKS, also the apex of the ellipsoidal azimuth and projection zero point
PK	Pole core
PL	Pole strip
plas	plastic
P_{Mitte}	Point in the centre of the alignment element
PRW	Rotor angle
p_x, p_y, p_z	Line or track load x, y and z direction
Q	Load cases of variable effects
QS	Quality assurance
q_x, q_y, q_z	Area load in x, y and z direction
r	Earth radius
r	right, right-hand
R	Guideway radius of curvature
R	Radius
R	Regulation
RAMS	R - Reliability A - Availability M - Maintainability S - Safety
R_H	Horizontal radius
RH	Horizontal curve radius
$R_{H\ min}$	Minimum permissible horizontal radius
$R_{H,P}$	Horizontal radius at point P
$R_{K,W}$	Vertical radius (crown, trough in the gradient) $\equiv R_V$
RKK	Three-dimensional curve coordinate system
RKK	Three-dimensional curve coordinate system
Rl	Regulation
Rm	Mean earth radius (for calculating projection distortions)
RMS	RMS Value (Root Mean Square)
R_V	Vertical radius
RV	Vertical curve radius
$R_{V\ min}$	Minimum permissible vertical radius
$R_{x,y}$	Three-dimensional radius by overlaying a gradient curvature (radius) with a horizontal curvature (radius)
Rx,z	Three-dimensional radius by overlaying horizontal curvature and gradient curvature
Rx,z_{min}	Minimum permissible three-dimensional radius (as a function of the guideway warp)
R_{xy}	Curve radius
s	Section, distance

Abbreviation	Definition
S	Guideway gauge
S	Track centres
S	Gap dimension
S	Wake
S	Centre of gravity
s_0	Nominal air gap levitation magnet / guide magnet
SA	Stator section
SB	Safe Brake
SE	Stator plane
Sekt	Section
S_F	Nominal gap, guiding
SFE	Lateral guide rail plane
SFS	Lateral guide rail
SFZ	Railway vehicle
SGN	Sign (algebraic) of a number
SIAB	sichere Antriebsabschaltung (safe drive shutdown)
SK	Lateral force
SP	Stator pack
SPB	Stator pack mounting, fastener
SPD	Surge Protection Device as per /DIN EN 62305-1/
S_R	Nominal gap, guiding on bend
SS	Number of vibration cycles
St	Support, support point, span
S_T	Support skid gap
stat	static
SW	Safety wind
t	Sheet metal thickness
t	Time
T	Temperature
T_0	Nominal / construction temperature
TFK	Beam fabrication coordinate system
TK	Support skid
T_l	Temperature of the left-hand edge of the loadbearing cross-section
TM	Levitation magnet
TMT	A "levitation magnet half" (= partial magnet) assigned to a levitation control circuit
T_o	Object temperature at the upper chord
TP	Trigonometrical survey point
T_r	Temperature of the right-hand edge of the loadbearing cross-section
TRS	Traction regulation and control

Abbreviation	Definition
T_u	Object temperature at the lower chord
TVE	Transrapid Versuchsanlage Emsland (Transrapid Test Facility)
t_{ZM}	Hover clearance (nominal dimension distance stator plane to slide plane)
u	bottom
URS	Converter regulation and control
USV	Uninterruptible Power Supply (UPS)
UW	Substation
v	Speed
V	Vertical
V	Offset
V	Transfer force (at bearers)
VDE	Verband Deutscher Elektrotechniker (German Association for Electrical, Electronic & Information Technologies)
VDI	Verein Deutscher Ingenieure (German Institute of Engineers
v_e	Design speed
$v_{Einsatz}$	Working speed of the on-board energy supply
v_{Fzg}	Vehicle speed
v_{Grenz}	Vehicle speed limit
v_{max}	Location-dependent maximum speed for the maximum running profile
Vor	Preload
v_W	Wind speed
w	Deflection
W	Trough
W	Wind
WK	Car body
WLZ	Wind load zone
WSB	Eddy-current brake
WSE	Material fatigue
WSV	Alternating step method
W_y	Guideway track width (distance between lateral guide rails)
W_z	Nominal hover clearance of guideway between top of slide plane and bottom of stator pack
X	Designation for the longitudinal axis of the MKS (= determining straight line) through P_0
X_0	Addend for the zero offset in X direction in the MKS
x_{2E}	Distance of levitation frame 2 end section to section coupling
x_i	x-value at point "i"($i=1\rightarrow n$)
x_{iE}	Distance of the z-setdown spring i from the section coupling
x_{NiE}	Distance of the z-setdown spring i from the car body pitch pivot point
x_{sE}	x-distance from centre of gravity end section to section coupling

Abbreviation	Definition
x_{si}	Distance from resulting force application point air suspension circuit i to section coupling
x_{SWE}	Distance from side wind force end section to section coupling
x_{ZFi}	Distance from y-auxiliary spring i to section coupling
Y	Designation for the transverse axis of the MKS (perpendicular to X)
Y	Vehicle track width
Y_0	Addend for the zero offset in Y direction in the MKS
Y_0	Vehicle nominal track width with non excited guide magnets (vehicle set down)
y_i	y-value at point "i"(i=1→n)
y_K	y-offset of the section coupling
$y_{Lw,Ist}$	y-actual-value for the longwave deviation
$y_{Lw,max}$	Permissible maximum y-value for the longwave deviation
y_p	y-coordinate car body oscillation force application point
y_{piE}	y-displacement pendulum i end section
y_{sWK}	y-centre of gravity coordinates car body
Z	Hover clearance between bottom of support skid and top of levitation magnet
Z_0	Hover clearance: nominal dimension *(Hover clearance vehicle: Distance between the bottom of the support skid and the top of the levitation magnet based on nominal load on the levitation magnet with the vehicle hovering)*
z_C	z-coordinate pivot point, car body axial rotation
ZG	Load case designation for permissible vehicle weight
z_i	z-value at point "i"(i=1 to n)
$z_{i,Ist}$	z-value in actual position at point "i"
Z_{Ist}	Hover clearance: existing z-actual-value
z_K	z-offset of the section coupling
z_{piE}	z-displacement pendulum i end section
z_{sE}	z-distance from centre of gravity end section to section coupling
Z_{Soll}	Hover clearance: planned nominal value
z_{sWK}	z-centre-of-gravity coordinate car body
Zw	Gusset solution
ZWK	Constraining force
ÜA	Beginning of clothoid
ÜE	End of clothoid
$å_o$	Omnidirectional jolt
$å_{o\ max}$	Maximum permissible omnidirectional jolt
$å_x$	Linear jolt
$å_y$	Lateral jolt

Abbreviation	Definition
$å_{y\ max}$	Maximum permissible lateral jolt
$å_z$	Vertical jolt
$å_{z\ max}$	Maximum permissible vertical jolt

Definitions

Term	Definition
Acceleration deficit (downhill force)	Unbalanced lateral acceleration which on a transversely inclined guideway acts towards the down-angled surface of the guideway (inside of the bend).
Acceleration surplus	Unbalanced lateral acceleration which on a transversely inclined guideway acts towards the outside of the bend, towards the up-angled surface of the guideway.
Actual running profile	Location-dependent speed profile that sets in according to the input of the nominal running profile depending on the given constraints (e.g. the available power).
Alignment-accompanying height datum point field	Height datum points as a basis for the construction-accompanying survey work in the elevation component (Z) of the maglev coordinate system.
Alignment-accompanying position datum point field	Position datum points as a basis for the construction-accompanying survey work in the ground plan component (X,Y) of the maglev coordinate system.
A-loads	Loads from normal operation for fatigue strength calculations.
Alternating step method	Stator section changeover method with two right-hand and two left-hand motor systems with reciprocally offset stator sections. Within a motor system, the changeover is currentless, usually causing a dip in thrust.
Aptitude	Aptitude denotes the fulfilment of psychological and cognitive requirements for a person to perform a defined activity.
Automatic braking	Braking manoeuvre automatically initiated by the operation control system to the stopping place currently defined by the OCS.
Automatic mode	Operating mode in which the protection of train operations is completely technical and the control is automatic.
Automatic stop	Stop by a train at a stopping place after initiation and execution of automatic braking to that place.
Automatic stop service station	Stop by a train at a service station after initiation and execution of automatic braking to that place.

Term	Definition
Availability	The ability of a product to be in a state in which it can fulfil a required function under given conditions at a given time or during a given period or provided that the required external aids are made available (as per /EN 50126/).
Azimuth	Angle which at a point P forms a random surface curve with the meridian through P. In the ellipsoidal azimuth, the lines run on the surface of the selected ellipsoid of revolution.
Bending point	Track-switching device that uses elastic deformation of the guideway superstructure (multiple-bay beam) to facilitate the switch to other tracks while complying with the geometrical inputs.
Brake acceleration	Acceleration component which brings about the retardation of the vehicle in the longitudinal direction of the guideway centreline and parallel to the guideway surface, sign (-).
Buffer time	Addition to the minimum signal headway that must be allowed for when designing the schedule so as to minimise the delay carryover in case of irregularities.
Building coordinate system	A system of coordinates (X,Y,Z) used for the three-dimensional design, alignment and monitoring of engineering structures.
Building horizon	Mean elevation to which the ground plan components of the maglev system of coordinates (X,Y) are reduced.
Calibration guideway	Section of the maintenance guideway with heightened requirements for the positional accuracy of the functional planes for commissioning the MSB vehicle or individual modules.
Cantilever arm	Lateral sections of the guideway superstructures which support the long stator, the lateral guide rails and the slide rails.
Car body	The car body encompasses all loadbearing parts in the primary power stream above the magnetic drivetrain. It includes all components which are attached to these parts and which directly contribute to its strength, rigidity and stability.
Cartesian coordinates	Coordinates which determine points in space, expressed by values (x, y, z) on axes that are perpendicular to each other.

Term	Definition
Chainage	Continuous true-to-length dimensioning (kilometre marking) of the guideway or line axis, either in ground plan or in three-dimensional space according to requirements.
Cleaning	Cleaning tasks and measures which according to Section 3 /MdBO/ support safe and proper operation or which, as a marketing instrument, assist the positive overall image of the MSB.
Clearance gauge	Contour line in a section plane normal to the guideway axis - or in the case of dual-track guideways normal to the line axis - which defines the space that must be kept clear of obstructions and which rotates with the transverse inclination of the guideway about the three-dimensional curve. Dedicated system structures may be present up to the "limiting line for fixed internals".
Clothoid	Transitional bend with a linearly increasing or diminishing curvature.
Collision	Collision between vehicles or between vehicles and other objects.
Conformal projection	A map projection which is a conformal mapping, i.e. one for which local (infinitesimal) angles on a sphere are mapped to the same angles in the projection. Used for example in the cylindrical projections according to Gauß-Krüger or in the Universal Transverse Mercator Grid System (UTM).
Connection guideway	Distance between the danger point and the destination point of a stopping place (both relative to the front of the train).
Constraint	Point strictly specified locally or by planning that must be allowed for in the detailed alignment.
Converter	Device for generating a traction current for a motor system.
Converter regulation/control	Part of the drive regulation/control system for regulating and controlling the converter.
Criterion of inclination change	Angle deviation of two adjacent 1 m long functional-plane elements in y and z direction.
Cross-over	Device which uses bending points to facilitate the switch from one track to another parallel track without interrupting the journey.

Term	Definition
Current stopping place	Stopping place which the MSB vehicle can currently reach. This stopping place is approached in case of an automatic stop. Within the running profile monitoring system, there is always exactly one current stopping place for the MSB vehicle.
Danger point	Nadir of the safe braking profile, marks (in the direction of travel) the end of a stopping place.
Delay	Train arrival or departure at a station that is late compared with the timetable, above a project-specifically defined threshold.
Design speed	Speed stipulated for each track section at the start of the planning of the track alignment which adheres to the comfort parameters. The value is a constant over a definable track section. (Note: The actual speeds and running profiles in a project are the result of the alignment based on the draft design and on the system limits and system parameters.)
Diagnosis	The collection, storage and evaluation of information about the operational status and functional capability of a system to support operation or maintenance.
Diagnostic system	Facility for monitoring certain variables and process states for deviations from the desired nominal state.
Drive	Subsystem that provides the traction power for MSB vehicles.
Drive acceleration (ax)	Acceleration component which brings about the drive of the vehicle, in the longitudinal direction of the guideway centreline and parallel to the guideway surface, sign (+).
Drive block	Part of the drive in the substation for transforming the traction energy for a vehicle.
Drive circuit	Line-side drive components of a drive sector.
Drive control system	Collective term for the regulating and control devices of the drive sector.
Drive sector	A section of the line in which a maximum of one vehicle can be driven.
Drive unit	Components of the drive sector for operating a vehicle, consisting of one or two drive blocks and the drive circuit of the drive sectors.
Element	Depending on the subject matter, the unit on the lowest level of consideration regarded as indivisible (as per /DIN 40150/).

Term	Definition
Elevated guideway	Sections of guideway at a guideway height of 3.5 m < H ≤ 20 m (H > 20 m in special cases) are referred to as elevated.
Elevation reference surface	Equipotential surface as a reference for elevations.
Empirical value	Value assessed conservatively based on measurements on the existing MSB system. Must be reviewed project-specifically.
Energy supply	Subsystem for providing the energy for the complete system.
Entrepreneur (according to AEG/)	Railways are public utilities or private enterprises which provide rail traffic services (rail traffic companies) or which operate a railway infrastructure (railway infrastructure companies). Rail traffic services are the carriage of persons or goods on a railway infrastructure. Rail traffic companies must be able to ensure train traction.
Environment	Totality of all influences to which a system, subsystem or component is actually exposed or could be exposed during manufacture, storage, transport, integration and use.
Equipment	Functional, physical item (as per /DIN 50129/).
Equipotential surface	Surface of constant gravity potential.
Evacuation stopping place	Defined section of line to allow the stopping of trains in emergencies, provided with facilities for the rapid and easy evacuation of persons from the vehicle onto an alighting platform.
External on-board energy infeed	Stationary items of equipment for the energy supply of vehicles that are assigned to the Drive and Energy Supply subsystem. They do not include the transmission components on the guideway and in the vehicle.
External on-board energy supply	All electrical items of equipment for the supply of the MSB vehicles with electrical energy.
Fail-safe	Concept incorporated in the design of a product to ensure that, if it fails, it will enter or maintain a safe state (as per /EN 50129/).
Fault-tree analysis	An analytical method for determining which failure types of the product, of the sub-product or external events or combinations of these can lead to an agreed failure type of the product; the analysis being represented in the form of a fault tree (as per /EN 50126/).
Fitness	Fitness refers to the fulfilment of the physical requirements to perform a defined activity by a person.

Term	Definition
Free (unbalanced) lateral acceleration	Acceleration surplus (acts towards the outside of a bend: a_y = positive), Acceleration deficit (acts towards the inside of a bend: a_y = negative).
Free bearing	Bearing of a geodesic grid (1, 2 or 3-dimensional) on approximate coordinates while minimising the remaining gaps. Deformation of the grid by connection constraints is avoided in this way.
Function	Type of action or activity by which a product fulfils its intended purpose (as per /EN 50129/).
Functional plane	System-characterising reference planes for the levitation/guidance functions of the vehicle
Functional unit	Item that is delineated according to task or action. Derived terms as a function of the consideration criteria are: • Constructional unit • Operational unit • Maintenance unit (as per /DIN 40150/)
Geoid	A shape of the Earth described by an equipotential surface of the Earth's gravitational field (normal to the force of gravity) level with mean seal level notionally continued under the continents.
Global Positioning System	Satellite-assisted method for absolute or relative positioning.
Gradient	Course of the three-dimensional curve of the guideway in longitudinal section.
Grid North	The direction of the gridlines running parallel with the main meridian of the geodetic system of coordinates.
Guide value	Value which, if necessary together with other guide values, is according to practice capable of fulfilling the requirements.
Guideway	Track structure which absorbs all forces resulting from the vehicles and the environment and transmits them to the subsoil, and which contains or carries the modules that are necessary for vehicle hovering (levitation, guidance, drive and brakes).
Guideway axis	The centreline between the slide planes of the guideway. It is equivalent to the three-dimensional curve.

Term	Definition
Guideway beam	Discretely borne support system with a beam-type supporting action; it is usual to use single and dual bay beams for standard guideway and multi-bay beams for track-switching equipment.
Guideway bearer	Collective term for all elements/modules such as guideway beam bearer, supports etc.
Guideway construction methods	Definition of the guideway depending on the materials used for the guideway superstructures (e.g. steel construction, concrete construction, hybrid construction)
Guideway designs	Manufacturer-specific execution of a guideway construction method.
Guideway elements	Collective term for all components and modules of the guideway.
Guideway equipment	MSB-specific and design specific modules/components of the guideway.
Guideway plates	Special type of guideway beam; support system with a two-dimensional or plate-like supporting action due to its short length (or span) relative to its width.
Guideway speed limit	Location-dependent profile of the maximum permissible speed of an aligned route, derived from the maximum effects applied in the guideway design due to non-frequent or exceptional design situations.
Guideway substructures	Foundation, supports and similar components that transmit the forces from the guideway superstructures and the environment to the subsoil.
Guideway superstructures	Guideway beam and guideway plates (including the guideway equipment) which absorb the effects from the vehicles and the environment and transmit them to the guideway substructures.
Guideway surface	Surface passing through the slide plane, contains the three-dimensional curve.
Guideway types	Definition of the guideway superstructures as a function of the span; a distinction is made between standard guideway superstructures (standard guideway beam Type I and Type II, standard guideway plates Type III) and special guideway superstructures (special guideway beams, special guideway plates).
Head Injury Criterion	Measure for the risk of a head injury in a vehicle collision (as per /HIC/). *Note: With a value of less than 1,000 it can be assumed that there will be no severe head injuries.*

Term	Definition
Immediate stop	An immediate activation of the Safe Brake with full unregulated braking force continuously to a standstill and setdown irrespective of stopping places. Accompanied by a safe drive shutdown.
Inhibition	Levitation and starting of a stopped vehicle prevented by safety systems.
Installations	Land, sites, structures and items of equipment, except vehicles, that are used for the operation, its processing and protection.
Interface	An interface is a point of contact, connection or separation of systems or components.
Journey	Movement of vehicles on the guideway.
Kilometre marking	Three-dimensional developed length of the three-dimensional curve (same as chainage).
Kinematic gauge	Is the theoretical enveloping line of a vehicle based on normal coordinates, taking into account the least favourable positions of the levitation chassis relative to the guideway and the quasi-static movements of the car body. Random factors (vibration, asymmetries) are not allowed for.
Lateral acceleration, unbalanced	Acceleration component parallel to the guideway surface and normal to the guideway axis, sign (+) acceleration in direction of travel to the left, (-) acceleration to the right.
Lateral guidance planes	Functional planes formed by the lateral outer faces of the lateral guide rails.
Lateral guide rails	Guideway-side modules on the outsides of the cantilever arms used to withstand mechanical and electromagnetic effects.
Lateral pressure ($\mathring{a}_y$)	Differential change in the unbalanced lateral acceleration (a_y) per unit of time.
Least favourably specified conditions	Combination of specified conditions which produces the least favourable effects for a considered functional unit or a considered process in regard to its specified function.
Levitation	Combination of the carrying and guidance functions of the vehicle.
Levitation profile	Location-dependent speed profile leading to the associated stopping place that can be attained with the vehicle's levitation capability.

Term	Definition
Limiting running profile	Speed profile that allows for all speed limitations that must be observed for safety purposes (line speed limit and safe braking profile) depending on the location. The profile is dependent on the stopping place.
Line	Is the aligned course of one or more parallel-laid guideways equipped with safety equipment, chainage and ancillary installations.
Line axis	The course of the centreline of two guideway axes on dual-track guideways.
Line cable system	Three-phase medium-voltage cable arrangement that connects the switching points to the substations.
Line cross-section	Representation of guideway and peripheral line equipment in cross-section at any point on the line.
Line speed limit	Location-dependent minimum out of vehicle speed limit, tunnel speed limit and guideway speed limit.
Linear generator	Vehicle-side equipment for on-board energy generation.
Linear inclination (s, b)	Angle (b) by which the guideway axis is inclined to the horizontal in the direction of chainage. (s) = Tangent value of the angle (b). Sign (+) for rising, (-) for falling guideway axis, expressed in [°] or [%].
Linear jolt (åx)	Differential change in the drive and brake acceleration (ax) per unit of time
Local maintenance depot	Maintenance facility where parts of the maintenance resources and maintenance management are held locally on site for the maintenance of MSB subsystems.
Long stator	Guideway-side module of the drive system consisting of stator packs, stator pack attachment, motor winding and the associated earthing.
Long-stator drive	Device for propelling and braking MSB vehicles, consisting of components of the Drive subsystem (supplying the tractive power) and the long-stator motors themselves.
Long-stator winding	Motor winding with earthing equipment and connection to the switching points.
Long-wave deviation	Determined deviation from the nominal position on the basis of discrete measurements.
Maglev Coordinate System (MKS)	Special object-based system of position and elevation coordinates for three-dimensional detailing, construction and structure monitoring (X,Y,Z).

Term	Definition
Magnetic drivetrain	The magnetic drivetrain includes all supporting parts beneath the car body which lie within the primary force flow. It comprises the loadbearing parts of the structure, the secondary suspension and x-articulation as interface with the car body, the magnet articulations and the magnets (levitation, guidance and brake magnets). It also includes all components which are attached to these parts and which directly contribute to their strength, rigidity and stability.
Main alignment point	Point on the three-dimensional curve at which 2 adjacent alignment elements of ground plan or elevation coincide.
Maintenance	Combination of all technical and administrative measures and management measures during the life-cycle of an item to maintain or restore its functional condition so that it can perform the required function. 'Item' in this context means any part, component, device, subsystem, any functional unit, equipment or system which can be considered on its own (EN 31051 and DIN EN 13306). For distinctions, see also Winter service and Vegetation control.
Maintenance centre	Maintenance facility where the essential maintenance resources and maintenance management for the maintenance of the MSB subsystems are held centrally.
Maintenance concept	Concept for the operational and organisational performance of maintenance.
Maintenance guideway	Guideway within a vehicle maintenance area with heightened requirements in regard to access to the modules of the MSB vehicle.
Maintenance installations	Installations for the maintenance of all subsystems. Depending on the specific project, they can be central, decentral or an appropriate combination of both.

Term	Definition
Maintenance instructions	Maintenance instructions are written by the manufacturer of a system / item. They contain all instructions, data and steps that are necessary to perform a maintenance operation. They also contain information about occupational health and safety and environmental protection necessitated by the individual steps or the supplies and consumables used, and information about the necessary maintenance aids. Maintenance instructions are project and location dependent.
Maintenance management	All management activities which determine the objectives, strategy and responsibilities of maintenance and implement them through means such as maintenance planning, control and monitoring and improvement of the organisation methods including commercial aspects (as per /EN 13306/).
Maintenance management system	Electronic system to assist maintenance management (/DIN EN 13306/).
Maintenance programme	Definition of the maintenance measures for a subsystem. Maintenance programmes are updated in line with operational experience.
Maintenance resources	Includes infrastructure, personnel, material, work equipment and inspection and test equipment for maintenance.
Maximum acceleration deficit of the drive	Maximum acceleration limit which may act from the drive to accelerate or retard the MSB vehicle in the longitudinal direction (x-direction) of the guideway axis in the event of a fault, allowing for least favourably specified drive parameters.
Maximum guideway speed	Location-dependent profile of the maximum permissible speed of an aligned route, derived from the maximum effects of frequent design situations used in the guideway design.
Maximum line speed	Location-dependent minimum out of maximum vehicle speed, maximum tunnel speed and maximum guideway speed.
Maximum operational speed	The maximum speed that is desirable for operational reasons. It can be defined by sections.

Term	Definition
Maximum power deficit of the drive	Maximum power limit which the drive may generate in the event of a fault, allowing for least favourably specified drive parameters, as the interface force between long stator (guideway) and the MSB vehicle in the longitudinal direction (x-direction) of the guideway axis.
Maximum running profile	OCS-monitored, location-dependent and stopping place-dependent maximum speed profile for achieving the limiting running profile. If exceeded, there is a Safe Drive Shutdown and the Safe Brake is activated.
Maximum speed profile	Maximum speed profile dependent on the location and stopping place which can be used operationally from a technical viewpoint. Lies around the standard tolerance of the drive under the maximum running profile and may not exceed the maximum line speed.
Maximum tunnel speed	Location-dependent profile of the greatest permissible speed in a tunnel, derived from the greatest permissible pressure loads of the vehicle in the tunnel for frequent design situations.
Maximum vehicle speed	Maximum permissible speed (constant variable) derived from the maximum effects of frequent design situations used in the vehicle design.
Maximum vehicle weight	Dead weight of the vehicle with increased payload in an exceptional operating situation (e.g. evacuation of adjacent sections in case of fire).
Mean Down Time	The average time for which a failed module is not available pending re-commissioning.
Mean Time Between Failures	The average time between two failures of a module.
Mean Time to Repair	The average repair time.
Mean vehicle weight	Dead weight of the vehicle with frequently expected payload component.
Minimum line speed	Location-dependent speed that is at least attainable by the drive taking account of project-specifically defined constraints and failure scenarios. Must be allowed for when designing stopping places.
Minimum running profile	OCS-monitored, location-dependent and stopping place-dependent minimum speed profile for achieving the safe levitation profile. If undershot, the drive is reliably shut down.

Term	Definition
Modes	Defined and clearly delimited types of train operation which differ in their technical and nontechnical measures for the execution of journeys.
Module	Mass-produced or individually manufactured component, or a functional set of mass-produced or individually manufactured components, which form a whole (as per /EN 61508-4/).
Motor regulation/control	Central part of the drive regulation/control system for primary regulation/control tasks such as vehicle guidance and organisation of the drive unit.
Motor system	Consists of one or more converters, line controlgear and a line cable system with the associated switching points and stator sections. A drive unit consists of one or two motor systems.
MSB Vehicle	Vehicle equipped with magnetic levitation and guidance functions for the carriage of passengers and/or goods.
National reference system	System of coordinates of the official national survey.
Nominal precamber	Superelevation of the guideway beam in the z-direction, to largely offset the deformations due to vehicle and temperature effects.
Nominal running profile	Location-dependent minimum out of nominal speed and maximum running profile less positioning and drive control tolerances as nominal values for the drive to approach the destination point of a stopping place.
Nominal speed	Location-dependent minimum out of recommended line speed and maximum line speed as graduated and smoothed nominal values for the drive, e.g. for purposes of travelling-time simulation.
Normal acceleration (a_z)	acceleration component normal to the guideway surface that deviates from the normal free-fall acceleration (vertical direction), sign (+) in the direction of normal free-fall acceleration, sign (-) contrary to the direction of normal free-fall acceleration.
Normal free-fall acceleration (g)	Acceleration due to gravity ($g = 9.81$ m/s^2).
Normal operation	Fully technically protected train operations. *Note: The term 'normal operation' results from an operational analysis according to /MbBO/ Section 24.*

Term	Definition
Offset	Linear deviation of two adjacent functional plane elements in y and z-direction.
Operate and observe	Part of the Man/Machine Interface of the Drive and Energy Supply subsystem. System for process monitoring and operation.
Operating manual	Contractor's instructions for the safe execution and monitoring of train operations which take into consideration normal operation as well as non-standard operating states and the interface with maintenance.
Operation	Operation is the totality of all measures used to carry passengers and goods (Section 2, (1) /MbBO/).
Operation Control System	The operation control system provides the components for securing, monitoring and controlling the operation.
Operation personnel	See Public employee.
Operationally related active module	Module that is required to maintain regular operation or fault-mode operation.
Operations control centre	Central installation with equipment for signalling, control and communication and with operating and display devices of the MSB subsystems.
Payload	Weight of the persons (incl. baggage) or goods that are being carried.
Permissible vehicle weight	Vehicle tare weight with maximum payload.
Personnel responsibility	The performance of defined safety-related duties by personnel.
Pitching	Rotational motion of the car body or levitation chassis about the y-axis
Planning coordinate system (planning system)	The coordinate system used for the particular planning purpose. Here: National system for preliminary design, rough planning and/or maglev coordinate system for detailed alignment and construction.
Point	Guideway element that permits switching from one track to another at track changes or line junctions without interrupting the journey. Points in the high-speed maglev are bending points.
Polygonal line	Used for determining datum points of position by lines. The polygonal points to be coordinated are derived from the measured side lengths of the train and the angles of refraction measured at its vertices.

Term	Definition
Primary datum point frame	Primary position and elevation datum points of the maglev coordinate system as a basis for the detailed alignment and for laying out the position and elevation datum point fields that accompany the alignment.
Primary environment	The environment which acts on a subsystem of the maglev without being influenced by it ("original climate").
Primary structure	Special building structure to take the guideway superstructures and if necessary structural installations of the line peripherals (e.g. bridge with noise attenuation).
Process instructions	Process instructions contain general information and regulations for work procedures (e.g. processes, organisation, ordering of maintenance work, general guidelines for performing work, documentation of measures etc.). Process instructions are project and site dependent.
Projection reduction	Any necessary improvements that must be made to measured variables when projecting on the flat surface.
Projection surface	Mathematically defined surface onto which points or objects of the physical surface of the Earth are projected.
Proof of safety	Documented proof that a product meets the specified safety requirements (as per /EN 50129/).
Proximity principle	Basic principle of all geodesic measurements, calculations and marking-out, which states that particular attention must be given to existing geometric relationships between neighbouring object points.
Public employee	Section 26, (2) /MbBO/ A public employee is a person who is engaged 1. in train operations, 2. in the control or monitoring of operations, 3. as a responsible person in the maintenance of installations or vehicles, 4. as manager or supervisor of operational personnel according to Numbers 1 to 3.
Quality	Quality is the entirety of properties and characteristics of a product or service that relates to its ability to fulfil defined or implied requirements.

Term	Definition
Quality assurance process	Verification of whether the system-technical requirements of the Design Principles and, if applicable, of the project specifications have been complied with. The verification is carried out as part of quality assurance process when planning and executing the particular subsystem.
Raised walkway	An elevated walkway running alongside the guideway that is provided for the rescue and evacuation of passengers at special evacuation stopping places.
High-speed Maglev System	A magnetic levitation railway as defined by the Allgemeines Magnetschwebebahngesetz (/AMbG/).
Reachability point	Nadir of the levitation profile, marks (in the direction of travel) the start of a stopping place.
Recommended line speed	Minimum recommended speed out of travelling comfort and maximum operating speed, possibly allowing for other project-specific inputs (e.g. energy demand, sound attenuation).
Recommended speed for travelling comfort	Local speed at which exactly the project-specifically defined comfort parameters are achieved with the given alignment.
Redundancy	Provision of one or more additional, usually identical measures in order to maintain the failure tolerance (/DIN 50129/).
Reference position	Reference position used to synchronise the positioning system at defined reference points on the line.
Reference temperature	Project-related reference temperature for the geometrical design and tolerancing of components. Usually half-way between the max. and min. anticipated component temperature.
Regular operation	Operation action without the operator's responsibility for safety, i.e. without personnel responsibility. Responsibility for safety lies with the OCS.
Relative position	The relative position is formed continuously during the journey and is based on the last valid reference position.
Reliability	Ability of a unit to provide a required function under given conditions for a given time (as per /EN 50129/).
Reserve	Setting of the moving guideway elements, continuous and fully technical protection of the guideway to be travelled, and assignment of only one OCS-protected vehicle to that guideway.

Term	Definition
RMS value (root-mean-square)	RMS value is the quadratic mean (Root Mean Square) of a periodic signal.
Rolling	Rotational motion of the car body or levitation chassis about the x-axis
Route peripherals	Collective term for • small structures needed close to the guideway route (e.g. radio masts, switching points) that are required for systems engineering purposes, • other necessary structures closely associated with the guideway in their arrangement (e.g. noise barrier wall, sight screen).
Running profile	A characteristic which indicates the vehicle speed as a function of the vehicle position taking account of operational and alignment data and which is relative to a stopping place.
Running profile monitoring	Subfunction of the operational control system's safety function. Monitors the vehicle speed for violation of technical safety inputs (running profiles).
Running resistance	The running resistance consists of three components • aerodynamic resistance FA (the increase in tunnels must be determined for the specific structure), • running resistance FM due to the magnetization/demagnetization of long stator and lateral guide rail of the guideway, • running resistance FB due to on-board energy generation by linear generator for the vehicle.
Safe Brake	Safe-life brake built into the train, e.g. implemented by a destination-controlled eddy-current brake and the train sliding to a stop on support skids.
Safe braking profile	Location-dependent speed profile leading to the associated stopping place that can be attained with the Safe Brake.
Safe drive shutdown	Function for the safe shutdown of the long-stator drive.
Safe Position	Positional, speed and direction-of-travel information of a vehicle verified by a safety system.

Term	Definition
Safe-life	Describes a property/function that is present/available throughout the entire useful life; implemented alternatively by • Failure prevention based on operationally safe design and comprehensive inspection and testing in production and maintenance, or • Redundancy with failure tolerance for redundant modules, and a residual probability of failure of the function that is acceptable compared with the risk and proven by fault-tree analysis.
Safety	Freedom from unacceptable risks of loss (as per /DIN 50129/).
Safety management	Safety management is the organisation put in place by an MSB contractor and the precautions he takes to guarantee the safe control of his operational procedures.
Schedule	Definition of the planned journeys of the trains in regard to departure and arrival stations, traffic days, travel times.
Secondary environment	Environmental characteristics induced by the operation of a technical system and a downstream constructional unit. Compared with the primary environment, the secondary environment may involve new characteristics that differ from one another for individual modules.
Sector overlap	A functionality that in defined sections of track allows the drive and safety functions of those drive and/or safety sections to be taken over by neighbouring drive and/or safety sections.
Security	Measures to protect, monitor and prevent attacks on MSB installations.
Service journey	A journey with no passengers, e.g. transfer journeys.
Service life	Predicted minimum period of time in which a part or module displays service strength against a defined load population. Depending on the loads which actually occur in operation, the predicted service life is reviewed on the basis of the results of the inspections according to the maintenance programme and adjusted as necessary.

Term	Definition
Service station	Stopping place where repairs to the vehicle can be carried out.
Service stopping place	Section of line used for unscheduled stops by trains.
Service strength	Load-bearing capacity taking account of the effect from operation and the environment with a defined frequency and duration of the load.
Setdown speed	Speed at which the vehicle setdown sequence is initiated by the OCS.
Short interruption of the grid	Loss of public energy supply for a period ≥ 1s (based on /EN 50160/).
Shortwave deviation	Overlaying of the longwave deviation as absolute boundary for the spatial extent of a functional plane.
Sinusoid	Transitional bend with a sinusoidally increasing or diminishing curvature.
Slide plane	Functional plane formed by the surfaces of the slide rails.
Slide rail	Guideway-side modules on top of the cantilever arms used to take mechanical effects.
Sliding distance	Distance which a new sliding skid can cover on the slide rail with the vehicle at nominal mass and in dry conditions until the skid requires maintenance.
Special guideway beams	Guideway beams whose design (e.g. cross-section, span) differs from the project-specifically defined standard guideway beam types.
Special structures	Usually one-off/special structures to take the guideway (primary support structures and tunnels).
Special vehicle	Vehicles (wheeled vehicles or MSB vehicles with special equipment) which run on the guideway during the construction and commissioning of the MSB or for maintenance, winter service, vegetation control or rescue duties.
Standard (regular) guideway beam	Characterisation of guideway beams by project-specific input of constraints (e.g. standard span) which constitutes the basis for economical manufacture in regard to economies of scale; standard guideway beam types can be constructed by different methods and in different designs.
Start journey	Journey to verify the start point given by the traffic movement director and for failure disclosure of positioning.
Station	Operating installation for the scheduled stop of trains and the switching of passengers and freight.

Term	Definition
Stator pack	Part of the long stator; core stack consisting of bonded magnetic sheet steel laminations with a defined geometry, coating and integrated elements for mounting onto the cantilever arms.
Stator planes	Functional planes formed by the underside of the stator packs.
Stator section	Switchable stator winding section on a guideway side that can be supplied independently.
Stator section changeover	Transition from one stator section to the next synchronous with the vehicle's motion over the corresponding stator sections. Different methods are used, e.g. alternating step method und three-step method.
Stopping place	A defined section of track for the scheduled or unscheduled stopping of trains; stopping places are stations (scheduled stop) and service stopping places (unscheduled stop).
Substation	Enclosed electrical plant which essentially contains the components of the drive, the energy supply and the OCS.
Subsystem	Part of a system which fulfils a specific function (/DIN 50129/).
Switching point	Line-side device for switching stator sections.
System	Set of subsystems which interact according to a design (as per /DIN 50129/).
System engineering trials	Provision of the required proofs under near-application (boundary) conditions, integrated into the complete system of vehicle, drive, operation control system and guideway.
System lengths	Dimensions in the x-direction, derived from the distance between the individual phases of the motor winding (n × 86 mm, smallest divisible system dimension).
System parameter	Generic, non derivable variable by which the maglev system is characterised in the given version.
Three-dimensional curve / spatial guideway axis	Spatial course of the axis line of the guideway. The three-dimensional curve is generated by computationally superimposing the alignment and gradient definitions.
Three-step method	Stator section changeover method with three circuit cable systems in which the left and right separate and mutually offset stator sections are fed independently of each other and without a changeover delay.

Term	Definition
Tilting	Rotation of a functional plane about the measurement point of the y/z plane.
Track alignment	Axial curve of the guideway in plan view. Synonymous with alignment axis.
Track centres	Horizontal distance between the guideway axes of the dual-track guideway.
Track-switching devices	Moving guideway elements used to switch a vehicle from one track to other tracks.
Train	Technically protected guideway-bound vehicle in operation.
Train journey	A train journey is a controlled, technically monitored and technically protected movement by a train between a start point and a destination point.
Train operations	The preparation and execution of journeys with vehicles and special vehicles.
Transformation	Conversion of points from one coordinate system to another.
Translation	Displacement (usually along one of the coordinate axes).
Transverse inclination	Angle by which the guideway surface is rotated from the horizontal, sign (+) for clockwise rotation, (-) for counterclockwise rotation (looking in the direction of ascending kilometre markings), expressed in [°].
Transverse inclination tolerance	Deviation from the nominal transverse inclination.
Traverser	A track-switching device by which a stationary vehicle can be switched to different tracks by the parallel traversing of the guideway superstructure.
Tunnel speed limit	Location-dependent profile of the maximum permissible speed in a tunnel, derived from the maximum permissible pressure loads of the vehicle in the tunnel as a result of non frequent or exceptional design situations.

Term	Definition
Tunnels	Tunnels are structures which allow a man-made underground passage. When they are constructed • underground they count as tunnels irrespective of length, • by the open cut tunnelling method they count as tunnels from a closed length of 300 m and over. For shorter structures, the requirements defined for tunnels must be applied analogously in regard to stability and design.
Turntable	A track-switching device by which a stationary vehicle can be switched to different tracks by swivelling/rotating the guideway superstructure.
Undulation of the geoid	Separation between the geoid and the ellipsoid.
Uninterruptible Power Supply (UPS)	Equipment for generating a supply voltage without interruptions in the event of a mains power failure.
Usability	"Usability is the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. The context of use consists of the users, tasks, equipment (hardware, software and materials) and the physical and societal environments in which the product is used." (EN ISO 9241, Part 11)
Useful life	Guide value for the period of time in which a subsystem can be used. The useful life is used as a basis for the maintenance strategy and when planning spare parts supplies. Parts/modules with a life shorter than the useful life are replaced as part of in-operation maintenance.
Vegetation control	Totality of all measures for keeping the defined clearance gauge of the MSB system clear of vegetation including preventive measures against falling trees.
Vehicle	MSB vehicles and special vehicles (see also the definitions of MSB vehicle and special vehicle).
Vehicle exterior	Term used for the various EMC and lightning protection areas provided on the outside of the vehicle.
Vehicle gauge	Contour line based on the cross-section to be investigated, that may not be crossed by any part of the vehicle (vehicle contour).

Term	Definition
Vehicle section	Unit for forming a vehicle.
Vehicle speed limit	Maximum permissible speed (constant variable) derived from the maximum effects used in the vehicle design due to non-frequent or exceptional design situations.
Vehicle tare weight	Weight of the vehicle including equipment (e.g. seating) excluding payload.
Vertical jolt	Differential change in normal acceleration (a_z) per unit of time.
Walkway	An at-grade walkway running alongside the guideway that is provided for the rescue and evacuation of passengers at special evacuation stopping places.
Warping	Change in transverse inclination per unit of length, dimension [°/m].
Winter service	Totality of all technical and non-technical measures taken to maintain the defined environmental conditions for MSB operation in winter conditions. Includes the planning, organisation and implementation of the measures for the guideway and MSB system parts, as well as general winter service measures around the traffic installations, operating installations and route infrastructure.
Work instructions	Work instructions comprise the maintenance instructions and supplement them with particular local and/or project-specific characteristics. These special characteristics may relate to the use of special tools, carrying out work within the scope of the local infrastructure, or information about the work sequence. The additional requirements which these special characteristics involve for occupational safety and environmental protection are contained here. Work instructions are project and site dependent.
Yaw	Rotational motion of the car body or levitation chassis about the z-axis

High-speed Maglev System Design Principles

Complete System Annex 2 Statutes, regulations, standards and directives

Distribution

This document has been released for publication by the Technical Committee "Complete System".

Change history

Release date: 15.02.2007; white paper, Technical Committee "Complete System"

List of contents

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General

Purpose of the document, scope

This document contains statutes, regulations, standards and directives for MSB systems.

MSB Design Principles

This document is an annex to the Design Principles Complete System and so forms part of a documentation for high-speed maglev systems consisting of different design principles.
The high-level "complete system" design principles and their annexes apply uniformly for the whole documentation:

- MSB Design Principles Complete System, Doc. No.: 50630, /MSB AG-GESAMTSYS/
    - Annex 1: MSB Abbreviations and Definitions, Doc. No.: 67536, /MSB AG-ABK&DEF/
    - Annex 2: MSB Statutes, Regulations, Standards and Directives, Doc. No.: 67539, /MSB AG-NORM&RILI/
    - Annex 3: MSB Environment, Doc. No.: 67285, /MSB AG-UMWELT/
    - Annex 4: MSB Rules for Operation and Maintenance, Doc. No.: 69061, /MSB AG-BTR/
    - Annex 5: MSB Noise, Doc. No.: 72963, /MSB AG-SCHALL/

Abbreviations and definitions

The abbreviations and definitions given in /MSB AG-ABK&DEF/ apply.

Statutes, regulations, standards and directives

The statutes, regulations, standards and directives are listed in this document.

Identification and binding value of requirements

The requirements of /DIN 820/ were applied analogously in the preparation of this document.

In the following chapters and the annexes of this document

- Requirements are shown in normal font
- Explanations, guide values and examples are shown in italics

The degree to which the requirements are binding has been defined by reference to /DIN 820-2/ Annex G, and has been taken into consideration when formulating the individual requirements.

Design Principles

Short form	Description
/MSB AG-GESAMTSYS/	MSB Design Principles Complete System, Doc. No.: 50630, with the annexes:
/MSB AG-ABK&DEF/	Annex 1: MSB Abbreviations and Definitions, Doc. No.: 67536,
/MSB AG-NORM&RILI/	Annex 2: MSB Statutes, Regulations, Standards and Directives, Doc. No.: 67539,
/MSB AG-UMWELT/	Annex 3: MSB Environmental Conditions, Doc. No.: 67285,
/MSB AG-BTR/	Annex 4: MSB Rules for Operation (Train Operation and Maintenance), Doc. No.: 69061,
/MSB AG-SCHALL/	Annex 5: MSB Noise, Doc. No.: 72963,
/MSB AG-FZ GEN/	MSB Design Principles Vehicle, Part I: General Requirements, Doc. No.: 67698,
/MSB AG-FZ BEM/	MSB Design Principles Vehicle, Part II: Dimensioning, Doc. No.: 67694,
/MSB AG-FZ KIN/	MSB Design Principles Vehicle, Part III: Kinematic Gauge, Doc. No.: 67650,
/MSB AG-FZ TRAFÜ/	MSB Design Principles Vehicle, Part IV: Support/Guidance System, Doc. No.: 73388,
/MSB AG-FZ BREMS/	MSB Design Principles Vehicle, Part V: Brake System, Doc. No.: 73389,
/MSB AG-ANT/	MSB Design Principles Drive and Energy Supply, Doc. No.: 50998,
/MSB AG-BLT/	MSB Design Principles Operation Control System, Doc. No.: 53328,
/MSB AG-FW ÜBG/	MSB Design Principles Guideway, Part I: High-level Requirements, Doc. No.: 57284,
/MSB AG-FW BEM/	MSB Design Principles Guideway, Part II: Dimensioning, Doc. No.: 67694,
/MSB AG-FW GEO/	MSB Design Principles Guideway, Part III: Geometry, Doc. No.: 41727,
/MSB AG-FW TRAS/	MSB Design Principles Guideway, Part IV: Alignment, Doc. No.: 60640,
/MSB AG-FW VERM/	MSB Design Principles Guideway, Part V: Surveying, Doc. No.: 60641,
/MSB AG-FW IH/	MSB Design Principles Guideway, Part VI: Maintenance, Doc. No.: 63842,

Table 8: Design Principles

Statutes and Ordinances

The statutes and ordinances used in the MSB Design Principles are listed below. The edition indicated is the version of the statutes and ordinances at the time of issue of the MSB Design Principles.

Statute	Description
/26. BImSchV/	Twenty-Sixth Ordinance on the Implementation of the Federal Immission Control Law (Electromagnetic Field Ordinance - 26. BImSchV) "Ordinance on Electromagnetic Fields of 16 December 1996 (BGBl. I p. 1966)"
/AMbG/	"General Magnetic Levitation Railway Law of 19 July 1996 (BGBl. I p. 1019), last amended by Article 303 of the Ordinance of 31 October 2006 (BGBl. I p. 2407)"
/Occupation Safety/	Statutes and ordinances on occupational safety /ArbSchG/, /ArbstättV/, /ASiG/, /BaustellV/, /BetrSichV/, /BildscharbV/, /GPSG/, /GPSGV/, /GSGV/, /LasthandhabV/, /PSA-BV/.
/ArbSchG/	"Occupational Safely Law of 07 August 1996 (BGBl. I p. 1246), last amended by Article 227 of the Ordinance of 31 October 2006 (BGBl. I p. 2407)"
/ArbStättV/	"Health and safety at work act of 12 August 2004 (BGBl. I p. 2179), amended by Article 388 of the Ordinance of 31 October 2006 (BGBl. I p. 2407)"
/ASiG/	"Law on company doctors, safety engineers and other specialists for occupational safety of 12 December 1973 (BGBl. I p. 1885), last amended by Article 226 of the Ordinance of 31 October 2006 (BGBl. I p. 2407)"
/BaustellV/	"Construction Site Ordinance of 10 June 1998 (BGBl. I p. 1283), amended by Article 15 of the Ordinance of 23 December 2004 (BGBl. I p. 3758)"
/BetrSichV/	"Ordinance on Industrial Safety and Health of 27 September 2002 (BGBl. I p. 3777), last amended by Article 439 of the Ordinance of 31 October 2006 (BGBl. I p. 2407)"
/BildscharbV/	"VDU Work Ordinance of 04 December 1996 (BGBl. I p. 1843), last amended by Article 437 of the Ordinance of 31 October 2006 (BGBl. I p. 2407)"
/BImSchG/	"Federal Immission Control Law in the version of the proclamation of 26 September 2002 (BGBl. I p. 3830), last amended by Article 3 of the Law of 18 December 2006 (BGBl. I p. 3180)"
/BNatSchG/	"Federal Nature Conservation Law of 25 March 2002 (BGBl. I p. 1193), last amended by Article 8 of the Law of 09 December 2006 (BGBl. I p. 2833)"
/ChemG/	"Chemicals Law in the version of the proclamation of 20 June 2002 (BGBl. I p. 2090), last amended by Article 231 of the Ordinance of 31 October 2006 (BGBl. I p. 2407)"
/GefStoffV/	"Hazardous Substances Ordinance of 23 December 2004 (BGBl. I p. 3758, 3759), last amended by Article 442 of the Ordinance of 31 October 2006 (BGBl. I p. 2407)"
/GPSG/	"Equipment and Product Safety Law of 06 January 2004 (BGBl. I p. 2 (219)), last amended by Article 3 Paragraph 33 of the Law of 07 July 2005 (BGBl. I p. 1970)"
/GPSGV/	Machine Ordinance "Ninth Ordinance on the Equipment and Product Safety Law (Machine Ordinance) of 12 May 1993 (BGBl. I p. 704), last amended by Article 14 of the Ordinance of 23 December 2004 (BGBl. I p. 3758)"
/KrW- AbfG/	"Recycling and Waste Management Law of 27 September 1994 (BGBl. I p. 2705), last amended by Article 7 of the Law of 09 December 2006 (BGBl. I p. 2819)"

Statute	Description
/LasthandhabV/	"Load Handling Ordinance of 04 December 1996 (BGBl. I p. 1842), last amended by Article 436 of the Ordinance of 31 October 2006 (BGBl. I p. 2407)"
/MbBO/	"Maglev Construction and Operation Ordinance of 23 September 1997 (BGBl. I p. 2329)"
/MSB-LSchV/	"Maglev Noise Control Ordinance of 23 September 1997 (BGBl. I p. 2329, 2338)“
/PERSCH/	Legislation on the protection of persons /ArbSchG/, /BetrSichV/, /BildscharbV/, /PSA-BV/, /LasthandhabV/, /ArbStättV/, /BaustellV/, /GPSG/, /GPSGV/, /ASiG/, /ChemG/, /GefStoffV/.
/PSA-BV/	"Ordinance on the Use of PPE of 04 December 1996 (BGBl. I p. 1841)"
/Directive 2004/49/EC/	Corrigendum to Directive 2004/49/EC of the European Parliament and of the Council of 29 April 2004 on safety on the Community’s railways and amending Council Directive 95/18/EC on the licensing of railway undertakings and Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification ("Railway Safety Directive") *Official Journal of the European Union L 164 of 30 April 2004)*
/Directive 98/37/	Directive 98/37/EC Directive 98/37/EC of the European Parliament and of the Council of 22 June 1998 on the approximation of the laws of the Member States relating to machinery *Official journal no. L 207 of 23.07.1998 p. 0001 - 0046*
/Environment/	Environmental protection laws /BImSchG/, /BNatSchG/, /ChemG/, /GefStoffV/, /KrW- AbfG/, /WHG/
/WHG/	"Water Management Law in the version of the proclamation of 19 August 2002 (BGBl. I p. 3245), last amended by Article 2 of the Law of 25 June 2005 (BGBl. I p. 1746)"

Table 9:Statutes and Ordinances

Standards and Directives

The standards and guidelines referred to in the MSB Design Principles are listed below. The edition indicated is the version of the standards and guidelines at the time of issue of the MSB Design Principles.

Standard	Description
/BrandReg/	"Rules for the fire safety assessment of rail vehicles as part of acceptance according to Section 32 EBO **-** Principles of fire safety requirements based on EN 45545", EBA 2006-06-01
/DIN 1055-100/	Effects on Structures - Part 100: Fundamentals of structural engineering - Safety concept and design rules 2001-03-01
/DIN 1076/	Highway structures - Testing and inspection 1999-11-01
/DIN 18014/	Foundation earth electrodes 1994-02-01
/DIN 31051/	Fundamentals of Maintenance 2003-06-01
/DIN 4149/	Structures in German earthquake zones - Design loads, dimensioning and construction of conventional buildings 2005-04-01
/DIN 5510-1/	Preventive fire protection in railway rolling stock; fire protection classes, fire protection measures and proofs 1988-10-01
/DIN 5510-2/	Preventive fire protection in railway rolling stock - Part 2: Combustion behaviour and secondary combustion phenomena of materials and components; Classification, requirements and test methods Draft 2003-09-01
/DIN 5510-4/	Preventive fire protection in railway rolling stock; Design engineering of vehicles; Safety engineering requirements 1988-10-01
/DIN 5510-5/	Preventive fire protection in railway rolling stock; Electrical equipment; Safety engineering requirements 1988-10-01
/DIN 5510-6/	Preventive fire protection in rail vehicles; Accompanying measures; Function of the emergency brake, information systems, fire alarms, fire fighting equipment; Safety engineering requirements 1988-10-01
/DIN 57510/ /DIN VDE 0510/ /VDE 0510/	VDE Regulations for accumulators and battery systems 1977-01-01

Standard	Description
/DIN 820-2/	Standardization - Part 2: Presentation of documents (ISO/IEC Directives - Part 2, modified); Trilingual version CEN/CENELEC-Internal Regulations - Part 3: Rules for the structure and drafting of CEN/CENELEC publications 2004-10-01
/DIN EN 12663/	Railway applications - Structural requirements of rolling stock bodies; (German version EN 12663:2000) 2000-10-01
/DIN EN 13306/	Maintenance terminology; Trilingual version EN 13306:2001 2001-09-01
/DIN EN 14750-1/	Railway applications - Air conditioning for urban and suburban rolling stock - Part 1: Comfort parameters; (German version EN 14750-1:2006) 2006-08-01
/DIN EN 50121/	Standard series: Railway applications - Electromagnetic Compatibility
/DIN EN 50121-1/ (VDE 0115-121-1)	Railway applications - Electromagnetic Compatibility - Part 1: General; (German version EN 50121-1:2000 / *DIN V ENV 50121-1 (1997-02) also applies up to 2003-04-01.)* 2001-05-01
/DIN EN 50121-2/ (VDE 0115-121-2)	Railway applications - Electromagnetic Compatibility - Part 2: Radiated EMI of the whole rail system into the environment; (German version EN 50121-2:2000 / *DIN V ENV 50121-2 (1997-02) also applies up to 2003-04-01.)* 2001-05-01
/DIN EN 50121-3-1/ (VDE 0115-121-3-1)	Railway applications - Electromagnetic Compatibility - Part 3-1: Railway vehicles; train and complete vehicle; (German version EN 50121-3-1:2000 / *DIN V ENV 50121-3-1 (1997-02) also applies up to 2003-04-01.)* 2001-05-01
/DIN EN 50121-3-2/ (VDE 0115-121-3-2)	Railway applications - Electromagnetic Compatibility - Part 3-2: Railway vehicles; Devices; (German version EN 50121-3-2:2000 / *DIN V ENV 50121-3-2 (1997-02) also applies up to 2003-04-01.)* 2001-05-01
/DIN EN 50121-4/ (VDE 0115-121-4)	Railway applications - Electromagnetic Compatibility - Part 4: Radiated EMI and immunity of signalling and communications equipment; (German version EN 50121-4:2000 / *DIN V ENV 50121-4 (1997-02) also applies up to 2003-04-01.)* 2001-05-01
/DIN EN 50121-5/ (VDE 0115-121-5)	Railway applications - Electromagnetic Compatibility - Part 5: Radiated EMI and immunity of stationary installations and equipment of the railway energy supply (German version EN 50121-5:2000 / *DIN V ENV 50121-5 (1997-02) also applies up to 2003-04-01.)* 2001-05-01
/DIN EN 50126/ (VDE 0115-103)	Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS); (German version EN 50126:1999) 2000-03-01
/DIN EN 50128/ (VDE 0831-128)	Railway applications - Communications, signalling and processing systems - Software for railway control and protection systems; (German version EN 50128:200) 2001-11-01

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/DIN EN 50129/ (VDE 0831-129)	Railway applications. Communication, signalling and processing systems. Safety related electronic systems for signalling ; (German version EN 50129:2003 / *DIN V ENV 50129 (1999-07) also applies up to 2005-12-01.)* 2003-12-01
/DIN EN 50153/ (VDE 0115-2)	Railway applications - Rolling stock - Protective provisions relating to electrical hazards; (German version EN 50153:2002 / *DIN EN 50153 (1996-12) also applies up to 2005-05-01.)* 2003-07-01
/DIN EN 50159-1/ (VDE 0831-159-1)	Railway applications - Communication, signalling and processing systems - Part 1: Safety-related communication in closed transmission systems; (German version EN 50159-1:2001) 2001-11-01
/DIN EN 50159-2/ (VDE 0831-159-2)	Railway applications - Communication, signalling and processing systems - Part 2: Safety-related communication in open transmission systems; (German version EN 50159-2:2001) 2001-12-01
/DIN EN 50160/	Voltage characteristics of electricity supplied by public distribution systems; (German version EN 50160:1999) 2000-03-01
/DIN EN 50178/ (VDE 0160)	Electronic equipment for use in power installations; (German version EN 50178:1997) 1998-04-01
/DIN EN 60068/	Standards family, environmental tests
/DIN EN 60071-1/ (VDE 0111-1)	Insulation co-ordination - Part 1: Definitions, principles and rules (IEC 60071-1:2006); (German version EN 60071-1:2006 / DIN EN 60071-1 (1996-07) also applies up to 2009-03-01.) 2006-11-01
/DIN EN 60071-2/ (VDE 0111-2)	Insulation co-ordination - Part 2: Application guide (IEC 60071-2:1996); German version EN 60071-2:1997 1997-09-01
/DIN EN 60076-/	Standard series: Power transformers
/DIN EN 60076-1/ (VDE 0532-76-1)	Power transformers - Part 1: General (IEC 60076-1:1993, modified + A1:1999); (German version EN 60076-1:1997 + A1:2000 + A12:2002 / DIN EN 60076-1 (1997-12) and DIN EN 60076-1/A1 (2001-07) also apply up to 2005-02-01.) 2003-01-01
/DIN EN 60076-10/ (VDE 0532-76-10)	Power transformers - Part 10: Determination of sound levels (IEC 60076-10:2001); German version EN 60076-10:2001 / DIN EN 60551 (1993-11) and DIN EN 60551/A1 (1998-02) also apply up to 2004-06-01. 2002-04-01
/DIN EN 60076-11/ (VDE 0532-76-11)	Power transformers - Part 11: Dry-type transformers (IEC 60076-11:2004); German version EN 60076-11:2004 / DIN EN 60726 (2003-10) also applies up to 2007-07-01. 2005-04-01
/DIN EN 60076-2/ (VDE 0532-102)	Power transformers - Part 2: Temperature rise (IEC 60076-2:1993, modified); German version EN 60076-2:1997 1997-12-01

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/DIN EN 60076-3 CORRIGENDUM 1/ (VDE 0532-3 CORRIGENDUM 1)	Corrigenda to DIN EN 60076-3 (VDE 0532 Part 3):2001-11 2002-04-01
/DIN EN 60076-3/ (VDE 0532-3)	Power transformers - Part 3: Insulation levels, dielectric tests and external clearances in air (IEC 60076-3:2000 + Corrigendum:2000); German version EN 60076-3:2001 / DIN VDE 0532-3 (1987-07) and DIN VDE 0532-3/A1 (1995-12) also apply up to 2004-01-01. 2001-11-01
/DIN EN 60076-4/ (VDE 0532-76-4)	Power transformers - Part 4: Guide to the lightning impulse and switching impulse testing of power transformers and reactors (IEC 60076-4:2002); German version EN 60076-4:2002 / DIN VDE 0532-13 (1984-07) also applies up to 2005-09-01. 2003-06-01
/DIN EN 60076-5/ (VDE 0532-76-5)	Power transformers - Part 5: Ability to withstand short-circuit (IEC 60076-5:2006); German version EN 60076-5:2006 / DIN EN 60076-5 (2001-11) also applies up to 2009-04-01. 2007-01-01
/DIN EN 60228/ (VDE 0295)	Conductors of insulated cables (IEC 60228:2004); (German version EN 60228:2005 + Corrigendum:2005 / DIN VDE 0295 (1992-06) also applies up to 2007-12-01.) 2005-09-01
/DIN EN 60529/ (VDE 0470-1)	Degrees of protection provided by enclosures (IP code) (IEC 60529:1989 + A1:1999); (German version EN 60529:1991 + A1:2000 / DIN VDE 0470-1 (1992-11) also applies up to 2003-01-01.) 2000-09-01
/DIN EN 60664-1/ (VDE 0110-1)	Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests (IEC 60664-1:1992 + A1:2000 + A2:2002); (German version EN 60664-1:2003 / DIN VDE 0110-1 (1997-04) also applies up to 2006-04-01.) 2003-11-01
/DIN EN 60694/ (VDE 0670-1000)	Common specifications for high-voltage switchgear and controlgear standards (IEC 60694:1996 + Corr. 1:2001 + A1:2000 + A2:2001 + Corr. 1:2001); (German version EN 60694:1996 + A1:2000 + A2:2001 / DIN EN 60694 (1998-10) also applies up to 2003-11-01.) 2002-09-01
/DIN EN 60695-1-1/ (VDE 0471-1-1)	Fire hazard testing - Part 1-1: Guidance for assessing fire hazard of electrotechnical products; General guidance (IEC 60695-1-1:1999 + Corrigendum 2000); (German version EN 60695-1-1:2000 / DIN EN 60695-1-1 (1996-07) also applies up to 2003-01-01.) 2000-10-01
/DIN EN 60909-0/ (VDE 0102)	Short-circuit currents in three-phase a.c. systems - Part 0: Calculation of currents (IEC 60909-0:2001); (German version EN 60909-0:2001 / DIN VDE 0102 (1990-01) also applies up to 2003-01-01.) 2002-07-01
/DIN EN 61378-1/ (VDE 0532-41)	Converter transformers - Part 1: Transformers for industrial applications (IEC 61378-1:1997); (German version EN 61378-1:1998 + Corrigendum 1998) 1999-09-01

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/DIN EN 61508-1/ (VDE 0803-1)	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 1: General requirements (IEC 61508-1:1998 + Corrigendum 1999); (German version EN 61508-1:2001) 2002-11-01
/DIN EN 61508-2/ (VDE 0803-2)	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 2: Requirements for electrical/electronic/programmable electronic safety-related systems (IEC 61508-2:2000); German version EN 61508-2:2001 2002-12-01
/DIN EN 61508-3/ (VDE 0803-3)	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 3: Software requirements (IEC 61508-3:1998 + Corrigendum 1999); German version EN 61508-3:2001 2002-12-01
/DIN EN 61508-4/ (VDE 0803-4)	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 4: Definitions and abbreviations (IEC 61508-4:1998 + Corrigendum 1999); German version EN 61508-4:2001 2002-11-01
/DIN EN 61508-5/ (VDE 0803-5)	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 5: Examples of methods for the determination of safety integrity levels (IEC 61508-5:1998 + Corrigendum 1999); German version EN 61508-5:2001 2002-11-01
/DIN EN 61508-6/ (VDE 0803-6)	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 6: Guidance on the application of IEC 61508-2 and IEC 61508-3 (IEC 61508-6:2000); German version EN 61508-6:2001 2003-06-01
/DIN EN 61508-7/ (VDE 0803-7)	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 7: Overview of techniques and measures (IEC 61508-7:2000); German version EN 61508-7:2001 2003-06-01
/DIN EN 61642/ (VDE 0560-430)	Industrial a.c. networks affected by harmonics. Application of filters and shunt capacitors (IEC 61642:1997); (German version EN 61642:1997) 1998-11-01
/DIN EN 62040/	Standard series: Uninterruptible Power System (UPS)
/DIN EN 62040-1-1/ (VDE 0558-511)	Uninterruptible power systems (UPS) - Part 1-1: General and safety requirements for UPS used in operator access areas (IEC 62040-1-1:2002 + Corrigendum 2002); (German version EN 62040-1-1:2003 / DIN EN 50091-1-1 (1997-07) also applies up to 2005-11-01.) 2003-10-01
/DIN EN 62040-1-2/ (VDE 0558-512)	Uninterruptible power systems (UPS) - Part 1-2: General and safety requirements for UPS used in restricted access locations (IEC 62040-1-1:2002 + Corrigendum 2002); (German version EN 62040-1-2:2003 / DIN EN 50091-1-2 (1999-05) and DIN EN 50091-1-2 Corrigendum 1 (2000-07) also apply up to 2005-11-01.) 2003-10-01

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/DIN EN 62040-2/ (VDE 0558-520)	Uninterruptible power systems (UPS) - Part 2: Electromagnetic compatibility (EMC) requirements (IEC 62040-2:2005); German version EN 62040-2:2006 / DIN EN 50091-2 (1996-05) also applies up to 2008-10-01.) 2006-07-01
/DIN EN 62040-3/ (VDE 0558-530)	Uninterruptible power systems (UPS) - Part 3: Methods of specifying the performance and test requirements (IEC 62040-3:1999, modified); (German version EN 62040-3:2001 / DIN VDE 0558-5 (1988-09) and DIN VDE 0558-6 (1992-04) also apply up to 2003-08-01.) 2002-02-01
/DIN EN 62271/	Standard series: High voltage switchgear and controlgear
/DIN EN 62271-100/ (VDE 0671-100)	High-voltage switchgear and controlgear - Part 100: High-voltage alternating-current circuit-breakers (IEC 62271-100:2001 + A1:2002 + Corrigendum 1:2002 + Corrigendum 2:2003); (German version EN 62271-100:2001 + A1:2002 / DIN VDE 0670-101 (1992-12), DIN VDE 0670-102 (1992-12), DIN VDE 0670-103 (1992-10), DIN VDE 0670-104 (1992-10), DIN VDE 0670-105 (1992-10) and DIN VDE 0670-106 (1992-10) also apply up to 2004-09-01.) 2004-04-01
/DIN EN 62271-102/ (VDE 0671-102)	High-voltage switchgear and controlgear - Part 102: Alternating current disconnectors and earthing switches (IEC 62271-102:2001 + Corrigendum 1:2002 + Corrigendum 2:2003); (German version EN 62271-102:2002 / DIN EN 60129 (1998-03), DIN EN 61129 (1995-02), DIN EN 61129/A1 (1998-01) and DIN EN 61259 (1996-06) also apply up to 2005-03-01.) 2003-10-01
/DIN EN 62271-105/ (VDE 0671-105)	High-voltage switchgear and controlgear - Part 105: Alternating current switch-fuse combinations (IEC 62271-105:2002); (German version EN 62271-105:2003 / DIN EN 60420 (1994-09) also applies up to 2005-10-01.) 2003-12-01
/DIN EN 62271-107/ (VDE 0671-107)	High-voltage switchgear and controlgear - Part 107: Alternating current fused circuit-switchers for rated voltages above 1 kV up to and including 52 kV (IEC 62271-107:2005); (German version EN 62271-107:2005) 2006-07-01
/DIN EN 62271-108/ (VDE 0671-108)	High-voltage switchgear and controlgear - Part 108: High-voltage alternating current disconnecting circuit-breakers for rated voltages of 72.5 kV and above (IEC 62271-108:2005); (German version EN 62271-108:2006) 2006-10-01
/DIN EN 62271-110/ (VDE 0671-110)	High-voltage switchgear and controlgear - Part 110: Inductive load switching (IEC 62271-110:2005); (German version EN 62271-110:2005) 2006-07-01
/DIN EN 62271-2/ (VDE 0671-2)	High-voltage switchgear and controlgear - Part 2: Seismic qualification for rated voltages of 72.5 kV and above (IEC 62271-2:2003); (German version EN 62271-2:2003 2004-01-01

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/DIN EN 62271-200/ (VDE 0671-200)	High-voltage switchgear and controlgear - Part 200: A.C. metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV (IEC 62271-200:2003); (German version EN 62271-200:2004 / DIN EN 60298 (1998-05), DIN EN 60298 Corrigendum 1 (1999-03) and DIN EN 60298 Corrigendum 2 (2001-09) also apply up to 2007-02-01.) 2004-10-01
/DIN EN 62271-203/ (VDE 0671-203)	High-voltage switchgear and controlgear - Part 203: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV (IEC 62271-203:2003); (German version EN 62271-203:2004 / DIN EN 60517 (1998-10) and DIN EN 60517 Corrigendum 1 (2001-08) also apply up to 2007-02-01.) 2004-11-01
/DIN EN 62305/	Standard series: Protection against lightning
/DIN EN 62305-1/ (VDE 0185-305-1)	Protection against lightning - Part 1: General principles (IEC 62305-1:2006); (German version EN 62305-1:2006 / DIN V VDE V 0185-1 (2002-11) also applies up 2008-10-01.) 2006-10-01
/DIN EN 62305-2/ (VDE 0185-305-2)	Protection against lightning - Part 2: Risk management (IEC 62305-2:2006); (German version EN 62305-2:2006 / DIN V VDE V 0185-2 (2002-11), DIN V VDE V 0185-2 Corrigendum 1 (2004-02) and DIN V VDE V 0185-2 Supplement 1 (2004-06) also apply up to 2008-10-01.) 2006-10-01
/DIN EN 62305-3/ (VDE 0185-305-3)	Protection against lightning - Part 3: Physical damage to structures and life hazard (IEC 62305-3:2006, modified); (German version EN 62305-3:2006 / DIN V VDE V 0185-3 (2002-11) and DIN V VDE V 0185-3/A1 (2005-06) also apply up to 2008-10-01.) 2006-10-01
/DIN EN 62305-4/ (VDE 0185-305-4)	Protection against lightning - Part 4: Electrical and electronic systems within structures (IEC 62305-4:2006); (German version EN 62305-4:2006 / DIN V VDE V 0185-4 (2002-11) also applies up 2008-10-01.) 2006-10-01
/DIN EN ISO 12944-1/	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 1: General introduction (ISO 12944-1:1998); (German version EN ISO 12944-1:1998) 1998-07-01
/DIN EN ISO 12944-2/	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 2: Classification of environments (ISO 12944-2:1998); (German version EN ISO 12944-2:1998) 1998-07-01
/DIN EN ISO 12944-3/	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 3: Design considerations (ISO 12944-3:1998); (German version EN ISO 12944-3:1998) 1998-07-01
/DIN EN ISO 12944-4/	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 4: Types of surface and surface preparation (ISO 12944-4:1998); (German version EN ISO 12944-4:1998) 1998-07-01

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/DIN EN ISO 12944-5/	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 5: Protective paint systems (ISO 12944-5:1998); (German version EN ISO 12944-5:1998) 1998-07-01
/DIN EN ISO 12944-6/	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 6: Laboratory performance test methods and assessment criteria (ISO 12944-6:1998); (German version EN ISO 12944-6:1998) 1998-07-01
/DIN EN ISO 12944-7/	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 7: Execution and supervision of paint work (ISO 12944-7:1998); (German version EN ISO 12944-7:1998) 1998-07-01
/DIN EN ISO 12944-8/	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 8: Development of specifications for new work and maintenance (ISO 12944-8:1998); (German version EN ISO 12944-8:1998) 1998-07-01
/DIN EN ISO 3095/	Railway applications - Acoustics - Measurement of noise emitted by railbound vehicles (ISO 3095:2005); (German version EN ISO 3095:2005) 2005-11-01
/DIN EN ISO 9000/	Quality management systems - Fundamentals and vocabulary (ISO 9000:2005); Trilingual version EN ISO 9000:2005 DIN EN ISO 9000
/DIN EN ISO 9001/	Quality management systems - Requirements (ISO 9001:2000-09); Trilingual version EN ISO 9001:2000 2000-12-01
/DIN EN ISO 9004/	Quality management systems - Guidelines for performance improvements (ISO 9004:2000); Trilingual version EN ISO 9004:2000 2000-12-01
/DIN Technical Report 101/	Actions on bridges; March 2003; ISBN-3-410-15007-2; 2003-01-01
/DIN VDE 0100/ (VDE 0100)	Provisions for the Erection of Power Installations with Rated Voltages Below 1000 V / 01 November 1958 in the version of May 1973 / Was withdrawn in error. The sections that are reproduced in Supplement 2 of May 2001 in Table 2 still apply / observe the transitional period defined by DIN VDE 0100-443 (2002-01) and DIN VDE 0100-530 (2005-06), up to 2006-05-31. 1973-05-01
/DIN VDE 0101/ (VDE 0101)	Power installations exceeding 1 kV; (German version HD 637 S1:1999 / DIN VDE 0101 (1989-05) and DIN VDE 0141 (1989-07) also apply up to 2001-01-01. / observe the transitional period defined by DIN EN 60204-11 (2001-05), up to 2003-09-01.) 2000-01-01
/DIN VDE 0105-100/ (VDE 0105-100)	Operation of electrical installations - Part 100: General requirements / DIN VDE 0105-100 (2000-06) and DIN VDE 0105-100/A3 (2003-11) also apply up to 2007-07-01. 2005-06-01

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/DIN VDE 0276-632/ (VDE 0276-632)	Power cables with extruded insulation and their accessories for rated voltages above 36 kV (U<(Index)m> = 42 kV) up to 150 kV (U<(Index)m> = 170 kV); (German version HD 632 S1 Parts 1, 3D, 4D, 5D:1998) 1999-05-01
/DIN VDE 0888/	Standard series: Optical fibre cables for communication systems
/DIN VDE 0888-3 CORRIGENDUM 1/ /VDE 0888-3 CORRIGENDUM 1/	Corrigendum to DIN VDE 0888-3 (VDE 0888 Part 3):1999-10 2001-08-01
/DIN VDE 0888-3/ (VDE 0888-3)	Optical fibre cables for communication systems - Part 3: Outdoor cables 1999-10-01
/DIN VDE 0888-4/ (VDE 0888-4)	Optical fibre cables for communication systems - Part 4: Indoor cables with one fibre 1999-10-01
/DIN VDE 0888-5/ (VDE 0888-5)	Optical fibre cables for communication systems - Part 5: Outdoor fan-out cables 1999-10-01
/DIN VDE 0888-6/ (VDE 0888-6)	Optical fibre cables for communication systems - Part 6: Indoor cables with several fibres 1999-10-01
/EBA-Lf Station/	EBA - Guide "Fire protection in passenger transport installations of the federal railways"; January 2001 also additional information for the guide when used for passenger transport installations of maglev railways; April 2002
/EBA-RL MSB Tunnel/	Guide for the construction and operation of maglev tunnels in regard to fire and emergency management and hazard prevention; German Federal Railway Authority; 2005-03-01
/EN 10106/	Cold rolled non-oriented electrical steel sheet and strip delivered in the fully processed state; German version EN 10106:1995 1996-02-01
/EN 1317-1/	Road restraint systems - Part 1: Terminology and general criteria for test methods 1998-04-01
/EN 1363-1/	Fire resistance tests - Part 1: General requirements 1999-08-01
/EN 14067-2/	Railway applications - Aerodynamics - Part 2: Aerodynamics on open track 2003-04-01
/EN 14067-3/	Railway applications - Aerodynamics - Part 3: Aerodynamics in tunnels 2003-04-01
/EN 1990/	Eurocode: Basis of structural design 2002-04-01
/EN 1991/	Standard series Eurocode 1: Actions on structures
/EN 1991-1-1/	Eurocode 1: Actions on structures- Part 1-1: Densities, self-weight, imposed loads for buildings 2002-04-01

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/EN 1991-1-2/	Eurocode 1 - Actions on structures - Part 1-2: General actions; Actions on structures exposed to fire 2002-11-01
/EN 1991-1-3/	Eurocode 1 - Actions on structures - Part 1-3: General actions, snow loads 2003-07-01
/EN 1991-1-4/	Eurocode 1 - Actions on structures - Part 1-4: General actions, wind loads 2005-04-01
/EN 1991-1-5/	Eurocode 1 - Actions on structures - Part 1-5: General actions; temperature actions 2003-11-01
/EN 1991-1-6/	Eurocode 1 - Actions on structures - Part 1-6: General actions - Actions during execution 2005-06-01
/EN 1991-1-7/	Eurocode 1 - Actions on structures - Part 1-7: General actions - accidental actions 2006-07-01
/EN 1991-2/	Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges 2003-09-01
/EN 1991-3/	Eurocode 1 - Actions on structures - Part 3: Actions induced by cranes and machinery 2006-07-01
/EN 1992/	Standard series Eurocode 2: Design of concrete structures
/EN 1992-1-1/	Eurocode 2: Design of concrete structures - Part 1-1: General rules for build-ings 2004-12-01
/EN 1992-1-2/	Eurocode 2: Design of concrete structures - Part 1-2: General rules - Structural fire design 2004-12-01
/EN 1992-2/	Eurocode 2 - Design of concrete structures - Part 2: Concrete bridges - Design and detailing rules 2005-10-01
/EN 1992-3/	Eurocode 2 - Design of concrete structures - Part 3: Liquid retaining and con-tainment structures 2006-06-01
/EN 1993/	Standards family Eurocode 3: Design of steel structures; July 2005
/EN 1998/	Standards family Eurocode 8: Design of structures for earthquake resistance; December 2004
/EN 1999/	Standards family Eurocode 9: Design of aluminium structures; Preliminary standard: October 2000
/EN 50124-1/	Railway applications - Insulation coordination - Part 1: Basic requirements; Clearances and creepage distances for all electrical and electronic equipment 2001-03-01
/EN 50125/	Standards series - Railway applications

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/EN 50125-1/	Railway applications - Environmental conditions for equipment - Part 1: Equipment on board rolling stock 1999-09-01
/EN 50125-2/	Railway applications - Environmental conditions for equipment - Part 2: Fixed electrical installations 2002-12-01
/EN 50125-3/	Railway applications - Environmental conditions for equipment - Part 3: Equipment for signalling and telecommunications 2003-01-01
/EN 50207/	Railway applications - Electronic power converters for rolling stock 2000-09-01
/EN 60721/	Standard series: Classification of environmental conditions
/EN 60721-1/	Classification of environmental conditions - Part 1: Environmental parameters and their severities (IEC 60721-1:1990 + A1:1992) 1995-04-01
/EN 60721-1/A2	Classification of environmental conditions - Part 1: Environmental parameters and their limits; Amendment A2 (IEC 60721-1:1990/A2:1995) 1995-07-01
/EN 60721-3-0/	Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities - Introduction (IEC 60721-3-0:1984 + A1:1987) 1993-07-01
/EN 60721-3-1/	Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities; section 1: Storage (IEC 60721-3-1:1997) 1997-03-01
/EN 60721-3-2/	Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities; section 2: Transport (IEC 60721-3-2:1997) 1997-03-01
/EN 60721-3-3/	Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities - Section 3: Stationary use at weatherprotected locations (IEC 60721-3-3:1994) 1995-01-01
/EN 60721-3-3/A2/	Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities - Section 3: Stationary use at weatherprotected locations; Amendment A2 (IEC 60721-3-3:1994/A2:1996)) 1997-01-01
/EN 60721-3-4/	Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities - Section 4: Stationary use at non-weatherprotected locations (IEC 60721-3-4:1994) 1995-02-01
/EN 60721-3-4/A1/	Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities - Section 4: Stationary use at non-weatherprotected locations; Amendment A1 (IEC 60721-3-4:1995/A1:1996) 1997-01-01

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/EN 60721-3-5/	Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities; Section 5: Ground vehicle installations (IEC 60721-3-5:1997) 1997-04-01
/EN 61373/	Railway applications - Rolling stock equipment - Shock and vibration tests (IEC 61373:1999) 1999-04-01
/EN ISO 12543/	Standard series: Glass in building - Laminated glass and laminated safety glass -
/ERRI B 153 RP-1/	APPLICATION OF STANDARD ISO 2631 TO RAILWAY ROLLING STOCK Study of the different application methods of ISO 2631 used in the railway sector 1981-09-01
/ISO 2631/	Standard series: Mechanical Vibration
/ISO 2631-1/	Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements - / Corrected version of July 1997 1997-05-01
/ISO 2631-2/	Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 2: Vibration in buildings (1 Hz - 80 Hz) 2003-04-01
/ISO 2631-5/	Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 5: Method for evaluation of vibration containing multiple shocks 2004-02-01
/prEN 50126-2/	Railway Applications The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) Part 2: Guide to the application on EN 50126 for Safety Draft July 05
/R009-004/	Railway specifications. Systematic allocation of safety integrity requirements. CENELEC Report R009-004:2001
/RI-EDV-AP-2001/	Guideline for the preparation and testing of IT-aided stability calculations; National Association of Checking Engineers in Construction; April 2001
/RPS/	Guidelines for passive safety equipment on highways HIGHWAYS AND TRANSPORT RESEARCH ASSOCIATION, WORKING PARTY ON TRAFFIC GUIDANCE AND SAFETY 1989
/TL 918300 Sheet 87/	Deutsche Bahn AG, corrosion protection, technical delivery conditions;
/UIC 651/	Layout on drivers' cab in locomotives, railcars, multiple-unit trains and driving trailers; July 2002
/Wiesinger/	Prof. Dr. Wiesinger Study into the lightning threat and electrostatic threat to maglev railways, May 1979

Table 10: Standards and Directives

High-speed Maglev System Design Principles

Complete System Annex 3 Environmental Conditions

Distribution

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General

Purpose of the document, scope

This document specifies the environmental conditions of the MSB system independently of any particular project.
This design principles applies to a high-speed maglev system according to the General Maglev System Act /AMbG/.
The parameters of the primary environment specified in this document should be used as a basis for the design of the MSB system in an application project.
To guarantee the required degree of resistance to environmental conditions, the said conditions should be used as a basis for the system development, qualification and verification of subsystems and modules for the particular application project.
Parameters that differ in specific projects must be taken into consideration in the design and the necessary verifications carried out.
The monitoring of the primary environmental parameters specified in this document, and the taking of the appropriate measures if the limits indicated here are exceeded, is not a matter for this document and will be dealt with in the corresponding project-specific documents.
The environmental conditions for operation, storage and transport according to /EN 60721/ are defined in Chapter 5.
The environmental conditions prevailing inside buildings or other weather-protected installations are not a matter for this document.
Conditions that are a function of a specific project-dependent route alignment, e.g. local geology/hydrology, are not covered by this document.

MSB Design Principles

This document is an annex to the Design Principles Complete System and so forms part of a documentation for high-speed maglev systems consisting of different design principles. The document tree is shown in Figure 1 /MSB AG-GESAMTSYS/.
The high-level "complete system" design principles and its annexes apply uniformly for the whole documentation:

- MSB Design Principles Complete System, Doc. No.: 50630, /MSB AG-GESAMTSYS/
  - Annex 1: Abbreviations and Definitions, Doc. No.: 67536, /MSB AG-ABK&DEF/

- Annex 2: Statutes, Regulations, Standards and Directives, Doc. No.: 67539, /MSB AG-NORM&RILI/
- Annex 3: Environmental Conditions, Doc. No.: 67285, /MSB AG-UMWELT/
- Annex 4: Rules for Operation (Train Operation and Maintenance), Doc. No.: 69061,
/MSB AG-BTR/
- Annex 5: Noise, Doc. No.: 72963, /MSB AG-SCHALL/

Abbreviations and definitions

The abbreviations and definitions given in /MSB AG-ABK&DEF/ apply.

Statutes, regulations, standards and guide-lines

The normative documents listed in /MSB AG-NORM&RILI/ contain requirements that form part of the High-speed Maglev System Design Principles by cross reference in the High-speed Maglev System Design Principles. Where normative documents in /MSB AG-NORM&RILI/ are dated, subsequent changes or revisions of these publications do not apply. With undated references, the latest version of the normative document that is referred to applies.
The version of the standards and guidelines to be observed in an MSB project must be decided bindingly on a project-specific basis.

Identification and binding value of require-ments

The requirements of /DIN 820/ were essentially applied in the preparation of this document. In the following chapters and the annexes of this document

- Requirements are shown in normal font
- Explanations, guide values and examples are shown in *italics*

The degree to which the requirements are binding has been defined by reference to /DIN 820-2/ Annex G, and has been taken into consideration when formulating the individual require-ments.

Resistance to environmental conditions

This Design Principles Environment is intended to facilitate, for a design of a high-speed maglev system, a resistance to environmental conditions according to the characteristics and data specified below.
The MSB system must be designed so that unrestricted operation is possible within the environmental conditions specified below.

Climate

The climatic data are based on the key data of the climatic class ***"widespread"*** *according to /EN 60721-2/.*
The associated climatic classes for operation, transport and storage must conform to the requirements of /EN 60721-3-1/, /EN 60721-3-2/, /EN 60721-3-3/, /EN 60721-3-4/ und /EN 60721-3-5/ where applicable.
The following requirements must be observed:

Air pressure

Climatic classes according to /EN 60721-3-4/, /EN 60721-3-1/ and /EN 60721-3-2/: 4K3, 1K5, 2K4.

Parameter	Value	Unit
Air pressure (train operation, storage, maritime and land transport)	70 - 106 (equivalent to 0 m to 3000 m above SL)	kPa

Table 11: Air pressure for train operation, storage, maritime and land transport

Parameter	Value	Unit
Air pressure (air cargo conditions)	55	kPa

Table 12: Air pressure, air transport

Relative humidity

Climatic classes according to /EN 60721-3-4/, /EN 60721-3-1/ and /EN 60721-3-2/: 4K3, 1K5, 2K4 or /DIN EN 50125-3/ Table 3; Climatic class T1.

Parameter	Value	Unit
Relative humidity (train operation, storage, maritime and land transport)	15 to 100	%

Table 13: Relative humidity, train operation, storage, maritime and land transport

Climatic classes according to /EN 60721-3-4/, /EN 60721-3-1/ and /EN 60721-3-2/: 4K3, 1K5, 2K4.

Parameter	Value	Unit
Relative humidity (air cargo conditions)	20 to 40	%

Table 14: Relative humidity, air transport

Air temperature

Climatic class according to /EN 60721-3-5/: 5K2 or /DIN EN 50125-3/, Table 2; Climatic class T1 (outdoors).

Parameter	Value	Unit
Air temperature (train operation)	-25 to + 40	°C

Table 15: Air temperature, train operation

Climatic classes according to /EN 60721-3-1/ and /EN 60721-3-2/: 1K5, 2K4.

Parameter	Value	Unit
Air temperature (storage and transport)	-40 to + 70	°C

Table 16: Air temperature, storage and transport

Parameter	Value	Unit
Annual mean temperature, Temperate Zones	10	°C
Annual mean temperature, Subtropical Zones	20	°C

Table 17: Annual mean temperatures

Change in weather in the course of a day

Parameter	Value	Unit
Temperature change per day max.	40	K/day
Temperature change per day, mean	15	K/day
Temperature change, operation, max.	10	K/h
Temperature change, storage and transport max.	20	K/h

Table 18: Temperature change

Parameter	Value	Unit
Humidity change max.	50	%

Table 19: Humidity change

Parameter	Value	Unit
Air pressure change max.	10	kPa

Table 20: Air pressure change

Wind

Maintaining train operations with the project-specifically defined maximum line speed must be possible for the wind speeds given below for the "10-min average for every 10 years" according to wind load zone II as per /DIN EN 1991-1-4 /.
Train operation may be continued at a higher wind speed with project-dependent additional operational measures (e.g. reduced running speed) and/or special measures (e.g. structural measures).
Typical wind speeds in m/s for wind load zone II according to /DIN EN 1991-1-4/ at heights of 5m, 10m and 20m:

Parameter	Value	Unit
Wind speed at 5m height, max. 10 min. average		
per year	19.0	m/s
every 10 years	22.4	m/s
every 50 years	24.7	m/s
every 100 years	25.8	m/s

Table 21: Wind speed at 5m height, max. 10 min. average

Parameter	Value	Unit
Wind speed at 10m height, max. 10 min. average		
per year	21.3	m/s
every 10 years	25.0	m/s
every 50 years	27.6	m/s
every 100 years	28.8	m/s

Table 22: Wind speed at 10m height, max. 10 min. average

Parameter	Value	Unit
Wind speed at 20m height, max. 10 min. average		
per year	23.7	m/s
every 10 years	27.9	m/s
every 50 years	30.8	m/s
every 100 years	32.0	m/s

Table 23: Wind speed at 20m height, max. 10 min. average

Parameter	Value	Unit
Gusting speed for height 5m		
per year 1-second value	30.7	m/s
per year 5-second value	27.2	m/s
every 10 years 1-second value	36.1	m/s
every 10 years 5-second value	32.2	m/s

Table 24: Gusting speed for height 5m

Parameter	Value	Unit
Gusting speed for height 10m		
per year 1-second value	33.1	m/s
per year 5-second value	29.4	m/s
every 10 years 1-second value	39.0	m/s
every 10 years 5-second value	34.6	m/s

Table 25: Gusting speed for height 10m

Parameter	Value	Unit
Gusting speed for height 20m		
per year 1-second value	35.7	m/s
per year 5-second value	31.7	m/s
every 10 years 1-second value	42.1	m/s
every 10 years 5-second value	37.3	m/s

Table 26: Gusting speed for height 20m

Parameter	**Value**	**Unit**
Annual action time of the 10-minute averages at 10 m height		
Wind speed > 10 m/s	74	h
Wind speed >17 m/s	3	h

Table 27: Annual action time of the 10-minute averages at 10 m height

Rain

Limit for transport and operation according to /EN 60721-3-2/, /EN 60721-3-5/:2K4, 5K3 or DIN EN 50125-3, Chapter 4.6, Climatic class T1.

Parameter	**Value**	**Unit**
Rain volume - general	6	mm/min
Rain volume - Limit for radio design	project-specific *)	

*) *The propagation properties of radio links, especially at higher frequencies, depend on precipitation, among other factors. Precipitation leads to higher path attenuation, so appropriate signal level reserves (headroom) must be allowed for when designing the links. Rain has the greatest effect on path attenuation and so is used when calculating the signal level reserve. The path attenuation due to rain is due chiefly to the rainfall rate measured in mm/h, besides other factors such as the distribution of the raindrop size.*
For the purpose of designing radio links therefore, the upper limit for rain intensity is not defined according to a climatic class but from an analysis of rainfall statistics from the local weather service. As well as the rainfall rate, the probability of occurrence of the upper limit must also be determined for the project zone. A guideline figure here is that the defined upper limit for the rainfall rate is not exceeded with a time probability of >99.99 % p.a.
This is not a limit in the strict sense of leading to a system malfunction if exceeded, rather that beyond this recommended value the system's reserves are generally reduced in terms of radio range in individual sections of the line that are affected. This would not normally impact on train operations.

Table 28: Rainfall rate

Snow

Parameter	**Value**	**Unit**
Tolerable depth of snow on guideway table	10	cm

Table 29: Depth of snow

Ice

Parameter	Value	Unit
Permissible guideway icing		
mean layer thicknesses on the slide plane	10	mm
mean layer thicknesses in levitation/guidance area	5	mm
max. local layer thicknesses, max. 2 m long on the slide plane	20	mm
local layer thicknesses, max. 2 m long in levitation/guidance area	10	mm

Table 30: Permissible guideway icing

Solar irradiation

Climatic classes according to /EN 60721-3-1/ to /EN 60721-3-5/: 1K4, 2K4, 4K3, 5K3 or /DIN EN 50125-3/ Chapter 4.9.

Parameter	Value	Unit
Maximum hourly global irradiation	1120	W/m^2

Table 31: Solar irradiation (for storage, transport and operation)

Atmospheric parameters

Rain

Parameter	Value	Unit
pH rain	3.4 to 7.6 (mean value 5.4) *	-

**: The natural pH of rain is approx. 5.5, while the pH of "acid rain" in Germany is 4...4.6.*
This value for the pH of rain is a "meaningful" figure with an "adequate safety reserve" which takes account of the average range of rain pH value observed in Nature.

Table 32: pH of rain

This figure must be reviewed project-specifically and adjusted as necessary.

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Chemically Active Substances

Contaminant load as per /EN 60721-3-4/ 4C3 for the mean values, and /EN 60721-3-4/ 4C4 for the peak value / limits. Requirement for the mean values identical with /EN 50125-3/, Table 4, heavy contamination.

Environmental parameter	Mean *	Limit **	Unit
Sea salt	Occurrence of salt spray		---
Sulphur dioxide	5.0	40	mg/m^3
Hydrogen sulphide	3.0	70	mg/m^3
Chlorine	0.3	3.0	mg/m^3
Hydrogen chloride	1.0	5.0	mg/m^3
Hydrogen fluoride	0.1	2.0	mg/m^3
Ammonia	10	175	mg/m^3
Ozone	0.1	2.0	mg/m^3
Nitrous oxides (given in equivalent values to nitrogen dioxide)	3.0	20	mg/m^3
*) Figures are the mean values of Class 4C3 of EN 60721-3-4			
**) Figures are the mean values of Class 4C3 of EN 60721-3-4			

Table 33: Air, loading by chemically active substances

Mechanically active substances

Loading from mechanically active substances according to /EN 60721-3-4/.

Environmental parameter	Class		
	4S1 *	4S2 **	Unit
Sand in the air	30	300	mg/m^3
Dust (suspended matter)	0.5	5	mg/m^3
Dust (precipitation)	15.0	20	mg / (m^2 h)
*) Used in sparsely populated areas, not near to sources of sand			
**) Used in areas with sources of sand or dust, including densely populated areas			

Table 34: Air, loading by mechanically active substances

Lightning

The MSB system must be protected from the actions of lightning specified below. Lightning protection for structures must comply with local building regulations.

Frequency

Parameter	Value	Unit
Lightning strikes	20 *	strikes per square kilometre/year

*) This frequency of lightning strike is a meaningful figure with an adequate "safety interval" from the average "lightning characteristics" observed in nature based on /WIESINGER/.

Table 35: Frequency of lightning strike

Intensity

according to /DIN EN 62305-1/ (VDE 0185-305-1)

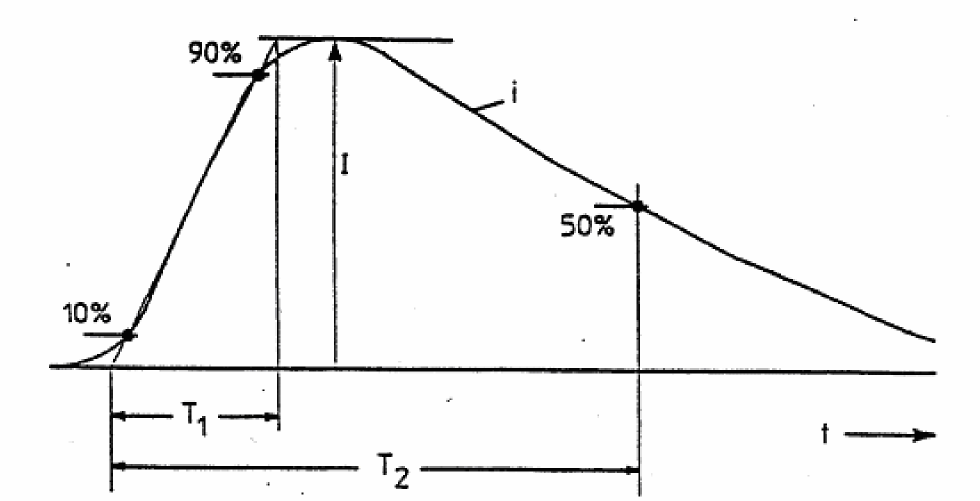

Figure 34: First lightning discharge impulse and subsequent discharge impulse

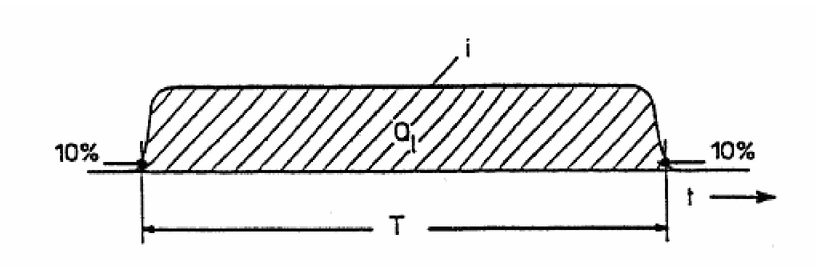

Figure 35: Sustained discharge impulse

Lightning current parameters of the first lightning discharge impulse

Parameter	Value	Unit
Peak current I	200	kA
Front time T_1	10	µs
Time to half-value T_2	350	µs
Charge of the transient discharge pulse Q_s	100	C
Specific energy W/R	10	MJ/Ω

Table 36: Lightning current parameters of the first lightning discharge impulse (see Figure 34)

Lightning current parameters of the subsequent lightning discharge impulse

Parameter	Value	Unit
Peak current I	50	kA
Front time T_1	0.25	µs
Time to half-value T_2	100	µs
Mittlere Steilheit I/T_1	200	kA/µs

Table 37: Lightning current parameters of the subsequent lightning discharge impulse (see Figure 34)

Lightning current parameters of the sustained lightning discharge impulse

Parameter	Value	Unit
Charge Q_l	200	C
Time T	0.5	s

Table 38: Lightning current parameters of the sustained lightning discharge impulse (see Figure 35)

Electrical and magnetic field strengths

Parameter	Value	Unit
dH/dt	$3.2*10^{11}$	A/(m*s)
H	$3.2*10^{5}$	A/m
dE/dt	$5.0 * 10^{11}$	V/(m*s)
E	$5*10^{5}$	V/m

Table 39: Distance from main lightning current path: 0.1 m

Parameter	**Value**	**Unit**
dH/dt	$3.2*10^{10}$	A/(m*s)
H	$3.2*10^{4}$	A/m
dE/dt	$5.0 * 10^{11}$	V/(m*s)
E	$5*10^{5}$	V/m

Table 40: Distance from main lightning current path: 1 mEarthquake

The local building regulations must be complied with in regard to earthquake safety when designing structures for a specific project. For projects in Germany, and depending on the specific project, the relevant earthquake strengths according to
/DIN 4149/, "Structures in German earthquake zones" must be determined and used as a basis for structure design.

Immunity from electromagnetic interference

The immunity of MSB subsystems from interference must basically conform to European standard DIN EN 50121 (Electromagnetic Compatibility; Railway Applications). The intended performance characteristics of the MSB system must not be impaired by interference-field strengths or conducted interference up to the limits given below.

Subsystems	**Limits as per standard**
Stationary installations and equipment for the drive and energy supply	DIN EN 50121-5
Vehicle	DIN EN 50121-3-1
appliances installed in vehicles	DIN EN 50121-3-2
Signalling and communications equipment incl. OCS radio	DIN EN 50121-4

Table 41: European standards for the immunity of MSB subsystems

Specification of parameters for the secondary environment

This chapter lists the parameters for the secondary environment for the subsystems 'MSB vehicle' and 'Installations'. It specifies the environmental spaces and
EMC/ lightning protection zones according to /DIN EN 62305-1/ (VDE 0185-305-1).
The following figures are based on operational experience with the secondary environment. They reflect the current level of knowledge and should be confirmed project-specifically and/or adjusted and verified as required. Adjusted values must be indicated in the project-specific documentation (delivery specification, technical reports). The values in this document apply in the absence of an explicit agreement.
The operational experience reflected in this document is based on MSB vehicles TR07 and TR08 on the TVE and on the Shanghai Transrapid project.
The parameters for the EMC / lightning protection zones must allow for the radiation-related electromagnetic effects due to lightning strike and to all types of field-related interference effects, e.g. radio transmitters.

Secondary environment in MSB vehicle

The following requirements apply to all components and mount-on parts in and on the MSB vehicle.
The environmental spaces of the MSB vehicle are shown in Figure 36 .

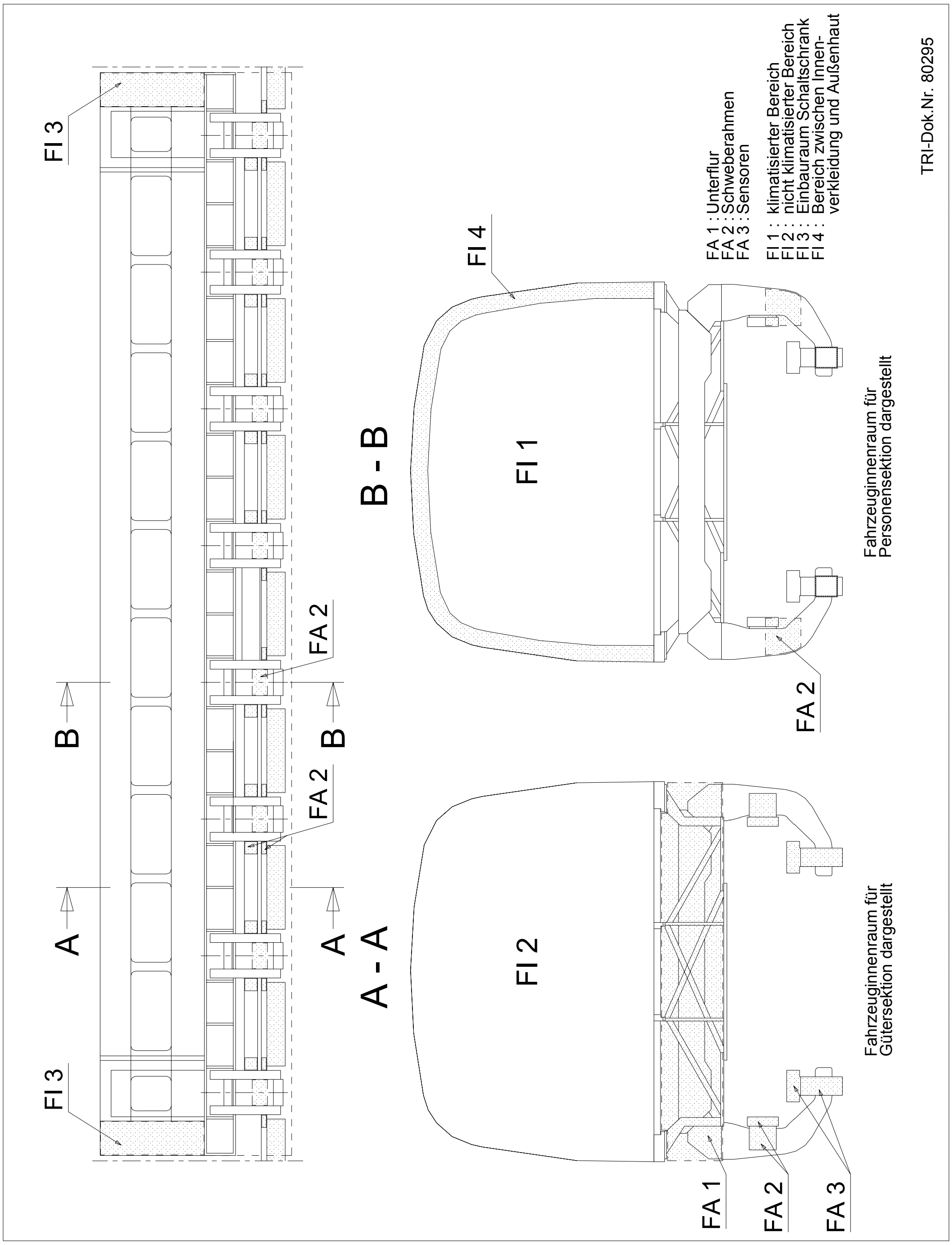
FI 3
FI 3
A
A
B
B
FA 2
FA 2
A - A
B - B
FI 1
FI 2
FI 4
FA 1
FA 2
FA 2
FA 3
FA 1 : Unterflur
FA 2 : Schweberahmen
FA 3 : Sensoren
FI 1 : klimatisierter Bereich
FI 2 : nicht klimatisierter Bereich
FI 3 : Einbauraum Schaltschrank
FI 4 : Bereich zwischen Innen- verkleidung und Außenhaut
TRI-Dok.Nr. 80295
Fahrzeuginnenraum für Personensektion dargestellt
Fahrzeuginnenraum für Gütersektion dargestellt

Figure 36: Environmental spaces of the MSB vehicle (typical arrangement)

Vehicle Exterior (FA):

- Underfloor (FA1),
  Space envelope for electrical/electronic modules, cable trunking, compressed air supply equipment
- Levitation frame (FA2),
  - Space envelope for guide magnets
  - Space envelope for brake magnets
  - Space envelope for sensor electronics
  - Panelling and mechanical structure levitation frame
- Space envelope (FA3) for
  - Levitation magnets
  - Sensors.

Vehicle Interior (FI):

- Airconditioned area (FI1),
  Space envelope for service/communication/operating equipment
- Non airconditioned area (FI2)
  Space envelope for loading equipment
- Control cubicle vehicle section (FI3)
  Space envelope for control/safety equipment
- Ceiling/wall behind panelling (FI4)
  Space envelope for cables, lighting.

Vehicle - Exteriors (FA)

Exterior - Underfloor (FA1)

Parameter	Value	Unit
Temperature		
Min. operating temperature for electronic components/batteries*)	-25	°C
Max. temperature rise compared with primary environment	10	K
Mean temperature rise compared with primary environment	5	K

*) When used with outside air temperature -25 °C to -40 °C it must be ensured that

- the components do not fall below min. operating temperature during train operations,
- parked vehicles are not allowed to cool to below -25 °C before startup and during preparation for train operation.

Parameter	Value	Unit

Parameter	Value	Unit
Humidity (relative humidity)		
Annual mean	≤90	%
Maximum value on 30 days spread over the year continuous	100	%
Condensation	yes	-

Parameter	Value	Unit
Pollution		
Pollution degree according to /DIN EN 60664-1/	4	-
Degree of protection for internals according to /DIN EN 60529/	IP 65	-

Table 42: Temperature, humidity and pollution in FA1

Exterior - levitation frame (FA2)

Parameter	Value	Unit
Temperature		
Min. operating temperature for electronic components/batteries*)	-25	°C
Max. temperature rise compared with primary environment	10	K
Mean temperature rise compared with primary environment	5	K

*) When used with outside air temperature <-25 °C to -40 °C it must be ensured that

- the components do not fall below min. operating temperature during train operations,
- parked vehicles are not allowed to cool to below -25 °C before startup and during preparation for train operation.

Parameter	Value	Unit
Humidity (relative humidity)		
Annual mean	≤90	%
Maximum value on 30 days spread over the year continuous	100	%
Condensation	yes	-

Parameter	Value	Unit
Pollution		
Pollution degree according to /DIN EN 60664-1/	4	-
Degree of protection for internals according to /DIN EN 60529/	IP 65	-

Table 43: Temperature, humidity and pollution in FA2

Exterior - Space envelope for levitation magnets, sensors (FA3)

Parameter	Value	Unit
Temperature		
Min. operating temperature for electronic components/batteries*)	-25	°C
max. Temperature rise compared with primary environment Space envelope for sensor electronics in the magnet back	25	K
Max. temperature rise compared with primary environment Space envelope for sensors in the magnet pole area on the side facing the winding	80	K
Mean temperature rise compared with primary environment Space envelope for sensor electronics in the magnet back	10	K
Mean temperature rise compared with primary environment Space envelope for sensors in the magnet pole area on the side facing the winding	30	K

*) When used with outside air temperature < -25 °C to -40 °C it must be ensured that

- the components do not fall below min. operating temperature during train operations,
- parked vehicles are not allowed to cool to below -25 °C before startup and during preparation for train operation.

Parameter	Value	Unit
Humidity (relative humidity)		
Annual mean	≤90	%
Maximum value on 30 days spread over the year continuous	100	%
Condensation	yes	-

Parameter	Value	Unit
Pollution		
Pollution degree according to /DIN EN 60664-1/	4	-
Degree of protection for internals according to /DIN EN 60529/	IP 65	-

Table 44: Temperature, humidity and pollution in FA3

Vehicle - Interiors (FI)

Interior - Airconditioned area (FI1)

Parameter	Value	Unit
Temperature		
Min. interior temperature *)	5	°C
Mean temperature in train operations (active air-conditioning)	**)	
Max. temperature rise compared with primary environment in train operation (inactive air-conditioning)	10	K

*) Vehicles parked during breaks in operation are air-conditioned such that the minimum interior temperature is maintained. Maintenance with vehicle deactivation is carried out in a heated workshop. The minimum interior temperature following maintenance is tested with the air-conditioning off according to the maintenance manual.
**) The mean room temperature follows the temperature curve shown in Annex A of /DIN EN 14750-1/ as a function of the outside temperature.

Parameter	Value	Unit
Humidity (relative humidity)		
Annual mean	≤65	%
Maximum value on 60 days spread over the year continuous	85	%
Condensation	no	-

Parameter	Value	Unit
Pollution		
Pollution degree according to /DIN EN 60664-1/	2	-
Degree of protection according to /DIN EN 60529/	IP 54	-

Table 45: Temperature, humidity and pollution in FI1

Interior - Non airconditioned area (FI2)

Parameter	Value	Unit
Temperature		
Min. interior temperature	-25	°C
Mean temperature in train operations (active air-conditioning)	------	-
Max. temperature rise compared with primary environment in train operation (inactive air-conditioning)	10	K

Parameter	Value	Unit
Humidity (relative humidity)		
Annual mean	≤65	%
Maximum value on 60 days spread over the year continuous	85	%
Condensation	light condensation	-

Parameter	Value	Unit
Pollution		
Pollution degree according to /DIN EN 60664-1/	2	-
Degree of protection according to /DIN EN 60529/	IP 54	-

Table 46: Temperature, humidity and pollution in FI2

Interior - Control cubicle vehicle section (FI3)

Parameter	Value	Unit
Temperature		
Min. interior temperature *)	5	°C
Mean temperature in train operations (active air-conditioning)	25	°C
Max. temperature rise compared with primary environment in train operation (inactive air-conditioning).**)	10	K
Max. temperature rise compared with primary environment in train operation (inactive air-conditioning).**)	5	K

*) Vehicles parked during breaks in operation are air-conditioned such that the minimum interior temperature is maintained. Maintenance with vehicle deactivation is carried out in a heated workshop. The minimum interior temperature following maintenance is tested with the air-conditioning off according to the maintenance manual.
**) The interior temperature following maintenance is tested with the air-conditioning off according to the maintenance manual.
***)When used with outside air temperature > 40 °C to 45 °C, the space envelope is ventilated with ambient air.

Parameter	Value	Unit
Humidity (relative atmospheric humidity)		
Annual mean	≤65	%
Maximum value on 60 days spread over the year continuous	85	%
Condensation	no	-

Parameter	Value	Unit
Pollution		

Parameter	Value	Unit
Pollution degree according to /DIN EN 60664-1/	2	-
Degree of protection according to /DIN EN 60529/	IP 54	-

Table 47: Temperature, humidity and pollution in FI3

Interior - Ceiling/wall behind panelling (FI4)

Parameter	Value	Unit
Temperature		
Min. interior temperature	- 25	°C
Mean temperature in train operations (active air-conditioning)	-----	-
Max. temperature rise compared with primary environment in train operation (inactive air-conditioning)	15	K

Parameter	Value	Unit
Humidity (relative humidity)		
Annual mean	≤65	%
Maximum value on 60 days spread over the year continuous	85	%
Condensation	no	-

Parameter	Value	Unit
Pollution		
Pollution degree according to /DIN EN 60664-1/	2	-
Degree of protection according to /DIN EN 60529/	IP 54	-

Table 48: Temperature, humidity and pollution in FI4

Mechanical excitation

The vehicle is excited to vibrate as its passes over the beams. The figures given below should be regarded as actions on the components of the vehicle's exterior areas.

Source	Length	Max. frequency *)
Bay-wide guideway beams, beam precamber and longwave deviation from the nominal position	31 m	4.5 Hz
Stator pack, fitting tolerance	1.032 m	135 Hz
Stator slot pitch	86 mm	1.6 kHz

*) The effect may be reduced if a maximum vehicle speed of less than 500 km/h is proposed in the application project concerned.

Table 49: Source of vibration excitation at v = 500 km/h.

The actions due to vibration and shock are given in /MSB AG-FZ BEM/.

ESD Protection

The secondary environment in the vehicle can be electrostatically charged during noncontact levitation relative to the stationary installations. From the safety aspect, the secondary environment in the vehicle must be electrostatically discharged in such a way that the energy remaining after the discharge according to Section 17, Paragraph MbBO is less than 350 mJ.

EMC / Lightning protection

Definition of EMC / lightning protection zones

The EMC / lightning protection zones must be separated by electromagnetic shields.
Lines with cross the zone boundaries must be provided with protective circuits.
Four EMC / lightning protection zones are defined for the vehicle, and are characterised by the following threats (see Figure 39) :

Zone 0_A

- Direct lightning strike possible.
- Main and partial stroke current paths are inside the zone
- Unattenuated field effect

Zone 0_B

- No direct lightning strike possible
- No main and partial stroke current paths
- Virtually unattenuated field effect

Zone 1

- No direct lightning strike possible
- No main and partial stroke current paths
- Field attenuation must satisfy the following minimum values:
  - for magnetic fields: as per Figure 37
  - for electrical fields: as per Figure 38

Zone 2

- No direct lightning strike possible
- No main and partial stroke current paths
- Field attenuation must satisfy the following minimum values:
  - for magnetic fields based on Zone 0_A: as per Figure 37
  - for magnetic fields based on Zone 1: as per Figure 37
  - for electrical fields based on Zone 0_A: as per Figure 38
  - for electrical fields based on Zone 1: as per Figure 38

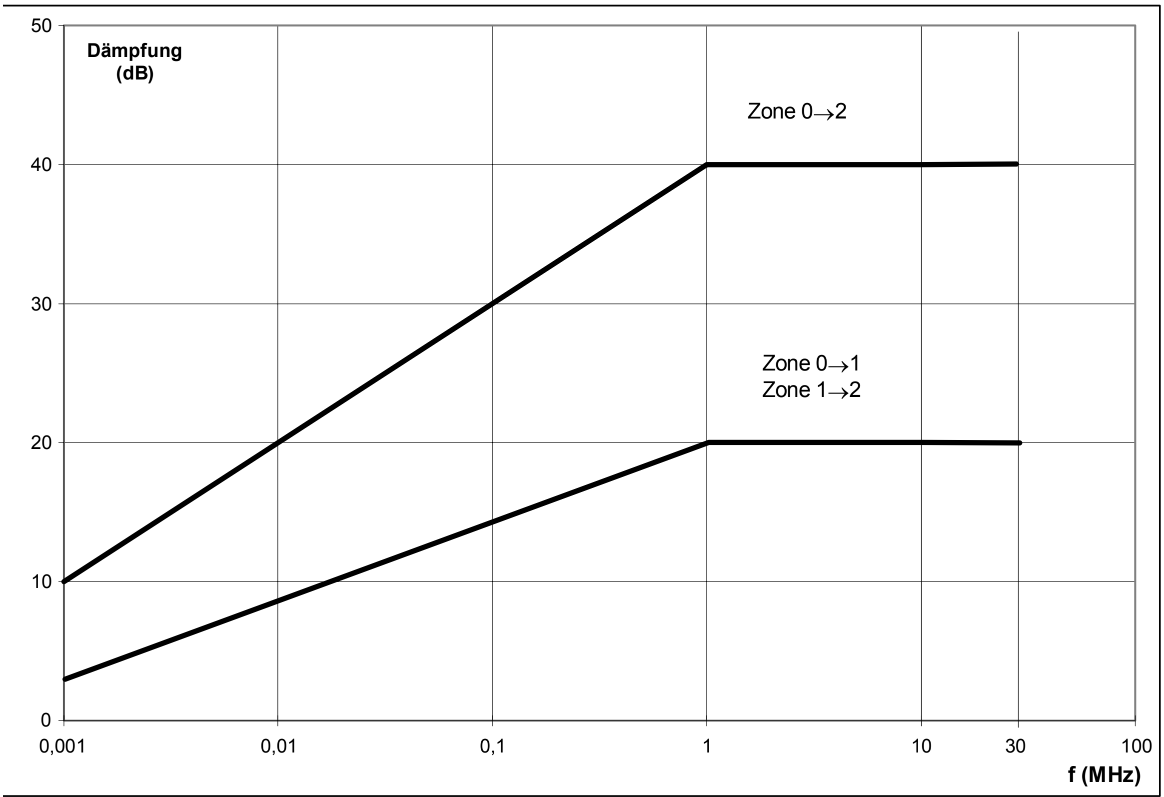

Figure 37: Magnetic field attenuation

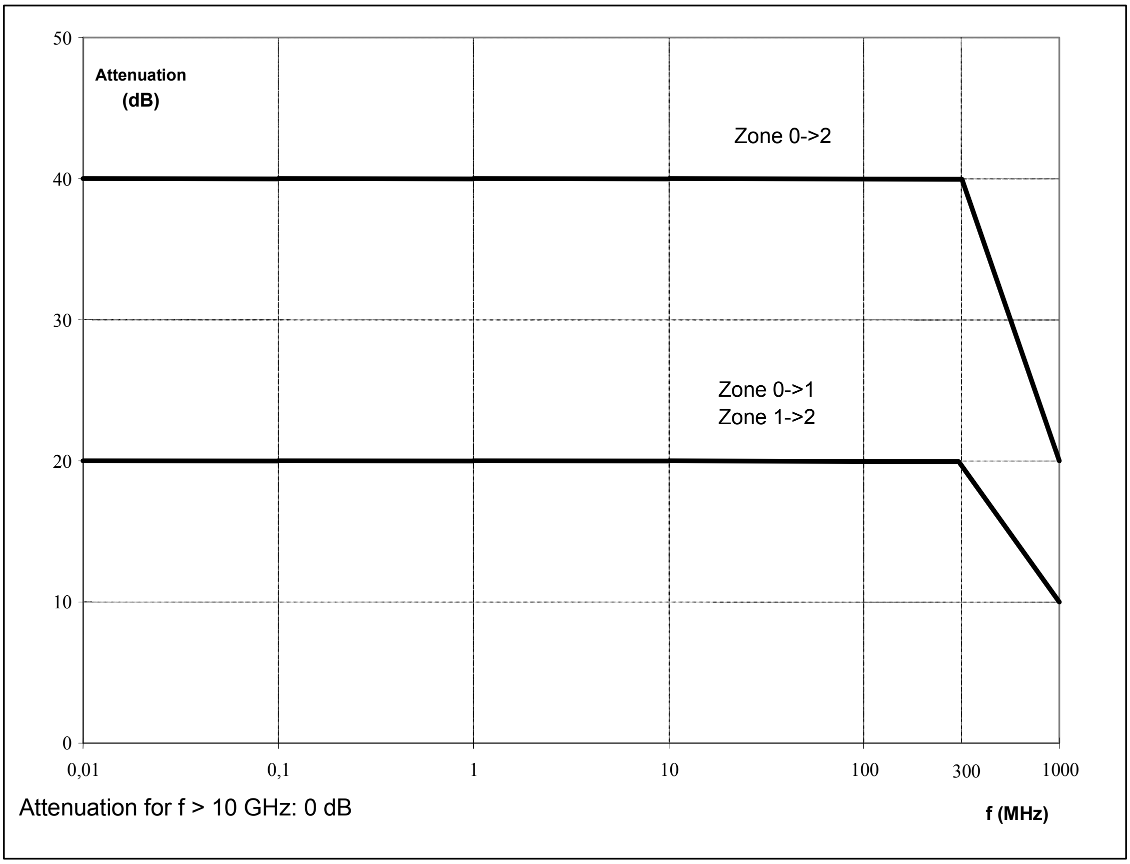

Figure 38: Electrical field attenuation

Assignment of the EMC / lightning protection zones to the space envelopes

The EMC / lightning protection zones are assigned to the space envelopes as follows:

Zone 0_A

- Exposed areas
- Unshielded or unprotected underfloor area

Zone 0_B

- Car body interior, outside control cubicles and other shields
- Underfloor areas protected from main and partial lightning currents

Zone 1

- Shielded cable trunking
- Interior of control cubicles inside the car body
- Cores outside singly shielded cables
- Housing interiors

Zone 2

Housing or cable shield interior. The housings and cables can be inside zones 0_A, 0_B or 1. The required shield attenuation values must be achieved.

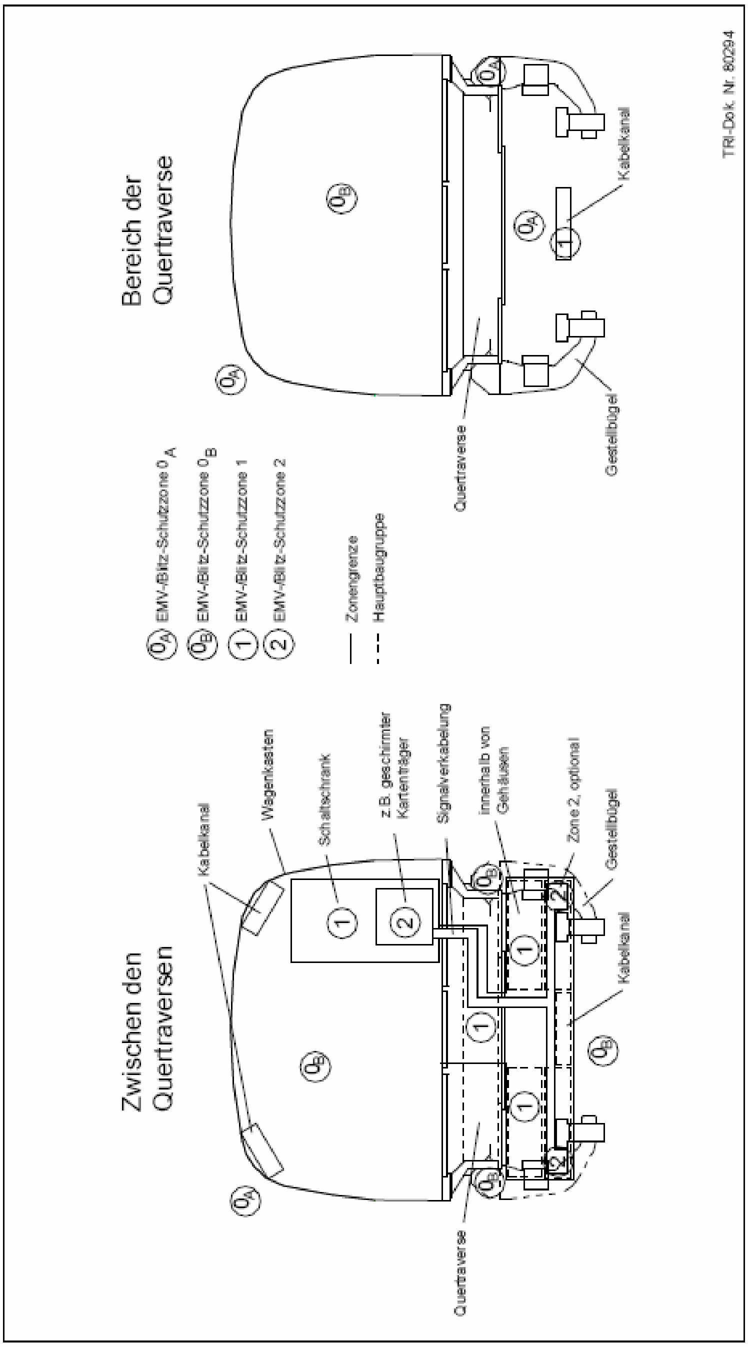

Figure 39: EMC / lightning protection zones of the MSB vehicle

Direct lightning strike - Threat levels for EMC / lightning protection zone 0_A

At least two lightning flashover points per lightning impulse current, i.e. at least two lightning current paths, must be expected in the event of a lightning strike into the vehicle.
The design of the lightning current-carrying equipotential bonding conductors, the shielding and the electronic components is based on two partial stroke impulse currents with identical lightning parameters.
This results in the following reduction factors compared with the lightning parameters given in Chapter 0:

- Lightning current peak value: 2
- Lightning impulse charge: 2
- Specific lightning energy: 4

For sustained current, the parameters are taken from Chapter 0.
A minimum distance of 0.1 m between the sink and the lightning current paths is assumed when determining the limits of the lightning threat.
The minimum distance must be guaranteed by design engineering. With greater distances, the threat values decrease proportional to the distance.
The maximum magnetic field threat values H or dH/dt are given according to /DIN EN 62305-4/ by the distance and the maximum lightning current values I or dI/dt.
H and I are derived from the first stroke, dH/dt and dI/dt from the subsequent strokes.
In the event of lightning strike according to / DIN EN 62305-4/ the electrical field E or dE/dt is largely independent of distance at ranges of up to approx. 100 m from the strike point.

Lightning strike current

Lightning strike current (see Figure 35 and Figure 34):

Parameter	Value	Unit
Peak current I	100	kA
Charge of the transient discharge pulse Q_s	50	C
Specific energy W/R	2.5	MJ/Ω

Table 50: Lightning current parameters of the first lightning discharge impulse

Parameter	Value	Unit
Peak current I	25	kA
Mean steepness I/T_1	100	kA/µs

Table 51: Lightning current parameters of the subsequent discharge impulse

Parameter	**Value**	**Unit**
Peak current value main lightning current path	100	kA
Peak current value partial lightning current path	5	kA
Current profile	as first lightning discharge impulse, see Figure 34	-

Table 52: Currents in the lightning and partial lightning current paths

Fields and induced voltages

Parameter	**EMC / Lightning Protection Zones**				**Unit**
	0_A	0_B	1	2	
dH/dt	$1.6 \cdot 10^{11}$	$1.6 \cdot 10^{11}$	$1.6 \cdot 10^{10}$	$1.6 \cdot 10^{9}$	A/ms
H	$1.6 \cdot 10^{5}$	$1.6 \cdot 10^{5}$	$1.0 \cdot 10^{5}$	$6.3 \cdot 10^{4}$	A/m
dE/dt	$5.0 \cdot 10^{11}$	$<5.0 \cdot 10^{11}$	$<5.0 \cdot 10^{10}$	$<5.0 \cdot 10^{9}$	V/ms
E	$5.0 \cdot 10^{5}$	$<5.0 \cdot 10^{5}$	$<5.0 \cdot 10^{4}$	$<5.0 \cdot 10^{3}$	V/m

Table 53: Fields and field changes; distance from lightning current path: 0.1 m

Parameter	**EMC / Lightning Protection Zones**				**Unit**
	0_A	0_B	1	2	
dH/dt	$1.6 \cdot 10^{10}$	$1.6 \cdot 10^{10}$	$1.6 \cdot 10^{9}$	$1.6 \cdot 10^{8}$	A/ms
H	$1.6 \cdot 10^{4}$	$1.6 \cdot 10^{4}$	$1.0 \cdot 10^{4}$	$6.3 \cdot 10^{3}$	A/m
dE/dt	$5.0 \cdot 10^{11}$	$<5.0 \cdot 10^{11}$	$<5.0 \cdot 10^{10}$	$<5.0 \cdot 10^{9}$	V/ms
E	$5.0 \cdot 10^{5}$	$<5.0 \cdot 10^{5}$	$<5.0 \cdot 10^{4}$	$<5.0 \cdot 10^{3}$	V/m

Table 54: Fields and field changes; distance from lightning current path: 1 m

Parameter	**EMC / Lightning Protection Zones**				**Unit**
	0_A	0_B	1	2	
U_{ind} in 10x10 cm measurement loop with one turn	2 000	2 000	200	20	V
U_{ind} in 2-core cable, core spacing: 1 cm, length: 1 m	20 000	20 000	2 000	200	V

Table 55: Induced voltages by magnetic field in lightning strike; distance from lightning current path: 0.1 m

Parameter	EMC / Lightning Protection Zones				Unit
	0_A	0_B	1	2	
U_{ind} in 10x10 cm measurement loop with one turn	200	2 00	20	2	V
U_{ind} in zweiadriges Kabel, core spacing: 1 cm, length: 1 m	2 000	2 000	200	20	V

Table 56: Induced voltages by magnetic field in lightning strike; distance from lightning current path: 1 m

Radiated Interference

The immunity of the MSB vehicle to radiated interference must meet the requirements of /DIN EN 50121/ Part 3-1. The requirements of /DIN EN 50121/ Part 3-2 must be satisfied for the immunity of devices and equipment installed in the vehicle.
The above requirements must be permanently guaranteed by design engineering measures.

Limits of immunity for high frequency fields

Parameter	EMC / Lightning Protection Zones			
Field strength in [V/m]	0_A	0_B	1	2
Frequency range 0.15 MHz - 1 GHz	20	20	< 12	< 1.2
Frequency range 1-4 GHz				
• Vehicle interior (FI1-FI3) - at 0.2 m min. distance from mobile radio devices -		20	< 20	< 20
• Underfloor area (FA1-FA3) - at 0.4 m min. distance from mobile radio devices -	20	20	< 20	< 20
Frequency range 37-39.5 GHz				
- Vehicle interior (FI1-FI3)		2.1	< 2.1	< 2.1
- Underfloor area (FA1-FA3)	0.21	0.21	< 0.21	< 0.21
- Field strength is greatly reduced compared with primary environment as the lightning protection zones are not in the radio beam range -				

Table 57: Electromagnetic interference field strengths in the EMC / lightning protection zones

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Limits of immunity for magnetic fields

Parameter	EMC / Lightning Protection Zones			
Continuous magnetic field strength in [A/m]	0_A	0_B	1	2
16 2/3 Hz	100	100	100	100
50 Hz	100	100	100	100

Table 58: Magnetic interference field strengths in the EMC / lightning protection zones

It must be assumed that the fields in Zone 0_B are attenuated by the car body compared with Zone 0_A. However the car body attenuation is not separately measured so it is conservatively taken to be 0 dB, i.e. without attenuation.
The levels for Zone 0_B contain possible room resonances in the vehicle interior and the fields of mobile radio devices.
The shield attenuation in Zones 1 and 2 is maintained by design reserves and/or by maintenance.

Secondary environment in installations

The proper operation of the following installations muss must be guaranteed within the secondary environmental conditions specified in the sections below.

Secondary environment on the long stator

The following environmental conditions that are given for the long-stator winding also apply by analogy to other items of equipment and mount-on parts of the guideway beams.
It must be remembered that the secondary environmental conditions depend on the design of the guideway beams and substructures.
The following values must be verified and defined project-specifically.

Temperature

Parameter	**Value**	**Unit**
Max. temperature rise of the long-stator space envelope compared with the primary environment	5	K

Table 59: Temperature

Mechanical load on the long-stator winding

The following effects from the guideway beam taken into consideration when determining the mechanical load:

- Effects from the static and dynamic deformation of the beam due to operations and to the beam's natural oscillations that can be caused especially by slow moving MSB vehicles.
- Effects from deformation of the beam due to temperature changes
  - Linear expansion
  - Deformation due to non-uniform temperature distribution
- Deformation of the substructures due to operation (driving/braking)

The natural oscillation behaviour of the various items of equipment and mount-on parts must also be allowed for when determining the mechanical load.

Parameter	Value	Unit
Effect on the long-stator winding from guideway beam vibration		
Max. frequency	35	Hz
Acceleration in x-direction (RMS)	20	m/s²
Acceleration in y-direction (RMS)	50	m/s²
Acceleration in z-direction (RMS)	50	m/s²
Tägliche Dauer der Einwirkung (akkumuliert)	5	min

Table 60: Typical vibration effects on a the long stator

Parameter	Value	Unit
Mechanical movement at the beam joints		
Limits of deviation from nom. dimension	-32 to +63	mm

Table 61: Deviation from nominal dimension at beam joints

Parameter	Value	Unit
Movement cycle at the beam joints due to temperature response curve		
Maximum daily beam expansion gap change in x-direction	30	mm
Mean daily beam expansion gap change in x-direction	12	mm
Mean annual beam expansion gap change in x-direction	12	mm

Table 62: Thermal effect at the beam joints

Parameter	Value	Unit
Movement cycle due to effects from operation		
Max. number of cycles	200	1/day
Min. cycle time resulting from min. train length	1	s
Max. change in beam expansion gap in x-direction (at max. speed)	3.5	mm
Mean change in beam expansion gap in x-direction (at max. speed)	2	mm

Table 63: Effect of vehicle acceleration and retardation and resulting change in beam expansion gap

Pollution Degree

The requirements of /DIN EN 60664-1/ for pollution degree 4 must be satisfied.

EMC / Lightning protection

The requirements defined in / DIN EN 62305-4/ for LPZ 0_B must be satisfied.

Secondary environment inside buildings (e.g. substations, switching points, point switching boxes)

The values for airconditioned service/machine rooms must be defined project-specifically.

Climate

Must be defined project-specifically.

Pollution Degree

The requirements of /DIN EN 60664-1/ for pollution degree 2 must be satisfied.

EMC / Lightning protection

The requirements defined in / DIN EN 62305-4/ for LPZ 0_B must be satisfied as a minimum. Any necessary defining of areas with Zones LPZ 1 or LPZ 2 must be done as part of the EMC building design.

Environmental conditions with covered guideway sections

The following differences compared with guideway sections directly exposed to the actions of the primary environment must be considered for guideway sections that are covered over:

Characteristic	Differences
Temperature	The max. limits of the primary environment are not achieved.
Humidity	Higher than the average for the primary environment
Wind	max. 10 min. mean: 10 m/s
Ice/snow	No snow or ice cover of the guideway's functional surfaces
Effective length of the cover in relation to wind and ice/snow	The length of the covered structure less 10 m for each transitional section is used as a guide value. The actual length must be defined project-specifically.

Table 64: Environmental conditions in covered guideway sections

Environmental conditions in tunnel sections

In a tunnel, the environmental conditions of temperature, humidity, air movement / wind must be considered depending on the particular locality and as a function of parameters such as the number of tracks, tunnel structure, train sequence etc.
The environmental conditions for a particular tunnel will therefore have to be defined project-specifically.
The data given the following sections, based on Annex A of /DIN EN 50125-2/, must therefore be regarded as guide values.

Temperature

For tunnels less than 2000 m long and in the first and last 1000 m section of tunnels longer than 2000 m, the same temperature assumptions should be made as for open air.
The lowest temperature in the central section of long tunnels (> 2000 m) can be assumed to be 20 K higher than in open air and the highest temperature can be reduced by 5 K.

Humidity

Humidity tends to be low where the tunnel walls can prevent a significant amount of humidity from penetrating.
Structural measures against humidity penetration must be defined project-specifically.
The max. absolute humidity in the tunnel must be assumed according to /DIN EN 50125-3/, Table 3 as 30 g/m^3.

Wind

A figure of 3 m/s can be assumed for the 10 min. mean wind speed.

High-speed Maglev System
Design Principles

Complete System
Annex 4 Rules for Operation
(Train Operation and Maintenance)

Distribution

This documents has been approved for publication by the Technical Committee Rules for Operation (Train Operation and Maintenance).

Change history

Release date: 15.02.2007, white paper, Technical Committee Rules for Operation

List of contents

General

Purpose of the document, scope

This design principles applies to a high-speed maglev system according to the General Maglev System Act /AMbG/.
Sections 24 and 8 /MbBO/ require the MSB entrepreneur to establish rules for operation.
This document contains the non project-specific requirements for rules for the operation of MSB systems, consisting of train operation and maintenance.
This Design Principles applies in conjunction with the High-speed Maglev System Design Principles Complete System /MSB AG-GESAMTSYS/ and its Annexes.
This Design Principles governs the operation of MSB systems.
Separate rules must be established for operation during the construction and commissioning of MSB systems.
The following statements relate to the MSB entrepreneur's rules for operation (train operation and maintenance), referred to hereafter as the "body of rules", for the use of MSB systems to carry passengers.
The carriage of goods must be considered separately.
The requirements are addressed to MSB entrepreneurs (as per Section 5 /AMbG/).
The requirements are also addressed to the manufacturers of the MSB system and its components in so far as they make statements about required documentation and impose conditions on the organisation and procedures for the operation of the MSB system that must be taken into consideration in the design of all subject areas of the MSB system.
Where the MSB entrepreneur's or manufacturer's internal rules differ from the requirements of this Design Principles, those internal rules may be retained subject to evidence of equivalent safety or, in the case of definitions and vocabulary, subject to proof of analogous meaning.

High-speed Maglev System Design Principles

This document forms part of documentation for high-speed maglev systems consisting of a series of Design Principles. The document tree is shown in Figure 1 /MSB AG-GESAMTSYS/.
The high-level "complete system" design principles and its annexes apply uniformly for the whole documentation:

- High-speed Maglev System Design Principles Complete System, Doc. No.: 50630, /MSB AG-GESAMTSYS/
  - Annex 1: High-speed Maglev System Abbreviations and Definitions, Doc. No.: 67536, /MSB AG-ABK&DEF/
  - Annex 2: High-speed Maglev System Statutes, Regulations, Standards and Directives, Doc. No.: 67539, /MSB AG-NORM&RILI/

- Annex 3: High-speed Maglev System Environmental Conditions, Doc. No.: 67285, /MSB AG-UMWELT/
- Annex 5: High-speed Maglev System Noise, Doc. No.: 72963, /MSB AG-SCHALL/

Abbreviations and definitions

The abbreviations and definitions given in /MSB AG-ABK&DEF/ apply.
Instead of the term "train operation" as used in this document, the term "operation" is also in commonly used among operators of track-guided transport systems and may therefore be used in the body of rules of the MSB entrepreneur instead of the term "train operation". This also applies to corresponding word combinations.

Statutes, regulations, standards and guidelines

The normative documents listed in /MSB AG-NORM&RILI/ contain requirements that form part of the High-speed Maglev System Design Principles by cross reference in the High-speed Maglev System Design Principles.
Where normative documents in /MSB AG-NORM&RILI/ are dated, subsequent changes or revisions of these publications do not apply.
With undated references, the latest version of the normative document that is referred to applies.
The version of the standards and guidelines to be observed in an MSB project must be decided bindingly on a project-specific basis.
A list of statutes, ordinances, standards and directives for the MSB entrepreneur's body of rules will be found in the document Maglev High-speed System Design Principles Complete System, Annex 2: Statutes, Regulations, Standards and Directives /MSB AG-NORM&RILI/.

Identification and binding value of requirements

The requirements of /DIN 820/, Part 2, were essentially applied in the preparation of this document.
In the following chapters and the annexes of this document

- Requirements are shown in normal font
- Explanations, guide values and examples are shown in *italics*

Preparation of the body of rules for operation

The entirety of the rules must be:

- complete,
- consistent,
- free from contradiction

within themselves.
The rules must conform to the MSB entrepreneur's requirements relating to safety management, especially according to /DIN EN 61508/, /DIN EN 50126/ and /DIN EN 50129/ (see Chapter 0).
Requirements in the body of rules must be checked for consistency with the project-specific safety, operation and maintenance concept.
The terms and abbreviations used in the body of rules must be clearly defined. The defined terms and abbreviations must be used consistently.
The structure of the body of rules must be user-friendly.
A body of rules is ***user-friendly*** *in particular when*

- *it directly addresses the individual target groups,*
- *its contents are presented in a clear, understandable and descriptive manner, and*
- *the auxiliary verbs in it are used according to DIN 820-2/ Annex G.*

The body of rules must be practicable.
A body of rules is ***practicable*** *when*

- *the rules it contains optimally support the specified functionality of the deployed technology, and*
- *all users can apply the rules well and without particular difficulty in operation.*

The body of rules should be modular in structure.
It is ***modular in structure*** *when it consists of individual self-contained modules which are mutually compatible.*

Structure, breakdown and scope of the body of rules for operation

Structure and breakdown of the body of rules

The body of rules must present the structure and breakdown of the rules in a suitable form, e.g. as a table of contents.
Additional provisions can be published as annexes or supplements. The body of rules may contain printed forms to aid working.
If the MSB entrepreneur stipulates uniform principles for the drafting, structure, presentation and documentation of rules, then these principles should be applied to the entire body of rules.

Parts of the body of rules

The basic understanding of the MBS system that is necessary for the work by the personnel must be conveyed to the personnel.
The description and presentation must include the installations that are relevant for operation. The installations should be presented in clear form in a location plan.
The MSB vehicles and special vehicles used in the project as well as any trailers and work scaffolding must be described.
The body of rules for the operation of the MSB system consists of:

- rules for train operations,
- rules for maintenance,
- general organisational rules for operation (train operations and maintenance).

General organisational rules must at least describe the division and distribution of responsibilities within the MSB entrepreneur's organisation.
General organisational rules can exist either as a separate document or can be incorporated into the rules for train operations or rules for maintenance.
The general organisational rules must be formulated so that it is clear how the defined safety objectives are to be achieved under the given project-specific system preconditions and within the project-specific operational framework.
The rules must clearly set out the principle for the division of responsibility for safety related and non safety related (e.g. commercial) factors of operation in the organisation as well as in the work and management processes, systems and types.
Other applicable documents must be defined in the body of rules. They are subject to the same quality criteria as the body of rules itself.
Examples of other applicable documents:

- Operating instructions of the MSB system manufacturers,
- Maintenance instructions of the MSB system manufacturers.

Basic documents used to prepare the body of rules do not form part of it.
Examples of basic documents:

- the safety related instructions for use (SAV) of the MSB system manufacturers,

- the instructions according to /Directive 98/37/EC/,
- conditions and secondary provisions in official decisions / permits,
- documents necessitated by requirements in relevant legislation, regulations, standards and directives (e.g. manuals for Safety Management / Quality Management).

Management types and systems

Safety Management System (SMS)

The MSB entrepreneur must put in place a safety management system based on /Directive 2004/49/EC/.
The SMS is the organisation established by an MSB entrepreneur and the precautions he takes to guarantee the safe execution of his operational procedures.
The SMS must guarantee that the rules for organisation, train operations and maintenance which arise out of the project-specific safety concept are incorporated into the body of rules.

Quality Management (QM)

The measures and rules for quality management must be presented in the body of rules and conform to the applicable regional, national and international regulations, standards (e.g. /standards series EN ISO 9000 ff./) and the MSB entrepreneur's QM Manual.
Rules for quality assurance, quality planning and the quality procedures must be contained in the body of rules if they relate to the safety of the operation of the MSB system.

Occupational Safety Management

The measures and arrangements put in place for occupational safety must be set out in the body of rules and must satisfy the applicable regional, national and international rules, standards, regulations and national legislation.
Personnel protection must be assured by appropriate arrangements.
The national legislation includes a collection of statutes and ordinances on this subject that are contained in /MSB AG-NORM&RILI/ /PERSSCH/.
The occupational safety arrangements may be summarised in a suitable manner, e.g. in the form of an occupational safety management system.

Environmental Protection Management

The measures and arrangements put in place for environmental protection must be set out in the body of rules and must satisfy the applicable regional, national and international rules, standards, regulations and national legislation. The current environmental findings must be taken into consideration.
The national legislation includes a collection of statutes and ordinances on this subject that are contained in /MSB AG-NORM&RILI/ /PERSSCH/.
The reviews of work processes and work contents and their impact on the environment and the measures for reviewing compliance with environmental protection measures must be defined in the body of rules.
The environmental protection arrangements may be summarised in a suitable manner, e.g. in the form of an environmental protection management system.

Need for regulation - Train operations and maintenance

High-level Requirements

Monitoring of Limits

The MSB entrepreneur must monitor compliance with the limits and other specified values defined in the Design Principles Complete System and Subsystems.
The corresponding rules, recording and analysis procedures, assessment criteria and the measures to be taken in case of noncompliance must be defined project-specifically in the body of rules.
The body of rules must define how the effects of special load cases are registered their reliability assured in accordance with the MSB Design Principles Complete System /MSB AG-GESAMTSYS/.

Requirements for the train operation and maintenance personnel

The body of rules must describe for each workplace the requirements which the MSB entrepreneur makes regarding personnel suitability, fitness and qualification.
The body of rules must stipulate that every activity in train operations and maintenance may only be carried out by suitable, fit and qualified personnel.
The procedures used to determine the suitability and fitness of personnel, the regular review and requirements governing review intervals, periods and documentation must be laid down in the body of rules.
Personnel training/qualification must be anchored in the body of rules at least to the extent that it is clearly stated which duties, competences and responsibilities of the personnel are associated with which minimum qualification.
It must be clearly stated how the qualification is obtained, if necessary how it is regularly repeated and/or received, and how all qualifications of the personnel are organised, documented and administered.

Communication requirements

Rules for safety related communication including technical and organisational requirements must be defined.
Technical communications equipment, its fallback policies in the event of fault or failure, and its integration into operational procedures must be described.
The rules for recording and storing communications must be defined.

Need for regulation - Train operations

Rules for train operations

The rules for train operations must be defined in the Operation Manual according to Section 24 /MbBO/ and must cover at least the entire train operations.

The train operations must be carried out in one of the following two modes (see High-speed Maglev System Design Principles Complete System /MSB AG-GESAMTSYS/, Chapter 6.3.1.2):

- Normal operation
- Departure from normal operation.

The option of executing both modes simultaneously must be provided so far as is technically possible and desirable for operational reasons.
The body of rules must lay down the conditions under which maintenance operations may be performed in the event of disruptions in train operations.
Responsibilities during this process must be described.
Arrangements must be put in place in the event of an nonscheduled stop by the MSB vehicle.
In the event of disruptions in train operations which involve evacuation of the MSB vehicle, the body of rules must state how the evacuation must be initiated and carried out.
The safety related planning and dispatching processes for the train operations must be described.
Planning and dispatching processes are safety related when they ensure that specified limits for the MSB system are complied with or their realisation may affect the integrity of persons and property.

"Normal operation" mode

The constraints for normal operation (see Annex 1: High-speed Maglev System Abbreviations and Definitions /MSB AG-ABK&DEF/) must be laid down and described in the rules for train operations.
In the body of rules, the MSB entrepreneur must define (see also Section 22 /MbBO/):

- operational preconditions for the start and sequence of normal operation,
- technical preconditions for the start and sequence of normal operation,
- changes between manually and automatically generated journey inputs within normal operation,
- conditions for leaving the normal operation mode,
- requirements and procedures for return to the normal operation mode,
- procedures when journey preconditions are no longer met.

When individual processes require actions by the operating personnel in normal operation, these actions must be described.
The actions and restrictions necessary to prevent or avert potential hazardous states in normal operation must be described.
The measures that must be taken in the event of foreseeable technical and operational disruptions in the operation flow must be described.
The measures that must be taken in the event of foreseeable hazardous incidents must be described.
The monitoring activities, measures and intervention in the control and protection of train operations to be carried out by operating personnel in response to technical or operational requirements must be described.

Where train operations are carried out simultaneously with construction and/or maintenance operations, it must be decided

- whether and how far construction and/or maintenance operations (e.g. subsystem related, locally closed sections of line) may take place during normal operation, and
- how the areas in which construction and/or maintenance operations are being carried out should be closed off and secured.

Responsibilities during this process must be defined.

"Departure from normal operation" mode

The functions that are not contained in the technical protection system must be defined in the rules for train operation.
If necessary, appropriate safety measures (technical and/or organisational) must be described in the body of rules.
The measures to be taken under personnel responsibility must be described in the body of rules.
In the body of rules, the MSB entrepreneur must define (see also Section 22 /MbBO/):

- operational preconditions for the start and sequence of the "departure from normal operation" mode,
- technical preconditions for the start and sequence of the "departure from normal operation" mode,
- changes between manually and automatically generated journey inputs within the "departure from normal operation" mode,
- conditions for leaving the "departure from normal operation" mode,
- requirements and procedures for return to the "departure from normal operation" mode,
- procedures when journey preconditions are no longer met.

Provisions in the body of rules must ensure that the "departure from normal operation" mode does not lead to an unsafe state of the MSB system.
The body of rules must define the conditions under which train operations are to be interrupted due to the "departure from normal operation" mode.
Project-specific technical characteristics of the installations and of the MSB vehicles must be taken into consideration when defining actions and measures taken under personnel responsibility.
Automatic responses by the technical MSB equipment during the "departure from normal operation" mode and the extent of the remaining technical protection must be described for the train operation personnel.
This also applies to the monitoring activities, measures and intervention in the control and protection of train operations to be carried out by operating personnel in response to technical or non technical requirements.
Operations-monitoring measures for the systematic detection, identification/evaluation and documentation of causes for the "departure from normal operation" mode must be defined in the body of rules.

The body of rules must define how the traffic movement director is to be informed of circumstances that may lead to the "departure from normal operation" mode.
The nature, format and scope of communication during the "departure from normal operation" mode must be specified in the body of rules.
Actions for individual measures and operator interventions to ensure the required level of safety under personnel responsibility, especially in an emergency situation, must be defined in the body of rules in a suitable format (checklists, flow charts etc.).
Where train operations are carried out simultaneously with construction and/or maintenance operations, it must be decided

- whether and how far construction and/or maintenance operations (e.g. subsystem related, locally closed sections of line) may take place during "departure from normal operation" mode, and
- how the areas in which construction and/or maintenance operations are being carried out should be closed off and secured.

Responsibilities during this process must be defined.

Train operations with special vehicles

The body of rules must define types of special vehicles project-specifically.
Rules for moving special vehicles must be defined project-specifically.
Sequences, operator actions and communication as well as technical and non technical measures will depend on the technical equipment of the special vehicles.
The body of rules must indicate the conditions under which special vehicles may travel on the MSB line (environmental conditions, MSB vehicles in service etc.).
Depending on the equipment of the special vehicles, measures against gauge profile violations must be laid down.
Depending on the equipment of the special vehicles, measures for the avoidance of collisions with

- other special vehicles,
- MSB vehicles,
- installations,
- persons and objects that project into the gauge profile

must be defined.
Parking and standby positions for special vehicles and the measures for immobilising the special vehicles must be defined project-specifically.

Need for regulation for special measures

Security

The body of rules must describe the security system and security tasks in relation to the MSB system. It must describe:

- the principles and objectives of security,
- the responsibility and acting persons for security,

- the tasks and scope of building security,
- the tasks and scope of organisational security,
- the documentation, verification and reporting of security.

It must be stipulated which security measures must be defined as a minimum. This relates to all active and passive measures such as:

- security of vehicles and installations from unauthorised access and unauthorised intervention,
- response to alarms and emergency calls,
- Co-operation with authorities and organisations with security duties (BOS),
- involvement of surveillance and security services.

Winter service

The rules for train operations must define the limits within which the safe operation of the MSB system is also possible under winter weather conditions. The limits are specified in Annex 3: High-speed Maglev System Environmental conditions /MSB AG-UMWELT/.
The following limits are mentioned by way of example:

- the permissible thickness of guideway icing (levitation / guidance areas),
- the acceptable depth of snow on the guideway table and under the gradient.

The rules for train operations must state that the MSB system may only be operated within the specified limits.
They must also indicate the responsibilities and measures for an approach to the limits being detected in good time and being responded to with the necessary measures in accordance with requirements.
General winter service measures around the traffic installations, the maintenance centre and the transport routes that may also be performed by third parties must be project-specifically regulated.

Vegetation control

Vegetation stocks long the MSB route must be monitored and cared for by regular inspections.
Measures must be defined for keeping the clearance gauge free. The following categories must be taken into consideration:

- Measures to protect against clearance gauge violation,
- Measures for detecting a clearance gauge violation,
- Measures for eliminating a clearance gauge violation.

The vegetation control measures must take into account that encroachment into the clearance gauge due to natural growth is impossible and due to environmental influences (e.g. wind break, snow loads on the vegetation) is largely prevented.

Need for regulation - Maintenance

Rules for maintenance

Contents of the rules for maintenance

The principles of maintenance and the complete subdivision of maintenance into its basic actions are laid down in /DIN 31051/.
The basic terminology of maintenance and the classification of maintenance into different types are defined in /DIN EN 13306/. /DIN EN 50126/ also applies.
These principles, subdivisions, terms and classifications must be used in the body of rules for maintenance.
The maintenance of the MSB subsystems must be combined in an appropriate manner with the maintenance of the MSB Complete System. The rules for maintenance must reflect this.
The rules for maintenance consist of:

- maintenance programme,
- maintenance instructions (for all of the maintenance measures listed in the maintenance programme),
- rules containing project-specific or location specific supplements (e.g. as work instructions and procedures).

Maintenance programme

A maintenance programme for the Complete System must be prepared on the basis of the "Principles and procedures for creating the maintenance programme" (see /MbBO/ Section 8).
The maintenance programme must be prepared having particular regard to the following points:

- The maintenance programmes for the subsystems must contain all necessary maintenance measures for the particular subsystem.
- The maintenance programmes for the subsystems must cover the Complete System.
- The manufacturer of a particular item must list the possible faults and malfunctions of that item and clearly assign them to a fault class.
- The necessary responses and action by personnel must be defined for each fault class. The action must at least take account of the impact of malfunctions and faults on the safety of the system.
- To identify the necessary maintenance measures, structural and/or functional analyses of all MSB subsystems must be carried out, and the action defined, based on accepted methods (e.g. FMEA /MSB AG-ABK&DEF/). The frequencies/intervals of the maintenance measures must be defined on this basis.
- A product structure plan is the basis for the structural and functional analysis.
- A classification and/or prioritisation of maintenance measures in regard to their safety relevance must be provided.

The body of rules must clearly indicate the differentiation of responses to different classes / priorities of maintenance measure.
Further requirements governing the creation of the maintenance programme - where they exist - are contained in the respective Design Principles for the subsystems.

Maintenance instructions

Maintenance instructions must exist for all maintenance measures defined in the maintenance programme.
The maintenance instructions must be prepared by the manufacturer of the particular technical item under consideration (e.g. subsystem manufacturer).
They should be uniform in structure and presentation.
The maintenance instructions must contain all the information that is necessary to carry out the maintenance measure.

Rules for the performance of maintenance measures

The maintenance rules must contain project and/or location specific information and instructions for the technical performance of the maintenance measures, e.g. in the form of work instructions. These supplement the maintenance instructions.
The naming of the project and/or location specific information and instructions for the technical performance of maintenance measures shall be at the discretion of the entrepreneur.
The project and/or location specific information and instructions should contain at the least the following particulars:

- description of how the maintenance measures are carried out,
- use of specific work aids/tools,
- particulars about the use of the infrastructure,
- specific information about occupational safety/environmental protection and the use of personal protective equipment,
- specific details about personnel qualification.

The project and/or location specific information and instructions, details and additions must not unduly alter the contents of the maintenance instructions.

Rules for the sequence / organisation of maintenance measures

The maintenance rules must contain project and/or location specific information and instructions about the sequence and/or organisation of maintenance measures, e.g. in the form of process instructions. These supplement the maintenance instructions.
The naming of the project and/or location specific information and instructions about the sequence and/or organisation of maintenance measures shall be at the discretion of the entrepreneur.
The project and/or location specific information and instructions should contain at the least the following particulars:

- procedures for access to and presence in maintenance areas,
- logging in/out, and safety procedures as well as warning procedures for maintenance work,

- ordering maintenance work,
- carrying out maintenance work,
- completion and confirmation of maintenance work,
- documenting maintenance work.

For fast moving and automatically operated vehicles, warning procedures are not suitable as organisational measures for the protection of personnel inside the guideway danger area, and must be excluded.

The project and/or location specific information and instructions, details and additions must not unduly alter the contents of the maintenance instructions.

Maintenance management

The body of rules must present the complete maintenance process for the vehicles and installations, including maintenance management and the maintenance strategy.
All planning and scheduling processes for maintenance must be described.
The safety related planning and scheduling processes must be identified.

Planning and dispatching processes are safety related when they ensure that specified limits for the MSB system are complied with or their realisation may affect the integrity of persons and property.

Consideration must be given to the following requirements for maintenance management in addition to the requirements of Chapter 0:

- The body of rules for maintenance must be linked through the interface rules for train operations and maintenance to the rules for train operations, and be consistent with them.
- Rules arising out of existing statutes, standards and directives (e.g. occupational safety, environmental protection, fire safety, quality management etc.) must be anchored in the body of rules. This can be done by defining specific rules or by references to the applicable documents.

Maintenance measures

Principles for the performance of maintenance measures

The "performance of maintenance measures" process sequence comprises the sub-processes of planning, ordering, performing, completion and confirmation/documentation.
The sub-processes must be comprehensively described in the body of rules. The description must provide at least the following particulars for all sub-processes:

- contents of the sub-process,
- sub-process sequence,
- acting and responsible persons,
- input variables of the sub-process,
- output variables of the sub-process.

The sub-process in which a maintenance measure is, and the person responsible for signing off that maintenance measure, must be identifiable at all times. The technical and/or organisational arrangements that are necessary for this must be written down.

Planning of maintenance measures

Planning means the preparation of the future performance of maintenance measures. This preparation relates to the resources of time, dates, personnel, material and infrastructure.
The planning must cover at least those measures identified in the maintenance programme as safety related and measures covered by a statutory duty to produce supporting documentation.
Beside the requirements referred to in Chapter 0, the body of rules must also contain particulars of the planning time and planning period and about how the planning is made known.

Ordering of maintenance measures

The principle of maintenance performance, "no work without an order", must be enshrined in the body of rules.
The contents of the order and the format (printed paper forms, computer forms etc.) must be defined.
The ordering of maintenance measures must be verifiable.

Performance of maintenance measures

The maintenance measures must be performed according to the manufacturer's technical instructions and the organisational rules of Maintenance.
Procedures for monitoring the maintenance measures must be defined.
The procedures and the acting and responsible persons for controlling the maintenance tasks (e.g. in the event of plan/actual deviations) must be defined.
Rules must be laid down for executing vehicle movements for maintenance purposes. The rules must relate to the items listed in Chapter 0.

Completion of maintenance measures

The completion of maintenance measures determined by reporting the technical completion of the ordered measure.
Additional special rules must be made for safety related activities (e.g. the 'two pairs of eyes' principle).
The contents of the completion report and the format (printed paper forms, computer forms etc.) must be defined.
The completion report must be verifiable.

Confirmation/documentation of maintenance measures

The confirmation of a maintenance measure is determined by the detailed description of the activity that has actually been carried out.
The data that are required for the confirmation of the completed measures must be defined.
The contents of the confirmation and the format (printed paper forms, computer forms etc.) must be defined.
The confirmation must be verifiable.

The lifecycle of replaced/repaired modules/smallest replaceable units must be clearly and verifiably documented together with a fault description, the cause of the fault and the repair carried out (if applicable, destruction of the faulty part and replacement by a new part).

Need for regulation Interface between train operations and maintenance

Principles of interfacing between train operations and maintenance

The operation of the MSB system is divided into train operations and maintenance.
There may be different areas of responsibility in the train operations and the maintenance of the MSB system.
The individual areas of responsibility must be clearly described and separated from each other in the body of rules.
In train operations and in maintenance, the areas of responsibility must be clearly allocated at all times.
Train operations and maintenance can take place both simultaneously and consecutively.
Where train operations and maintenance take place simultaneously, the body of rules must define criteria for the nature and scope of admissibility.
The framework conditions and prerequisites must be described and regulated.
Train operations and maintenance can take place simultaneously when reciprocal safety risks do not arise.
If train operations and maintenance take place consecutively the body of rules must contain arrangements for the transfer of responsibility.
In both instances, the body of rules must describe:

- the organisation of the interfaces,
- the technical systems involved in the interface,
- the content and limits of the activities,
- responsibility for initiating the measures,
- the boundaries of responsibility for the complete system or subsystems,
- the acting function owners,
- the communication and information flows,
- the necessary documentation,
- the issuing of orders and suspension / clearance procedures,
- the safety procedures,
- the hand-over and acceptance procedures,
- the performance of the maintenance measures.

The following communication rules in particular must be put in writing for train operations and for the interface between train operations and maintenance:

- information about vehicle movements,
- warning procedures,
- written instructions,
- information about temporary/local restrictions and special features,
- rules governing how the persons responsible interact,
- transmission of clearances and suspensions.

For fast moving and automatically operated vehicles, warning procedures are not suitable as organisational measures for the protection of personnel inside the guideway danger area, and must be excluded.

Clearance procedure

The body of rules must define responsibility for technical clearances of the system or - if intended - of system components, both for the organisation and for the management and work processes.
Technical and non technical journey preconditions must be met before train operations can commence.
These journey preconditions must be described in the body of rules according to /MbBO/ Section 22.
The various responsibilities for confirming compliance with the individual journey preconditions must also be defined in the body of rules.
Compliance with the journey precondition must be confirmed according to an appropriate clearance procedure.
The clearance procedure must also describe the associated verification processes.
Compliance with the technical journey preconditions must be established and confirmed by the area of responsibility of Maintenance. This confirmation certifies that the technical requirements (functional capability as per /DIN 31051/ and /DIN EN 13306/) for the use of the system (subsystem, complete system) are fulfilled.
The non technical journey preconditions must be confirmed in the area of responsibility of train operations.
If there is provision for clearing the parts of a subsystem, then the above mentioned descriptions must relate accordingly to the level of those parts of the subsystems. The parts must be defined.
The clearance procedures, clearance conditions and the withdrawal of clearances must be described in the body of rules. The description must cover at least the following points:

- the persons acting (person responsible, recipient etc.),
- the content of the message (technical, operational, subsystem etc.),
- an indication of the criteria against which checks are made,
- the possible restrictions/constraints,
- the format and/or manner (e.g. in writing, electronic),
- the documentation.

Hand-over and acceptance procedure

Responsibility for the handed over/accepted system/subsystem changes upon hand-over/acceptance. If there is provision for handing over/accepting the parts of a subsystem, then the above mentioned descriptions must relate accordingly to the level of those parts of the subsystems. The parts must be defined.
The technical and organisational procedures of the hand-over and acceptance must be described in the body of rules. This description must at least contain:

- the persons acting in the hand-over/acceptance (person responsible, recipient etc.),
- the content of the hand-over/acceptance report (technical, operational, subsystem etc.),
- the basis for the hand-over/acceptance (the criteria it is checked against),
- the format and/or manner of the hand-over/acceptance (e.g. in writing, electronic),
- the documentation of the hand-over/acceptance.

For mobile systems (MSB vehicles, special vehicles etc.) the local hand-over/acceptance point must be indicated and any particular features of the process must be described.

Train operations support by Maintenance

Support for the train operations personnel by the maintenance personnel may be necessary depending on the technical equipment of the MSB system.
If this support is required, it must be described in the body of rules. The scope of the support must include at least the following points:

- monitoring the technical operating status,
- evaluating the technical operating status,
- documenting particular aspects during the train operations,
- support and assistance when malfunctions occur.

The necessary reporting and communication paths and the interaction between the function owners of train operations and maintenance must be described.
If necessary, hierarchically graded courses of action must be described depending on the potential impacts of malfunctions on the safety of the MSB system.

High-speed Maglev System Design Principles

Complete System, Annex 5 Sound

Distribution

- This document was released for publication by the Complete System Technical Committee.

Amendment Summary

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General

Document purpose and scope

The present document defines the procedures for the determination by measurement of the $DF_{z,me}$ and $D_{Fz,ae}$ sound level differences for new vehicles and D_{Fb} for new guideways as the basis for certification within the meaning of the footnote provision of the Maglev Noise Abatement Order [Magnetschwebebahn-Lärmschutzverordnung /MSB-LSV/]. The setting of the sound level differences listed in the Maglev Noise Abatement Order may need additional certification with regard to permanence.
Each of the tables listed in the Maglev Noise Abatement Order for "$_{DFz,me}$ and $D_{Fz,ae}$ sound level differences due to different vehicle types" (/MSB-LSV/, Table 3) and "D_{Fb} sound level differences due to different guideway types" (/MSB-LSV/, Table 4) contains footnotes instructing that appropriate correction values, i.e. other values for $D_{Fz,me}$, $D_{Fz,ae}$ and $D_{Fb,}$ be used for other noise emission proven in the long term.
In defining the certification procedures for the above sound level differences, use is essentially made of the procedure in the "Project-accompanying Sound 03/Sound -Transrapid Committee", which worked on the text of the current /MSB-LSV/. The present document contains a detailed description of all the necessary measurements and evaluation methods on the basis of which determination of the $DF_{z,me}$, $D_{Fz,ae}$ and D_{Fb} sound level differences must be carried out. The present document shall be used as the base document for the certification of vehicle and guideway subsystems.
The present Design Principles apply to a high-speed maglev system pursuant to the General Maglev Act [Allgemeines Magnetschwebebahngesetz /AMbG/].

High-speed Maglev System Implementation Bases

This document forms part of a set of documentation for high-speed maglev systems comprising several Implementation Bases. The document tree is shown in Figure 1 /MSB AGGESAMTSYS/.
The overriding Complete System Design Principles and its Annexes apply uniformly to the full set of documentation:

- High-speed Maglev System Design Principles Complete System, doc. no.: 50630, /MSB AG-GESAMTSYS/,
  with annexes:
  - Annex 1: Abbreviations and definitions, doc. no.: 67536, /MSB AG-ABK&DEF/
  - Annex 2: Acts, Orders, Standards and Directives, doc. no.: 67539, /MSB AG-NORM&RILI/
  - Annex 3: Environment, doc. no.: 67285, /MSB AG-ENVIRONMENT/

- Annex 4: Rules for operation and maintenance, doc. no.: 69061, /MSB AG-BTR/
- Annex 5: Sound, doc. no.: 72963, /MSB AG-SCHALL/, (present document)

Abbreviations, definitions and symbols

The abbreviations and definitions given in /MSB AG-ABK&DEF/ apply.
The abbreviations and definitions below represent abbreviations and definitions specific to Design Principles Sound:

Symbol	Unit	Meaning
• C	dB(A)	Constants in Equation (6)
C_{test}	dB(A)	Allowance for sound propagation influences pursuant to /MSB-LSV/ at the measuring point of the guideway test specimen
C_{ref}	dB(A)	Allowance for sound propagation influences pursuant to /MSB-LSV/ at the measuring point of the reference concrete guideway
$D_{BM,k}$	dB(A)	Sound level difference due to ground and meteorology damping
D_{Fb}	dB(A)	Sound level difference due to different guideway types
$D_{Fb,test}$	dB(A)	D_{Fb} value of guideway test specimen
$D_{Fb,ref}$	dB(A)	D_{Fb} value of reference concrete guideway
D_{Fz}	dB(A)	Sound level differences due to different vehicle types
$D_{Fz,me}$	dB(A)	Sound level difference due to different vehicle types, mechanical proportion
$D_{Fz,ae}$	dB(A)	Sound level difference due to different vehicle types, aerodynamic proportion
D_{FzH}	dB(A)	Auxiliary variable in the determination of D_{Fb}
$D_{FzH,me}$	dB(A)	Auxiliary variable in the determination of D_{Fb}, mechanical proportion
$D_{FzH,ae}$	dB(A)	Auxiliary variable in the determination of D_{Fb}, aerodynamic proportion
$D_{L,k}$	dB(A)	Sound level difference due to air absorption
$D_{s,k}$	dB(A)	Sound level difference due to distance
L_A	dB(A)	A- and FAST evaluated sound pressure level
$L_{Am,E}$	dB(A)	Event level by averaging over event time T_E
$L_{Am,E,evl}$	dB(A)	Event level by averaging over event time $T_{E,evl}$
$L_{Am,E,r}$	dB(A)	Event level by averaging over event time $T_{E,r}$
$L_{Am,1h}$	dB(A)	Hourly averaging level for one vehicle pass per hour
$L_{Am,1h,evl}$	dB(A)	Hourly averaging level for one vehicle pass per hour (array method)
$L_{Am,1h,corr}$	dB(A)	• Hourly averaging level corrected for number of sections (Equation (2))
$L_{Am,1h,r}$	dB(A)	Hourly averaging level for one vehicle pass per hour (single microphone method at reduced measurement distance)
$L_{E,me}$	dB(A)	Mechanical proportion of emission level pursuant to /MSB-LSV/

Symbol	Unit	Meaning
$L_{E,ae}$	dB(A)	Aerodynamic proportion of emission level pursuant to /MSB-LSV/
L_r	dB(A)	Total rating sound level pursuant to /MSB-LSV/
$\Delta L_{Am,1h}$	dB(A)	Difference between the hourly averaging level (Equation (5)) taken at the measuring point of the guideway test specimen and at the measuring point of the reference concrete guideway
ΔL_{Diff}	dB(A)	Difference between total rating sound level and corrected hourly averaging level (Equation (4))
ΔL_k	dB(A)	Sum of sound level differences in the part section method according to /MSB-LSV/
ΔL_{Sec}	dB(A)	Sound level difference due to number of vehicle sections
a, b, c	-	Coefficients of a second grade equalising polynomial (Equation (3))
k	-	Running index in the part section method according to /MSB-LSV/
l	m	Length of vehicle from nose tip to rear end
l_k	m	Part section length
p	Pa	Sound pressure
R	m	Radius of route
S	dB(A)	Correction level to allow for special features of lines
t	s	Time
t_1	s	Time at start of averaging time T_E
$t_{1,evl}$	s	Time at start of averaging time $T_{E,evl}$ (array method)
$t_{1,r}$	s	Time at start of averaging time $T_{E,r}$ (single microphone method at reduced measuring distance)
t_2	s	Time at end of averaging time T_E
$t_{2,evl}$	s	Time at end of averaging time $T_{E,evl}$ (array method)
$t_{2,r}$	s	Time at end of averaging time $T_{E,r}$ (single microphone method at reduced measuring distance)
T_E	s	Averaging time for the event level
$T_{E,evl}$	s	Averaging time for the event level (array method)
$T_{E,r}$	s	Averaging time for the event level (single microphone method at reduced measuring distance)
T_M	s	Measuring time
v	km/h	Vehicle velocity

Symbol	Unit	Meaning
v_0	km/h	Reference velocity (v_0 = 100 km/h)

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Term/ Abbreviation	Meaning
Emission location	Top guideway edge at guideway support centre in the measurement cross-section according to /MSB-LSV/
Immission locati-on	Location of a microphone or microphone array
Short laid length	Guideway test specimen of laid length > 24 m and < 250 m
Maximum sound level	Maximum sound level in time behaviour $L_A(t)$ during passage of the vehicle
Measuring point	Immediate surroundings within range of emission and immission location
Measurement cross-section	Plane through immission location with guideway as the normal
Section	With a vehicle unit assumed at approx. 25 m in length
TGE	Top guideway edge
TETF	Transrapid Emsland Test Facility

Acts, Orders, Standards and Directives

The normative documents listed in /MSB AG-NORM&RILI/ contain stipulations which become part of the High-speed Maglev System Design Principles by virtue of reference in the High-speed Maglev System Implementation Bases. When normative documents in /MSB AG-NORM&RILI/ are dated, later amendments or revisions of these publications do not apply. When references are undated, the most recent issue of the normative document referred to is applicable.
The issue date of the Standards and Directives to be taken into account in a maglev project shall be fixed with binding force for that specific project.
The abbreviations and definitions below represent specific abbreviations and definitions of Design Principles Sound:
In this document particular reference is made to the Orders and Standards listed below.

Abbreviation	Orders and Standards
/MbBO/	High-speed Maglev System – Construction and Operating Regulations [Magnetschwebebahn – Bau- und Betriebsordnung – MbBO] (Article 1 of the Maglev Construction and Operating Regulations)
/MSB-LSV/	Maglev System – Noise Abatement Order [Magnetschwebebahn – Lärmschutzverordnung]

	(Article 2 of the Maglev Construction and Operating Regulations)
• /DIN EN ISO 3095/	Acoustics – Measurement of noise emitted by railbound vehicles

Identification and mandatory requirements

In compiling the present document, the regulations conforming to /DIN 820/ were applied by analogy.
In the following chapters of this document

- requirements are denoted by regular font
- explanatory notes, guideline values and examples are denoted by *italics*.

Compiling a test specification

The contractor selected to take measurements and evaluate data for determination of the DF_z sound level differences of a new vehicle and the DF_b sound level difference of a guideway test specimen shall submit a test specification to the client. Before measurements are taken, this shall be discussed and agreed with the competent supervisory and licensing authority or with an expert appointed by same. The test specification shall contain the following essential points:

- a statement to the effect that the measurement conditions at the planned measuring points in the area of the reference concrete guideway and of the guideway test specimen conform to the data specified in Chapter 0, particularly as regards the position of the immission locations,

- a statement to the effect that the acoustic condition of the vehicle to be used when taking the measurements meets the requirements stipulated in Chapter 0,

- the submission of a flow chart guaranteeing the number and velocities of the vehicle passes for each measuring point required according to Chapter 0.

- a list of the measurement and data recording equipment anticipated for use, and

- proof of familiarity with the methods of data evaluation and determination of DF_z and D_{Fb} sound level differences described in Chapter 0 and particularly in Chapter 0.

NB: The intended contractor shall in particular describe the details of his knowledge of the measurement and evaluation methods used (see Chapters 0 and 0) to the Supervisory and Licensing Authority or the appointed expert, a prerequisite being that the contractor has had sufficient practical experience of these methods of measurement.

Taking measurements

In the measurements described in this chapter to determine DF_z sound level differences, i.e. of $D_{Fz,me}$ and $D_{Fz,ae}$, and of DF_b sound level differences, there shall be compliance with the general terms of reference in Chapter 0. The following two chapters give further measurement conditions relating solely to the determination of DF_z sound level differences (Chapter 0) and the determination of the DF_b sound level difference (Chapter 0). Here the D_{Fb} value of a guideway test specimen shall in principle be determined at only one measuring point at which the line comprises a “long” extension of the test specimen guideway type (see Chapter 0). Should this exceptionally be impossible since, as a prototype carrier, the guideway test specimen only has a “short” laid length of typically between 25 and 60 m, D_{Fb} shall be determined by means of a single microphone method at a reduced measuring distance and by means of a method using a microphone array. The special measurement conditions in this regard are described in Chapter 0. Chapter 0 further gives the points required for all the measurement methods within the measurement documentation framework.

General measurement terms of reference

When taking measurements on vehicles and guideways the following requirements, based on /DIN EN ISO 3095/, shall be met for proof of sound emission. The general terms of reference for measurements comprise requirements for measurement and immission location, the vehicles and their passes, the velocity classification and number of same, the weather conditions, and data relating to measurement quantity and measuring equipment.

Requirements for measurement and immission locations

The terrain at the measuring location shall be open and level, at least on the side of the route on which sound immission is measured. As little reflection as possible shall be ensured on the away-facing side. There should be arable land and/or meadows in the area between guideway and immission location; low growth is permissible. Sound propagation, interfering obstacles and unacceptable reflecting surfaces are not permitted in the surroundings of the immission location on the route side of the measurement for up to three times the measuring distance.
The measuring locations used shall only be sections in which the route runs straight ($R > 10.000$ m). Guideway banking of $\leq 2°$ is permitted. In the area of the measuring location the guideway must be constructed from the identical guideway type over a “long” extension. A “long” extension means that the same guideway type is present for at least 125 m on either side of the measurement cross-section.
The measuring location shall be selected so that the background noise can be ignored during all vehicle passes. For this the A- and FAST-rated sound pressure level caused by interfering sound sources shall be at least 15 dB(A) below the maximum sound level measured during a pass and also the third-octave levels relevant to the maximum level shall be at least 15 dB(A) above those of the background noise. Should it be impossible to comply with the requisite sound level difference of 15 dB(A) due to an unforeseen sound event (e.g. overflying aircraft) during an individual pass, the measurement in question shall be discarded and the pass repeated as a matter of principle.

Where the guideway to be tested is of the "long" extension type, the measurement cross-section shall without exception be located centrally between two adjacent supports. The measurement distance between guideway support centre and immission location projected vertically to the ground in the measurement cross-section shall be 25 m.

The height of the immission location shall be:

- 3.5 m above ground at TGE heights of up to 7.0 m above ground,
- 3.5 m below TGE at TGE heights over 7.0 m above ground.

Requirements for vehicles and their passes

When taking measurements to determine the D_{Fz} sound level differences, the vehicle shall be in the acoustic condition corresponding to the operational application, or for which the DF_z sound level differences pursuant to /MSB-LSV/ are to be determined. As part of the determination of the D_{Fb} sound level difference the vehicle may also have a different acoustic condition during measurement, as prior to determining D_{Fb}, the D_{FzH} auxiliary variables (see Chapter 0) of the current vehicle must he measured and then used. The vehicle length and number of sections during the measurements described here are optional.

NB: Corrections in respect of number of sections are allowed for in the D_{Fz} determination in Chapter 0.

In all the measurements taken here the requirement is for passes at a constant velocity, in each case in the range of 125 m plus half the vehicle length on either side of the measurement cross-section. As previous experience has shown that the direction of travel, the section actually in front, the facing side of the vehicle and the loading condition of the vehicle have no influence on the sound pressure level measured at the immission location, runs in different directions and at different loadings may be used when determining D_{Fz} and D_{Fb}. However, a record shall be made of the direction of travel, the forward section, the facing side of the vehicle and the loading.

With new vehicles a test shall be conducted (e.g. using design documentation and/or measurements) to determine whether their sound emission is the same on both sides of the vehicle. Where emissions differ according to vehicle side, the D_{Fz} values of the vehicle shall be determined for the side of the vehicle with the higher sound emission. When emissions differ according to vehicle side, the auxiliary variable D_{FzH} pursuant to Chapter 0 and the D_{Fb} value of the guideway shall always be determined on the same side of the vehicle.

Velocity rating and number of passes

Each of the velocity ranges required to determine DF_z and D_{Fb} sound level differences is given in Chapters 0 and 0. In every case, however, pass velocities shall be graduated in steps of 10 km/h. At least two runs shall be measured for each velocity step. At least three measurements shall be taken at maximum velocity.

Weather requirements

Wind speeds for immission location measurements shall not exceed 5 m/s. There shall be no snow on the ground within the measuring point area. No measurements shall be taken when it is raining.

Measurement variable and measuring equipment

The measurement variable is the sound pressure p at the immission location. In each case the measurement variable shall be recorded either as the time curve of the sound pressure p(t) or as the time curve of the A- and FAST-rated sound pressure level $L_A(t)$ over a sufficient measurement period T_M. Measurement commences when the noise of passage starts to be clearly distinguishable from the background noise, and ends when the noise of passage is once again masked by the background noise. The p(t) and $L_A(t)$ time curves obtained for the individual vehicle passes shall be evaluated as specified in Chapter 0.
The requirements for measuring equipment and the calibration thereof shall be those specified in /DIN EN ISO 3095/. The entire equipment chain and the sound level meter shall be calibrated on each measuring day before and after measurement. If the equipment chain is modified, fresh calibrations shall be carried out before and after the modification. The calibration signals shall be stored and the calibration process logged.

Additional measurement conditions for the determination of D_{Fz}

When taking measurements to determine the D_{Fz} sound level differences, the following measurement conditions shall be met in addition to the general requirements for measurements stipulated in Chapter 0:

- The vehicle passes shall be measured at a measuring location at which the route comprises the reference concrete guideway of construction phase 1 or 2 of the TETF, i.e. constructed prior to 1989. A D_{Fb} value of 0 dB(A) is set for this type of guideway in /MSB-LSV/.
- Passes in the velocity range from 130 to at least 400 km/h shall be measured, i.e. subject to the criteria of Chapter 0 the number of runs shall be at least 57.

Additional measurement conditions for the determination of D_{Fb}

The following measurement conditions shall be met in addition to the general requirements for measurements in accordance with Chapter 0 when taking measurements to determine the D_{Fb} sound level difference:

- It is permissible to give the D_{Fb} value of a guideway type for limited velocity ranges, namely up to and including 300 km/h, from > 300 km/h up to and including 400 km/h and from > 400 km/h up to the maximum authorised guideway velocity. Passes on the guideway test specimen may therefore only be required in commensurately restricted velocity ranges. Hence from case to case the velocity range in the measurements for the determination of D_{Fb} may extend from 130 to 300 km/h, from 130 to 400 km/h or up to the maximum authorised velocity for the guideway. The relevant minimum numbers of passes are obtained according to Chapter 0.

- Determination of the D_{Fb} value assumes knowledge of the D_{FzH}, i.e. $D_{FzH,me}$ and $D_{FzH,ae}$ auxiliary variables of the vehicle which carried out the passes on the guideway test specimen. The D_{FzH} values may actually be calculated from this vehicle's existing measurement data taken during the measurement of passes on the reference concrete guideway, but they should preferably be determined by a new measurement taken just beforehand with this vehicle on the reference concrete guideway (cf. Chapter 0). If relevant modifications were carried out on the vehicle since the last sound emission measurement, the D_{FzH} auxiliary variables shall be re-determined. When determining D_{Fb}, D_{FzH} values shall refer to the velocity range of up to at least 400 km/h, irrespective of any restricted velocity range.

Additional measurement conditions when determining D_{Fb} on short laid lengths of guideway test specimen

With a guideway test specimen of "short" laid length, the D_{Fb} value shall be determined by means of the single microphone method at a reduced measuring distance and by means of the array method, the stipulation being to take these measurements by both methods simultaneously.
There should be a slight deviation from the requirement that the measurement cross-section be located exactly centrally between two adjacent supports if there is a reflecting object centrally between the supports.

Measurement method with single microphones at a reduced measuring distance

When taking measurements with a single microphone on a "short" laid length of guideway test specimen, the measuring distance shall be reduced in order to minimise the influence of adjacent guideways of a different type; the measuring distance between the centre of the guideway support and immission location in the measurement cross-section projected vertically to the ground shall be 12.5 m if the laid length of the test specimen is ≥ 49 m and < 250 m, and 6.5 m if the test specimen length is > 24 m and < 49 m. Furthermore, allowance shall be made for the vertical directional characteristic of guideway and vehicle by means of simultaneous measurement at the required distance at two immission locations of different height, so that two sound pressure signals p(t) and two sound level patterns $L_A(t)$ must be recorded. The heights of the immission locations shall be fixed as follows:

- the top immission location is at TGE level,

- the bottom immission location is 3.5 m below TGE, but at least 1.0 m above ground.

Due to the “short” laid length of the guideway test specimen, the minimum range of the vehicle’s constant pass velocity is reduced to the actual length of the test specimen plus half the vehicle length before and after the test specimen.
As the determination of the D_{Fb} value in Chapter 0 is based on a comparative measurement at the reference concrete guideway, the measurements at the most recent measuring location must be taken at the same reduced measuring distance as at the guideway test specimen, at two immission heights corresponding to the TGE height of the reference concrete guideway.

NB: During passage of the vehicle, particularly at high velocities, instantaneous pressure fluctuations occur at the nose and rear end area of the vehicle; these may produce signal saturation at immission locations 6.5 m away, so for this measuring distance it is recommended that if necessary a high-pass filter with a limit frequency of approx. 20 Hz be inserted at the signal amplification input.

Measurement method with a microphone array

To determine the D_{Fb} value of a guideway test specimen with a “short” laid length, a measurement method with a microphone array is specified in addition to the method described in Chapter 0. The array method serves to measure the D_{Fb} value of the immission location at a distance of 25 m from the guideway support centre, i.e. at

- a height of 3.5 m above ground for TGE levels of up to 7.0 m above ground and
- a height of 3.5 m below TGE for TGE levels above 7.0 m above ground.

During measurement a linear, hence one-dimensional, array in horizontal and parallel orientation to the guideway is used, the central microphone of which is located in the measurement cross-section. While the sound emissions of adjacent guideways of different design are cut out by the strong horizontal directivity of this array, such an array has the characteristics of a single microphone in the vertical direction, i.e. influences on the immission level are correctly reproduced during measurement due to the vertical directional characteristic of guideway and vehicle as well as due to ground reflection.
Lateral, and hence unwanted, portions of sound are sufficiently reduced by the array on reception if, when straight focussing centrally between two supports, the array resolution and the width of the array main lobe in the object plane is a maximum of 5 m at a distance of 25 m. Furthermore, with such a resolution for the suppression of the emissions of adjacent carriers, a distance between the array main lobe and the secondary lobes, i.e. an array dynamic of at least 10 dB is required, as is obtained by a linear array even without shading.

As the resolution of an array depends greatly on the frequency, and the main lobe width when straight focussing in the whole frequency range evaluated should deviate by no more than ±20 % relative to a mean value, the array configuration used here is a “box array”, i.e. an array in which there are a number of sub-arrays. Each sub-array is designed for a definite frequency range, each of which has a mean resolution of 4 m in the object plane at a distance of 25 m.

Here the use of the array described below, the “WH10x array”, is mandatory as the implementation of an array satisfying the above requirements. By multiple use its total 27 microphones are split into groups for 10 sub-arrays. Each sub-array comprises seven microphones, only the sub-array with the smallest microphone distance of 4 cm comprises nine microphones. Table 3 lists the microphone positions in the WH10x-Array, with microphone number 14 representing the array centre.

Microphone number	Position [m]	Microphone number	Position [m]
1	3.52	15	-0.04
2	2.56	16	-0.08
3	1.92	17	-0.12
4	1.28	18	-0.16
5	0.96	19	-0.24
6	0.64	20	-0.32
7	0.48	21	-0.48
8	0.32	22	-0.64
9	0.24	23	-0.96
10	0.16	24	-1.28
11	0.12	25	-1.92
12	0.08	26	-2.56
13	0.04	27	-3.52
14	0	-	-

- Table 0-1: Microphone positions in the WH10x array

As in measurements with single microphones, the requirements formulated in Chapter 0 apply to the array microphones and their calibration. Because of the limited frequency range in array measurements (125 to 8000 Hz in the WH10x array, see Chapter 0), the criteria in respect of constancy and consistency of the amplitude and phase characteristics of the individual array microphones must only be met in this limited frequency range.

Owing to the simultaneous signal detection of the 27 microphones in the WH10x array and at least one further time signal which, due to a trigger mechanism (e.g. by means of a light barrier), receives information on the vehicle position relative to the time signals of the array microphones and on vehicle velocity, at least a 28-channel, i.e. usually a 32-channel data acquisition system shall be used when taking measurements. At a minimum sampling frequency of 25 kHz per channel, required because of array technology, the storage capacity of the data acquisition systems shall be designed to allow the continuous recording of signals over a time span of up to 15 s. The deep pass filters required for each channel in A/D conversion shall be designed at least as 2nd order filters with a limit frequency corresponding to the sampling frequency selected.

The data acquisition system must allow the recorded signals to be checked immediately after each measurement, i.e. vehicle pass (monitoring saturation, interference, adequate vehicle pass lead time and wake time, etc.), so that the doubtful pass can be repeated if necessary.

The data loss of at most one channel or microphone during recording can be tolerated, as long as it is not microphone number 14 or the channel with the trigger signal.

As in the measurement procedure in Chapter 0, the array measurement shall also be carried out both at the measuring location with the guideway test specimen and at the measuring location with the reference concrete guideway, as the comparative data are needed for the determination of D_{Fb} according to Chapter 0.

Documentation of measurement procedure

The measurement procedure shall be logged in the measurement report. This shall describe at least the following:

- the purpose of the measurements,
- the measuring location with its acoustically relevant boundary conditions (on both sides of the route),
- the guideway type and its TGE height above ground in the measurement cross-section as well as the extension of this guideway type on either side of the measurement cross-section,
- the position of the immission location(s) with regard to distance from the guideway support centre as well as the height(s) of the immission location(s) above ground,
- the vehicle, its number of sections and length, its loading condition and, if necessary, data on acoustically-relevant modifications,
- the chronological sequence of measurements and passes, giving the vehicle velocity, direction of travel, the lead section, the facing side of the vehicle, the loading and any problems which may have occurred,
- the meteorological data during individual vehicle passes (temperature, air pressure, atmospheric humidity, wind speed and direction), and
- the measuring equipment used, i.e. the equipment chain from microphones to data recording equipment or sound level meters, giving details of calibration and calibration times.

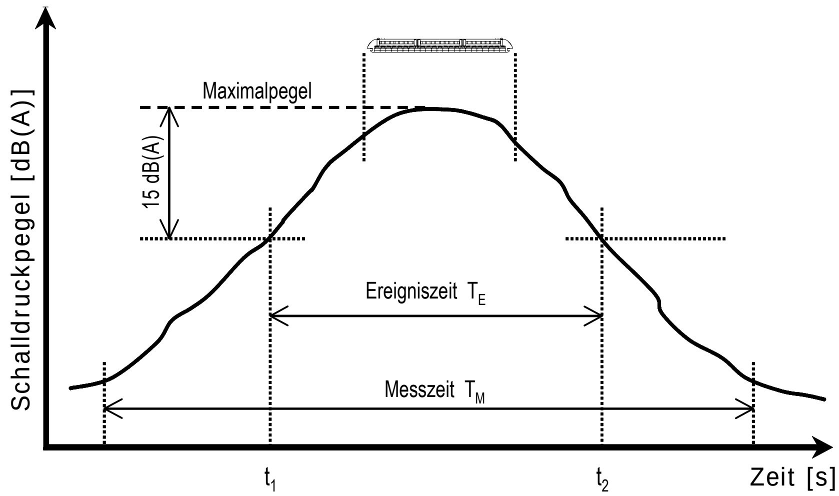
Further documentation requirements relating to data evaluation are given in Chapter 0 and to the determination of D_{Fz} and D_{Fb} in Chapter 0.

Evaluation of measurement data

After taking the measurements in accordance with Chapter 0, analog or digitally stored time signals of the sound pressure p(t) or time curves of the sound pressure level $L_A(t)$ over a sufficient measuring time T_M in each case (see Chapter 0) are available for the determination of both the D_{Fz} sound level differences and the D_{Fb} sound level difference for specific numbers of vehicle passes in each case. The evaluation of these measurement data is described in the present chapter.

Calculation of hourly averaging level

The hourly averaging level $L_{Am,1h}$ shall be calculated for each pass measured and for each immission location. First the event level $L_{Am,E}$ is calculated by averaging $L_A(t)$ over the averaging time T_E. Here $T_E = t_2 - t_1$ is the "event time", which begins relative to a vehicle pass at time t_1, when the level L_A during the vehicle's approach is for the first time 15 dB(A) below the maximum level during the vehicle's passage, and ends at time t_2, when after the vehicle's passage the level L_A has for the last time faded by 15 dB(A) relative to the maximum level. Figure 40 shows the measuring time T_M and the event time T_E with times t_1 and t_2 using the example of a typical sound level curve $L_A(t)$ during the passage of a vehicle.



- Figure 40: Explanation of measuring time T_M and event time T_E

- Schalldruckpegel = sound pressure level; Maximalpegel = maximum level; Ereigniszeit = event time; Messzeit = measuring time; Zeit = time

The hourly averaging level follows from the event level $L_{Am,E}$ by adding the term $10lg(T_E/3600\ s)$, the result being mathematically rounded to one decimal place. The hourly averaging levels $L_{Am,1h}$ thus calculated for one pass per hour in each case constitute the basis for determination of the D_{Fz} and D_{Fb} sound level differences in Chapter 0.

Additional terms of reference for evaluations with short laid lengths of guideway test specimen

Separate terms of reference shall be observed with regard to evaluation of the sound pressure signals p(t) or sound level patterns $L_A(t)$ recorded by the measurement method using single microphones at a reduced measuring distance according to Chapter 0 and by the array method according to Chapter 0, as described in the following two chapters.

Data evaluation in the measuring method with single microphones at a reduced measuring distance

In the present measuring method the hourly averaging level $L_{Am,1h}$ is calculated in principle as described in Chapter 0, but a reduced event time $T_{E,r} = t_{2,r} - t_{1,r}$ is introduced. Here $t_{1,r}$ is the time at which the vehicle nose reaches the guideway test specimen, and $t_{2,r}$ the time at which the rear end of the vehicle leaves the guideway test specimen. This definition of times $t_{1,r}$ and $t_{2,r}$ ensures that during the event time at least one part of the vehicle is travelling over the guideway test specimen. By averaging over the time $T_{E,r}$, first the event level $L_{Am,E,r}$ is calculated, then the hourly averaging level $L_{Am,1h,r}$ by adding the term $10lg(T_{E,r}/3600\ s)$ and mathematical rounding to one decimal place.
The hourly averaging level $L_{Am,1h,r}$ for the top and bottom immission location shall be given for each vehicle pass. For reasons of comparability, the hourly averaging levels at the measuring location shall be determined with the reference concrete guideway under the same geometric conditions as with measurement at the guideway test specimen, i.e. the extension of the reference concrete guideway on either side of the measurement cross-section shall be assumed to be identical with the extension of the guideway test specimen on either side of the measurement cross-section. From this it follows that the difference $t_{2,r} - t_{1,r}$ and therefore the event time $T_{E,r}$ are the same at both measuring locations. The hourly averaging levels $L_{Am,1h,r}$ thus calculated at the reference concrete guideway and the guideway test specimen are the input variables for the determination of D_{Fb} in Chapters 0 and 0.

Data evaluation in the array measurement method

The recorded signals of the 27 microphones in the WH10x array shall be evaluated separately without using shading factors by means of the “delay-and-sum beam forming” algorithm (see I.E. Johnson and D. E. Dudgeon, Array Signal Processing: Concepts and Techniques, P T R Prentice Hall, 1993) in the time range for each of the 10 sub-arrays. Table 0-1 shows the assignment of individual microphones to the sub-arrays. When calculating the composite array signals, the requisite sampled values of the microphone signals shall be generated by linear interpolation of the real time signal sample values. The results of beam forming in the individual sub-arrays apply to the frequency ranges listed in Table 0-1. The WH10x array consequently accounts for the total frequency range of 125 to 8000 Hz sufficient for the determination of D_{Fb} .

Sub-array	Contains microphones numbered	Frequency range [Hz]
WH128	1, 2, 4, 14, 24, 26, 27	125 - 250
WH096	2, 3, 5, 14, 23, 25, 26	250 - 355
WH064	3, 4, 6, 14, 22, 24, 25	355 - 500
WH048	4, 5, 7, 14, 21, 23, 24	500 - 710
WH032	5, 6, 8, 14, 20, 22, 23	710 - 1000
WH024	6, 7, 9, 14, 19, 21, 22	1000 - 1410
WH016	7, 8, 10, 14, 18, 20, 21	1410 - 2000
WH012	8, 9, 11, 14, 17, 19, 20	2000 - 2820
WH008	9, 10, 12, 14, 16, 18, 19	2820 - 4000
WH004	10, 11, 12, 13, 14, 15, 16, 17, 18	4000 - 8000

- Table 0-1: Sub-arrays of the WH10x array with associated microphones and frequency ranges

The evaluation mode chosen during beam forming shall be a fixed focus with vertical alignment to the line of microphones. Here – in accordance with the positioning of the array during measurements – the focal point shall be 25 m from the array. Data evaluation shall be carried out at each sub-array for measuring and focal points at 1.0 m intervals along the passing vehicle, i.e. at time intervals corresponding to the progression of the vehicle by 1.0 m at the current vehicle velocity. At each of these measuring points the composite array signal shall again be averaged over a time which equals the progression of the vehicle by 5.0 m.

Data evaluation shall commence approx. 100 m in front of the vehicle nose and finish approx. 100 m behind the end of the vehicle. The trigger signal recorded at the same time serves to link the vehicle position with the sound pressure signals.

The sound level patterns thus calculated and also A-rated for each sub-array in the part frequency ranges of Table 0-1 shall then be energetically totalled, thus giving the time curve of the sound pressure level in the 125 to 8000 Hz frequency range measured by the WH10x array for the relevant vehicle pass. In the array method the determination of the associated event level is linked to the “extended vehicle length” “(evl)”, i.e. with the length of the vehicle extended by 24.0 m: the event time $T_{E,evl}$ commences at time $t_{1,evl}$, at which the nose of the vehicle is still 12.0 m in front of the measurement cross-section, and finishes at time $t_{2,evl}$, at which, once the vehicle has passed, its rear end is 12.0 m away from the measurement cross-section. By averaging over the event time $T_{E,evl} = t_{2,evl} - t_{1,evl}$ first the event level $L_{Am,E,evl}$, then the hourly averaging level $L_{Am,1h,evl}$ is calculated by adding $10lg(T_{E,evl} /3600\ s)$ and mathematical rounding to one decimal place.
The method of data evaluation thus described shall be applied equally to the measurements at the vehicle test specimen as well as at the reference concrete guideway. The relevant hourly averaging levels $L_{Am,1h,evl}$ are the input variables for the determination of D_{Fb} in Chapters 0 and 0.

Documentation for measurement data evaluation

The results of the measurement data evaluation carried out in accordance with Chapters 0 and 0 shall be fully documented in tabular form in the measurement report, i.e. for each measured pass and for each immission location the vehicle velocity, the event time T_E (and $T_{E,r}$ or $T_{E,evl}$), the event level $L_{Am,E}$ (and $L_{Am,E,r}$ or $L_{Am,E,evl}$) and the hourly averaging level $L_{Am,1h}$ (and $L_{Am,1h,r}$ or $L_{Am,1h,evl}$) shall be given, the vehicle velocity being the velocity notified for the measuring point by the operator of the maglev section. Results of passes in which the calculated levels appear doubtful owing to an obvious measuring error shall still be listed in the table, but shall be highlighted. However they shall not be taken into account when determining D_{Fz} and. D_{Fb} in Chapter 0. The causes of the measuring error shall be described.

In addition to the above documentation of the measurement results in tabular form, the curves $L_A(t)$ for all the passes and for each immission location shall be represented in graph form over the measuring period T_M. In this sound level recording the times t_1 and $t_{1,r}$, t_2 and $t_{2,r}$ shall be identified for calculation of the event level. When measurements are made with the microphone array, the time curves of the composite array signal calculated according to Chapter 0 with the times $t_{1,evl}$ and $t_{2,evl}$ shall be logged as sound level recording $L_A(t)$. The representation of the most recent sound level recording may be restricted to the area approx. 100 m in front of the nose of the vehicle to approx. 100 m behind the end of the vehicle instead of the measuring time T_M.

Furthermore, sound pressure third-octave spectra shall be compiled in absolute levels from the 25 Hz third-octave centre frequency to the 10 kHz third-octave centre frequency – but in the array method only for the third octaves from 160 to 6300 Hz. For this the evaluation of each run at 150, 200, 250, 300 and, depending upon the requisite velocity range, 350 and 400 km/h is sufficient. For the third-octave spectra the time signal p(t) – in the array method the composite signal of the time signals p(t) of the array microphones – shall be evaluated over the event time of the relevant pass. The representation of unrated or A-rated third-octave spectra is permissible; the corresponding choice shall be made clear in the ordinate labelling. Each third-octave spectrum must, moreover, give the “linear”, i.e. unrated and A-rated total sound level as the energetic sum of the aforementioned third-octave levels.

Determination of D_{Fz} and D_{Fb} sound level differences

The $L_{Am,1h}$ hourly averaging levels for the individual vehicle passes calculated according to Chapter 0 are the basis for determining D_{Fz} sound level differences, i.e. $D_{Fz,me}$ and $D_{Fz,ae}$ described below, as well as the D_{Fb} sound level difference.

Determination of $D_{Fz,me}$ and $D_{Fz,ae}$ values

To determine $D_{Fz,me}$ and $D_{Fz,ae}$ values only the measurement results for the passes on the reference concrete guideway according to Chapter 0 shall be used under the measurement conditions also given in this chapter. As, according to Chapter 0, the length of the vehicle and its number of sections is optional in measurements to determine D_{Fz}, with reference to the measured hourly averaging levels $L_{Am,1h}$ this means a necessary correction by values ΔL_{Sec}, which depend on the number of sections and the vehicle velocity and are given below for 2- to 10-section vehicles.

NB: The compilation of /MSB-LSV/ was based on measured immission levels from passes of the TR 07/1 comprising two sections. Values for multiple-section vehicles were predicted with the aid of model calculations based on a sound source location on the TR 07/1. These predicted values were used as substitutes for the missing measurements for multi-section vehicles and used to compile the formulae (2.1) and (2.2) in /MSB-LSV/ for taking the vehicle length into consideration. Within this method the immission levels during the measurement and model calculations were below the arithmetic values then laid down in /MSB-LSV/ (by up to 1.2 dB(A) for a 2-section vehicle and by up to 2.1 dB(A) for a 4-section vehicle). These differences were accepted as a conservative assessment and are reflected in the ΔL_{Sec} *correction values.*

The ΔL_{Sec} values for correction of the measured $L_{Am,1h}$ hourly averaging levels are given by Equations (1a-1i), and in the calculation below shall be mathematically rounded to two decimal places:

$$\Delta L_{Sec}(2\ \text{sections},v) = -2.7 + 16.5 \cdot \lg(v/v_0) - 17.9 \cdot (\lg(v/v_0))^2\ \ [\text{dB(A)}], \quad (1a)$$
$$\Delta L_{Sec}(3\ \text{sections},v) = -2.5 + 17.5 \cdot \lg(v/v_0) - 18.7 \cdot (\lg(v/v_0))^2\ \ [\text{dB(A)}], \quad (1b)$$
$$\Delta L_{Sec}(4\ \text{sections},v) = -2.4 + 18.4 \cdot \lg(v/v_0) - 19.6 \cdot (\lg(v/v_0))^2\ \ [\text{dB(A)}], \quad (1c)$$
$$\Delta L_{Sec}(5\ \text{sections},v) = -2.4 + 19.0 \cdot \lg(v/v_0) - 19.5 \cdot (\lg(v/v_0))^2\ \ [\text{dB(A)}], \quad (1d)$$
$$\Delta L_{Sec}(6\ \text{sections},v) = -2.4 + 19.5 \cdot \lg(v/v_0) - 19.4 \cdot (\lg(v/v_0))^2\ \ [\text{dB(A)}], \quad (1e)$$
$$\Delta L_{Sec}(7\ \text{sections},v) = -2.4 + 19.4 \cdot \lg(v/v_0) - 18.7 \cdot (\lg(v/v_0))^2\ \ [\text{dB(A)}], \quad (1f)$$
$$\Delta L_{Sec}(8\ \text{sections},v) = -2.3 + 19.3 \cdot \lg(v/v_0) - 18.0 \cdot (\lg(v/v_0))^2\ \ [\text{dB(A)}], \quad (1g)$$
$$\Delta L_{Sec}(9\ \text{sections},v) = -2.3 + 18.9 \cdot \lg(v/v_0) - 17.0 \cdot (\lg(v/v_0))^2\ \ [\text{dB(A)}], \quad (1h)$$
$$\Delta L_{Sec}(10\ \text{sections},v) = -2.2 + 18.5 \cdot \lg(v/v_0) - 16.0 \cdot (\lg(v/v_0))^2\ \ [\text{dB(A)}]. \quad (1i)$$

- Equations (1a-1i)

NB: Equations (1a-1i) are based on a section length of approx. 25 m. Should the section length deviate substantially from this, the equation for the nearest vehicle length shall be used.

Accordingly the corrected $L_{Am,1h,corr}$ hourly averaging levels for the measured passes at the relevant velocity v with ΔL_{Sec} for the number of sections during measurement are

$$L_{Am,1h,corr} = L_{Am,1h} + \Delta L_{Sec}\ [\text{dB(A)}]. \quad (2)$$

- Equation (2)

The next thing to determine, on the basis of the thus corrected $L_{Am,1h,corr}$ hourly averaging levels available in 10 km/h steps from 130 to at least 400 km/h, is an equalising second grade polynomial of the form

$$L_{Am,1h,corr}(v) = a + b \cdot \lg(v/v_0) + c \cdot (\lg(v/v_0))^2 \ \text{[dB(A)]}, \qquad (3)$$

- Equation (3)

the coefficients a, b and c being calculated by the smallest error square method and the vehicle velocities of the individual $L_{Am,1h,corr}$ hourly averaging levels being the velocities given by the operator of the maglev sector. The polynomial $L_{Am,1h,corr}(v)$ is the representative of the measured values in the following. It is basically only valid within the range of the velocities measured. An exception, however, is the velocity range below 170 km/h where, according to the ruling in /MSB-LSV/ sub-section 2.5, the hourly averaging levels shall be set to the value at 170 km/h. Furthermore, in cases where $L_{Am,1h,corr}$ hourly averaging levels above the pass measured at the highest velocity are required, these may be extrapolated by using the polynomial up to velocities which are no more than 5 % higher than the highest measured velocity.
Determination of the values of $D_{Fz,me}$ and $D_{Fz,ae}$ is carried out as part of the iterative procedure described below. Here the levels of the polynomial $L_{Am,1h,corr}(v)$ are compared with those of the total rating sound level $L_r(v)$ calculated according to /MSB-LSV/. To do this the total rating sound level is calculated as the energetic sum of the mechanical and aerodynamic rating sound level for different combinations of $D_{Fz,me}$ and $D_{Fz,ae}$ for the period of one hour for one pass in this time by means of the part-section method for the geometric situation when taking the measurement at the reference concrete guideway. Here part sections over a length of at least 500 m on both sides of the measurement cross-section shall be included. When calculating the rating sound level, the correction level S allowing for the special features of railways (see /MSB-LSV/) shall be ignored.
The iteration method comprises the following part steps:

1) Calculation of the total rating sound level $L_r(v)$ for a combination of $D_{Fz,me}$ and $D_{Fz,ae}$ values,

2) Calculation of the sound level differences $\Delta L_{Diff}(v)$ between the calculated total rating sound level $L_r(v)$ and the polynomial $L_{Am,1h,corr}(v)$ in the velocity range of 170 km/h to at least 400 km/h in steps of 1 km/h according to

$$\Delta L_{Diff}(v) = L_r(v) - L_{Am,1h,corr}(v) \ \text{[dB(A)]}, \qquad (4)$$

- Equation (4)

3) Mathematical rounding of the values of $\Delta L_{Diff}(v)$ to one decimal place,

4) Variation of the $D_{Fz,me}$ and $D_{Fz,ae}$ values in 0.5 dB steps to determine the combination of values at which both the following conditions are met:

   a) The rounded sound level differences $\Delta L_{Diff}(v) \geq 0$ for all the velocities between 170 km/h and the highest velocity (at least 400 km/h, see Chapter 0); this condition shall be checked at 1 km/h steps to ensure that the predicted total rating sound levels always lie above the measured values (represented by the values of the polynomial $L_{Am,1h,corr}(v)$).

b) In the range from 170 km/h to the highest velocity (at least 400 km/h, see Chapter 0), the sum of the squares of the rounded $\Delta L_{Diff}(v)$ sound level differences is minimal. When calculating this sum the graduation is again 1 km/h.

The combination of D_{Fz} values found on completion of step 4 of the iteration process represents the values for $D_{Fz,me}$ und $D_{Fz,ae}$ sought for a new vehicle.

Determination of the D_{Fb} value

Determination of the D_{Fb} value assumes knowledge of the D_{FzH} auxiliary variables, i.e. of $D_{FzH,me}$ and $D_{FzH,ae}$, of the vehicle with which the passes on the guideway test specimen were carried out and for which the D_{Fb} value is to be determined. Here the D_{FzH} values in principle represent the D_{Fz} sound level differences; however they are determined without the ΔL_{Sec} corrections relating to the number of sections. In general they are based on preliminary measurements at the reference concrete guideway taken just prior to the actual measurements at the guideway test specimen.

Preliminary measurements and data evaluation for determination of D_{FzH} values

The preliminary measurements to determine the D_{FzH} values on the reference concrete guideway are subject to the requirements given in Chapter 0. Even evaluation of the measurement data does not differ from that for the determination of D_{Fz}. The calculation of $D_{FzH,me}$ and $D_{FzH,ae}$ is therefore carried out analogously using the iteration method from Chapter 0. However four exceptions should be noted here:

- The $L_{Am,1h}$ hourly averaging levels are not acted upon by the correction values ΔL_{Sec}, so that the equalising polynomial from Equation (3) is derived from the values actually measured for the hourly averaging levels.
- The rounding of $\Delta L_{Diff}(v)$ in step 3 of the iteration process is omitted.
- In step 4 of the iteration process the variation of the $D_{FzH,me}$ and $D_{FzH,ae}$ values is carried out in 0.1 dB steps and
- the condition $\Delta L_{Diff}(v) \geq 0$ is not applicable.

The combination of D_{FzH} values found on completion of step 4 of the iteration process represents the values sought for $D_{FzH,me}$ and $D_{FzH,ae}$.

Determination of D_{Fb} value on the basis of D_{FzH} values

To determine the D_{Fb} value of the guideway test specimen, the differential curve $\Delta L_{Am,1h}(v)$ is first created from the $L_{Am,1h,test}$ hourly averaging levels measured at the measuring location with the guideway test specimen and from the $L_{Am,1h,ref}$ sound levels measured at the reference location with the reference concrete guideway in the velocity range common to both measuring locations, namely

$$\Delta L_{Am,1h}(v) = L_{Am,1h,test}(v) - L_{Am,1h,ref}(v) \quad [dB(A)], \tag{5}$$

- Equation (5)

where $L_{Am,1h,test}(v)$ and $L_{Am,1h,ref}(v)$ are equalising polynomials to be determined according to Equation (3). The curve path $\Delta L_{Am,1h}(v)$ is therefore representative of the sound level difference determined at the immission location with the guideway test specimen relative to the immission location with the reference concrete guideway subject to the velocity. Knowing the auxiliary variables $D_{FzH,me}$ and $D_{FzH,ae}$ of the current vehicle, i.e. the vehicle with which the passes on the guideway test specimen were carried out, the D_{Fb} value of the guideway test specimen, i.e. $D_{Fb,test}$, is calculated using Equation (6):

$$D_{Fb,test}(v) = 10\lg(10^{(\Delta L_{Am,1h}-C)/10} + 10^{(\Delta L_{Am,1h}-C+L_{E,ae}-L_{E,me})/10} - 10^{(L_{E,ae}-L_{E,me})/10}) \ [dB(A)] \tag{6}$$

- Equation (6)

where $L_{E,me} = 40 + D_{FzH,me} + 10\lg(l/100\ m) + 20\lg(v/v_0) + D_{Fb,ref}$ [dB(A)],

$L_{E,ae} = 24 + D_{FzH,ae} + 10\lg((0.6\cdot l + 40)/100\ m) + 60\lg(v/v_0)$ [dB(A)],

$D_{Fb,ref} = 0$

$C = C_{test} - C_{ref}$ [dB(A)],

where $C_{test} = 10\lg\sum_k 10^{\Delta L_{k,test}/10}$ [dB(A)] (according to the part-section method of /MSB-LSV/),

$C_{ref} = 10\lg\sum_k 10^{\Delta L_{k,ref}/10}$ [dB(A)] (according to the part-section method of MSB-LSV/),

where $\Delta L_{k,test} = 18 + 10\lg(l_{k,test}) + D_{s,k,test} + D_{L,k,test} + D_{BM,k,test}$ [dB(A)],

$\Delta L_{k,ref} = 18 + 10\lg(l_{k,ref}) + D_{s,k,ref} + D_{L,k,ref} + D_{BM,k,ref}$ [dB(A)].

NB: The terms C_{test} and C_{ref} allow for different above-ground heights of the guideway top edge and of the immission location at the measuring point of the guideway test specimen and the reference concrete guideway. If the heights of the top guideway edge at both measuring locations are the same, the difference C_{test} - C_{ref} is zero, so that term C in Equation (6) is not applicable.

Equation (6) applies expressly only to the boundary conditions to be observed during measurements under the terms of reference in Chapter 0. It should again be noted that in (6) part-sections over a length of at least 500 m on either side of the measurement cross-section must be included within the framework of the part-section method.

The maximum value of $D_{Fb,test}$ determined according to Equation (6) in the velocity range from 170 km/h onwards shall be rounded up in 0.5 dB steps. The resultant value represents the sought D_{Fb} value of the guideway test specimen. According to Chapter 0 it is permissible to give the D_{Fb} value of the guideway test specimen in velocity ranges, namely up to and including 300 km/h, from > 300 km/h up to and including 400 km/h and in the range above that, so the determination of D_{Fb} by means of Equation (6) shall if necessary be carried out separately in the individual velocity ranges. The D_{Fb} values thus obtainable shall be identified in relation to their scope.

Additional terms of reference for the determination of D_{Fb} on short laid lengths of the guideway test specimen

The greater value determined in each case from the single microphone method at a reduced measuring distance and the array method is set as the D_{Fb} value of the guideway test specimen. This rule applies to the total velocity range from 170 km/h onwards, and also separately for the partial velocity ranges possible according to Chapter 0. The following details should also be noted:

- The determination of D_{Fb} by the single microphone method at reduced measuring distance is effected in principle as described in Chapter 0. However, for the $\Delta L_{Am,1h}(v)$ sound level differences in Equation (5), when calculating the polynomials $L_{Am,1h,test}(v)$ and $L_{Am,1h,ref}(v)$ according to Equation (3), all the $L_{Am,1h,r}$ hourly averaging levels determined at one measuring point, i.e. the levels from both immission heights, are included at the same time. If term C in Equation (6) has to be taken into account due to the different heights of the immission locations at both measuring locations, the height of the immission location for each measuring location required to calculate C_{test} and C_{ref} shall be averaged from both immission location heights of each measuring location.

- The determination of D_{Fb} by the array method is effected congruently as described in Chapter 0. The $L_{Am,1h,evl}$ hourly averaging levels are used when calculating the polynomials $L_{Am,1h,test}(v)$ and $L_{Am,1h,ref}(v)$ according to Equation (3).

NB: By taking into account the hourly averaging levels measured in two immission location heights by the single microphone method, the averaging obtained in the polynomial calculation for each measuring location reduces the errors caused by the vertical directional characteristic of guideway and vehicle.

Documentation for determination of D_{Fz} and D_{Fb} sound level differences

The documentation relating to the values for $D_{Fz,me}$ and $D_{Fz,ae}$ for a new vehicle found by the iterative method in Chapter 0 comprises two graphs intended to illustrate the "best" adjustment of the total rating sound levels calculated according to /MSB-LSV/ to the corrected hourly averaging levels measured at the reference concrete guideway. The first graph shall compare:

- the individual corrected $L_{Am,1h,corr}$ hourly averaging levels,
- the equalising polynomial $L_{Am,1h,corr}(v)$ derived from these values, and

- the curve of the total rating sound level $L_r(v)$ calculated according to /MSB-LSV/.

Plotted in the second graph is the curve of the $\Delta L_{Diff}(v)$ sound level difference according to (4) which led to discontinuation of the iteration process.

As part of the determination of the $\mathbf{D_{Fb}}$ value for the guideway test specimen, a graph is first drawn by analogy with the determination of D_{Fz} values in respect of the values for $D_{FzH,me}$ and $D_{FzH,ae}$ resulting from the iteration process according to Chapter 0. This graph shall show

- the individual measured hourly averaging levels $L_{Am,1h}$,
- the equalising polynomial $L_{Am,1h}(v)$ derived from these values, and
- the curve of the total rating sound level $L_r(v)$ calculated according to /MSB-LSV/ with $D_{FzH,me}$ for $D_{Fz,me}$ and $D_{FzH,ae}$ for $D_{Fz,ae}$

for the case of "best" adjustment of the total rating sound level to be calculated and the hourly averaging levels measured. This "best" adjustment shall be illustrated by another graph in which is plotted the curve of the $\Delta L_{Diff}(v)$ sound level difference according to (4) which led to discontinuation of the iteration process.
Furthermore, the measured values at the guideway test specimen shall be recorded in a graph

- the individual measured $L_{Am,1h,test}$ hourly averaging levels and
- the equalising polynomial $L_{Am,1h,test}(v)$ derived from these values.

To record the D_{Fb} value determined by means of Equation (6), two graphs shall be drawn showing

- the measured $\Delta L_{Am,1h}$ sound level difference as a function of velocity, and
- the calculated $D_{Fb,test}$ values as a function of velocity

in the velocity range from 170 km/h onwards. On the one hand the latter graph illustrates the dependence of the $D_{Fb,test}$ values on the velocity of the vehicle, on the other it shows the velocity at which the maximum value of $D_{Fb,test}$, and hence ultimately the D_{Fb} value, of the guideway test specimen was determined.

Annex

In this Annex an example is used to illustrate the determination of D_{Fz}-, D_{FzH}- and D_{Fb} values and the result documentation. Table 0-1 lists hypothetical $L_{Am,1h}$ hourly averaging levels which should have been measured under conditions according to Chapter 0 at the reference concrete guideway and determined according to the terms of reference given in Chapter 0.

The present example assumes the following boundary conditions and hypothetical readings:

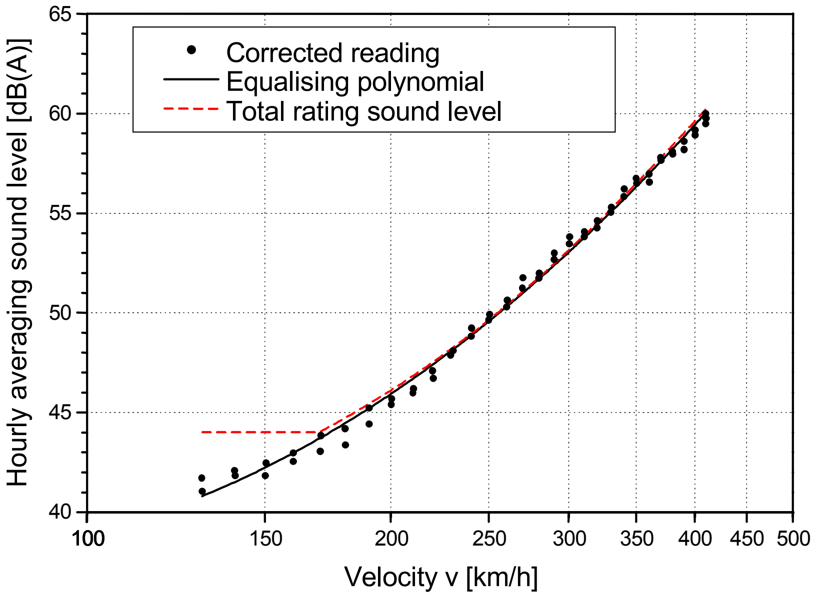
- single microphone at a distance of 25 m from the guideway support centre
- "long" extension of guideway,
- top guideway edge in the measurement cross-section at a height of 6.7 m above the ground,
- vehicle of 79.2 m in length.

v [km/h]	$L_{Am,1h}$ [dB(A)]	v [km/h]	$L_{Am,1h}$ [dB(A)]	v [km/h]	$L_{Am,1h}$ [dB(A)]
129.9	41.9	229.2	46.6	330.1	53.6
130.0	42.5	230.3	46.8	330.5	53.8
139.9	42.5	240.1	47.4	339.9	54.4
140.1	42.2	240.3	47.9	340.3	54.8
150.1	41.9	249.9	48.2	349.7	55.3
150.4	42.5	250.3	48.5	350.1	55.1
160.0	42.3	260.2	48.8	360.1	55.6
160.1	42.7	260.5	49.2	360.4	55.2
170.1	42.6	269.8	49.7	369.7	56.5
170.4	43.4	270.2	50.3	370.1	56.3
180.1	43.5	280.0	50.2	379.7	56.8
180.2	42.7	280.2	50.5	380.1	56.7
190.1	43.6	289.9	51.2	390.0	57.0
190.3	44.4	290.2	51.5	390.2	57.4
200.1	44.4	300.2	51.9	400.1	58.0
200.3	44.7	300.6	52.3	400.3	57.7
210.2	44.9	310.5	52.3	409.6	58.4
210.4	45.1	310.8	52.6	409.9	58.9
219.8	45.9	319.9	52.8	410.3	58.6
220.2	45.5	320.1	53.1	-	-

- Table 0-1: Hourly averaging levels hypothetically determined at the measuring location with the reference concrete guideway

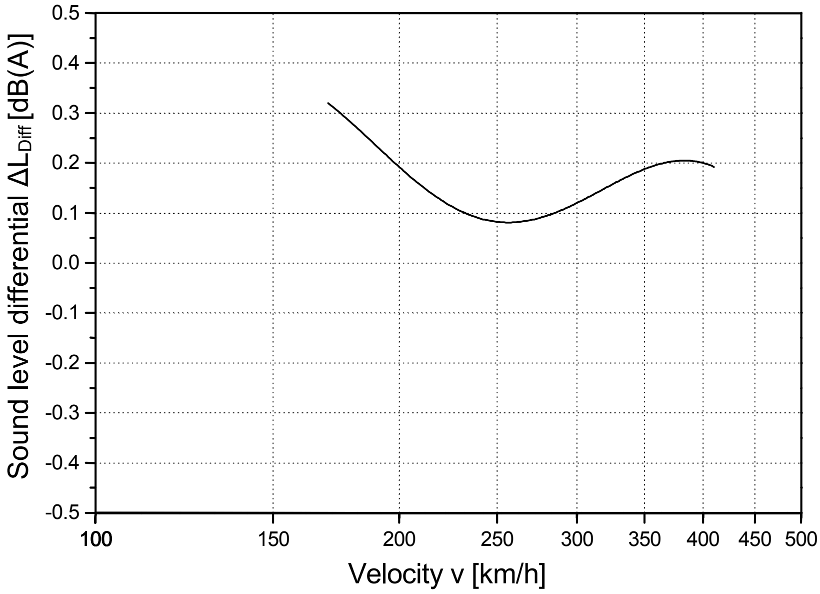
Example for determination of D_{Fz} sound level differences $D_{Fz,me}$ and $D_{Fz,ae}$

The $L_{Am,1h}$ hourly averaging levels from Table 0-1 are first corrected with regard to the number of sections of the vehicle according to Equation (2). The resultant $L_{Am,1h,corr}$ hourly averaging levels are entered in Figure 41 (in accordance with Chapter 0). From the $L_{Am,1h,corr}$ levels the equalising polynomial $L_{Am,1h,corr}(v)$ is then formed according to Equation (3) and added to Figure 41 (see Chapter 0). In the present example the values a = 38.90, b = 12.62 and c = 35.70 are obtained for the coefficients of the equalising polynomials.
By applying the iteration process set out in Chapter 0, the $D_{Fz,me}$ and $D_{Fz,ae}$ values are determined which deliver the "best" adjustment of the $L_r(v)$ total rating sound level calculated in accordance with /MSB-LSV/ to the equalising polynomial $L_{Am,1h,corr}(v)$, special note being taken of the fact that the calculated total rating sound level must always be above the equalising polynomial. In this example the values determined are $D_{Fz,me}$ = -0.5 dB(A) and $D_{Fz,ae}$ = -0.5 dB(A). The curve of the total rating sound level for both these values is also entered in Figure 41 (see Chapter 0).
For the rest, the value for C_{ref} needed for calculation of the total rating sound level at the reference concrete guideway based on the geometric conditions given above and the part sections taken into consideration over ± 500 m on either side of the measurement cross-section is 0.0218 dB(A).



- Figure 41: Corrected $L_{Am,1h,corr}$ hourly averaging levels, equalising polynomial $L_{Am,1h,corr}(v)$ and total rating sound level $L_r(v)$ based on the D_{Fz} values determined by the iteration method

According to the terms of reference in Chapter 0, in Figure 42 the curve of the ΔL_{Diff} sound level differential according to Equation (4) is shown as the difference of the total rating sound level and equalising polynomial curves from Figure 41. Figure 42 serves as proof that in the determination of $D_{Fz,me}$ and $D_{Fz,ae}$ the condition $\Delta L_{Diff} \geq 0$ was complied with the total velocity range from 170 km/h to the maximum velocity.



- Figure 42: Sound level difference $\Delta L_{Diff}(v)$ of total rating sound level and equalising polynomial from Figure 41

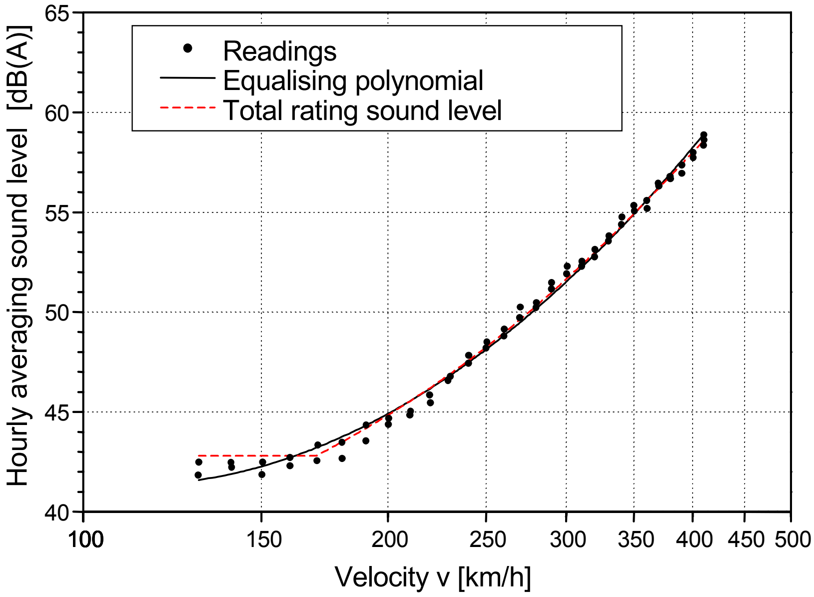
Example for determination of sound level difference D_{Fb}

In a first step, measurements are taken at the reference guideway to determine for the vehicle the auxiliary variables $D_{FzH,me}$ and $D_{FzH,ae}$ at which the runs on the guideway test specimen were carried out. The sound level difference D_{Fb} is then determined from the difference between the hourly averaging levels measured at the guideway test specimen and at the reference concrete guideway.

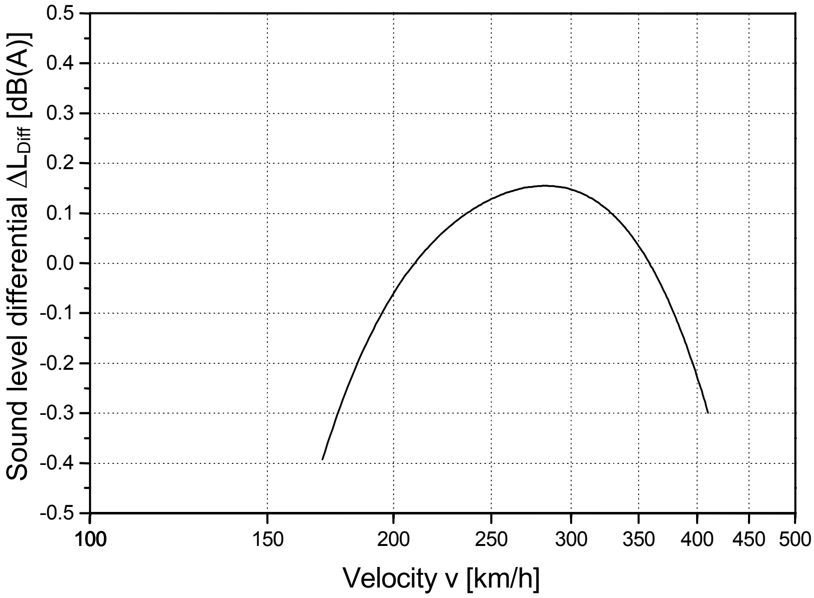
Determination of auxiliary variables $D_{FzH,me}$ and $D_{FzH,ae}$

First, in accordance with Chapter 0, the hourly averaging levels $L_{Am,1h} = L_{Am,1h,ref}$ from Table 0-1 determined at the reference concrete guideway are represented by a graph (see Figure 43). No correction is made in respect of the number of vehicle sections. An equalising polynomial $L_{Am,1h,ref}(v)$ is adjusted to these values using Equation (3) and also represented by a graph (see Figure 43). In the example the values given for the coefficients of this equalising polynomial are a = 41.43, b = -4.81 and c = 54.38.

Using the iteration method modified according to Chapter 0, the auxiliary variables $D_{FzH,me}$ and $D_{FzH,ae}$ are determined by the “best” adjustment of the $L_r(v)$ total rating sound level to the equalising polynomial $L_{Am,1h,ref}(v)$ calculated according to /MSB-LSV/. In accordance with Chapter 0, the curve of $L_r(v)$ in Figure 43 predicted by the values found for $D_{FzH,me}$ and $D_{FzH,ae}$ is added. In the present example the iteration method gives the values $D_{FzH,me}$ = -1.6 dB(A) and $D_{FzH,ae}$ = -2.2 dB(A). For the D_{FzH} values thus determined the curve of the ΔL_{Diff} sound level differential according to Equation (4) is shown in accordance with Chapter 0 in a separate graph (see Figure 44) as the difference of the total rating sound level and equalising polynomial curves from Figure 43.



• Figure 43: $L_{Am,1h,ref}$ hourly averaging level, equalising polynomial $L_{Am,1h,ref}(v)$ and $L_r(v)$ total rating sound level based on the D_{FzH} values determined by the modified iteration method



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• Figure 44: $\Delta L_{Diff}(v)$ sound level differential of total rating sound level and equalising polynomial from Figure 43

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Determination of D_{Fb} value for a guideway test specimen with long extension

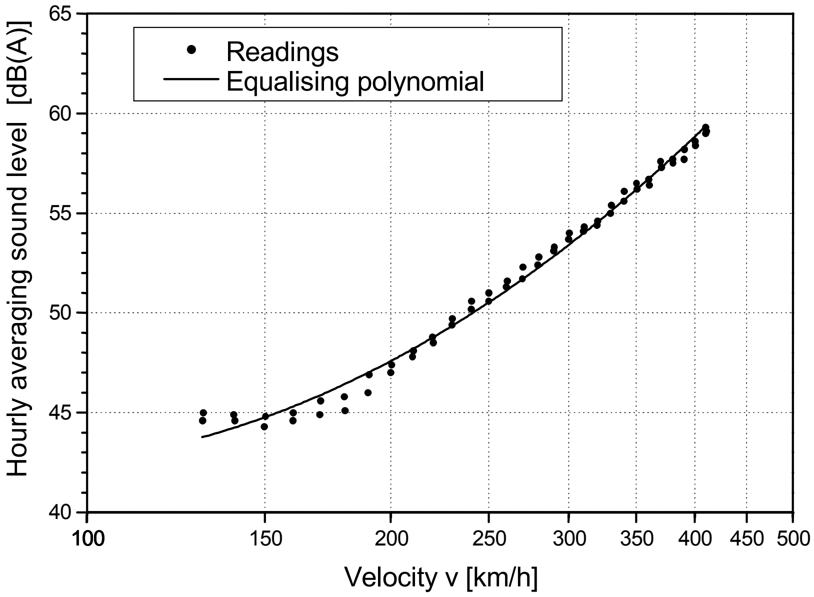
Once the auxiliary variables $D_{FzH,me}$ and $D_{FzH,ae}$ are determined, the D_{Fb} value of the guideway test specimen can be calculated using Equation (6). For this Table 0-2 lists hypothetical $L_{Am,1h}$ hourly averaging levels which should have been measured under conditions according to Chapter 0 on the guideway test specimen and determined according to the terms of reference in Chapter 0.
The present example assumes the following boundary conditions and hypothetical readings:

- single microphone at a distance of 25 m from the guideway support centre,
- "long" extension of guideway,
- Top guideway edge in the measured cross-section at a height of 6.5 m above ground.

v [km/h]	$L_{Am,1h}$ [dB(A)]	v [km/h]	$L_{Am,1h}$ [dB(A)]	v [km/h]	$L_{Am,1h}$ [dB(A)]
130.1	44.6	229.7	49.4	329.8	55.0
130.3	45.0	230.1	49.7	330.4	55.4
139.8	44.9	240.0	50.2	340.0	55.6
140.0	44.6	240.2	50.6	340.4	56.1
149.8	44.3	249.8	50.6	349.9	56.5
150.2	44.8	250.1	51.0	350.3	56.2
159.9	44.6	260.1	51.3	359.8	56.7
160.1	45.0	260.5	51.6	360.3	56.4
170.0	44.9	269.7	51.7	369.7	57.6
170.3	45.6	270.1	52.3	370.3	57.3
179.9	45.8	279.5	52.4	379.9	57.7
180.1	45.1	280.1	52.8	380.2	57.5
189.8	46.0	289.8	53.1	390.1	57.7
190.1	46.9	290.2	53.3	390.4	58.2
199.9	47.0	299.7	53.7	399.8	58.6
200.3	47.4	300.3	54.0	400.4	58.4
210.0	47.8	310.1	54.1	409.6	59.0
210.4	48.1	310.5	54.3	410.0	59.3
219.7	48.8	319.9	54.4	410.4	59.1
220.2	48.5	320.3	54.6	-	-

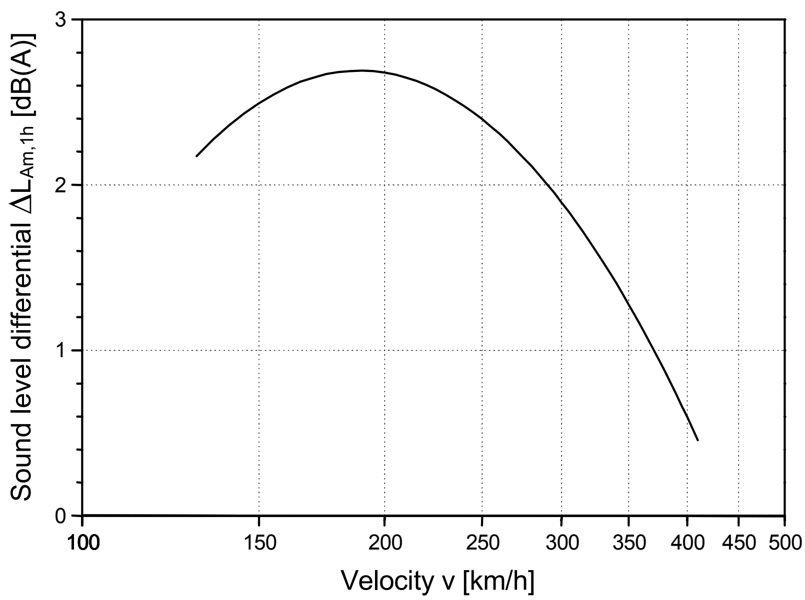
- Table 0-2: Hypothetical hourly averaging levels determined at the measuring location with the guideway test specimen

The equalising polynomial $L_{Am,1h,test}(v)$ is first formed from the hourly averaging levels $L_{Am,1h} = L_{Am,1h,test}$ in Table 0-2, and in accordance with Chapter 0 represented together with the $L_{Am,1h,test}$ sound levels (see Figure 45). In the present example the values for the coefficients of the equalising polynomial are a = 42.62, b = 6.06 and c = 34.69.



- Figure 45: $L_{Am,1h,test}$ hourly averaging level and equalising polynomial $L_{Am,1h,test}(v)$

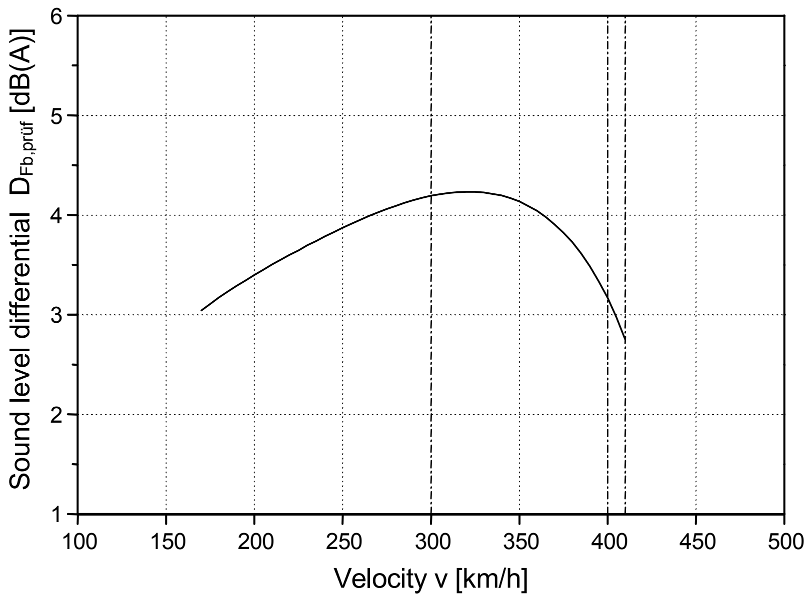
With the polynomial $L_{Am,1h,ref}(v)$ already calculated above, Equation (5) is used to obtain the $\Delta L_{Am,1h}(v)$ sound level differential which represents the input variable for Equation (6) resulting from the measurements. The curve of $\Delta L_{Am,1h}(v)$ is represented in a separate graph according to Chapter 0 as an important intermediate variable in the determination of D_{Fb} (see Figure 46).



- Figure 46: $\Delta L_{Am,1h}(v)$ sound level differential

The next step is to determine $D_{Fb,test}(v)$ from $\Delta L_{Am,1h}(v)$ using Equation (6). Here the term $C = C_{test} - C_{ref}$ must be calculated at both measuring locations with due regard to the geometric circumstances. The value 0.0218 dB(A) was already determined for C_{ref} in Chapter 0 . Due to the slightly changed geometric situation relative to the reference concrete guideway at the measuring location with the guideway test specimen (see above) this gives C_{test} = 0.0144 dB(A), so that for C a value of -0.0075 dB(A) is obtained.
In Figure 47, as a result of the calculations using Equation (6), the values of $D_{Fb,test}(v)$ are plotted as a function of vehicle velocity. The D_{Fb} value of the guideway test specimen is now obtained from the maximum value of $D_{Fb,test}$ rounded up in 0.5 dB steps, either in the total velocity range from 170 km/h onwards or in the part ranges possible according to Chapter 0. In the present example these are:

- D_{Fb} = 4.5 dB(A) in the total velocity range up to 410 km/h,
- D_{Fb} = 4.5 dB(A) in the part range up to 300 km/h,
- D_{Fb} = 4.5 dB(A) in the part range $300 < v \leq 400$ km/h,
- D_{Fb} = 3.5 dB(A) in the part range $400 < v \leq 410$ km/h.

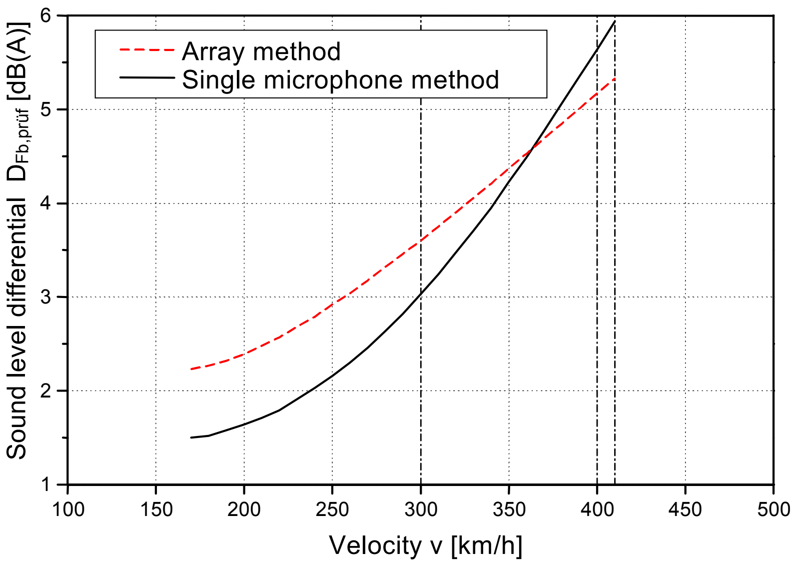


- Figure 47: Calculated $D_{Fb,test}$ values of a guideway test specimen for hypothetical measurements on a specimen with a “long” extension

Determination of D_{Fb} value for a guideway test specimen of short laid length

Finally, for a guideway test specimen of “short” laid length, Figure 48 shows the example of a D_{Fb} determination result using the single microphone method at a reduced measurement distance and the array method, whereby the terms of reference in Chapter 8.3 shall be noted. These stipulate in particular that the D_{Fb} value of the guideway test specimen shall be the greater of the two values determined by both methods, both in the total velocity range from 170 km/h onwards and separately in the part velocity ranges. Consequently the D_{Fb} value in the present example after being rounded up in 0.5 dB steps is

- D_{Fb} = 6.0 dB(A) in the total velocity range to 410 km/h, determined from the single microphone measurement,
- D_{Fb} = 4.0 dB(A) in the part range up to 300 km/h, determined from the array measurement,
- D_{Fb} = 6.0 dB(A) in the part range $300 < v \leq 400$ km/h, determined from the single microphone measurement,
- D_{Fb} = 6.0 dB(A) in the part range $400 < v \leq 410$ km/h, determined from the single microphone measurement.



- Figure 48: Calculated $D_{Fb,test}$ values of a guideway test specimen for hypothetical measurements on a specimen of “short” laid length

NB: Re the very different curves of $D_{Fb,test}$ as a function of velocity in Figure 47 and Figure 48, it should be noted that Figure 47 reflects a possible case in which the increased sound emission of the guideway test specimen is based solely on an additional proportion with a *mechanical cause. In the hypothetical case of Figure 48, on the other hand, both mechanical and aerodynamic causes are responsible for the greater radiation of the test specimen.*

High-speed Maglev System
Design Principles

Vehicle
Part I
General Requirements

Distribution

This document was released for publication by the Vehicle Technical Committee.

Amendment summary:

Date of release: 15.02.2007; White Paper, Vehicle Technical Committee.

Table of Contents

Table of Figures

General

Purpose and scope

The present Design Principles Vehicle Part I “General Requirements” lay down the general requirements for the vehicle and the certification procedure

The present Design Principles apply to a high-speed maglev system pursuant to the General Maglev Act [Allgemeines Magnetschwebebahngesetz /AMbG/].

The present document shall be applied to the specification, execution and certification of maglev vehicles.

Project-specific requirements shall be agreed between the approval authority, high-speed maglev system operator (operator) and vehicle supplier. These shall be documented in the target requirements (supply and performance specification) based on the maglev operator’s specification.

The term “vehicle” in the Design Principles Vehicle (Parts I – V) shall exclusively be taken to mean a levitated vehicle of a high-speed maglev system.

Deviations from the requirements and stipulations in this document require proof of identical safety.

This Part I of the Design Principles Vehicle comprises:

- Definitions of the vehicle structure and assemblies;
- General requirements for vehicles;
- Requirements for acceptance.

High-speed Maglev System Implementation Bases

This document forms part of a set of documentation for high-speed maglev systems comprising several Implementation Bases. The documentation tree is shown in Figure 1 /MSB AG-GESAMTSYS/.
The parent Design Principles Complete System and the Annexes thereof apply uniformly to the full set of documentation:

- High-speed Maglev System Design Principles Complete System, doc. no.: 50630, /MSB AG-GESAMTSYS/, with Annexes:
    - Annex 1: Abbreviations and definitions, doc. no.: 67536, /MSB AG-ABK&DEF/
    - Annex 2: Acts, Orders, Standards and Directives, doc. no.: 67539, /MSB AG-NORM&RILI/

- Annex 3: Environmental Conditions, doc. no.: 67285, /MSB AG-ENVIRONMENT/
- Annex 4: Operating Rules (Driving and Maintenance), doc. no.: 69061, /MSB AG-BTR/
- Annex 5: Sound, doc. no.: 72963, /MSB AG-SCHALL/

The documentation relating to the vehicle comprises the following:

- High-speed Maglev System Design Principles Vehicle, Part I: General Requirements, doc. no.: 67698, /MSB AG-FZ GEN/
- High-speed Maglev System Design Principles Vehicle, Part II: Dimensioning, doc. no.: 67694, /MSB AG-FZ BEM/
- High-speed Maglev System Design Principles Vehicle, Part III: Kinematic gauge, doc. no.: 67650, /MSB AG-FZ KIN/
- High-speed Maglev System Design Principles Vehicle, Part IV: Support/guidance Engineering, doc. no.: 73388, /MSB AG-FZ TRAFÜ/
- High-speed Maglev System Design Principles Vehicle, Part V: Brake Engineering, doc. no.: 73389, /MSB AG-FZ BREMS/

Overriding definitions of the interfaces between the individual subsystems are given in High-speed Maglev System Complete System /MSB AG-GESAMTSYS /. The High-speed Maglev System Design Principles Complete System shall therefore always be used in conjunction with the other Implementation Bases.

The contents of Parts I to V of the High-speed Maglev System Implementation Bases Vehicle are summarised under the bullet points below:

Part I General Requirements

- Definitions of the vehicle structure and assemblies;
- General requirements for vehicles;
- Requirements for acceptance.

Part II Design

- Stipulation of operating conditions, influences and combinations of influences;
- Certification of static strength and fatigue strength, stability and rigidity.

Part III Kinematic gauge

- Definition of the kinematic functions;
- Definition of the relevant geometric data and failure states;
- Terms of reference for proof of gauge.

Part IV Support/guidance Engineering

- Definition of the support/guidance system;
- Requirements for support/guidance system functions;
- Influences of the support/guidance system on the guideway.

Part V Brake Engineering

- Definition of braking equipment;
- Requirements for functions of the braking equipment;
- Influences of braking equipment on the guideway.

Abbreviations and definitions

The abbreviations and definitions given in /MSB AG-ABK&DEF/ apply.

Acts, Orders, Standards and Directives

The normative documents listed in /MSB AG-NORM&RILI/ contain stipulations which become part of the High-speed Maglev System Implementation Bases by virtue of reference in the High-speed Maglev System Implementation Bases. When normative documents in /MSB AG-NORM&RILI/ are dated, later amendments or revisions of these publications do not apply. When references are undated, the most recent issue of the normative document referred to is applicable.

The issue date of the Standards and Directives to be taken into account in a maglev project shall be fixed with binding force for that specific project.

The checklist in Annex 0 of this document mentions Standards, compliance with which – inasmuch as applicable to the high-speed maglev system – can be checked in principle on acceptance of the vehicle pursuant to Section 6 /MbBO/.

The attached checklist serves as an example. It shall be agreed on a project-specific basis between the approval authority, the high-speed maglev system operator and the vehicle supplier, together with the Standards and test and certification procedures to be used.

If Standards for the high-speed maglev system are not recognised as uniquely applicable, further maglev-specific Implementation Bases may be compiled by the Maglev Technical Committee Vehicle.

There are, in addition, other Standards, e.g. material standards, fabrication standards, maintenance standards, compliance with which is not explicitly checked as part of acceptance pursuant to Section 6 /MbBO/, but compliance with which is the responsibility of the manufacturer or operator.

Identification and binding force of requirements

In compiling the present document, the regulations conforming to /DIN 820/ were essentially applied.
In the following chapters and annexes of this document

- requirements are denoted by regular font
- *explanatory notes, guideline values and examples are denoted by italics.*

If references are made in this document to project-specific regulations in an individual case, this means that agreement shall be reached between manufacturer and operator (*e.g. in specifications or a contractual arrangement)* in consultation with the approval authority.

References

The references listed below represent a summary of the reference sources referred to in this document. A complete list of all the reference documentation referred to in the MSB Implementation Bases will be found in /MSB AG-NORM&RILI/.

Document	Description
/BrandReg/	Regulation for the fire safety rating of railbound vehicles as part of acceptance in accordance with Section 32 EBO; Principles of fire safety requirements with reference to EN 45545; Agreement between Federal Railways Office, Deutsche Bahn AG, German Railway Industry Association, 01.06.2006

Definitions (vehicle-specific)

Fig. 49 and Fig. 50 show the side and front view and cross-section of a typical vehicle and explain the characteristic dimensions.

The vehicles shall be formed from vehicle sections which are autarkic in respect of support and guidance function, braking equipment, on-board energy supply and bodywork.

The connection of vehicle sections may be effected by section-connecting lift magnets and by a section coupling (see Fig. 49, Fig. 54, Fig. 56).

There are end sections and mid sections. An end section differs from a mid section in having a nose additional to the cell structure (Fig. 54).

The underbody structure of the support/guidance system below the nose may be a nose fairing rigidly mounted to the frame (see Fig. 55).

The equipment of the operational control system, radio facilities and detection devices required for the functioning of the operational controls and the drive can be integrated in the end sections.

A vehicle may have 2 end sections and up to 8 mid sections[1)].

The system length of a vehicle section must correspond to the geometric length of an L_{MS} mid section.

L_{MS} is equivalent to 8 times the lift magnet system length ($L_{sys,TM}$) and 96 times the pole pitch ($e_{x,pole\ pitch}$):

$$
\begin{aligned}
L_{MS} &= 8 \cdot L_{sys,TM} = 96 \cdot e_{x,pole\ pitch} \\
&= 8 \cdot 3\,096\ mm = 96 \cdot 258\ mm \\
&= 24\,768\ mm
\end{aligned}
$$

L_{MS} is the geometric length of a mid section over centre of section coupling or centre of section-connecting lift magnets.

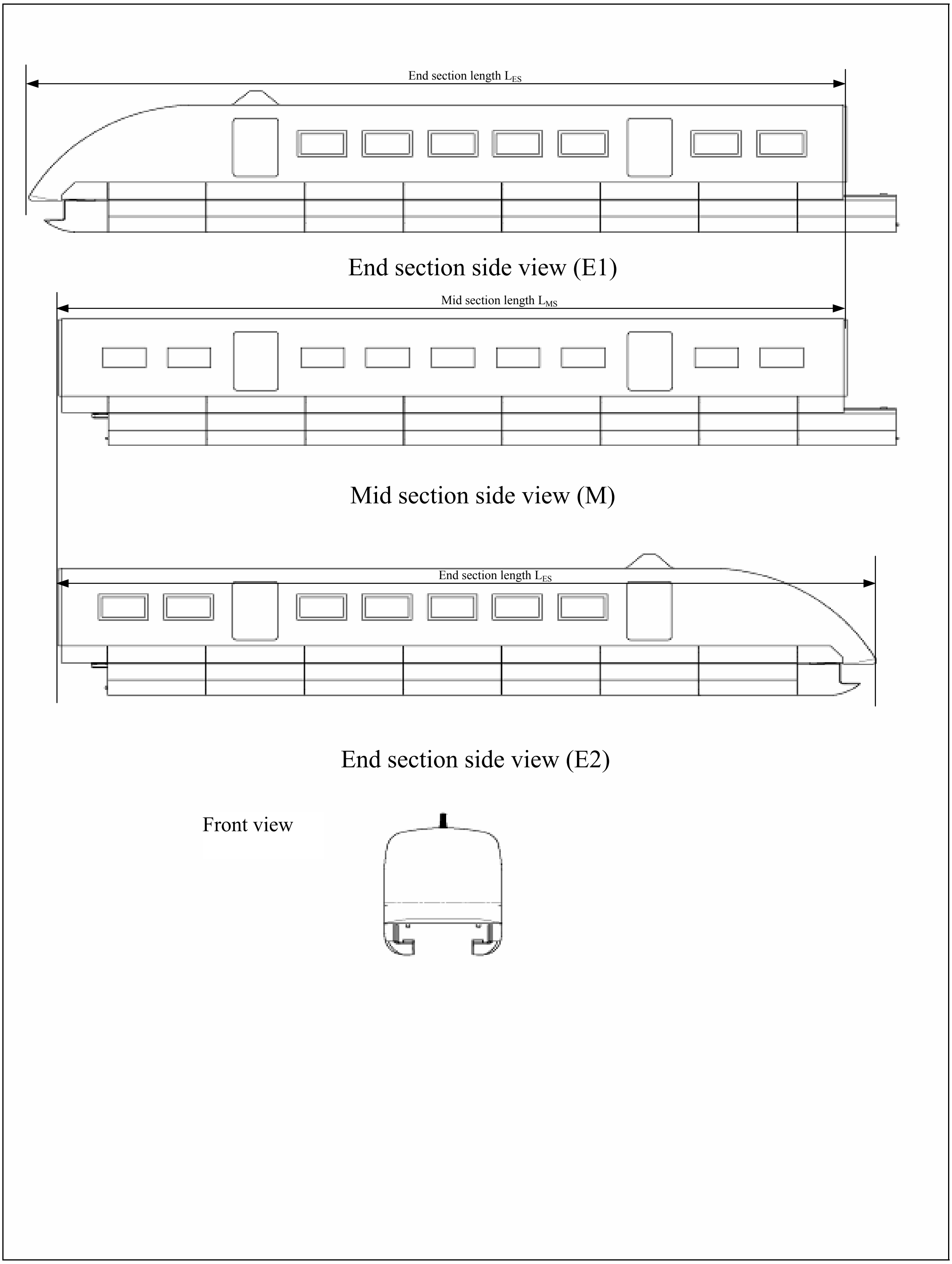
The geometric length of the end section L_{ES} may deviate from the system length of the mid section L_{MS} – depending on the design and dimensions of the nose.

The geometric vehicle length L_{Veh} of a vehicle with 2 end sections and n mid sections is:

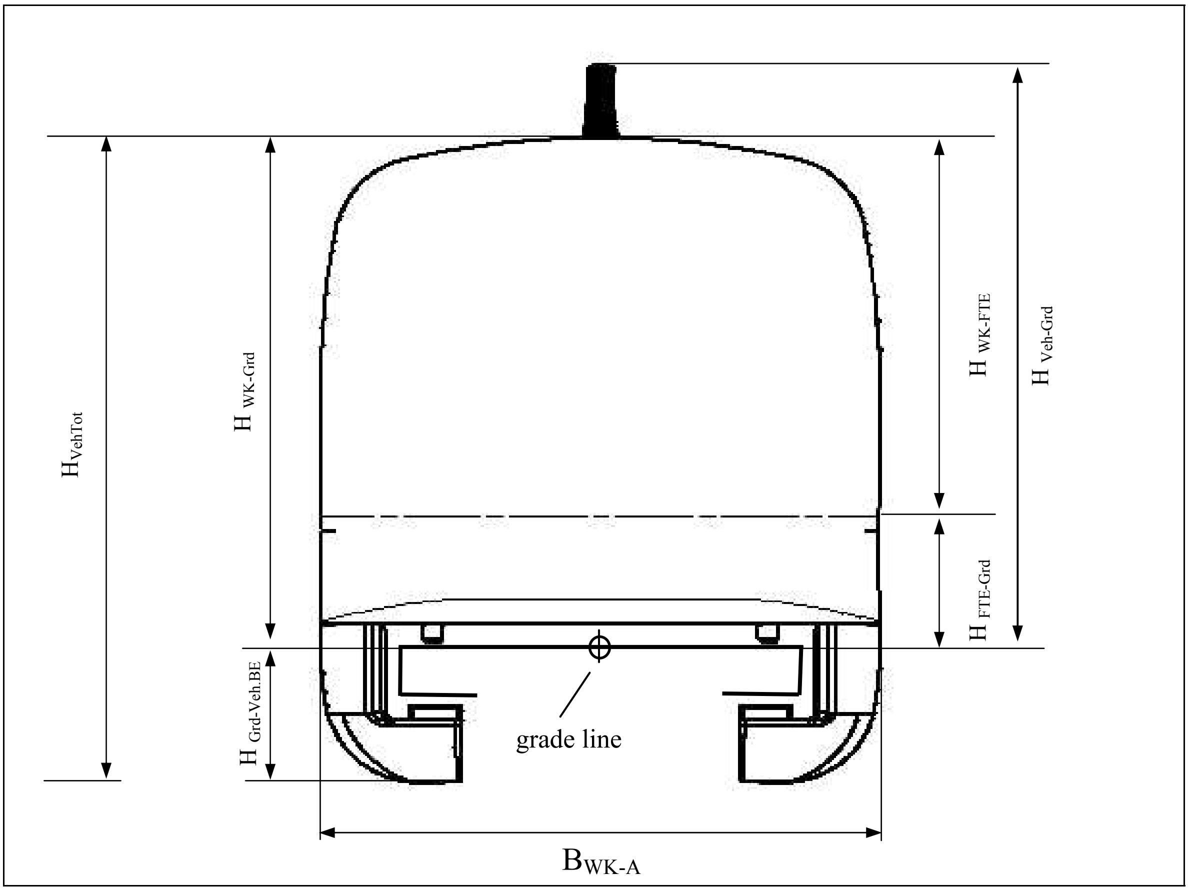
$$L_{Veh} = 2 \cdot L_{ES} + n \cdot L_{MS} .$$

[1)] Vehicles with only one end section may be used for special applications. Corresponding project-specific adjustments are required.

Vehicles with up to 20 sections may be configured for special applications; here separate certification is required.



- Fig. 49: *Side view and front view of a vehicle (schematic diagram)*



• Fig. 50: *Vehicle cross-section (schematic diagram)*

Designation	**Abbreviation**
External body width	B_{WK-A}
Height body over grade line (without antenna)	H_{WK-Grd}
Height floor top edge over grade line	$H_{FTE-Grd}$
Height vehicle (incl. antenna) over grade line	$H_{Veh-Grd}$
Height outside body over floor top edge	H_{WK-FTE}
Height grade line over vehicle bottom edge	$H_{Grd-Veh.BE}$
Total vehicle height (without antenna)	$H_{Veh.tot}$

The vehicle is divided up as shown in the diagrams (Fig. 51 to Fig. 53*).*

The vehicle section may comprise the body and support/guidance system (Fig. 51). The bodywork may comprise the body structure with cell and underfloor as well as the body equipment (Fig. 52).

The cell may comprise the cell structure, nose (end section only) and windows (Fig. 54).

The cell structure may comprise floor, side walls, windows and roof.

The outer shell may comprise the elements shown in Fig. 55.

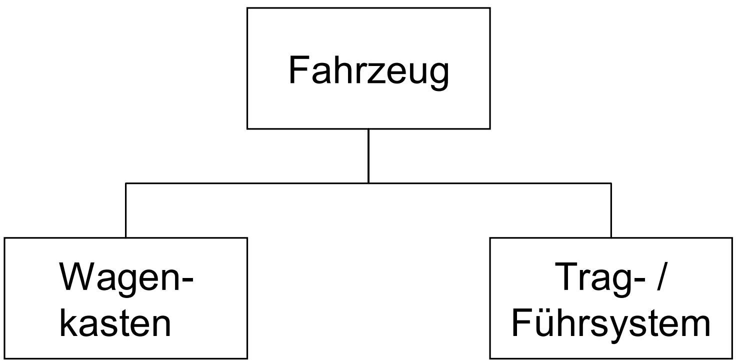
The support/guidance system may comprise the structural assemblies including the shell (magnetic running gear) and the functional assemblies (electrical and electronic subassemblies) including the on-board energy supply.

The braking equipment may be integrated in the support/guidance system. The brake power may be generated by brake magnets and removed via the support/guidance structure (Fig. 56, Fig. 57).

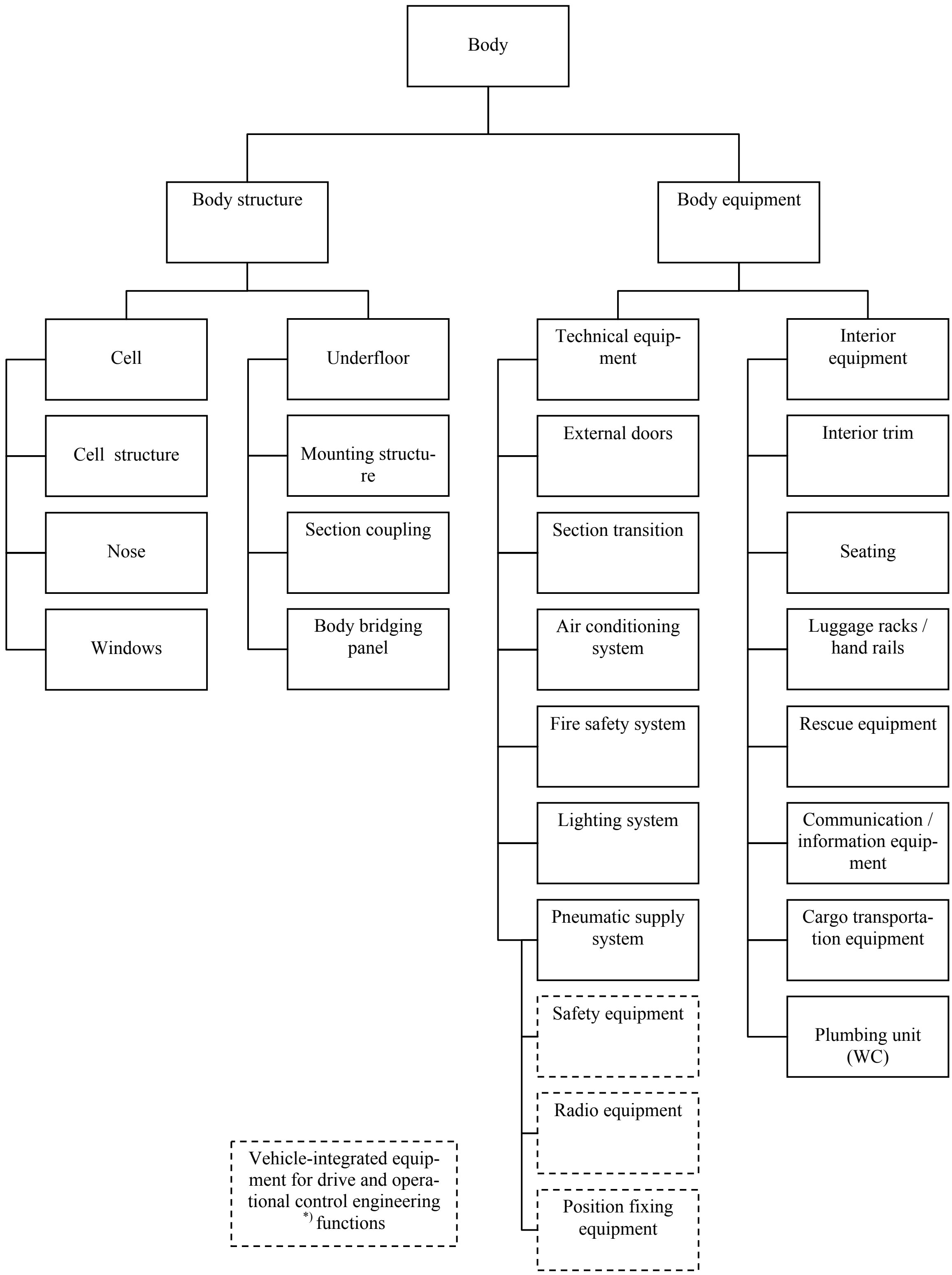
The operational control engineering equipment may be integrated in the body as part of the technical equipment and have interfaces for the vehicle's on-board energy supply as well as for body equipment (e.g. doors) using control and monitoring signals, and for the support/guidance system (magnetic running gear) including braking equipment. These interfaces shall be specified between control engineering and vehicle.

Equipment for position fixing for the operation of drive and control engineering may be integrated in the support/guidance system.

The requirements for position fixing shall be specified from the drive or control engineering side.

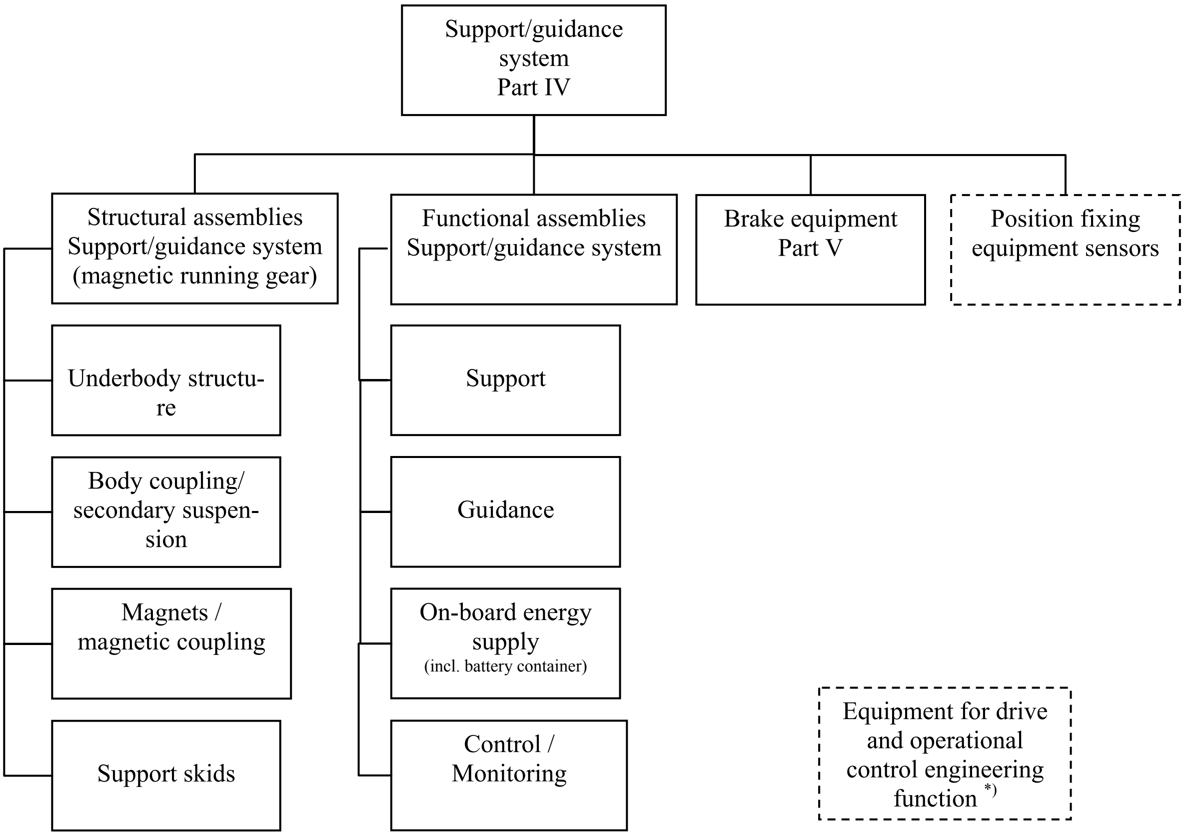


- Fahrzeug = vehicle; Wagenkasten = body; Trag-/Führsystem = support/guidance system
-
- Fig. 51: Main subdivision of vehicle



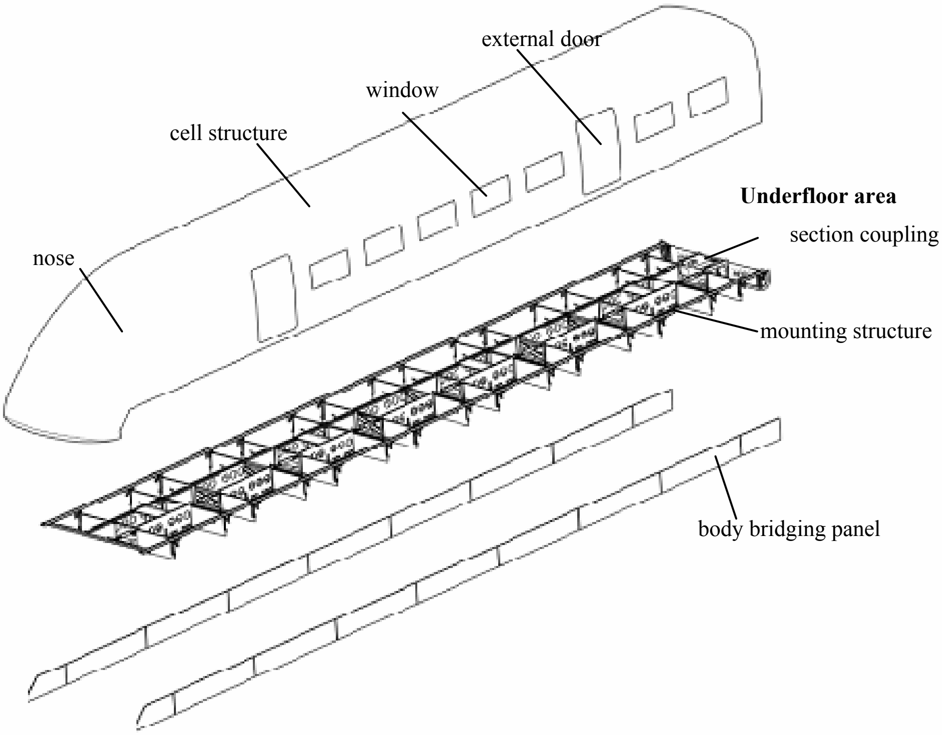
- Fig. 52: Subdivision of body
- *) **Position and velocity information needed for vehicle operation can be generated by the functional assemblies of the support/guidance system and/or by the position fixing equipment for the drive and operational control engineering functions.**

•

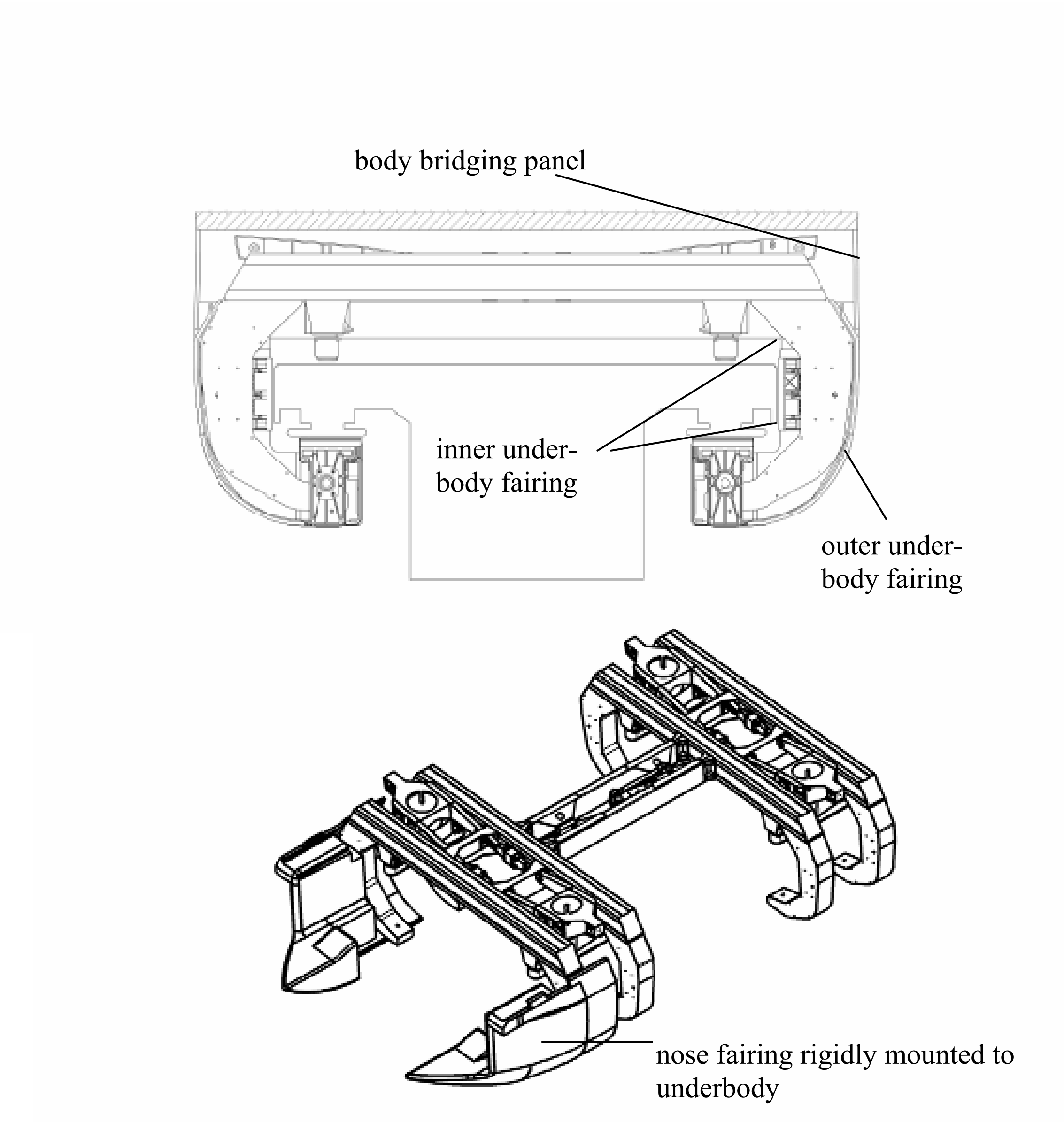


• Fig. 53: Subdivision of support/guidance system

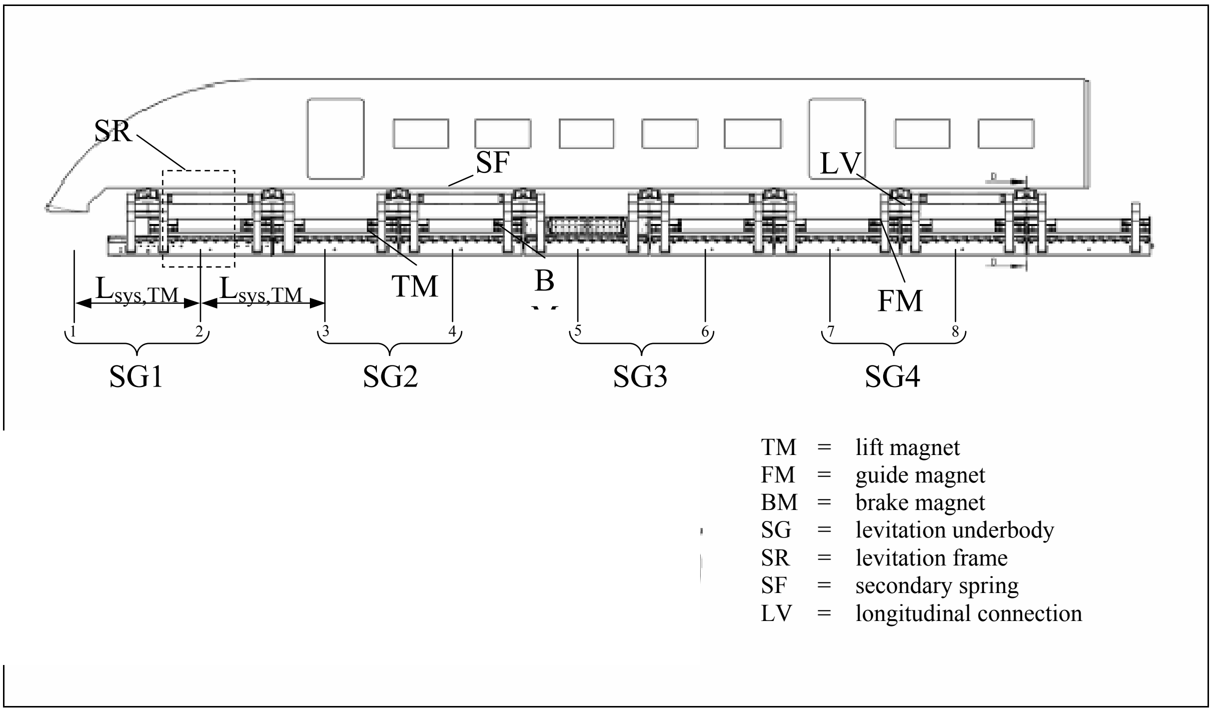
• *) **Position and velocity information needed for vehicle operation can be generated by the functional assemblies of the support/guidance system and/or by the position fixing equipment for the drive and operational control engineering functions.**



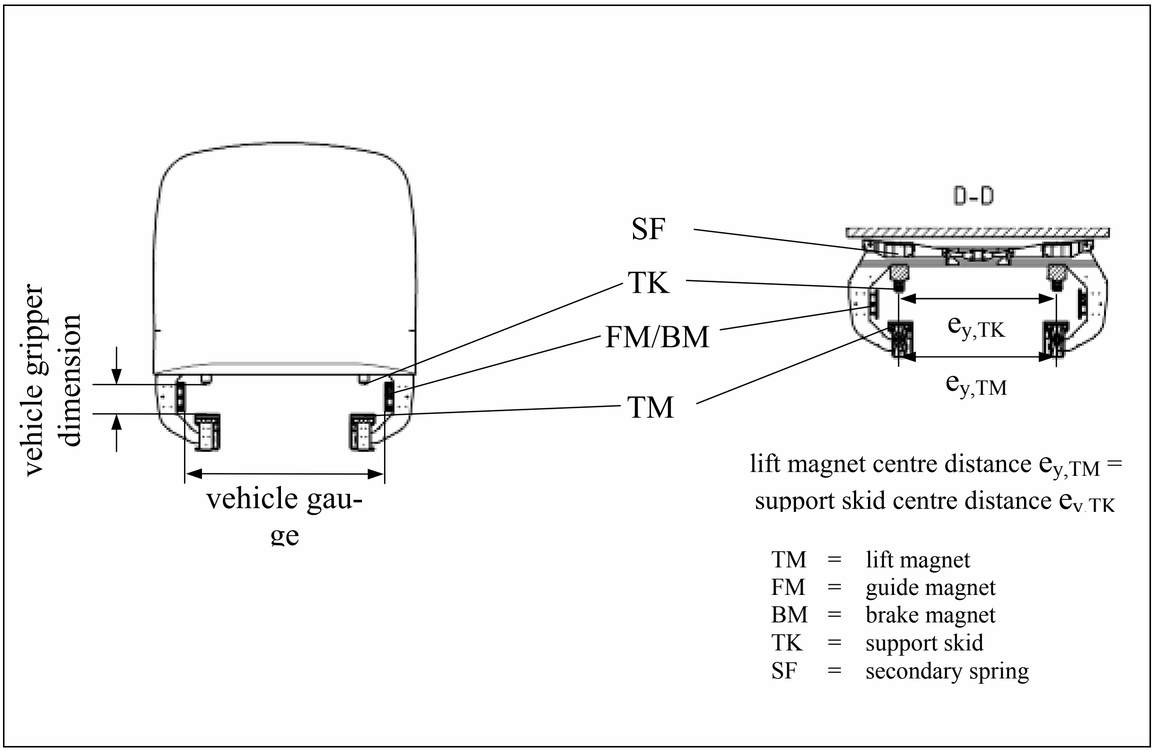
- Fig. 54: *Designations of essential body structure assemblies (examples)*



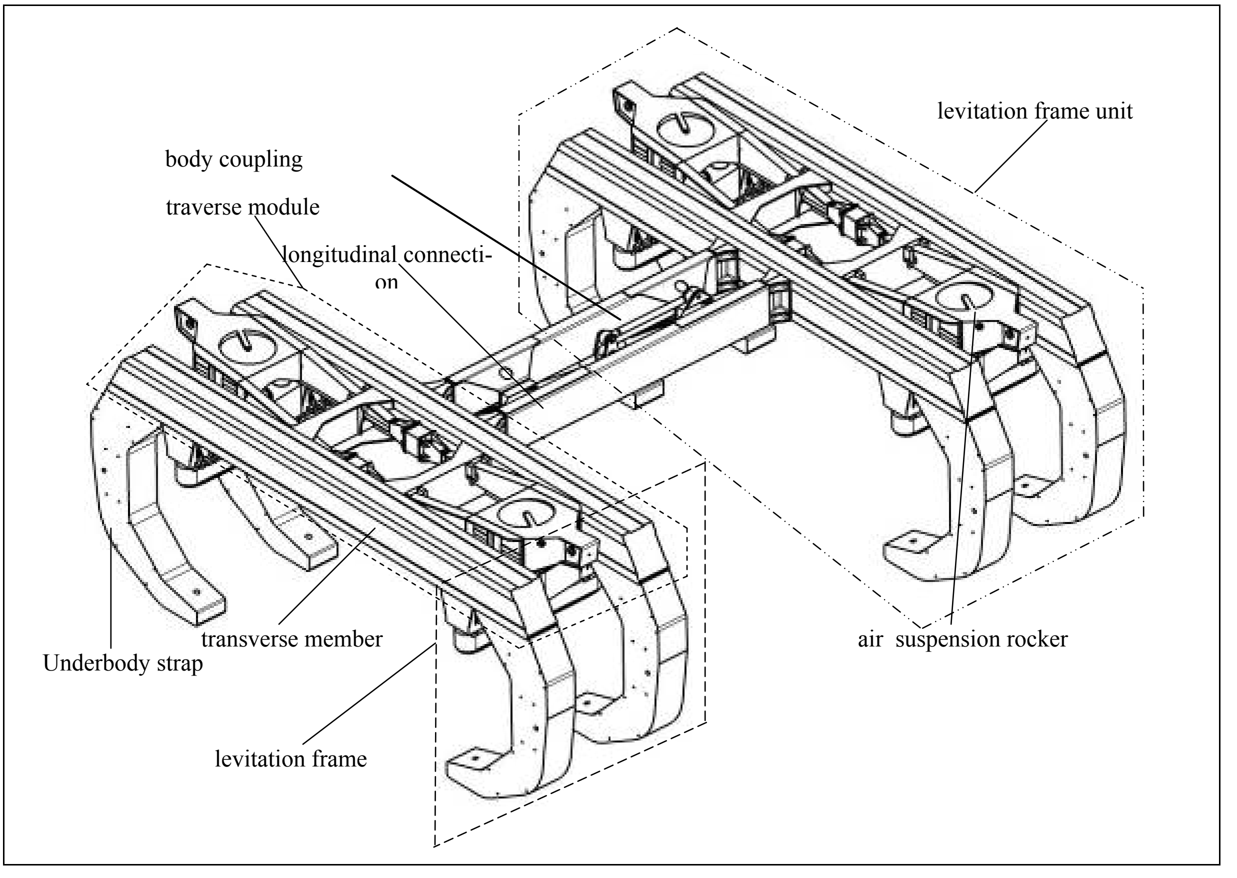
- Fig. 55: *Designations of fairing elements of body and support/guidance system (schematic diagram)*



- Fig. 56: *Designations of essential assemblies of the support/guidance system (schematic diagram side view)*



- Fig. 57: *Designations of essential assemblies and dimensions of the support/guidance system (schematic diagram cross-section)*



• Fig. 58: *Designations of essential assemblies of the underbody structure (schematic diagram)*

General requirements

Function

- This is covered by the description in /MSB AG-GESAMTSYS/.

Design of mechanical components

Fundamental design principles

- The design of load-transmitting structural and fairing parts as well as of externally mounted and built-in components which do not perform a load-transmitting function shall be governed by Part II /MSB AG-FZ BEM/.

Collision behaviour

The obstructions defined in /MSB AG-GESAMTSYS/ shall be regarded as a representative spectrum of collision-causing obstructions which can get into the free space of the vehicle due to environmental or third-party influence.

Collision behaviour shall be determined using numerical simulation calculations und assessed with regard to the impact on vehicle structure and human safety.

In order to obtain the collision behaviour specified in /MSB AG-GESAMTSYS/, chapter 5.4.7.2, the following requirements shall be met:

- no separation of support skids and magnets from the vehicle structure,
- no deformation of cable ducts leading to the failure of safety-related functions,
- no passenger compartment deformation which could pose a threat to personal safety *(deformation with possible threat to personal safety is limited to the end section nose)*.
- The acceleration acting on the entire vehicle caused by collision in accordance with defined scenarios shall be tolerated by the assemblies not directly affected by the collision in such a manner that they do not become detached and hence do not affect personal safety.

The nose space shall not be accessible to passengers. The nose space is not a workplace.[2]

[2] If the nose space is defined as a workplace, the collision scenarios shall take this into consideration.

Safety requirements

Safety-related functions

A safety certificate taking account of the requirements arising from the project-specific safety concept (see also /MSB AG-FZ TRAFÜ/ and /MSB AG-FZ BREMS/) shall be furnished for the following functions:

- Support and guidance,
- Safe braking,
- On-board energy supply.

Other safety-related functions and equipment shall be implemented and certified in accordance with the relevant Standards. See Chapter 0, Annex for definition and certification. The list of acceptance requirements in Chapter 0, Annex is based on experience gained on railways and high-speed maglev systems.

/EN 50128/ shall be used for software-implemented safety-related functions.

Fire safety

Fire safety design

In the fire safety design of the vehicles due regard shall be paid to the safety objectives given in Design Principles Complete System Chapter 5.4.1.1.

Essential fire safety requirements are specified in /MbBO/ (Chapter 4 Vehicles, Section 17 (5). This relates, among other things, to classification of the maglev vehicle according to DIN 5510-1, fire safety level 4, as well as to the fact that in the event of fire in one vehicle section, people must be protected for at least 30 min. in the other vehicle sections pending rescue.

The subject-specific regulations from /BrandReg/ shall be used[3)] to the extent applicable to the fire safety design and acceptance of maglev vehicles.

The fire safety requirements of the MbBO are covered by /BrandReg/.

Based on /BrandReg/, the maglev vehicle for passenger transportation corresponding to vehicle type “electric and diesel train units – d” (Chapter 3.2) must be operated with the classification E4 (Chapter 3.3) if side evacuation is impossible or presents considerable difficulty on a section of more than 500 m.

[3)] The scope of /BrandReg/ relates to rail vehicles. /BrandReg/ does not cover automatically propelled trains. The acceptance of maglev vehicles is effected according to Section 6, /MbBO/.

The manufacturer shall draw up a vehicle-related fire safety concept (FSC). This shall be used as the basis for the fire safety design and certification of the vehicle as well as for the safety concept in accordance with /MbBO/. Here special allowance shall be made for the fact that during automatic operation there may be no trained personnel in the vehicle.

One component of the FSC shall be a consideration of fire risks and their possible impacts. Here there shall be an indication of the system-specific interlinking of engineering, structural and operational measures.

In accordance with /MbBO/, Section 17 (5) (4), the vehicles shall be equipped with automatic fire alarms and portable fire extinguishers. The fire extinguishers shall be kept in easily accessible locations inside the vehicle and clearly labelled. They shall be distributed uniformly throughout the length of the vehicle and provided at the ends of the vehicle.

In addition to this, the following areas shall be monitored by fire alarms:

- all areas accessible to passengers,
- the fresh air supply,
- toilets (*if present*),
- separate engineering areas and separate luggage areas (*depending on the fire risk*).

When the fire alarm device is activated, the fire alarm shall sound in the vehicle and immediately be transmitted to the operations centre and displayed there. Automatic control procedures shall be triggered by the fire alarm system installed in the vehicle. *For example, this includes shutting down the air treatment system, if there is one, and triggering the fire-fighting system.*

The engineering equipment of the vehicle shall be designed as far as possible to preclude the starting of a fire, and so that the impacts with reference to the safety targets defined in /MSB AG-GESAMTSYS/, Chapter 5.4.1.1 remain acceptable. The specification of the equipment shall be based on the fire risk analysis, among other things.

With reference to the safety targets defined in the Implementation Bases Complete System Chapter 5.4.1.1, the requirement with regard to a fire event focussing on "waiting areas" is fleshed out as follows:

A possible fire event in a vehicle section or in the engineering area shall not lead to loss of the support, guidance or safe braking functions, or of vehicle stability or vehicle-side operational control engineering, at least for the period required to reach a suitable stopping place for evacuation[4]. Over this period and the evacuation period the people waiting in the vehicle shall be guaranteed conditions acceptable for health.

With regard to minimising the danger to rescue teams, technical installations not associated with an emergency function shall be shut down. This shall be indicated to the rescue teams in suitable form. If this is not possible, an appropriate shutdown device shall be provided on the vehicle.

If necessary, further fire safety measures shall be laid down on a project-specific basis, depending on the operational function and defined operational boundary conditions.

[4] Suitable stopping places for evacuation must be laid down on a project-specific basis.

Fire safety certification

With due regard to the certification requirements listed in /BrandReg/, individual certificates shall be provided for the following, depending on the transport function (e.g. passenger transport):

- Fire safety certificate of suitability of materials used
  (*e.g. seats*),
- Certificates for fire compartmentalising assemblies and functions
  (*e.g. end doors*),
- Proof of functionality of electrical safety equipment
  (*e.g. contactors*),
- Proof of functionality of fire detection systems and fire-fighting systems, if present,
- Proof of the support/guidance function of the high-speed maglev system;
  the magnetic support function of the vehicle gives the motivity of the vehicle together with the operational viability of the drive,
- Proof of functionality of operational control engineering equipment in the vehicle, see /MSB AG-GESAMTSYS/, chapter 5.4.1.2.2.1;
  the fire safety features of the vehicle's operational control engineering equipment shall be covered as part of vehicle fire safety testing,
- Proof of functionality of communications equipment
  (*e.g. emergency call equipment*),
- Proof of functionality of emergency exits (*e.g. door opening from inside*) and rescue equipment (*e.g. ladders*),
- Installation plans for fire safety aids (*e.g. fire extinguishers*) and communications equipment (*e.g. monitors*) as well as signs (*e.g. pictograms*),
- Proof of third-party rescue facilities (*e.g. emergency door opening from outside*),
- Proof of equal safety for measures deviating from regulatory requirements (*e.g. material requirements*),
- Proof of an adequate time span for passenger evacuation based on the "passenger compartment" design fire scenario at a continuously increasing heat release rate to a maximum value of at least 120 kW after 5 min. (minimum fire load of 136 MJ as well as calorific value at 21 MJ/kg);
  a different specification may be agreed on a project-specific basis, depending on transport function.

Body

Characteristic body bending frequency: see /MSB AG-FZ BEM/, proof of rigidity.

The data specified in /MSB AG-FZ TRAFÜ/ applies to fairing parts and the seals thereof.

Lighting system

Once the on-board electrical system has been inactivated, emergency lighting in the passenger compartment shall be effective for a period of 1 h, see Chapter 0, (III).

The need for persistent escape signs shall be checked on a project-specific basis.

Support/guidance system, braking equipment

The requirements for the support/guidance system are covered in /MSB AG-FZ TRAFÜ/.

The requirements for the braking equipment are covered in /MSB AG-FZ BREMS/.

The requirements for the on-board energy supply from the S/G system, the braking e-quipment and the operational control equipment integrated in the vehicle are described in /MSB AG-FZ TRAFÜ/.

Battery containers

The supply and removal of air from the battery container housings shall be monitored. See /DIN 57510/, /VDE 0510/ for ventilation periods (e.g. overrun after vehicle shutdown).

The intake and outlet battery container ventilation apertures shall be geometrically arran-ged to preclude battery waste air being sucked in by the air conditioning equipment when the vehicle is moving or at a standstill. Air conduction shall be guaranteed under all cli-matic conditions, including winter.

Inadvertent opening of the containers shall be impossible at voltages over 60V.

Annex Weighing the Maglev Vehicle

Preparation

A project-specific test specification shall be submitted before taking the measurements for the determination of weight.

This serves the purpose of defining the prerequisites, sequence, basic conditions and type of documentation prior to measurement.

The test specification shall include the following essential points:

- Objective and background of measurements,
- Definition of essential basic conditions (e.g. separate section couplings etc.),
- Description of test method (sequence, plausibility checks etc.),
- Planning variables for the trial (e.g. time requirement, boundary conditions in conduct of testing),
- Description of measuring equipment (accuracy class, calibration),
- Description of requisite documentation (tables, photographs etc.).

Terms of reference and boundary conditions

Different terms of reference may apply to the determination of weight for maglev vehicles, depending on target definition and measurement conditions (e.g. section coupling condition / measurement below support skid or back of support magnet).

To determine the vehicle weight for maglev vehicles, the measurements shall be taken at the individual levitation frames of the left and right side of the vehicle in each case.

Two categories may be taken into consideration for the condition of the vehicle during measurement:

- Measurement of vehicle weight without section coupling engaged,
- Measurement with section coupling engaged, the supporting forces transmitted by the section coupling then having to be measured as well.

The following boundary conditions shall be met in order to ensure a representative weight determination:

- The vehicle shall be in the equipped condition (at least with active levelling control).
- The vehicle shall be in the weigher, i.e. the permissible deviations within the support skid bottom edge reference plane are ± 2 mm relative to the skid linings when new. This tolerance applies in relation to the levitation frame currently to be measured, at least to all the levitation frames assigned to the same pneumatic spring circuit, and to

the levitation frames assigned to the adjacent pneumatic spring circuit in the current section belonging to the same pneumatic spring circuit in the adjacent section, the last requirement only relating to the case when measurement is carried out without a separated section coupling. These conditions apply in the further course of the text if this tolerance is named.

- The whole train must have levitated completely at least once prior to measurement, so that internal distortion forces are reduced.
- The bellows present in section transition areas shall be dismantled during measurement in order to preclude any force transmission through same.
- When weight is determined without first detaching the section coupling, the coupling forces transmitted shall also be measured.
- During sequential measurement, i.e. when the weight is not measured simultaneously at all levitation frames, sufficient repeat measurements shall be carried out in order to preclude the influence of any existing distortions or other error sources.
- The tolerance of the measuring equipment shall not exceed ± 2 %.

The weight of the vehicle may be measured at various locations.

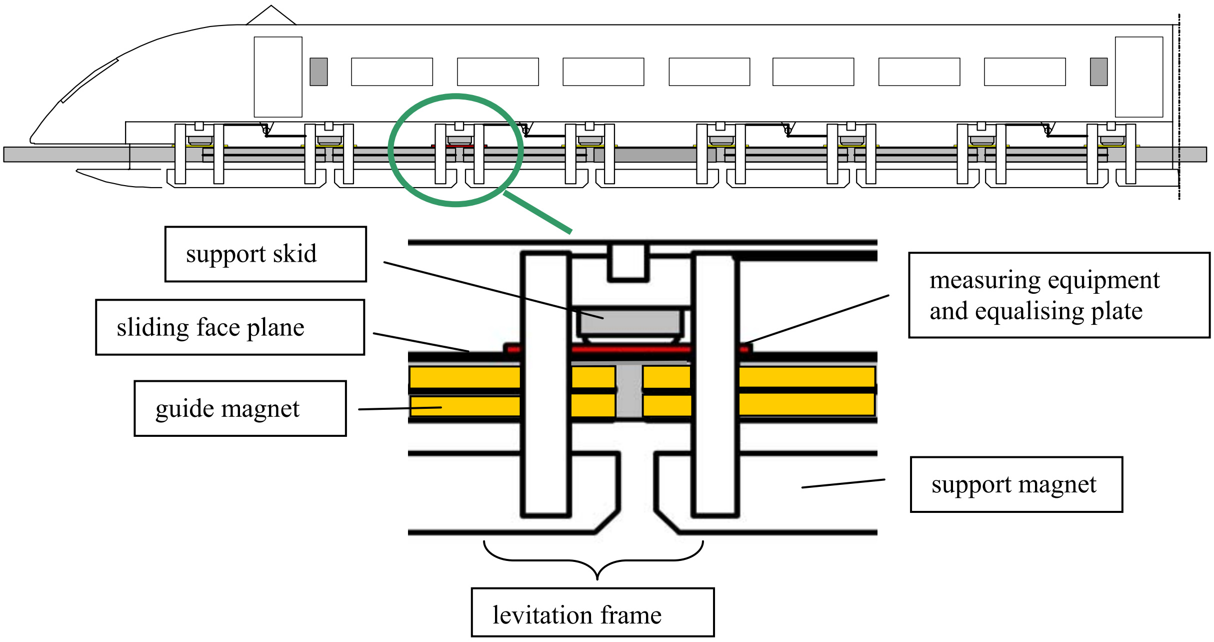
Two commonly used methods and the boundary conditions specifically to be taken into account are described below.

As a rule measurement is accompanied by a weight statement tracking the changes caused by items fitted and/or removed.

Any deviation from the specified procedure before or during measurement shall be agreed on a project-specific basis.

Measurement below support skids

When measurements are taken below the support skids, the measuring equipment must be located between the support skid and sliding face or top guideway edge with the vehicle lowered.



- Fig. 59: *Schematic diagram for the method of measurement beneath the support skid*

During measurement, care shall be taken to comply with the maximum deviation of ± 2 mm in the plane of the support skid bottom edges. It shall also be ensured that the levelling control is in the steady state.

The following applies to measurement:

- For simultaneous measurement at all levitation frames of the section, measuring equipment is placed beneath the support skids.
- For sequential measurement, the section is completely packed underneath with equalising plates which are successively exchanged for measuring equipment of the same height.

In the aforementioned measurement method beneath the support skids it may be possible to achieve easier introduction of the measuring equipment (weighing plates between support skids and guideway) with a different parameter set (smaller support gap).

Measurement beneath the backs of the support magnets

When determining the vehicle weight beneath the backs of the support magnets, the measuring equipment must be located between support magnet bottom edge and a support (e.g. prop). In this measurement method the vehicle shall be lowered onto the supports from the levitating state. It shall be ensured that the support skids have no contact with the guideway during measurement.

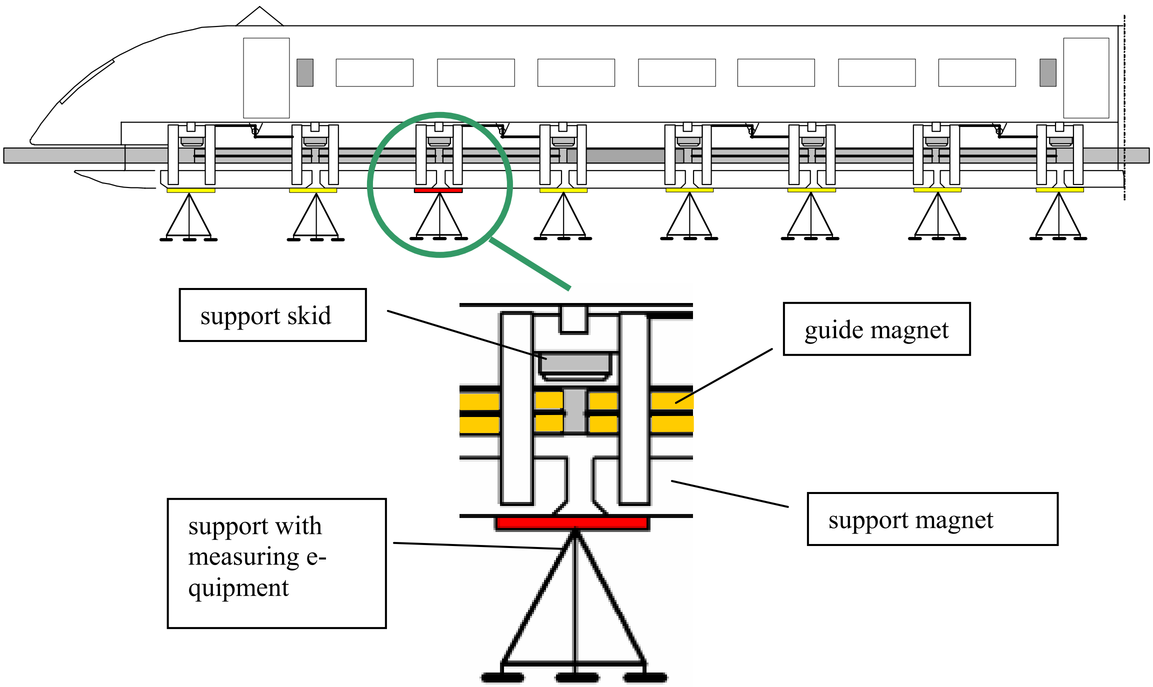


Fig. 60: *Schematic diagram of the method of measurement beneath the backs of the support magnets*

Care shall be taken not to exceed a deviation of ± 2 mm in the plane of the support skid bottom edges during measurement. Here it shall also be ensured that the levelling control is in the steady state.

It is recommended that reference marks be introduced in order to comply with the tolerances relative to the support skid bottom edges. However these should not be located in areas of which the geometric position (relative to the bottom edge of the support skids) is influenced by the introduction of a load to the underbody straps.

The following applies to measurement:

- For simultaneous measurements at all levitation frames of the section, measuring equipment shall be placed at an appropriate height beneath the backs of the support magnets and the vehicle lowered on top.
- For sequential measurement, the section shall be supported completely at the appropriate height beneath the backs of the support magnets. To determine the weight at individual levitation frames, the supports shall be successively replaced by a support with integrated measuring equipment.

Supplementary measured quantities

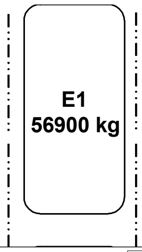
In order to ensure that recording of the relevant influencing factors is as complete as possible when taking weight measurements, the additional measurement of the pneumatic spring pressures and the vehicle's levelling position is advisable.

When determining the vehicle's weight and simultaneously measuring the coupling force, it is advisable to take further measurements with an extra weight (mass > 500 kg) at various x-positions in the body, so as to mathematically simulate the influence of a variable payload on the support behaviour of the section coupling.

Evaluation

The evaluation of the weighing shall list the weights determined at all levitation frames, in each case separately by left and right side of the vehicle. This data shall be supplemented by the calculated total weight of the individual sections. For a visual representation of the weight distribution over the total length of the vehicle, a supplementary schematic drawing similar to Fig. 61 is recommended.

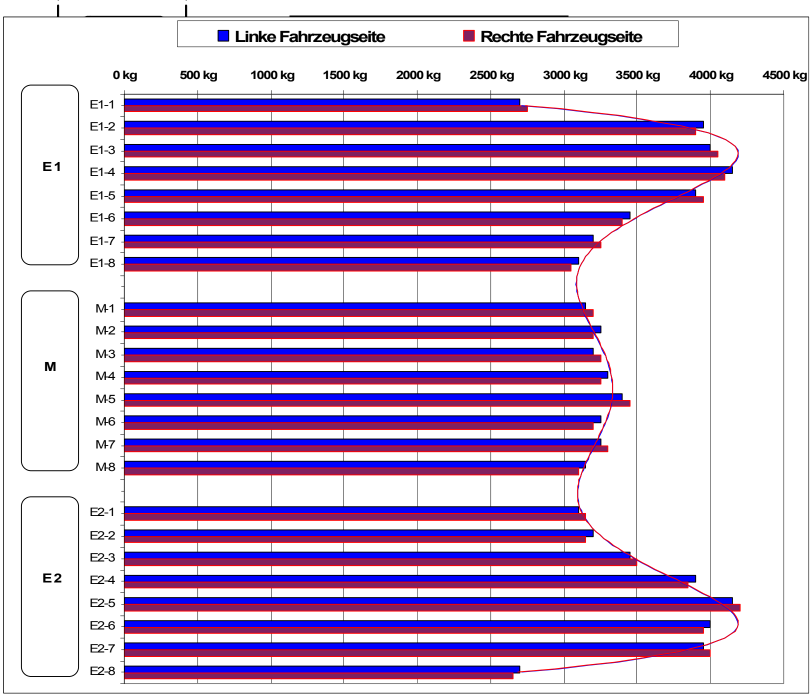
E1-SR1-L	2700 kg
E1-SR2-L	3950 kg
E1-SR3-L	4000 kg
E1-SR4-L	4150 kg
E1-SR5-L	3900 kg
E1-SR6-L	3450 kg
E1-SR7-L	3200 kg
E1-SR8-L	3100 kg



2750 kg	E1-SR1-R
3900 kg	E1-SR2-R
4050 kg	E1-SR3-R
4100 kg	E1-SR4-R
3950 kg	E1-SR5-R
3400 kg	E1-SR6-R
3250 kg	E1-SR7-R
3050 kg	E1-SR8-R

M-SR1-L	3150 kg
M-SR2-L	3250 kg
M-SR3-L	3200 kg
M-SR4-L	3300 kg
M-SR5-L	3400 kg
M-SR6-L	3250 kg
M-SR7-L	3250 kg
M-SR8-L	3150 kg

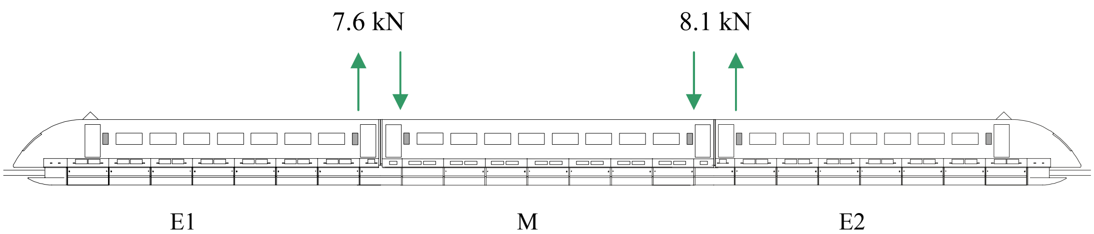
E2-SR1-L	3100 kg
E2-SR2-L	3200 kg
E2-SR3-L	3450 kg
E2-SR4-L	3900 kg
E2-SR5-L	4150 kg
E2-SR6-L	4000 kg
E2-SR7-L	3950 kg
E2-SR8-L	2700 kg



- Linke Fahrzeugseite = left side of vehicle; Rechte Fahrzeugseite = right side of vehicle

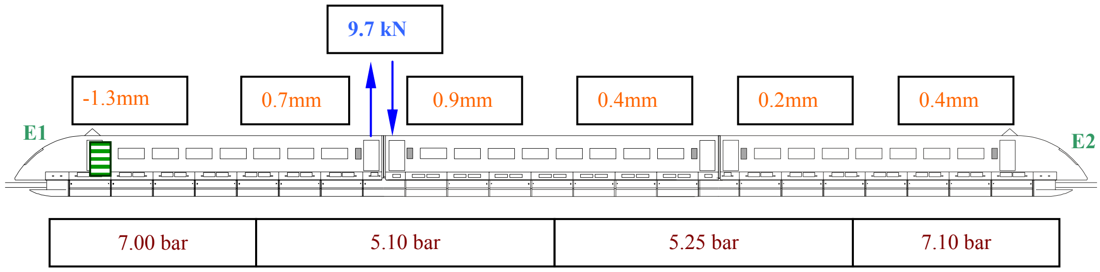
- Fig. 61: *Example of measurement results for a vehicle with three sections in the form of a table and chart (hypothetical measured values)*

A schematic diagram like the example shown in Fig. 62 is recommended for giving the coupling supporting forces and their effective direction. This shall clearly show how the force acts on the different components.



- *Fig. 62: Example of a schematic diagram for the coupling supporting forces and their effective direction on a vehicle with three sections*
- **(Arrows show the direction of force with which the sections act on the coupling bolts / hypothetical measured values)**

If the weight measurements are supplemented by the quantities given in Chapter 0, a representation according to the schematic diagram illustrated as an example in Fig. 63 is recommended. The graphics should show the pneumatic spring pressures, the levelling position of the body, the measured coupling supporting force and the position of the extra weight ().



- *Fig. 63: Example of a schematic diagram showing the supplementary measured quantities for pneumatic spring pressure, levelling position, coupling supporting force and position of the extra weights on a vehicle with three sections*
- **(showing individual measurement in which one coupling force is measured / hypothetical measured values)**

Documentation

The documentation of weighing serves to ensure the reproducibility of measurement results.

Documentation shall contain the elements below:

- Weighing sequence (particularly for sequential measurement of individual levitation frames) and status of section couplings,
- Note on the weight of the missing transition magnets if individual sections are measured,
- Documentation of the vehicle's equipment status using a list and/or photographs (missing or additional components etc.),
- Representation of results of additional measurements for plausibility testing,
- Calibration results of measuring equipment.

Annex List of requirements for acceptance (example)

Requirements for the acceptance of high-speed maglev system vehicles in accordance with Section 6 (1) /MbBO/.

The attached checklist serves as an example. It shall be agreed on a project-specific basis between the approval authority, the high-speed maglev system operator and the vehicle supplier, together with Standards and test and certification procedures to be used.

The list of requirements for acceptance included in this Chapter is based on experience gained on railways and high-speed maglev systems. It supplements /MSB AG-NORM&RILI/.

In the "Documents" column the certification documents relating to the relevant features shall be named on a project-specific basis.

Overview:

I. General
II. Basic vehicle parameters
III. Vehicle requirements
IV. Construction and fabrication requirements
V. Body requirements
VI. Support/guidance system
VII. Software
VIII. Braking equipment
IX. Systems subject to monitoring
X. Interior equipment
XI. On-board energy supply / electrical equipment
XII. Controls and communications, other safety equipment
XIII. Environmental protection provisions
XIV. Occupational safety / personal safety
XV. Fire safety

I. General

1	Filing of application	Filing of application		Including a declaration as to the section or route network on which the vehicle will be used within the scope of AMbG.
2	Declaration on compliance with MbBO	Declaration that no deviation from the standards of the MbBO is intended and that MbBO standards will be complied with.	Section 3 MbBO Section 5 MbBO	
3	Declaration on compliance with accepted code of engineering practice	Declaration that no deviation from the accepted code of engineering practice is intended. In the event of deviations: furnish approval authority with proof of identical safety	Section 3 MbBO Section 3 (2) sentence 2 MbBO	
4	Declaration of compliance with all safety concept requirements	Safety concept (incl. rescue concept) Safety targets Proof of implementation of the measures in the vehicle with detailed reference to the corresponding reference in the safety concept	Section 23 MbBO	Implementation of the safety concept for the section or route network on which the vehicle will be operated. In addition to the requirements directly contained in the MbBO and the accepted code of engineering practice, the safety concept according to Section 23 MbBO may give rise to further requirements from a maglev vehicle. In part these requirements first create the prerequisite for the application of a Standard (e.g. specification of a safety requirement level conforming to DIN EN 50128).
5		Complete system contract specification		Analogous to VwV Section 32 EBO
6		Performance specification		Analogous to VwV Section 32 EBO
7		Certificate of conformity with the principles and procedures for compilation of the maintenance programs	Principles and procedures for the compilation of maintenance programs in accordance with Section 8 (2) MbBO	

8		Interface documents / Complete system contract specification (5), Complete system performance specification (6)	Design Principles Complete System / Design Principles of further sub-systems	
9		Certification of manufacturer's / supplier's quality management system	DIN ISO 9001	The approval authority may conduct a random check on the effectiveness of the quality management sys-tem.

II. Basic vehicle parameters

1	General technical specifications	Technical data on vehicle Performance specification Application for acceptance Section 6 MbBO		
1.1		Designation of vehicle type		
1.2		Vehicle no.		
1.3		Serial no.		
1.4		Year of manufacture		
1.5		Manufacturer		
1.6		Owner/operator		
2		Driving capacity		
2.1	not applicable			
2.2		Operating concept from contract specification / performance specification Maximum velocity, Operational control velocity	See Design Principles Complete System Annex 1	
2.3		Vehicle length		
2.4		▪ Unladen weight ▪ Skid loads ▪ Loads on section couplings ▪ Position of centre of gravity	See Chapter 0, Annex Weighing	Analogous to TETF Practice
2.5		Permissible total weight		

2.6		Max. vehicle weight per unit of length		
2.7		Number of places (number of seats and standing places), persons per unit of area		
2.8		Number of compartments		
2.10		Number of toilets, washrooms		
2.11		Number of other spaces (e.g. luggage stowage spaces)		
2.12		Number of vehicle sections		
2.13		Levitation frames: arrangement and design, number of levitation frames, distance between levitation frames		
2.14		Max. loads acting on support and guidance units	Design Principles Vehicle Part II Design	Shall be derived from contract specification and complete system performance specification
2.15		Drive power	see Point I, (8)	On a project-specific basis, see contract specification and complete system performance specification
2.16		Smallest practicable radius	Design Principles Complete System	

III. Vehicle requirements

1	Vehicle limitation, vehicle kinematics	Drawing, proof in accordance with /MSB AG-BEM/	Section 17 (3) MbBO in conjunction with Annex to Section 14 MbBO and IB Vehicle Part III, Section 14 MbBO	Based on the methodology of UIC 505. The expert report on kinematic vehicle limitation should contain the following statement: "I hereby confirm that the vehicle loading gauge was calculated (according to …..). The loading gauge for the kinematic space requirement of the vehicle shown in the Annex to Section 14 MbBO is not exceeded, not even in cases where ….". Certificate according to IB Vehicle Part III
2	Signal equipment	Drawing/ description: - head light - release signal	DS / DV 301 "Signal book"	Deviations shall be agreed on a project-specific basis
3	Vehicle addresses	Drawing/ description; list of signs and addresses	UIC 640 ISO 7001:1990 (pictograms)	Deviations shall be agreed on a project-specific basis
4	Vehicle-side gap bridging in embarkation area	Performance specification	Section 15 MbBO DIN EN 14752 (Railway applications – bodyside entrance systems), compliance with TSI-PRM	If present Ensure coordination with platform doors (Section 15 MbBO)!
5	Malfunction and emergency concept / emergency exit concept	Number, description, drawing with position of emergency exits Safety concept	Section 18 (3) MbBO DIN 5510 EBA Manual Fire Safety in Passenger Transport Systems of the Federal Railways	Differentiation in rescue concept according to Section 23 MbBO: Rescue concept according to Section 23 MbBO lays down emergency concept (relative to complete system). As part of vehicle acceptance pursuant to Section 6 MbBO, checking to see whether the measures within

		Signage concept	/BrandReg/	the safety concept (and rescue concept) as well as the statutory requirements and accepted code of engineering practice have been implemented in the actual vehicle.
6	Pressure tight-ness / Pressure viability	Contract specification Performance specification	UIC 660 /MSB AG-GESAMTSYS/	Shall be derived for subsequent implementation from contract specification and complete system performance specification
7	Pressure wave effects	Contract specification Performance specification		Shall be derived for subsequent implementation from contract specification and complete system performance specification
8	Climatic envi-ronmental condi-tions	Contract specification Performance specification	In accordance with /MSB AG-Environment/	To be stipulated on a project-specific basis. Official explanatory notes to Section 17 MbBO: the vehicles shall meet all the operating and environ-mental conditions to be covered
9	Aerodynamics	Performance specification	En 14067, UIC 660, DB RIL 807-04 (side wind)	

IV. Construction and fabrication requirements

1	Bolted joints	Drawings/ descriptions/ testing of structure for proof against loss; Performance specification Setting the scope of certification and certification procedure (if necessary experimentally)	Environmental requirements in the relevant installation space DIN 25201	Securing of bolted joints Proof against loss is particularly important in maglev vehicles, as the guideway gradient is considerably greater than in railways and the velocities are also higher as a rule.
2	Rivet joints	Drawings Setting the scope of certification and certification procedure (if necessary experimentally) Test report on relevant component tests		Project-specific certification required. Frictional connection / positive connection (dependent on rivet type and material pairing)
3	Welded assemblies	Drawings	"Administrative Directive for requirements for the welding of rail vehicles and parts within the purview of the EBA"; DIN 6700	Particularly DIN 6700 Part 2 → EBA-recognised specialist welding companies!
4	Adhesive joints	Drawings/ descriptions/strength certificates/ Manufacturing procedure for vehicle construction (bodywork mechanics)	DIN 6701, Part 1 and 2 DVS Fact sheet M 1618 (01/2002 edition) Elastic thick layer adhesion in rail vehicle construction	For elastic thick layer adhesive joints (nose)

V. Bodywork requirements

1	Determination of vehicle weight	Mathematical proof and proof by measurement	The measurement method is described in Chapter 0 of this document.	
2	Vehicle construction	General drawing (shell and levitation underbody) with dimensioning; vehicle body measurement (drawing and measurement sheet) Statement of materials used (load transmitting parts) Arrangement of individual components Jointing procedures		
3	Determination of position of centre of gravity	Mathematical or experimental proof		Each vehicle section
4	Representation of lifting points	Drawings, Transportation requirement		All lifting points shall, where applicable, be indelibly marked on the hardware concerned
5	Clearance at ends of vehicle	Drawing Description clearance at coupling end	UIC 521, Couplings.	If present
6	Bodywork of one section including equipment	Proof relating to collision scenarios	Contract specification/performance specification Section 17 (2) MbBO MSB document Basis of Dimensioning IB Vehicle Part II, IB Complete System	Section 17 (2) MbBO: "The impact of the vehicle on the guideway shall not exceed the impact allowed for during guideway design". The impact shall be derived for subsequent implementation from contract specification and complete system performance specification.
7	Coupling of sections	Description of construction, mathematical and experimental proof	Section 20 (2) MbBO UIC 572 IB Vehicle Part II	

			The measurement method for determining the loading of the section coupling is described in Chapter 0 of this document.	
8	Externally moun-ted components	Drawing/ description/ proof of structural durability and proof against loss under the environmental conditions ruling at the in-stallation location Contract specification/ performance speci-fication	IB Vehicle Part II	Example: radome
9	Transitions	Drawing/ description	Contract specification / performance specifi-cation	
10		External panes	Section 18 (1) MbBO	
10.1	Windscreens (where present)	Drawing / description	UIC 651 TSI HGV Vehicles: Chapters 6.3.2 and 4.3.19	Criteria: ▪ Optical quality ▪ De-icing, condensation prevention. Windscreen cleaning effected according to pro-ject-specific terms of reference. ▪ Projectile strike
10.2	Side windows	Drawing / description	UIC 564 – 1 UIC 660 UIC 567 BN 918511 PA-1300, DB Systems engineering test pro-gram for window systems, 2005 edition.	UIC 564-1 does not cover the HGV velocity range. HGV side windows are therefore tested under PA-1300, 2005 edition DB Systems engineering test program for window systems. Testing is conducted with reference to UIC 564-1. The load level and number of load cycles shall be agreed on the basis of the usage spectrum (load collective) and meaningful additions.
11	Doors		Section 18 (1) MbBO	

11.1	Entrance doors	Safety concept Departure preparation procedure Drawing / description Proof of safety functions under given environmental conditions according to contract specification	Section 18 (2) (1) and (2) MbBO VDV 111 DIN EN 14752 UIC 560 UIC 566 DIN 32974 (Acoustic signals)	Cf. also official explanatory notes on Section 18 MbBO: “Door locking according to paragraph 2 is of particular importance at high velocities.” Automatic door locking when the vehicle is not lowered shall be defined by means of risk analysis. Description of the interaction of vehicle door, platform door and gap bridging.
11.2	Section transition doors	Drawing / description Safety concept Proof of safety functions	Section 17 (5) (3) MbBO if necessary DIN 5510 VDV 111 DIN EN 14752 UIC 560	If necessary Section 17 (5)(3) MbBO: 30 min – criterion
11.3	WC doors	Drawing / description		
12	Handles, hand rails, steps	Drawing / description	According to pertinent Railway Standards	
13	Fastening devices for luggage containers	Drawing / description		Movement of containers may be safety-related

VI. Support/guidance system

1	Support/guidance structure (levitation frame, support and guidance magnets) Support skids etc.	Proof of static and dynamic strength (mathematical and / or experimental) Details of materials used, particularly support skids: Thermal behaviour Mechanical behaviour, breaking strength Wear Coefficient of friction support skid / sliding face	Implementation |Basis Vehicle Part IV Support /guidance system & Part II Design	Nominal values shall be set on a project-specific basis.
2	Functions of levitation engineering: ▪ safe support function, ▪ safe guidance function in conjunction with safe on-board energy supply	Safety concept Drawings/ descriptions: ▪ Gap measurement units ▪ Magnet controls ▪ Failure behaviour	Design Principles Vehicle Part IV Support /guidance system	
3	Vertical loads, transverse forces, longitudinal forces	Proof that max. vertical loads plus transverse and longitudinal forces are not exceeded	Design Principles Part IV T/F System and Part II Design	

VII. Software

1	Classification of software	Classification as ▪ Non safety-related software, safety requirement level (SRL) = 0 or ▪ Safety-related SRL > 0	EN 50128 *EN 61508*	Examples: ▪ Support /guidance system ▪ On-board energy supply ▪ Braking equipment ▪ Door controls ▪ Air conditioning equipment ▪ Fire safety equipment ▪ Communications equipment
2	Safety-related functions	e.g.: ▪ Brakes, ▪ Embarkation and debarkation, ▪ Interfaces to train protection etc. ▪ all equipment which ○ engages with the functional train control system, ○ causes the station master to act, ○ diagnoses temperatures or fumes.	Safety concept EN 50128 Guide for the application of EN 50128 to rail vehicles (09/2005 Edition)	
3	Software creation process	Expert opinion on execution of the Standard	EN 50128	The experimental model shall be executed with the SRL hereby formed in accordance with the applicable level of EN 50128. All steps shall be documented and filed and if necessary validated by the expert.

VIII. Braking equipment

		Brakes		
1	Braking equipment	▪ Drawing, ▪ Performance specification, ▪ Description of braking system, components and operation, braking calculation, ▪ Service brake, safe brake, stop brake etc. ▪ Brake testing.	Section 20 MbBO in conjunction with Section 13 Design Principles Vehicle Part V	Boundary conditions on a project-specific basis according to contract specification / performance specification
2	Brake engineering tests	Braking power etc.		Boundary conditions on a project-specific basis according to contract specification / performance specification

IX. Systems subject to monitoring

1	Pressure vessel systems (pneu-matic springs etc.)	Description of system with air requirement calculation General drawing of vehicle with position of pressure vessels, safety valves and pressure control devices and pipeline configuration Pipe connection diagram, vessel drawing with parts list Declaration of conformity according to Article 11 of Directive 87/404 EEC or test certificate issued by a recognised expert Certificate for component-tested safety valves according to AD Fact Sheet A2, paragraph 10 Compressor ratings Commissioning certificate, test certificates of the technical expert according to TRB 505, 511,512, 513, and pre-commissioning test certificate according to Section 21 (2) MbBO Maintenance requirements Operating instructions	Section 21 MbBO in conjunction with "Directive for systems of Federal Railway vehicles subject to monito-ring under Section 33 EBO", Issued: 1.11.2003, in particular Annex 2 Pressure Equipment Directive 97/23/EC AD 2000 DIN EN 286-4 DIN 31051	

2	Batteries incl. ventilation	Description of system, drawings, etc. ▪ Safety ▪ Earthing	DIN 57510 VDE 0510 Contract specification/performance specification Safety concept Section 21 MbBO in conjunction with “Directive for systems of Federal Railway vehicles subject to monitoring under Section 33 EBO”, Issued: 1.11.2003, in particular Annex 4.7	

X. Interior equipment

1	Passenger compartment	Description/drawing	Section 17 (1) MbBO in conjunction with Section 3 (3) MbBO Disabled Equality Act [Behindertengleichstellungsgesetz (BGG)] TSI vehicles: Chapter 7.4.3 (Study COST 335) Compliance with DIN 33402-1 and DIN 33402-3 TSI PRM UIC 565-3 UIC 563 Federal Ministry of Transport, Construction and Housing [BMVBW] - Manual “direct”, 56/2001 Computer-aided detection and evaluation of barriers Deutsche Bahn AG program (Publisher: DB Personenverkehr, P.VMX, 06.2006)	Ease of access for people with disabilities; installation of secure wheelchair places; possibly Federal Register 49 (USA)

2	Interior trim	Description/drawing of ▪ insulation ▪ floor construction ▪ partitions ▪ wall cladding ▪ ceilings ▪ materials used ▪ luggage and coat hooks ▪ mirrors and other glass components ▪ restraining equipment ▪ seats ▪ restraints for wheelchairs Performance specification	Section 18 (1) MbBO DIN 5510 / level 4 in conjunction with /BrandReg/ UIC 562 UIC 564 – 1 DB TT73 Basic principles for the constructi-on and testing of passenger seats in rail ve-hicles Deutsche Bahn AG program (Publisher: DB Personenverkehr, P.VMX, 06.2006)	
3	Side corridor	Description/drawing	UIC 567 - 1 UIC 567 - 2	
4	Vestibules	Description		
5	Air conditioning	Description / drawing / certificates ▪ vibration test ▪ performance test ▪ CO_2 content ▪ emergency lighting	Safety concept EN14750-1 and EN 14750-2 EN 13129-1, EN 13129-2, DIN EN 61373 in conjunction with /MSB AG-FZ BEM/	Classification in Cat. A or B is made on a project-specific basis according to EN 14750-1.
6	WC	Description		where present
7	Drinking water	Approval certificate	Section 72 Infection Protection Act [Infekti-	where present

	system	Drawing with parts lists Description	onsschuzgesetz (IfSG)], Section 23 Drinking Water Order [Trinkw-VO] in conjunction with Directive on "Exercise of official supervision under Section 72 of the Infection Protection Act in the Federal Railways sphere in drinking water supply and waste water removal installations in rail vehicles and fixed installations for the filling and disposal thereof"; EN1508 DIN 1988 Codes of Practice for drinking water installations DVGW Code of Practice W270: Multiplication of micro-organisms on materials for the drinking water sphere KTW Plastics and drinking water	
8	Service water system	Drawing	EN 1508	where present
9	Wastewater system	Drawing	Water Management Act [Wasserhaushaltsgesetz (WHG)] UIC 563	where present
10	Repeater	Functional description, incorporation in EMC plan	See XI, 2	where present
11	Emergency escape windows	Functional description	Regulation for the testing of emergency entrance and exit windows in rail vehicles, EBA, 27.03.2006, (http://www.eisenbahn-bundesamt.de/Service/files/31_32_33_6_1_VwV_NEA.pdf)	where present

XI. On-board energy supply / electrical equipment

1	Current collector	Description of type, drawing, strength calculation, determination of loads acting on the conductor rail	EN 50121	where present EMC rail applications
2	Electrical equipment	Description ▪ Block diagram/ flow diagrams ▪ Supply from linear generator / batteries/ conductor rail ▪ Earthing concept (impedance test), in particular earthing via the support skids ▪ High-voltage test (test report) ▪ Lightning protection ▪ Electromagnetic compatibility (EMC) test ▪ Safety precautions relative to electrical hazards	Section 17 (4) MbBO EMVG Act relating to the electromagnetic compatibility of equipment, EN 50121 EMC Rail Applications RL 89/336/EC Electromagnetic Compatibility Directive EBA Supplement on compliance with electromagnetic compatibility (EMC) limit values by rail vehicles DIN EN 50155 **VDE 0115-200**:2004-01 Rail applications – Electronic devices on rail vehicles – German version EN 50155:2001 + A1:2002 + Corrigendum 2003	Electric strength according to VDE 0160 Electric field strength according to DIN EN 61000-4-3 = VDE 0847-4-3 Magnetic field strength according to DIN EN 61000-4-8 = VDE 0847-4-8 Burst according to DIN EN 61000-4-4 = VDE 0847-4-4 Surge according to DIN EN 61000-4-5 = VDE 0847-4-5 ESD according to DIN EN 61000-4-2 = VDE 0847-4-2 Induced disturbance variables according to DIN EN 61000-4-6 = VDE 0847-4-6 Overvoltages according to DIN EN 50178 = VDE 0160 Standards according to test specifications DIN EN 50121-1 **VDE 0115-121-1**:2001-05 Rail applications – Electromagnetic compatibility - General – German version EN 50121-1:2000 DIN EN 50121-2 **VDE 0115-121-2**:2001-05

				Rail applications - Electromagnetic compatibility – Total rail system interference emission to the outside world – German version EN 50121-2:2000 DIN EN 50121-3-1 **VDE 0115-121-3-1**:2001-05 Rail applications - Electromagnetic compatibility – Rail vehicles – Train and complete vehicle - German version EN 50121-3-1:2000 DIN EN 50121-3-2 **VDE 0115-121-3-2**:2001-05 Rail applications - Electromagnetic compatibility – Rail vehicles - Equipment - German version EN 50121-3-2:2000 DIN EN 50121-4 **VDE 0115-121-4**:2001-05 Rail applications - Electromagnetic compatibility – Interference emission and interference resistance of signal and telecommunications equipment - German version EN 50121-4:2000 DIN EN 50121-5 **VDE 0115-121-5**:2001-05 Rail applications - Electromagnetic compatibility – Interference emission and interference resistance of fixed installations and equipment of the rail energy supply - German version EN 50121-5:2000
3	Lighting / Emergency lighting	Description Performance / service life	UIC 555, Safety concept EN 13272 EN 50172	Application EN 50172 on a project-specific basis (on decision to use e.g. persistent escape sign)

XII. Controls and communications, other safety equipment

1	Control enginee-ring (hardware/ soft-ware)	Description / safety certificate of signal processing	DIN EN 50155 **VDE 0115-200**:2004-01 Rail applications - Electronic equipment on rail vehicles - German version EN 50155:2001 + A1:2002 +Corrigendum 2003 DIN EN 50126 IEC 61508 DIN EN 50128 EBA Fact Sheet Guide for the application of EN 50128 on rail vehicles (Issue 09/2005)	
2	Emergency call equipment / Loudspeaker system for broadcasting	Description / certificates	Safety concept Section 18 (2) number 3 MbBO TSI Vehicles: Chapter 4.3.16	
3	Emergency ligh-ting	see Lighting	EN 13272	XI.3
4	Emergency ven-tilation	see Air conditioning		X.5
5	Emergency door release	see Entrance doors		V.11

XIII. Environmental protection provisions

1	Safety data sheets	Application Fact Sheet Mid Section Application Fact Sheet End Section		Comparable ICE specimen
2	Sanitary installa-tions	Proof of environmental compatibility of sanitary installation	UIC 567 UIC 563	where present
3	Absence of as-bestos	Declaration / proof	Asbestos Prohibition	
4	Absence of CFCs	Declaration / proof	CFC- Halogen Prohibition Order	
5	Outside noise	Proof of sound emission	High-speed Maglev System Order Article 2: Maglev Noise Abatement Order Design Principles Complete System Annex 5 DIN EN ISO 3095	
6	Recycling		VDI-2243	

XIV. Occupational safety / Personal safety

1	Occupational safety	Proof of compliance with occupational safety ▪ Measurement and evaluation of whole-body vibration ▪ Light conditions in passenger compartments	Contract specification UIC 651 DIN 45641 ISO 2631 UIC 513 EN 13272 ERRI B 153 VDI 2057	Where work spaces are provided. Efforts should be made to obtain the opinion / participation of the responsible accident insurer.
2	Internal noise		UIC 567 DIN ISO 3381 (11.05) TSI-HGV Vehicles, Chapter 4.2.7.6, Rev. 2006	Fixing of internal noise level project specific TSI relates to driver's cab
3	Protection against electric shocks		MbBO Section 17 (4) EN 50153, EN 50125-1, EN 60309, VDE 0115 Part 2, UIC 533 EN 50215	

XV. Fire Safety

1	Structural design, equipment and concept	Proof of compliance with fire safety provisions	Section 17 (5) MbBO /BrandReg/ (01.06. 2006) DIN 5510 VBG 125 (Fire extinguisher pictogram) DIN 4844 (Safety identification) EN 1363-1 (Component testing fireproof bulkhead) EN 60695 (Test for evaluation of fire risk) DB TT73 Principles for the construction and testing of passenger seats in rail vehicles BN 918 433	Fire safety level 4 See Chapter 0
2	Automatic fire alarm	Description / drawings / certificates (trial)	Section 17 (5) (4) MbBO EN 61508 EBA Fact Sheet "Ionisation smoke alarms in trackbound vehicles"	
3	Portable fire extinguishers	Description / drawing	Section 17 (5) (4) MbBO	
4	Dangers in rescue force access	Safety concept Documents for rescue services: Application Fact Sheet Mid Section, Application Fact Sheet End Section, Emergency equipment		
5	First aid resources	Description	Section 18 (2) (4) MbBO	

High-speed Maglev System
Design principles

Vehicle
Part II
Dimensioning

Distributor

This document was released for publication by the Vehicle Technical Committee.

Summary of amendments

Date of release: 15.02.2007; White Paper, Vehicle Technical Committee.

Table of Contents

LIST OF ILLUSTRATIONS

LIST OF TABLES

General

Objective and scope

- This document contains the non-project-specific requirements for dimensioning of maglev vehicles.

These design principles are applicable to high-speed maglev systems pursuant to the General Maglev Act (German designation: AmbG).

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- Part II of the “High-speed Maglev System Design Principles, Vehicle”
  - lays down the operating conditions, load cases and load case combinations,
  - covers demonstration of load-bearing capacity (static strength, stability and rigidity) and fatigue strength,
  - defines the safety factors for the material parameters to be used,
  - and includes the principles for guaranteeing the structure by means of tests.

The principles for establishing the characteristic and representative values of the loads are contained mainly in MSB AG-GESAMTSYS. The indicated values are based on operating experience and/or are guidelines pursuant to the Maglev Construction and Operation Order (German designation: MbBO) for dimensioning and demonstration of maglev vehicles. The targets in this document represent the current level of knowledge and must be confirmed and/or altered and verified on a project-specific basis. Altered values must be indicated in the project-specific documents (delivery specification, technical reports). If no explicit agreement is reached, the values in this document shall apply.

The operating experience on which this document is based relates to the maglev vehicles TR07 and TR08 on the TVE (Transrapid testing facility) and on the Transrapid Shanghai Project. As a result of this operating experience, it has been verified that, with dimensioning using the targets contained in this document, the loadings which occur during operation, including a sufficient margin, do not exceed the permissible load-bearing capability of the components.

These design principles were drawn up following the existing standards of wheel-rail technology in DIN EN 12663 and DIN EN 13749. The demonstration procedure, which consists of theoretical proof and testing, ands the general requirements regarding strength have been extensively adopted, including the content on materials, safety factors etc. The individual load cases and the load case combinations have been defined specifically for maglev vehicles and therefore differ from these standards.

High-speed Maglev System - Design Principles

This document forms part of reference material for high-speed maglev systems consisting of several design principles.
The documentation tree is shown in figure 1 of MSB AG-GESAMTSYS.
The overarching Design Principles (Overall System) and the annexes thereto apply uniformly to all the reference material:

- High-speed Maglev System Design Principles (Overall System), Doc. No: 50630, MSB AG-GESAMTSYS, with annexes:
  - Annex 1: Abbreviations and Definitions, Doc. No: 67536, MSB AG-ABK&DEF
  - Annex 2: Acts, Orders, Standards and Guidelines, Doc. No: 67539, MSB AG-NORM&RILI
  - Annex 3: Environmental Conditions, Doc. No: 67285, MSB AG-UMWELT
  - Annex 4: Rules for operation (driving and maintenance), Doc. No: 69061, MSB AG-BTR
  - Annex 5: Sound, Doc. No: 72963, MSB AG-SCHALL

The reference material regarding the vehicle includes the following documents:

- High-speed Maglev System Design Principles, Vehicle Part I: General Requirements, Doc. No: 67698, MSB AG-FZ GEN
- High-speed Maglev System Design Principles, Vehicle Part II: Dimensioning, Doc. No: 67694, MSB AG-FZ BEM
- High-speed Maglev System Design Principles, Vehicle Part III: Kinematic Gauge, Doc. No: 67650, MSB AG-FZ KIN
- High-speed Maglev System Design Principles, Vehicle Part IV: Support/Guidance Engineering, Doc. No: 73388, MSB AG-FZ TRAFÜ
- High-speed Maglev System Design Principles, Vehicle Part V: Braking Technology, Doc. No: 73389, MSB AG-FZ BREMS

Abbreviations and Definitions

- The abbreviations and definitions set out in MSB AG-ABK&DEF are applicable.

Acts, Orders, Standards and Guidelines

The standards documents listed in MSB AG-NORM&RILI include provisions which become part of the High-speed Maglev System Design Principles as a result of being referred to in the High-speed Maglev System Design Principles. In the case of dated standards documents in MSB AG-NORM&RILI, subsequent amendments or revisions of these publications are not applicable. In the case of undated references, the latest edition of the standards document in question is applicable.

The status of the standards and guidelines to be taken into account in a maglev project must be laid down on a project-specific basis.

Identification and compulsory nature of the requirements

- Essentially, the rules pursuant to DIN 820 have been used in drawing up this document.
- In the following chapters of this document,
- requirements / targets are identified in standard text
- explanations, standard values and examples are identified in italics
- in accordance with MSB AG-FZGEN.
- If, in particular cases, this document refers to project-specific arrangements, this means that agreement must be reached between manufacturer and contractor (*e.g. in specifications or a contractual arrangement)* with consultation of the licensing authority.

References

Document	Description
DIN EN 12663	Structural requirements of railway vehicle bodies, October 2000
DIN EN 13749	Methods of specifying structural requirements of bogie frames, July 2005

Definitions (subsystem-specific)

Coordinate system

- x-direction: in running direction of the vehicle
- y-direction: at right angles to the running direction
  positive axis in running direction oriented to the right
- z-direction: vertical to the running direction, positive axis oriented downwards
- Origin of the coordinate system is the intersection point of mean perpendicular and sliding surface of the guideway.

•

Articulation forces

• The directions of the forces which are passed via the linkages of the support and guidance magnets to the frame structure, as outlined in Figure 64, are applicable.

• The terms used for the forces are explained in Table 3.

•

• F_{xTM}, F_{zTM}	• Articulation forces of the support magnets
• F_{yFM}	• Articulation forces of the guidance magnets

Table 3: Terms used for the articulation forces

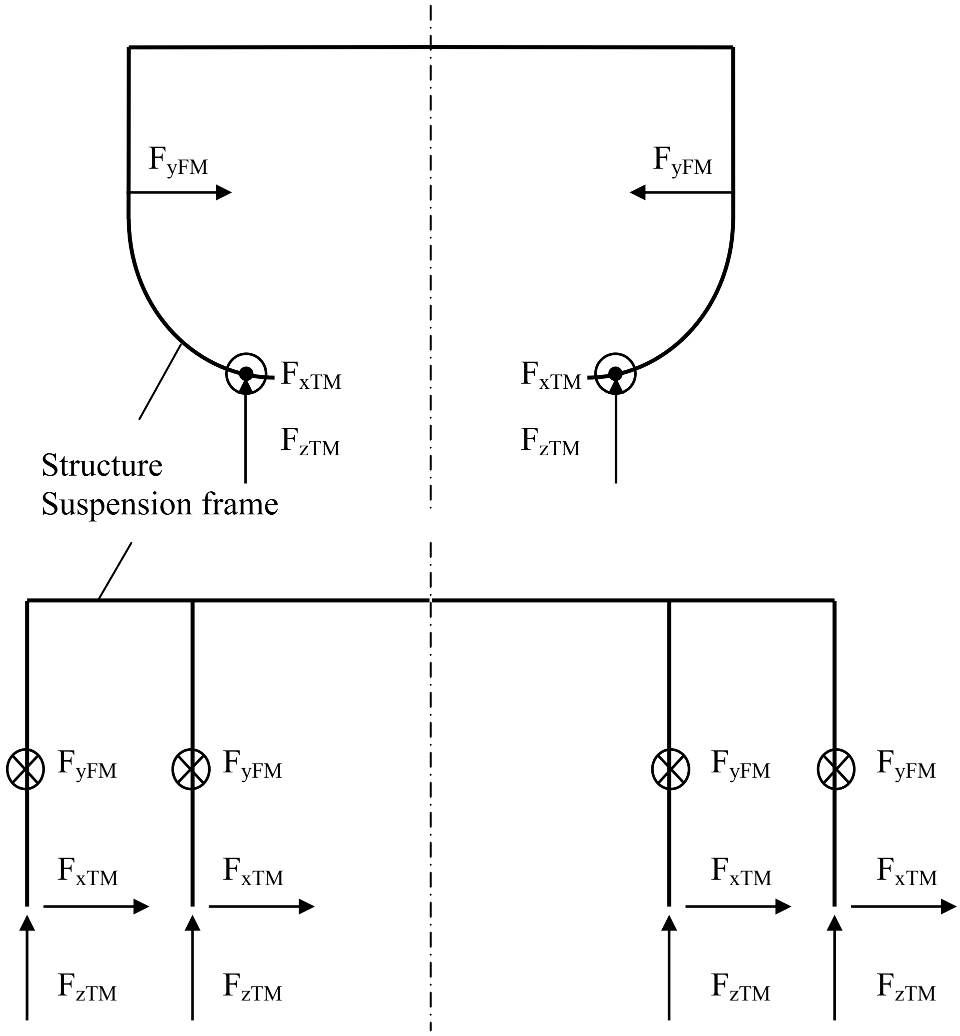

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Figure 64: Articulation forces on the frame structure

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General

A-loads	Loads from operation in failure-free state for demonstration of fatigue strength
S-loads	Maximum possible loads during operation in failure-free state and/or subject to exceptional actions for demonstration of load-bearing capacity

Vehicle weights for passenger transport

- The weight of the maglev vehicles and the payloads to be taken into account shall be laid down specific to each project.
- *Vehicle sections for passenger transport include luggage compartments (e.g. for passengers' luggage).*

Vehicle deadweight

- *Definition of the vehicle deadweight, see MSB AG-ABK&DEF Annex 1: Weight of the vehicle incl. equipment (e.g. seating) without payload.*
- *The overall masses of the operating staff and working stocks are included – where present.*

Payload for passenger vehicles

- Typical passenger weights
- Long-distance traffic 80 kg per passenger with luggage
- Regional traffic 70 kg per passenger
- Airport link 90 kg per passenger with luggage

- Typical passenger densities in standing room areas
- Long-distance traffic no standing room
- Regional traffic 320 kg/m²
- Airport link 1 person / m² (80 % of journeys)
  2 people / m² (15 % of journeys)
  320 kg/m² (5 % of journeys)
- Typical weight per unit area in luggage area:

- 300 kg/m²
- The weights to be assessed must be confirmed specific for each project or be laid down differently.

Vehicle weight with payload

- Weight of the fully equipped vehicle with payload
- Average vehicle weight: 80% payload
- Permissible vehicle weight: 100% payload
- *The payload for vehicle sections for passenger transport depends on the number of passenger seats and, in standing room areas, on the number of passengers per m². These values are set by the operator taking into account the legal provisions regarding this matter and give the mass of the load and/or passengers which may be carried on the maglev train.*

Maximum vehicle weight

- Weight of the fully equipped vehicle subject to exceptional action.
- *The maximum vehicle weight of a section occurs in exceptional operating situations (evacuation into neighbouring sections).*
- Typical value for standing room area: see Chapter 0

Vehicle weights for goods transport

- The payload for goods sections shall be laid down on a project-specific basis and gives the weight of the load which may be carried on the maglev train.

Design release

- For the release of the design, a release programme must be implemented by the manufacturer of the vehicle.
- *The aim of the release programme is to demonstrate that the design of the carriage body and of the magnetic running gear complies with the conditions laid down in the technical specification.*
- The release programme must show that the behaviour of the vehicle assemblies manufactured according to design targets permits appropriate operation without the occurrence of failure or breakdown, permanent deformation or fatigue cracks. In addition, it must be demonstrated that further components or sub-assemblies are not adversely affected.
- The release programme must contain detailed information concerning how release of the design should proceed and must indicate the necessary parameters for application of the various parts of the procedure. These parameters must be laid down in three stages:
- the release procedure (e.g. combination of load cases for calculations and static tests, programmes for fatigue tests, tracks for track tests);
- the values of the different load cases;
- the release criteria (processing of the measured or calculated values, loading limits, criteria for implementing fatigue tests).
- *The details regarding the release programme are listed in the following section 0.*
-

Structural requirements

General

- The maglev vehicles of the maglev system must withstand the maximum loads in accordance with the operating requirements and must achieve the required service life under normal operating conditions with appropriate probability of survival.
- The capacity of the maglev vehicle to resist permanent deformations and breakdown must be demonstrated by means of calculation and/or testing.
- The vehicle strength shall be assessed according to the following criteria:

- Assessment of the exceptional loads, i.e. the maximum stresses which must be withstood while maintaining full operating capacity (S-loads).
- Observation of sufficient safety so that uncertainties are covered in the demonstration, and no risks occur for passengers or third parties if the specified loads are exceeded.
- Demonstration of sufficient rigidity so that the deformations under specified loads and the characteristic frequencies of the structures conform to the limits determined by the operating requirements.
- Tolerability of operating or cyclical loads so that structural strength is not impaired during the stated service life (A-loads).

- *The above requirements shall be demonstrated by means of calculations in accordance with Chapter 0 by demonstrating the load-bearing capacity or in accordance with Chapter 0 by demonstrating the fatigue strength.*
- The operator must provide all data which determine the expected operating conditions, (“project-specific statement”). In cooperation with the operator, it is the task of the manufacturer to deduce all major load cases from these data so that they can be used as evidence and to ensure that the design complies with them.
- Where designs of existing vehicles for which safety has already been demonstrated are developed further, earlier data may be used for a comparative demonstration if operating conditions are the same. Changes in assemblies must generally be indicated. If changes which are relevant for dimensioning are proposed, after agreement with the licensing authorities, the components must be recalculated, if necessary, and/or be checked by means of a test. When using construction materials, the vehicle manufacturer or its sub-contractor must ensure that they have appropriate data regarding compliance with the materials requirements. These data (standards etc) must conform to the current state of the art.

Parameters influencing maglev vehicles

Design loads

- All design loads which are used as a basis for the vehicle design must include all necessary tolerances for uncertainties in their values. The design loads laid down in Chapter 0 include these tolerances.

Materials

General

- The minimum values of the material properties in accordance with the specifications for the materials used must be used for the design of the vehicle structure. If the material properties are affected by, for example,
- stress speed,
- time (e.g. ageing),
- environment (absorption of humidity, temperature etc.),
- welding or other manufacturing processes,
- suitable minimum material characteristics must be used.
-

Permitted material characteristics

Static strength

- The underlying static material characteristics, where available, must comply with the minimum yield and/or proof stresses and the tensile strength of the materials data. The values used should be taken from the corresponding European or national standards. If such standards are not available, the most appropriate alternative data sources must be used on a project-specific basis.

Fatigue strength

- The strength behaviour of the materials under oscillating loading must be taken from the current European or national standards. If such standards are not available, the most appropriate alternative data sources must be used. At the same time, reference may also be made to alternative data sources of equivalent status on a project-specific basis. The manufacturer must identify substantiated materials data. Such materials data may be established by means of suitable tests with regard to the use.

- In general, suitable materials data must satisfy the following requirements:
- Use of the fatigue strength data from recognised standards such as Eurocode 3 for steel materials and Eurocode 9 for aluminium materials.
- A preferred probability of survival of 97.5%, at least 95%.
- For materials not included in recognised standards, for which the values are established from other reliable sources or from tests:
  - A minimum number of $2 \cdot 10^6$ cycles with constant amplitude for steel materials, in accordance with the endurance limit,
  - A minimum number of $1 \cdot 10^7$ cycles with constant amplitude for aluminium materials, in accordance with the fatigue limit.
- Classification of the designs (including the stress concentrations) in relation to stress concentrations.
- Data regarding capacity to withstand stresses obtained from small bar-shaped test objects shall be checked on actual components with regard to their transferability.
- The stress-number curve, which is used to represent the fatigue behaviour of a material, must show the influences named in Chapter 0 and the lower limit of the reproducibility defined previously.
- The manufacturing and quality assurance procedures must highlight product qualities which conform to the design data.

Uncertainties

- The following influences produce uncertainties in the design and must be taken into account:
- a) Dimensional tolerances
- In general it is acceptable to use the nominal sizes of the components as a basis for the calculations. Minimum dimensions have to be taken into account only if substantial reductions in the thickness (because of wear etc.) are typical for operation of the component. Appropriate protection against corrosion is an integral part of the vehicle specification. The loss of material caused by this can usually be disregarded.
- b) Manufacturing process
- The characteristics displayed by the material in an actual component may differ from those deduced from test samples. Such differences can be traced back to variations in the manufacturing process and to the workmanship, which cannot be detected in any practicable quality control procedure.
- c) Accuracy of calculations
- Every calculation procedure includes approximate values and simplifications. It is the manufacturer’s responsibility to apply the calculation procedure deliberately conservatively to the design. Allowance must be made in the calculation procedure for the uncertainties described in a) and b) by means of a factor. This “safety factor”, denoted by S, must be used when the calculated stress is compared with the material limit value.

•

Demonstration of static strength and structural stability

- The following statements represent the minimum requirements for metallic materials and must be taken into account. For non-metallic materials, the safety factors shall be agreed between operator, manufacturer and supervisory authority.

Demonstration of load-bearing capacity

- Calculation and testing (see Chapter 0) shall be used to demonstrate that no permanent deformation or breakdown of the entire structure and/or individual parts will occur in the prescribed load cases pursuant to Chapter 0 and the load case combinations in accordance with Chapter 0. These requirements must be met by observing Chapter 0. If the structure is also restricted by the conditions in Chapter 0 and Chapter 0, these must also be observed.

-

General stress demonstration

Yield or proof stress

- If the strength of the structure is established exclusively by means of calculation, S_1 must = 1.15 for metallic materials for each individual load case. For specific projects, S_1 may be assumed to be 1.0, if:

- the load cases are checked by tests or
- it can be shown that the uncertainties referred to in Chapter 0 are very small, or
- the superimposition of the load cases is demonstrated by means of calculation (see Chapter 0) and
- there is sufficient operating experience. This must be substantiated in a comprehensible manner.

- Under the static load cases, as set out in Chapter 0, the ratio of the permissible to the calculated stress must be greater than or equal to S_1:

$$\frac{R}{\sigma_{be}} \geq S_1$$

- Where:

R is the material yield stress (R_{el}) or 0.2% - proof stress (R_{p02}), in N/mm².
σ_{be} is the calculated stress in N/mm²

- When determining the stress levels of ductile materials, it is not necessary to take into account features which produce a local stress concentration. However, if the calculation includes local stress concentrations, the theoretical stress may exceed the material yield stress or 0.2% -

proof stress. These ranges in local plastic deformation in connection with stress concentrations must be so small that they do not cause any significant permanent deformation when the load is removed.

Tensile strength

- It is necessary to provide a safety margin between the maximum stress and the load-bearing capability. This is achieved by incorporating a safety factor S_2, where the ratio between tensile strength and calculated stress must be greater than or equal to S_2. (S_2 includes the safety factor S_1)

$$\frac{R_m}{\sigma_{be}} \geq S_2$$

- Where:
  R_m is the tensile strength of the material in N/mm²,
  σ_{be} is the calculated stress in N/mm².
- As a rule S_2 is equal to 1.5, but the factor can be reduced if at least one of the following conditions is met:
- there are alternative elements with sufficient load-bearing capacity;
- parts of the structure are designed in such a way that they fail in a controlled way;
- the calculations are so accurate that there is great confidence in the load-bearing capacity of the critical structural areas.
- The processing of stress concentrations as described in Chapter 0 is also applicable to this case. The effect of stress concentrations must be taken into account in more detail for non-ductile, if such stresses cannot be relieved by local plastic deformations.
- A lower value for S_2 must be laid down on a project-specific basis.
-

Stability failure

- Local instability in the form of elastic buckling is permitted provided that alternative elements with sufficient load-bearing capacity are present and the yield or proof stress criterion is observed.

- The vehicle design must include a margin of safety against a global failure as a result of instability. This is achieved by ensuring that the ratio between critical buckling or warping stress and calculated stress is greater than or equal to S_3 is:

$$\frac{\sigma_{kKB}}{\sigma_{be}} \geq S_3$$

- Where:
  σ_{kKB} is the critical buckling or warping stress in N/mm²,
  σ_{be} is the calculated stress in N/mm².

- As a rule S_3 is equal to 1.5. The factor can be reduced if the structure is designed so that it fails in a controlled way. A lower value for S_3 must be laid down on a project-specific basis.
-

Demonstration of rigidity

- The rigidities of the vehicle assemblies must ensure the transmission of the specified loads while observing the necessary loading gauges and preventing undue dynamic reactions.
- The necessary rigidity may be set as maximum deformation under a prescribed load or as minimum natural frequency. The requirements are applicable to the complete carriage body and/or the magnetic running gear and also to individual components or assemblies.
- *The necessary body rigidity is fixed by means of the minimum natural frequency (bending natural frequency).*
- The first bending natural frequency for the fully equipped carriage body assumed to be freely levitated must be at least 7 Hz at an operating maximum speed of 500 km/h (experimental value).
- *This value is obtained from the quotient of the vehicle maximum speed 500 km/h and the guideway-support length 25 m plus reserve.*
- At an operating maximum speed of less than 500 km/h the natural frequency can be reduced to 500 km/h in linear proportion to the operating maximum speed.
- *At an operating maximum speed of 400 km/h a bending natural frequency of 5.6 Hz is sufficient.*
- *The requirement applies even where guideway supports with a support length > 25 m are used.*
- The natural frequency must be demonstrated theoretically.
- Requirements in excess of this must be laid down on a project-specific basis.

Demonstration of fatigue strength

- The required service life or endurance limit of the structure in the prescribed load cases pursuant to Chapter 0 and the load case combinations pursuant to Chapter 0 must be demonstrated by means of calculations and testing (see Chapter 0). The proofs must comply with the requirements in Chapter 0 and Chapter 0.

-

General

- Account must be taken of the fact that the carriage body of the maglev vehicle as well as the magnetic running gear are exposed to a great many dynamic loads of varying sizes during their operating life.
- *The effect of these loads is most obvious in critical areas of the structure. Examples of such areas are:*
- *sites where forces are introduced (including mounts for items of equipment),*
- *connections between components (e.g. welds, bolted connections),*
- *changes in geometry leading to stress concentrations (e.g. corners of doors and windows).*
- These critical areas must be identified. In this, the manufacturers' experience must be taken in to account in conjunction with the results of calculations and tests. Detailed investigations of the local areas may be necessary.
- Fatigue strength may be demonstrated using two different calculation methods:
- Demonstration of endurance limit (see Chapter 0),
- Demonstration of structural durability (see Chapter 0).
- Account must be taken of the fact that the nature and quality of the available data affect the choice of the procedures described in Chapter 0. The procedure applied must be laid down on a project-specific basis.
- If the investigated dynamic load cases in the fatigue calculation already include tolerances for uncertainties, and provided that the minimum material characteristics as described in Chapter 0 are used, no further safety factor is necessary in this calculation.
- *Procedures to demonstrate fatigue behaviour experimentally or to check the calculation results are described in Chapter 0.*

Calculation method

Demonstration of endurance limit

- This is permissible if the materials data show that there is a fatigue limit. The fatigue limit is the stress at which no fatigue damage occurs provided that all dynamic load cycles remain below it.
- The necessary fatigue strength has been demonstrated if the stresses as a result of all suitable combinations of steady load situations as laid down in Chapter 0 remain below the fatigue limit.

Demonstration of structural durability

- This is to be demonstrated if it is impractical to keep the stress level below the endurance limit for all fundamental load combinations, or if no endurance limit can be laid down for the material.
- Each load case defined in Chapter 0 must be shown with regard to amplitude and number of cycles by means of representative curves. Due account must be taken of concurrent load combinations. Damage as a result of each such case is then assessed again using a suitable material S-N curve (stress-number curve). The total damage is determined in accordance with a proven damage accumulation hypothesis (such as Palmgren-Miner, for example).
- Load curves and combinations may be simplified provided that this produces results which are reliable in appropriate respects.

Experimental demonstration of strength

- The release procedure for the strength of vehicle assemblies provides for experimental proof in addition to proof based on calculations:
- static tests,
- fatigue tests,
- track tests.
- Usually, tests must be carried out to provide complete proof of strength and stability in accordance with the requirements of Chapter 0. It is not necessary to carry out tests if checked data from earlier tests on similar structures are available and tests and calculations agree with each other. If, however, there have been significant changes in the design or the operating conditions, tests must be carried out.
- The test programme must be laid down on a project-specific basis.

- The specific aims of the static tests and fatigue tests are:
- to test the strength of the structure when this is exposed to the maximum load,
- to check that there is no permanent deformation after the maximum load has been removed,
- to demonstrate the strength of the structure in the operating load cases,
- to determine the dynamic behaviour of the structure.

- If necessary, see above, the tests must include the following:
- static simulation of selected load cases,
- measurement of stresses by means of a strain gauge or other suitable procedure,
- measurement of structural deformation under loading,
- measurement of natural frequency behaviour.

- The tested components and/or assemblies must be of the same kind and manufacture as those subsequently used in operation. The test stand equipment must be properly and practicably capable of applying the same loading to which the components and/or assemblies are exposed in subsequent operation when they have been installed.

Static tests

- The general purpose of static tests is to establish that components and/or assemblies are not exposed to the risk of excessive deflections or permanent deformation in the case of exceptional loads.
- Tests can be carried out to verify the proofs provided by means of calculations.

Generally, in the tests, strain controls are carried out in the areas of the components and/or assemblies subject to heavy stresses by means of resistance strain gauges, which measure in one direction at points where the stress act in only one direction, but in at least two directions at all other points.

- The test programme for static tests must include the following information:
- size and position of the forces to be applied,
- combination of the forces to be applied,
- evaluation and interpretation procedure for the measured stresses,
- stress limit values,
- all further release criteria,
- measuring point plan for strain controls.

- The measurements to be carried out in the entire test must be recorded in such a way as to allow analysis of all measuring points in each load case, i.e. it must be ensured that at least the minimum and maximum stress is determined.
- The maximum value of the principal stress σ_{max} and the minimum value of the principal stress σ_{min} define the mean value σ_m and the amplitude σ_a.

- Mean values and amplitudes of the principal stress according to subsequent correlation must be compared with the load-bearing capability of the material (e.g. fatigue limits) and evaluated.

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$$

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2}$$

- Where:

σ_m is the mean value of the principal stress
σ_a is the amplitude of the principal stress
σ_{max} is the maximum value of the principal stress
σ_{min} is the minimum value of the principal stress

Structural durability and endurance limit tests

- Endurance tests consist of a main test and, possibly, additional specific tests.
- The aim of the main test is to confirm that the strength of the assemblies and/or components is sufficient with regard to the principle loads acting in them. Principal loads are loads which trigger stresses in the entire structure.
- Further tests may be carried out if necessary, particularly in the light of the results of calculations or static tests. These tests relate to forces which act only locally.
- Fatigue tests must be carried out on vehicle parts of the primary power flux which are exposed to dynamic loads, if the calculation includes uncertainties or if measurement results from the operation of that detail type are not available.
- Fatigue tests shall be carried out for components of the magnetic running gear (levitation chassis and secondary suspension). For the frame of the carriage body, the mathematical model must at least be verified by means of static tests.
- The following test types may be used:
- Laboratory fatigue tests in which suitable load curves are applied to the vehicle assemblies for the entire service life. No cracks which would adversely affect the safety or availability of the structure may occur;
- Fatigue calculation on the basis of strain controls using the data from the test or from other static tests;
- Fatigue calculation on the basis of strain controls using the data on representative operating conditions.
- The test programme for endurance tests must include the following information:
- forces to be applied and their position (static constant loads and dynamic parts),
- combination of the different forces, taking into account the phase relationships of different cyclical forces and their relative frequency,
- number of cycles (loadings),
- evaluation process,

- release criteria,
- measuring points plan for strain controls.

- In general, for reasons of costs and time, only one assembly and/or one component is examined in the endurance test. As soon as it has been demonstrated that the specimen conforms to the initial requirements, the test loads can be gradually increased. In this way it is possible to determine the safety margin which covers the spread of the endurance limits.
- For materials which have similar spreads in load-bearing capability, such as welds in steel structures, the test procedure and the decision-making criterion in accordance with DIN EN 13749, Annex G are used.

Track tests

- Track tests must be carried out in order to demonstrate the operational requirements regarding the vehicle as well as the design loads and stresses in service.
- As a rule, they are carried out as part of the commissioning of the vehicle and must be laid down on a project-specific basis.

The programme for track tests must contain at least the following information:

- the vehicle to be used as well as the guideway-support types,
- description of the journeys to be undertaken (load cases, speeds, etc.),
- load conditions of the vehicle,
- assessment and interpretation procedures for the stresses,
- permissible load limits,
- all additional release criteria,
- measuring points plan for e.g. position measurements, acceleration measurements, power and strain controls.

Load cases

- This section sets out the load cases which are to be used when designing maglev vehicle structures (carriage bodies, magnetic running gear, cowling parts etc.). It contains the minimum load cases to be taken into account for demonstrating the load-bearing capacity and the fatigue strength.
- The targets indicated for the load cases represent minimum requirements. If an operator considers higher values to be necessary to achieve safe operation, it must lay down the requirement. A lower value is acceptable for certain operating conditions or structural features if there are technical grounds to prove this. In addition to the fixed load cases and all further requirements or variations determined by the operator, it is the manufacturer's responsibility to ensure that the structure can withstand every other relevant static or dynamic load which occurs during the operation of the maglev vehicle.
- The load cases for mechanical assemblies are classified in the following way according to the probability of their occurrence:
- operation in failure-free state: continuous occurrence,
- exceptional loads (operation with failures and/or subject to exceptional actions): frequency of occurrence 10 per annum per component of 100 per annum per section.
- These values represent the current level of knowledge and must be verified by recording evaluations of mechanical assemblies as part of maintenance. The demonstrations must be adjusted on the basis of these recordings, if necessary.
- In accordance with MSB AG-GESAMTSYS, load cases resulting from malfunctions or failures, for which the probability of occurrence is less than 10^{-6} per annum, are not demonstrated.

A-loads (load cases for demonstration of fatigue strength)

- The data regarding A-loads apply with regard to demonstration of fatigue strength as demonstration of endurance limit. For cases in which it is necessary or wiser to demonstrate structural durability, load spectra based on the following information must be deduced.

Inertia forces

Vehicle weight

- The possible loading states (vehicle deadweight, vehicle weight with payload) must be taken into account.
- The average vehicle weight is assessed for long-distance vehicles with restriction on access (no standing room). Non-uniform load distributions as a result of payload fluctuations (non-uniform distribution of the payload in x- and y-direction) are covered by the increase in the support magnetic forces. An increase of 5% in the mean ultimate load per support magnet linkage is assessed as the experimental value.

- For vehicles such as airport links with a restriction on the number of seats and 320 kg/m² of standing room area, the following typical load states serve as *guideline values*:
- *Case 1: 80 % of the journeys with all seats occupied and standing room density of one person/m² (standard capacity utilisation)*
- *Case 2: 15 % of the journeys with all seats occupied and standing room density of two persons/m² (full use of capacity)*
- *Case 3: 5 % of the journeys with all seats occupied and a maximum standing room density of 320 kg/m² (maximum use of capacity).*
- The endurance limit must be demonstrated with the loading state ‘full use of capacity in accordance with case 2. Accumulations of snow must be taken into account in accordance with Chapter 0 on a project-specific basis.
- In the case of operation with no restriction on access, passenger numbers must be recorded during operation (e.g. statistical evaluation) and, if necessary, appropriate measures must be taken.
- Unless otherwise agreed with the operator, the data for airport links are used for regional transport.
-

Passing over concave and/or convex transition curves

- Allowance must be made for the inertia forces when passing over the alignment elements of concave/convex transition curves by assessment of the target for the maximum free vertical acceleration.
- Target:
-

a_{zmax} (convex transition curve) = -06 m/s²

a_{zmax} (concave transition curve) = 1.2 m/s²

Operational accumulations of snow

- Loads resulting from accumulations of snow are not relevant for the carriage body and the secondary suspension.
- Accumulations of snow in cavities of the magnetic running gear, anticipated during operation, must be taken into account for the purposes of the demonstration. A covering of snow and ice on the cowling of the magnetic running gear – inside and outside – may result in an increase in the quantities in the magnetic running gear. Additional constraining forces caused by a reduction in the maglev vehicle kinematics or a change in the maglev vehicle aerodynamics do not occur because of the cowling of the magnetic running gear. If necessary, additional measures must be agreed with the operator until project-specific operating experience is available.
- The snow quantities to be assessed in operation for the load case of snow accumulation in the maglev vehicle depend on the climatic zone of use and must be laid down on a project-specific basis.

- Unless otherwise agreed, the quantities are calculated on the basis of wet snow in accordance with Table 5.
-
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Acceleration / braking with propulsion alternating step process

- *The thrust forces are transmitted as quasi-static forces between long stator and support magnet by interaction of support magnetic field and synchronous long stator current.*
- The inertia forces occurring during acceleration/braking with long stator propulsion must be taken into account.
- There are various, project-specific processes available for motor section switching: alternating step, three-step, leapfrog and time-shifting processes.
- The following points must be taken into account:
- A location- and time-dependent thrust change, which is different on both sidewalls of the maglev vehicle, acts on the maglev vehicle during motor section switching. In order to minimise the onset of the thrust, the propulsion force on the active motor side can be increased. There is no thrust on the opposite side at this time.
- To deduce the inertia forces, only the alternating step process at the time of section switching is taken into account, as the stresses caused by the asymmetrical load introduction during the section switching process are the greatest, and this covers all other processes.
- By agreement with the operator, the three-step process can also be taken into account on a project-specific basis, as the loads are lower in this case as a result of the symmetrical introduction of the force.
- The x-force to be assessed in the alternating step process corresponds to half of the thrust on a maglev vehicle section and is applied on one vehicle side. The mean propulsion acceleration a_{xmitt} is assessed for operation in failure-free state.

  Specification (experimental value from TVE):
  Acceleration: $a_{xmitt} = \pm 0.8$ m/s²
  Thrust of the active motor side: 73 % of the propulsive force per section

Normal running with propulsion alternating step procedure

- It is necessary to allow for the fact that forces from normal running are covered, see Chapter 0. If structural durability is demonstrated instead of endurance limit, the vehicle thrust is to be determined subject to the aerodynamic loads and the alignment for $a_x = 0$ m/s².
-

Free lateral acceleration

- The inertia forces from unbalanced lateral accelerations can be taken into account by assessing the maximum operational free lateral acceleration.
- *That means that, for simplification, it is conservatively assumed that curves ≥ 1000 m are taken exclusively with maximum free operational lateral acceleration.*
- Maximum value for cornering:

- a_{ymax} = ± 1,5 m/s².

Dynamics of vehicle movement

- The dynamic forces and moments (vehicle movement dynamics) resulting from the long-wave positional tolerances of the functional surfaces of long stator and lateral guide rails must be combined with the static reaction forces at the interfaces.
- Alternating forces resulting from the magnetic action of the long stator nuts on the support magnets and from short-wave positional tolerances or misalignments of stator packs and lateral guide rails act as high-frequency noise and may be disregarded in the demonstrations. These alternating forces must be taken into account when assessing the natural oscillation and resonance behaviour and must be established as mechanical stress due to oscillation in the environmental spaces of the maglev vehicle on a project-specific basis.
- If the vehicle movement dynamics are taken into account via forces, no additional oscillatory factor must be used.

Carriage body

- An oscillatory factor of f = 1.0 ± 0.12 (verified value for carriage bodies with pneumatic suspension) must be assessed as the target for dimensioning of the bodies.

Support/guidance system structure

- Parts of the dynamic loads from vehicle movement dynamics must be added to the existing constant load from propulsion/braking, support and guidance as quasi-static loads for each levitation chassis on the most unfavourable basis. It is not necessary to allow for an additional adjustment over and above an oscillatory factor.
- Target for each linkage: (verified values for the structure of the support/guidance system):
- ΔF_{xTMA} = ± 1.0 kN propulsion/braking (includes alternating step process)
- ΔF_{yFMA} = ± 9.0 kN guidance
- ΔF_{zTMA} = ± 4.0 kN support

Cowlings

- The following acceleration values must be assessed as the targets for the **external and internal frame cowlings** for the environmental space of the levitation frame (maximum values from TVE experience):
- a_x = ± 2.0 m/s²
- a_y = ± 15 m/s²
- a_z = ± 15 m/s²
-
- Target for the **nose cowling fixed to the frame**:
- a_x = ± 8.m/s²

- $a_y = \pm 15.0$ m/s²
- $a_z = +15.0$ m/s² / -10.0 m/s²

- Target for the carriage body transition plate**:**
- $a_x = \pm 3.5$ m/s²
- $a_y = \pm 10.0$ m/s²
- $a_z = \pm 3.2$ m/s²
- For other vehicle configurations or suspension characteristics, estimates should be made on the basis of adjusted oscillatory factors or dynamic loads and be verified when brought into service.
-

Settled maglev vehicle

- *Lifting/settling at v_{Fzg} = 0 km/h at stations and service stops.*
- As a rule, loads for the settled vehicle are to be taken into account only for the magnetic running gear (load reversal at the support magnet linkages). Operating loads can be disregarded for the carriage bodies.

Constraining forces resulting from alignment

- Account must be taken of the fact that return forces occur in the magnetic running gear when horizontal radius R_H is < 2000 m and guideway distortion α' is greater than 0,1°/m.
- Unless the project-specific parameters are different, the following alignment parameters must be used for the demonstration:
- Allowance may be made for the constraining forces which are relevant for operation by superimposing the curve radius R_H = 1000 m, the operationally aligned guideway gradient $\alpha = 12^0$ and the guideway distortion $\alpha' = 0.1\ ^0$/m.

Initial stress caused by guidance magnet loads

- If there are no project-specific data available, allowance must be made for an initial stress force on the guidance magnet linkages.
- Target:
- F_{yFM0} = 4.5 kN (approx. 50% of the vehicle movement dynamics)

Aerodynamic loads

- A distinction must be made when considering aerodynamic loads for the individual maglev vehicle sections (carriage body nose, cylindrical area of the body, nose inlets, vehicle undercarriage, frame cowlings).
- The following points must be taken into account:
- A location-dependent, non-uniform pressure distribution occurs on the surface of the nose area in the leading and following-on section.
- In the cylindrical area of the maglev vehicle the pressure loads are to a large extent constant.

- The end section can therefore be divided into two zones. The division in the zones can be taken from the following illustration.

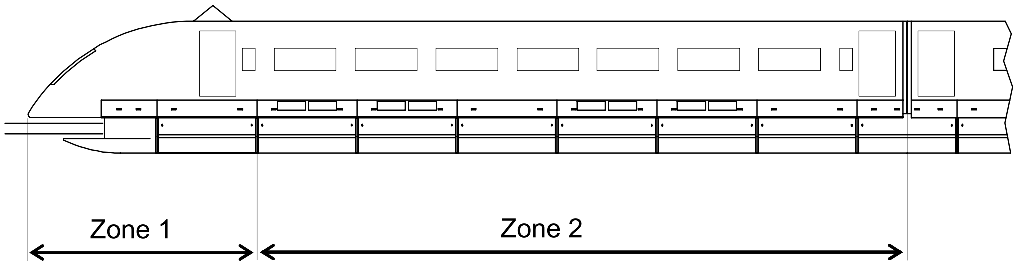

Figure 65: Zoning of the end section with regard to aerodynamic effects

- *Zone 1 comprises the nose area up to the transition to the cylindrical area of the body. The flap of the external frame cowling at the transition from zone 1 to zone 2 is still completely attached to zone 1. The middle sections are calculated with loads from zone 2.*
- If the aerodynamic loads are not indicated specifically for the project, data from worked vehicles can be used if the shape of the head is comparable.
- Unless agreed differently with the operator, the endurance limit demonstration can be provided at aerodynamic loads for the maximum vehicle speed and for the maximum tunnel speed.

Aerodynamic loads from relative wind

- The speed-dependent local pressure distribution in the nose area (zone 1) and the constant pressure distribution in the cylindrical area of the maglev vehicle (zone 2) must be taken into account as quasi-static loads acting on the surface of the maglev vehicle.
- Loads from relative wind on the internal frame cowling and body undercarriage cowlings may likewise be assessed as quasi-static loads.
- *Loads from relative wind include the effects of contrary wind. The wind-speed value to be taken into account for A-loads, v_W = 10 m/s, is lower than 10 % of the maximum vehicle speed.*
-

Aerodynamic loads from crosswind

- Unless different arrangements are made, the following targets are applicable (see also MSB AG-Umwelt, Chapter 5.1.5):
- A permanently acting, operational crosswind of v_W = 10 m/s is taken to be the statically applied load.
- *On the basis of experience so far, the effective duration of a 10 min. mean value for wind > 10 m/s in a 10 m high guideway is 74 h per annum. That means that, for 99 % of the annual operating time, a wind of $\leq$ 10 m/s can be expected.*
- The overall height of the vehicle excluding aerial shall be assessed as the relevant height for determining crosswind forces.

Forces on the carriage body

- The body transition plate must be taken into account in the carriage body (see illustration in MSB AG-FZ GEN.
- The resulting force from the crosswind may be taken into account as a quasi-static area force acting on the carriage body.
- *This load is dispersed by the support/guidance system.*
- Account must be taken of the fact that substantially higher aerodynamic loads are acting on the leading nose section than on the following-on nose section in a crosswind and that these are therefore determining for ascertaining the interface loads.

Forces on the external frame cowling

- Account must be taken of the fact that the maximum loads act on the external frame cowling of zone 1. The resulting forces on the external frame cowling must, therefore, be deduced from the pressure distribution in zone 1 and taken into account as a quasi-static load.
- Account must be taken of the fact that the internal frame cowling and the body undercarriage are not subject to any relevant loads as a result of crosswind.

Aerodynamic loads from trains passing

- The amplitudes of the pressure action on the bodies in free field shall be deduced as a function of speed, track centre distance and the guideway lateral inclination.
- The pressure amplitude acting at the vehicle speed and the projected guideway lateral inclination must be assumed for each passing of trains.
- *A corresponding function is included in MSB AG-GESAMTSYS.*
- If there are no specified data to the contrary available, this function may be used in the demonstration. These data must be verified as part of the approval pursuant to MbBO.
- For the global and local stresses on the structure or individual assemblies, the maximum amplitude of the alternating pressure wave for the maximum vehicle speed v_{max} may be used for the demonstration compared with operating loads.
- The alternating pressure wave may be conservatively idealised as a step function. It may be assumed that the loads act as quasi-static alternating quantities on a vehicle side, where two alternating pressure waves have to be taken into account for trains passing (action of nose and rear).

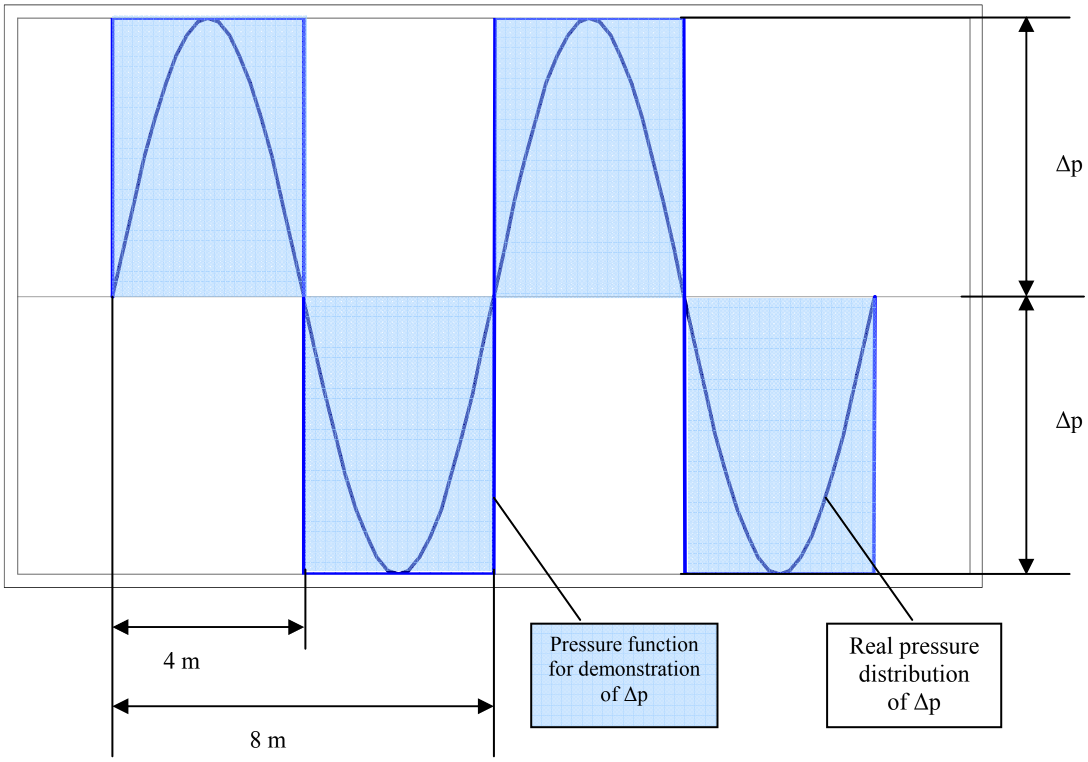

Figure 66: Alternating pressure wave nose/rear effect

- The following points must be taken into account:
- The length of the pressure/drag load assessed in accordance with Figure 66 is 4 m in each case, the two pressure/drag amplitudes 8 m.
- The alternating pressure waves run along the entire train.
- The most unfavourable positions lengthwise along the vehicle must be taken into account for the demonstration.
- An oscillatory factor of 1.15 must be taken into account to allow for structural dynamics. The assumptions must be verified as part of commissioning.
- Additional loads caused by trains passing are not to be taken into account when dimensioning the guidance system.
- The maximum vehicle speed v_{max} must be applied for the A-loads.
- Example for deducing the alternating pressure amplitude in accordance with MSB AG-GESAMTSYS:

	Cylindrical part of body	Nose/rear of body
Trains passing (v_{max} = 400 km/h)	$\Delta p = \pm 1900 \cdot 1.15$	$\Delta p = p(x, y, z) \pm 1900 \cdot 1.15$
Δp Pressure change in [Pa] p(x, y, z) Pressure at nose resulting from c_p-distribution Distance between side walls of passing vehicles 1.1 m Guideway lateral inclination α = 12°		

Table 70: Example of pressure amplitudes with trains passing

- The frame cowlings can be treated in the same way as the cylindrical part of the carriage body – unless otherwise agreed for specific projects.

Aerodynamic loads when passing through tunnels and open cuts

- Compression stresses as a result of tunnel operation, with/without trains passing in single and double tubes, must be taken into account on a project-specific basis.
- Trains passing are only to be taken into account where there is appropriate alignment or appropriate operating concepts.
- For the A-loads, the scheduled vehicle speed $v_{max(Tunnel)}$ is to be assessed in the tunnel.
- As a result of the pressure difference between external and internal pressure, varying loads occur on the pressure-tight carriage body. The amplitude and the number of relevant pressure changes (loadings), which are dependent on vehicle speed, tunnel length, size of the obstruction and the pressure tightness coefficient of the carriage body, must be ascertained on a project-specific basis or may be taken from comparable applications.
- The following must be taken into account:
- The differential pressure between "pressure-tight" interior and external area of the vehicle is dimensioning. In this case, the stationary maximum differential pressure is assessed for the maximum vehicle speed in the tunnel. The pressure/drag loads are applied as a constant value on the total carriage body. The areas of the magnetic running gear which are not designed as pressure-tight are not subject to any relevant stresses as a result of the pressure compensation.
- The internal and external compressive values to be assessed must be determined and assessed on a project-specific basis by means of suitable simulation and measurement processes.
- The Δp –values must be multiplied by a dynamic factor 1.15.
- The compressive values for zone 1 must be superimposed with the pressure distribution from steady travel outside the tunnel (free-field travel).
- If project-specific pressure curves are available, these may be used.
- To allow for passing through open cuts, the assessments for tunnel operation apply mutatis mutandis.
- The assumptions regarding tunnel operation and passing through open cuts must be verified by appropriate measurements on a project-specific basis as part of the approval.
-

Aerodynamic loads from lift

- *The aerodynamic lift of the carriage body acts in the opposite direction to the gravitational force and can be disregarded in dimensioning of the body. The loads via the vehicle movement dynamics, see Chapter 0, are recorded for the magnetic running gear.*

Loads resulting from temperature changes

- Allowance must be made for stresses on structures (e.g. carriage body) resulting from temperature changes.
- Effects of a possible temperature-dependent extension of long vehicles (*more than 8 sections*) on the propulsion thrust must be adjusted to the propulsion subsystem on a project-specific basis.

S-loads in failure-free system state for demonstration of load-bearing capacity

- In principle, the statements pursuant to Chapter 0 are applicable. Differences to allow mainly for maximum operating loads are described below.

Inertia forces

Vehicle weight

- The weight with 100 % payload (permissible vehicle weight, see Chapter 0) is to be taken into account.
-

Passing over concave and/or convex transition curves

Allowance must be made for the inertia forces when passing over the alignment elements of concave/convex transition curves with the accelerations pursuant to Chapter 0.

Maximum snow accumulations

- The maximum snow accumulations to be expected in the cavities of the magnetic running gear must be taken into account for the demonstration.
- Appropriate measures must be taken to preclude the occurrence of inadmissible constraining forces inside the magnetic running gear through a reduction of the kinematics of the vehicle as a result of snow covering. If necessary, provision must be made for operational measures in extreme winter conditions, and the snow loads to be assessed and the supplementary measures must be laid down until project-specific operating data are available.
- The maximum snow quantities to be assessed for the load case of snow accumulation in the vehicle depend on the climatic zone where the vehicle is used and must be laid down for the specific project.
- To demonstrate load-bearing capacity, the snow accumulations are determined by the maximum possible volume of the magnetic running gear. The manufacturer must make realistic assumptions regarding the possible volume and the snow density. If necessary, additional measures must be laid down until project-specific experience is available.
- The snow densities indicated in Table 5 must be assessed to calculate the weight of snow. Unless otherwise agreed, the quantities are to be calculated on the basis of wet snow.

Snow condition	Density of snow [kg/m^3]
New snow	100
Old snow	300

Wet snow	500

Table 5: Snow densities for different aggregation conditions

Acceleration / braking with propulsion alternating step process

- As stated in Chapter 0, the alternating step process must be taken into account at the moment of motor section switching to demonstrate the acceleration/braking loads.
- For operation in failure-free state with S-loads, the maximum propulsion acceleration pursuant to MSB AG-GESAMTSYS a_{xmax} must be assessed.
- Target: Maximum value: $a_{xmax} = \pm 1.5$ m/s²

Thrust of the active motor side: 73 % of the propulsive force per section

- Dynamic canting may be disregarded as the maximum thrust is used for calculation.
-

Normal running with propulsion alternating step procedure

- Account must be taken of the fact that the inertia forces correspond to the A-loads from Chapter 0 and are covered by the loads from Chapter 0 for demonstration of load-bearing capacity.
-

Free lateral acceleration

- The maximum specified free lateral acceleration must be assessed to record the maximum operational inertia forces from unbalanced lateral accelerations.
- Maximum value for travel over points:
- $a_{ymax} = \pm 2.0$ m/s²

Dynamics of vehicle movement

Carriage body

- The same oscillatory factors as for the A-loads in Chapter 0 are applied for dimensioning for S-loads.

Magnetic running gear

- Part of the dynamic loads from vehicle movement dynamics must be added to the existing constant load from propulsion/braking, support and guidance as quasi-static loads for the magnetic running gear. An additional adjustment over and above an oscillatory factor is not necessary.
- Target (verified values for magnetic running gear TR08):
- $\Delta F_{xTMA} = \pm 1.2$ kN propulsion/braking (includes alternating step process)
- $\Delta F_{yFMA} = \pm 9$ kN guidance
- $\Delta F_{zTMA} = \pm 5$ kN support

Cowlings

- The same values as for the A-loads in Chapter 0 are applied for dimensioning of the **exter-nal and internal frame cowlings**.
- Target for the **nose cowling fixed to the frame**:
- $a_x = \pm 16.0$ m/s²
- $a_y = \pm 25.0$ m/s²
- $a_z = +21.0$ m/s² / -10.0 m/s²
- The same values as for the A-loads in Chapter 0 are assessed for dimensioning of the body transition plate.
- For other vehicle configurations or suspension characteristics, estimates must be made on the basis of appropriately adjusted oscillatory factors or dynamic loads, analogous to Chapter 0, and must be verified when brought into service.
-

Settled maglev vehicle

- The same values as for the A-loads in 0 are assessed for dimensioning of the vehicle as-semblies for S-loads. Demonstration of the inertia forces is covered by Chapter 0.

Constraining forces resulting from alignment

- The two cases, “minimum horizontal radius without guideway lateral inclination” and “max. guideway distortion”, must be taken into account to determine the maximum operating constraining forces.
- Unless other arrangements have been laid down between operator and manufacturer, the following alignment parameters must be used for the demonstration:
- Case 1: Minimum horizontal radius, radius R_H = 350 m, α = 0° (v_{Fzg} = 100 km/h)
- Case 2: Maximum guideway distortion, radius $R_H = R_V = \infty$, α' = 0.15°/m

Initial stress caused by guidance magnet loads

- The same values as for the A-loads in Chapter 0 must be used for dimensioning of the vehicle assemblies for S-loads.

Aerodynamic loads

- The statements in Chapter 0 shall be applied mutatis mutandis with the following targets for vehicle speed:

Line travel without tunnel:
v_{grenz} = vehicle limit speed

Tunnel operation
v_{grenz}(tunnel) = specified tunnel limit speed of the vehicle

-

Aerodynamic loads from relative wind

- The statements in Chapter 0 are applicable. Unlike the A-loads, the vehicle limit speed must be fixed.

Aerodynamic loads from crosswind

- The statements in Chapter 0 are applicable.
- The following load cases may be assessed to allow for the maximum operating loads; see also MSB AG-Umwelt, Chapter 5.1.5:
- Case 1: Continuous maximum crosswind of v_W = 37.3 m/s at v_{mitt}
- Case 2: Continuous maximum crosswind of v_W = 37.3 m/s at v_{max}
- Case 3: Continuous maximum crosswind of v_W = 10.0 m/s at v_{max}
-
- *The 5-second gust of v_W = 37.3 m/s at a height of 20 m, occurring every 10 years, is treated as maximum load in the combinations of actions. Primary supporting frameworks, which are con-*

structed with additional wind protection where appropriate, are provided for higher guideway sections.

- *In cases 2 and 3, the maximum vehicle speed is set as the vehicle speed.*
-

Aerodynamic loads from trains passing

- The statements in Chapter 0 are applicable.
- Unlike the A-loads, the vehicle limit speed must be set in order to establish the pressure alternating amplitude.
-

Aerodynamic loads from tunnel operation

- The statements in Chapter 0 are applicable.
- The demonstration must be at maximum static pressure difference during tunnel operation.
- Maximum value: $\Delta p = \pm 5500$ Pa.
- The demonstration must be at a pressure of ± 6000 Pa for the design (increased safety factor 500 Pa).
- Allowance for trains passing may result in higher pressure/drag loads. These must be laid down on a project-specific basis.
-

Aerodynamic loads from lift

- See Chapter 0.

Loads resulting from temperature changes

- See Chapter 0.

S-loads during operation with failures for demonstration of load-bearing capacity

- Because there is little probability of occurrence of the exceptional load cases and the corresponding load case combinations pursuant to Chapter 0, a safety factor of S = 1.0 can be used in calculating for the demonstration.

Automated application of brakes with safety brake in the case of brake control-circuit failure

- *During automated application of brakes with the safety brake (eddy current brake) and long stator drive switched off, the vehicle settles steadily at the specified settling speed. The load case* *pursuant to Chapter 0 relates to the state before settling. Loads from the state "settled vehicle" are covered by specified special load cases.*

- The following effects must be taken into account for the load case represented by automated application of brakes with safety brake (eddy current brake) with failure of a brake circuit:
- Magnetic braking and accelerating forces as well as mechanical compressive and frictional forces at the interface between braking magnet and lateral guide rails.
- Because of the non-uniform braking force of the individual maglev vehicle sections, the assumed simultaneous failure of a brake control circuit also leads to a quasi-static transmission of braking forces between the maglev vehicle sections.
- Non-uniform braking forces of the individual maglev vehicle sections also occur with local guideway icing (different friction values of the braking magnets adjacent to the lateral guide rails).
- The asymmetrical braking magnet-accelerating forces resulting from failure of a brake circuit are dispersed on both sides of the guideway via the adjacent guidance control circuits.
- Where applicable, account must be taken on a project-specific basis of superimposition of the drive and eddy current brake and the superimposition of the eddy current and skid brake (settled skid), if the probability of their occurring is > 10^{-6} per annum.
- Allowance must be made for the following effects from the safety brake as the subject of additional operating cases:
- slipping of the vehicle on support skids at a vehicle speed ≤ settling speed including stopping shock (see Chapters 0, 0),
- non-uniform braking forces of the individual maglev vehicle sections as a result of local guideway icing (different friction values at the support skids where the vehicle slips, see Chapter 0).
- The maximum decelerations occurring and the forces at the vehicle/guideway interface (frictional forces) must be laid down and taken into account on a project-specific basis.

Failure of an on-board power supply

- *The load case covers operation with support/guidance control circuits switched off, either separately or in combination. The failure of an on-board power supply causes the failure of individual support and guidance control circuits distributed over several levitation frames. The support/guidance control circuits are not adjacent.*
- *The load case relates to the non-contact levitated vehicle, as support and guidance control circuits are redundant and the support/guidance function is maintained. The loads at the interfaces between support magnet and long stator and between guidance magnet and lateral guide rails are transmitted in accordance with the target for the magnet control circuits.*
- *Dual failures of adjacent support or guidance control circuits result in mechanical load dispersal via contact forces (see mechanical support, Chapter 0 or mechanical guidance, Chapter 0.*
- *As a result of failure of a support control circuit, increased magnetic quasi-static and dynamic forces occur at the support magnet – long stator interface, and as a result of failure of a guidance control circuit at the guidance magnet – lateral guide rail interface.*
- The moment of the failure up to and including partial venting of the pneumatic springs must be taken into account for support control circuits.

- The maximum decelerations occurring must be laid down and taken into account on a project-specific basis.

Local mechanical guidance

- *In local mechanical guidance, the guidance loads are dispersed by mechanical contact of the guidance magnets with the guideway lateral guide rails.*
- The mechanical compressive forces occurring at the interface between guidance magnet and lateral guide rail must be taken into account.
- With local mechanical guidance, a distinction must be made between:
- Running along onto the lateral guide rails as a result of failure of two adjacent guidance control circuits and operation with mechanically guided levitation frame over a track to be set with the operator on a project-specific basis.
- Running into local ice layers:
  The maximum impact load must be set on a project-specific basis. If transferable data are available from comparable structures, these may be set. Otherwise, the loads and stresses must be ascertained by numerical simulation and/or experimental proof.
- The maximum decelerations occurring and the forces at the vehicle-guideway interface (frictional forces) must be laid down and taken into account with the operator on a project-specific basis.
- Running into layers of ice, the depths of which exceed the permissible values, must be treated as collision with an obstacle. It is not necessary to refer to the loads occurring for dimensioning with regard to load-bearing capacity, but it is necessary to ensure that no parts can break off and leave the maglev vehicle.
- The dynamic loads when running along on lateral guide rails must be taken into account with an oscillatory coefficient of 1.15. Otherwise, dynamic forces on the guidance magnet, which result from the positional tolerances and misalignments of the lateral guide rails during sliding and act as high-frequency noise, may be disregarded.
- The mechanical guidance function over the specified track and the magnitude of the oscillatory factor may be demonstrated by means of experimental values with work vehicles. If it is not possible to refer to experience with work vehicles and implemented slide combinations, trial investigations agreed with the operator must be carried out as part of the commissioning process.

Local mechanical support

- *In local mechanical support, the support forces at the support skids are dispersed by mechanical contact with the guideway sliding surface.*
- The mechanical forces occurring at the interface between support magnet and slide rail must be taken into account.
- With local mechanical support, a distinction must be made between:
- Settling of a support skid as a result of dual failure of two adjacent support control circuits with/without venting of the pneumatic springs.
  Afterwards, operation with mechanically supported levitation frame over a track agreed with the operator on a project-specific basis, taking into account mechanical support with non, par-

tially or fully vented pneumatic springs.
The forces during controlled settling must be taken into account as static forces.
The impact factor for controlled settling of the vehicle is 1.0 (experimental value).

- Running of a support skid into a local, specified layer of ice:
  The loads occurring in x- and z-direction are covered by the load case "uncontrolled settling" (see 0) and are not demonstrated separately.

- The maximum decelerations occurring and the forces at the vehicle/guideway interface (frictional forces) must be laid down and taken into account on a project-specific basis.

- Dynamic forces on the support skids resulting from the positional tolerances and misalignments of the slide rail during sliding must be taken into account by means of an oscillatory factor of 1.15.

- The mechanical support function of a levitation frame over the specified track and the oscillatory factor may be demonstrated by means of experimental values with work vehicles. If it is not possible to refer on experience with work vehicles and implemented slide combinations, trial investigations agreed with the operator must be carried out as part of the commissioning process.

- Target for the maximum permissible impact load:

- F_z = 100 kN (corresponds to an impact factor of approx. 2).

- Permissible ice-layer thicknesses must be fixed with the operator on a project- specific basis.

- Running onto layers of ice, the depths of which exceed the permissible values, must be treated as collision with an obstacle. If transferable data from comparable structures are available, these may be applied. Otherwise, the loads and stresses must be determined by numerical simulation and/or demonstrated experimentally. It is not necessary to refer to the loads occurring in a collision for dimensioning with regard to load-bearing capacity.

Uncontrolled settling of support skids on one side

- *The load case relates to the uncontrolled settling of the maglev vehicle on one side onto the support skids (of one side of a vehicle) as a result of a defective short circuit in a long stator motor section. The magnetic feedback of the short circuit currents in the long stator lead to the support control circuit being switched off, which is reversible.*

- The information in Chapter 0 must be used for the maximum impact load / support skid.

- Target for friction coefficient:
  μ_R = 0.3.

- The maximum vehicle speed and the maximum support skid gap (at settling speed) must be set for the simulation of uncontrolled settling on one side.

- *The support skid gap is made up of the static nominal value and a gap variance – resulting from the control dynamics and the component tolerances.*

- A simultaneity factor of ψ = 0.8 must be set for the distribution of the individual skid gaps over the vehicle.

Slipping / vibration

- *Slipping/vibration (asynchronous movement of the maglev vehicle with the magnetic long stator-travelling field) causes increased magnetic, quasi-static and dynamic forces at the lift magnet/long stator interface.*
- Slipping /vibration must be taken into account as an action:
- Target for magnetic forces:

$F_{zTM} = \pm 2.5$ kN/m
$F_{xTM} = \pm 2.0$ kN/m

- Maximum frequency 538 Hz.
- *Demonstration of the load case is covered by demonstration of the alternating step process pursuant to Chapter* ***Error! Reference source not found.****.*
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-

Change in coefficient of friction in sliding, settled maglev vehicle

- Where changes occur in the coefficient of friction as a result of the environment (icing of guideway, wet track etc.), allowance must be made for local differences in the coefficient of friction in accordance with minimum or maximum coefficients of friction laid down on a project-specific basis. The stresses initiated as a result of non-uniform distribution of interface loads must be taken into account.
- *The different coefficients of friction at the support skids or at the braking magnet slide plates result in non-uniform braking forces of the individual maglev vehicle sections.*
- Target for the change in coefficient of friction:

$\Delta\mu_R = 0.3$.

Stopping shock from automated application of brakes with the safety brake

- Account must be taken of the stopping shock from slipping of the vehicle as a result of moving from sliding friction to static friction at the support skid / slide rail interface.
- Target for sliding of support skid:

$\mu_R = 0.3$.

- Target for moving from sliding friction to static friction:

$\mu_{TK\text{-}GL \rightarrow Haft} = 0.5$.

- *The coefficient of friction covers the short-term peak forces of the stopping shock (approx - 200 ms).*

Exceeding of payload in exceptional operating situations

- Evacuation of a section in the case of fire must be taken to represent exceeding of the payload in exceptional operating situations.
- *The passengers from the section to be evacuated are led to the adjacent section so that the maximum payload is exceeded.*
- It may be assumed that the increased weight to be demonstrated is evenly distributed as a result of the high density of people.
- Target for maglev vehicles:
All seats occupied, standing room density 500 kg/m².
- The weight targets must be agreed with the operator.

Exceeding the maximum track speed

- *The load case takes into account incorrect exceeding of maximum guideway speed as a result of an error in propulsion control/control system.*
- The values for accelerations for cornering and passing through concave transition curves must be increased to demonstrate the load case.
- Target:
Increase in accelerations by 20 %.
- The effect of the aerodynamic loads must be tested separately (load cases are not superimposed).

Exceeding of thrust as a result of propulsion failures

- The following propulsion failures must be taken into account:
- Failure of the propulsion function of one guideway side (single-sided propulsion), introduction of a load into the vehicle on the opposite side; this failure acts like propulsion via alternating step process at the time of motor section switch.
- Exceeding the thrust through the long stator propulsion as a result of defective control of the long stator current with uniform distribution to the left and right side of the vehicle.

  Target: Thrust F_x = 250 kN per maglev vehicle (see MSB AG-GESAMTSYS, Chapter 9, No 7).
- *The yawing moment caused by the introduction of thrust on one side results in increased magnetic force at the guidance magnet/lateral guide rail interface.*
- Because of the low probability of this occurring, a safety factor of S = 1.0 can be used for calculating this load case.

Entering the shading coil

- Braking of the maglev vehicle by entering areas of the long stator system with shading coil at the end of the track.

- The load case is covered by the other load cases for operation with failure or exceptional action during propulsion and braking.

Position of the maglev vehicle with maximum lateral inclination

- Allowance must be made for the load case of lifting / settling / standing of the maglev vehicle according to worst-case stop on guideway with maximum lateral inclination.
- *The load case "position of the maglev vehicle at maximum wind speed of 37.3 m/s to be taken into account (100-year maximum value)" is not considered. Loads from this action are not relevant for dimensioning of the maglev vehicle structure, as experience shows that the impact pressure caused by crosswinds for the 100-year maximum value at a height of 20 m in wind load zone III is clearly below the static and dynamic design pressure of the carriage body. At a considered maglev vehicle height of 4.16 m, the force transmitted to the guideway every m from the impact pressure on the magnetic running gear is lower than the force which is transmitted in the case of a stationary maglev vehicle with 16° guideway lateral inclination at right angles to the longitudinal axis.*
- The stopping forces in the x- and y-direction with longitudinally and laterally inclined guideway must be taken into account as static forces.
- Maximum values: $\alpha = 16°$

Elevation of maglev vehicle with frozen support skids

- The load case must be demonstrated unless specific agreements concerning additional measures have been reached with the operator (heated stop etc.).
- The x- and z-loads when detaching a support skid which is frozen to the slide rail must be taken into account in the demonstration of the components in the power flux.
- Target for each support skid:
- Tractive force in z-direction $F_z = 50.0$ kN,
- Thrust in x-direction $F_x = 25.0$ kN.

Failure of nose pneumatic spring

- During operation in failure-free state, the body is supported over all z-supports of the carriage body.
- *The loads at the z-support (pendulum) result from the pressure of the related pneumatic spring. After venting of a pneumatic spring, in the case of partial venting reduced loads are dispersed by the associated pendulum, and in the case of full venting no loads are dispersed. The differential forces are in part taken over by the other pendulums by rearrangement of the loads.*
- For dimensioning the body with mounting structure, the case of full venting at the nose pneumatic springs (pendulum at the nose without power) must be demonstrated as the most unfavourable load case.

Collision situations

- The representative collision situations pursuant to MSB AG-GESAMTSYS or MSB AG-FZ GEN must be established numerically.
- The collision situations must be defined in the corresponding specifications of the assemblies; they are not relevant for dimensioning within the meaning of this document.
- Separate documentary proof must be drawn up for the design of the assemblies relevant in collisions, with the following objectives:
- compliance with the acceleration values in the body, as given in MSB AG-GESAMTSYS,
- no risk to tracking or to the stability of the guideway,
- continuation of the journey after a collision (no “blocking” of the vehicle), termination of passenger travel and travel to maintenance for inspection and repair / replacement of the components concerned,
- deformations of the body must be limited so that people are not trapped in the compartment,
- risk examination to assess components which fly off on a case-related basis.

Transport

- Allowance is made for transport of the maglev vehicle without magnet modules, with static ultimate/lifting loads and a proportion of the impact load during transport and assembly.
- The following actions must be demonstrated for the vehicle configurations to be transported:
- Elevation with special lifting devices.
- To demonstrate elevation, a factor of 1.1 must be taken into account. The masses actually elevated must be taken into account.
- It must be possible for the vehicle structure to be transported without magnet modules (levitation frame with support, guidance and braking magnets).

Superimposition of load cases

Demonstration of load-bearing capacity

- The load cases from A-loads must be superimposed in accordance with Table 72 for the demonstrations. Only the most unfavourable combinations have to be demonstrated.

Loads from running (S-loads)	**Load case combinations S**								
	1	2	3	4	5	6			
Inertia forces from:									
• Vehicle weight from Chapter 0	X	X	X	X	X	X			
• Acceleration/braking with alternating step process with $a_{xmax} = 1.5$ m/s²	X	X	X	X	X				
• Passing over concave/convex transition curves with $a_{zmax} = + 1.2$ m/s² / -0.6 m/s²	X	X	X	X	X				
• Free lateral acceleration with $a_{ymax} = 2.0$ m/s²	X	X	X	X	X				
• Vehicle movement dynamics	X	X		X	X				
• Settled maglev vehicle						X			
Constraining forces resulting from alignment									
• Radius $R_H = 350$ m, $\alpha = 0^0$ ($v_{Fzg} \leq 1\ 00$ km/h)			X						
• Radius $R_H = R_V = \infty$, $\alpha' = 0.15\ ^0$/m	X	X			X				
Initial stress caused by guidance magnet loads	X	X	X	X	X				
Aerodynamic loads from									
• Relative wind v_{grenz}	X	X							
• Relative wind v_{max}					X				
• Crosswind $v_W = 10.0$ m/s	X		X						
$v_W = 37.3$ m/s					X				
• Trains passing, pressure load at v_{grenz}		X							
• Tunnel operation, pressure load at $v_{grenz\ (tunnel)}$				X					
Temperature	X	X	X	X	X	X			
Snow accumulation maglev vehicle (maximum)	X	X	X	X	X	X			

Table 72: Superimposition of the S-loads from operation in failure-free state

- Comments on Table 72:

Trains passing and crosswind are not superimposed because of the shadow effect.
The load case of normal running is not taken into account in the superimposition table, as the stresses from the load cases of propulsion/braking with alternating step process are greater. At a running speed of v < 100 km/h, the vehicle movement dynamics and the actions from aerodynamics are disregarded because of the negligible effect. If relevant for the specific project, tunnel operation and trains passing must be superimposed.

- The following points must be taken into account:
- The load case combinations from operation in failure-free state in accordance with Table 72 may occur in combination with certain load cases in the event of failure or exceptional action from Table 73.

- Because of the low probability of occurrence, superimposition is undertaken in that case with a maximum of one of the load cases in the event of failure or exceptional action.

The superimpositions must be determined on a project-specific basis.

Loads in the event of failure and/or exceptional actions (S-loads)	
- Automated application of brakes with safety brake with asymmetric introduction of braking force in the case of brake control-circuit failure	
Failure of an on-board power supply	
- Local mechanical guidance	
- Local mechanical support	
- Uncontrolled settling of support skids on one side	
- Slipping/vibration	
- Change in coefficient of friction in sliding, settled maglev vehicle	
- Stopping shock from automated application of brakes	
- Exceeding of payload in exceptional operating situations (maximum vehicle weight in accordance with Chapter 0)	
- Exceeding of maximum track speed	
- Exceeding of thrust as a result of propulsion failure	
- Entering the shading coil	
- Failure of nose pneumatic spring	
- Position of the maglev vehicle with lateral inclination $\alpha = 16°$	
- Elevation of maglev vehicle with frozen support skids	
- Transport/assembly conditions: maglev vehicle equipped, without magnet modules	

Table 73: S-loads from load cases in the event of failure and/or exceptional actions

-
- *Comments on Table 73:*
- *The load case "position of the maglev vehicle with lateral inclination" with a maximum marked-out lateral inclination of α = 16° is dimensioning for forces in y-direction only for the support skid and its fixing. The load case "elevation of maglev vehicle with frozen support skids" is dimensioning in the x- and y-direction only for establishing the layers on the support skids. These two combinations of actions must therefore taken into account separately, and not combined with other actions.*
- *The combination of the load case "change in coefficient of friction in sliding, settled maglev vehicle" with a running speed of v_{max} does not occur as, in operation, the maglev vehicle is settled only at v_{Fzg} < settling speed.*
- *Similarly, the combination of the load case "change in coefficient of friction in sliding, settled maglev vehicle" with tunnel operation does not occur, as it is assumed that the coefficient of friction of the slide rail in the tunnel always remains within the usual tolerance.*

Demonstration of fatigue strength

Demonstration of endurance limit

- The load situations from A-loads must be superimposed in accordance with Table 74 for the demonstrations. Only the most unfavourable combinations have to be demonstrated.
-

Loads from running (A-loads)	Load case combinations A						
	1	2	3	4	5	6	
Inertia forces from:							
• Total weight according to Chapter 0	X	X	X	X	X	X	
• Acceleration / braking with alternating step process, a_{xmitt}	X	X			X		
• Normal running with alternating step process			X	X			
• Passing over concave/convex transition curves with a_{zmax}= + 1.2 m/s² / -0.6 m/s²	X	X	X	X	X		
• Free lateral acceleration with a_{ymax} = 1.5 m/s²	X	X	X	X	X		
• Vehicle movement dynamics/oscillatory factor	X	X	X	X	X		
• Settled maglev vehicle						X	
Constraining forces resulting from alignment							
• Radius R_H = 1000 m, $\alpha = 12^0$, $\alpha' = 0.1\ ^0$/m	X	X	X	X			
Aerodynamic loads from							
• Relative wind with v_{max}	X	X	X	X			
• Crosswind v_W = 10.0 m/s	X		X				
• Trains passing, pressure load at v_{max}		X		X			
• Tunnel operation, pressure load at $v_{max\ (Tunnel)}$					X		
Snow accumulation, maglev vehicle (operational)	X	X	X	X	X	X	

Table 74: Superimposition of the A-loads from operation in failure-free state

Comments on Table 74:
Trains passing and crosswind are not superimposed because of the shadow effect. The superimposing of A3 and A4 are covered by A1 and A2. If relevant for the specific project, tunnel operation and trains passing must be superimposed.

Demonstration of structural durability

- Load spectrums for the demonstration of structural durability must be agreed with the operator or the licensing authority on the basis of project-specific data – unless transferable data from earlier applications are available.
- The demonstration must relate to the service life required by the operator. In this respect, the vehicle service life and the life of the individual assemblies are not identical in all cases. For assemblies which have a life shorter than the vehicle service life, maintenance measures must be agreed in consultation with the operator (inspection intervals, repair and replacement measures,

information regarding disclosure of defects). If required, additional demonstration methods such as failure mode and effects analyses (FMEA) may be taken into consideration in order to assess component failures.

Annex – Loading of mounting parts and attachments

- *The test criteria for qualification of the mounting parts and attachments with regard to load-bearing capability against “vibration/shock” effects are set out below with reference to DIN EN 61373 and MSB AG-UMWELT.*

Definition of environmental spaces

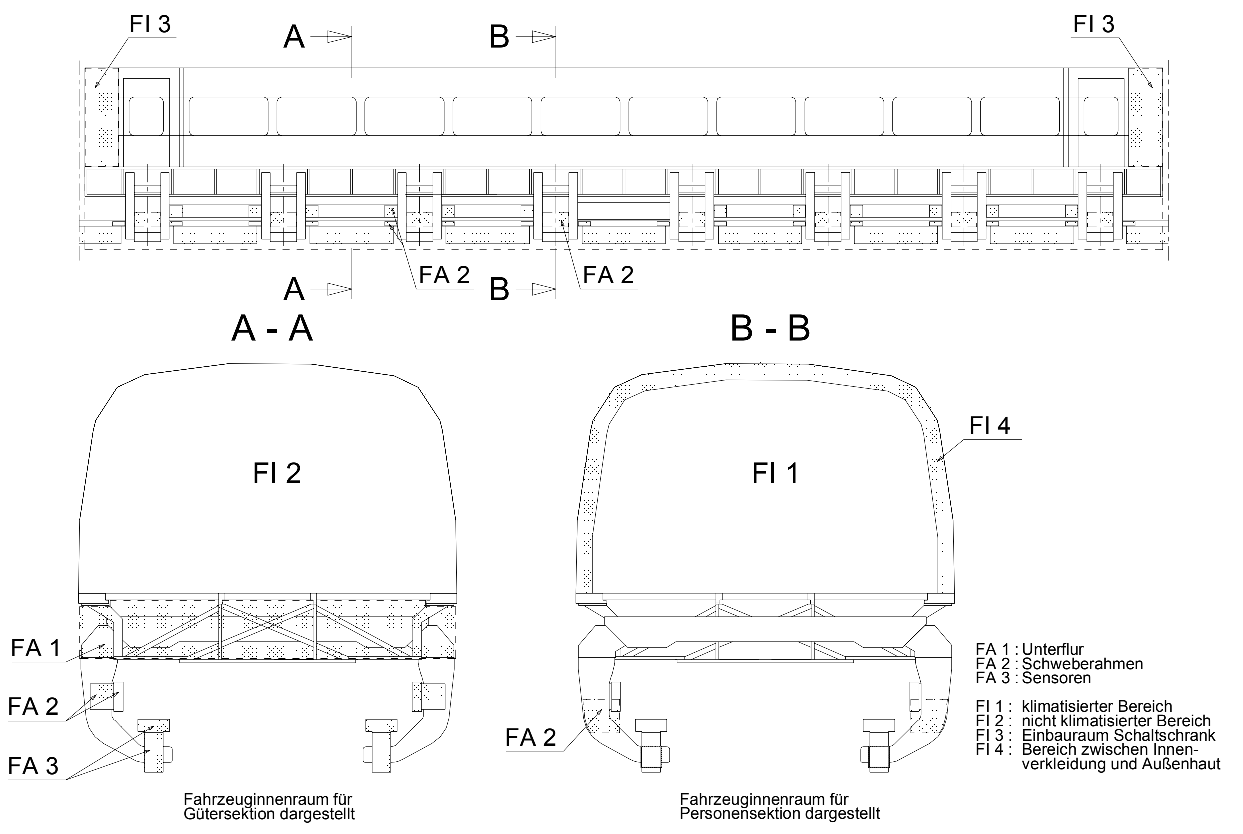


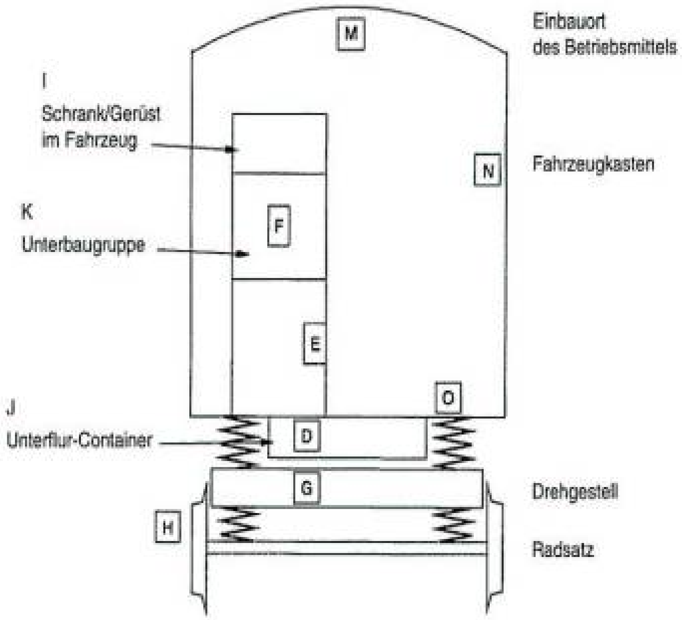
Figure 67: Environmental spaces from MSB AG-UMWELT

FI 2
Vehicle interior shown for goods section

FI 1
Vehicle interior shown for passenger section

FA 1: under-floor
FA 2: levitation frame
FA 3: sensors
FI 1: air-conditioned area
FI 2: non-air-conditioned area
FI 3: switchgear clearance
FI 4: Area between internal cladding

and outer skin



I = cabinet/housing in the vehicle
K = sub-assembly
J = under-floor container
M = installation place for equipment
N = vehicle body
G = bogie
H = wheel set

Category	Position	Description of the installation place of the equipment
1 Class A	M, N, O, I and J	Describes components/equipment which are fixed on or in the vehicle body
1 Class B	D	Describes components/equipment, installed in a container, which is fixed in the underframe to the vehicle body
1 Class B	K and E	Describes components/equipment, installed in a large cabinet/ housing, which is fixed to the vehicle body
1 Class B	F	Describes components/equipment as a part of a subassembly, installed in a cabinet/housing, which is fixed to the vehicle body
2	G	Casings, components/equipment, which are fixed to the bogie of a rail vehicle
3	H	Casings, components/equipment, which are fixed to the wheel set of a rail vehicle

Figure 68: Environmental spaces (categories) from DIN EN 61373

:

Maglev – Design Principles Overall System, Annex 3 MAGLEV – Environmental spaces MSB AG-UMWELT	DIN EN 61373
Environmental space	Category
FA 3	Category 3
FA 2	Category 2
FA 1	Category 1 Class B
FI 1 – FI 4	Category 1 Class A or Class B

Table 75: Comparison of the clearances

Test levels

- *The relevant actions for loading of the mounting parts and attachments by "vibration/shock" are taken from measurements on vehicles TR07, TR08 and Transrapid Shanghai.*
- The actions determined on the basis of the results of these measurements are shown in Table 76. The values in Table 76 must be referred to as test levels for functional testing of the assemblies. The test levels and test duration for the life testing must be deduced on the basis of DIN EN 61373.
- The values given in the following table must be verified for modified components or configurations of the vehicle and guideway engineering.
-

Environmental space category	**Direction**	**Acceleration level (FRTL-level pursuant to DIN EN 61373) [m/s²]**	**Test level of the life testing as actual value [m/s²]**	**Test duration [h]**	**Test frequency [Hz]**
FA 1 Cat 1/ Cl B	lengthwise (x)	0.20	1.6	5	10 – 150
	transverse (y)	0.45	3.6	5	
	vertical (z)	0.75	6.0	5	
FA 2 Cat 2	lengthwise (x) 1)	1.0	8	5	10 - 1600
	transverse (y) 1)	4.0	32	5	
	vertical (z) 1)	5.0	40	5	
FA 3 Cat 3	lengthwise (x) 1)	25.0	100	73	10 – 1600
	transverse (y) 1)	30.0	100	152	
	vertical (z) 1)	30.0	100	152	
FI 1-4 Cat 1/ Cl A Cat 1/ Cl B	lengthwise (x)	0.20	1.6	5	10 -150
	transverse (y)	0.45	3.6	5	
	vertical (z)	0.75	6.0	5	
		Peak acceleration [m/s²]			**Shock duration [ms]**
All	vertical	300			11
	transverse	300			11
	lengthwise	300			11

1) Test frequency for all support and/or guidance magnets in accordance with DIN EN 61373

Table 76: Test levels for vibration/shock

High-speed Maglev System
Design Principles

Vehicle
Part III
Kinematic Gauge

Distributor:

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Summary of amendments

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Table of Contents

LIST OF ILLUSTRATIONS

LIST OF TABLES

General

Objective and scope

- These "High-speed Maglev System Design Principles, Vehicle Part III – kinematic gauge" lay down the procedure for demonstrating the kinematic gauge of maglev vehicles pursuant to MSB AG-FZ GEN.

These design principles are applicable to high-speed maglev systems pursuant to the General Maglev Act (German designation: AmbG).

- The design principles give a general description for demonstration of the kinematic space requirement of the vehicle. It is to be used for furnishing proof regarding the vehicle. [5]
- This document includes the

definition of the vehicle kinematics to be taken into account,

definition of the relevant actions,

procedure for demonstrating the loading gauge.

- The following points must be taken into account:

Unlike DIN EN 27505, the necessary loading gauge is not calculated; however the swept envelope is considered in accordance with the Maglev Construction and Operation Order (German designation: MbBO), fig. 1, to ensure compliance with the default loading gauge. The geometrically possible vehicle states must be determined for this purpose, and it must be demonstrated that space remains for clearance and/or the centre is not impaired.

The loading gauge pursuant to the MbBO, fig. 1 is applicable (see also Chapter 0). The design principles describe the minimum requirements for the demonstration procedure. Departures from the design principles are permissible only if equivalent safety can be demonstrated.

The demonstration is confined to the moving vehicle and to the stationary vehicle with closed entrance doors. Open doors may exceed the loading gauge profile pursuant to MbBO, fig. 1 (see also Chapter 0) only during changeover of passengers and during cleaning and maintenance. Following the example of UIC 505-1, only operationally relevant vehicle states, and no worst-case situations, are considered in order to demonstrate the kinematic gauge. Certain abnormal incidents which result in the maglev vehicles exceeding the loading gauge must be investigated by the manufacturer, and if necessary their effects must be the subject of special measures (operating arrangements, fault reports etc.), which are to be drawn up by the operator.

[5] To provide a general understanding, design-specific features of the Transrapid are used in part for explaining the demonstration procedure. The corresponding features are applicable on a project-specific basis.

High-speed Maglev System – Design Principles

This document forms part of reference material regarding high-speed maglev systems consisting of several design principles. The documentation tree is shown in figure 1 of MSB AG-GESAMTSYS. The overarching design principles (Overall System) and the annexes thereto apply uniformly to all the reference material:

- High-speed Maglev System Design Principles (Overall System), Doc. No: 50630, MSB AG-GESAMTSYS, with annexes:
  - Annex 1: Abbreviations and Definitions, Doc. No: 67536, MSB AG-ABK&DEF
  - Annex 2: Acts, Orders, Standards and Guidelines, Doc. No: 67539, MSB AG-NORM&RILI
  - Annex 3: Environmental Conditions, Doc. No: 67285, MSB AG-UMWELT
  - Annex 4: Rules for operation (driving and maintenance), Doc. No: 69061, MSB AG-BTR
  - Annex 5: Sound, Doc. No: 72963, MSB AG-SCHALL

The reference material regarding the vehicle includes the following documents:

- High-speed Maglev System Design Principles, Vehicle Part I: General Requirements, Doc. No: 67698, MSB AG-FZ GEN
- High-speed Maglev System Design Principles, Vehicle Part II: Dimensioning, Doc. No: 67694, MSB AG-FZ BEM
- High-speed Maglev System Design Principles, Vehicle Part III: Kinematic Gauge, Doc. No: 67650, MSB AG-FZ KIN
- High-speed Maglev System Design Principles, Vehicle Part IV: Support/Guidance Engineering, Doc. No: 73388, MSB AG-FZ TRAFÜ
- High-speed Maglev System Design Principles, Vehicle Part V: Braking Technology, Doc. No: 73389, MSB AG-FZ BREMS

Abbreviations and definitions

The abbreviations and definitions set out in MSB AG-ABK&DEF are applicable.

Acts, Orders, Standards and Guidelines

The standards documents listed in MSB AG-NORM&RILI include provisions which become part of the High-speed Maglev System Design Principles as a result of being referred to in the High-speed Maglev System Design Principles. In the case of dated standards documents in MSB AG-NORM&RILI, subsequent amendments or revisions of these publications are not applicable. In the case of undated references, the latest edition of the standards document in question is applicable.

The status of the standards and guidelines to be taken into account in a maglev project must be laid down on a project-specific basis.

Identification and compulsory nature of the requirements

- Essentially, the rules pursuant to DIN 820 have been used in drawing up this document.
- In the following chapters of this document

requirements are identified in standard text

explanations, standard values and examples are identified in *italics*

- in accordance with MSB AG-FZGEN.
- If, in particular cases, this document refers to project-specific arrangements, this means that agreement must be reached between manufacturer and contractor (*e.g. in specifications or a contractual arrangement)* with consultation of the licensing authority.

References

Document	Description
DIN 27505	Railway vehicles - Vehicle gauge and obstruction gauge Position: Draft 01.01.1999
UIC 505-1	Rail Transport Stock - Rolling stock constructional gauge Position: November 2003 (9th edition)

Definitions (subsystem-specific)

Coordinate system

- Coordinate system, see Figure 69:

x-direction: in direction of end section 1 of the vehicle

y-direction: at right angles to the running direction in the sliding surface to the right

z-direction: vertical to the running direction, positive axis oriented downwards

- Origin of the coordinate system is the gradients of the guideway and, in the x-direction for the vehicle, the guideway centre; see MSB AG-GESAMTSYS, figure 3 and figure. When considering individual sections, the origin lies in the x-direction in the centre of the section coupling.

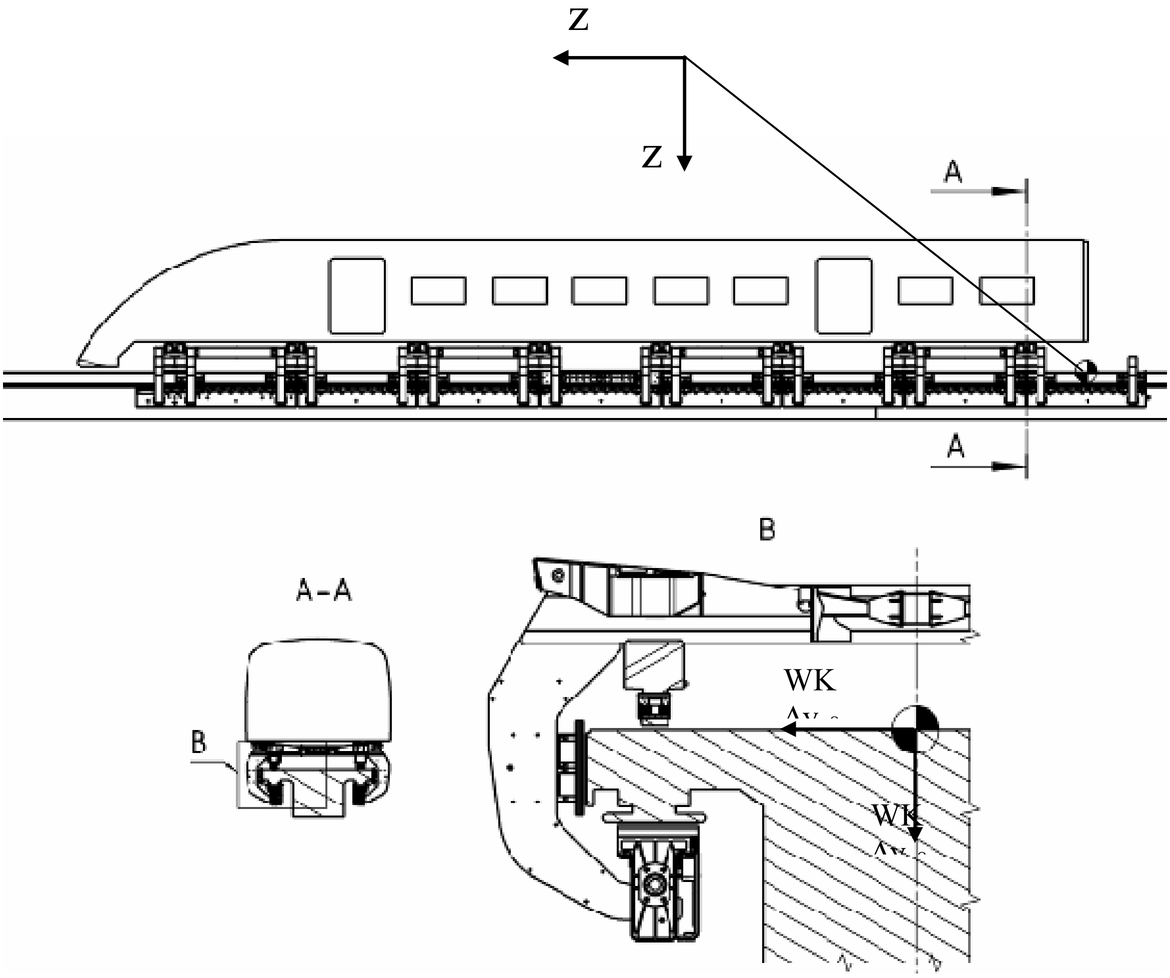


Figure 69: Vehicle coordinate system

Concepts

- The definitions in MSB AG-ABK&DEF are applicable. The concepts explained in this chapter are necessary for understanding of this document. They complement the concepts in MSB AG-ABK&DEF.

Normal coordinates	Orthogonal coordinates defined in a plane normal to the centreline of the guideway in nominal position. Horizontal axis (y-axis): intersection of the specified plane and the sliding surface (running surface in the case of railway vehicles). Vertical axis (z-axis): Perpendicular to horizontal axis, at equal distance from the slide rails (rails in the case of railway vehicles).
Maximum construction gauge	Profile, in relation to the cross section to be investigated, which the various parts of the vehicles must respect (vehicle profile)
Kinematic gauge	This is the theoretical centre of a vehicle in relation to the normal coordinates, taking into account the most unfavourable positions of the levitation chassis on the guideway and the quasi-static movements of the carriage body. No account is taken of random factors (oscillations, asymmetries).
Rolling	Rotational motion of the carriage body or levitation chassis around the x-axis
Pitching	Rotational motion of the carriage body or levitation chassis around the y-axis
Yawing	Rotational motion of the carriage body or levitation chassis around the z-axis

Abbreviations

- The abbreviations pursuant to MSB AG-ABK&DEF are applicable. The abbreviations explained in this chapter are necessary for understanding of this document. They complement the concepts in MSB AG-ABK&DEF.
-

GE	Sliding surface
GL	Slide rail
GLM	Sliding surface centre distance
a_y	Free y-lateral acceleration (cornering)
a_z	z-acceleration (g + passing over concave / convex transition curves)
C	Centre of rotation of the carriage body rotation
c	Spring constants
c_{piE}	Stiffness of the z-settling springs i, in relation to the swing axle
c_{ZF}	Stiffness of the y-auxiliary springs
$c_{\eta WK}$	Roll stiffness of carriage body, in relation to pendulum
d	Distance between guidance magnet gap sensors
F_{Kz1}	z-coupling force of section coupling of end section 1 to central section
F_{Kz2}	z-coupling force of section coupling of end section 2 to central section
F_{mWKy}	y-inertia force of carriage body (cant deficiency)
F_{mWKz}	z-inertia force of carriage body
F_{piy}	y-pendular force of levitation frame i
F_{piz}	z-pendular force of levitation frame i
F_{p1z}	z-pendular force of nose levitation frame end section
ΔF_{pz}	Deviation of z-pendular force from nominal load
F_{pzLFi}	z-pendular force pneumatic spring circuit i
F_{ZFiy}	y-force at y-auxiliary springs of levitation frame i
F_{ySW}	Crosswind force on end section E, central section M
F_{zWK}	z-forces of carriage body end section E, central section M
F_{yWK}	y-forces of carriage body end section E, central section M
Δf_y	Force-dependent static y- deflection of the frame structure with excited guidance magnet and deviation from the nominal load
Δf_z	Force-dependent static deflection or rebound in the case of deviations from the nominal load
Δf_{zG}	Force-dependent static deflection or rebound of the frame structure in the case of deviations from the nominal load
Δf_{zTM}	Force-dependent static deflection or rebound of the support magnet linkage in the

	case of deviations from the nominal load
Δf_{zTK}	Static deflection of the support skid in settled vehicle
F	Nominal gap guidance
F_R	Guidance gap on cornering (nominal gap)
f_z	z-displacements
L_{FM}	Magnet length of guidance magnet
l_p	Pendulum length
m_{WK}	Carriage body mass
M_T	Rolling moment carriage body
ΔP	Wear on terminal strip of guidance magnet
P	Maximum terminal strip wear
R	Guideway radius of curvature (R_{xz} or R_{xy})
R_{xz}	Radius convex / concave transition curve
R_{xy}	Radius of curve
S	Projection in cornering
s_0	Nominal air gap of support / guidance magnet
Δs	Dynamic gap deviation in support / guidance air gap
Δs_1	Gap difference in guidance magnet centre during cornering
Δs_2	Gap difference at the guidance magnet end during cornering
T	Support skid gap
ΔV	Wear on support skid coating
W_z	Nominal dimension of guideway gripper between top of the sliding surface and lower surface of the stator pack
ΔW_z	z-construction tolerances of guideway gripper dimension
W_y	Guideway track gauge (distance between lateral guide rails)
ΔW_y	y-construction tolerances of guideway track gauge
x_{iE}	Distance from the z-settling spring i to the section coupling
x_{NiE}	Distance from the z-settling spring i to the pivot point of carriage body pitching
x_{si}	Distance from resulting point of application of force of pneumatic spring circuit i to section coupling
x_{sE}	x-distance from end section centre of gravity to section coupling
x_{SWE}	Distance from end section crosswind to section coupling
x_{ZFi}	Distance from y-auxiliary spring i to section coupling
x_{2E}	Distance from levitation frame of end section 2 to section coupling
y_K	y-displacement of the section coupling
y_{sWK}	y-centre of gravity coordinates of carriage body
y_{piE}	y-displacement of pendulum i of end section

Δy_i	y-displacement of levitation frame i
Y	Vehicle track gauge
Y_A	Vehicle track gauge in failure situations or with mechanical guidance
Y_0	Nominal vehicle track gauge with non-excited guidance magnets (settled vehicle)
Δy	y-construction tolerances of vehicle track gauge
y_p	y-coordinates point of application of force of carriage body pendulum
z_K	z-displacement of the section coupling
z_{sE}	z-distance from end section centre of gravity to section coupling
z_{piE}	z-displacement of pendulum i end section
z_{sWK}	z-centre of gravity coordinates of carriage body
z_C	z-coordinates pivot point of carriage body rolling
Δz_i	z-displacement of levitation frame i
Z	Gripper dimension between lower surface of support skid and top of support magnet
Z_0	Nominal dimension of vehicle gripper between lower surface of support skid and top of support magnet in relation to the nominal load on the support magnet (levitated vehicle)
Δz	z-construction tolerances vehicle gripper dimension
α	Guideway – angle of lateral inclination
γ bzw. γ_{xz}	Pitch angle (rotation around y-axis)
γ_{0xz}	Static pitch angle from asymmetry of loading
δ bzw. δ_{xy}	Yaw angle (rotation around the z-axis)
δ_{0xy}	Static yaw angle from asymmetry of loading
η bzw. η_{yz}	Roll angle (rotation around x-axis)
η_{0yz}	Static roll angle from asymmetry of loading
η_{yzFy}	Roll angle of carriage body from centrifugal force and crosswind
$\eta_{yz\alpha'}$	Roll angle of carriage body from guideway canting

Definitions and terminology

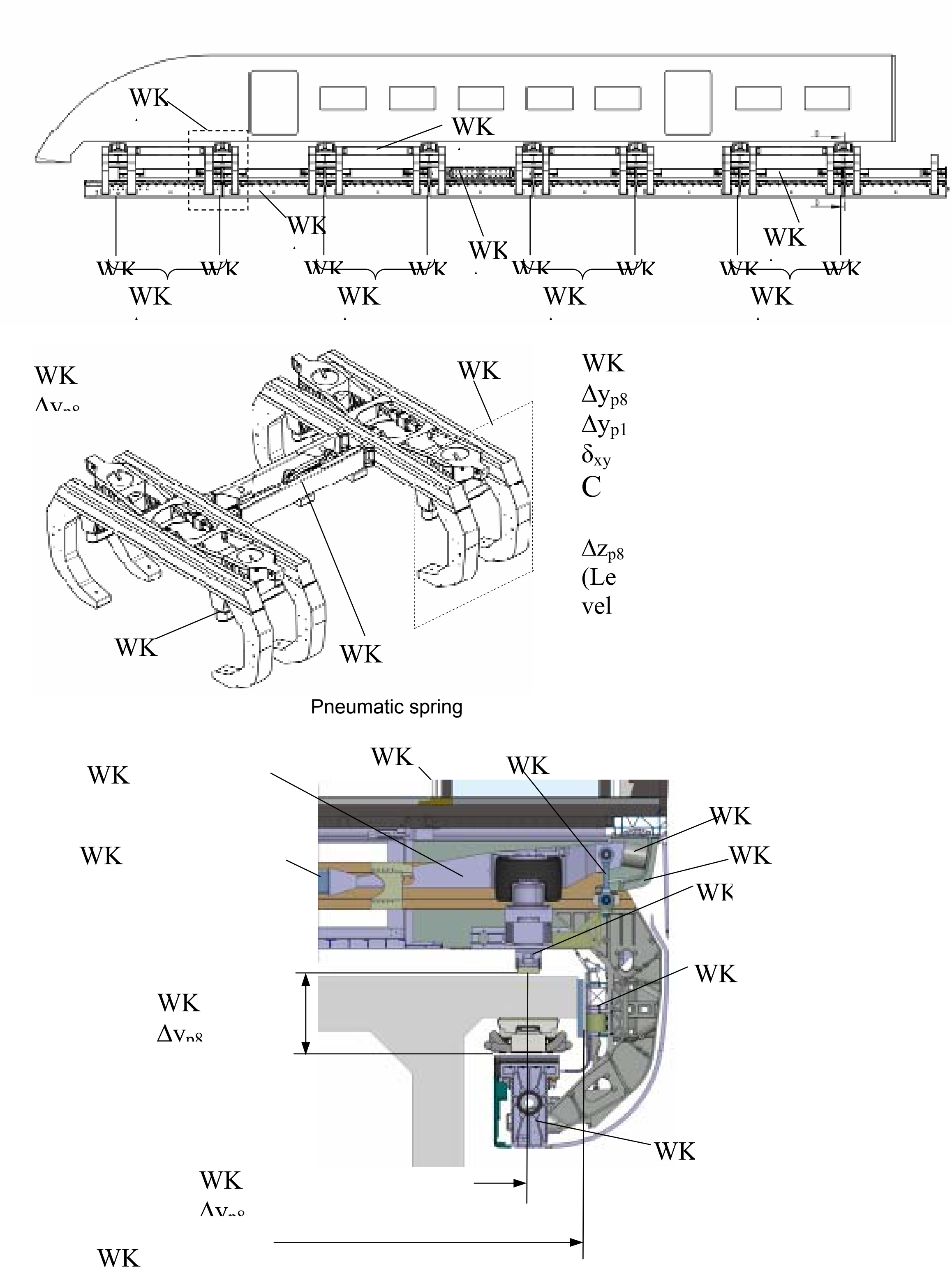


Figure 70: *Side view and cross-section of a vehicle (diagrammatic representation)*

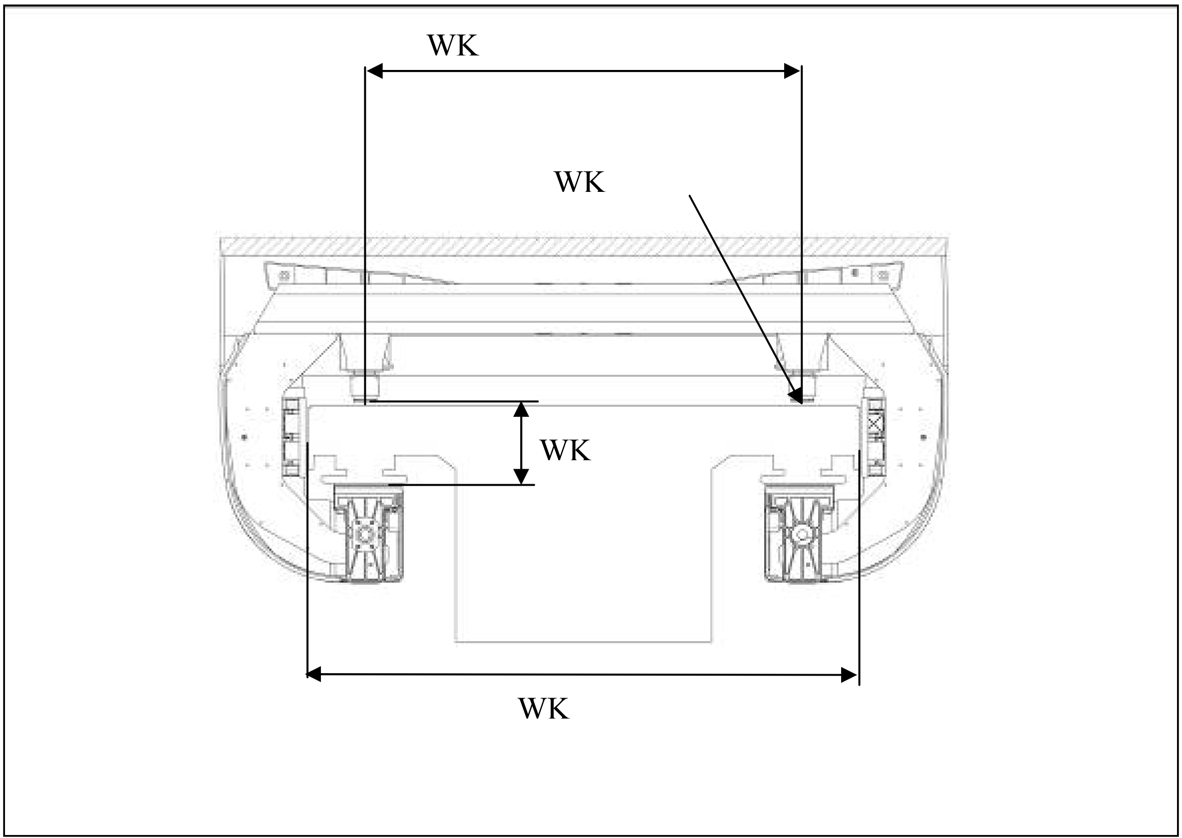


Figure 71: Relevant geometric definitions of guideway dimensions

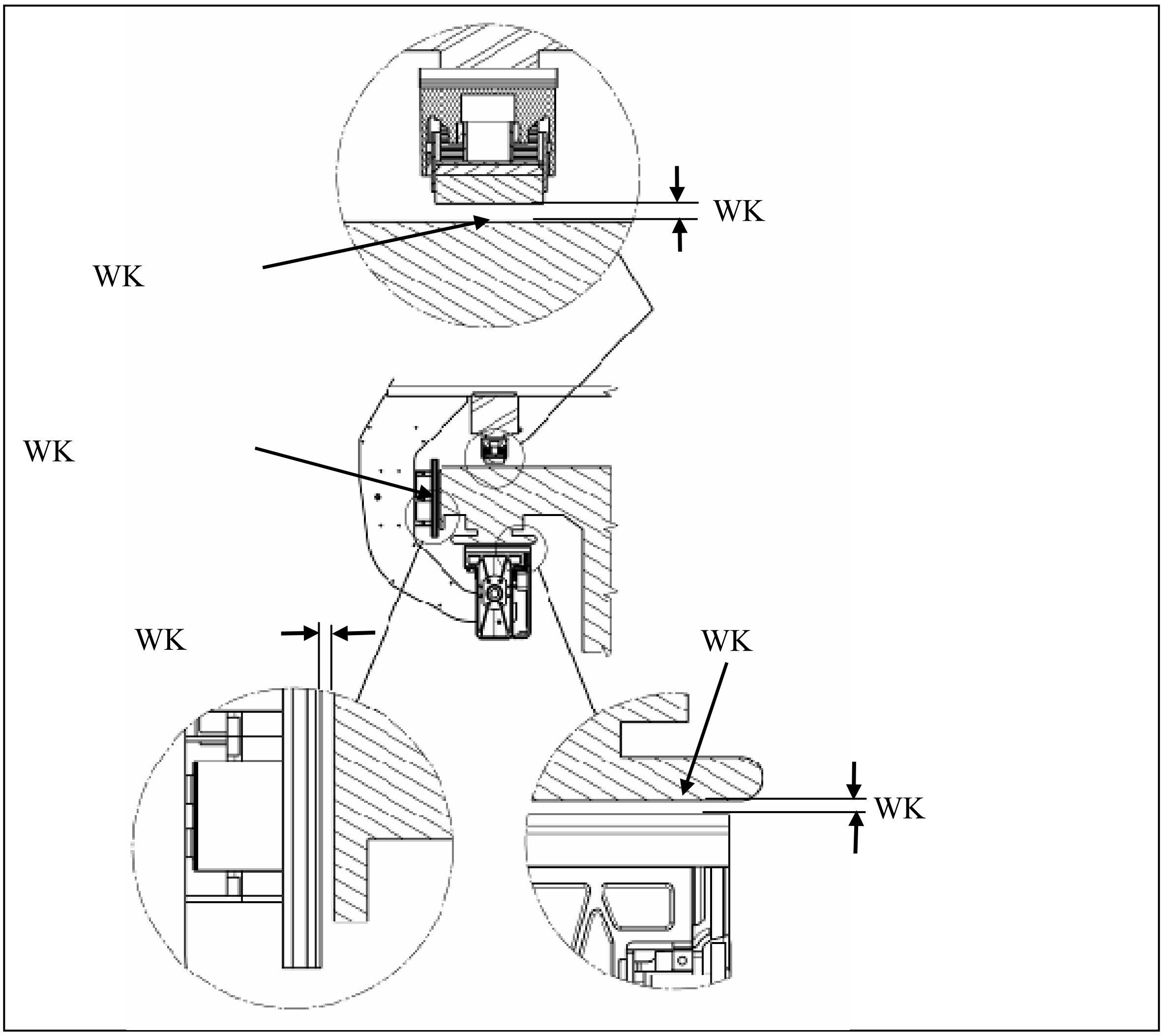


Figure 72: Characteristic quantities for the kinematics of maglev vehicles

Alignment parameters

- The following alignment parameters must be taken into account:

Concave transition curve:	Vertical radius R_{xz}	530 m
Convex transition curve:	Vertical radius R_{xz}	530 m
Curve:	Horizontal radius R_{xy}	1000 m

- Different values may be agreed on a project-specific basis. Smaller specified alignment parameters must be demonstrated by the manufacturer with regard to the aspect of non-contact between guideway and vehicle.
- *These investigations do not form part of the demonstration regarding the kinematic gauge.*

Loading gauge

- The loading gauge shown in Figure 73 corresponds to the loading gauge line C (MbBO) for straight tracks. Figure 74 shows the loading gauge for curve radii < 3500 m. Dimensions of the guideway boundary not shown in the MbBO have been added without an indication of tolerances.

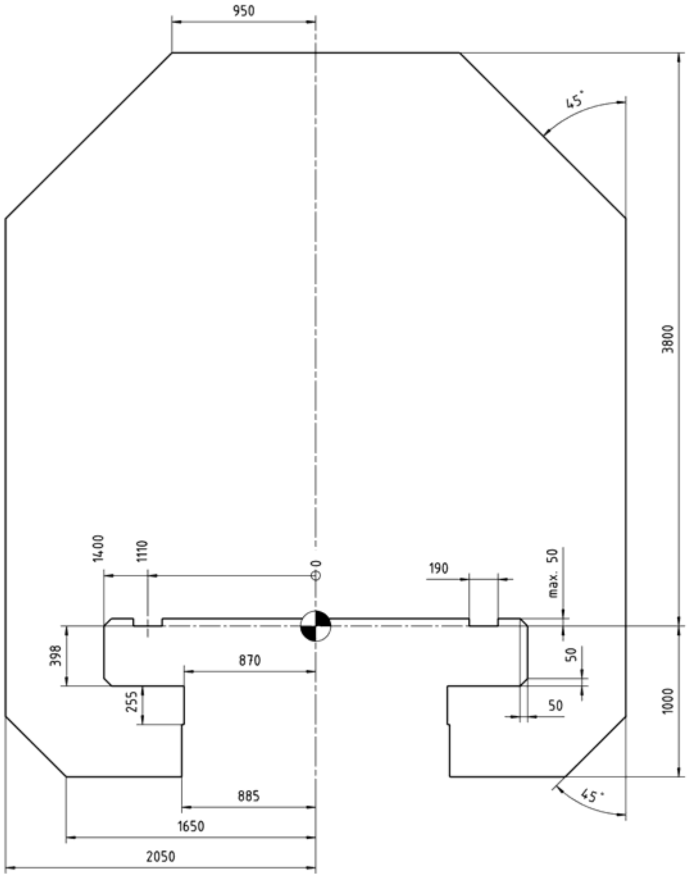


Figure 73: Gauge of maglev vehicles – straight track

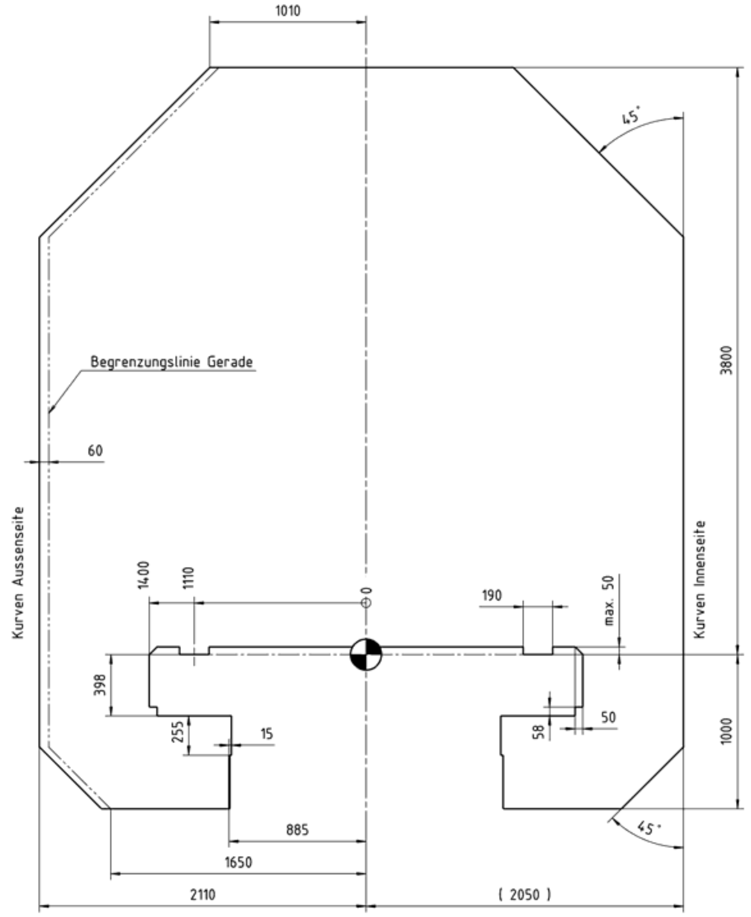


Figure 74: Loading gauge of maglev vehicles – curve radius 350 m to 3500 m

Key

Begrenzungslinie Gerade = Loading gauge straight track
Kurven Aussenseite = Outside of curves
Kurven Innenseite = Inside of curves

Demonstration procedure

- The following procedure should be used to demonstrate the kinematic gauge of the maglev vehicle. Differences must be agreed on a project-specific basis.
- The displacements and torsions of the carriage body and the displacements of the levitation chassis must be applied to the guideway.
- *The superimposing of the carriage body displacements with the displacements of the levitation chassis produces the overall displacements of the carriage body.*
- The overall displacement of the carriage body must be determined by superimposing the carriage body displacement with the displacements of the levitation chassis.
- The resulting displacements of the vehicle external profile must be checked against the loading gauge in the MbBO.
- The carriage body must then be regarded as a rigid body. The elastic forces of the levitation chassis to be taken into account must then be included in the corresponding displacements of the levitation chassis.
- The displacements / deformations of the carriage body and the levitation chassis must be determined separately and then superimposed.
- *The displacements are deduced for the carriage body in Chapter 0, and for the levitation chassis in Chapter 0.*
- Analytical procedures or suitable software applications (e.g. CAD software products) may be used for this definitive examination of the boundary envelope.
- The following conditions must form the basis for the demonstration procedure, where applicable:

Centres of rotation are assumed in order to deduce the displacements from rolling / pitching / yawing. The resulting centre of rotation shifts as a result of superimposing of the displacements. The position of the resulting centre of rotation precludes certain superimpositions because of the constraining kinematic conditions.
The position of the resulting centre of rotation must be tested. The individual movements must be corrected subsequently when the individual displacements are superimposed.

Construction tolerances of the carriage body must be taken into account. The construction tolerances of the levitation chassis should be disregarded as support and guidance gaps are adjusted to the specified dimension.

The specified wear caused by vehicles on the support skid coatings and the terminal strips of the guidance magnets must be taken into account.

Wear and construction tolerances in respect of the guideway are disregarded. These are recorded above range B, MbBO, fig. 1.

Deflections and elastic deformations (bending, torsion) for the carriage body must not be taken into account.
The elastic deformations from support (z-loads) and guidance (y-loads) must be taken into account for the levitation chassis.

Pneumatic suspension:
A distinction must be made between the cases of pressurised and/or deflated cushions. With

depressurised pneumatic springs, allowance must be made for the spring suspension via the settling springs.

Rubber and steel springs
Deflection under static load must be taken into account, if necessary allowance for additional deflection from dynamic stresses. Deflections because of suspension tolerances may be disregarded. *These are included in the adjustment tolerances of the magnet linkages.*

The support/guidance function of the maglev vehicle is designed as an active system; in the case of failure, the function of the individual systems is taken over by adjacent systems on the basis of the redundant design. Corresponding proof is provided inter alia *by means of FMEA analyses during the development of the Transrapid vehicles. Adequate support behaviour is also validated by means of the demonstration.*
Component failure of structural assemblies of the support / guidance system (components in the primary power flux, e.g. support bracket) may not lead to the loading gauges pursuant to Chapter 0 being breached.

In the case of a specified failure of the magnetic support or guidance function, the loads are dispersed mechanically via the support skids and/or guidance magnets. This state must be taken into account when deducing the support or guidance gap.

Crosswind action must be taken into account. The aerodynamic lift on the carriage body may be disregarded. Local aerodynamic loads from trains passing and tunnel operation may also be disregarded.[6]

The different loading states must be taken into account (vehicle deadweight, mean and permissible vehicle weight as well as maximum vehicle weight, see also MSB AG-FZ BEM).
Maximum carriage body load: assessment of the larger value of

a. 30 % excess load in relation to the maximum payload at maximum capacity utilisation,

b. Load in the case of evacuation (maximum vehicle weight), if relevant for the application.

An additional clearance requirement for attachments to the carriage body (e.g. radio aerials, Figure 80) must be taken into account on a project-specific basis.

[6] Local effects are not taken into account because the carriage body is regarded as a rigid body. The required vehicle rigidity is dealt with in MSB AG-FZ BEM.

Kinematic degrees of freedom of carriage body

- *The carriage body has the following rigid-body degrees of freedom:*

z-displacement of carriage body (deflection, rebound),

y-displacements (lateral movements),

rolling around the longitudinal axis (roll in the case of rail vehicles),

pitching around the transverse axis (non-uniform z-displacement),

yawing around the vertical axis (non-uniform y-displacement).

- *Below, the z-displacements are considered with pitching of the carriage body, and the y-displacements together with yawing of the carriage body.*
- *To obtain the absolute carriage body displacements, the displacements of the levitation chassis must be superimposed with the displacements deduced below.*
- The statements in the sections of Chapter 0 must be taken into account.

Rolling of carriage body

- The quasi-static rolling of the carriage body is considered on the basis of the characteristics of the secondary suspension. Stops which limit the movement of the carriage body to the levitation chassis are taken into account. Characteristic quantity is the roll angle η_{yz}.

Concepts regarding carriage body rolling

Pivot point of carriage body rolling

- The centre of rotation of carriage body rolling C (roll centre C in rail vehicles) is not fixed because of the pendulum characteristics. For straight rolling it is situated in the vehicle centre in the section coupling (Figure 75). The centre of rotation C moves upwards as a result of the lateral displacement caused by the gravity pendulum.
- As the roll angle would be reduced as a result of the upward displacement of the centre of rotation, the centre of rotation C is situated in the section coupling for the purposes of demonstration and is assumed to be fixed.
-

Asymmetry η_{0yz}

- Asymmetry η_{0yz} is the static roll angle of the carriage body as a result of offset of the load with a level guideway. The offset is recorded by means of the position of the carriage body centre of gravity x_{SE}.
-

Guideway canting

- Guideway canting (lateral inclination α) means the difference in elevation of the inner curve of the stator surfaces compared to the outer curve.

Rolling caused by cant deficiency

- The cant deficiency is the dimension by which the actual guideway cant differs from the compensatory cant. The maximum lateral acceleration a_y is set for the investigations.
-

Rolling caused by gravity

- When the vehicle is standing on a canted guideway, the sliding surface of which forms an angle α with the horizontal line, the carriage body rotates and forms an angle η_{yz} with the perpendicular to the guideway.
- The roll angle is dependent on the load state of the vehicle. The greatest load value in the most unfavourable load state is taken into account.

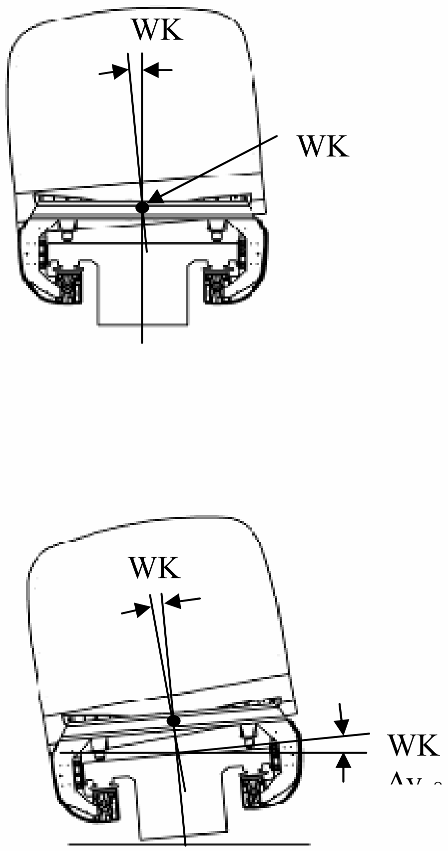


Figure 75: Vehicle kinematics – Rolling of carriage body

Rolling load cases to be examined

- The **roll angle** can be calculated in accordance with Chapter 0. The calculation method applies to maglev vehicles in accordance with MSB AG-FZ GEN.
- The settling springs are disregarded when determining the roll stiffness. Depressurised pneumatic springs, i.e. where the carriage body is supported on the 16 settling springs, result in a higher roll stiffness and thus a reduced roll angle. The structure leaves the loading gauge as a result of the simultaneous lowering of the level. Thus, an intact pneumatic suspension (if present) is taken into consideration for rolling.
- The following cases must be tested:

Vehicle stands on maximum canted guideway – rolling caused by gravity

Vehicle runs on guideway with cant deficiency – rolling caused by centrifugal force

The effect of crosswind and asymmetry η_{0yz} must be taken into account for both cases.

- The input parameters for deducing the roll angle of the carriage body are given in Chapter 0. Depending on the superimposition of load cases, the data to be taken into account such as guideway alignment, lateral accelerations to be assessed, carriage body dimensions, asymmetries of the load and crosswind speeds are given in the chapter.

Z-displacements / pitching of carriage body

- The quasi-static deflection/rebound and pitching of the carriage body is considered on the basis of the secondary suspension characteristics.
- Stops which limit the movement of the carriage body to the levitation chassis are taken into account. Characteristic quantity: displacement z and pitch angle γ_{xz}.

Concepts regarding carriage body z-displacements / pitching

Pivot point of carriage body pitching

- With active pneumatic suspension the pivot point is situated in the section coupling (Figure 76).
- With full venting of a pneumatic spring circuit, the pivot point ideally lies in the level recording point of the adjacent active pneumatic spring circuit of the section. The level recording points are vehicle-specific and, pursuant to MSB AG-FZ GEN, are located in the first and last levitation frame for maglev vehicles (Figure 76).
-

Vehicle height

The vehicle heights for the empty (unloaded) and full (loaded) vehicle considered.

Downward vertical displacements f_1

- The vertical displacement f_1 [7] is made up of the deflection Δfz and the supplementary displacements f_z (see 0). In a levitated vehicle, the deflection Δf_z is made up of the spring travel of the secondary suspension, the spring travel of the support magnet linkage and the elastic force of the levitation chassis. In a settled vehicle, the deflection Δf_z consists of the spring travel of the secondary suspension and the deflection of the support skid. The values for spring travel of the secondary suspension correspond to the derived carriage body displacements.
- The deflection of the levitation chassis is considered separately in 0.
- The vertical deflection is taken into account at max. operating loading.

Upward vertical displacement f_2

- The vertical displacement f_2 [7] is obtained from the rebound Δf_z of the secondary suspension and the levitation chassis.
- In a levitated vehicle, the rebound Δf_z is made up of the spring travel of the secondary suspension, the spring travel of the support magnet linkage and the elastic force of the levitation chassis.
- In a settled vehicle, the rebound Δf_z corresponds to the spring travel of the secondary suspension, i.e. the derived carriage body displacements.

[7] For terminology, see DIN 27505

- The rebound of the levitation chassis is considered separately in 0.
- Allowance is for the vertical rebound in the case of an unoccupied carriage body, taking into account the dynamic displacements and the new state.

Additional vertical displacements f_z

- Additional vertical displacements caused by a longitudinal and lateral inclination of the carriage body.

Lateral compression of one body side: deflection in phase on all levitation frames towards the same guideway side. The displacements are covered in the chapter on rolling 0.

Longitudinal compression of one body end: deflection in phase on the opposite levitation frames of the levitation chassis (pitching), e.g. in the event of failure of a pneumatic spring circuit.

Additional vertical displacement from the suspension gap control of the levitation chassis. The displacements of the levitation chassis are taken into account in the kinematics of the levitation chassis in Chapter 0.

Asymmetry γ_{0xz}

- Asymmetry γ_{0xz} is the static pitch angle of the carriage body as a result of offset of the load in the longitudinal direction of the vehicle with a level guideway. The action is taken into account via the position of the carriage body centre of gravity.

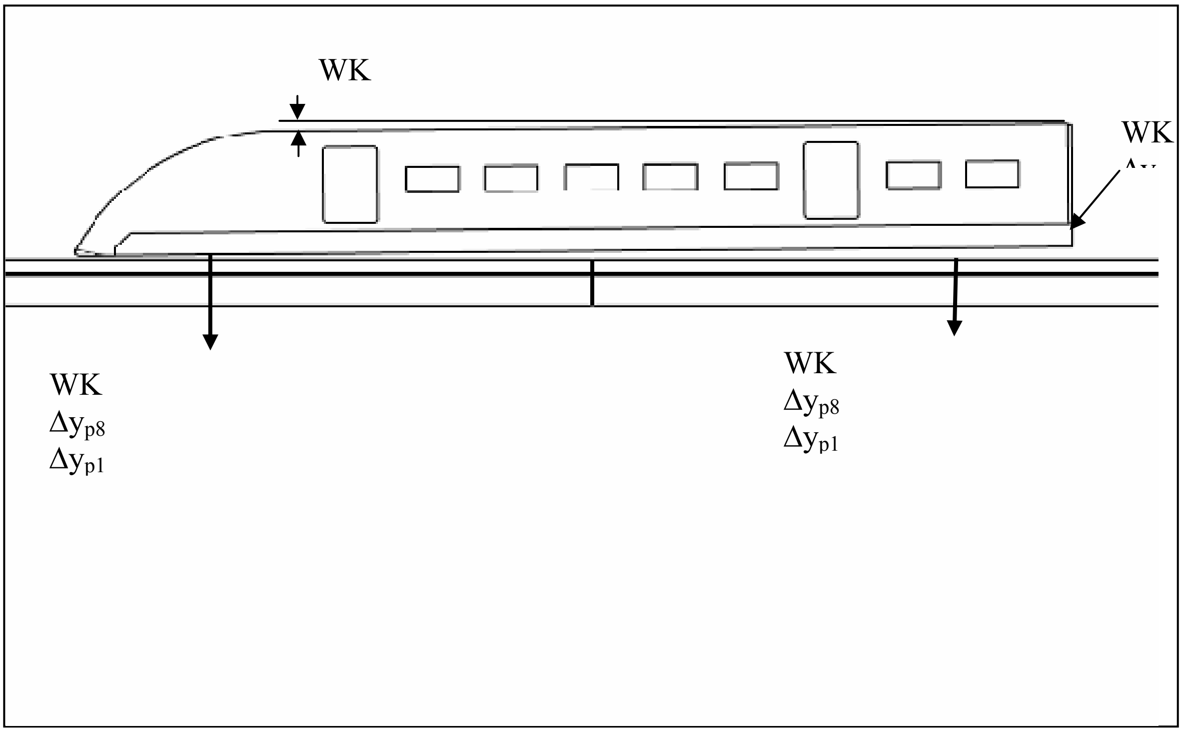


Figure 76: Vehicle kinematics - z-displacements / pitching of carriage body

Z-displacement / pitching load cases to be examined

- The highest z-level of the carriage body occurs with active pneumatic suspension (pressurised pneumatic springs). If individual springs fail, the level is maintained by the level control; negligible pitching occurs. The operational pitching is deduced taking into account the active pneumatic spring system.
- *The maximum pitching occurs for the "theoretically constructible" operating malfunction of a depressurised pneumatic spring circuit.*
- The design of the pneumatic spring circuits and the allocation of the springs to the pneumatic spring circuits must be such that the probability of occurrence of undue pitching is negligible.
- The maximum pitch angles of a section occur for the case of an active pneumatic spring circuit (z-level in the level recording point in nominal position) and a depressurised pneumatic spring circuit (z-level lowered on the settling springs). For information purposes, the correlations for deduction of the pitch angle are included in the annex. The case of upward rebound (pressure of pneumatic spring circuits above nominal pressure) is not considered as, for this case, the pitch angle is clearly smaller compared to the stated malfunction situations and anyway is covered by the load case of empty weight or loading asymmetry.
- The **pitch angle and the z-displacements of the carriage body** may be calculated in accordance with Chapter 0.

Vehicle in nominal operation (two active pneumatic spring circuits) with max. z-level in accordance with Chapter 0

Vehicle on depressurised pneumatic springs in accordance with Chapter 0 with minimum z-level

Vehicle in the case of malfunction with depressurised nose spring circuit in accordance with Chapter 0 with maximum negative pitch angle (nose lowering)

Vehicle in the case of malfunction with depressurised rear spring circuit in accordance with Chapter 0 with maximum positive pitch angle (rear lowering)

- The following cases must be examined:

Deflection/rebound of carriage body as a result of load states (empty weight, max. weight in accordance with Chapter 0)

Vehicle running on guideway with vertical radius R_{xz}

Deflection/rebound of one end of carriage body as a result of starting / braking at maximum acceleration / deceleration

- The effect of crosswind and asymmetry γ_{0xz} must be taken into account for the cases.
- In addition, the fault "lowering of one end of carriage body as a result of failure of a pneumatic spring circuit" must be assessed by the manufacturer, and a supplementary operating measure, where necessary, must be defined.
- Only the end section has to be considered in all demonstrations. The middle sections are covered by the demonstrations.
- The input parameters for deducing the pitch angle and z-displacements of the carriage body are given in Chapter 0. Depending on the superimposition of load cases, the data to

be taken into account such as accelerations / decelerations to be assessed, carriage body dimensions and asymmetries of the load are given in the chapter.

Y-displacement / yawing of carriage body

- The quasi-static yawing of the carriage body is considered on the basis of the secondary suspension properties.
- The lateral displacements and/or the yawing of the carriage body depend on the suspension characteristics of the secondary suspension (gravity pendulum, arrangement of the y-auxiliary springs).
- Characteristic quantity: Lateral displacement y, yaw angle δ_{xy} (see Figure 77).

Concepts regarding carriage body y-displacements / yawing

Yawing pivot point

- The pivot point is situated in the section coupling.

Geometric overthrow

Offset of a vehicle element caused by cornering
On the same side of the guideway centreline, it is assumed that all points in the same carriage body cross-section have the same geometric overthrow (regarded as rigid body).

S projections

Offset of the vehicle end cross-sections caused by cornering

Asymmetry δ_{0xy}

Asymmetry δ_{0xy} is the static yaw angle of the carriage body as a result of offset of the load in the longitudinal direction of the vehicle with a straight guideway. The action is taken into account via the position of the carriage body centre of gravity.

Lateral displacements

The lateral displacement of the carriage body is made up of the following parts:

Geometric displacement caused by the vehicle position on a curve and on a straight track where the vehicle vertical axis is located perpendicular to the guideway;

Quasi-static displacement y of the secondary suspension;

Quasi-static lateral displacement of the levitation chassis. The displacements of the levitation chassis are taken into account in the kinematics of the levitation chassis in Chapter 0.

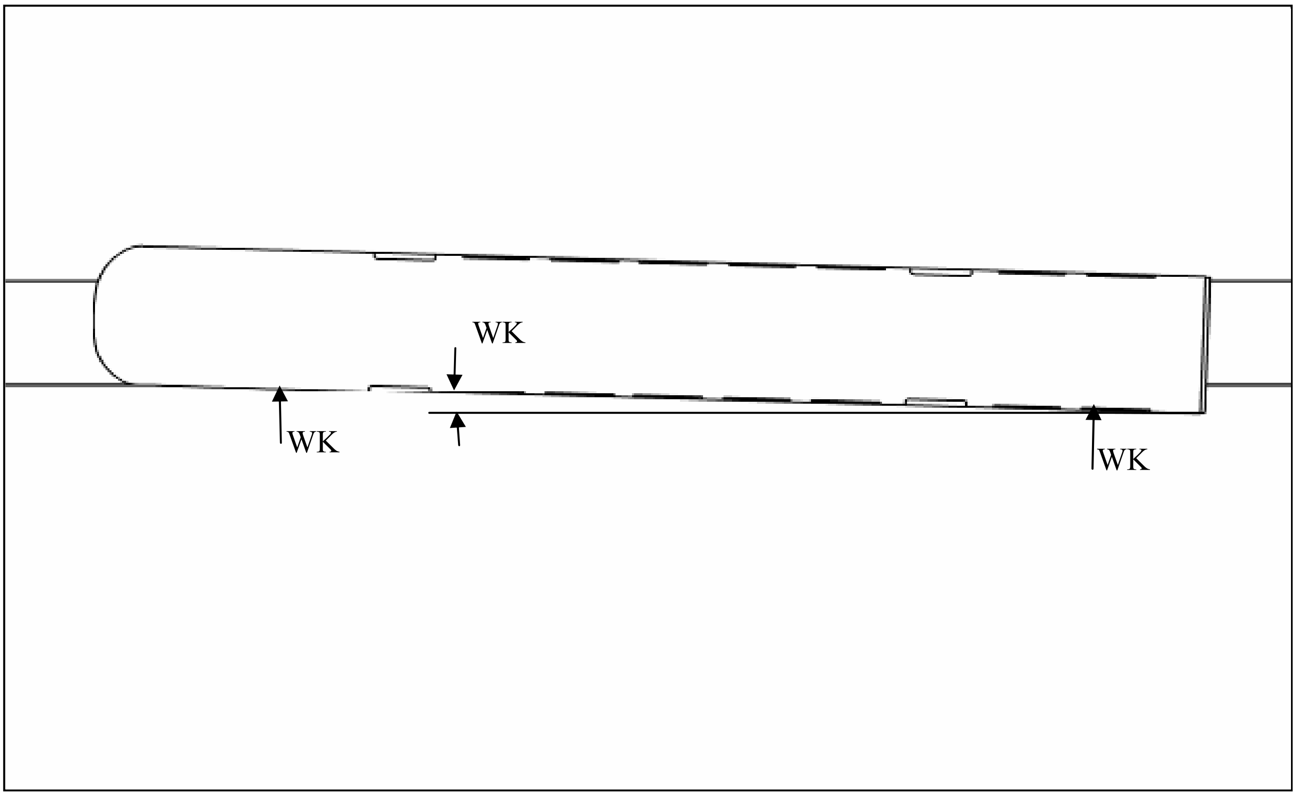


Figure 77: Vehicle kinematics – y-displacements / yawing of carriage body

Y-displacement / yawing load cases to be examined

- The **yaw angle and y-displacements of the carriage body** may be calculated in accordance with Chapter 0.
- The following cases must be examined:

Vehicle runs on guideway with cant deficiency – displacement and yawing as a result of centrifugal force

Vehicle runs on guideway with horizontal radius R_{xy}.

- The effect of crosswind and asymmetry δ_{0xy} must be taken into account for both cases.
- The geometric overthrow and S projections when all displacements (carriage body and running gear) are superimposed can be determined by means of suitable calculation methods (e.g. CAD models).
- The input parameters for deducing the yaw angle and y-displacements are given in Chapter 0. Depending on the superimposition of load cases, the data to be taken into account such as guideway alignment, lateral accelerations to be assessed, carriage body dimensions, asymmetries of the load and crosswind speeds are given in the chapter.

Kinematics between levitation chassis and guideway

- The statements in the sections of Chapter 0 must be taken into account.

Kinematic degrees of freedom of levitation chassis

- *The non-contact support and guidance allows the following rigid body degrees of freedom of the levitation chassis:*

z-displacement of levitation chassis through support gap control

y-displacement of levitation chassis through guidance gap control (track centre control)

rolling around the longitudinal axis caused by non-uniform support gap left/right (non-uniform z-displacements)

pitching around the transverse axis caused by non-uniform support gap front/ rear (non-uniform z-displacement),

yawing around the vertical axis caused by non-uniform guidance gap front/rear (non-uniform y-displacement)

- *In normal operation the relative movements of the levitation chassis to the guideway result from the dynamic gap differences at the support and guidance magnets.*
- *The maximum displacements occur in the case of failures of the electromagnetic support/guidance system. These possible movements are limited as follows:*

In the z-direction, upwards by minimum gap monitoring or, in borderline cases, by touching of the support magnet on the stator, downwards mechanically by the support skid.

In the y-direction, mechanically by the track channel of the guidance magnets (start-up of guidance magnet on lateral guide rail).

- *The support and/or guidance gaps are measured at the position of the gap sensors.*
- The following operating states must be taken into account:

Controlled settling of the whole vehicle in a standing position

Normal operation with support gap and track centre control

- In addition to the operating states, the following specific operating cases must be taken into account:

Settling of individual support frames after failure of two dedicated support control circuits (local mechanical support on support skid)

Failure of two dedicated guidance magnet control circuits (local mechanical guidance with guidance magnet)

Controlled settling of the whole vehicle from low speed after automatic application of brakes with eddy current brake

Uncontrolled settling on one side in the case of a short circuit in the propulsion coil

Displacements of levitation chassis

- *The air gaps between levitation chassis and guideway are deduced below.*
- These determine the possible displacements of the levitation chassis and their position in relation to the guideway.

Support gap and support skid gap

- In nominal state, the vehicle levitates at a defined support gap s_0. Upward displacement of the vehicle is limited by the support magnet resting on the stator surface, and downward displacement by the contact of the support skid with the sliding surface.
-

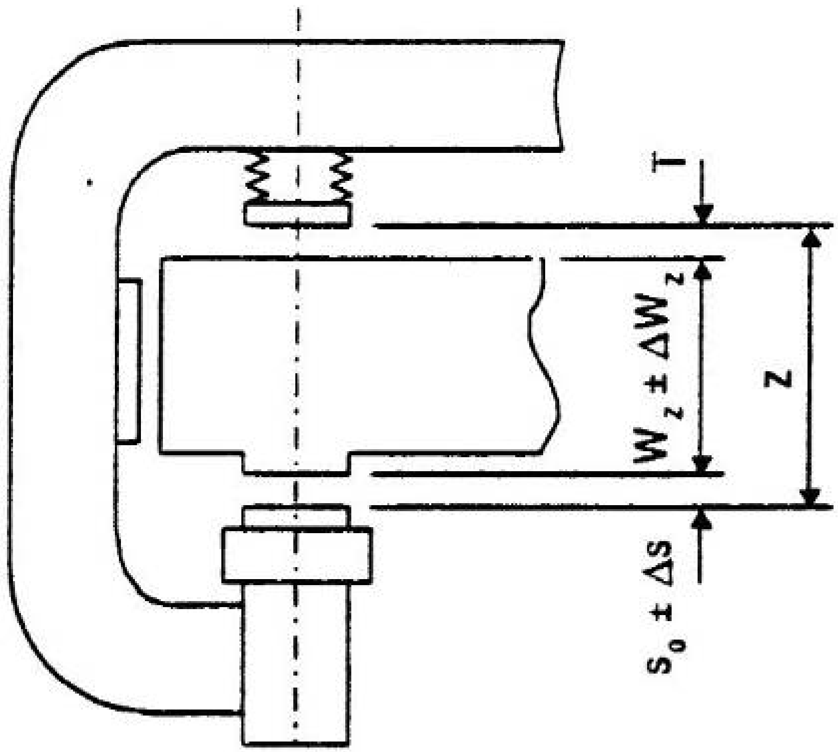


Figure 78: Vehicle kinematics – Gap balance support (z-direction)

- Allowing for skid wear ΔV, the **actual gripper dimension of the vehicle** between the top of the support magnet and the lower surface of the support skid is calculated generally to be

$$Z = Z_0 \pm \Delta z + \Delta f_z + \Delta V$$ **Equation 1**

- To demonstrate the loading gauge 0, the ΔW_z tolerances for the guideway are set at zero.
-
- For the **levitated vehicle**, the deflection/rebound of the levitation chassis and of the support magnet linkage must be taken into account if there is a deviation from the nominal load.

$$\Delta f_z = \Delta f_{zG} + \Delta f_{zTM}$$ **Equation 2**

-
- For the **settled vehicle**, the rebound of the levitation chassis and the support magnet linkage and the deflection of the support skid must be taken into account.

$$\Delta f_z = \Delta f_{zG} + \Delta f_{zTM} + \Delta f_{zTK}$$ **Equation 3**

-
- The levitated vehicle is shown in nominal position in the construction documents.
- $\Delta f_z = 0$
-
- The **support gap** determines the maximum upward displacement of the levitation frame. Allowing for the support dynamics in accordance with
- Figure 78, it amounts to

$$s = s_0 \pm \Delta s$$ **Equation 4**

- For the tests, the gap s_0 corresponds to the max. value for upward displacement.
-
- The **support skid gap** determines the maximum downward displacement of the levitation frame. Allowing for the support dynamics in accordance with
- Figure 78, it amounts to

$$T = Z_0 + \Delta z + \Delta V - W_z - (s_0 \pm \Delta s)$$ **Equation 5**

-

Guidance gap

- In nominal state, the vehicle levitates at a defined guidance gap F. Lateral displacement of the vehicle is limited in both directions ± by the guidance magnet resting on the lateral guide rails of the guideway.
- With track centre control, the track gauge of the vehicle between the guidance magnets is

$\mathbf{Y = Y_0 \pm \Delta y - \Delta f_y}$ **Equation 6**

-
- For the **levitated vehicle**, deflection/rebound of the levitation chassis Δf_y occurs if there is a deviation from the nominal load. This value can generally be disregarded.
- The maximum guidance gap occurs during mechanical guidance. The guidance magnet of one side of the levitation frame rests on the lateral guide rail and is not subject to any force. The opposite guidance magnet is subject to applied force.
- The vehicle gauge is then

$\mathbf{Y_A = Y_0 \pm \Delta y + \Delta P}$ **Equation 7**

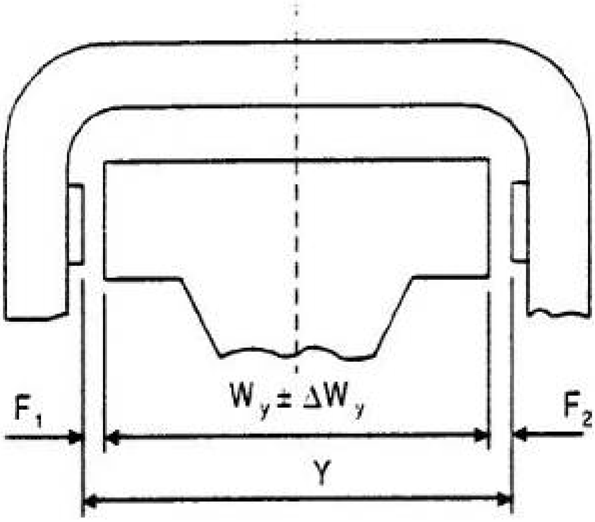


Figure 79: Vehicle kinematics – Gap balance guidance (y-direction)

-
- P represents the maximum abrasion of the terminal strips.
- As it concerns a wear state defined as the most unfavourable, the wear should not be assessed simultaneously for all guidance magnets. Therefore, the full wear is assessed only for one vehicle side.
- $\Delta P = P$
- Thus, the sum of both guidance gaps is calculated at

$$F_{Amax} = Y_0 + \Delta y + P - W_y \qquad \textbf{Equation 8}$$

- To demonstrate the loading gauge 0, the ΔW_y tolerances for the guideway are set at zero.
- For the side of the levitation frame resting on the guideway, the value of the displacement of the levitation chassis from the nominal position is
- $dy = F_{Amax} - F$
- where F corresponds to the nominal gap of the starting position.
-
- The reduction in the guidance gap during cornering in accordance with 0 can be taken into account with radii of curve of < 1000 m.
-

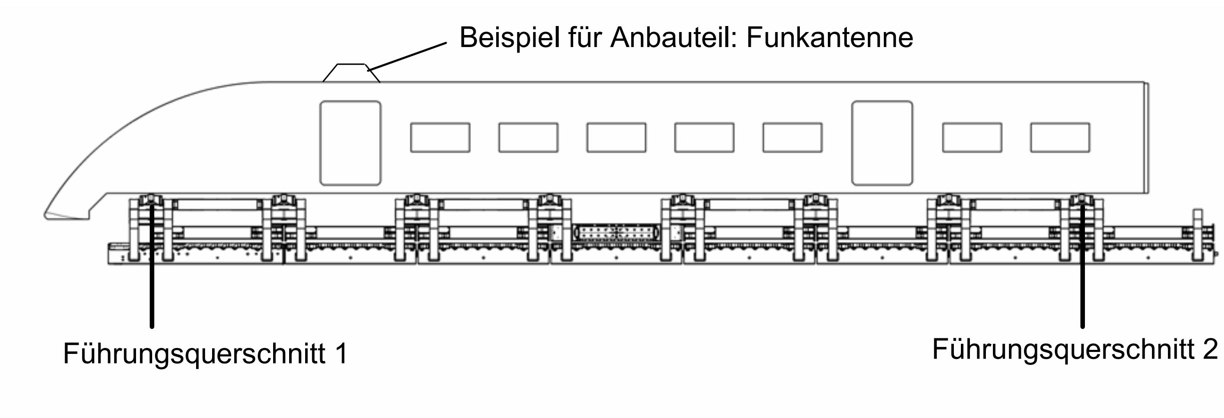
Torsions of the levitation chassis

- *The z- and y-displacements of the levitation chassis (support and guidance gap, support skid gap) cause rolling, pitching and yawing of the levitation chassis.*
- *For the vehicle kinematic gauge, the unfavourable carriage body positions occur with the onset of displacements (support and guidance gap).*
- The pitch and yaw torsions reduce the displacements of the carriage body and do not have to be taken into account.
- The rolling of the levitation chassis must be taken into account since the vehicle roll angle increases.

Demonstration of the vehicle kinematic gauge

Guidance cross-sections

- The following statements regarding processing of the guidance cross-sections must be taken into account:
- The adjustment of the vehicle in relation to the guideway is determined by means of the vehicle cross-sections.
- Maglev vehicles have 4 levitation chassis per section.
- To demonstrate the kinematic gauge, the guidance cross-sections are located in the first and last levitation chassis.
- The position of the carriage body in relation to the two levitation chassis is determined from the position of the linkage consoles of the x-linkage of the carriage body (x- and y-position centre of levitation chassis, y-position centre carriage body).
- The position of the two middle levitation chassis must be checked for this defined carriage body position.
- The two middle chassis have a fixed relationship to the guideway and to the carriage body; in terms of the guideway via the support and guidance gaps, in terms of the carriage body via the pendulum (y- and z-displacements).
- If a geometric constraining condition occurs because of these chassis, the position of the carriage body must be adjusted, otherwise the middle levitation chassis are disregarded.



Example of attachment: radio aerial

Guidance cross-section 1 Guidance cross-section 2

Figure 80: Positioning of vehicle on the guideway

Load cases / geometric situations to be considered

- As a minimum requirement, the operating load cases in accordance with Chapter 0 must be demonstrated.
- The specific operating cases, see Chapter 0, must be examined by the manufacturer with regard to possible effects. Any operational measures which may be required must be named and must be agreed and laid down with the operator and the licensing authority.

Operating load cases

- The following table contains the load case combinations A to D of the running train which have to be considered. In addition, the table shows which actions are superimposed when determining vehicle kinematics. The actions to be taken into account in maintenance facilities for demonstrating the kinematic gauge must be agreed with the operator.
-

Operating cases – vehicle kinematics	Case			
	A	B	C	D
Inertial forces from:				
• Empty weight		X		X
• Maximum operational loading (1.3 times maximum payload)	X		X	
• Maximum deceleration / acceleration a_x	X	X	X	X
• Maximum lateral acceleration a_y	X	X		
• Maximum vertical acceleration from concave/convex transition curve a_z			X	X
• Asymmetry of the load	X		X	
Alignment				
• Vehicle on curved track	X	X		
• Vehicle on straight track, concave/ convex transition curve incl. vehicle movement dynamics			X	X
Crosswind				
• Crosswind acting constantly during operation	X	X	X	X

Table 77: Operating cases for vehicle dynamics

- The values to be assessed for wind speeds, weights and alignment as well as the asymmetry of the load must be laid down on a project-specific basis. Superimposition of load cases may also be laid down on a project-specific basis.
- Unless otherwise agreed for specific projects, the following values are applicable:

Alignment parameter in accordance with Chapter 0
The vehicle movement dynamics of the carriage body as a consequence of the guideway are to be set as $\Delta z = \pm 10$mm (experimental value).

Operational crosswind v_w = 10 m/s.

As the maximum **levitation chassis displacements** are not dependent on suspension characteristics, a conservative assumption of an “extreme position” of the first levitation chassis is used (guidance cross-section of the section nose in accordance with Chapter 0) with simultaneous nominal position of the second levitation chassis (guidance cross-section of the section rear in accordance with Chapter 0). This method is sensible, as only the first or, where appropriate, last levitation chassis is considered and the two middle levitation chassis in between are disregarded. If these intervening middle chassis are taken into account, this produces smaller pitch and yaw angles.

<u>Levitation chassis position of guidance cross-section of nose:</u>
The guidance magnets of the guidance-cross sections rest on the inside of the curve during cornering; allowance is made for the operationally permissible wear on the terminal strips. Two cases are distinguished for the z-position of the levitation frames:

a) the support magnet of the first chassis rests on the lower edge of the guideway (maximum pitch of carriage body caused by upward displacements of the levitation chassis)
b) taking into account the static deflection and the permissible operational wear, the support skid of the first chassis rests on the slide rail (maximum pitch of carriage body caused by downward displacements of the levitation chassis)

<u>Levitation chassis position of guidance cross-section of rear:</u>

- Nominal dimensions for support, guidance and skid gaps:

  - *<u>Examples of gap dimensions:</u>*

    Support gap *10 mm*
    Guidance gap *11 mm*
    Support skid gap *16 mm*

  - *<u>Examples of wear values:</u>*

    Operational wear, and not the maximum possible wear, is assessed for the support skid coatings and terminal strips. The wear parameters must be laid down on a project-specific basis.

    Skid coatings:
    CFC: *1.5 mm*
    GKB 5: *5 mm*
    Terminal strips guidance magnet: *1.0 mm.*

Specific operating cases

- The following cases should be assessed by the manufacturer as part of the examination of malfunctions. The cases are not superimposed with other load cases. Worst-case load cases: malfunctions in the sense of a marginal consideration, which can be disregarded on the basis of the probability of their occurrence:

- failure of individual pneumatic spring circuits
- carriage body on settling springs (discharged pneumatic springs)

- Specific load cases: specified specific operating cases:

maximum crosswind 37 m/s

maximum carriage body load (evacuation case)

uncontrolled settling on one side in the event of winding short circuit

maximum support skid wear

- The maximum wear may be utilised only in the case of mechanical support of a levitation frame, which counts as a specific operating case, as far as a stopping place to be laid down on a project-specific basis (see also MSB AG-BLT, Chapter 6.3.3.1). Maintenance measures are carried out after occurrence of this event.
- The levitation chassis (guidance cross-sections) must be arranged in nominal position.

Annex (for information purposes)

Deduction of the kinematic degrees of freedom of carriage body

Roll angle of carriage body

The pendular forces ΔF_{pz} from y-carriage body forces F_{yWk} are calculated as

$$\Delta F_{pz} = 0{,}5 \cdot F_{yWK} \cdot \frac{z_{sWK} - z_C}{y_p}$$

Equation 9

where $\mathbf{F_{yWk} = F_{ySW} + F_{mWKy}}$ **Equation 10**

$\mathbf{F_{mWKy} = m_{WK} \cdot a_y}$ **Equation 11**

The <u>carriage body roll angle from crosswind and centrifugal forces</u> η_{yzFy} occurs as

$$\eta_{yzFy} = \frac{M_T}{c_{\eta WK}} = \frac{2 \cdot \Delta F_{pz} \cdot y_p}{c_{\eta WK}} = F_{yWK} \cdot \frac{z_{sWK} - z_C}{c_{\eta WK}}$$

$$\eta_{yzFy} = (m_{WK} \cdot a_y + F_{ySW}) \cdot \frac{z_{sWK} - z_C}{c_{\eta WK}}$$

Equation 12

The <u>carriage body roll angle from guideway canting</u> $\eta_{yz\alpha'}$ occurs with the rolling moment $M_{T\alpha'}$

$$M_{T\alpha'} = (z_{sWK} - z_C) \cdot \sin\alpha' \cdot F_{mWKz}$$

where $F_{mWKz} = m_{WK} \cdot a_z$ z-inertial force of carriage body

$$\eta_{yz\alpha'} = \frac{M_T}{c_{\eta WK}} = F_{mWKz} \cdot \frac{z_{sWK} - z_C}{c_{\eta WK}} \cdot \sin\alpha'$$

$$\eta_{yz\alpha'} = \frac{M_T}{c_{\eta WK}} = m_{WK} \cdot a_z \cdot \frac{z_{sWK} - z_C}{c_{\eta WK}} \cdot \sin\alpha'$$

Equation 13

Z-displacements and pitch angle of carriage body

Active suspension

The z-pendular forces are deduced as follows for a 3-section vehicle on the basis of the 5 + 3 pneumatic spring interconnection of the end section. As the end section is relevant for the investigation, the number of sections is of no importance. A change in the pneumatic spring interconnection requires adjustment of the equations.

Statically defined, a carriage body is supported via two pneumatic spring circuits, with levitation frames 1 to 5 of the end section (nose) being supplied by pneumatic spring circuit 1, and levitation frames 6 to 8 of the end section and levitation frames 1 – 4 of the middle section by pneumatic spring circuit 2. The pneumatic springs of a circuit have the same pressure p_1 or p_2 with the pendular forces F_{pzLF1} (pneumatic spring circuit 1) and F_{pzLF2} (pneumatic spring circuit 2).

On the basis of the installed pneumatic spring, the pendular force of the first suspension spring is

$F_{p1z} = 0.5 \cdot F_{pzLF1}$ nose levitation frame Equation 14

The residual pendular forces occur at

$F_{piz} = F_{pzLF1}$ i = 2.5 end section Equation 15

$F_{piz} = F_{pzLF2}$ i = 6.8 end section **Equation 16**

$F_{piz} = F_{pzLF2}$ i = 1.4 middle section **Equation 17**

The pendular forces F_{pzLF1} and F_{pzLF2} as well as the coupling force F_{Kz} are calculated via the system of equations to be solved by means of determinants, for example.

$A \cdot \bar{x} = b$ at

$$\begin{bmatrix} 18 & 28 & 0 \\ 9 & 6 & 1 \\ 9x_{s1} & 6x_{s2} & 0 \end{bmatrix} \cdot \begin{bmatrix} F_{pzLF1} \\ F_{pzLF2} \\ F_{Kz} \end{bmatrix} = \begin{bmatrix} 2 \cdot F_{zWKE} + F_{zWKM} \\ F_{zWKE} \\ F_{zWKE} \cdot x_{sE} + F_{xWKE} \cdot z_{sE} \end{bmatrix}$$

Equation 18

Nose pneumatic spring circuit depressurised

If the nose pneumatic spring circuit is depressurised, the carriage body end section is supported on levitation frames 1 to 5 via the settling springs.

In deducing the pendular forces and the pitch angle, it is assumed that the residual pendular loads are supported via the pneumatic suspension.

The forces of the settling springs in relation to the swing axle are

$F_{pizE} = c_{piE} \cdot z_{piE}$

For the pitch angle η, the distance x_{NiE} from the settling springs to the assumed pitch pivot point of the carriage body (level measuring point of the adjacent pneumatic spring circuit) gives a settling spring deflection of

$z_{piE} = \tan \eta \cdot x_{NiE}$ Equation 19

The pendular forces are calculated as

$F_{pizE1} = c_{piE} \cdot z_{piE}$	i = 1.5 end section 1 (nose pneumatic spring circuit depressurised)	Equation 20
$F_{pizE1} = F_{pzLF2}$	i = 6.8 end section 1	Equation. 21
$F_{pizM} = F_{pzLF2}$	i = 1.4 middle section	Equation 22
$F_{p1zE2} = 0.5 \cdot F_{pzLF1}$	nose levitation frame end section 2	Equation 23
$F_{pizE2} = F_{pzLF1}$	i = 2.5 end section 2	Equation. 24

The pitch angle η, the pneumatic spring circuit forces F_{pzLF1} and F_{pzLF2} as well as the coupling forces F_{Kz1} (end section 1) and F_{Kz2} (end section 2) are obtained by solving the following system of equations:

$A \cdot \overline{x} = b$ at

$$\begin{bmatrix} \sum_{i=1}^{5}(c_{piE} \cdot x_{NiE}) & 9 & 28 & 0 & 0 \\ \sum_{i=1}^{5}(c_{piE} \cdot x_{NiE}) \cdot x_{iE}) & 0 & 6 \cdot x_{s2} & 0 & 0 \\ \sum_{i=1}^{5}(c_{piE} \cdot x_{NiE}) & 0 & 6 & 1 & 0 \\ 0 & 9 & 6 & 0 & 1 \\ 0 & 9 \cdot x_{s1} & 6 \cdot x_{s2} & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} \tan\eta \\ F_{pzLF1} \\ F_{pzLF2} \\ F_{Kz1} \\ F_{Kz1} \end{bmatrix} = \begin{bmatrix} 2 \cdot F_{zWKE} + F_{zWKM} \\ F_{zWKE} \cdot x_{sE} + F_{xWKE} \cdot z_{sE} \\ F_{zWKE} \\ F_{zWKE} \\ F_{zWKE} \cdot x_{sE} + F_{xWKE} \cdot z_{sE} \end{bmatrix}$$

Equation 25

For non-linear characteristics c_{iE} or c_{piE}, the system of equations must be solved iteratively, where applicable.

Pneumatic spring circuit of E/M section junction depressurised

If the pneumatic spring circuit at the E/M section junction is depressurised, the carriage body end section is supported on levitation frames 1 to 5 via the pneumatic springs of the nose pneumatic spring circuit and the settling springs of levitation frames 6 to 8.

To deduce the pendular forces and the pitch angle, only the end section is considered. i.e. the support from the middle section is disregarded. The level recording point (z-displacement zero) is located on levitation frame 2. This point is also the pivot point.

The forces of the settling springs in relation to the swing axle are

$F_{pizE} = c_{piE} \cdot z_{piE}$

For the pitch angle η, the distance x_{NiE} from the settling springs to the assumed pitch pivot point of the carriage body (level measuring point of the nose pneumatic spring circuit) gives a settling spring deflection of

$z_{piE} = \tan\eta \cdot x_{NiE}$ Equation 26

The pendular forces are calculated as

$F_{p1z} = 0.5 \cdot F_{pzLF1}$ nose levitation frame Equation 27

$F_{piz} = F_{pzLF1}$ i = 2.5 levitation frames 2 to 5 Equation 28

$F_{pizE1} = c_{piE} \cdot z_{piE}$ i = 6.8 (pneumatic spring circuit 2 depressurised) Equation 29

The pitch angle η and the pneumatic spring circuit forces F_{pzLF1} are obtained by solving the following system of equations:

$A \cdot \bar{x} = b$ at

$$\begin{bmatrix} 9 & \sum_{i=6}^{8}\left[c_{iE} \cdot (x_{2E} - x_{iE})\right] \\ 9 \cdot x_{s1} & \sum_{i=6}^{8}\left[c_{iE} \cdot (x_{iE} \cdot x_{2E} - x_{iE}^2)\right] \end{bmatrix} \begin{bmatrix} F_{pzLF1} \\ \tan\eta \end{bmatrix} = \begin{bmatrix} F_{zWKE} \\ F_{zWKE} \cdot x_{sE} + F_{xWKE} \cdot z_{sE} \end{bmatrix}$$

Equation 30

All pneumatic spring circuits depressurised – support on settling springs

With pneumatic springs depressurised, the carriage body is supported exclusively on the settling springs.
The forces of the settling springs in relation to the swing axle are:

$F_{pizE} = c_{piE} \cdot z_{piE}$

The pitch pivot point of the carriage body is located in the section coupling. The displacement z_0 of the section coupling gives the following values for the z-displacements of the settling springs:

$z_{piE} = z_K + \Delta z_{piE}$ Equation 31

and with the distance x_{iE} from the settling springs to the section coupling the pitch angle η is

$$\eta = \arctan \frac{z_{piE}}{x_{iE}}$$

Equation 32

The pendular forces are calculated as

$F_{pizE1} = c_{piE} \cdot z_{piE}$ end section Equation 33

The pitch angle η and the static basic deflection z_K are obtained from the following system of equations:

$A \cdot \bar{x} = b$ at

$$\begin{bmatrix} \sum_{i=1}^{8} c_{piE} + \sum_{i=1}^{4} c_{piM} & \sum_{i=1}^{8} (c_{piE} \cdot x_{iE}) \\ \sum_{i=1}^{8} (c_{piE} \cdot x_{iE}) & \sum_{i=1}^{8} (c_{piE} \cdot x_{iE}^2) \end{bmatrix} \cdot \begin{bmatrix} z_0 \\ \tan\eta \end{bmatrix} = \begin{bmatrix} 0{,}5F_{zWKE} + 0{,}25F_{zWKM} \\ 0{,}5(F_{zWKE} \cdot x_{sE} + F_{xWKE} \cdot z_{sE}) \end{bmatrix}$$

Equation 34

Y-displacements and yaw angle of carriage body

The y-pendular loads and the yaw angle of the carriage body can be deduced analogously to the z-pendular loads and the pitch angle. Similarly, a 5 + 3 pneumatic spring interconnection of the end section is taken as the basis.

Y-auxiliary springs are arranged at levitation frames 2 and 3 and also at 6 and 7, parallel to the pendulums.

As has already been stated, if the pneumatic spring interconnection and/or the arrangement of the y-auxiliary springs are changed, it is necessary to adjust the equations.

The static basic displacement in a lateral direction is y_0; this corresponds to the y-displacement of the section coupling y_K.

The additional y-displacement from yawing Δy_i for the levitation frames i = 1.8 results from the yaw angle δ_{xy}

$$\tan\delta_{xy} = \frac{\Delta y_i}{x_{ZFi}} \qquad \text{Equation 35}$$

The y-displacement of the points of application of the end-section pendulum is

$$y_{pi} = y_K + \Delta y_i \qquad \text{where } i = 1.8 \qquad \text{Equation 36}$$

The pendular forces are calculated at

$$F_{piy} = \frac{y_{pi}}{l_p} \cdot F_{piz} \qquad i = 1.8 \qquad \text{Equation 37}$$

The forces at the y-auxiliary spring are obtained from the correlation

$$F_{ZFiy} = c_{ZF} \cdot y_{pi} \qquad \text{Equation 38}$$

The yaw angle δ_{xy} and the static basic deflection y_K are obtained from the following system of equations:

$A \cdot \bar{x} = b$ where

$$f_1 = 2\sum_{i=1}^{8}(F_{pizE} \cdot \frac{x_{iE}}{l_p}) + c_{ZF} \cdot (x_{2E} + x_{3E} + x_{6E} + x_{7E})$$

$$f_2 = 2\sum_{i=1}^{8}(F_{pizE} \cdot \frac{x_{iE}^2}{l_p}) + c_{ZF} \cdot (x_{2E}^2 + x_{3E}^2 + x_{6E}^2 + x_{7E}^2)$$

$$f_3 = \frac{2}{l_p}\sum_{i=1}^{8} F_{pizE} + \frac{2}{l_p}\sum_{i=1}^{4} F_{pizM} + 6 \cdot c_{ZF}$$

$$f_4 = \frac{2}{l_p}\sum_{i=1}^{8} (F_{pizE} \cdot x_{iE} + c_{ZF} + x_{2E} \cdot (x_{2E} + x_{3E} + x_{6E} + x_{7E}))$$

$$\begin{bmatrix} f_1 & f_2 \\ f_3 & f_4 \end{bmatrix} \cdot \begin{bmatrix} y_0 \\ \tan\delta_{xy} \end{bmatrix} = \begin{bmatrix} F_{yWKE} \cdot x_{sE} + F_{ySWE} \cdot x_{SWE} \\ F_{yWKE} + 0{,}5F_{yWKM} + F_{ySWE} + 0{,}5F_{ySWM} \end{bmatrix}$$ Equation 39

Guidance gap correction for curved guideway

In a curved guideway, location-dependent deviations in the actual air gap compared to the set gap occur over the magnet length as a result of the curvature of the lateral guide rail. The size of this deviation depends on the radius of curve R and on the position of the gap sensors (distance d). The guideway curvature reduces the free air gap. In accordance with Figure 81 the set air gap occurs at the measuring position of the gap sensors; between the sensors the air gap is reduced by Δs_1, and at the magnet end it increases by Δs_2. The gap Δs_1 is relevant.

The cumulative gap <u>on cornering</u> is

$F_R = \Delta s_1 + \Delta s_2$ Equation 40

$$F_R = R - \sqrt{R^2 - \left(\frac{L_{FM}}{2}\right)^2}$$ Equation 41

The <u>gap difference at the centre of the guidance magnet</u> is calculated at

$$\Delta s_1 = R - \sqrt{R^2 - \left(\frac{d}{2}\right)^2},$$ Equation 42

The <u>gap difference at the end of the guidance magnet</u> is calculated at

$\Delta s2 = FR - \Delta s1$ Equation 43

Correction values for a designed magnet length L_{TM} = 3050 mm and a sensor distance of approx. 2300 mm.

Radius [m]	F_R [mm]	Δs_1 [mm]	Δs_2 [mm]
350	3,3	1,8	1,5
1000	1,2	0,7	0,5
2000	0,6	0,3	0,3
Straight track	0	0	0

Table 78: Effect of radius of curve on guidance magnet air gap

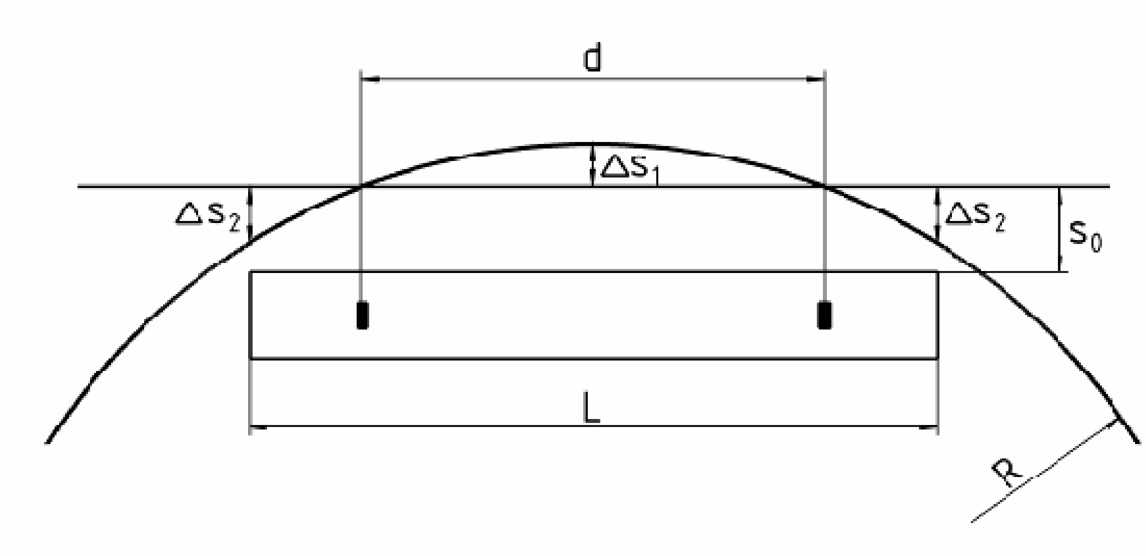


Figure 81: Guidance gap correction for cornering

High-speed Maglev system
Design principles

Vehicle
Part IV
Levitation and guidance systems

Distribution

The Vehicle Committee has released this document for publication.

Revisions

Date of release: 15.02.2007; White Paper, Vehicle Committee.

Contents

List of figures

List of tables

General

Purpose and applications

This "High-speed magnetic levitation railway vehicle design principles, part IV - levitation and guidance systems" sets out the requirements for the traction and driving systems of the high-speed MAGLEV system vehicles that do not depend on the project concerned.

This design principles applies to a Maglev system in accordance with the General Maglev System Act /AMbG/.

Part IV is to be used for the specification, execution and certification of the levitation and guidance system of Maglev vehicles and covers:

- Definition of the levitation and guidance system,
- Requirements for the functions of the levitation and guidance system,
- The actions of the levitation and guidance system on the guideway.

High-speed MAGLEV system design principles

This document is part of the documentation for high-speed magnetic levitation railways consisting of a number of design principles. Figure 1 /MSB AG-GESAMTSYS/ shows the documentation tree.

The overall design principles for the complete system and its appendices apply uniformly to all the documentation:

- High-speed MAGLEV system design principles, complete system, Document no.: 50630, /MSB AG-GESAMTSYS/, with appendices:
  - Annex 1: Abbreviations and definitions, Document no.: 67536, /MSB AG-ABK&DEF/
  - Annex 2: Legislation, regulations, standards and directives, Document no.: 67539, /MSB AG-NORM&RILI/
  - Annex 3: Environmental constraints, Document no.: 67285, /MSB AG-UMWELT/
  - Annex 4: Operating rules (operation and maintenance), Document no.: 69061, /MSB AG-BTR/
  - Annex 5: Noise, Document no.: 72963, /MSB AG-SCHALL/

The documentation on the vehicle consists of the following documents:

- High-speed Maglev system design principles, vehicle, Part I.: Design principles, Document no.: 67698, /MSB AG-FZ GEN/
- High-speed Maglev system design principles, vehicle, Part II.: Design, document no.: 67694, /MSB AG-FZ BEM/
- High-speed Maglev system design principles, vehicle, Part III.: Kinematic limits, Document no.: 67650, /MSB AG-FZ KIN/

- High-speed Maglev system design principles, vehicle, Part IV.: Levitation and guidance systems, Document no.: 73388, /MSB AG-FZ TRAFÜ/
- High-speed Maglev system design principles, vehicle, Part V.: Braking system, Document no.: 73389, /MSB AG-FZ BREMS/

Abbreviations and Definitions

The abbreviations and definitions supplied in /MSB AG-ABK&DEF/ should be used.

Legislation, regulations, standards and directives

The prescriptive documents listed in /MSB AG-NORM&RILI/ contain definitions that are referred to in the high-speed Maglev system design principles and have become part of the high-speed Maglev system design principles. Where prescriptive documents in /MSB AG-NORM&RILI/ are dated, subsequent changes or revisions of these publications do not apply. Where references are undated, the latest edition of the prescriptive documents referred to is applicable.

The edition of the standards and guidelines to be adhered to in a Maglev project must be made binding for each specific project.

Identification and mandatory nature of requirements

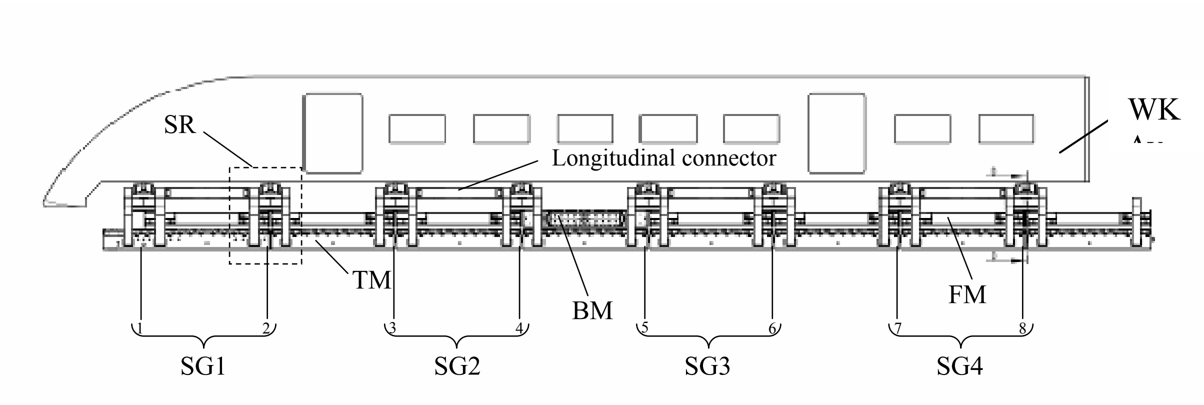
The content of the present document is substantially based on the provisions of /DIN 820/ .

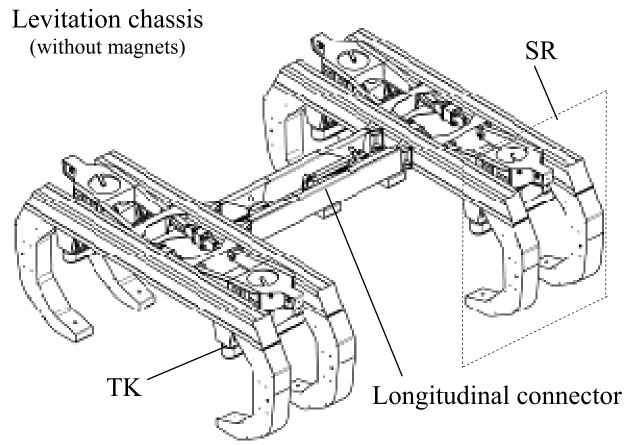
In the following chapters of this document, and in the appendices,

- Requirements are shown in standard type
- Explanations, guidelines and examples are shown in italic.

Where notes on project-specific regulations are given in this document for individual cases, (*e.g. in a specification or a contractual regulation*) this means that the manufacturer and the contractor must consult the approvals authorities and come to an agreement.

Definitions (vehicle-specific)





SG = Levitation chassis
SR = Levitation undercarriage
(2 levitation frames + connecting parts)
TM = Support magnet
FM = Guidance magnet
BM = Braking magnet
TK = Support skid
WK = Carriage body

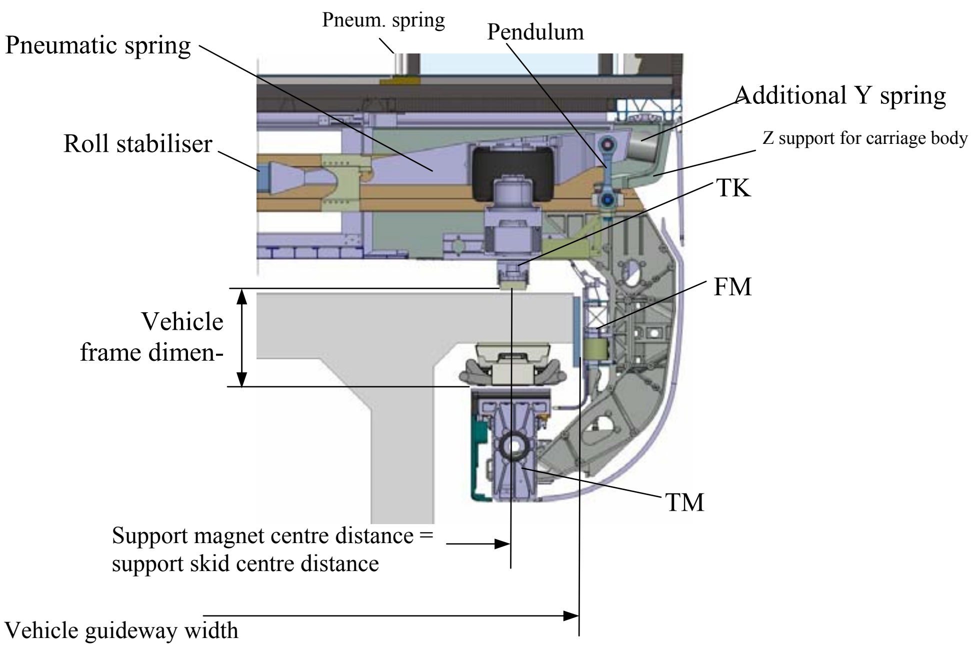


Fig. 82: *Side view and cross-section (showing the principle)*

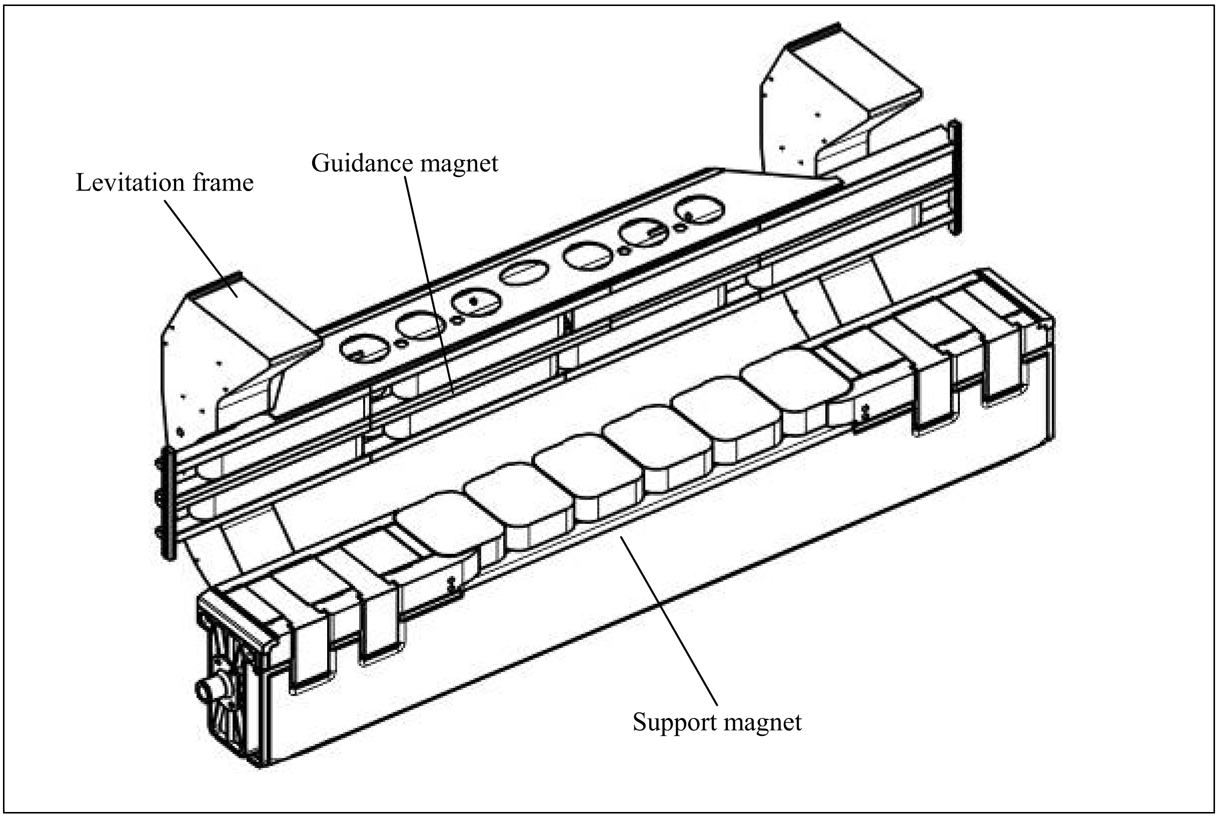


Fig. 83: *Magnet module (example)*

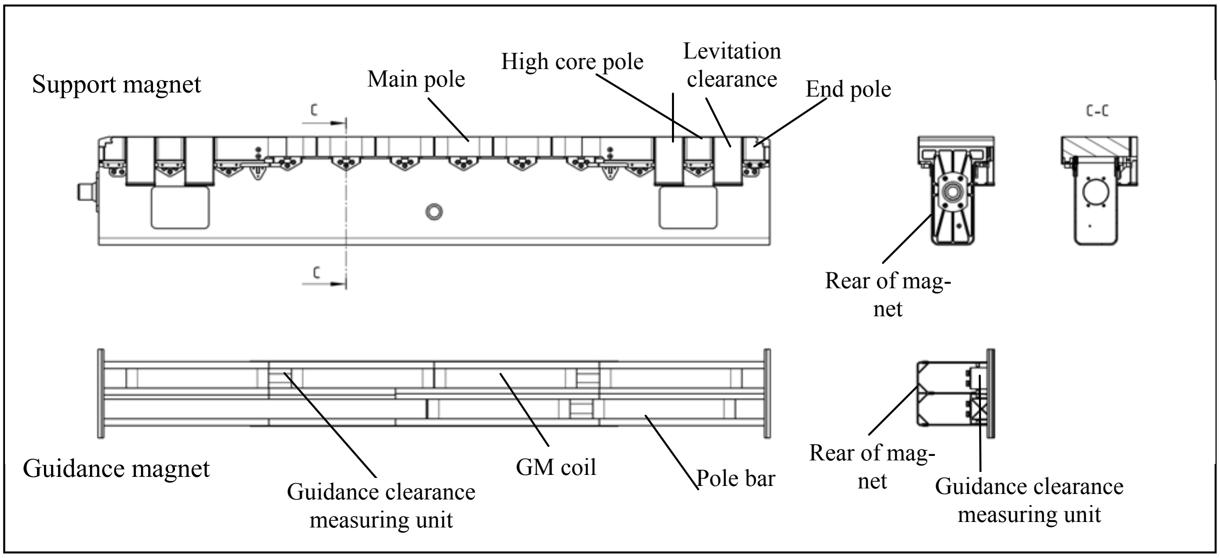


Fig. 84: *Levitation / Guidance magnets (example)*

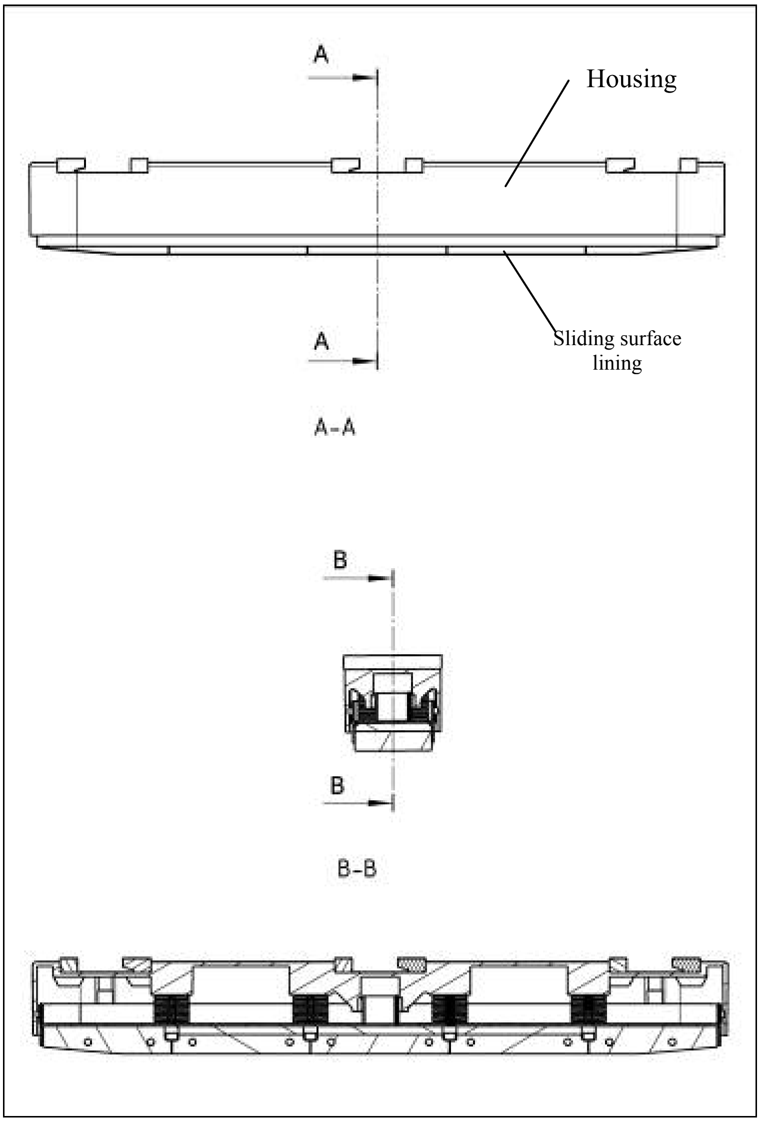


Fig. 85: *Support skid (example)*

Design principles for the levitation and guidance system

Operation

See description in /MSB AG-GESAMTSYS/.

The levitation and guidance system of the Maglev vehicles must perform the following functions over the whole of the specified speed and distance ranges:

- Magnetic support and guidance by means of controlled stored levitation and guidance magnets.
- Mechanical support using support skids in accidental situations or breakdowns or when the vehicle is standing (set down), for frequency compare /MSB AG-FZ BEM/, chapter 8.
- Mechanical guidance, e.g. using sliding elements on the guidance magnets in the event of rare technical faults or breakdowns and in accidental operating situations
(superimposition of the actions of extreme operating situations).
In tight curves ($R_H < 600$ m) it may be necessary to limit the speed in order to have freedom of movement.

Design

The loads that are borne by the structural components and pivots of the levitation and guidance system must be determined using /MSB AG-FZ BEM/ and taken into account in their design.

These loads must be documented in a specification (Design loads).

Proof of load-bearing capability (general stress certificate) and fatigue resistance according to the requirements set out in /MSB AG-FZ BEM/ must be provided for the components that transfer the load.

Determination of the clearance between the support magnets and the stator pack, between the guidance magnets and the lateral guidance rails and between the support skids and sliding surface must take account of structural tolerances, load-dependent deformation, relevant operational influences (e.g. route, speed, wear on the sliding surface lining, etc.) and environmental conditions and must be documented in a clearance statement.

Safety requirements

The levitation and guidance system, consisting of the magnetic and mechanical equipment, must conform to the safety requirements as per §19, /MbBO/.

General

The levitation and guidance function must be executed so that it is safe for all of its service life.

This property must be proven by means of a safety certificate to /EN 50126/. The safety certificate is based on a risk analysis. The risk analysis must include the following elements:

- Description of the levitation and guidance system and the protective functions,
- Description of the assemblies participating in the levitation and guidance system, their functions, connections and actions on each other,
- Identification of assemblies and functions that are responsible for safety.

Information on methods of performing the risk analysis is given in /prEN 50126-2/ and /prR009-004/.

The requirements for and tests on the structural assemblies of the levitation and guidance system are given in chapter 0.

The requirements for and tests on the functional assemblies of the levitation and guidance system are given in chapter 0.

The SIL level according to /EN 50129/ for the electronic equipment of the levitation and guidance system must be determined on the basis of the risk analysis and must be taken into account when performing the hardware certification.

The level of the safety requirements for the software in the levitation and guidance system that has been determined on the basis of the risk analysis must be taken into consideration when performing the certification to /EN 50128/.

Possible faults must be identified using a suitable analysis and must be taken into account in the safety certificate.

A suitable analysis must include consideration of at least the following faults:

- Fault in the on-board energy supply,
- Untimely execution of a set-down command,
- System failure (of software or hardware).

Certification of the lifetime safety of the levitation and guidance system must be performed using a suitable method of analysis before the system is commissioned. The theoretical certificate must be verified after the start of operation by evaluating the life cycle data of the assemblies.

Requirements for the on-board energy supply

The specifications for the on-board energy supply can be found in the specifications for the levitation and guidance system, the safe brake and the other vehicle systems that are relevant to safety. The following information applies to the levitation and guidance system.

The availability of the on-board energy supply as a whole must be guaranteed to match the requirements of the safety design (e.g. *Failure of the collector rail power from more than one subnetwork*), if, as a consequence of this, the vehicle should be wholly or partly set down or the safe brake should fail.

Since it is not possible to prevent individual faults in electrical systems with sufficient certainty, there is an inevitable requirement for redundancy, i.e. the number of independent and electrically / mechanically separate networks provided for each section must be sufficient to ensure that one faulty network does not affect the remaining networks and the levitation and guidance function is maintained.

To increase availability, these networks should be potential-free, i.e. without a direct electrical connection to the vehicle chassis, so that they do not switch off in the event of a short-circuit.

Furthermore equipment must be provided to guarantee the required performance from the mains to maintain the levitation and guidance function (e.g. batteries) and to guarantee that the vehicle levitates and brakes safely once it has started off (see also/MSB AG-BLT/, chapter 6.3.3.1 and chapter 6.3.3.3).

The possible untimely switching off of all networks that are needed to maintain the levitation and guidance function and the braking function during a mission, e.g. by triggering a central shutdown command, must be prevented by means of a suitable technical device. A shutdown command must only be effective when the vehicle is stationary and set down.

Faults and failures in the shutdown control must not lead to an unwanted shutdown. If the shutdown command becomes ineffective as a result of a fault or failure it must still be possible to shut the vehicle down. Access to the corresponding shutdown equipment must be obstructed in such a way that only trained operators can actuate the shutdown.

The following must be taken into account:
Evidence that a failure of the on-board energy supply is sufficiently unlikely is deemed to be provided if the on-board energy supply has been certified in accordance with chapter 0 and the following certificates are available:

1) Adequate redundancy
Adequate redundancy means that the number of separate independent electric and mechanical networks is such that in spite of increasing network failure there is still enough on-board power available to maintain the functions of levitation and guidance according to the specifications of the safety system.

2) Electrical and mechanical separation of networks
Networks are deemed to be electrically and mechanically separate if they have a certificate of conformance with the requirements of /EN 50124-1/ "Railway applications - Insulation coordination". Certification requires type testing of the assemblies, manufacturing tests during construction of the vehicle and commissioning tests on a vehicle.

3) Performance of the networks
Proof is required, in the form of figures and actual practice, that the planned and available devices for maintaining the performance of the networks perform their functions in the event of

the partial or complete failure of the external on-board power supplies. Certification must take place for representative driving profiles under the conditions of use specific to the project.

4) Shutdown
Proof using circuit documentation and practical trials is required that the central shutdown command is only effective when the vehicle is stationary and set down.
A safety certificate for the shutdown control must be based on a suitable analysis. Evidence is required that every anticipated failure leads to a safe response, i.e. not to the triggering of a shutdown.
Furthermore proof is required, through examination of the design drawings and the vehicle controls, that access to manually operated shutdown devices has been made so difficult that only trained operators can actuate the shutdown command.

Requirements for the execution of a set-down command

The central set-down command must be generated - and must be linked in each levitation and guidance unit by a logical AND to the independently determined speed - in such a way that the command to set down can only be decentrally effective when the vehicle speed is lower than the permitted set-down speed.

A certificate is required for the set-down control to the effect that the set-down command can only become effective below the set-down speed and, with sufficient probability, also in the event of all foreseeable failures.

Systematic faults in the magnet control equipment

Certification that systematic faults are sufficiently unlikely is required in accordance with EN 50128 and EN 50129. This applies to the hardware and, if present, the software of the equipment that is relevant to safety in the measurement, control, regulation and monitoring systems of the magnet regulating circuits.

Diagnostic and control equipment should be provided separately as part of the hardware.

Maintenance of the safety characteristic of magnet control circuits

Electromagnetic levitation is a controlled state in which a preset air gap between the stator pack or lateral guidance rail and the levitation and guidance magnets is maintained to defined tolerances according to a project-specific clearance balance.

Faults in the power pack or in the equipment for measurement, control, regulation and supervision of the magnet control circuits can cause the magnetic force to increase such that the clearance becomes zero and non-permissible forces act on the structure of the vehicle and guideway. This type of failure must therefore be prevented by a suitable and sufficiently reliable failsafe monitoring system.

If a permanent fault occurs in the monitoring equipment this must also lead to the release of the magnetic field. The monitoring equipment must be assigned to each magnet control circuit independently.

For the magnet control circuit monitoring equipment that is to be executed so as to fail safe, certification must use an analysis of the actions of failure to show that the probability of these actions causing the magnetic circuit to shut down immediately in the event of failure is sufficient.

Examination of the circuit diagrams and practical tests of the complete magnet control circuits must show that the monitoring equipment is inevitably activated when the magnet clearance regulation is switched on and that it is not subject to external influences.

Lightning overspill

For levitating vehicle sections paths and lightning overspill points to the guideway must be defined on the vehicle as provision for lightning overspill.

ESD

Electrostatic discharge from the vehicle must be dissipated in all operating conditions where there is a possibility of contact between the vehicle and persons connected to earth potential.

/MbBO/, §17(4) applies.

Requirements for the assemblies of the levitation and guidance system

Structural assemblies of the levitation and guidance system

The structural assemblies of the levitation and guidance system must be designed according to /MSB AG-FZ BEM/.

Chassis structure and panelling

Chassis structure

The functionality of components for vehicle dynamics and driving on bends, over rises and in depressions and the corresponding clearances must be designed in such a way that there is no impairment of the driving performance of the vehicle under the environmental conditions set out in /MSB AG-UMWELT/ or defined specifically for the project.

Fastenings and connections must be accessible for inspection.

Steps must be taken to ensure against loss of components.

The structure of the chassis must be executed so that if one component fails it does not cause a potentially unsafe condition. This property must be demonstrated with a failure modes and effects analysis (FMEA).

The structure of the chassis must be executed so that the specific behaviour in the cases of collision described in chapter 8.4 of /MSB AG-FZ BEM/ is guaranteed.

Panelling of the chassis

The parts of the panelling must be designed to have endurance strength, taking into account the design loads to /MSB AG-FZ BEM/ and considering forms of natural vibration and resonance behaviour and also considering the stresses arising from manual operations during maintenance.

Where parts of the outer panelling have to be removable for purposes of accessibility to the underfloor cavities during maintenance, fasteners should be provided that show (e.g. visually) when their condition, locked or unlocked, has been changed, but not their actual current position.

Carriage body pivot / secondary suspension

Z suspension

Support for the carriage bodies is determined statically and must be made dynamically separate from the levitation and guidance system (*preferably by means of pneumatic springs*).
The travel of the spring between the levitation chassis and the carriage body must be limited both upwards and downwards.

Level regulation / pneumatic spring control

The supply and discharge of air in the pneumatic spring bellows must only be possible when the control unit is actively controlled.

Provision must be made for an adjustable partial reduction of the pressure in the pneumatic spring bellows.

Monitoring of the pressures in the distribution lines and the individual pneumatic springs must be provided. A failure should be reported by the vehicle diagnostic system for repair purposes. Data from the diagnostics should unambiguously identify and locate the affected assembly. The system reaction must be defined for each specific project.

Y suspension

Displacements in the Y direction must be taken into account in /MSB AG-FZ KIN/.

Roll stabiliser

Possible rolling of the carriage body must be taken into account in /MSB AG-FZ KIN/.

For reasons of comfort, rolling of the carriage body against the levitation undercarriage must be restricted and the amount defined specifically for the project.

In the event of side wind or maximum lateral acceleration, the preset carriage body roll value of 1.5° must be taken into account.

Behaviour in the event of failure

The failure of individual pneumatic and electrical assemblies of the Z suspension, together with the action of the mechanical assemblies of the secondary suspension, must not cause any interruption of movement. This property must be demonstrated with a suitable analysis, see chapter 0.

The operation and failure behaviour of the pneumatic and electrical assemblies of the Z suspension, together with the action of the mechanical assemblies of the secondary suspension, must be verified as part of commissioning the vehicle.

If a defined pressure in the pneumatic springs is not reached the bellows concerned must be separated from the collective line.

Magnet pivot

The magnet pivot must be executed in such a way that the failure of an individual part does not impair the safety and availability of the levitation and guidance function. This property must be demonstrated with a suitable analysis.

This means that if there is a failure operation can continue and a safe condition is maintained.

Failures must be detected by inspections.

Support skid

The limit values for static and dynamic forces must be verified specifically for the project.

The execution of the support skids and the equipment from which they hang must have sufficient suspension and damping to ensure that the limits for the loads arising in the event of uncontrolled setting down are not exceeded.

Damage to the sliding surface lining or the support skid suspension must not result in loss of mechanical load-bearing capacity.

Failures and wear must be detected by inspections.

Behaviour in the event of failure must be demonstrated with a suitable analysis, see chapter 0.

Sliding behaviour must be demonstrated with reference to the wear and heating criteria with prototypes and/or a representative vehicle.
The impact load behaviour must be demonstrated by means of tests or digital simulations.

Functional assemblies of the levitation and guidance system

Levitation function

Levitation control

Decentralized control of the levitation clearance must be provided in autonomous redundant assemblies. If project-specific limits (e.g. minimum clearance) are contravened, the control circuit must switch off so rapidly that there is no possibility of the project-specific design loads for the vehicle and guideway being exceeded. This process must be reversible.

Measuring the levitation clearance.

The levitation clearance between the pole surface of the support magnets and the surface of the stator bundles facing the support magnet must be checked using a contactless levitation clearance measurement system.

When designing the levitation clearance measurement system the expansion gaps at the ends of the guideway beams, at track switching devices, at transitions from supports to primary load-bearing structures and between neighbouring stator packs must be observed.

Factors influencing accuracy of measurement of the levitation clearance must be taken into account.

Levitation clearance measurement requirements for the stator bundle properties must be defined specifically for the project, see /MSB AG-FW ÜBG/.

Power generation

An example of the levitation chassis with support magnets is shown in Fig. 83.

Project-specific limits are required for the rolling of the support magnet about the X axis during levitation. The action of possible rolling on the distribution of power and the size of the clearance must be taken into account.

Provision must be made for the poles of a support magnet to be electrically distributed between at least two independent control circuits.

The control circuits should permit translatory motion in the z direction and rotation about the y axis.

Behaviour in the event of failure

The levitation control circuits must have monitoring equipment that, in the event of failure of an operational component and loss of redundancy, switches off the control circuit sufficiently quickly to ensure that there is no possibility of the project-specific design loads for the vehicle and guideway being exceeded.

If an individual levitation control circuit fails the levitation function of the levitation undercarriage must be maintained by a redundant levitation circuit.

In the event of faults leading to the failure of the magnetic levitation function on one levitation undercarriage, the distance travelled must be automatically restricted by the operational control systems to the specified permissible slide path of the support skid / sliding surface. In this case the levitation function of the undercarriage must be transferred to a support skid. Operational reaction and repair are to be defined specifically for the project.

In the event of a short circuit of the long stator winding on one side of the guideway beam, reversible failure of the magnetic levitation function of the corresponding longitudinal side of the vehicle and the uncontrolled setting down of the vehicle on one side can be tolerated. The magnetic levitation function must be automatically restored when the vehicle has left the area of the shorted winding.

The levitation function must be guaranteed in the event of lightning striking the vehicle. It is permissible for individual circuits to switch off momentarily but there must be no permanent failure of the individual assemblies of the control circuit. Afterwards the control circuits that switched off must automatically re-energize.

Failure reporting, diagnostics

For maintenance purposes, loss of redundancy because of the failure of assemblies must be detected and made obvious by vehicle diagnostics.

Data from the diagnostics should unambiguously identify and locate the affected assembly.

Where devices that are relevant to safety do not automatically report failure, periodic functional tests / inspections must make failures obvious. The test criteria and intervals must be determined by means of a suitable analysis.

Certificates

A qualification test with prototypes must be performed on the assemblies of the magnet regulation circuit to certify the operation, failure behaviour, reporting of failures and environmental resistance.

A suitable analysis must be carried out to certify the lifetime reliability of the levitation and guidance function, see chapter 0.

Behaviour in the event of failure must be verified in tests by simulating the failure of components on individual levitation undercarriages on a test rig and in operation.

The reliability of the electronic assemblies of the magnet control circuit must be verified by determining the MTBF from the evaluation of life cycle data on representative assemblies after the start of operation.

The compatibility of the MTBF verified from life cycle data with the forecast statements of the analysis must be demonstrated.

Static and dynamic nominal stress on a test rig must demonstrate that the magnet control circuits are stable in operation.

Guidance function

Guidance control

Decentralized control of the guidance clearance must be provided in autonomous redundant assemblies.

Measurement of the guidance clearance

The guidance clearance between the pole surface of the guidance magnets and the surface of the lateral guidance rails must be checked using a contactless guidance clearance measurement system.

When designing the guidance clearance measurement system the expansion gaps at the ends of the guideway beams, at track switching devices, and transitions from supports to primary load-bearing structures and between neighbouring guidance rail elements must be observed.

Factors influencing accuracy of measurement of the guidance clearance must be taken into account.

Guidance clearance measurement requirements for the lateral guidance rail properties must be defined specifically for the project.

Power generation

An example of the levitation chassis with guidance magnets is shown in Fig. 83.

Project-specific limits are required for the rolling of the guidance magnet about the X axis during levitation. The action of possible rolling on the distribution of power and the size of the clearance must be taken into account.

Provision must be made for the windings of a guidance magnet to be electrically distributed between at least two independent control circuits.

The control circuits should permit translatory motion in the y direction and rotation about the z axis.

Behaviour in the event of failure

The individual guidance control circuits must have monitoring devices that reliably switch the control circuit off in the event of failure of an operational component.

If an individual guidance control circuit fails the guidance function of the levitation undercarriage must be maintained by a redundant guidance circuit.

In the event of faults leading to the loss of the electromagnetic guidance function of one levitation undercarriage, the distance travelled must be automatically restricted by the operational control systems to the specified permissible slide path of the mechanical sliding elements on the lateral guidance rail.
After failure of the magnetic guidance function on one levitation undercarriage the guidance function must be transferred to a mechanical guidance unit. Limiting values of the loads occurring and the permissible wear must be defined for the specific project.

Reactions in the event of a lightning strike must be similar to those described in chapter 0.

Failure reporting, diagnostics

Failure reporting must be along the lines of chapter 0.

Certificates

Certification procedure must be similar to that described in chapter 0 according to chapter 0.

On-board energy supply

Properties and functions

An on-board energy supply that will be reliable for all of its service life must be provided to ensure that the "levitation and guidance", "safe braking" and other vehicle systems that are relevant to safety are reliable for the lifetime of the vehicle.

Environmental conditions must be observed in accordance with /MSB AG-UMWELT/ or as defined for the project.

The on-board supply must also display lifetime reliability during and after the actions of lightning.

On-board circuits must be designed so that the vehicle can be set down with the power on at any time without the need for safety-related supervision by personnel.

Electrical safety

The on-board energy supply equipment must satisfy the following requirements:

- Protection against shock current,
- Production and maintenance of a zero potential condition during maintenance,
- Protection against overload and short circuit,

in accordance with the provisions of /EN 50153/ and /EN 50207/.

Uninterruptible power supply

In order to perform forced braking with the safe brake an uninterruptible power supply must be provided. This must take account of the most adverse environmental and operating conditions that have been specified.

An additional project-specific on-board energy reserve must be available when operating during a malfunction.

There must be an adequate supply of stored power, as defined for the project, to operate emergency lighting, emergency ventilation and communication devices after a stop resulting from a fault.

Where batteries are used, explosion prevention measures suitable for the battery type and in accordance with the safety design must be put in place (*e.g. battery ventilation with indication of failure and thermal monitoring and fan run-on after reset*).

Control and monitoring function

In the event of the failure of one or more devices that are relevant to the safe condition of the vehicle (e.g. on-board power units or battery ventilation) in one section of the vehicle, there must be an automatic fail-safe system reaction.

If there is less than the minimum power requirement in the energy store for the uninterruptible power supply to provide for a forced stop with the safe brake plus the minimum operating time for the safety consumers needed during the stoppage (*e.g. emergency lighting, ventilation and communication*), there must be an automatic fail-safe system reaction.

Behaviour in the event of failure

The failure of individual on-board energy supply assemblies or the failure of an individual on-board energy supply must not have any effect on operation. It must be possible to continue the journey as far as the next scheduled station.

Fault tolerance against earth faults must be provided , e.g. by IT networks with insulation monitoring, see also chapter 0.

Failure reporting, diagnostics

A loss of redundancy owing to assembly failure must be signalled by the vehicle diagnostic system for repair purposes.

Data from the diagnostics should unambiguously identify and locate the affected assembly.

Certificates

A qualification test with prototypes must be performed on the MSB-specific assemblies of the on-board energy supply to certify the operation, failure behaviour, reporting of failures and environmental resistance.

A suitable analysis must be carried out to certify the lifetime reliability of the function, see chapter 0.

Failure behaviour must be demonstrated in tests, e.g. by means of simulated assembly failures on a representative vehicle.

The reliability of the electronic assemblies for the supply of power to safety functions must be verified by determining the MTBF from the evaluation of life cycle data on representative assemblies after the start of operation.

The compatibility of the MTBF verified from life cycle data with the forecast statements of the analysis must be demonstrated.

Safety-relevant control / supervision

General

Safety-relevant control functions of the levitation and guidance system include:

- the transmission of control commands from the operational control system to devices for the regulation, control and supervision of the levitation and guidance function and the on-board energy supply,
- the generation of safety-relevant status information of the levitation and guidance function and the on-board energy supply and transmission to the operational control system.

Behaviour in the event of failure

The safety-relevant control and supervision must be designed to be redundant.

An individual instance must not lead to the loss or limitation of the control and monitoring functions. Failure of the control and monitoring functions must bring about an automatic failsafe reaction.

Failure reporting, diagnostics

A loss of redundancy must be signalled by the vehicle diagnostic system for repair purposes.

Data from the diagnostics should unambiguously identify and locate the affected assembly.

Certificates

Qualification tests of the control and monitoring equipment must be carried out with prototypes or on a representative vehicle.

The safety certification of the control and supervision for the levitation and guidance function and on-board energy supply must be performed in accordance with chapter 0.

Actions of the levitation and guidance system on the guideway

General

The forces given below correspond to the characteristic values[8] of the actions of the vehicle on the guideway at the vehicle-guideway interfaces.

Types and combinations of actions

The actions of the levitation and guidance system on the guideway act upon the following interfaces:

- *Support magnet - stator pack*
- *Guidance magnet - lateral guidance rail,*
- *Support skid - sliding surface*

The forces acting on the guideway arise from the following functions:

- *Magnetic and mechanical levitation,*
- *Magnetic and mechanical guidance,*
- *Driving and braking with the long stator propulsion system.*

The forces are influenced by the following actions:

- *Operation with a variable payload under varying environmental conditions,*
- *Operation following failure situations and accidental operating situations,*
- *Operation using the "safe brake" with the loads ensuing therefrom.*

The actions of the levitation and guidance system on the structure must be taken into consideration in accordance with chapter 0 when designing the assemblies.

The variable actions of the vehicle on the guideway must be taken into account when designing the guideway on the basis of /MSB AG-FW BEM/.

To ensure that the characteristic values for the actions arising from operation of the vehicle that are assumed in /MSB AG-FW BEM/ agree well enough with actions arising in practice, the values given in chapter 0 for the forces introduced into the guideway by the vehicle must not be exceeded (permissible tolerance when verifying the magnitude of the actions is 5%).

[8]) The most representative value of an action, from which it is assumed that there is a given probability that it will be neither exceeded or undershot during the reference period, taking into account the service life of the load-bearing structure and the corresponding measurement situation. In the case of a variable action the characteristic value is either an upper value for which there is a given probability that is not exceeded during the defined reference time or a defined nominal value if there is no known probability distribution (see also DIN EN 1990).

The magnitude of the characteristic values of the actions must be set down in a mandatory project-specific specification for every application.

The magnitudes of the characteristic values of the actions must be verified by taking measurements on a representative vehicle.

Characteristic values and load arrangements

General

The typical system length of a vehicle section (centre section) L_{MS} = 24.768 m (support magnet occupied length) is to be used as the reference value for the overall actions induced in the guideway by the support magnets and the guidance magnets in the x, y and z directions.

Half the length of a support magnet system $L_{SYS,TM} / 2$ is to be used for determining the reference value of the local actions induced in the guideway by the support magnets and the guidance magnets in the x, y and z directions.

The definitive loading conditions given in Table 79 below must be defined for certification purposes. In the context of the project, it may also be necessary to consider increased vehicle weight as a consequence of accumulated snow in the vehicle structure.

Value	Definition
Vehicle self weight	Weight of the vehicle section without payload [1)]
Mean vehicle weight	Weight of the vehicle section with standard load [2)]
Permitted vehicle weight	Weight of the vehicle section with maximum load [3)]
Maximum vehicle weight	Weight of the vehicle section in accidental operating situations [4)]
1) The payload is the weight of passengers with luggage or freight / freight containers 2) The mean weight can be defined, e.g. for a payload that is not exceeded in 80% of the journeys. This must be determined separately for each project. 3) Payload at maximum planned loading that is only exceeded in accidental operating situations; this must be determined separately for each project, e.g. all seats occupied, assuming 90 kg per passenger plus 320 kg pro m² of standing room. 4) Maximum possible payload in accidental operating situations; this must be determined separately for each project, e.g. all seats occupied, assuming 90 kg per passenger plus 500 kg pro m² of standing room.	

Table 79: Summary of vehicle loading conditions

Vehicle self weight and payload

The characteristic values of the static actions resulting from the vehicle loading conditions are given as the line load determined over the vehicle length in Table 80.

The static line loads given in Table 80 are to be used as a basis for determining the characteristic values of actions of the vehicle.

Static line load per m vehicle length (support magnet oc-cupied length) without snow in [kN/m]	**Vehicle self weight**	**Mean vehicle weight**	**Permitted vehicle weight**	**Maximum vehicle weight**
stat p_z	19 [1] (21)	26	29	31
[1] applies to light goods vehicles, for passenger vehicles a mean line load of 21 kN/m can be assumed.				

Table 80: Characteristic static line loads of the vehicle (averaged)

The permitted weight $G_{\text{Sekt zul}}$ of a vehicle section can be calculated with the aid of the following equation:

$G_{\text{Sekt zul}} = \text{stat } p_z \cdot L_{MS} / g$ where $g = 9.81 \text{ m/s}^2$.

Any possible local increases in the line load Δstat p_z as a result of uneven distribution of the vehicle weight over its length should be kept to a minimum.

A typical diagram for stat $p_z \pm \Delta$ stat p_z is shown in Fig. 86.

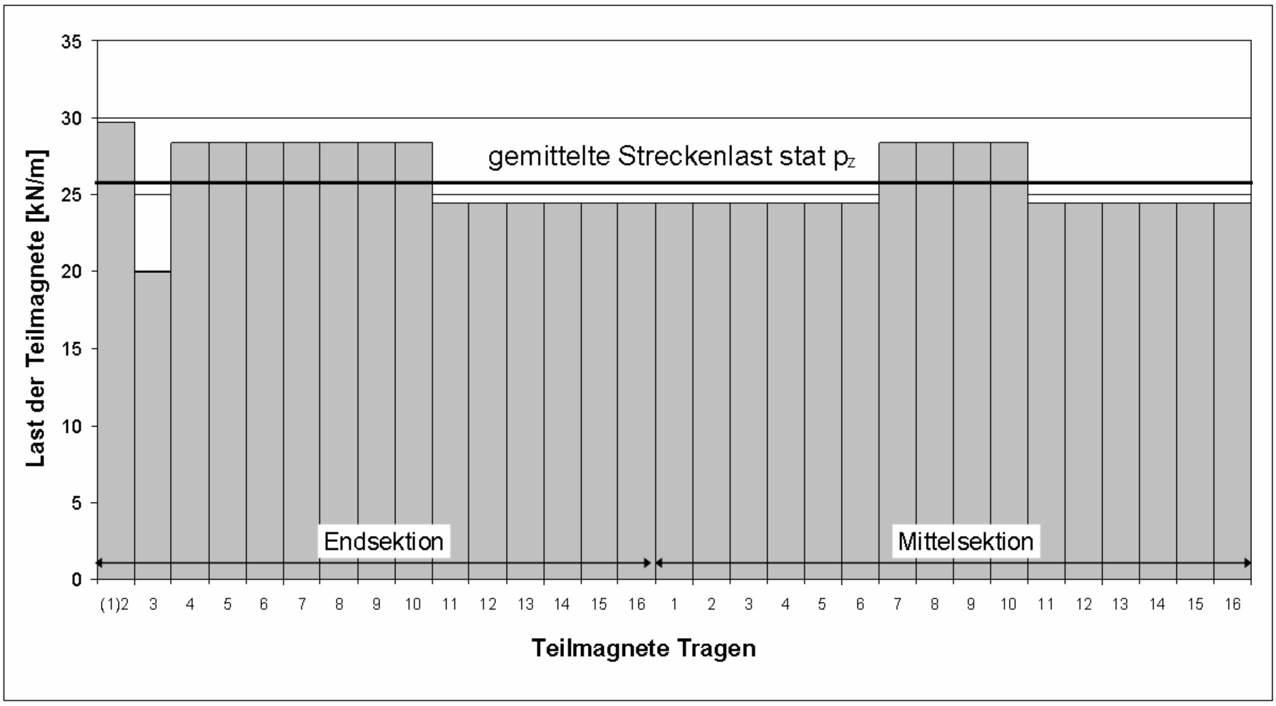


Fig. 86: Typical diagram for stat $p_z \pm \Delta$ stat p_z

Last der Teilmagnete	Load on partial magnets
Teilmagnete Tragen	Partial support magnets
gemittelte Streckenlast	Mean line load
Endsektion	End section
Mittelsektion	Centre section

Evidence of stat p_z and Δ stat p_z for the defining loading conditions must be provided by weighting. In certain cases the values of stat p_z and Δ stat p_z for the vehicle with payload can be calculated on the basis of the weighting in the unloaded state.

Quasi-static loads from driving dynamics

Driving over elements of the route such as bends, rises and depressions causes accelerations in the y and z directions and during driving and braking of the vehicle quasi-static loads are generated in the x, y and z directions and moments about the x, y and z axes which are affected by the location of the centre of gravity of the vehicle sections in the z direction.

These actions must be taken into account on the guideway side as mass forces in the x, y and z directions in accordance with /MSB AG-FW BEM/.

The centre of gravity of a section of the vehicle in the z direction must not exceed the following values[9]:

- For vehicle self weight 600 mm above the sliding surface,
- For mean vehicle weight: 700 mm above the sliding surface,
- For permitted vehicle weight: 850 mm above the sliding surface,
- For maximum vehicle weight: 950 mm above the sliding surface.

Quasi-static loads from side wind (without lift)

As a consequence of the quasi-stationary effect of side wind (mean value over 5 s according to/MSB AG-UMWELT/) on the vehicle, the vehicle transfers quasi-static loads to the guideway. The magnitude of the loads is determined by the speed of the side wind, the speed of the vehicle and the height and geometry of the front of the vehicle.

These actions resulting from side wind on the vehicle must be taken into account on the guideway side in accordance with /MSB AG-FW BEM/.

The actions given in the guideway design specifications and the associated distribution over the length of the vehicle are respected if the maximum local line load owing to side wind in the y direction $p_{y, SW}$ does not exceed the values given in Table 81.

9) The data is needed in this form for designing the guideway.

Maximum local line load from side wind in [kN/m]	Vehicle speed			
	200 km/h	300 km/h	400 km/h	500 km/h
$p_{y, SW}$	11.0	14.1	24.4	32.4
$p_{z, SW}$	± 5.4	± 6.4	±6.9	± 7.4
The loads apply for a side wind speed of 37 m/z to wind load zone II at a height of 20 m above ground.				

Table 81: Actions resulting in side wind on the vehicle

The load certification can be done by calculation and simulation of flow behaviour with a verified simulation model.

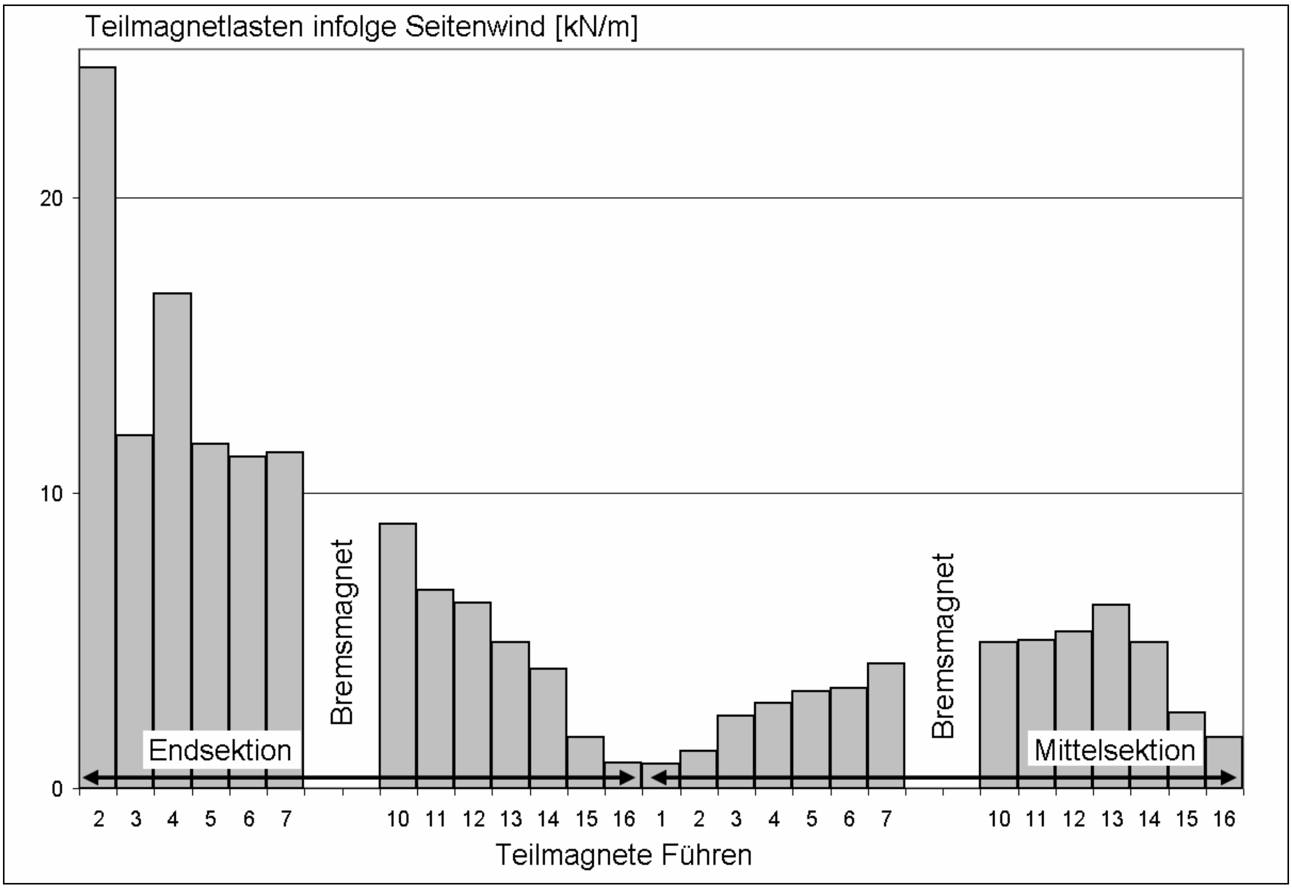


Fig. 87: Typical course of $p_{y, SW}$ where v_{Fzg}= 400 km/h and SW = 37m/s

Teilmagnelasten infolge Seitenwind	Loads on partial magnets as a result of side wind
Teilmagnete Führen	Partial guidance magnets
Bremsmagnet	braking magnet
Endsektion	End section
Mittelsektion	Centre section

Quasi-static loads from restoring forces in small radius curves

In small radius curves, reset forces arise between the levitation chassis of the levitation and guidance system and the carriage body (constraining forces), and these are transmitted to the guideway as quasi-static loads in the
y direction. The maximum loads in each instance are transferred from the guidance magnets to the ends and in the area of the centre of the section.

The actions given in the guideway design specifications and their distribution over the length of the vehicle (see Fig. 88) are respected if the maximum local constraining force in the y direction $p_{y,\,ZWG}$ does not exceed the values given in Table 82.

Characteristic values of the maximum constraining force in curves in [kN/m]	Radius of curve R_H = 350 m	Radius of curve R_H = 1,000 m	Radius of curve R_H = 2,000 m
$p_{y,\,ZWG}$	21	7	0

Table 82: Maximum local constraining force

The forces can be determined by calculation.

The calculation must be verified by measuring individual restoring forces in a representative vehicle and curved section.

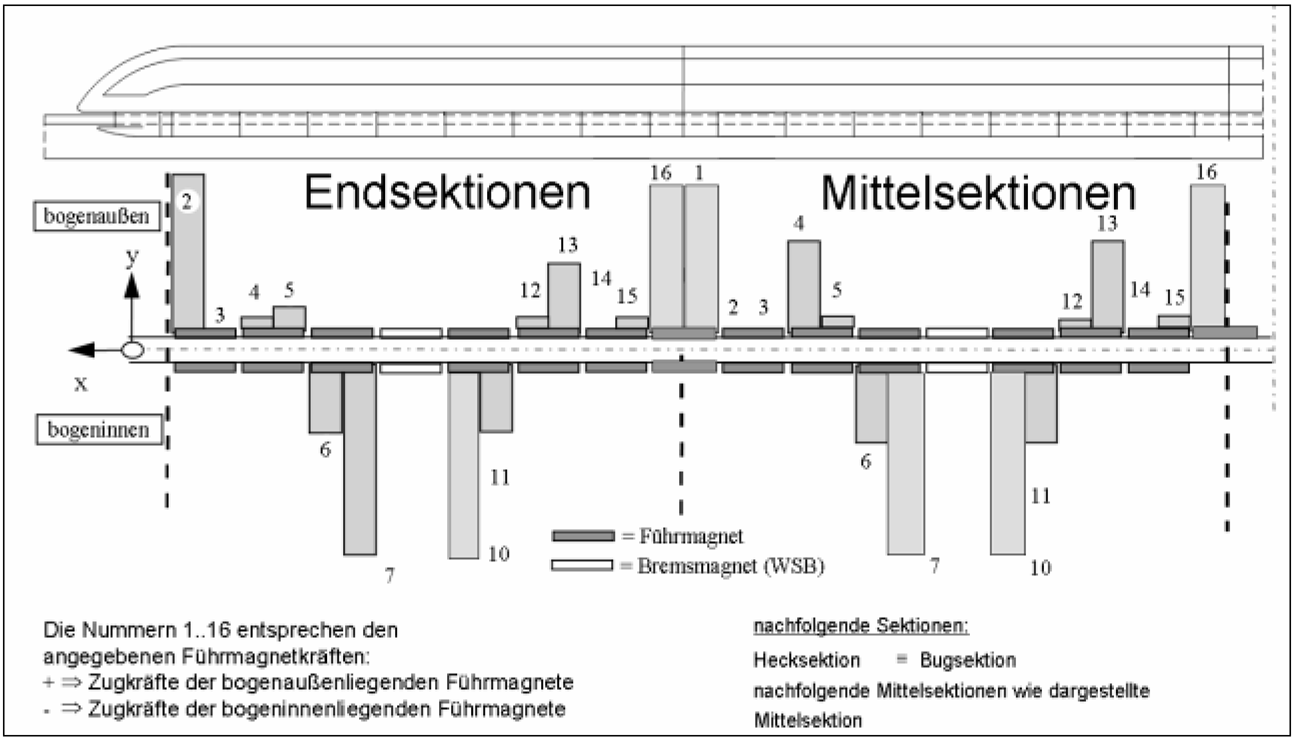


Fig. 88: Typical response for $p_{y,\,ZWG}$

Endsektionen	End sections
Mittelsektionen	Centre sections

Bogenaußen	Bow outside
Bogeninnen	Bow inside
Führmagnet	Guidance magnet
Bremsmagnet	Braking magnet
Die Nummern 1 ... 16 entsprechen den angegebenen Führmagnetkräften.	The numbers 1-16 correspond to the guidance magnet forces shown.
Zugkräfte der bogenaußenliegenden Furhmagnete	Tensile forces of the guidance magnets outside the bow
Zugkräfte der bogeninnenliegenden Furhmagnete	Tensile forces of the guidance magnets inside the bow
nachfolgende Sektionen	Following sections
Hecksektion = Bugsektion	Tail section = bow section
nachfolgende Mittelsektionen wie dargestellte Mittelsektion	Following centre sections as centre section shown

Loads from driving and braking with the long stator

For the maximum overall actions of a vehicle section on the guideway a maximum force in the x direction that is obtained from the product of the permitted vehicle weight with the maximum permitted acceleration or braking deceleration of (a_x = 1.5 m/s²) is to be used as a regularly repeating action (see Table 83).

This also covers the propulsion/braking situations where the track rises and falls.

For the maximum overall actions of a vehicle section on the guideway a maximum force in the X direction of 250 kN / section is to be used as accidental action (see Table 83).

Characteristic values of maximum forces as a result of propulsion and using the propulsion system for braking	
Regularly repeating action with permitted vehicle weight ($a_x \leq 1.5$ m/s²)	F_x = 110 kN / section
Accidental action e.g. if the propulsion function is faulty	Case 1: F_x = 185 kN / section (distribution ratio 0.73 / 0.27 on the right and left sides of the vehicle)
	Case 2: F_x = 250 kN / section (uniform distribution ratio on the right and left sides of the vehicle)

Table 83: Driving and braking forces with the long stator

The following relationships between the local action in the z direction p_z and the local action in the x direction p_x must be taken into account:

$$p_x \pm \Delta p_x = (p_z \pm \Delta p) \cdot a_x / g$$

Maximum loads at the support magnet - stator pack interface

Induced loads

At the interface between the support magnet (TM) and the stator level there is a magnetic transfer of quasi-static and dynamic tensile forces in the z direction and there is a magnetic transfer of thrust forces in the x direction via the propulsion function of the long stator.

The following values must be taken into consideration as characteristic values for the maximum loads per metre of half magnet length:

Design situations	Direction of action	Load per m of support magnet
Max. static tensile force from - permitted total weight	z direction	16 kN/m
Max. dynamic tensile force from - permitted total weight - $a_y = 1.5 m/s^2$, $a_z = 1.2 m/s^2$, Side wind 10m/s at 400 km/h	z direction	20 kN/m
Max. local tensile force in sectional magnet operation and - permitted total weight - $a_y = 1.5 m/s^2$, $a_z = 1.2 m/s^2$, Side wind 37m/s at 400 km/h, $F_{z\_dyn\_max}$	z direction	45 kN/m
Maximum thrust of the propulsion system without technical failures or faults(max $a_x = 1.5 m/s^2$) from - permitted overall weight (inc. uneven distribution)	x direction	2.25 kN/m
Maximum thrust in the event of failure of the propulsion system (see Table 83)	x direction	Case 1: 5.5 kN/m
		Case 2: 5.0 kN/m
Max. local thrust in the event of failure of a levitation control device	x direction	4 kN/m

The maximum levitation force of the support magnet must be limited to 45 kN/m.

Table 84: Maximum support magnet load

For local load distribution see Fig. 89 and Fig. 90.

Dynamic excitation

The local distribution of the forces of the support magnets in the x direction is subject to periodicity of phase spacing that acts on the guideway as a force wave and moves along the guideway at the vehicle speed v. In the guideway the force wave coming from the vehicle acts as a locally pulsating steady force at a frequency fe that is dependent on the wavelength of the force λ_e, its harmonics and the vehicle speed.

$$f_e = v / \lambda_e$$

The following actions must be taken into account with respect to dynamic excitation of the guide-way:

Continuously acting variable forces as the vehicle travels over the guideway:

- Geometry of the support magnet poles
  magnetic effect of the pole geometry at the surface of the pole. e.g. from slots for linear generators
- Geometry of the arrangement of the support magnet poles in the response of a support magnet, local movement of the force along the support magnet
- Geometry of the arrangement of the support magnet poles at the ends of a support magnet, local movement of the force in the area between two support magnets resulting from a different geometry at the end of the magnet poles from that in the centre
- Force caused by pitching of the support magnet because of the propulsion forces transmitted, torsion of the individual support magnets about the y axis, "misalignment" (Fig. 89)

Variable forces acting occasionally as the vehicle travels over the guideway:

- Forces in the region of two support magnets after the failure of one magnet control device (Fig. 90)

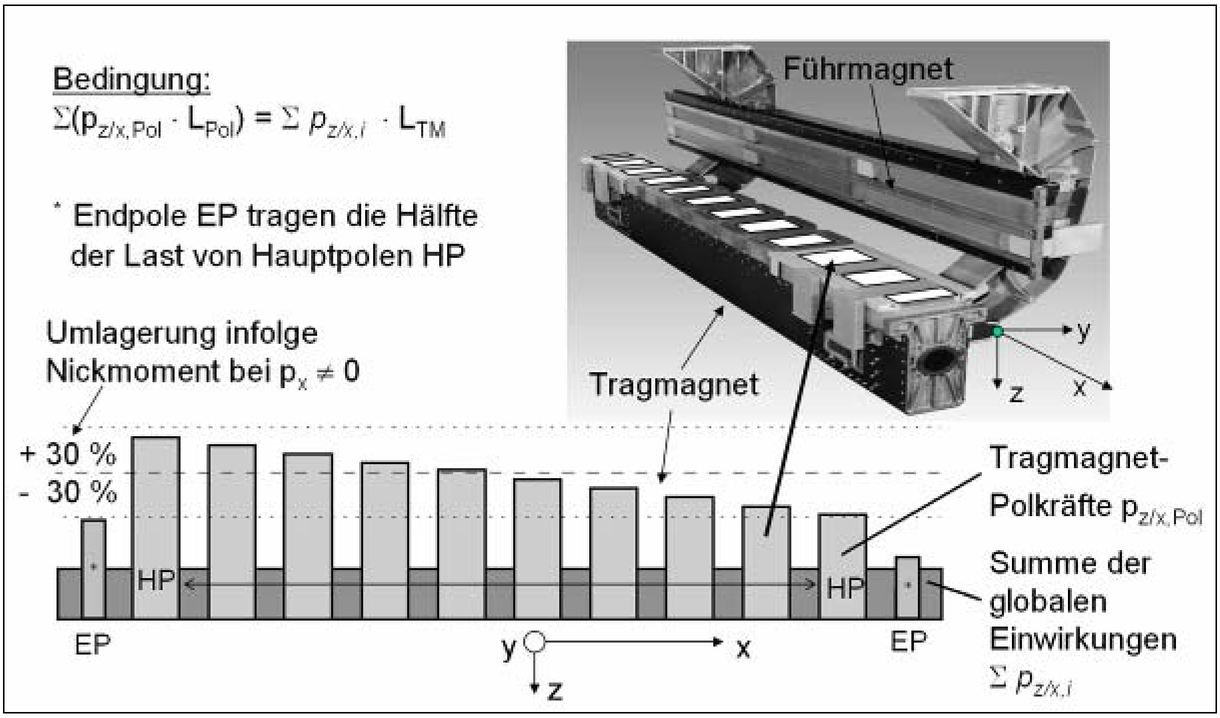


Fig. 89: *Typical load arrangement for support magnet without technical faults and breakdowns (Example)*

Bedingung	Condition
Endpolen EP tragen die Hälfte der last von Hauptpolen HP	End poles bear half of the loads of main poles HP
Führmagnet	Guidance magnet
Tragmagnet	Support magnet
Umlagerung infolge Nickmoment bei px ≠ 0	Superimposition owing to pitching moment when px ≠

Tragmagnet-Polkräfte	Support magnet pole forces
Summe der globalen Einwirkungen	Sum of total actions

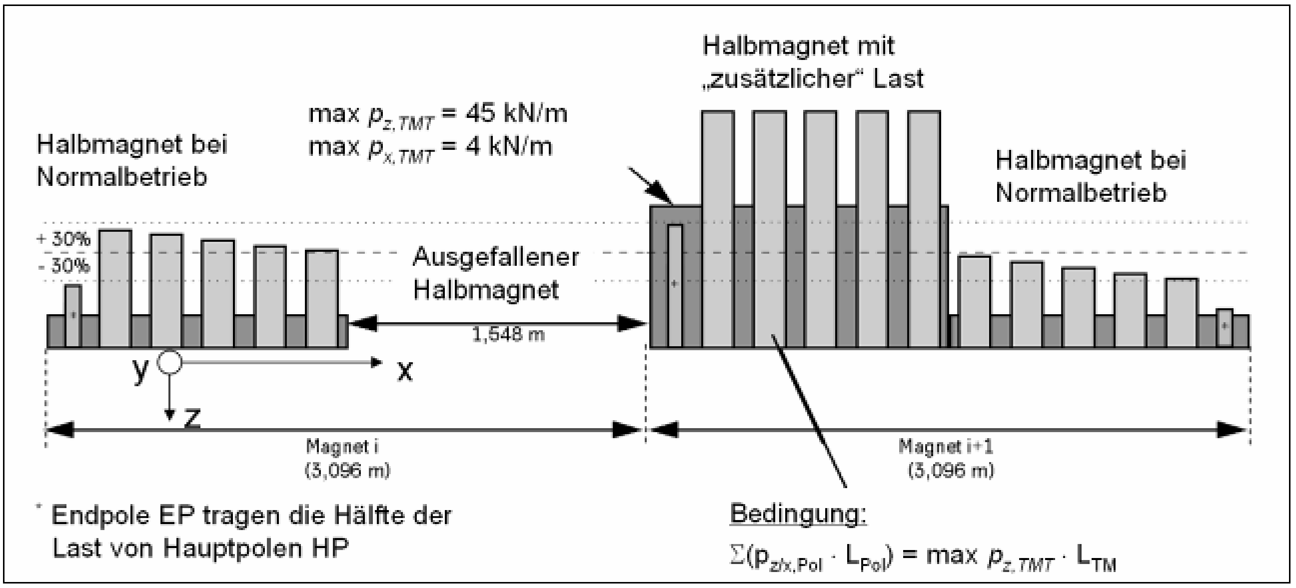


Fig. 90: *Typical load arrangement for support magnet in the event of a support magnet circuit failure (Example)*

Halbmagnet bei Normalbetrieb	Half magnet in normal operation
Halbmagnet mit "zusätzlicher" last	Half magnet with "additional" load
Ausgefallener Halbmagnet	Failed half magnet
Endpolen EP tragen die Hälfte der last von Haupt-polen HP	End poles bear half of the loads of main poles HP
Bedingung	Condition

Maximum loads at the support magnet - lateral guidance rail interface

Induced loads

The following loads are transmitted at the interface between the guidance magnet (FM) and the lateral guidance rail (SFS):

- *Magnetic quasi-static and dynamic tensile forces in the y direction during operation without technical failures or faults,*
- *Mechanical quasi-static and dynamic compressive forces in the y direction during operation with technical failures or faults,*
- *Frictional forces in the x direction as a result of mechanical compressive forces during special operation.*

The following values must be taken into consideration as characteristic values for the maximum loads per metre of partial magnet length.

Design situations	Direction of action	Load per m of guidance magnet
Max. tensile force and - permitted total weight - a_y = 1.5 m/s², a_x = 1.1 m/s² (WSV), Side wind 10 m/s at 400 km/h, R_H = 1000 m	y direction	25 kN/m
Max. tensile force in sectional magnet operation and - permitted total weight - a_y = 1.5 m/s², a_x = 1.1 m/s²(WSV), R_H = 1000 m - Side wind 37 m/s at 400 km/h, $F_{z\_dyn\_mittel}$	y direction	32 kN/m [10]
- Max quasi-stationary compressive force in the event of failure of the magnetic guidance function in an individual levitation undercarriage	y direction	25 kN/m
- Frictional force from quasi-stationary compressive force	x direction	7.5 kN/m
The centre of gravity of the load introduced in the z direction varies with the type of guidance magnet and in the event of guidance control equipment failure.		

The maximum guidance force of a guidance magnet must be limited to 16 kN/m for a single pole and 32 kN/m for a double pole.

Table 85: Maximum line loads

For local load distribution and the definition of single pole / double pole see Fig. 91.

[10] *If the maximum guidance force of 32 kN/m is exceeded this leads to mechanical lateral guidance(see chapter 0).*

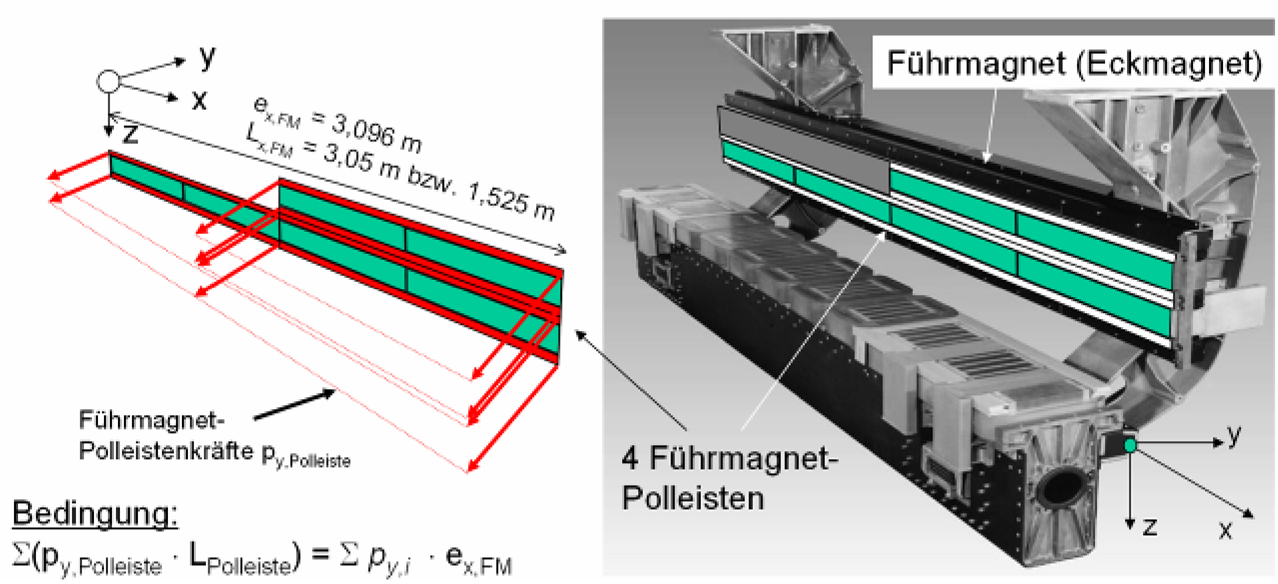
The following values must be taken into consideration as characteristic values for the maximum impact force:

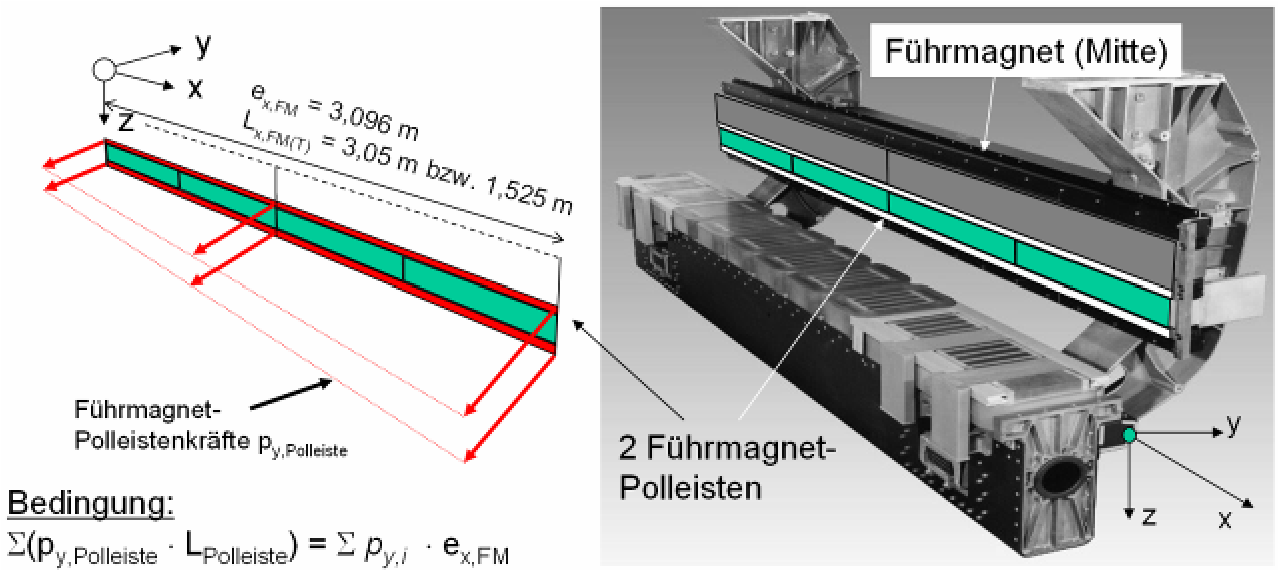
Design situations	Direction of action	Load per guidance magnet
- Max dynamic impact force in the event of failure of the magnetic guidance function in an individual levitation undercarriage and gusts of side wind.	y direction	115 kN
- Frictional force from dynamic impact force	x direction	34.5 kN
The centre of gravity of the load introduced in the z direction varies with the type of guidance magnet and in the event of guidance control equipment failure.		

Table 86: Maximum impact force

Dynamic excitation

In the case of the guideway, possible excitation from the arrangement of the guidance magnets must be taken into account.





Double pole: right-hand guidance magnet (corner magnet)

Single pole: left-hand guidance magnet (corner magnet)

Guidance magnet (centre)

Fig. 91: *Typical load arrangements of guidance magnets (example)*

Führmagnet-Polleistenkräfte	Guidance magnet pole strip forces
Bedingung	Condition
Führmagnet (Eckmagnet)	Guidance magnet (corner magnet)
Führmagnet-Polleisten	Guidance magnet pole strips
Führmagnet (Mitte)	Guidance magnet (centre)

Maximum loads at the support skid - sliding surface interface

Induced loads

In the event of levitation system failures the sliding surface (GL) at the interface between the support skid and the sliding surface is subjected to the following loads:

In the z direction (compressive load):

- *proportional quasi-static and dynamic load of a sliding levitation undercarriage*
- *transient impact load from the uncontrolled setting down of a levitation undercarriage*

in the x direction:

- *force resulting from the load in the z direction and the coefficient of friction.*

The following values must be taken into consideration as characteristic values for the maximum loads imposed by an individual support skid.

Characteristic values of the maximum skid forces in [kN]		**Direction of action**	**Load per support skid**
Static vehicle at 16° transverse inclination		y	14
Levitating vehicle	Quasi-static and dynamic compressive force	z	50
		x	15 or 25 in the event of stiction
	Impact force limit	z	100
		x	30
Frozen-on support skid		z	-50
		x	25

Table 87: Maximum support skid forces

For local load distribution see Fig. 92.

Dynamic excitation

Excitation as a result of local actions of the support skid can be ignored as far as the guideway is concerned.

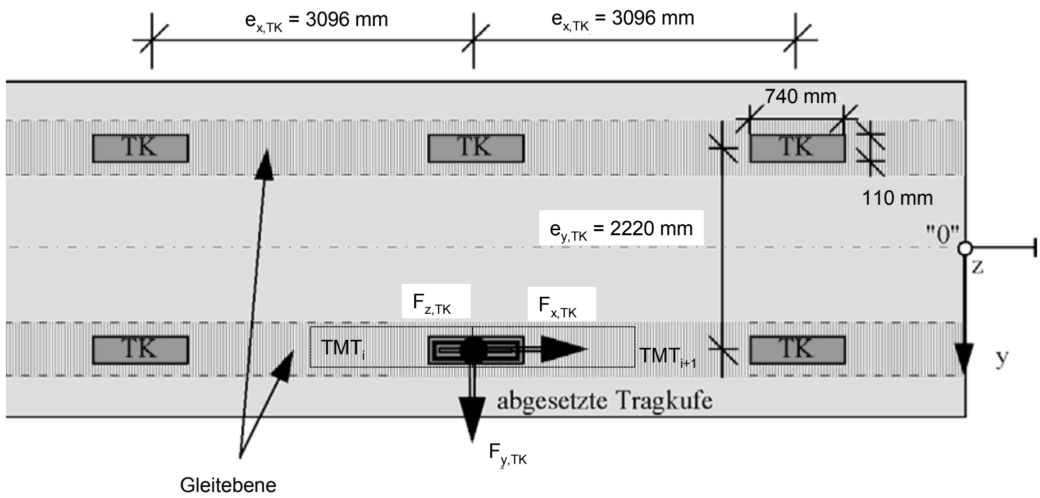


Fig. 92: *Load arrangements of support skid (example*

abgesetzte Tragkufe	Set down support skid
Gleitebene	Slideway

High-speed Maglev System
Design principles

Vehicle
Part V
Brake system

Distribution

The Vehicle Committee has released this document for publication.

Revisions

Date of release: 15.02.2007; White Paper, Vehicle Committee.

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General

Purpose and applications

- This "High-speed magnetic levitation railway vehicle design principles, part V - Brake systems" sets out the requirements for the safe braking systems installed in the vehicle.
- It applies to a Maglev system in accordance with the General Maglev System Act /AMbG/.
- The "long stator" control braking system is not covered in this document (see /MSB AG-GESAMTSYS/).
- Part V is to be used for the specification, execution and certification of the braking systems of MAGLEV vehicles.
- Any deviations from the requirements and definitions given in this document require equal safety in accordance with /MbBO/ of the certificate.
- Part V of the "MAGLEV vehicle performance specification" comprises:

Definition of the braking equipment;

Requirements for the braking equipment;

The actions of the braking equipment on the guideway;

Description of the interfaces with other systems (on-board operational control system (BLT), on-board energy supply).

- The requirements for a secure vehicle braking system are summarized. The document does not include a description of the braking control and monitoring by the BLT. This is given in /MSB AG-BLT/.

High-speed Maglev system design principles

- This document is part of the documentation for high-speed magnetic levitation railways consisting of a number of design principles. Figure 1 /MSB AG-GESAMTSYS/ shows the documentation tree.
- The overall design principles for the complete system and its appendices apply uniformly to all the documentation.

- High-speed Maglev system design principles, complete system, Document no.: 50630, /MSB AG-GESAMTSYS/, with appendices:
  - Annex 1: Abbreviations and definitions, Document no.: 67536, /MSB AG-ABK&DEF/
  - Annex 2: Legislation, regulations, standards and directives, Document no.: 67539, /MSB AG-NORM&RILI/
  - Annex 3: Environmental constraints, Document no.: 67285, /MSB AG-UMWELT/
  - Annex 4: Operating rules (operation and maintenance), Document no.: 69061, /MSB AG-BTR/

- Annex 5: Noise, Document no.: 72963, /MSB AG-SCHALL/

The documentation on the vehicle consists of the following documents:

- High-speed Maglev system design principles, vehicle, Part I.: Design principles, Document no.: 67698, /MSB AG-FZ GEN/
- High-speed Maglev system design principles, vehicle, Part II.: Design, document no.: 67694, /MSB AG-FZ BEM/
- High-speed Maglev system design principles, vehicle, Part III.: Kinematic limits, Document no.: 67650, /MSB AG-FZ KIN/
- High-speed Maglev system design principles, vehicle, Part IV.: Levitation and guidance systems, Document no.: 73388, /MSB AG-FZ TRAFÜ/
- High-speed Maglev system design principles, vehicle, Part V.: Braking system, Document no.: 73389, /MSB AG-FZ BREMS/

Abbreviations and Definitions

- The abbreviations and definitions supplied in /MSB AG-ABK&DEF/ should be used.
- The following abbreviations apply in addition to /MSB AG-ABK&DEF/:
-

a Braking delay (instantaneous value)

F_G Baking force of the vehicle

F_{Brems} Braking force of the vehicle as a result of the action of the braking equipment

F_W Train resistance of the vehicle

F_H Holding brake effort

m Vehicle earth

m_b Set-down part of the vehicle mass

s Local variable

v speed (instantaneous)

v_0 Braking output rate

μ_H Coefficient of friction for the holding brake function

$\mu_{H\,min}$ Minimum coefficient of friction for the holding brake function on an iced-up guideway

Legislation, regulations, standards and directives

- The prescriptive documents listed in /MSB AG-NORM&RILI/ contain definitions that are referred to in the high-speed Maglev system design principles and have become part of the high-speed Maglev system design principles. Where prescriptive documents in /MSB AG-NORM&RILI/ are dated, subsequent changes or revisions of these publications do not apply. Where references are undated, the latest edition of the prescriptive documents referred to is applicable.
- The edition of the standards and guidelines to be adhered to in a Maglev project must be made binding for each specific project.

Identification and mandatory nature of requirements

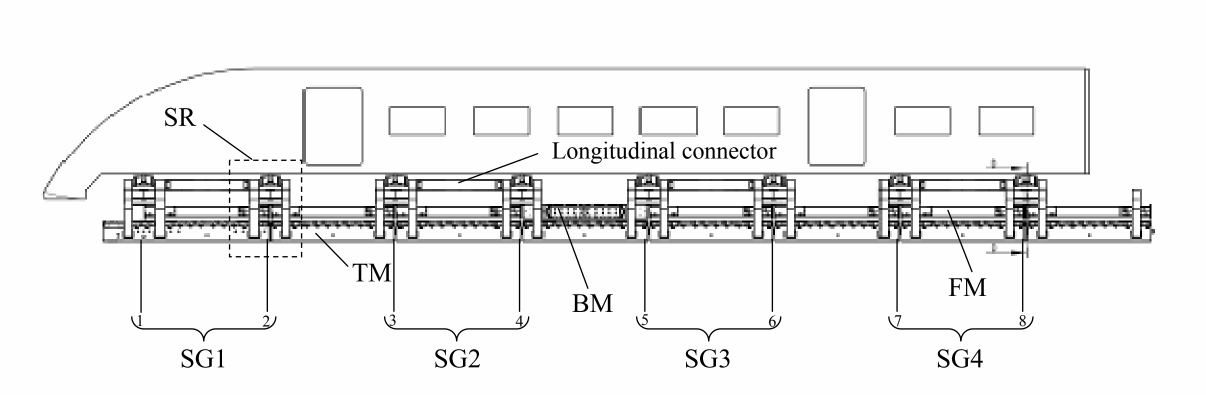
- The content of the present document is substantially based on the provisions of /DIN 820/ .
- In the following chapters of this document, and in the appendices,

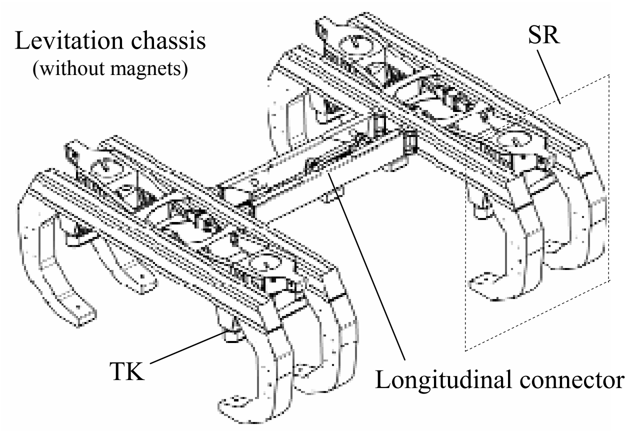
Requirements are shown in standard type

Explanations, guidelines and examples are shown in *italic.*

-
- Where notes on project-specific regulations are given in this document for individual cases, (*e.g. in a specification or a contractual regulation*) this means that the manufacturer and the contractor must consult the approvals authorities and come to an agreement.

Definitions (vehicle-specific)





SG = Levitation chassis (LC)
SR = Levitation undercarriage (2 levitation frames +connecting parts)
TM = Support magnet
FM = Guidance magnet
BM = Braking magnet
TK = Support skid
WK = Carriage body

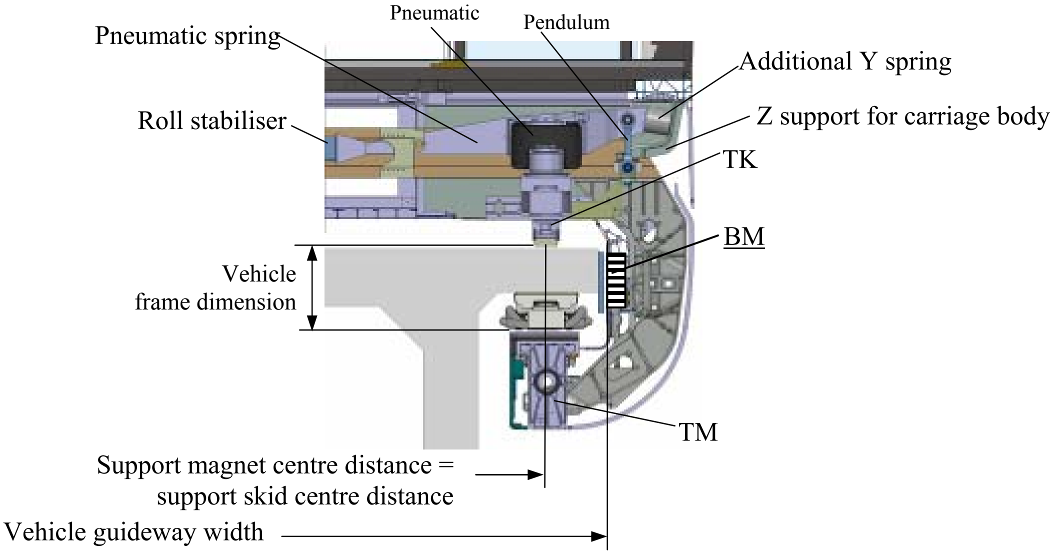


Fig. 93: *Side view and cross-section of a vehicle, identifying the braking equipment (schematic)*

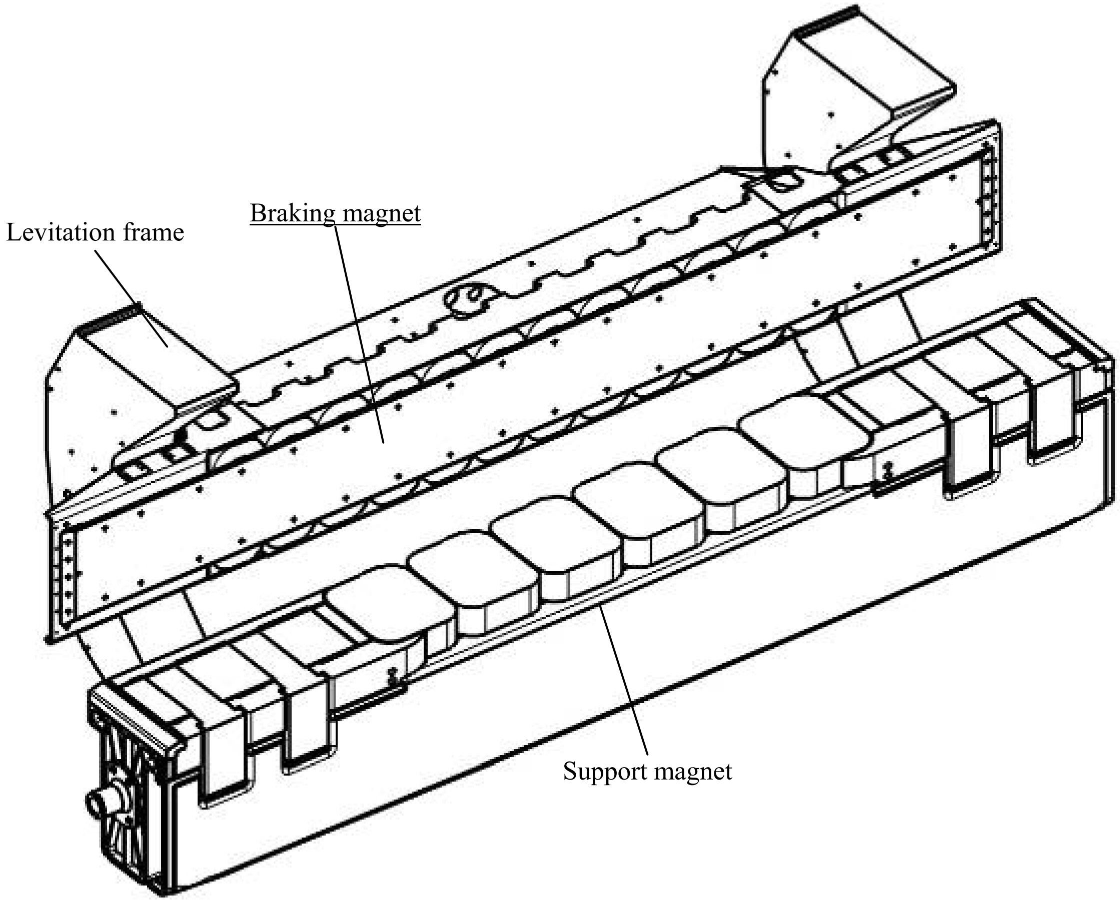


Fig. 94: *Magnet module (example)*

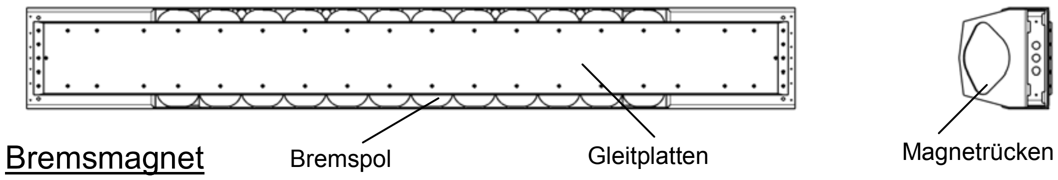


Fig. 95: *View of a braking magnet (example), definition of the essential components*

Bremsmagnet	Braking magnet
Bremspol	Braking pole
Gleitplatten	Sliding plates
Magnetrücken	Rear of magnet

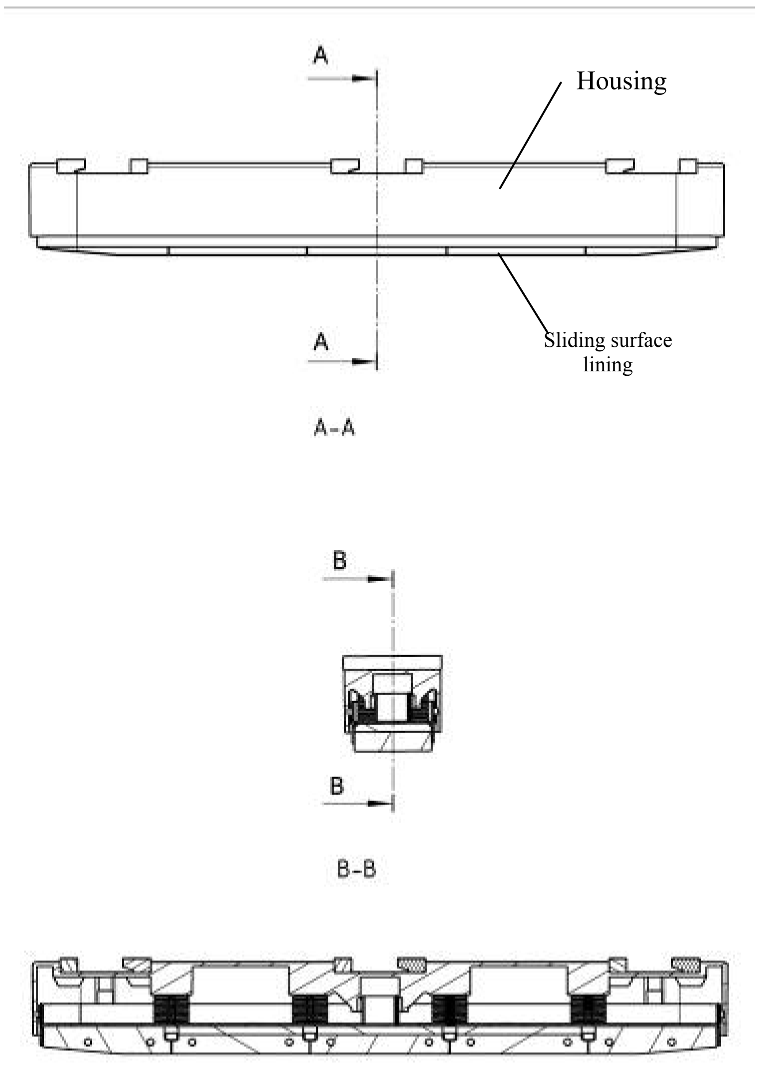


Fig. 96: *Support skid (example)*

General requirements of the braking system

Subsystems and equipment

- *The description in /MSB AG-GESAMTSYS/ is applicable.*
- *The following brakes are available for the vehicle:*

Braking function of the long stator propulsion system, used in fault-free condition (operating brake);

Safety brake, controlled by BLT devices in the vehicle.

- *The "long stator propulsion" braking function is not covered in this document (see /MSB AG-GESAMTSYS/).*
- *This design principles controls the demands that the vehicle makes on the braking system (safe brake) and their actions on the guideway. The propulsion system shutdown and the vehicle's own braking system are controlled by the operational control system, which also prevents inadmissible superimposition effects. This design principles does not cover these functions[11].*
- *Examples of the subsystems and equipment used in the safety brake are defined in Fig. 97. In this example the control and monitoring of the safe brake that the BLT has to implement is done in the vehicle using the following subsystems and equipment:*

The control signals from the BLT to activate the braking function and to control the effect of braking are transmitted to the braking magnet control devices.

The braking magnet control devices control the current in the braking magnets and perform distributed monitoring of the brake devices concerned.

The monitoring signals from the brakes of the magnet control devices are transmitted to the BLT.

The braking magnets generate speed-dependent eddy currents in the lateral guidance rails of the guideway and these result in deceleration forces on the braking magnets. In addition the braking magnets create forces of attraction on the lateral guidance rails. In the lower speed range the braking magnets apply themselves because of the forces of attraction on the lateral guidance rails and generate frictional forces between the sliding plates of the braking magnets and the lateral guidance rails.

The forces acting on the brake are directed into the vehicle by the guidance parts and structural parts of the brake.

Immediately before the vehicle comes to a standstill, the BLT switches the brake off and the vehicle is set down by the support skids on the sliding surface, acting on control signals from the BLT to the support magnet control devices.

The support skids take over the function of a holding brake.

The monitoring signals from the on-board networks and the support magnet control devices are transmitted to the BLT.

[11]The design principles describes the construction requirements for the safe brake that are not project-dependent and are based on specific construction features.

- *The generation of the braking force as per chapter 0 (in Fig. 97 Braking magnet, structural guidance parts for the brake, braking magnet control equipment and the control and supervision of the braking effect in accordance with chapter 0 (in Fig. 97 Transmission of brake control and monitoring signals from and to the BLT, generation of safety-relevant status information in the magnet control equipment) are part of this design principles (/MSB AG-FZ BREMS/).*

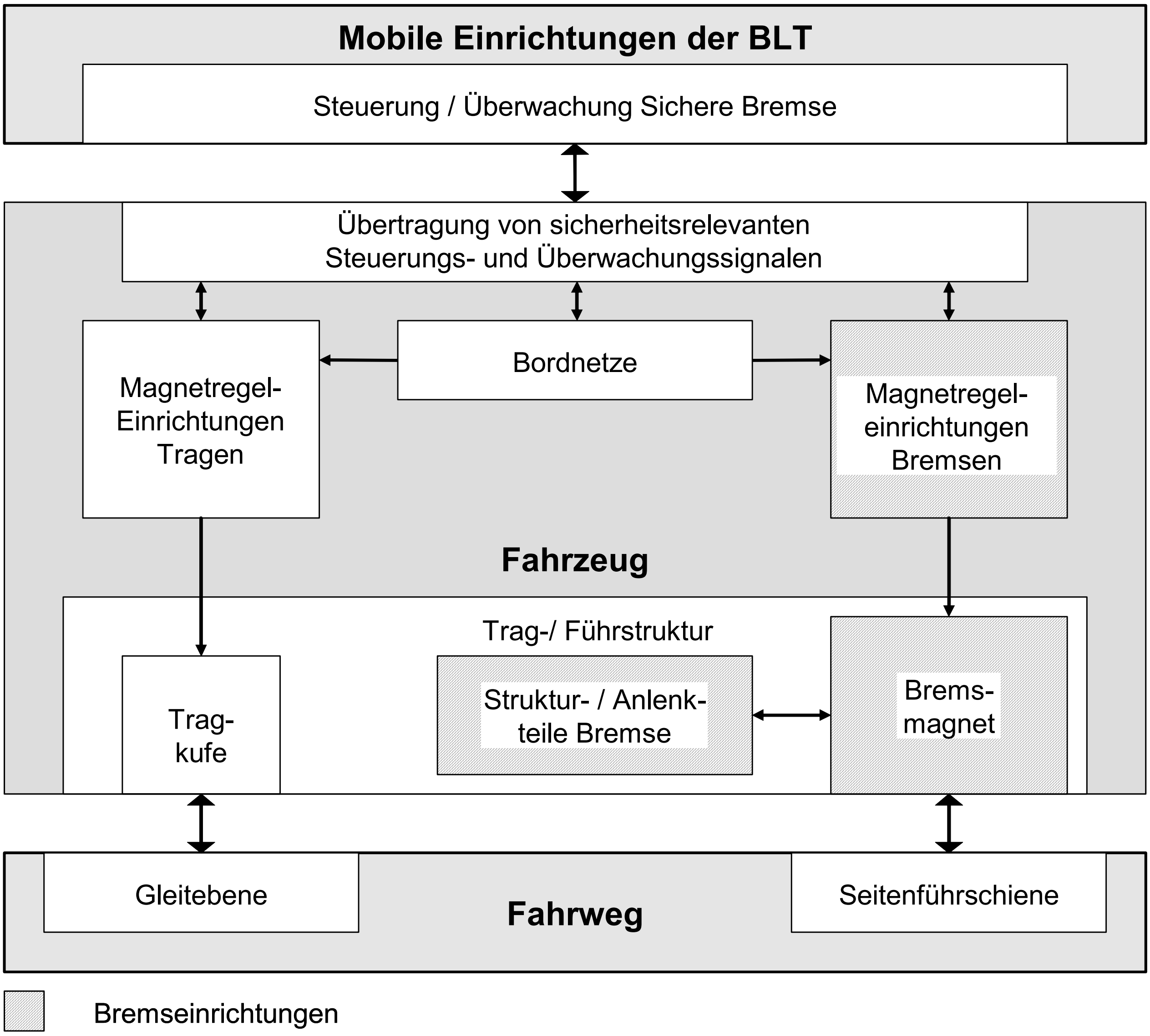


Fig. 97: *Subsystems and equipment involved in safe braking (example)*

Mobile Einrichtungen der BLT	Mobile BLT equipment
Steuerung/Überwachung sichere Bremse	Control/monitoring of the safe brake

Übertragung von sicherheitsrelevanten Steuerungs- und Überwachungssignalen	Transmission of safety-relevant control and monitoring signals
Magnetregel-Einrichtungen Tragen	Magnet control equipment for support
Bordnetze	On-board power supplies
Magnetregel-Einrichtungen Bremsen	Magnet control equipment for brakes
Fahrzeug	Vehicle
Tragkufe	Support skid
Struktur/Anlenkteile Bremse	Structural and pivoting parts for brakes
Bremsmagnet	Braking magnet
Gleitebene	Sliding surface
Fahrweg	Guideway
Seitenführschiene	Lateral guidance rail
Bremseinrichtungen	Braking equipment

- *Functions of the BLT that are necessary for the use of safe braking*

Control and supervision of brake testing,

Control and supervision of safe braking,

Maximum profile monitoring,

Minimum profile monitoring,

Safe location,

Safe propulsion shutdown,

- *are in the design principles for the BLT (/MSB AG-BLT/).*
- *The levitation and guidance structure and the support and guidance magnet regulation devices are dealt with in the design principles for the levitation and guidance system (/MSB AG-FZ TRAFÜ/).*
- *The design of the structural components of the brake is given in /MSB AG-FZ BEM/.*

Operation

- The vehicle's own safe brake must be designed in such a way that the vehicle can brake independently at a defined stopping place using its own operational control system equipment.
- The vehicle's own safe brake must have the following functions:

BLT can actuate the brake at any time,

BLT can control the magnitude of the braking effect,

Stopping brake function.

- Sections 13 and 20 of the MbBO apply to the stopping brake function. The conversion must be certified separately for each project. The requirements of /MSB AG-GESAMTSYS/ are applicable. A stopping position, once adopted, must be maintained.
- *Braking ability is determined by the speed-dependent effective braking power of the vehicle F_G when long stator propulsion is switched off and by the brake winding time t_e after activation by the BLT.*
- *The following applies in general for F_G:*
-

$$F_G = F_{Brems} + F_W$$

where F_{Brems}: *Braking force of the vehicle as a result of the action of the braking equipment*

F_W: *Train resistance of the vehicle*

- Braking ability must be verified by means of tests.
- The speed-dependent braking force for a given vehicle mass m is calculated as
-

$$F_G (v) = a (v) \cdot m .$$

- The train resistance F_W must be verified by means of suitable levitation tests with the vehicle not propelled and not braked in the same way as F_G .
- The stopping brake function can be achieved by setting the vehicle down on the support skids.
- *The stopping brake force F_H is determined by the set-down proportion of the vehicle mass m_b and the coefficient of friction μ_H acting on the area of contact between the guideway and the vehicle.*
- *The stopping brake function is present when the stopping brake force is greater than the force acting on the stationary vehicle in the x direction. This is made up of the incline output force during longitudinal inclination and the aerodynamic force due to wind in the x direction.*
- When certifying the stopping brake function, a project-specific safety factor > 1 must be taken into account.
- *An example of the maximum and minimum braking characteristics that can be achieved with the safe braking system for a vehicle section is given in Fig. 98.*
- For each project the limits must be balanced against the requirements of the BLT and the design of the guideway. The project-specific defined values must be adhered to.

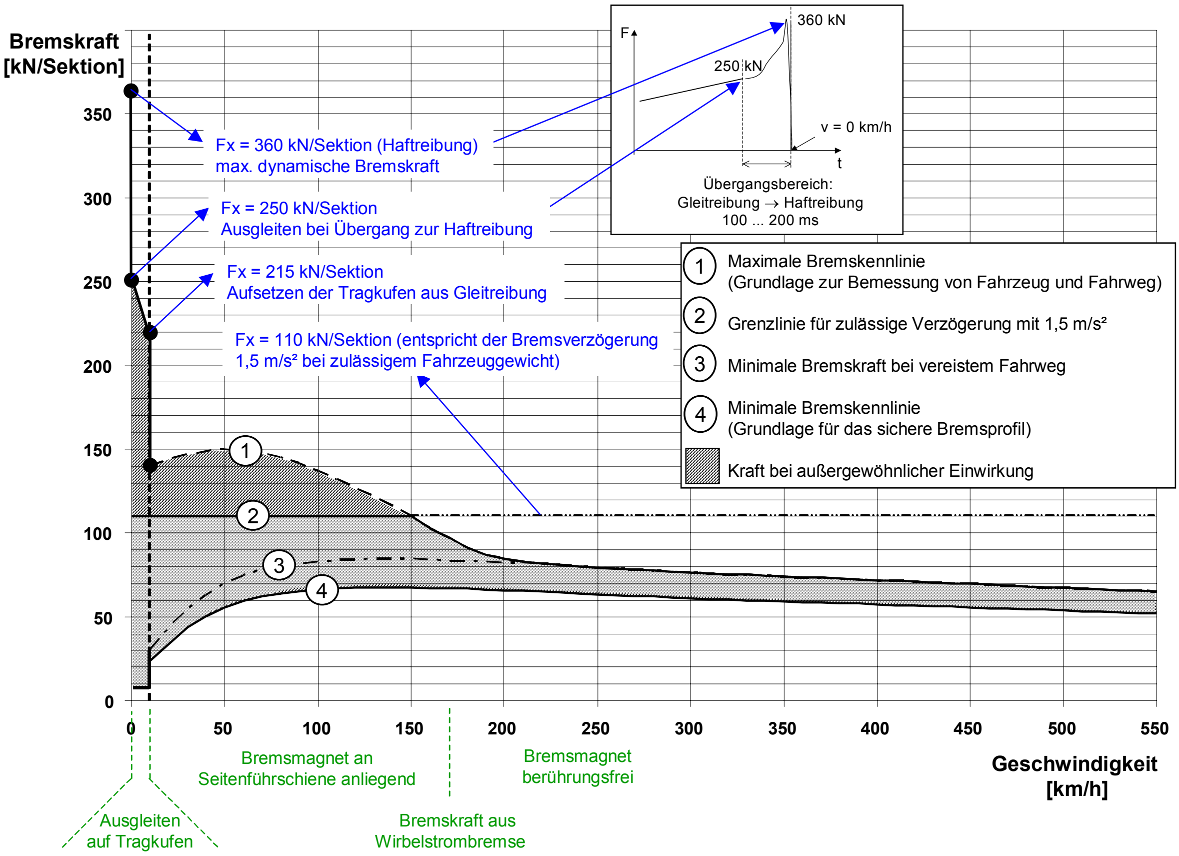


Fig. 98: *Braking characteristic for the safe brake for a vehicle section* (Figure 10 taken from chapter 8.5 of /MSB AG-GESAMTSYS/)

Bremskraft [kN /Sektion]	Braking force [kN/section]
Fx = 360 kN/Sektion (Haftreibung)	Fx = 360 kN/section (stiction)
max. dynamische Bremskraft	Max dynamic braking force
Fx = 250 kN/Sektion	Fx = 250 kN/section
Ausgleiten bei Übergang zur haftreibung	Slip on transition to stiction
Fx = 215 kN/Sektion	Fx = 215 kN/section
aufsetzen der Tragkufen aus Gleitreibung	Support skids applied by sliding friction
Fx = 110 kN/Sektion	Fx = 110 kN/section
(entspricht der Bremsverzögerung 1,5 m/s^2 bei zulässigem Fahrzeuggewicht)	(equivalent to braking delay of 1.5 m/s^2 for permissible vehicle weight)
Übergangsbereich: Gleitreibung → Haftreibung	Transition area: sliding friction → stiction
Maximale Bremskennlinie (Grundlage für Bemessung fon Fahrzeug und Fahrweg)	Maximum braking characteristic (Design basis for vehicle and guideway)
Grenzlinie für zulässiger Verzögerung mit 1,5 m/s^2	Threshold for permissible braking at 1.5 m/s^2
Minimale Bremskraft bei vereistem Fahrweg	Minimum braking force for iced-up guideway
Minimale Bremskennlinie	Minimum braking characteristic
Kraft bei außergewöhnlicher einwirkung	Force in the event of accidental action
Ausgleiten auf Tragkufen	Slip on support skids
Bremsmagnet an Seitenführscheine anliegend	Braking magnet adjacent to lateral guidance rail
Bremskraft aus Wirbelstrombremse	Braking force from eddy current brake
Bremsmagnet berührungsfrei	Braking magnet not in contact
Geschwindigkeit	Speed

Design and ratings

- The loads that are borne by the structural components and pivots of the equipment producing the braking force must be taken into account, using the Vehicle design principles, Part II /MSB AG-FW BEM/, during the design process.
- The loads specific to the project must be documented.
- Proof of load-bearing capability (general stress certificate) and fatigue resistance according to the requirements set out in Part II /MSB AG-FW BEM/ must be provided for the components that transfer the load.
- The braking elements must take all of the geometric constraints in accordance with /MSB AG-FW GEO/ fully into account. At the same time it must be ensured that the action of braking has no effect on the permitted surface deviations that would place the system at risk.

Safety requirements

- The systems relevant to safety must be planned and certified to /DIN EN 50126/ as a general rule.
- *Fig. 99 and Fig. 100 give examples of a structure for this task.*
- The control and operation of the safe brake with spot braking must be safe over the entire speed range for its lifetime (Safe-Life). The permissible failure rate for the safe brake over an assumed period of operation (being driven and at a standstill) must be determined by a risk analysis.
- *Information on methods of performing the risk analysis is given in /prEN 50,126-2/ and /prR009-004/.*
- The speed range must include the maximum speed according to the maximum trip profile right down to a standstill. The speed range can be covered by one or more braking systems, e.g. an eddy current system combined with a friction brake.
- The safe life requirement must cover the most unfavourable specified boundary conditions such as maximum load, following wind, descent, actions from the primary environment, particularly wintry weather and lightning, and also technical faults and breakdowns.
- To achieve the required failure rate the safe brake can be executed with redundant braking equipment. Breakdowns in the redundant safe brake or a reduction in braking force due to technical faults or breakdowns must not affect the safe-life qualities of the safe brake.
- Certification of the safe-life property must be performed using a suitable method of analysis, e.g. a fault tree analysis before the system is commissioned. This theoretical certificate must be backed up by experimental verification of the assembly failure rates assumed in the analysis and by practical tests to demonstrate the failure behaviour in the event of the failure of assemblies. The analysis must include a common cause fault analysis.
- A safety certificate including risk analysis to /DIN EN 50126/ is required for the safe brake.
- *The requirements for and tests on the equipment for producing the braking force are given in chapter 0.*
- *The requirements for and tests on the equipment for controlling and monitoring the braking force are given in chapter 0.*
- The SIL level according to /DIN EN 50129/ for the electronic equipment for producing the braking force and for controlling and monitoring it must be determined on the basis of the risk analysis and must be taken into account when performing the certification.
- The level of the safety requirements for the software in the braking system that has been determined on the basis of the risk analysis must be taken into consideration when performing the certification to /DIN EN 50128/.
- A suitable analysis must include consideration of at least the following faults:

Fault in the on-board energy supply,

Anticipated or delayed execution of a set-down command,

System failure (of software or hardware),.

Untimely lifting of the vehicle.

Requirements for the on-board energy supply

- *The system characteristics of the safe brake set functional and safety-relevant requirements for the on-board energy supply and proof is required that these have been met, see / MSB AG-FZ TRAFÜ/.*
- In order to perform forced braking with the safe brake an uninterruptible power supply must be provided. This must take account of the most adverse environmental and operating conditions that have been specified.

Requirements for the execution of a set-down command.

- The set-down command must be generated in such a way - and must be linked by a logical AND with the speed determined independently in each levitation and guidance unit in such a way - that the command to set down can only be decentrally effective when the vehicle speed is lower than the permitted set-down speed.
- A certificate is required for the set-down control to the effect that the set-down command can only become effective below the set-down speed and, with sufficient probability, also in the event of all foreseeable failures.

Systematic faults in the braking system

- Certification that systematic faults are sufficiently unlikely or that their effects are under control is required in accordance with /DIN EN 50129/. This applies to the hardware and, if present, the software of the equipment that is relevant to safety in the measurement, control, regulation and monitoring systems of the magnet regulating circuits of the safe brake.
- Diagnostic and control equipment should be provided separately as part of the hardware and software.
-

Taking friction pairing into account

Braking magnet / lateral guidance rail,

- *The mutual action of the forces from the braking magnet and lateral guidance rail components guarantees the effectiveness of the safe brake. The braking effect is created by an eddy current effect and, in the lower speed range, by mechanical friction.*
- The normal forces, frictional characteristics and surface pressure acting between the lateral guidance rail and sliding plate must be taken into account during design work.
- Wear on the sliding plates must be taken into account in the maintenance schedule.
- The properties of the frictional pairing of sliding plate and lateral guidance rails must be defined and certified for each project. Suitable test rig results can be used for this.

Support skids / sliding surface

- *The support skid and sliding surface come into mechanical contact when the magnetic levitation function is interrupted.*
- *This happens*

when the vehicle is set down,

when the levitation system is in emergency running mode,

as a contributory braking function of the safe brake at low speeds, e.g. ≤ 10 km/h (project-specific figure),

as a stopping brake function.

- Wear on the support skids must be taken into account in the maintenance schedule.
- The properties of the frictional pairing of support skid and sliding surface must be defined and certified for each project. Suitable test rig results can be used for this.

Requirements for the braking equipment

Generation of braking force

Properties and functions

- *The braking forces of the safe brake are generated by:*

Braking systems that give rise to braking forces via the interface with the guideway,

Braking systems that give rise to a stopping force via the interface with the guideway when the vehicle is at a standstill.

Effect of failure

- The failure of one braking system must not adversely affect the operation of the other braking systems.
- The risk of the following failures occurring within the braking systems per year and per vehicle, which must be determined in advance in a risk analysis, must not exceed:

Failures that lead to the partial or complete activation of the safe brake by the BLT without a command,

Failures that lead to the defined maximum braking force being exceeded,

Failures that lead to the defined minimum braking force being exceeded.

- Where they interact with the levitation and guidance system, failures of brake systems must be taken into account in the design and execution of the levitation and guidance system.
- Where they interact with the operation of the safe brake, failures in the levitation and guidance system must be taken into account in the design and execution of the braking systems.

Failure reporting

- In addition to notification from and to the BLT, failures in the braking systems must be fail-safe.
- Where monitoring devices that are relevant to safety do not automatically report failure, periodic functional tests / inspections must make failures obvious.
- The times of failure reporting that are required in order to comply with the preset failure rate according to the risk analysis must be adhered to.
- The test criteria and intervals must be determined by means of a suitable analysis, e.g. fault tree analysis, FMEA

Certificates

- A qualification test with prototypes must be performed on the braking systems to certify the operation, failure behaviour, reporting of failures and environmental resistance.

- the speed-dependent curves for braking power F_{Brems}, both at full availability and also at a specified maximum number of failed brake circuits , and the train resistance F_W must be certified by performing tests on a representative vehicle under defined environmental conditions and rated load.
- The speed-dependent curve of the minimum effective braking force F_{Brems} under the most unfavourable environmental conditions, rated load and failure conditions can be obtained by calculation.
- The braking force certificate must take into account those failures that are within the acceptable failure rate according to the risk analysis (see chapter 0).
- A suitable analysis must be carried out to certify the safe life function, e.g. fault tree analysis. The analysis must include a common cause fault analysis.
- A suitable analysis, e.g. a fault tree analysis, must show that the following events have a risk of occurring per year and per vehicle that is to be determined beforehand in a risk analysis:

Full or partial application of the brakes without a command or control from the BLT,

Failure to reach a required braking force or exceeding the maximum permitted braking force over the whole of the speed range including standstill.

- Failure behaviour must be demonstrated in tests that simulate assembly failures.
- The reliability of the electronic braking systems must be verified by determining the MTBF from the evaluation of life cycle data on representative assemblies during operation.
- The compatibility of the MTBF verified from life cycle data with the forecast statements of the analysis must be demonstrated.

Control and monitoring of the braking effect

Properties and functions

- *The safety-relevant control and monitoring functions of the safe brake include:*

transmission of control commands from the BLT to the baking systems in order to activate the braking function and control the braking effect

generation of safety-relevant status information to monitor the braking systems and transmission of this information to the BLT.

- *This design principles does not cover non-safety-relevant status information (e.g. diagnostic messages).*

Behaviour in the event of failure

- An individual failure of the control / monitoring systems must not lead to the loss or limitation of a safety-relevant control and monitoring function.
- The failure of a safety-relevant control / monitoring system that is due to the multiple failure of redundant assemblies must lead to an automatic failsafe system reaction.
- *The triggering of this failsafe system reaction is guaranteed by the operational control system and is not part of this design principles.*

Certificates

- Qualification tests of the assemblies must be carried out with prototypes or on a representative vehicle.
- The control and monitoring equipment must be taken into account in the analysis to show the probability of occurrence of an insufficient or unforeseen application of the brakes (see chapter 6.1). The analysis must include a common cause fault analysis.

Actions of the braking equipment on the guideway

General

- *The forces given below correspond to the characteristic values of the actions of the vehicle on the guideway at the vehicle-guideway interfaces.*

Types and combinations of actions

- *The actions of the braking system on the guideway act upon the following interfaces:*
-
- *Braking magnet - lateral guidance rail,*
- *Support skid - sliding surface*
- *The forces acting on the guideway are the result of the following functions:*
-
- *magnetic braking effect caused by the eddy currents induced in the lateral guidance rails by the braking magnet,*
- *magnetic tensile force on the lateral guidance rails as reaction rails of the braking magnets,*
- *mechanical braking effect owing to friction between the braking magnet and the lateral guidance rail,*
- *mechanical braking effect owing to friction between the support skid and the sliding surface.*
- The effect of weathering on the magnetic braking effect can be disregarded.
- *The magnetic braking effect is influenced by variations in environmental conditions via the effective coefficient of friction.*
- The actions of the braking systems on the structure and the force introduction into the levitation and guidance system must be taken into consideration in accordance with chapter 0 when designing the assemblies.
- The actions on the guideway must be taken into account in the guideway design specifications as variable and/or unusual actions from the vehicle.
- To ensure that the actions arising from operation of the vehicle that are assumed in the guideway design specifications agree well enough with actions arising in practice, the values given in chapter 0 for the forces transmitted by the vehicle must not be exceeded (permissible tolerance when verifying the magnitude of the actions is 5%).
- The magnitude of the characteristic values of the actions must be set down in a mandatory project-specific specification for every application.
- The magnitude of the actions must be demonstrated by calculation or by testing on a representative vehicle.

Forces and load arrangements

Overall actions on the guideway

- A characteristic value of a force of 250 kN in the x direction is to be used for the maximum overall braking effect of a vehicle section on the guideway given a permitted overall weight according to chapter 9 of /MSB AG-GESAMTSYS/ and a speed v > 0 km/h.
- At the changeover from v > 0 km/h to v = 0 km/h the effect of the transition from sliding friction to static friction must be taken into consideration. At this point a transient maximum force of 360 kN in the x direction can occur, with a duration of action in the order of 100 ms to 200 ms.

Braking magnet - lateral guidance rail interface

- *At the interface between the braking magnet (BM) and the lateral guidance rail (SFS) there is a magnetic transfer of tensile forces in the y direction and a magnetic and mechanical transfer of braking forces in the x direction.*
- The material of the lateral guidance rail must satisfy the requirements of /MSB AG-GESAMTSYS/, chapter 6.1.4.3.6. The energy contributed by the braking system of the safe brake to the lateral guidance rail, which is converted to heat, must also be taken into consideration.
- *Magnetic braking forces in the x direction arise as a result of eddy currents induced in the SFS by the braking magnets.*
- *Mechanical braking forces in the x direction arise as a result of frictional forces resulting from the magnetic attraction between the BM and the SFS.*
- The following values must be taken into consideration as characteristic values for the maximum quasi-static loads imposed by an individual braking magnet.
-

Type of action	Direction of action	Load per braking magnet	Load per m of SFS
Tensile force	y direction	50 kN	25 kN/m [1)]
Longitudinal force	x direction	75 kN	37.5 kN/m

[1)] Locally the load may be 50 % higher

Table 88: Characteristic values for the maximum quasi-static loads imposed by an individual braking magnet

Support skid / sliding surface interface

- *At the interface between the support skid and the sliding surface (GE) there is a transfer of quasi-static weight force in the z direction and a force resulting from weight force and the coefficient of friction in the x direction.*
- The following values must be taken into consideration as characteristic values for the maximum quasi-static loads imposed by an individual support skid.

Type of action	Direction of action	Load per support skid
Compressive force	z direction	50 kN
Longitudinal force	x direction	15 kN quasi-stationary when i v > 0 km/h max. 25 kN transient when v → 0 km/h

Table 89: Characteristic values for the maximum quasi-static loads imposed by an individual support skid

Date last printed 13.09.2007 10:42:00

Maglev system
"Safe brake" section

Description of the "Safe brake" section

Organisation and quality management

Project organisation
Organisations and subordinate organisations involved (organigram)
Quality management and quality assurance
Contact person

Safety management

1. Safety objectives taken from the MbBO
   - Bring the vehicle to a safe stop.
   - Keep the vehicle still when stopped.
   - Lower the vehicle speed and stop (e.g. when crossing points, etc.)
2. Safety management process
   - Planning the "Safe brake" section life cycle
3. Safety organisation
   - Distribution of functions
   - Employees, their responsibility and place in the organisation
4. Safety plan
5. Safety concept
   - Hazard log book (hazards found during the project)
6. Specification of safety requirements
   - Hazard analyses
     Detection and naming of hazards
   - Assessment and classification of risk
   - Assignment of safety requirements and objectives to functions, modules, work, etc.
7. Operating safety requirements and planned implementation thereof
8. Performance of the safety review according to schedule
9. Safety verification and validation and justification for same
10. Handing over of sections of the vehicle to the client
    - Organisation of inspection
11. Operation and maintenance

Fig. 99: Project structure for safety-relevant systems (Part I / project-specific example)

Fig. 100: Project structure for safety-relevant systems (Part II / project-specific example)

High-speed Maglev system Design principles

Propulsion system and power supply

Distribution

The Propulsion and Power Supply Committee has released this document for publication.

Revisions

Date of release: 15.02.2007; White Paper, Propulsion and Power Supply Committee.

Contents

TOC

General

Purpose of the document and scope of application

These design principles lay down the generally applicable technical and operational requirements for the propulsion and energy supply sections of a high-speed Maglev system. They are the basic criteria for design, planning and approval and for the implementation and operation of high-speed Maglev system projects.
These design principles are only applicable in combination with /MSB AG-GESAMTSYS/. This defines the basic functions of the complete system and the associated sections.
These design principles applies to a high-speed Maglev system in accordance with the General Maglev System Act /AMbG/.

High-speed Maglev system design principles

This document is part of the documentation for high-speed Maglev systems consisting of a number of design principles. Figure 1 /MSB AG-GESAMTSYS/ shows the documentation tree.
The overall design principles for the complete system and its appendices apply uniformly to all the documentation.

- High-speed Maglev system design principles, complete system, Document no.: 50630, /MSB AG-GESAMTSYS/, with appendices:
  - Annex 1: Abbreviations and definitions, Document no.: 67536, /MSB AG-ABK&DEF/
  - Annex 2: Legislation, regulations, standards and directives, Document no.: 67539, /MSB AG-NORM&RILI/
  - Annex 3: Environmental constraints, Document no.: 67285, /MSB AG-UMWELT/
  - Annex 4: Operating rules (operation and maintenance), Document no.: 69061, /MSB AG-BTR&IH/
  - Annex 5: Noise, Document no.: 72963, /MSB AG-SCHALL/

Abbreviations and Definitions

The abbreviations and definitions supplied in /MSB AG-ABK&DEF/ should be used.

Legislation, regulations, standards and directives

The prescriptive documents listed in /MSB AG-NORM&RILI/ contain definitions that are referred to in the high-speed Maglev system design principles and have become part of the high-speed Maglev system design principles. Where prescriptive documents in /MSB AG-NORM&RILI/ are dated, subsequent changes or revisions of these publications do not apply. Where references are undated, the latest edition of the prescriptive documents referred to is applicable.

The edition of the standards and guidelines to be adhered to in a Maglev project must be made binding for each specific project.
The following standards relating to the propulsion system and power supply must be given particular attention.
/DIN VDE 0100/ Erection of power installations with rated voltages up to 1000 V
/DIN VDE 0101/ Power installations with rated voltages above 1 kV
/DIN VDE 0105/ Operation of power installations
/DIN EN 62305/ Protection against lightning
/DIN EN 50121/ Railway applications - Electromagnetic compatibility
/DIN EN 60071/ Insulation coordination (for rated voltages above 1 kV)
/DIN EN 60228/ Conductors of insulated cables
/DIN VDE 0276/ Power cables with extruded insulation
/DIN EN 60664/ Insulation coordination for equipment with low-voltage systems
/DIN EN 60909-0/ Short-circuit currents in three-phase a.c. systems - Part 0: Calculation of currents
/DIN VDE 0888/ Fibre optic cable for communication systems and data processing installations
/DIN EN 60076/ Power transformers
/DIN EN 60694/, Common specifications for high-voltage switchgear and control gear standards
/DIN EN 62271/, High-voltage switchgear and control gear
/DIN EN 61642/ Industrial a.c. networks - Application of filters and shunt capacitors
/DIN EN 62040/ Uninterruptible power systems (UPS)
/DIN EN 61378-1/ Converter transformers
/DIN EN 50178/ Electronic equipment for use in power installations
Safety certificates for functions of the propulsion and power supply section must comply in all respects with the applicable standard /DIN EN 61508/.

Identification and mandatory nature of requirements

The content of the present document is substantially based on the provisions of /DIN 820/ .
In the following chapters of this document, and in the appendices,

- Requirements are shown in standard type
- Explanations, guidelines and examples are shown in *italic.*

The degree to which the requirements are mandatory has been laid down on the basis of /DIN 820-2/ Annex G and is reflected in the formulation of each requirement.

System requirements

Structure and design

Chapter 6.1.2 of /MSB AG GESAMTSYS/ deals with the structure and gives precedence to explaining the structure, functions and configuration parameters.
Figures 13, 14 and 15 of chapter 8 of /MSB AG GESAMTSYS/ also show the design and structure of the propulsion system and power supply.
The propulsion system and power supply must be designed specifically for each project.
The design should be based on the operating schedule, sequence of trains, train configuration and design speed, among other things.
Other basic data according to chapter 9 (Annex 1) of /MSB AG GESAMTSYS/ must be defined specifically for each project.
The propulsion system and power supply section should be configured so that functional units can be planned, manufactured, installed, commissioned and tested independently of each other as far as possible.
To achieve functional redundancy with tolerance of individual assembly failures, the stator sections must be distributed over at least two independent motor systems and must be so arranged that a Maglev vehicle always has at least two motor systems assigned to it.
Only one levitating vehicle must be present in a propulsion area.
A number of set-down Maglev vehicles must be able to be present in one propulsion area.
A propulsion area can have fixed sections of the route assigned to it, or certain sections optionally assigned to it (overlapping sections).
Propulsion areas must be assigned to safe areas that have been made safe by the operational control system.
As a rule, propulsion areas should be identical with areas that have been made safe by the operational control system. However, it is also possible for a number of propulsion areas to be assigned to a single safe area and vice versa. However, there must never be any propulsion areas that are not assigned to an area that has been made safe by the operational control system.
<u>Procedure for changing sections</u>
The propulsion system must control the procedure for changing sections, which must be defined separately for each project.
The alternating-step method and the three-step method are examples of section switching procedures.
Stator section switches should be planned at locations where jumps in the electrical angle of the long stator of >90° (1/2 phase spacing) can be expected. Exceptions can be defined for specific projects if the area concerned is substantially shorter than the length of the vehicle.
<u>Supply procedure</u>
The propulsion system must control the procedure for supplying current, which must be defined separately for each project.
Examples of supply procedures are single supply (supply of propulsion energy to a motor system from a substation) and double supply (simultaneous supply of propulsion energy to a motor system from two different substations).
<u>Design of the propulsion section</u>

The propulsion section must be designed as a system with insulated neutral point and earth-fault monitoring.
In an earthed network, earth currents would arise as a result of the jumps in potential from the converters. The IT system thus enables the propulsion section including the long stator to be checked for faults. A simple earth fault does not yet lead to a short circuit in the IT system.
The long stator winding wires must have screening and this is to be suitably earthed so that non-permissible voltages cannot be built up by the passing support magnets of the Maglev vehicle.
In functional terms, the screening arrangement is a cable screen but does not necessarily have to be a screen wire in the conventional sense, e.g. high-resistance conductive outer sheaths are also possible. When a vehicle passes by the support magnets create alternating magnetic fields that induce voltages in the screening. Thus non-permissible potentials can arise both inside the screening and against earths. In order to prevent this a quasi-continuous screen earthing is preferred, e.g. by contacting the screening in the stator grooves. Earthing of the screening is an essential prerequisite for the detection of earth faults in the long stator winding wires.

Behaviour in the event of failure

Brief interruptions of the supply network on the basis of /DIN EN 50160/ with a duration of <1s should not, as a general rule, lead to the interruption of a trip or to a timetable delay.

Safety requirements

The propulsion system and power supply section should not include any safety functions for operation in the sense of signal safety.
Failures or faulty behaviour of the propulsion that lead to violation of the minimum or maximum driving profile trigger a safe propulsion shutdown by the BLT. In addition to violation of the driving profile, the shutdown command for the propulsion system is also generated by multiple failure of some assemblies in the operational control system, e.g. in the event of radio failure.
Facilities for shutting down the propulsion system safely (SIAB) must be provided in the propulsion system and power supply section and these must prevent the flow of traction energy with adequate reliability.
The propulsion system must have protective devices that prevent non-permissible forces affecting the guideway and the Maglev vehicle. Corresponding protective thresholds are subject to project-specific definition.
In addition, the difference in tractive forces between the right and left stators must not exceed that given in /MSB AG GESAMTSYS/ chapter 9, no. 7.
Squirrel-cage windings (stator windings with neutral points at both ends for creating braking forces) must be designed to be sufficiently safe when they are taken into account in determining the safe braking profile.
The permissible failure probability for SIAB, protective devices and squirrel-cage windings is derived from a project-specific risk analysis, see chapters 5.4.1 and 6.1.3. of /MSB AG-GESAMTSYS/.

Regulation / Control

The propulsion system must be fully automatically regulated and controlled in accordance with the control commands and reference values of the BLT.

The BLT transmits to the propulsion system the location data that it needs to regulate and control it.
The requirements for the accuracy of the location and pole position data for the propulsion system are subject to project-specific definition.
A suitable configuration management system must be set up for all the regulation and control parameters and the software of the propulsion system.
The correct implementation of safety-relevant regulation and control parameters (protective thresholds) must be certified as part of the approval procedure.
These design parameters are used, e.g. in calculating the safety-relevant connecting guideways.
When assemblies are replaced the handover/acceptance procedure must apply to the whole of the regulation parameter set. There must be no need for individual regulation and control parameters to be set separately when assemblies are replaced.
The propulsion system must comply with the speed requirements of the BLT, taking accuracy of regulation into consideration.
The propulsion system moves the Maglev vehicle, keeping to the acceleration limits (see 0) set by the BLT and as rapidly as possible with the available power.
The accuracy of the regulation is subject to project-specific definition.
This accuracy affects the speeds, and therefore the trip times, that can be achieved.
The accuracy with which the propulsion system must control the target stop is subject to project-specific definition.
Stator section changes must comply with standard /ISO 2631/ relating to comfortable accelerations and jerking in the x direction.
For commissioning purposes a special operating mode must be provided in which the BLT and the propulsion system can be tested without moving a Maglev vehicle. In this case the simulated actual vehicle values must be transmitted to the BLT.
Project-specific data and software must be stored in such a way that if the supply voltage fails they are not lost and operation can recommence without local intervention on the resumption of power.

Requirements for the power supply

The power supply is used to provide electrical energy in accordance with the requirements of the Maglev sections. The requirements are substantially covered by the relevant electrotechnical standards (see /MSB AG-NORM&RILI/). In addition to these there are the Maglev-specific requirements set out in chapter 5.

The standards listed in chapter 4.4 must be observed.

Requirements for the propulsion system

Converters

Operation

The converters must convert the electrical energy from the given mains voltage and frequency into alternating current systems with continuously regulated voltage and frequency to supply the long stator windings.

The converters and section cables must be able to be connected together and disconnected from each other by means of switchgear.

Configuration

The converters must be designed for propulsion and braking by the motor for 4-quadrant operation. It must be possible to design the converters to supply current back to the mains.

Installation

The converters must be installed in closed electrical operating areas so that they are protected from unauthorised access.

Regulation / Control of the propulsion system

The functions of the propulsion regulation and control system are described in chapter 6.1.2 of /MSB AG-GESAMTSYS/. Some further details of requirements for the functions are given below.

Control of the propulsion system

The following input variable must be observed:

- Propulsion enable command from the BLT.

The following output variable must be provided:

- Status messages of fault classes (i.e. proportion of power still available out of total power) to the BLT with a high degree of reliability.

The following control function must be fulfilled:

- Automatic start-up and shut-down of the propulsion and power supply section.

Driving the vehicle

The propulsion system must drive a vehicle within a propulsion area according to instructions from the BLT.

The following input parameters (as per */MSB AG-GESAMTSYS/*) must be processed:

from the BLT:

- Target location,
- Preset speed profiles (upper and lower limits),
- Section data (to detect the position of track change equipment),
- Reference travel direction,
- Acceleration limits,
- Operating mode (see */MSB AG-GESAMTSYS/, Fig. 15),*

- Vehicle identification;

from the location detection in the Maglev vehicle, direct radio transmission:

- Vehicle location,
- Vehicle position signal,
- Vehicle identification.

The propulsion system must calculate the target braking curves $v_{soll}(x)$ to reach the prescribed target point according to /MSB AG-GESAMTSYS/ chapter 5.4.1.2.4.2 taking the maximum driving profile into account.
When calculating the target braking curves $v_{soll}(x)$ for the prescribed target point to /MSB AG-GESAMTSYS/ chapter 5.4.1.2.4.2, the currently available braking power of the propulsion system must be taken into account so that if the available propulsion power is lower than this the maximum driving profile is not violated and the safe brake does not have to be activated.
According to chapter 5.4.1.2.4.2 of /MSB AG-GESAMTSYS/ it is also possible for a project to have target points for which the two requirements for the propulsion system that are given above do not have to be met. These are target points of functional stopping places that are not required during operation but are used for technical purposes. These could include e.g. total failure in the location system, the data transmission system, the BLT or the propulsion system itself, i.e. cases where the propulsion system is usually shut down immediately on grounds of safety. These target points are then reached using the safe brake when needed.
Failures of the propulsion system that occur after target braking calculations are completed can lead to violation of the profile. For system behaviour in the event of profile violation see /MSB AG-GESAMTSYS/, *chapter 6.1.3.2*.
In addition the following functions must be provided:

- Standstill control (local control when setting down/lifting)
- Limitation of speed, acceleration and jerking in accordance with /MSB AG-GESAMTSYS/, chapter 9.

Section control

The section control must switch the supply and neutral point switches on and off at precisely the correct locations and must monitor feedback.
<u>Long stator protection</u>
Earth faults and interruptions must be recorded. The stator section concerned must be switched off. A short circuit in the windings must be prevented with a high degree of reliability by earth fault monitoring in the stator sections and the switching off of high earth fault currents, see chapter 5.4 of /MSB AG GESAMTSYS/.
As the cables of the long stator winding have an earthed screen or are earthed at the surface, an earth fault occurs before a short circuit. Because the network is not earthed, a second earth fault is already equivalent to a short circuit. Short circuits in the long stator winding can have repercussions on the levitation function of Maglev vehicles and cause the vehicle to be set down on one side in the vicinity of neutral points. Setting down on one side is a non-safety-relevant load case that is taken into account in the dimension design of the guideway and the vehicle.
If an earth fault is detected the earth fault current must be switched off by using a suitable switching device (supply switch or neutral point switch) to galvanically open the long stator winding at the supply or neutral point. Reconnection must be inhibited until the winding has been repaired.

Operation must be able to continue with propulsion on one side in the affected section. At this time the defective stator section must not connect to earth, as this would cause a short circuit in the winding.
Appropriate operating and maintenance regulations must be drawn up in respect of inhibition, earthing, repair and switching on again.
If it is not possible to detect all earth faults during operation, additional provision must be made for daily earth fault testing outside operation.
It must be possible to test the function of the earth fault detection. The checking intervals are subject to project-specific definition.
Protection of propulsion section
All installed parts of the propulsion section must be protected in accordance with the standards in force (see /MSB AG-NORM&RILI/). The fact that an IT system is present must be taken into account, particularly for earth fault recording.

Current regulation

Operation of the linear motor at either maximum efficiency or maximum thrust must be possible.
The stator current must normally be set in phase with the rotor voltage.
Reactive power control/current ripple (stator current in advance over rotor voltage) to maximise thrust in the event of voltage limitation must be possible.
If current ripple is used, the duration and magnitude of the current components working against the support magnet field of the Maglev vehicle is subject to project-specific definition in an interface specification with the vehicle section.
Converter and stator currents must be limited (to protect the installation) in accordance with the dynamic and thermal limits of the converter, section cables and stator winding.
The maximum thrust must be able to be limited by setting suitable current limits (see chapter 9 of /MSB AG GESAMTSYS/).
The substation output voltage must be limited to the permitted values in order to protect the installation.
Two converters must be able to provide a regulated supply to one motor system (double supply as per chapter 5.1).

Regulation / Control of the converter

The converter must be protected against overvoltage, overcurrent, overheating and earth fault (to protect the installation).
After the converter has been switched off because of a fault it must be possible for it to switch on again automatically once the cause of the fault has been eliminated or has disappeared.

Propulsion section

The energy must be transmitted from the substation to the long stator along the section cables and switching points.
The design of the equipment must take into account the Maglev-specific load that actually arises (variable frequency and amplitude, intermittent operation, harmonics).

Switching points

The switching points must make a remote-controlled switchable connection between the section cables and the stator sections.

A functional distinction must be made between supply switches and neutral point switches. It must be possible to integrate these spatially in a building if necessary.
The neutral point switches must also be switchable by remote control so that phase separation of the stator section is possible for checking for absence of earth faults and to enable operation to continue in the event of an earth fault.
The switch settings must be reported back.

Section cables

Section cables must be provided to transmit the traction energy from the substations to the switching points.
The particular requirements for laying the cables in the tunnel according to /MSB AG GESAMTSYS/, must be observed.
Error reporting
Earth faults and interruptions must be recorded. To expedite maintenance, the location of a fault must be able to be limited to a cable area between the two long stator supply points (switching points) closest to the location of the fault.
Behaviour in the event of failure
Reported faults must lead to the automatic switching off of cable supply in an outgoing switching station (switching station at the section cable terminal in the substation) and to the switching off of the switches in the switching points.

Long stator winding interface

The data given in chapter 6.1.2.3 of /MSB AG GESAMTSYS/ must be observed or defined specifically for the project.

Fixed-location pole position acquisition

For special layouts it must be possible to carry out fixed-location pole position acquisition (acquisition of the vehicle position in relation to the long stator winding) that enables acquisition of the relative vehicle position without reference to the location equipment in the vehicle itself. This must take into account the interface with the guideway section.
This equipment comes under the heading "Other extensions" in /MSB AG-FW/ Part 1.

Operation

Running of operation

Operation must be able to run fully automatically in accordance with /MSB AG-GESAMTSYS/.
The BLT must be able to power up (bring to a state of readiness) and power down (bring to a de-energized state) the propulsion system.
It must be possible to start up and shut down the energy supply by remote control.
The propulsion system must move the Maglev vehicle automatically according to the settings in the BLT.

Operating personnel

As the propulsion functions needed for operation run automatically according to the settings in the BLT, no operating personnel should be needed for the propulsion system and energy supply in normal operation.

Maintenance

Maintenance of the propulsion system and power supply section must be included in the maintenance of the complete system. A maintenance schedule within this framework must be drawn up.
Every assembly must be capable of separate replacement and inspection.

High-speed magnetic levitation railway
Design principles
Operational control systems

Distribution

The Operational Control Committee has released this document for publication.

Revisions

Date of release: 15.02.2007; White Paper, Operational Control Committee.

Contents

List of figures

General

Purpose and applications

This design principles specifies the characteristics of the operational control system for a high-speed Maglev system. Together with the other design principles and design specifications, these are the basic criteria for the design, planning and approval and implementation and operation of high-speed Maglev system projects.
This design principles applies to a high-speed Maglev system in accordance with the General Maglev System Act /AMbG/.

High-speed Maglev system design principles

This document is part of the documentation for high-speed magnetic levitation railways consisting of various design principles.
The overall design principles documents for the complete system and their appendices apply uniformly to all the documentation. They are:

- High-speed Maglev system design principles, complete system, Document no.: 50630, /MSB AG-GESAMTSYS/, with appendices:
    - Annex 1: Abbreviations and definitions, Document no.: 67536, /MSB AG-ABK&DEF/
    - Annex 2: Legislation, regulations, standards and directives, Document no.: 67539, /MSB AG-NORM&RILI/
    - Annex 3: Environmental constraints, Document no.: 67285, /MSB AG-UMWELT/
    - Annex 4: Operating rules (operation and maintenance), Document no.: 69061, /MSB AG-BTR&IH/
    - Annex 5: Noise, Document no.: 72963, /MSB AG-SCHALL/

Abbreviations and Definitions

The abbreviations and definitions supplied in /MSB AG-ABK&DEF/ should be used.
Definition of the BLT
The following definitions explain the specific meanings of the terms in the context of the BLT.

Operation	Operation is the sum of all the technical and non-technical means used for the preparation and performance of trips using the high-speed Maglev system that is approved for them.
Guideway (safety-related)	Uninterrupted and unbranched sequence of guideway sections that is temporarily formed for the control, monitoring and protection of trips. A safety-related guideway consists of at least one guideway section and always has one direction of travel.
Guideway section	From the purposes of the BLT, the physical guideway is divided into safety-related guideway sections along the guideway axis, without gaps or overlapping. The guideway section is the smallest unit for forming safety-related guideways.
Guideway element	A stationary device that is permanently assigned to a guideway

(safety-related)	section for the control, monitoring and protection of trips. Track changing equipment (points), platform doors and equipment that violates the structure gauge are all guideway elements.
Vehicle (safety-related)	Maglev vehicles and other vehicles equipped with BLT. Other vehicles without BLT are therefore not vehicles within the context of the BLT design principles.
Trips	A trip is a controlled, technically monitored and technically secured movement of a train between a departure point and a destination point. A trip begins when all the technical and operational requirements for travel are met. A trip ends according to plan when the destination is arrived at and the train is at a safe standstill.

Legislation, regulations, standards and directives

The prescriptive documents listed in /MSB AG-NORM&RILI/ contain definitions that are referred to in the high-speed Maglev system design principles and have become part of the high-speed Maglev system design principles. Where prescriptive documents in /MSB AG-NORM&RILI/ are dated, subsequent changes or revisions of these publications do not apply. Where references are undated, the latest edition of the prescriptive documents referred to is applicable.
The edition of the standards and guidelines to be adhered to in a Maglev project must be made binding for each specific project.

Identification and mandatory nature of requirements

The content of the present document is substantially based on the provisions of /DIN 820/ .
In the following chapters of this document, and in the appendices,

- Requirements are shown in standard type
- Explanations, guidelines and examples are shown in *italic.*

Requirements that are (must be) met by other sections are also shown in italic.
The degree to which the requirements are mandatory has been laid down on the basis of /DIN 820, Part 2, E and is reflected in the formulation of each requirement.

Overview of the operational control system

This overview describes the usual organisation of the "operational control system" in a track-guided railway system, as applied to the Transrapid type of high-speed Maglev system. Other structures or functional divisions are possible and are not intended to be excluded by this overview.

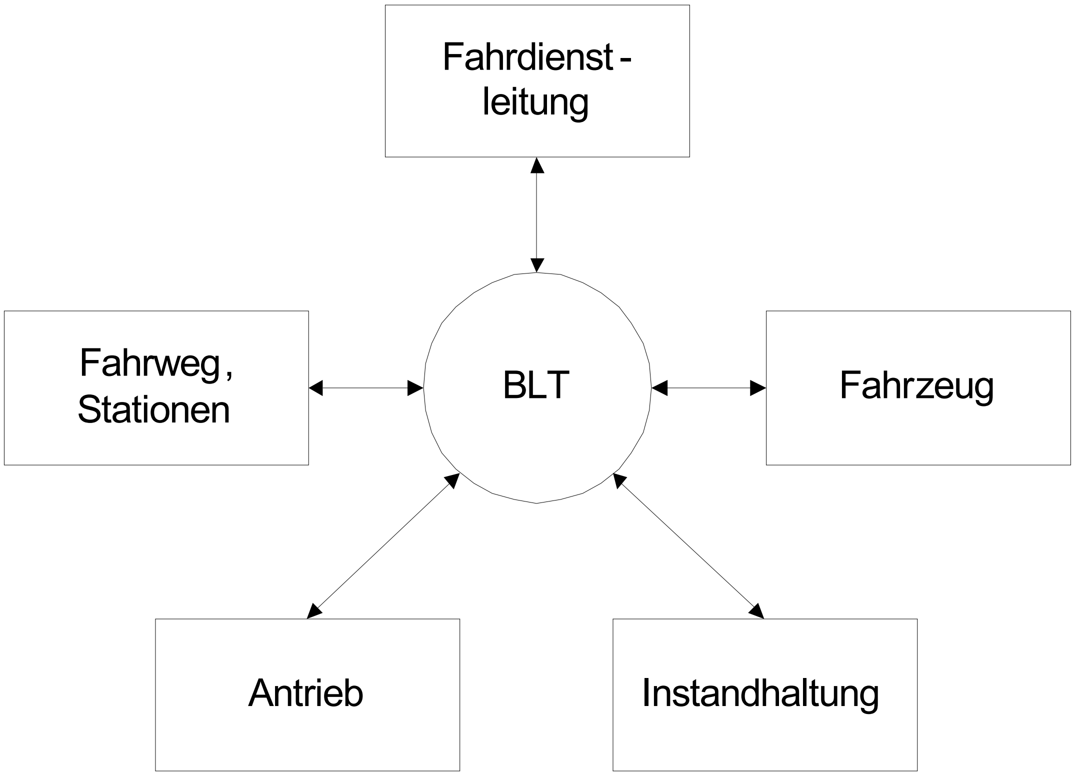


Figure 101: Organisation and interfaces of the operational control system

Fahrdienstleitung	Traffic controller
Fahrweg, Stationen	Guideway, stations
Fahrzeug	Vehicle
Antrieb	Propulsion system
Instandhaltung	Maintenance

The operational control system must include the components and functions for protecting, monitoring and controlling operation.

This design principles does not apply to the infrastructure control system, which includes:

- *Building control system, e.g. to control the lighting or ventilation of buildings, stations, tunnels etc.*
- *Engineering control rooms, e.g. for controlling and monitoring escalators or lifts*
- *Passenger information equipment*
- *Telecommunications equipment.*

The operational control system must connect the sections of the high-speed Maglev system to an overall system that is ready for operation.
The adjacent sections and operative levels of the BLT are:

- *Traffic superintendents*
- *Guideway and stations (including track change equipment and reference points for location)*
- *Vehicle (all technically protected vehicles)*
- *Propulsion system and power supply (substations with propulsion units)*
- *Maintenance.*

The BLT includes the ability to control train traffic in automatic operation in accordance with a prearranged timetable. The traffic superintendent must also be able to enter settings into the BLT manually.
The components of the operational control system can be mobile, e.g. security computer for a vehicle, or static, e.g. security computer for an area of guideway.
The fixed-location components can be further divided into central components of an operations centre and decentralized components.
The central components are divided into areas for operation and display, the timetable system and the diagnostic system and depending on the project these components can be brought together in a common operator interface.
It must be configured at the planning stage in accordance with the operator's specifications.

System requirements

The BLT must satisfy the requirements of /DIN EN 50126/, /DIN EN 50128/ and /DIN EN 50129/.
Characteristics of the safe state of the high-speed Maglev system are that every technically secured vehicle does not exceed a location-dependent speed under all foreseeable fault and emergency situations within a technically secured section with defined hazard rates and does not overrun a defined danger point and reaches a stopping place while levitating.
Characteristics of a fully technically secured system state are that the trips made are fully technically secured and that they are unsupervised.
The BLT must also enable release levels in addition to a fully technically secured system state.
An example of a release level can be an operating mode that requires the responsibility of personnel.
The following chapters describe the demands that this makes on the BLT.

Basic requirements

Operation must be controlled according to the requirements of an operating design that is to be drawn up specifically for the project concerned.
The traffic superintendent must be able to allow trip settings to be executed automatically.
The traffic superintendent must be able to input manual settings to control operation.
Supervised operational manoeuvres, *e.g. interventions by the traffic superintendent at safety level,* must be secured by operational and technical procedures.
The operational and technical procedures refer to operational regulations and technical process protection.
When the BLT is responsible for safety during operation it must not leave its safe system condition while personnel are performing control operations.
Operating errors by personnel in operations centres and trip personnel must have no effect on the operability of the BLT.
E.g. if the traffic superintendent enters a wrong input this must not cause the BLT system to crash. Operations that are not right for a given situation can have an adverse effect on operation. Supervised operations that do not comply with the rules can have an adverse effect on safety.
The reaction of the BLT to individual faults of a component must be error-tolerant but must not cause normal operation to stop.

Overview of functions

Figure 102 gives an overview of the most important operational control functions and data flows. BLT functions are shown in oval boxes and external components in rectangular boxes.

Figure 102: Overview of BLT functions and data flows

Fahrdienstleitung	Traffic controller
Meldungen, anzeigen	Messages, displays
Fahrtvorgaben	Trip settings
Fahrablaufsteurerung	Trip progress control
Fahrwegparameter	Guideway parameters
Fahrzeugparameter	Vehicle parameters
Fahrwegdaten	Guideway data
Fahrzeugdaten	Vehicle data
Fahrwegsicherung	Guideway protection

Fahrprofilüberwachung	Driving profile monitoring
Fahrzeugsicherung	Vehicle protection
Fahrzeugbewegung	Vehicle movement
Profilverletzung	Profile violation
Ortungsparameter	Location parameters
Lageinformationen, Meldungen	Position information, messages
Antriebsvorgaben	Propulsion system settings
Ort, Geschwindigkeit	Location, speed
Stellbefehle, Ausgaben	Actuator commands and output
Antriebsabschaltung	Propulsion system shutdown
Sichere Ortung	Safe location
Stellbefehle	Actuator commands
Eingaben	Inputs
Abschaltbefehl	Shutdown command
Ort, Geschwindigkeit	Location, speed
Fahrweg, Stationen	Guideway, stations
Antrieb	Propulsion system
Instandhaltung	Maintenance
Fahrzeug	Vehicle
Daten	Data
Datenübertragung	Data transmission

Functional requirements

According to /DIN EN 50126/ the operator is responsible for determining the safety requirements for the functions of the high-speed Maglev system in a risk analysis and assigning the results to the BLT functions.

Depending on the risks arising in the event or an operational failure, the functions of the BLT are divided into safety-relevant and non-safety relevant functions. The division must be done within the framework of the project-specific risk analysis that has been drawn up and the safety requirements for the various functions.

The safety-relevant functions of the BLT usually include vehicle protection, guideway protection, safe location, driving profile monitoring and safe shutdown of the propulsion system.

If safety-relevant functions fail, the safe system state must be maintained.

The probability of a function failing to the hazardous side must be made sufficiently low in accordance with the project-specific safety requirements that have been determined.

The safety-relevant functions must be implemented and certified in accordance with the corresponding specific safety requirements.

It must be possible to remove the safety-relevant functions of the BLT in a sequence of steps that build on each other.

Control of trip progress

Safe operation and display

The safety-relevant operations are supported by error-free status displays of the process during operation.
The status of mobile plant and equipment in guideway areas in which technically protected trips take place must be displayed by the safety and security system. This includes, for example:

- Track change equipment
- Platform doors

Areas (e.g. maintenance plant) in which fully protected trips do not take place can be project-specifically defined.
Sections of the guideway that are occupied by or reserved for a vehicle must be displayed by the safety and security system.
If the propulsion system is switched off this state must be displayed to the traffic superintendent.
For supervised operations, a safe procedure command input must be provided, e.g. to release locked sections of the guideway or for the use of vehicles.

Generation of trip settings

An operation schedule must be drawn up for each project and must contain the relevant data for automatic operation. The timetable settings will be derived from the operation schedule.
It must be possible to generate timetables automatically on the basis of timetable settings.
It must also be possible to draw timetables up manually.
Timetables must be available in a form that can be used as input data for automatic operation.
Timetables must be drawn up in such a way that an operation can be carried out as far as possible without stopping at operational stopping points.
The following data, for example, may be relevant in a timetable: Line number, trip number, destination, departure point and departure time.
It must be possible to generate trip settings for Maglev vehicles and the guideway automatically from the timetables.
It must also be possible to enter trip settings manually in the operations centre.
Alternatively, trip settings for the Maglev vehicle must be able to be entered manually in the vehicle.
These can be trip settings such as speed and direction of travel.
The BLT must be able to log actual trip details.
The logged trip details can be converted to timetables.
External interface:
Propulsion system settings must be transmitted to the propulsion system.
Propulsion trip settings include details of the reserved guideway, driving profile and limiting values for the trip.
It must be possible to generate and transmit other control data for the activation or deactivation of propulsion system functions, e.g. release commands and powering up or down, for specific projects.
Failure behaviour and the effect of failure
In the event of failure of the automatically generated trip settings, it must also be possible to enter manual trip settings in the operations centre.

If the automatically generated trip settings fail, the traffic superintendent may not be able to maintain operation according to the timetable, as all the trip settings will need to be entered by hand and this will be time-consuming.

Guideway setting

It must be possible for an operator to enter a changeover command for individual movable elements of the guideway.
It should be possible to set all the movable elements of the guideway for a predetermined combination of departure point and destination.
The implementation of guideway reservation requests and guideway settings from predetermined combinations of departure point and destination must take guideway safety requirements into account.
Failure behaviour and the effect of failure
If changeover commands for individual movable elements of the guideway are no longer possible the movable elements of the guideway can no longer be controlled remotely.
If changeover commands for individual movable elements of the guideway are no longer possible trips must still be able to take place on the guideway as it is set.
If the setting for a combination of departure point and destination is no longer possible, the guideway can no longer be set remotely.
If the setting for a combination of departure point and destination is no longer possible, it must still be possible to send changeover commands for individual movable elements of the guideway.

Generation and transmission of control data for the vehicle

Other control data for the activation or deactivation of vehicle system functions, e.g. air conditioning system, vehicle headlamps, internal lighting, can be generated and transmitted for specific projects.
Control data must be able to be generated automatically, depending on location or time.
It must also be possible to input control data manually.
It must be possible to transmit control data from the operations centre to the vehicle.
Failure behaviour and the effect of failure
Interruption during transmission of control data must not lead to malfunctions of the BLT.
A control data transmission failure must not lead to a direct safety reaction by the BLT.

Automatic operation

Automatic operation means that there is no need for any operations by personnel in order for a trip to take place. The traffic superintendent starts a defined program for trips and this is available as a timetable. The timetable will then run automatically.
The automatic control of trips is based on timetables that must be able to be stored in the BLT and then called up again.
The trip settings generated for the Maglev vehicles and the guideway from the timetables must run automatically without any manual operations.
This also includes, for example, triggering of the reservation of guideways, (chapter 0) and the setting of points (chapter)0).
The automatic control of trips must be independent of the technical protection system and free of reactions from it.

In automatic operation, the execution of trip settings must take into account the conditions of full technical protection.
In automatic operation only control operations, i.e. unsupervised operations, are permitted to be executed automatically.
In automatic operation it must be possible for the traffic superintendent to carry out manual operations.
Automatic mode must be designed in such a way that the Maglev vehicles depart on time in fault-free operation.
Deviations from the timetable, e.g. delays, must be automatically detected and displayed.
In the event of deviations from the timetable the planned schedule must be reinstated automatically.
This can be achieved, for example, by shortening standing times. The measures needed or permissible to achieve this are subject to project-specific definition.

Protection of the guideway

The guideway protection system must include all the guideways on which trips are to take place under the responsibility of technical safety.
These can be guideways in free sections, stations, stabling locations and maintenance locations.
Data on guideway protection must be prepared for the operations centre.
Guideway protection status messages are displayed in the operations centre.
Stationary equipment that violates the structure gauge must be included in the guideway protection system.
Stationary equipment within this definition may include shed doors and washing installations.
Project-specific exceptions are permissible for supervised trips.

Failure behaviour and the effect of failure

If the guideway protection system fails completely a forced stop at a stopping place must be executed.

Reservation of guideways

A guideway must be reserved so that a trip can take place.
Reservation of a guideway for a trip consists in setting the movable elements of the guideway, technically protecting the guideway to be travelled over without gaps and completely, and assigning this guideway exclusively to a vehicle.
Only the vehicle to which this reservation is assigned is allowed onto the reserved guideway.
Sections of reserved guideways must not be reserved for other trips.
This ensures that no other technically protected vehicle can enter a reserved guideway.
The BLT must ensure that a technically protected vehicle does not leave the guideway that has been reserved for it.
It must not be possible for track change equipment in reserved sections of guideway to be repositioned.
This applies to the repositioning of track change equipment either technically via the system or via manual intervention.

Occupation of guideways

The BLT must display a section of guideway as occupied and treat it as such when a technically protected vehicle is in this section.
A section of guideway must only be displayed and treated as no longer occupied when the technically protected vehicle has completely left it.

Sections of guideway that are occupied by a vehicle must only be included in a guideway reservation for this technically protected vehicle.
Control operations must not cause this occupation status to change.

Cancelling the reservation of guideways

After the technically protected vehicle has completely left a reserved section of guideway, reservation for this section must be automatically cancelled.
This requirement can be a project-specific condition for automatic operation.
In a climb where the kinetic energy of the vehicle is not sufficient for the next stopping place in the direction of travel to be reached, the guideway as far as the next stopping place behind the vehicle (including this stopping place) must remain reserved until the next stopping place in the direction of travel can be reached using the kinetic energy of the vehicle.
It must also be possible to cancel guideway reservations manually.
It should also be possible to use automatic trip settings to cancel guideway reservations (chapter 0).
Guideway reservations may be cancelled when there is no vehicle in the reserved guideway.
Guideway reservations may be cancelled when the vehicle in the reserved guideway is at a safe standstill.
Guideway reservations may be cancelled if this reserved guideway is not needed to reach a stopping point.

Blocking of guideways

It must be possible to block guideway sections manually.
Guideway reservations over blocked sections must only be done with supervision.
It must not be possible to block a guideway in a reserved guideway section.
This is to avoid, e.g. a blocked guideway causing a vehicle to stop outside a stopping place.
Failure behaviour and the effect of failure
After the failure and restoration of the guideway protection system the guideway blocking should be restored automatically.
This automatic restoration can be a project-specific requirement, depending on the risk analysis or the complexity of the installation.
If the guideway blocking is not automatically restored after a failure of the guideway protection system, the traffic superintendent must be shown that supervised restoration of guideway blockings is needed.

Release of guideway blocks

Manual guideway blocks must be released under supervision.
Manually blocked guideway sections must only be released one at a time.

Protection of track switching equipment

In general, a distinction is made between track switching equipment that does not require interruption of the trip (points) and track switching equipment that may require the trip to be interrupted (slewing platforms and sliding platforms).
A track switching device in a secured end position must have reached an end position, be locked and protected against readjustment.
The track switching equipment must only be included in guideway reservations when it is in its secured end position.

Vehicles must only be allowed to run over the track switching equipment when it is in its secured end position.
It must not be possible to readjust a track switching device in a reserved guideway section.
It must not be possible to readjust switching points when they have a vehicle on them.
Adjustment of a sliding or slewing platform with a vehicle on it is only permissible when the whole of the vehicle is on the sliding or slewing platform and is at a safe standstill.
It must be possible to issue a manual release to the local track switching equipment operator.
Release of local manual operation must only be possible when the track switching equipment is not included in a guideway reservation.
After release of local manual operation the track switching equipment must not be included in a guideway reservation.
It must be possible to lock track switching equipment manually to prevent readjustment.
Track switching equipment that has been locked to prevent readjustment must only be released under supervision.

Failure behaviour and the effect of failure

Failure of the protection function must not lead to release of the adjustment process.
The design of the track switching equipment must ensure that it is not possible for it to leave the secured end position by itself unless it has been released via the protection equipment.
If a safe end position has been reached after an adjustment process and no further release for adjustment has been issued, it should be possible to run vehicles over the track switching device even after failure of the end position feedback or the protection equipment.
After the safe end position has been reached the track switching equipment must remain in this position independently of failures of the control, monitoring or power supply systems.
If track switching devices are blocked to prevent readjustment, it should be possible to restore the block automatically after the failure and restoration of the track change switching device protection.
This automatic restoration can be a project-specific requirement, depending on the risk analysis or the complexity of the installation.
If this blocking is not automatically restored after a failure of the protection system, the traffic superintendent must be shown that supervised restoration of the blocking is needed.

Protection of the platform door system

Platform doors in a secured end position must be closed, locked and protected against opening.
Vehicles must only be allowed to run into a guideway section with platform doors when all the doors are in the secured end position.
The operational control system must only release platform doors for opening when the Maglev vehicle is opposite the platform doors and safely stopped.
A platform door must only be allowed to open automatically when the platform door is opposite a vehicle door and the gap between the two doors is as small as possible.
Vehicles must only be allowed to levitate and depart when all the platform doors are in the secured end position.
Project-specific local operation of platform doors may be provided for door and/or station maintenance purposes.
If local operation of platform doors is provided in a specific project, it must be possible for the local operation of platform doors to be enabled manually.
Release of local manual operation must only be possible when the guideway with the platform doors is not included in a guideway reservation.

After release of local manual operation the guideway with the platform doors must not be included in a guideway reservation.
Where other entrances or exits are provided in addition to the platform doors, project-specific requirements may be defined, e.g. depending on the risk analysis.
Failure behaviour and the effect of failure
Failure of the protection function must not lead to release of the opening process.
The design of the platform doors ensures that it is not possible for them to leave the secured end position independently unless they has been released via the protection equipment.
The BLT must show an alert in the event of failure of the safe end position report.
If the safe end position report for a platform door fails to arrive, a project-specific engineering reaction must take place. This can take the operating situation into account, e.g. arrival, departure or stop.
Local manual locking of platform doors with defective control or feedback must be possible (with supervision, apart from the BLT).
This will bypass the control and monitoring functions for the door concerned.

Vehicle protection systems

Vehicle protection systems must monitor and control the safety-relevant functions and conditions of Maglev vehicles that are described below.
They must therefore handle e.g. levitation, setting down, monitoring on-board energy and control of the safe brake via the vehicle control system.
It may be necessary to have a project-specific subset of these functions and conditions for other technically protected vehicles.

Monitoring the redundancy of safety-relevant vehicle functions

The vehicle section reports to the BLT that no failures or losses of redundancy of safety-relevant vehicle functions such as levitation/guidance, safe brake and on-board energy supply are present.
The BLT must continuously monitor the reports from the vehicle section concerning the failure-free state and complete redundancy of the safety-relevant vehicle functions.
The safety-relevant vehicle functions themselves are checked by the vehicle section without being initiated by the BLT.
The BLT must trigger a safety-related reaction if the report is cancelled.
The safety-related reaction should be in stages and run one step at a time.
A possible sequence for the multi-stage safety-related reaction is given below.

1. *Forced stop at a service station (continued trip via operational stopping places and stations)*
2. *Inhibition (continued trip via operational stopping places)*
3. *Forced stop at the current stopping place (trip not continued)####*

The stages and sequence of the safety-related reaction by the BLT are subject to project-specific definition.
The actual sequences and times must be defined at the interface between the BLT and the vehicle section.
Failure behaviour and the effect of failure
If the failure or loss of redundancy is reported on powering up the vehicle, the BLT must react immediately by inhibiting the Maglev vehicle concerned.
The most severe consequence of a complete loss of redundancy monitoring of vehicle functions is a forced stop at the current stopping place.

Control and supervision of brake testing

The following requirements only apply if the technically protected vehicles are fitted with an active safe braking system, e.g. eddy current braking circuits.
The BLT must monitor that functional testing of defined components of the safe braking system is initiated at fixed intervals (brake test).
The BLT must ensure that the brakes are not tested during a trip.
The BLT must ensure that the brakes are tested between powering up the vehicle and the end of the failure disclosure time.
If the brake check is not initiated between powering up the vehicle and the end of the failure disclosure time a safety-related reaction must be started.
The safety-related reaction should be executed in stages before the end of the failure disclosure time.
The BLT must ensure that the vehicle only levitates and departs after the brakes have been tested and confirmed OK.
It must be possible to initiate the brake check manually.
This is necessary, for example, after maintenance work on the safe brake components.
It should also be possible to initiate the brake check automatically from the timetable.
To maintain operational availability the brake test should be performed in due time before the expiry of the failure disclosure time.

Control and supervision of the on-board energy supply

Charge status of the on-board energy supply
The vehicle section must send a report to the BLT that the charge needed to complete a trip, including a stop with the safe brake, is guaranteed.
The BLT must monitor the reported charging status of the on-board energy supply of the Maglev vehicle.
This ensures that safety-relevant functions such as levitation and the safe brake can be executed according to specification.
The BLT must trigger a safety-related reaction if the report is cancelled.
Depending on the design of the on-board energy supply, a project-specific definition is required to state whether this safety-related reaction should be a forced stop or an immediate stop.
The BLT must ensure that the vehicle does not levitate and depart if the brakes have not been confirmed OK.
Loss of redundancy in the on-board energy supply
If the on-board energy supply loses redundancy the vehicle section sends a report to the BLT.
The BLT must monitor the reported redundancy status of the on-board energy supply of the Maglev vehicle.
The on-board energy supply must guarantee the levitation and safe braking of a vehicle after departure and as far as the next stop.
The BLT must report loss of redundancy to ensure that a stopped vehicle does not levitate and depart.

External on-board energy supply
Depending on the specific project, components of the Maglev vehicle for the external on-board energy supply must be included in the control and monitoring done by the BLT.
Where current collectors are used, a safety-relevant enable signal, for example, must be produced for the current collectors.
Failure behaviour and the effect of failure
In the event of loss of the control and monitoring functions of the on-board energy supply, or the loss of parts of these functions, the BLT must react when the Maglev vehicle is set down by inhibiting the vehicle concerned.
Loss of the control and monitoring functions of the on-board energy supply, or loss of parts of these functions during operation must lead to a forced stop at the current stopping place.
The on-board energy supply must guarantee the levitation and safe braking of a vehicle after departure and as far as the next stop.

Control and supervision of safe braking

The vehicle must be fitted with a safe brake. This enables it to be stopped safely in the event of propulsion system faults or certain BLT faults.
The safe brake must be controlled and monitored by the BLT.
Whenever the vehicle comes to a forced stop with the safe brake, the propulsion system must be switched off before the braking command is issued.
Depending on the location, it must be possible for the safe brake and the propulsion system to be effective simultaneously under exceptional circumstances.
The locations concerned are subject to project-specific definition.
These exceptional circumstances are allowed, if for example the guideway loads, vehicle loads and prescribed acceleration values are not exceeded.
The vehicle section monitors the brake circuits of the Maglev vehicle and transmits a report to the BLT that sufficient operation of the brake circuits is guaranteed.
The BLT must trigger a forced stop at the next service station if this report is cancelled.
Failure behaviour and the effect of failure
If the "Control and supervision of safe braking" function fails, maximum control of the safe brake must be used.
This leads to an uncontrolled stop of the vehicle without approaching a stopping place.
In the event of the complete failure of the location system or certain combinations of failures (multiple failures) of the BLT hardware maximum control of the safe brake is used and this can lead to a momentary superimposition of the traction or braking forces of the propulsion system and the safe brake.
The probability of occurrence and the maximum duration of superimposition of the braking forces of the propulsion system and the safe brake are subject to project-specific definition.
This superimposition must be regarded as a special load when designing the guideway and the vehicle, depending on the probability of its occurrence and the maximum duration.
Failures of redundancy must not cause untimely switching on or off of the safe brake.

Protection of the outer doors of the vehicle

Vehicle outer doors in a secured end position must be closed, locked and protected against opening.
Vehicles must only be allowed to levitate and depart when all the vehicle doors are in the secured end position.

The operational control system must only release vehicle doors for opening when the Maglev vehicle is safely stopped.
This door release must only be triggered at designed locations for the sides that are permitted there.
The door release must be able to be triggered automatically or manually by the traffic superintendent.
The safe end position status of the outer vehicle doors must be transmitted to the operations centre.
Failure behaviour and the effect of failure
Failure of the protection function for outer vehicle doors must lead to the BLT assuming that the doors are not locked and the BLT must react by inhibiting the Maglev vehicle concerned.
Failure of the protection function must not lead to release of the opening process.
The design of the vehicle outer doors ensures that it is not possible for them to leave the secured end position independently unless they has been released via the protection equipment.
The BLT must show an alert in the event of failure of the safe end position report.
If the safe end position report for a vehicle outer door fails to arrive, a project-specific engineering reaction must take place. This can take the operating situation into account, e.g. moving or stopped.
Manual local locking of doors with defective control or feedback must be possible (with supervision, apart from the BLT).
This will bypass the control and monitoring functions for the door concerned.

Control and supervision of levitation

The levitation control and monitoring function is the operational control part of the levitation function.
The BLT must control and monitor the levitation and setting down of the Maglev vehicle.
The BLT must ensure that the release for levitation of the Maglev vehicle can only be issued if all the safety-related requirements for travel are met and the departure order has been given.
The safety-related requirements for travel include, e.g. locking of the outer doors of the vehicle. Other project-specific safety-related requirements can be defined.
The BLT must ensure that the release for levitation of the Maglev vehicle can only be cancelled if all the safety-related requirements for setting down are met.
The safety-related requirements for setting down include, e.g. that the vehicle speed is lower than a setting-down speed that has been defined for the BLT. Other project-specific safety-related requirements for setting down can be defined.
Control-related requirements should also be met before the release for levitation can be cancelled.
The control-related requirements for setting down include e.g. a report from the propulsion system that the trip is completed.
After the release has been given for levitation of the Maglev vehicle by the BLT, the vehicle's levitation function must continue to be monitored until the next time it is set down.
So long as the BLT receives reports that the vehicle function levitation can no longer be maintained, the BLT must initiate a forced stop at the next service station. If no stopping place identified as a service station is reached within a time subject to project-specific definition, a forced stop must be automatically initiated.
This requires that until the forced stop at a service station is completed the vehicle levitation function is maintained.
Maglev vehicles must be set down while passengers board and leave the train.
Failure behaviour and the effect of failure

Complete loss of the levitation control function must lead to cancellation of the levitation release command.
Setting the vehicle down must then be the responsibility of the vehicle levitation function.

Forced stop

Forced stops are automatically generated by the BLT functions.
It must be possible to trigger forced stops manually.
It must be possible for personnel in the operations centre and in the Maglev vehicle to trigger a manual forced stop.
Specific projects may specify manual forced stops at other places, e.g. stations.
Manual forced stops can be executed as a forced stop at the current stopping place or as an immediate stop.
Automatic forced stops can be executed as a forced stop at a service station or a forced stop at the current stopping place or as an immediate stop.
The forced stop at the current stopping place can also be executed as a reversible forced stop.
Project-specific definition is required as to whether after cancellation of a manual forced stop, while the Maglev vehicle is at a standstill, it is permitted for it to start again immediately or whether this must be initiated by restating the trip settings.
Failure behaviour and the effect of failure
Faults in the forced stop function must lead to a safety-related reaction.

Monitoring of the driving profile

The BLT must monitor the vehicle speed, which must be within a permitted speed range.
The permitted speed range is between the maximum driving profile corresponding to the locally permissible maximum speed and the minimum driving profile corresponding to the local minimum speed for reaching the current stopping place.
The BLT must calculate the permitted speed range taking into consideration the current operating situation, e.g. from the position of points and low speed areas.

Monitoring of the maximum driving profile

The BLT must ensure that hazard points are not exceeded and the driving profile limit is observed.
Every hazard point must therefore have a local maximum driving profile defined for it in the BLT.
To determine the maximum driving profile, the BLT must take into account relevant system parameters such as reaction times, the safe brake characteristic and the route.
If the maximum driving profile is violated the propulsion system must be safely shut down and a reversible forced stop to the current stopping place using the safe brake must be triggered.
The forced braking may only be cancelled when the maximum driving profile is no longer exceeded.
Failure behaviour and the effect of failure
Faults in the maximum driving profile monitoring system must lead to a forced stop.
If the maximum driving profile monitoring system fails completely an immediate stop must be executed.

Monitoring of the minimum driving profile

The BLT must ensure that the Maglev vehicle can also reach the current stopping place without the propulsion system.
Every stopping place must therefore have a local minimum driving profile defined for it in the BLT.

To determine the minimum driving profile, the BLT must take into account relevant system parameters such as the safe levitation profile, reaction times and the route.
If the minimum profile is violated the BLT must actuate a safe shutdown of the propulsion system braking forces.
The safe brake can be used to stop the Maglev vehicle when it arrives at the stopping place.
The BLT must ensure that the Maglev vehicle is set down when the stopping place is reached.
The propulsion system shutdown command may only be cancelled when the minimum driving profile is reached again.
After starting out from a station it is not immediately possible to monitor the minimum driving profile. Project-specific provision should be made for evacuation facilities and an external on-board energy supply to cover the starting out areas in operational use.
The minimum driving profile monitoring system must be automatically activated when the minimum driving profile of the stopping place following the starting out area is exceeded.
It must be possible to switch off the monitoring of the minimum driving profile manually.
It is necessary to switch monitoring of the minimum driving profile off if, for example, travel at less than the minimum speed is necessary for operational reasons.

Safe propulsion system shutdown

The propulsion system in the high-speed Maglev system converts both traction energy and braking energy.
The propulsion system and power supply section must be equipped with devices for shutting down the propulsion system safely so that the flows of both traction energy and braking energy can be safely stopped.
The BLT must trigger the safe shutdown of the propulsion energy flow:

- If the maximum or minimum driving profile (chapter 0) is violated
- Before a forced braking manoeuvre with the safe brake (chapter 0)
- If the transmission of safety data (chapter 0) fails
- In the event of an immediate stop.

Depending on the reason for the shutdown, the propulsion energy in the section to be switched off must be reliably switched off within a defined time after the reason for switching off has arisen.
If there is a reason to switch off and a Maglev vehicle

- is in more than one propulsion area, e.g. during a change of propulsion, or
- is in a propulsion area that more than one converter can supply,

it must be ensured that no converter can supply current in these areas.
The safe shutdown of the propulsion system can be reversible or non-reversible.
If the propulsion system shutdown is reversible and the reason for shutting down is no longer present, the BLT must automatically re-enable the propulsion system.
Reasons for switching off reversible propulsion system shutdowns include forced braking when the driving profile is violated and the temporary failure of the transmission of safety data.
The BLT must not automatically re-enable the propulsion system after irreversible propulsion system shutdowns.
The propulsion system shuts down irreversibly on an immediate stop, e.g. after a complete failure of the safe location function (chapter **Error! Reference source not found.***) or the complete failure of maximum driving profile monitoring)chapter 0)*

After irreversible propulsion system shutdowns the traffic superintendent must re-enable the propulsion system manually.

Failure behaviour and the effect of failure

If the safe propulsion system shutdown fails completely the shutdown of the propulsion energy flow must be actuated.

How this is to be done must be defined at the interface between the BLT and the propulsion system.

If the safe propulsion system shutdown function fails completely during the braking procedure of the propulsion system, the vehicle may possibly stop before the current stopping place but within the reserved section.

Safe location

In accordance with /MSB AG-GESAMTSYS/ safe location consists of the safe location components of the BLT and their interfaces with the control-relevant localization and BLT functions.

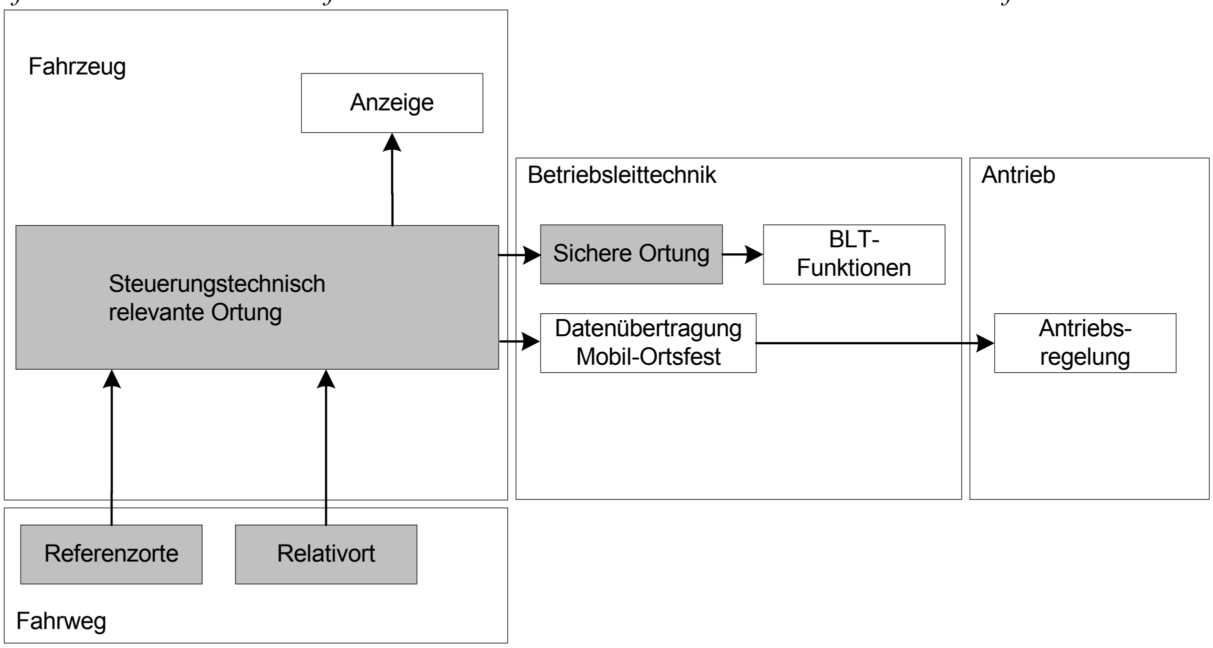


Figure 103: Structure of the location system

Fahrzeug	Vehicle
Anzeige	Display
Betriebsleittechnik	Operational control system (BLT)
Antrieb	Propulsion system
Sichere Ortung	Safe location
BLT-functionen	BLT functions
Steuerungstechnisch relevante Ortung	Location that is relevant to the controls
Datenübertragung Mobil-Ortsfest	Transmission of data between mobile and fixed locations
Antriebsregelung	Regulation of propulsion system
Referenzorte	Reference locations
Relativort	Relative location

Fahrweg	Guideway

In order for a trip to take place under complete technical protection the location, speed and direction of travel of every vehicle must be known to the safety-related BLT at all times (safe location).
The safe location includes the availability of reliable data on location, speed and direction of travel.
After a setting trip has been successfully completed the data on location, speed and direction of travel is deemed to be reliable.
The location data supplied from the control-relevant location equipment is checked by the BLT, e.g. by plausibility checking, mirroring against preset data and comparison with the individual items of location data.
Certain malfunctions, e.g. detection of direction of travel, can only be detected during travel.
After the Maglev vehicle has been equipped, after a failure of the safe location function or when the standstill time has exceeded the failure reporting time, a setting journey must be undertaken.
The permissible tolerances for location data must be defined on the basis of the specific properties of the location procedure selected and the project-specific extensions.
The permissible tolerances for vehicle speed must be defined on the basis of the specific properties of the location procedure selected and the project-specific extensions.
The permissible tolerances for detection of the direction of travel must be defined on the basis of the specific properties of the location procedure selected and the project-specific extensions.
The tolerances of every location procedure have physical limits. These depend on the structure and the selected location procedure. The tolerances affect the system layout and other system functions, e.g. stopping accuracy. The requirements for them are taken into account when selecting the location procedure.
If the safe location system fails completely the existing guideway reservation for this vehicle must be maintained.
A guideway reservation for this vehicle may only be cancelled after a complete failure of the safe location function when a safe location for this vehicle is known once again.
A safe location can also become known if it is reported under supervision and entered by means of a supervised operation.
Failure behaviour and the effect of failure
Loss of redundancy in the safe location function or its sections must lead, at its most severe, to a forced stop.
If the safe location system fails completely the BLT must execute an immediate stop.

Data transmission

Data transmission between the components of the BLT is identified by the volume of data, repetition rate, availability, bit error rate and the division into safety-relevant and non-safety-relevant transmission.
Data transmission takes place

- *between fixed and fixed, and*
- *between fixed and mobile*

components of the BLT.
The requirements for data transmission are subject to project-specific definition.
Project-specific definitions include the number of vehicles to be looked after at any one time.

Transmission of safety data

Suitable transmission procedures for safety-relevant communication in closed or open transmission systems must be laid down on the basis of the requirements for the transmission of safety-relevant data.
Project-specific definitions are required for every data transmission, whether the system is an open one or a closed one as described in /DIN EN 50159/.
This definition will give rise to various different requirements for the safety measures implemented in the transmission system.
When safety-relevant data is being transmitted corrupted data (mutilated sender identity, type error, mutilated value) and time errors (data delay too long, sequence errors) must be reliably detected. This is the minimum requirement.
Where safety-relevant data and non-safety-relevant data are transmitted together, the absence of interaction with the safety-relevant data must be guaranteed.
Since the transmission of safety-relevant data has precedence, there may be restrictions on the transmission of non-safety-relevant data.
The unsecured data transmission of the BLT should be open for use by other sections.
Project-specific use can be made of the BLT transmission function, e.g. to transmit passenger information data and communication data between the operations centre and the Maglev vehicle.
Since the transmission of data to and from the BLT components that is necessary for operation has precedence, there may restrictions on use by other sections.
Failure behaviour and the effect of failure
In the event of failure of the fixed-mobile transmission of safety-relevant data while the vehicle is moving a safe propulsion shutdown must take place.
If, additionally, a profile violation occurs, a reversible forced braking procedure to the current stopping place must take place as described in chapter 0.

Transmission of propulsion system data

The data transmission system of the BLT should be able to transmit data from the control-relevant location equipment to the propulsion regulation system.
Failure behaviour and the effect of failure
A failure of transmission from the control-relevant location equipment to the propulsion regulation system must not lead to a direct safety reaction by the BLT.
This can have an adverse effect on control of the destination stop accuracy of the propulsion system

Transmission of diagnostic data

The data transmission system of the BLT should be able to transmit diagnostic data from the fixed and mobile sections to central diagnostic equipment.
The requirements for diagnostic data transmission are subject to project-specific definition.
Failure behaviour and the effect of failure
A diagnostic data transmission failure must not lead to a direct safety reaction by the BLT.

Transmission of a passenger emergency call

Every Maglev vehicle is fitted with passenger emergency call equipment.
A passenger emergency call that is actuated in the Maglev vehicle must be reported in the operations centre.
The report must show which vehicle the passenger emergency call comes from.

The BLT function is only to transmit the emergency call.
In addition to the passenger emergency call, a two-way intercom connection must be provided between the person actuating the emergency call and the personnel in the operations centre who are responsible for such calls.
This two-way intercom connection must be useable at the same time as, and independently of, the operational speech transmissions (chapter 0).
Failure behaviour and the effect of failure
The reaction of the BLT to a failure of the passenger emergency call function must be subject to project-specific provisions.
A failure of fixed-mobile data transmission by the operational control system also leads to failure of the passenger emergency call function.

Transmission of a fire alarm

Every Maglev vehicle is fitted with an automatic fire alarm.
A fire alarm that is set off in the vehicle must be reported in the operations centre.
The report must show which vehicle the fire alarm comes from.
Whether section-specific fire alarms are needed can be determined on a project-specific basis.
Failure behaviour and the effect of failure
The reaction of the BLT to a failure of the fire alarm function must be subject to project-specific provisions.
A failure of fixed-mobile data transmission by the operational control system also leads to failure of the fire alarm function.

Operational speech transmission

Every Maglev vehicle is equipped with two-way speech transmission between the vehicle and the operations centre.
This can be used for communication with the driver during maintenance trips or when the Maglev system is being commissioned.
This operational speech transmission must be useable at the same time as, and independently of, the two-way intercom connection of the passenger emergency call (chapter 0).
The quality of the speech transmission must be adequate for operational purposes, e.g. speech must be comprehensible over background noise.
Failure behaviour and the effect of failure
Failure of the operational speech transmission system must not affect the operations of the BLT.
A failure of fixed-mobile data transmission by the operational control system also leads to failure of the operational speech transmission function.
If the speech connection fails the trip personnel and operations centre personnel can communicate over a diversity commercial radio system.

Environmental requirements

The environmental conditions and their limiting values are laid down in Annex 3 /MSB AG-UMWELT/ of the design principles documents.
The BLT must be able to operate within the limits given in /MSB AG-UMWELT/.

BLT diagnostics

Failures of BLT components must be reported and displayed in the operations centre.
This also applies to the failure of redundant functional units and communications channels, even when availability is still unrestricted.
The diagnostic system must enable failed units to be located, provided that they supply the required information.
If failures of components that are not part of the BLT are detected, the diagnostic system should report these to the BLT.
Whether diagnostic messages are displayed to the traffic superintendent or on the central diagnostic device is subject to project-specific definition.

Reporting of failures to interfaces with other subsystems

It may be worthwhile in certain projects to treat the failure of equipment in other subsystems partly or fully with operational control system resources if a suitable interface is available.
For every interface between the operational control system and another device, there must be a definition of the part played by the operational control system in reporting failure of the other device.
In accordance with the basic principle that functions that are not responsible for safety must be separated from those that are, failure reporting from a different device must only be reported to the operational control system in justified individual cases.
When the operational control system reports the failure of other equipment a definition is required as to whether the failure report

- is relevant to availability or
- is relevant to safety.

If the report of the failure of other equipment is relevant to safety, the anticipated failure rate of the other equipment at the interface and a maximum failure reporting time must be defined for the project.
Once the anticipated failure rate and maximum failure reporting time have been allocated, it should be possible for the operational control centre and the other equipment to check their safety status virtually independently.
The other subsystem must guarantee compliance with the maximum failure reporting time. This can be done, for instance, by performing automatic self-tests or operational settings or certifications that guarantee the regular stressing of the other equipment, e.g. the end position sensors of a track switching device.

Operation

Operating modes of the BLT

Operating modes are defined and unambiguously delimited types of operation that differ in their technical and non-technical measures for the running of trips.
The BLT must have provision for the following operating modes for Maglev vehicles:

- **Normal operation**
- **Deviations from normal operation**

Areas that are not protected by BLT equipment and in which vehicle movements are executed exclusively by personnel are exceptions.
The BLT must have provision for operating modes for special vehicles.
The operating modes for special vehicles are subject to project-specific definition.

"Normal operation" mode

Normal operation must be fully protected by the BLT.
In normal operation, it must be possible for the necessary trip settings for the guideway to be done either automatically or manually by the traffic superintendent.
In normal operation, it must be possible for the necessary trip settings for the vehicle to be done automatically or manually by the traffic superintendent or by operating equipment in the vehicle.

"Deviations from normal operation" mode

In the "Deviations from normal operation" mode, the guideway is fully technically protected and the BLT functions of controlling starting up, protecting the guideway, monitoring the driving profile, shutting down the propulsion system and safe location are unaffected. The safety-relevant status signals from the vehicle (monitored by the vehicle protection function of the BLT) are not fully monitored. This operating mode may be needed, e.g. for transportation to a maintenance installation. Responsibility for the vehicle equipment and for selection of this operating mode and the trip settings is borne by the operating or maintenance personnel in accordance with the regulations that are to be drawn up.
In "Deviations from normal" operation, it must be possible for the necessary trip settings for the guideway to be done either automatically or manually by the traffic superintendent.
In "Deviations from normal" operation, it must be possible for the necessary trip settings for the vehicle to be done either manually by the traffic superintendent or by operating equipment in the vehicle.
In "Deviations from normal" operation, the operational control system must ignore the (project-specific definitions of) impediments that prevent a vehicle in fully technically protected operation from running and as far as necessary, suitable (project-specifically defined) safety measures must be taken.
In "Deviations from normal" operation the BLT must ignore, e.g. a missing vehicle doors secured message.
Special rules for maintenance areas are subject to project-specific definition.

Maglev vehicle maintenance

The BLT must have a maintenance mode for the Maglev vehicle.

In the maintenance mode, technical protection is not complete. Responsibility for the vehicle equipment and for selection of maintenance mode and the trip settings is borne by the operating or maintenance personnel in accordance with the regulations that are to be drawn up.

While in "Maintenance mode" the BLT must maintain a safe shutdown of the propulsion system. It must be possible for the Maglev vehicle to levitate while maintenance mode is active in spite of any inhibition.

High-speed Maglev system design principles

Guideway
Part I
Overriding requirements

Distributor:

The Guideway Technical Committee has released this document for publication.

Revisions:

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Contents

General

Purpose and application

This "Design principles, guideway, Part I - overriding requirements" document contains the general project-independent requirements for the subsystem "Guideway" and describes its interfaces with the other high-speed Maglev system subsystems on the basis of the principles of design and construction complete system /MSB AG-GESAMTSYS/.

These design principles apply to a high-speed Maglev system in accordance with the *Allgemeinem Magnetschwebebahngesetz* /AMbG/ (General Maglev System Act).

The general system-related requirements of the guideway are predominantly based on research carried out on previously tested guideway construction types. In the case of new construction types, total adherence to these requirements must be proven or requirements compatible with the complete system must be determined in agreement with the local supervisory authority.

Part I of the high-speed Maglev system, design principles, guideway covers:

- Functional requirements;
- Design requirements;
- Verification procedure requirements;
- Operations, transport and assembly requirements;
- Quality assurance and documentation requirements.

The guideway must be constructed in accordance with the MbBO Maglev System Construction and Operating Regulations (for use in Germany) and other relevant regulations, in such a manner that it fulfils safety and regulation requirements. The guideway must conform to the MbBO regulations to fulfil the requirements or, in so far as these do not contain any applicable regulations, the relevant transferable generally accepted technical rules and standards (see § 3 paragraph (1) of the MbBO).

Furthermore it must fulfil the system-specific functional requirements as described in the high-speed Maglev system principles of design and construction guideway.

Any deviations from the requirements of the principles of design and construction guideway require verification of compatibility with the complete system and the approval of the responsible inspectorate.

High-speed Maglev system design principles

This document is part of the documentation for high-speed Maglev systems consisting of several design principles documents. The document tree is shown on figure 1 /MSB AG-GESAMTSYS/.

The overriding design principles, complete system and its annexes apply to the entire documentation:

- High-speed Maglev system design principles, doc. no.: 50630, /MSB AG-GESAMTSYS/, with its annexes:
  - Annex 1: Abbreviations and definitions, doc. no.: 67536, /MSB AG-ABK&DEF/
  - Annex 2: Laws, regulations, standards, and guidelines doc. no.: 67539, /MSB AG-NORM&RILI/

- Annex 3: Environmental factors, doc. no: 67285, /MSB AG-UMWELT/
- Annex 4: Rules of operation (vehicle operation and maintenance) doc. no.: 69061, /MSB AG-BTR&IH/
- Annex 5: Noise, doc.no.: 72963, /MSB AG-SCHALL/

As well as the subordinate, applicable documents:

- High-speed Maglev system design principles, part I: General requirements, doc. no: 67698, /MSB AG-FZ GEN/
- High-speed Maglev system design principles, part II: Design, doc. no: 67694, /MSB AG-FZ BEM/
- High-speed Maglev system design principles, part III: Kinematic gauge, doc. no.: 67650, /MSB AG-FZ KIN/
- High-speed Maglev system design principles, part IV: Support/guidance technology, doc. no: 73388, /MSB AG-FZ TRAFÜ/
- High-speed Maglev system, design principles, part V: Braking technology, doc. no.: 73389, /MSB AG-FZ BREMS/
- High-speed Maglev system design principles, propulsion and energy supply doc. no.: 50998, /MSB AG-ANT/
- High-speed Maglev system design principles, operational control systems, doc. no.: 53328, /MSB AG-BLT/
- High-speed Maglev system design principles, guideway part I: Overriding requirements, doc. no: 57284, /MSB AG-FW ÜBG/
- High-speed Maglev system design principles, guideway part II: Design, doc. no: 57288, /MSB AG-FW BEM/
- High-speed Maglev system design principles, guideway part III: Geometry, doc. no.: 41727, /MSB AG-FW GEO/
- High-speed Maglev system design principles, guideway part IV: Trassierung, Dok.-Nr.: 60640, /MSB AG-FW TRAS/
- High-speed Maglev system design principles, part V: Surveying, doc. no: 60641, /MSB AG-FW VERM/
- High-speed Maglev system design principles, guideway part VI: Maintenance, doc. no: 63842, /MSB AG-FW IH/

The following is a bullet point summary of parts I to VI of the high-speed Maglev system design principles, guideway:

Part I Overriding requirements

(1) Description of the structure of the guideway subsystem and its components;

(2) Definition of functional and design requirements of the individual components/modules;

(3) Definition of the verification procedure requirements;

(4) Definition of the required QA measures;

(5) Examples of tested system-related design and construction variations;

Part II Design

(1) Definition of actions on the guideway (incl. vehicle/guideway interaction);

(2) Definition of limit values for the guideway verification procedure (structural safety, material fatigue and serviceability);

(3) Definition of permissible deformations;

(4) Verification procedure guidelines;

Part III Geometry

(1) Definition of the target geometry of the guideway and permissible deviations (tolerances in the form of displacement, slope differences and gaps in functional levels);

(2) Benchmark definition for surveying the functional levels;

Part IV Line routeing

(1) Guideway line routeing guidelines;

(2) Definition of the permissible line routeing elements and routeing parameters;

Part V Surveying

(1) Description of the application of available coordinate systems;

(2) Requirements of the high-speed Maglev system coordinate system;

(3) Surveying method requirements;

Part VI Maintenance

(1) General; requirements for guideway maintenance;

(2) Fundamental requirements regarding the order of maintenance procedures;

(3) Fundamental requirements for the creation and content of maintenance programmes for guideway modules (incl. maintenance personnel requirements);

(4) Definition of the requirements for special vehicles on the guideway;

Abbreviations and definitions

The abbreviations and definitions provided in /MSB AG-ABK&DEF/ apply.

Laws, regulations, standards, and guidelines

The normative documents listed in /MSB AG-NORM&RILI/ contain stipulations that are referred to in the high-speed Maglev system design principles and thus form part of that document.

In the case of dated normative documents in /MSB AG-NORM&RILI/ later modifications or revisions of those publications do not apply. In the case of undated references, the last edition of the normative document in question applies.

The edition of the standards and guidelines to be observed in a high-speed Maglev system project must be bindingly agreed upon for each specific project. Description and obligation of requirements

Guidelines according to /DIN 820/ were generally used in the creation of this document.

In the following chapters and annexes of this document

- Requirements are shown in standard font
- Explanations, values and examples are shown in *italics*

.

Following the example of /DIN 820/, part 2, Annex G, the degree of obligation of the requirements has been determined and reflected in the phrasing of the requirements.

Table 90 shows the verb forms that have been used from /DIN 820/, tables G1 to G4. The additional verb form "shall" / "shall not" has also been added.

Meaning	Verb form	Paraphrase (only used in special circumstances)	Use
Requirement: Order	must	is to… is required The requirement is that … has to only … permissible **It is necessary**	… For binding requirements, i.e. those that must be observed without alteration.
Requirement: Prohibition	must not	is not permissible, [permitted], [authorized] it is forbidden is not to… is not to	
Requirement: Limited order	shall		The requirement is initially binding. However, in valid special cases exceptions may be allowed. Individual necessary exceptions must be justified in writing by the user and

Requirement: Limited prohibition	shall not		verification of an equal level of safety and system compatibility must be provided.
Recommendation	should	It is recommended that … Is generally …	When one of several options is particularly recommended, without referring to or excluding other options, or when (negative form) advising against a particular option, but not forbidding it.
	should not	is not recommended **should be avoided**	
Permissibility	may	is permitted is permissible … also …	… To convey that something is allowed.
	need not…	is not required … is not necessary	
Possibility	can	might It is possible that … allows… is able to …	… To convey a possibility.
	can not	might not It is not possible that … does not allow…	

Table 90: Verb forms used

Operational systems

The static systems for the high-speed Maglev system are referred to as operational systems. They includes the guideway, other structures and static facilities such as substations und stations.

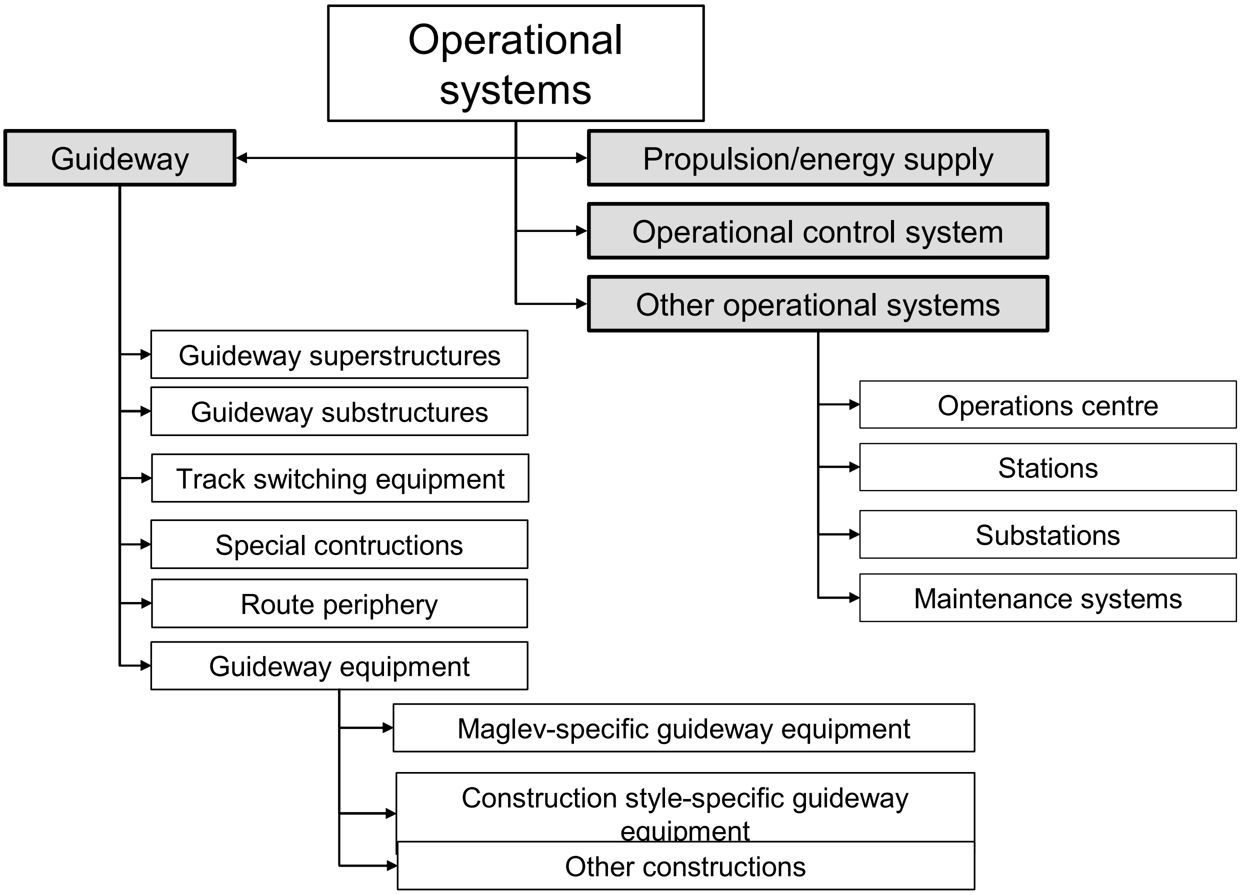

Figure 104: Overview of operational systems

Overriding requirements

General

The overriding requirements for all guideway modules and components of the Maglev system are defined below. The overriding guideway elements which form part of the operational systems can be seen on Figure 104.

Functional requirements

The overriding functional requirements relating to guideway modules/components are:

(1) The guideway must safely resist all actions resulting from operation and from the environment and transfer them to the foundations.

(2) Only tested components/modules should be used for Maglev operation. Otherwise it must be verified that they are compatible with the complete system.

(3) Throughout its required service life, the guideway must comply with the serviceability requirements without fail, under the specific boundary conditions. The service life must be determined for each individual project. 80 years can be used as a guide value.

(4) Risk of spontaneous failure of the guideway and/or its elements must be eliminated.

(5) The designs should be fault-tolerant and fault-revealing or redundant and fault-revealing.

(6) Risk of clearance violations through breakdown/failure of a component or a module (break, unacceptable deformation) and loss of function must be eliminated.

(7) Deformation changes or changes in gradient and/or displacement in the function levels as a result of failure (e.g. of fastening elements) must be recognisable during non-interruptive checks, before permissible deformation, gradient or displacements are exceeded.

Design requirements

The following overriding design requirements must be observed when designing and constructing all components/modules:

(1) All components/modules must be constructed so that they are able to safely withstand the specific action effects resulting from project-specific environmental conditions throughout their entire service life.

(2) The guideway must be designed so that the functional levels do not deviate in a non-permissible way from the three-dimensional curve path under the simultaneous influence of the actions from the vehicle and environment.

(3) The vehicle operation must not be adversely affected by potential vibration of the guideway as determined by the dynamic characteristics (stiffness, weight application, damping).

(4) Environmental requirements must be taken into consideration for each specific project in agreement with the responsible inspectorate. This includes, among others, wind, thermal, precipitation, ice and seismic actions.

(5) All guideway components/modules must be designed so that environmental emissions do not exceed the permissible values (see relevant regulations and legislation incl. MbB0). If permissible emission limit values cannot be adhered to along the line, additional measures must be implemented.

(6) The suitability of the selected materials and manufacturing processes must be verified by appropriate tests and/or certificates/documents/approval notifications.

(7) Where guideways are installed in tunnels and enclosed spaces, the current requirements for fire and catastrophe protection for guideways in tunnels or enclosed spaces must be observed when selecting materials. Individual requirements must be determined for each project.

(8) The position of the guideway is defined by the three-dimensional curves of the individual tracks determined within the framework of the project-specific line routeing and the accompanying guideway transverse gradient information α. The defined guideway coordinate systems (local and global) for the positions of these three-dimensional curves and construction (productions and assembly) of the guideway can be seen on Figure 105. The local coordinate system (beam production coordinate system) is explained in design principles, guideway, part III "Geometry" /MSB AG-FW GEO/. The global coordinate system (high-speed Maglev system coordinate system) is explained in design principles, guideway, part V "Surveying" /MSB AG-FW VERM/.

(9) The numbering of the guideway components/modules and other relevant details (bearing arrangement, type, etc.) are to be included in the maintenance documentation and the building directory.

(10) It must be possible to carry out maintenance of the guideway; especially the guideway superstructure and guideway equipment from the guideway surface (e.g. using special vehicles). The guideway design should be maintenance-free, require little service and allow automated inspection to be carried out.

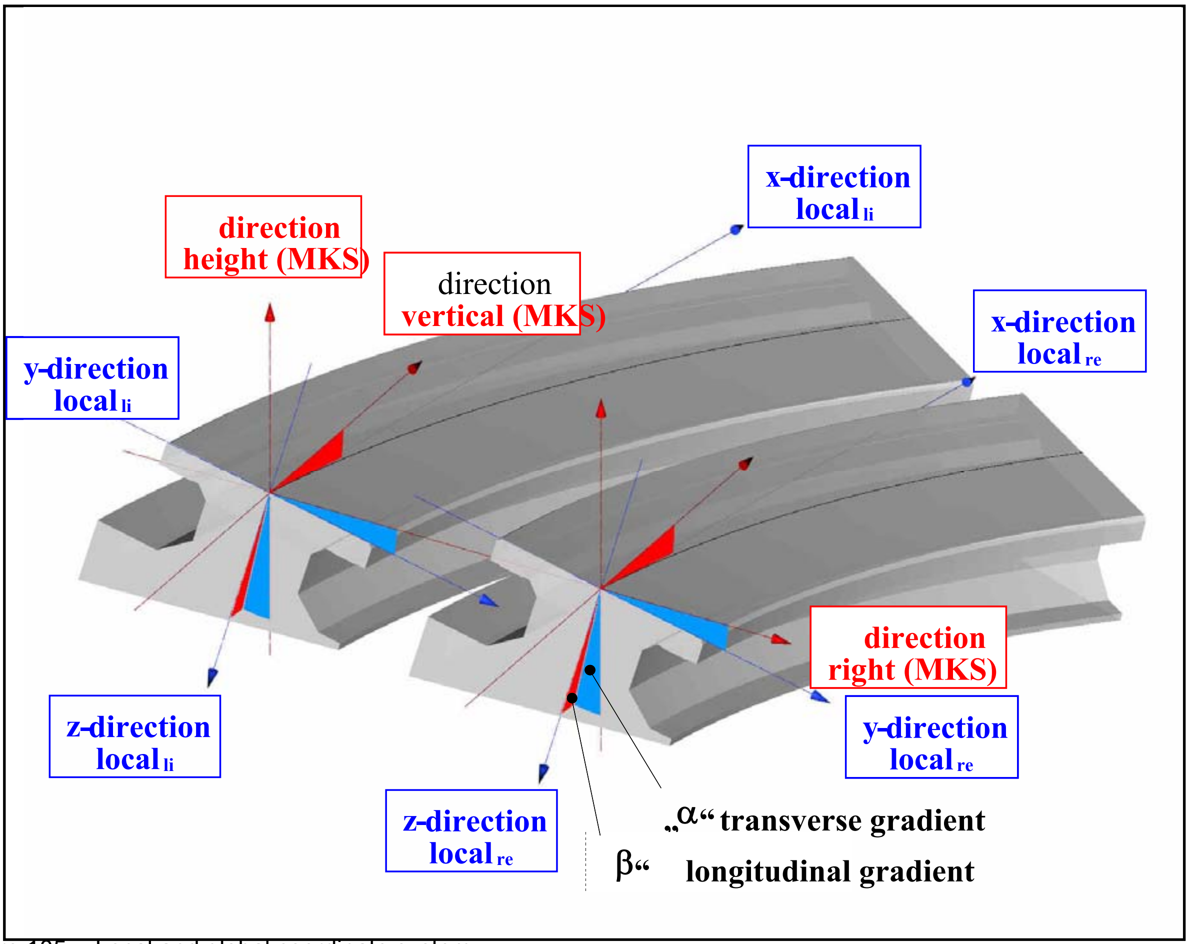

Figure 105: Local and global coordinate system

(11) Overriding values for clearance (loading gauge, kinematic envelope, boundary for fixed installations and the track centre distance) are defined in /MSB AG-GESAMTSYS/ If necessary, deviations from these values must be approved by the responsible inspectorate. Space requirements for guideway equipment are defined in /MSB AG-GESAMTSYS/.

(12) Space requirements for high-speed Maglev system-specific guideway equipment are shown on the following Figure 106. Measurements for the space requirements are defined in /MSB AG-FW GEO/ on the basis of /MSB AG-GESAMTSYS/.

(13) The maximum measurements for guideway superstructures provided as standard gauge in the annex for standard guideway types should be adhered to.

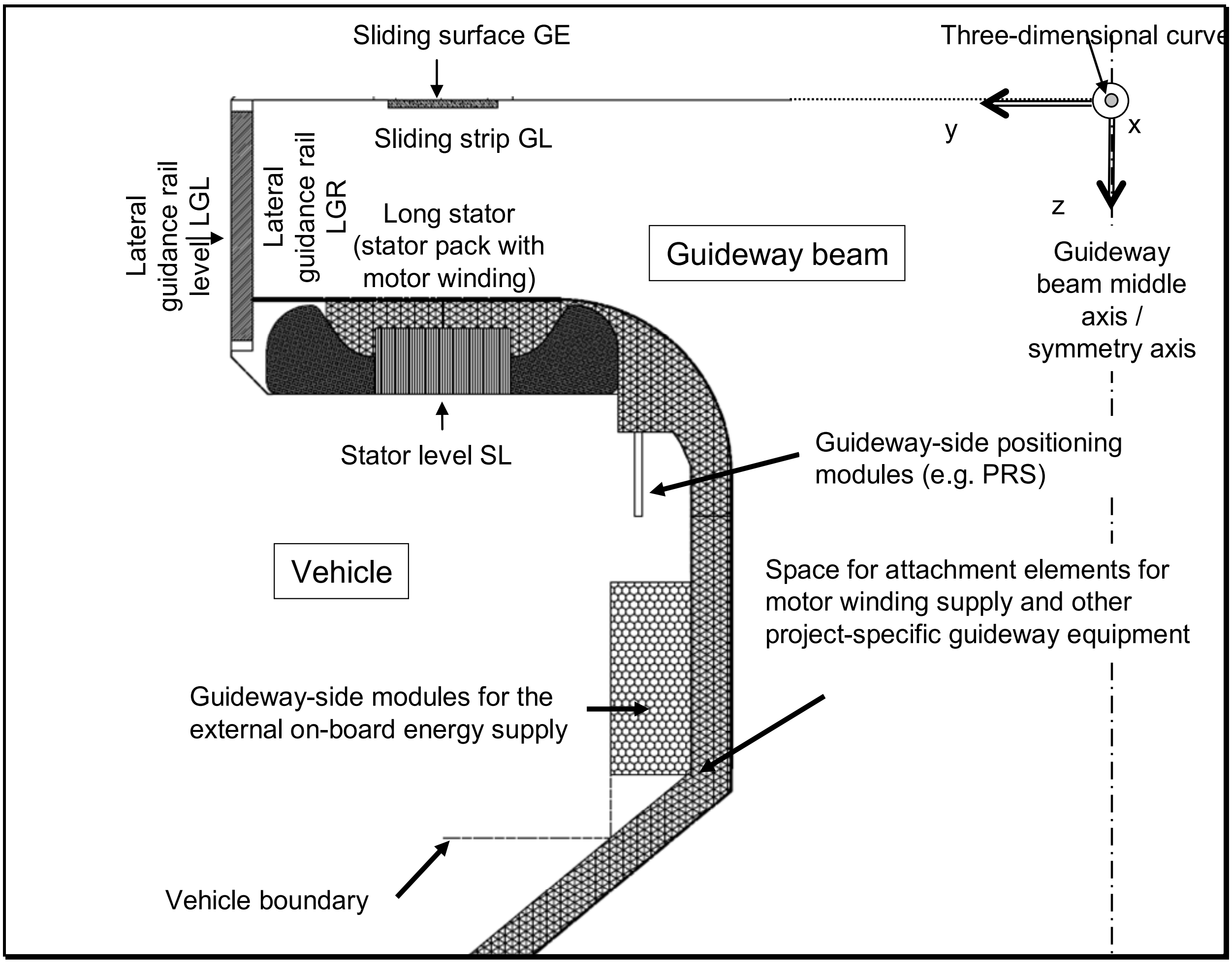

Figure 106: Overview of the space requirements of the high-speed Maglev system-specific guideway equipment

(14) The system lengths of guideway superstructures must be derived from the interval of the individual phases of the motor winding of 86 mm, which results from the pole pitch of the long stator motor of 258 mm (3 · 86 mm), and the resulting model system lengths of a standard stator pack of 1032 mm from 12 · 86 mm (n · 86 mm).

This results in the following potential control system span lengths (cf. Figure 111, 112, 113) of the guideway superstructures:

- *Guideway type I: n · 24.768 m or n · 30.960 m (24 or 30 · 1.032 m);*
- *Guideway type II: n · 12.384 m (12 · 1.032 m);*
- *Guideway type III: 6.192 m (6 · 1.032 m);*

(with n = 1 for single-span beam and n ≥ 2 for two and multiple-span beams)

(15) The system lengths must relate to the three-dimensional curve. In the case of curved guideways or guideways in dips or on hills, deviating lengths, which result on the functional levels /MSB AG-FW GEO/ and /MSB AG-FW TRA/, must be taken into account.

(16) A guideway, whose gradient lies at least 3.5 m above the ground, must be designated as an "elevated guideway".

Guideway type I is normally used for this type of guideway.

(17) A guideway, whose gradient lies between 1.25 m and 3.50 m above the ground, must be designated as an "at grade guideway".

Guideway type II or III is normally used for this type of guideway. The minimum gradient height of an at grade guideway depends on the existing transverse gradient of the installation area and project-specific boundary conditions (e.g. potential snow accumulation).

Verification procedure

The following verification procedure requirements are overriding for all guideway components/modules:

(1) The "Fundamentals of structural design" in Eurocode EN 1990 and DIN 1055-100 was used as the basis for the structure verification procedure.

(2) DIN VDE 0100 and DIN VDE 0101 were used as the basis of the verification procedure for electrical components and modules.

(3) The notes contained in the "Eisenbahnspezifischen Liste Technischer Baubestimmungen" (ELTB) (List of railway technical construction regulations) drawn up by the EBA (Federal Railway Authority) must be observed.

(4) The verification procedure for all guideway components and modules must be carried out using the following methodology, taking into account the actions resulting from the environment and operation detailed in /MSB AG-FW BEM/, the additional project-specific boundary conditions (service life, operating parameters etc.) as well as complying with the generally accepted technical rules and standards:

- Theoretical verification procedure
  (calculations);
- Empirical verification procedure
  (action effect measurements/test bench trials).

(5) If the verification procedure and its parameters are not defined in existing regulations (e.g. design principles, guideway, standards, guidelines, etc.) then they must be determined and agreed upon with the responsible inspectorate.

(6) The requirements of the high-speed Maglev system design principles must be adhered to during the verification process of project independent standardised components/modules. If, in exceptional cases, there are reasons why these requirements cannot be adhered to, it must be verified that it is equally as safe and a serviceability verification must be carried out.

(7) During the verification process, special attention must be paid to the dynamic excitation of the guideway resulting from the vehicle (see /MSB AG-FW BEM/).

(8) Environmental resistance and other characteristics such as effects on aerodynamics, noise, etc. must be verified.

(9) Potential time-dependent influences (e.g. subsidence of anti-corrosion coatings around prestressed screw connections, creep of prestressed elements) must be taken into consideration, and include a safety margin, in the verification procedure.

(10) If there are no permissible limit values available for certain components/modules, then these must be determined by test bench trials (e.g. component test, material test).

(11) Untested construction methods, components and modules may only be used commercially after they have undergone inspection and suitability tests in a test carried out under application-specific boundary conditions.

(12) In the case of untested materials, construction methods, components and modules, or untested combinations, it must be demonstrated that they are compatible with the complete system.

(13) The influential action effects and combined action effects determined by the theoretical tests should be reproducibly verified by measurements.

(14) The theoretical hypotheses used in the verification process, in particular actions not yet proven in a test run, must be verified by measurements during commissioning.

(15) The guideway safety level should at the very least correspond to the safety level of similar railway public transport.

(16) The project-specific risk analysis created on the basis of DIN EN 50126 can result in extensive safety-related requirements for the guideway and its components/modules.

(17) During the verification process, all guideway components/modules must be assessed (e.g. by FMEA) with regard to behaviour as the result of failure.

(18) Failure of components/modules must be excluded with sufficient reliability, taking into account the consequences of failure and economic viability.
For fail-safe designs additional verification process requirements must generally be taken into consideration:

- The influential action effects determined by the theoretical tests and the combined action effects applied in the verification process must be empirically verified before commercial use.
- Characteristics that are crucial for the correct functioning of the components/modules (e.g. material, absence of cracks, strength, compliance with specified measurements, pretensioning of screws) must be recognised as critical characteristics. For these characteristics a complete test appropriate to the significance of the component must be carried out.

(19) Fault-tolerant designs can be achieved with robust construction, for example:

- Components/modules do not break down suddenly and/or loss of sufficient bearing capacity is signalled by "large"/timely visible deformations or formation of cracks.

(20) Fault-tolerant designs can be verified by failure effect analysis (failure behaviour in the case of component failure), for example:

- In the case of theoretical (sudden) failure of a component, it must be proven that through load deflection, the bearing strength and the serviceability of all components and modules lying in the force path can be relied upon during their remaining service life or until repair.
- Load deflection can be carried out with diverse or homogeneous redundant load paths. In the event of component failure, it is permissible for the forces to be transferred along a load path that is also in operation when the system is functional ("hot" redundancy).
- In the case of redundant load paths that are not directly used when the system is functioning ("cold" redundancy), only the environmental actions and indirect actions from operation (e.g. beam vibrations) need be considered.
- The failure situations to be detected must be determined in agreement with the responsible inspectorate for all affected components/modules taking maintenance into consideration (failure detection, inspection intervals, etc.).
- In the event of a permissible fault reporting an operationally stable layout of the components/modules lying in the force path, which are to be considered in the failure situation,

specifying the permissible load cycle (vehicle passing) is sufficient for a project-specific utilisation profile. The permissible fault reporting/detection as part of guideway maintenance must be verified.

(21) The requirements to be fulfilled with regard to the necessary quality of the components/modules must be clearly and fully defined.

(22) If the evaluation methods for inspecting the required quality of the components/modules are not laid down in the present standards, etc., then they must be determined in agreement with the responsible inspectorate. Evidence that the evaluation methods were used in the evaluation must be provided.

(23) The production/assembly must be carried out in such a way that the boundary conditions used as a basis for the verification process are adhered to, with proof. Production/assembly instructions, which determine the processes and tools, all parameter values that must be adhered to and the permitted tolerances of the parameters, must be drawn up.

(24) The correct position of the high-speed Maglev system-specific guideway equipment must be verified before the guideway is commissioned by a clearance test and an inspection of the long and short wave deviations and the displacements.

(25) Adherence to the following general requirements is a prerequisite for achieving the required reliability und serviceability of the guideway:

- Qualified persons are appointed for the development, design and the verification process.
- It is constructed by carefully trained and qualified personnel.
- Appropriate supervision is ensured at the manufacturing plants, the production plants and at the construction site.
- The guideway is used in accordance with the planning assumptions.
- The guideway elements are correctly maintained. Prerequisite for this is a maintenance programme drawn up by the manufacturer.

Handling, transport and assembly

The manufacturer should draw up detailed instructions on handling, transport, assembly and disassembly for all guideways. These must take specific boundary conditions into account (layout, actions as a result of transport, etc.).

There is no need to create detailed instructions for handling, transport, assembly and disassembly for tried and tested subordinate components/modules.

All manufacturing/assembly procedures must be documented as part of the verification procedure.

General requirements for maintainability

The following basic requirements for the maintainability of guideway components and modules must be adhered to:

All guideway components and modules must be designed in a way that keeps maintenance expenditure to a minimum. Fault-tolerant, robust and if possible redundant designs are preferred.

(1) Guideway components and modules should be maintenance-free and require minimal service.

(2) Maintenance should only be planned when it is unavoidable (e.g. for moveable parts of the track switching equipment) or if maintenance is more favourable economically or in terms of operation in comparison to inspection/repair.

(3) The requirements from chapter 5.3.3 in /MSB AG-GESAMTSYS/ and /MSB AG-BTR&IH/ with regard to maintenance must be taken into account in the design of the guideway components and modules.

(4) Damage must reveal itself so that it can be reliably detected during the appropriate inspection process.

(5) Multiple failure of components/modules must be detectable by monitoring measures taking the individual designs into account in accordance with /MSB AG-BTR&IH/ and must be able to be restored to their normal state.

(6) The failure of a single component or a single module should not cause problems or interrupt vehicle operation.

Note: In the not entirely excluded event of entire guideway beams requiring replacement, vehicle operation can be restricted.

(7) During development and manufacture of the guideway, it is important to reduce the probability of (or ideally prevent) repair measures being required.

(8) Careful, error-free and proper manufacturing (assisted by a quality assurance system) will result in a high-quality guideway.

(9) All components and modules must be operationally stable, taking into consideration actions resulting from the environment and operation, throughout their designed service life.

(10) Designs that allow non-interruptive, predominantly automated inspection, are preferred.

(11) If direct detection of failure is not possible, then it must be verified that a potential fault can be detected indirectly (e.g. as a result of displacement changes on the functional level) before the fault becomes unacceptable.

(12) All guideway components and modules must be constructed in a way that keeps inspection to a minimum.

(13) Modules and components must be marked in order to enable clear classification as part of the automatic inspection process so that clear work orders can be issued.

(14) The maintenance period must be defined according to the specific project.

Guideway superstructure

General

The guideway superstructures form the guideway tracks. See Figure 107 for the subdivision of guideway superstructures.

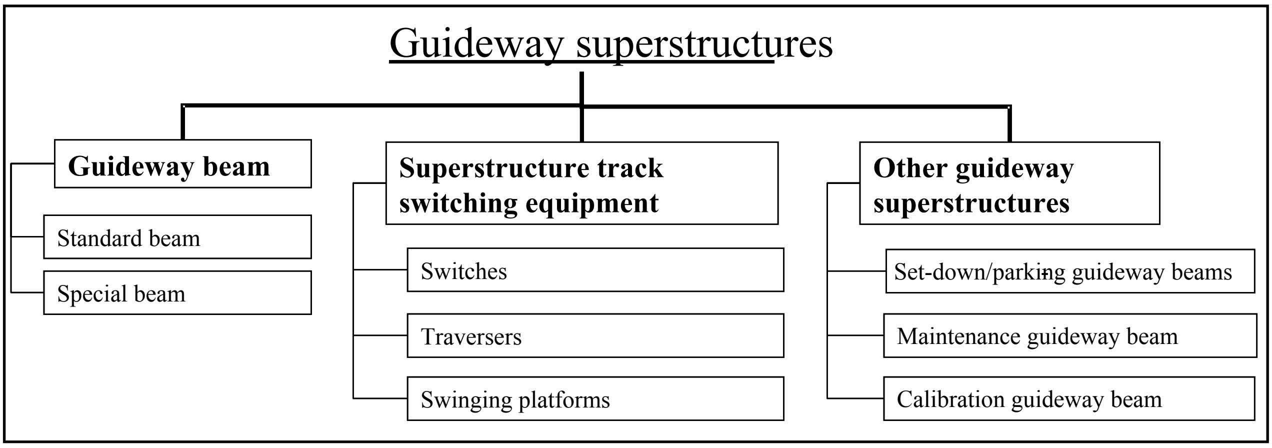

Figure 107: Types of guideway superstructure

(1) When planning high-speed Maglev system routes, the following standard guideway beam types (see. Figures 111, 112 and 113) should be used:

- Guideway beam type I: Single/multiple span beam with system lengths of > ≈ 16 m;
- Guideway beam type II: Single/multiple span beam with system lengths of ≤ ≈ 16 m;
- Guideway beam type III: Multiple span plates with small system lengths of, for example, ≈ 6 m;

(2) The choice of standard guideway beam types and system lengths will depend on the project.

(3) *Guideway beam types I and II are generally discretely supported on columns with individual foundations. The bearing pressure of guideway beam type III is generally transferred to the foundations via strip footing.*

(4) For the guideway beams the following "construction methods" are currently being tested:

- *Concrete construction (concrete beams/plates with integral (concrete) cantilever arms);*
- *Steel construction (steel beams/plates with integral (steel) cantilever arms);*
- *Hybrid construction (concrete beams/plates with attached steel modules as cantilever arms).*

Other construction methods, such as composite constructions, are also possible.

(5) Potential "designs" apply to the design of guideway superstructures (⇒ design-specific).

Functional requirements

The influential functional requirements for guideway superstructures are:

(1) Reliable support of actions resulting from operation and the environment and transferral to the guideway substructures;

(2) Reliable support of the Maglev-specific guideway equipment;

(3) Reliable support of other guideway equipment designs and methods;

(4) Guarantee of required positional accuracy of the Maglev-specific guideway equipment (tolerances and deformations).

Design requirements

The design requirements for guideway superstructures are:

(1) The cross section of the guideway superstructures should comply with the guidelines on Figures 106, 111, 112 and 113 as well as the defined installation space requirements for the system guideway equipment in accordance with /MSB AG-FW GEO/, whereby all guideway equipment connections should be accessible and serviceable in accordance with the design layout.

(2) The cross sections illustrated in Figures 106, 111, 112 and 113 may be exceeded if compatibility with the complete system is proven. The beam lengths provided are just examples (see chapter (7) 0).

(3) Materials (incl. corrosion protection) should be selected by taking into consideration the required service life according to state-of-the-art technology.

(4) Maintenance expenditure and unfavourable acoustic effects (noise emissions) should be kept to a minimum through an optimised cross section and surface design.

(5) The general requirements on corrosion protection must be observed to ensure durability and to minimise maintenance expenditure.

(6) All load-bearing components should be easily accessible for maintenance purposes.

(7) Box beams/cavities should be designed so there is no need to inspect the inside of them (e.g. closed steel box beam).

(8) The drainage for the guideway superstructures should be designed so that all rain water is able to run off the guideway. Drainage via the lateral guidance rails is permitted. On straight guideway areas, the guideway should be designed with a transverse gradient of 1.15° (corresponds to 2 %) for drainage.

(9) Transverse gaps between successive guideway beams should be closed (e.g. by a beam gap cover) if they can become larger than 20 mm (influencing variables: deformation of substructures, variation in the length of the superstructure as a result of temperature and concrete creep and shrinkage) and lie in sections that have vehicle passing speeds in accordance with the sectional actual travelling speed of > 150 km/h. The construction requirement and areas affected are subject to project-specific definition.

(10) Longitudinal gaps and other openings on the guideway surface should be avoided.
(11) To enable components to be mounted on the guideway superstructures, suitable connection points must be included in the design (e.g. spaces in reinforcing cage).
(12) If these connections affect the project independent structural verification of the guideway superstructures (structural safety and fatigue strength) type approval, then these connections must be taken into consideration when the verification process is created.The guideway superstructures must be clearly numbered according to project-specific guidelines. Track numbering is carried out continuously. The numbers must be legible and permanently marked on the upper surface of the guideway superstructures (if necessary above the relevant support point). It is recommended that the numbers are also marked on the sides. The numbering of the guideway superstructures and substructures must be coordinated.
(14) The design must ensure that the guideway superstructures can be inspected, as far as possible, with the aid of automated procedures (e.g. evaluation of video recordings).
(15) The design should ensure that repair measures that do not have to be planned well in advance (lead time < 3 months) can be carried out in the time available under all potential project-specific environmental conditions.

Verification process

The overriding requirements for the guideway verification process specified in chapter 0 must be observed.

This applies to the following in particular:

(1) In addition to the theoretical verification, guideway superstructures must be empirically classified with regard to the following characteristics:
- Verification of the dynamic behaviour and the dynamic action effects as the vehicle travels over the guideway at a velocity between v = 0 km/h (with a levitating vehicle) and $v = v_{max}$;
- Verification of satisfactory bearing strength and service strength;
- Verification of serviceability
- Adherence to noise emission limit values according to /MSB AG-GESAMTSYS/;
- Verification of maintainability (ease of inspection, accessibility, etc.).

(2) Research and findings from previous classifications (e.g. from a test run, from running application projects) must be drawn upon during the verification process for new guideway superstructures.

Handling, transport and assembly

(1) Devices appropriate for the design must be used for the transport and assembly of guideway superstructures to avoid mechanical damage and permanent deformation.
(2) The assembly process and the fine positioning of the guideway superstructures must be optimised for precision, speed and be able to be carried out in all weathers. Assembly and positioning instructions must be drawn up with all required details.

Guideway substructures

General

The purpose of guideway substructures is to:

- *bridge the height difference between the guideway substructures and the ground (guideway supports);*
- *transfer forces from the guideway superstructures to the foundations taking system-related requirements into account.*

Concrete and steel designs are currently being tested for the columns. Other designs are also possible.

The guideway foundations are generally made of concrete.

The arrangement of the guideway substructures is primarily dependent on rigidity requirements, which are determined by the permissible deformation and distortion according to /MSB AG-FW BEM/.
The aesthetic arrangement of the substructures depends on the following functional and design requirements.

See Figure 108 for the subdivision of guideway substructures.

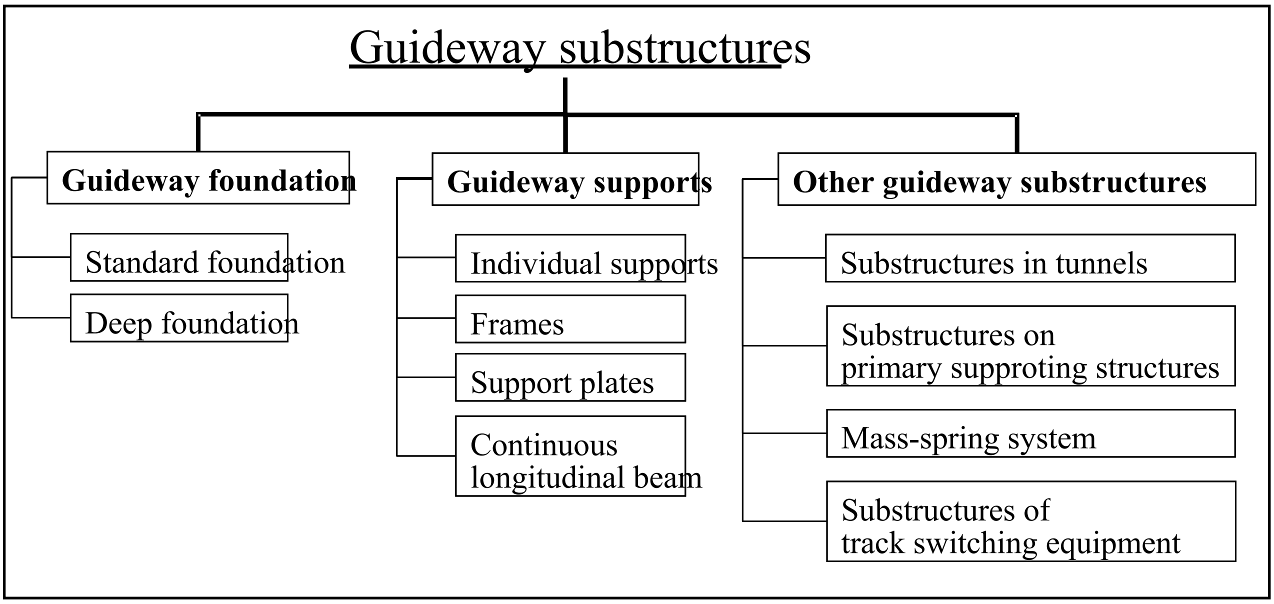

Figure 108: Types of guideway substructures

Functional requirements

The influential functional requirements for guideway substructures are:

(1) Guideway substructures must directly support the actions from the superstructures via the guideway bearing and reliably transfer them to the foundations (reliable support from guideway superstructures).

(2) Guideway equipment components and modules (e.g. motor winding power line and the external on-board energy supply) must be reliably incorporated.

(3) Guideway substructures must permanently guarantee the required positional accuracy of the superstructures.

Design requirements

The following design requirements must be considered when designing substructures:

(1) Safety devices must normally be included according to the project-specific safety concept to prevent impact of vehicles and devices on crossing and parallel routes.

(2) Separate substructures for consecutive guideway superstructures should be avoided.

(3) Dimensioned attachment points for connecting the guideway superstructure lightning protection system to the substructure reinforcement must be included in the design in accordance with generally accepted technical rules and standards.

(4) The design of the transitions between:

- Special structures and adjacent standard tracks,
- Discretely and continuously supported guideways and
- Guideways on mass-spring systems and adjacent guideways

must be verified as being compatible with the complete system.

(5) To enable components to be fitted retrospectively on the guideway substructures, suitable design measures must be included in the design (e.g. spaces in reinforcing cage). These must be agreed upon for each specific project.

(6) Attachment options for the long stator and external on-board energy supply cables must be included on all columns in the design.

(7) The guideway superstructures for the two tracks of the double track guideway should rest on shared substructures that are arranged radial to the line routeing axis.

Deviations from this are permitted e.g. in the case of expansion of the track centre distance or use of guideway beam type III. Sensitive areas of the guideway substructures (e.g. the area around the guideway support) must be designed so that damage can be detected through automated guideway inspection procedures

Verification process

The overriding requirements for the guideway verification process specified in chapter 0 must be observed.

The following requirements should be highlighted:

(1) When designing guideway substructures pay attention to the following project-specific points:

- Actions resulting from the superstructures, environment and operation;
- Permissible deformations;
- Static system for each guideway superstructure;
- Local foundation conditions;
- Local gradient heights of the tracks.

(2) When designing the foundations the (high) loading velocity and the dynamic forces (frequency, amplitudes) from the superstructures must also be observed.

(3) If there is no research available for a substructure construction type, then extensive theoretical and/or empirical verification must be provided.

Handling, transport and assembly

Guideway substructures are generally created by cast in-situ concrete methods. If using prefabricated parts (concrete prefabricated parts, stanchions, composite supports) then corresponding instructions for handling, transport, assembly must be created.

High-speed Maglev system-specific guideway equipment

General

"High-speed Maglev system-specific guideway equipment" includes all components and modules that are necessary for the operation of the train irrespective of the guideway construction (see Figure 109 and Figure 114).

The high-speed Maglev system-specific guideway equipment consists of:

- *Long stator;*
- *Lateral guidance rails;*
- *Gliding strips;*
- *Guideway-side components for the external onboard energy supply;*
- *Guideway-side components for positioning;*
- *Lightning protection and earthing of guideway equipment..*

The following describes the general requirements of high-speed Maglev system-specific guideway equipment elements.

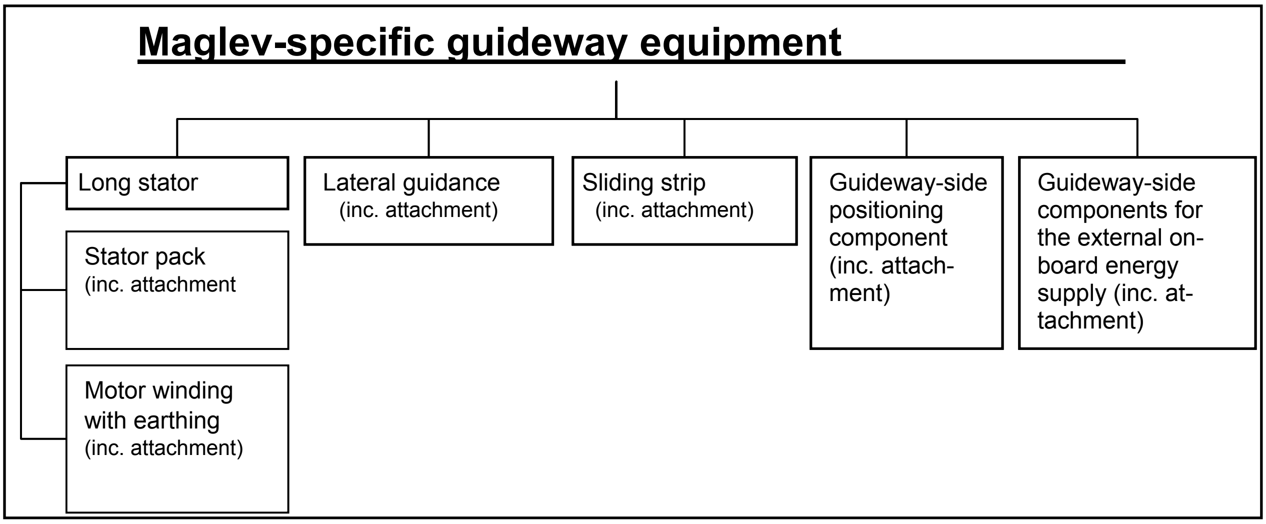

Figure 109: High-speed Maglev system-specific guideway equipment

Long stator

General

The long stator is part of the guideway and is used to propel Maglev vehicles.

It consists of the following elements:

(1) Stator pack, made up of:

- *An electric sheet steel pack with slots to receive the motor windings and to receive integrated elements for attachment to guideway superstructures*
  (An example stator pack is shown in Figure 115 in the annex);
- *Integrated elements for attachment to the stator pack on the guideway superstructure (e.g. slot traverses);*
- *Protective coating (corrosion protection).*

(2) Elements for attaching the stator packs to guideway superstructures (i.e. screws);3-phase motor winding (Figure 116 shows part of a long stator with a motor winding whose cables are individually laid one after the other);

(4) Motor winding earthing and additional fixture for the motor winding in the stator pack slots (e.g. earthing sleeves and cable).

Figure 117 and Figure 118 in the annex show an example of a redundant stator pack attachments solution.

The long stator is directly protected from lightning strike due to its position under the guideway. However, to avoid damage from indirect actions as a result of lightning strike, it must be guaranteed that lightning is conducted through the attachment in the supporting structure's earthing system.

Functional requirements

Stator packs

The interface between stator pack and motor winding must be designed so that the motor winding stays safely in place under all considered actions in accordance with /MSB AG-FW BEM/.

The stator pack performs the following functions:

(1) Controls the magnetic flux created by the vehicle support magnets, receives and conducts the forces generated by the magnetic flux (bearing forces);Receives and transfers the acceleration and braking force;

(2) Forms the reference surface (stator level) for measuring the air gap between stator pack and support magnet;

(3) Forms the reference surface for guideway monitoring (e.g. position monitoring using displacement measurement);

(4) Forms the tooth-slot effect for vehicle positioning;

(5) Forms the tooth-slot geometry for flux modulation to induce an electrical voltage in the vehicle's linear generators (on-board energy supply).

Attachment of stator pack

The following requirements must be taken into consideration for attaching stator packs to the guideway superstructures:

(1) The stator pack attachment must reliably hold the stator pack in place through all actions resulting from the environment and operation throughout the duration of the project-specific service life, according to /MSB AG-FW BEM/ see /MSB AG-FW GEO/).

(2) If the failure of one or more attachment elements cannot be excluded, limited safe vehicle operation must be guaranteed for a time period to be defined on a project-specific basis.

(3) Failure of attachment elements must be detectable by monitoring measures in accordance with /MSB AG-BTR&IH/ and elements must be able to be restored to their normal state.

(4) Violation of the permissible position deviations of the stator packs according to /MSB AG-FW GEO/ must be prevented.

Motor winding

(1) An electrical moving field is created via the motor winding, from which a thrust force for acceleration and deceleration of the vehicle is created through interaction with the magnetic field of the vehicle support magnet.

(2) The thrust forces are transferred to the supporting structure via the stator packs and their attachments.

Design requirements

Stator pack

(1) The stator pack components (sheet pack, coating and the integrated attachment elements) must be designed and assembled so that they meet the required service life taking into consideration actions from the environment and operation in accordance with /MSB AG-GESAMTSYS/.

(2) It should be designed so as to minimise maintenance expenditure.

(3) The quality of the electric sheet must meet the requirements of /MSB AG-GESAMTSYS/.

(4) The stacking factor of the sheet pack must not be less than 0.97 according to EN 10106.

(5) Normative dimensions of the sheet pack must be taken into consideration in accordance with /MSB AG-GESAMTSYS/;

(6) Stator pack length:

The system length of a stator pack is 1032 mm.

Due to the different lengths between the inside and outside of a curve, different physical stator pack lengths are required to create the guideway geometry.

The mechanical distance to the front surface of the stator packs should equal 0.5 mm to 2 mm in the support area. In areas with a small horizontal radius and in the case of track switching equipment, a maximum range of 0 to 10 mm must be adopted.

The required lengths of the individual stator packs and their arrangement on the guideway are project-specific and must be compatible with the vehicle levitation and guidance system.

(7) The geometry of the mounted stator packs must (taking into consideration the project-specific tolerances of the guideway attachment surface) meet the tolerance requirements of the stator level as defined in /MSB AG-FW GEO/.

(8) A consistent tooth-slot geometry must be adhered to with a grid of 86 mm.

(9) The coating material (corrosion protection) should be selected by taking into consideration the required service life and project-specific environmental factors. Suitable design and production measures should ensure that the permissible coating thickness on the stator level is not exceeded, thereby reducing the mechanical gap to an unacceptable level. The coating must not affect the electrical and electromagnetic properties of the sheet pack. The corrosion protection must completely cover the stator pack. It should also be permanently ductile and resistant to abrasion.

(10) The maximum permissible thickness for the corrosion protection on the stator levels may not exceed 1.8 mm (incl. all tolerances, tapers, etc.).

(11) The permissible stator pack installation space is shown on Figure 106 and in /MSB AG-FW GEO/.

(12) The dimensions of the integrated attachment elements must be defined according to the type of attachments, the static requirements and taking into consideration maintenance factors.

(13) The contact surfaces between the guideway cantilever arm and integrated elements for attaching the stator pack (e.g. slot traverse) must be designed so that the forces from the environment and operation cannot lead to unacceptable displacement of the stator packs.

(14) For the transfer of forces from actions to be considered, the contact surfaces between the stator pack attachment and the connecting surface on the supporting structure must satisfy the friction parameter that is used as the basis for the dimensioning.

Attachment of stator packet

(1) The attachment must be reasonably simple to detach without causing any damage to adjacent structures.

(2) It must be determined, on a project-specific basis, whether the falling off of failed attachment elements resulting in danger to third-parties must be prevented by implementing protection measures on project-specific guideway sections (e.g. at intersections with other infrastructure).

(3) Attachment elements, whose failure cannot be excluded, must be easy to replace (in between operating periods) in the event of their failure.

(4) The construction-specific connection design (guideway cantilever arm and integrated elements for stator pack attachment) must be taken into consideration in the development and dimensioning of attachment elements.

(5) The space available for the stator pack attachment (see Figure 106 und /MSB AG-FW GEO/) must be defined in agreement with the suppliers of the stator pack and the guideway beam. It must be individually verified as compatible with the complete system.

(6) Materials and manufacturing methods must be used that, in the event of a systematic failure, will not lead to a failure of the attachment (e.g. hydrogen embrittlement). The costs associated with using such materials and methods must be kept within reasonable limits.

(7) When selecting materials, the environmental influences (corrosion and ageing behaviour) must be taken into account with regard to the required service life .

Motor winding

(1) The motor winding must be designed so that the required service life is achieved, taking into consideration the specified actions from the environment and operation.

(2) Violation of the permissible clearance during the required service life must be excluded (taking specified actions from the environment and operation into consideration).

(3) The mechanical and geometrical characteristics of the cable used for the motor winding must be taken into consideration during the project-specific design of the attachment and assembly (attachment in stator pack slots taking into account the motor winding earthing and the tooth-slot geometry).

(4) The permissible minimum bending radius of the motor winding cable and the permissible installation space for the motor winding according to Figure 106, /MSB AG-FW GEO/ and /MSB AG-GESAMTSYS/ must be adhered to.

(5) The requirements for the electrical function of the motor winding are defined in /MSB AG-GESAMTSYS/.

(6) The requirements for the motor winding earthing result from the long stator protection and can be found in Maglev design principles, propulsion and energy supply /MSB AG-ANT/.

(7) The motor winding cable must be **self-extinguishing to prevent** fire.

(8) Additional requirements for the motor winding material in tunnels and at stations (enclosed spaces) can be defined on a project-specific basis (toxicity in the event of fire).

(9) The earthing design and the connection points for the motor winding must be determined on a project-specific basis, whereby the connection points for the motor winding earthing must be integrated into the earthing/lightning protection system of the guideway.

(10) On beam joints it must be ensured, through dimensionally stable arrangement of the motor windings, that movement of the beams in the x-, y- and z directions, resulting from operation and environment throughout the course of the required service life, does not lead to violation of the permissible installation space and to loss of serviceability.

(11) The determination of the local phase position of the motor winding must include verification of compatibility with the complete system. (see /AG MSB-GESAMTSYS/ chapter 8.2 fig. 5)

(12) An example of the 3-phase motor winding can be found in the annex (Figure 116).

(13) The interface between stator pack and motor winding must be designed so that the motor winding stays safely in place under all considered actions in accordance with /MSB AG-FW BEM/.

Verification process

Stator packs

The following component/module-specific requirements for the stator pack must also be observed as well as the overriding requirements for the guideway verification process specified in chapter 0.

(1) The verification process must focus on the following:

- Verification of the fatigue resistance taking into account dynamic loads;
- Verification of the dimensional accuracy, quality and durability of the coating;
- Verification of the electrical and electromagnetic characteristics.

(2) To ensure the quality of every individual stator pack a test instruction must be created that contains all the acceptance criteria to be verified along with the permissible tolerances. The acceptance tests must be recorded.

(3) For traceability, all stator packs must be clearly, individually and permanently marked.

Attachment of stator pack

The following component/module-specific requirements for the stator pack attachment must also be observed as well as the overriding requirements for the guideway verification process specified in chapter 0.

(1) Verification must also be drawn up for failure situations, assuming that failure of attachment elements is not excluded. The failure situations to be considered in connection with the detection system must be determined after verification of compatibility and in agreement with the responsible inspectorate.

(2) It must be verified that for the failure situations all the components and modules in the force path are designed for the entire project-specific service life.

(3) In the event of a credible fault appearance, an operationally stable design of the components/modules in the force path in the failure situation, specifying the permissible load cycle (vehicle passing), is sufficient. Credible fault appearance/detection as part of guideway maintenance must be verified.

Motor winding

The following component/module-specific requirements for the motor winding must also be observed as well as the overriding requirements for the guideway verification process specified in chapter 0.

(1) Adherence to the specified thermal behaviour of the long stator must be verified metrologically during operation.

(2) The theoretical load assumptions and serviceability must be verified by measurements both during prototype development as well as during operation of the final system.

(3) The current carrying capacity of the circuit, the shield and the electric strength of the windings must be verified.

(4) The fatigue resistance of the winding attachment, including the dimensional stability of the winding head, must be verified empirically.

(5) The material and structural strength of the motor winding must be verified through the mechanical load on the beam joint.

(6) Adherence to the lightning-impulse strength in accordance with /MSB AG-UMWELT/ as well as project-specific instructions must be verified.

(7) The permissible continuous current RMS value and current max. value must be empirically verified, taking into consideration the project-specific cycle time parameter and running time.

(8) It must be verified that the long stator protection is functioning correctly (earth-fault monitoring).

Handling, transport and assembly

Stator packs

Instructions on handling (transport and storage)and assembly must be drawn up for the stator pack. The following factors must be included:

(1) Mechanical damage must be prevented by appropriate transport methods and packaging to protect against impact.

(2) The intermediate storage surfaces must be designed so that the stator packs and and/or their transport packaging can be correctly set down and lifted again without causing any damage.

(3) The stator packs should be attached to the guideway superstructures by the manufacturer.

(4) If stator packs are fitted retrospectively at the site, then additional construction documents (assembly instructions and acceptance specifications) must be drawn up and verified as being compatible with the complete system and submitted to the responsible inspectorate for inspection.

Attachment of stator pack

(1) The assembly process and parameters must be specified in transport, storage and assembly instructions.

(2) The assembly parameters, such as starting torque/rotation angle, must be defined, monitored and documented.

(3) Connecting parts that have been used before (e.g. screws, washers, nuts) should not be reused. In exceptional cases (e.g. use of inserts that are embedded in concrete with thread (see Figure 117)) it must be checked whether the part is reusable before replacing the stator pack or attachment element.

Motor winding

(1) Detailed instructions for assembly, transport and intermediate storage must be drawn up in the form of assembly instructions according to the specific project and design employed.

(2) The free space within the gauge for the kinematic space requirement of the vehicle according to /MSB AG-GESAMTSYS/ (or beyond, following project-dependent agreement) is available for the manufacture and/or laying of windings from the guideway.

(3) Assembly devices for the long stator motor winding must fulfil the special vehicle requirements.

Lateral guidance rails / lateral guidance levels

General

The lateral guidance rails, which are an element of the high-speed Maglev system-specific guideway equipment, receive the mechanical and electromagnetic actions from the vehicle and special vehicles..

The fundamental arrangement of the lateral guidance rails on the cantilever arms of the guideway superstructures can be found in Figure 106 and /MSB AG-FW GEO/.

Functional requirements

Lateral guidance rails

The lateral guidance rails perform the following functions:

(1) Guide the magnetic flux from the guidance and braking magnet;

(2) Enable the generation of electrical eddy currents by interacting with the braking magnets;

(3) Receive the magnetic forces generated by the guidance and braking magnets and transfer them to the cantilever arm structure;

(4) Receive the forces initiated by special vehicles and transfer these to the cantilever arm structure;

(5) Mechanical guidance in the event of failure of the magnetic guidance function of the guidance magnets;

(6) Mechanical guidance of the braking magnets on the lateral guidance rails, receive and transfer the forces;

(7) Forms the reference surface for measuring the air gap between guidance magnet and lateral guidance rail;

(8) Forms the reference surface for guideway monitoring (e.g. displacement or displacement change detection);

(9) Transferral of excess voltage resulting from lightning on the vehicle;

(10) Lightning protection function for the motor winding.

Attachment of lateral guidance rails

(1) The attachment elements must reliably transfer the forces from the lateral guidance rails to the cantilever arm of the guideway superstructures.

Design requirements

Lateral guidance rails

(1) The lateral guidance rails should follow the course of the three-dimensional curve (transverse gradient, dips/hills, curves).

(2) Subject to the design used for the support, the lateral guidance rails may have a polygonal arrangement if it can be verified that this is compatible with the complete system.

(3) It must be guaranteed that inspection equipment will detect geometry changes and/or displacement before the permissible limit values for these deformations is exceeded.

(4) The range of possible materials for lateral guidance rails is defined in /MSB AG-GESAMTSYS/.

(5) Geometry:

- Thickness: $t_{LGR} \geq 30$ mm
- Height: $H_{LGR} \geq 300$ mm
- Length: Depending on the system, beam-length lateral guidance rails are advantageous.

  Shorter lengths can be used depending on the project.

(6) It must be verified that lateral guidance rails with segment lengths shorter than approx 3.0 m are compatible with the complete system. The edges of lateral guidance rails must be rounded on the joints within a carrier field or a beam joint according to the instructions in /MSB AG-FW GEO/.

(7) The requirements for the levelness and positional accuracy of lateral guidance rails are listed in /MSB AG-FW GEO/.

(8) The lateral guidance rails must be given a coating that will barely be damaged by potential mechanical loads and guarantee sufficient resistance to corrosive attack from the environment (see DIN EN ISO 12 944 Part 1 - 8 and TL 918300, page 87).

(9) The suitability of the coating must be proven with regard to the vehicle side guidance gap measurement (guidance gap sensors).

(10) The coefficients of friction must be adhered to in accordance with /MSB AG-FW BEM/.

(11) The lateral guidance rails must be connected to the guideway lightning protection system.

Attachment of lateral guidance rails

(1) The attachment elements for the lateral guidance rails must be designed, according to the selected design, so that they can safely and reliably withstand all actions to be considered from the environment and operation throughout the required service life (see /MSB AG-GESAMTSYS/).

(2) The attachment of the lateral guidance rails must not affect the correct functioning of the guidance sensors in an unacceptable manner. The guidance gap measurement areas are shown in /MSB AG-FW GEO/. If attachment elements are absolutely necessary in these areas, then the suitability of the design must be verified with regard to the guidance gap measurement.

(3) The attachment must be optimised with regard to maintainability (ease of access for inspection and repair).

Verification procedure

Lateral guidance rails

The overriding requirements for the guideway verification process specified in chapter 0 must be observed.

Attachment of lateral guidance rails

The requirements according to chapter 0 (stator pack attachment) must be observed alongside the overriding requirements for the guideway verification process given in chapter 0.

Handling, transport and assembly

(1) The lateral guidance rails and their attachment elements (specific to the design) must be handled correctly.

(2) The lateral guidance rails are normally attached to the guideway beams or guideway plates by the manufacturer as integrated parts of the supporting structure of the guideway superstructure or cantilever arm.

(3) If lateral guidance rails are fitted retrospectively, then construction documents (assembly instructions and acceptance specifications) must be drawn up and verified as being compatible with the complete system and submitted to the responsible inspectorate for inspection.

Gliding strips / gliding surfaces

General

The gliding strips, which are an element of the high-speed Maglev system-specific guideway equipment, are required during normal operation to deflect the mechanical forces from the stationary set-down vehicle via the support skids and to receive the mechanical actions from special vehicles. In the event of a malfunction, the force of the support skids from the moving vehicles are to be transferred to the guideway superstructures.

Functional requirements

The gliding strip performs the following functions:

(1) The gliding strip and its attachment element must be made so that they can reliably withstand the specified mechanical and thermal loads along with project-specific environmental conditions throughout the required service life in accordance with /MSB AG-GESAMTSYS/.

(2) Forms a fault-tolerant gliding surface with surface conditions defined on a project-specific basis for the mechanical support/gliding of the vehicle support skids;

(3) Receives the forces in the x-, y- and z-directions resulting from the support skids incl. the voltages resulting from temperature changes due to support skid friction as well as transferring these to the guideway superstructures;

(4) Receives the forces in the x-, y- and z-directions resulting from special vehicles as well as transferring these to the guideway superstructures;

Design requirements

Gliding strip/gliding surface

(1) The gliding strip can be designed as follows:

- As an integral part of the beam or plate (e.g. part of the deck plate);
- Attached as a sealed, screwed or dowelled joint to the cantilever arm;
- Indirectly attached to the cantilever arm (e.g. as an integral part of a functional module).

The position of the gliding surface is shown on Figure 106 and in /MSB AG-FW GEO/.

(2) The gliding surface must follow the course of the three-dimensional curve, taking the transverse gradient into account.

(3) Subject to the design, the gliding surface elements may have a polygonal arrangement if it can be verified that this is compatible with the complete system.

(4) Steel should be used for the gliding strips. If other materials are used, their suitability must be verified.

(5) Gliding surfaces must be given a coating that will barely be damaged by potential mechanical loads and guarantee a high degree of resistance to corrosive attack from the environment - including under conditions of mechanical stress (for metal gliding surfaces, see DIN EN ISO 12 944 Part 1 - 8 and TL 918300 page 87).

(6) Geometry:

- Thickness: Depends on static requirements
- Width: $B_{SS} \geq 150$ mm
- Length: Depending on the system, beam-length gliding surface elements are advantageous.

  Shorter lengths can be used depending on the project.

(7) It must be proven by extensive verification that gliding surface elements with segment lengths shorter than approx 3.0 m are compatible with the complete system.

(8) The requirements for the levelness and positional accuracy of gliding surfaces are listed in /MSB AG-FW GEO/.

(9) It must be guaranteed that inspection equipment (according to /MSB AG-GESAMTSYS/) will detect geometry changes and/or displacement before the permissible limit values for these deformations is exceeded.

(10) The maximum values for the coefficients of friction given in /MSB AG-FW BEM/ must be adhered to. Minimum values for the coefficients of frictions must be agreed on a project-specific basis.

(11) Metallic gliding surface elements must be correctly connected to the guideway lightning protection system.

Gliding strip attachment

(1) Attachment should be carried out according to the selected design.

(2) Attachment must be optimised with regard to maintainability (ease of access for inspection and repair).

Verification process

Gliding strip/gliding surface

The overriding requirements for the guideway verification process specified in chapter 0 must be observed.

Gliding strip attachment

The requirements according to chapter 0 (stator pack attachment) must be observed during the verification process for gliding surface attachment alongside the overriding requirements for the guideway verification process given in chapter 0.

Handling, transport and assembly

(1) The gliding strips and their attachment elements (specific to the design) must be handled correctly.

(2) The gliding strips are normally attached to the guideway beams or guideway plates by the manufacturer as integrated parts of the supporting structure of the guideway superstructure or cantilever arm.

(3) If the gliding strips are fitted retrospectively, then special construction documents (assembly instructions and acceptance specifications) must be drawn up and verified as being compatible with the complete system and submitted to the responsible inspectorate for inspection.

Components of the external on-board energy supply;

General

The external on-board energy supply provides electrical energy to the vehicle in areas in which it travels at a lower velocity (e.g. in stations including limited acceleration areas, at selected operational stopping points, evacuation points, parking areas and in maintenance areas).

The route sections requiring an external on-board energy supply are determined on a project-specific basis.

Potential designs for the external on-board energy supply are:

(1) *Current transfer via conduction: Conductor rail (guideway)/current collector (vehicle) as conductor rail system;*

(2) Non-contact energy transfer through induction.

(3) *The installation space for the guideway-side modules of the external energy supply can be seen in Figure 106* and in /MSB AG-FW GEO/.

The external on-board energy requirements defined in this document must be extended according to the project with requirements for the guideway, vehicle and propulsion subsystems depending on the design (loads, geometry, electrical properties, design details).

Conductor rails

Functional requirements

The conductor rails and their attachment elements must be made so that they can reliably withstand the specified mechanical and thermal loads along with project-specific environmental conditions throughout the required service life in accordance with /MSB AG-GESAMTSYS/.

The conductor rails perform the following functions:

(1) Form a contact surface for the vehicle current collector;

(2) Receive the contact forces in the x-, y- and z-directions resulting from the current collector as well as transferring these to the supporting structure;

(3) Transfer energy for uninterrupted vehicle energy supply;

(4) Enable reliable detection of unacceptable geometry changes and/or displacements.

Design requirements

(1) The conductor rails on the guideway beam should be made up of conductor rail profiles joined together by fixed and extendable connectors, which are attached to the guideway beam by a conductor rail support.
Note: The connectors should be part of the scope of supply of the conductor rail profile. The conductor rail support should be part of the scope of supply of the guideway beam.

(2) The conductor rail profile should be attached to the conductor rail support by a connection mechanism (isolator).

Note: This connection mechanism should be part of the scope of supply of the conductor rail profile;

(3) The conductor rail supports must be arranged, designed and verified for each individual support design and track switching device.

(4) Guideway superstructure movements (in x, y and z direction) must be taken into consideration when designing and arranging the fixed and extendable connectors.

(5) Conductor rails, connection mechanisms and their attachments to the conductor rail support must be designed as permanent elements without play.

(6) The conductor rail support and its attachments to the guideway must be designed as permanent elements without play.

(7) Conducting components must be adequately isolated.

(8) The position of the supply point for the conductor rail system must be agreed along with the supply points for the motor winding when compatibility with the complete system has been verified.

(9) Attachment mechanisms must be provided for the cable routing (e.g. anchor rails) at the supply points on the guideway super/substructures.

(10) An infringement of the space reserved for the vehicle by the conductor rail (e.g. due to failure of the conductor rail attachment) must be excluded.

(11) Failure of individual attachment elements must not result in loss of serviceability or structural safety and must be detectable.

(12) The position and dimensions of the space for the conductor rails and their attachment elements can be found in Figure 106 and /MSB AG-FW GEO/.

Verification process

The requirements according to chapter 0 (stator pack attachment) must be observed alongside the overriding requirements for the guideway verification process given in chapter 0.

In particular the following requirements must be observed:

(1) The design must use the project-specific specifications for the current collector/conductor rail interface on the basis of the overriding actions from the environment and operation specified in /MSB AG-FW BEM/.

(2) The vibration behaviour of the guideway superstructures (dependent on the design of the guideway, the vehicle and the vehicle passing speed) and the free vibration behaviour of the conductor rail support, as well as the conductor rail modules/components, must be taken into consideration when designing and arranging the conductor rail support, modules and components.

(3) The load assumptions and serviceability must be verified metrologically both during prototype development as well as during operation of the finished system;

(4) Temperature-related deformation of the guideway superstructures (longitudinal strain, vertical and lateral deformation) must be taken into account.

Handling, transport and assembly

Detailed instructions for assembly, transport and intermediate storage must be determined according to the specific project and design employed in the form of assembly instructions.

Inductive energy transfer

Inductive energy transfer is currently still in the development stage. The specific requirements for this module will be added once development is finished.

Positioning system components

General

The modules attached to the guideway provide the positioning system modules installed in the vehicle clear information on the absolute position and orientation of the vehicle.

Information can be transferred from the guideway to the vehicle using various systems. One solution that has been used is to transfer data via guideway-side position reference strips (PRR) and vehicle-side sensors (INKREFA read unit).

The PRR consists of a plastic plate with dimensions of approx. 260 mm x 150 mm x 5 mm (W x H x D).

They are attached to the beam with supports.

Functional requirements

(1) Providing coded reference information (reference spot) for vehicle-side determination of the absolute location and the vehicle orientation according to /MSB AG-GESAMTSYS/ (e.g. by position reference strips);

(2) When determining the exact location of the reference spots, the phase arrangement of the motor winding and the requirements of the operational control systems must be considered (see also /MSB AG-GESAMTSYS/).

Design requirements

(1) The design requirements for the guideway-side positioning system modules result from the choice of transmission technology.

Non-contact information transmission to the vehicle (if using position reference strips) can be taken as a starting point.

(2) The position of the positioning system modules lengthways on the guideway are determined on a project-specific basis.

(3) A reference spot is normally marked on each side of the guideway using three position reference strips (i.e. each reference spot is marked by 6 position reference strips).

(4) Attachment of the vehicle-side modules to the guideway must be carried out using special fixtures e.g. position reference strip support (PRS support), which must be made by the manufacturer of the guideway superstructure in accordance with the design.

(5) The space for guideway-side modules is specified in Figure 106 and /MSB AG-FW GEO/.

(6) Failure of attachment elements (supports) must be demonstrably excluded or detectable in good time.

(7) Temperature-related deformation of the guideway superstructures (longitudinal strain, vertical and lateral deformation) must be taken into account.

(8) Both the design-specific, dynamic excitation of the supports and their attachments, as well as the vibrations caused by the passing vehicle, must be considered in the design.

Verification process

(1) Along with the overriding requirements for the guideway verification process in chapter **0** the requirements according to chapter **0** (attachment of stator pack) are to be observed in particular.

(2) The vibration behaviour of the guideway superstructures and the free vibration behaviour of the locating modules/components for the guideway and their attachments are to be taken into account in the design of the locating modules/components close for the guideway and the elements used to secure them.

Handling, transport and assembly

(1) The detailed instructions for the assembly, transport and intermediate storage are to be set down in the form of assembly instructions specific to the project and design.

(2) The guideway positioning modules and components are only to be fitted following complete assembly of the guideway superstructures.

(3) For the project it is to be specifically prescribed whether guideway positioning modules and components are to be attached before or after installation of the motor winding and which modules and components specifically.

Construction style specific guideway equipment

General

The modules/components of the guideway equipment, the requirement and design development of which is dependent on the respective construction style and method of the guideway and is not maglev specific, will subsequently be identified as construction style specific guideway equipment.

The significant elements/modules of the construction style specific guideway equipment are:

(1) *Guideway supports/mountings;*

(2) Earth and lightning protection installation;

(3) Beam gap covers;

(4) *Other add ons*

Guideway support

Functional requirements

The external and internal forces and moments from the guideway superstructures are reliable and are to be passed on via the guideway supports/mountings to the guideway substructures while taking into account all specific boundary conditions (e.g. deformation of the guideway substructures).

Design requirements

The essential requirements of the design layout of the guideway supports are:

(1) The design development of the guideway supports is to be selected in connection with the static layout of the complete guideway superstructure and guideway substructure system.

(2) Suitable supporting systems are to be selected in accordance with the static system of the guideway superstructures (in figure 119 proven support instructions of single span and twin span support beam systems are given as an example).

(3) The determination of the support arrangement in the route taken (sequence fixed-/loose supports of beams following on from each other and in connection with the mounting of primary load bearing elements and other guideway superstructures (e.g. track switching equipment) requires verification of compatibility with the complete system.

(4) The guideway supports and especially the anchorings are to be constructed robustly.

(5) There must be no possibility of the failure of individual parts affecting the function of the relevant guideway support in a way which is inadmissible.

(6) The guideway supports must be clearly identifiable. This must be possible without dismantling of add on parts.

(7) For discretely supported guideway beams additional anchoring elements are not admissible. In order to guarantee positional stability the distance of the guideway support in direction y (support spread) must be sufficiently large and all project specific routing parameters and effects are to be taken into consideration.

(8) For cases of rare actions and combinations of actions it is possible to guarantee the required positional stability via additional fixtures which are normally not required in normal operation according to /MSB AG-FW BEM/ (i.e. are inactive).

(9) By choosing appropriate materials the wear and tear of the moving guideway supports is to be minimised.

(10) Shortcomings, damage and the wear to supports should be clearly noticeable and capable of diagnosis from outside without opening panels (e.g. automation).

(11) The guideway supports are to be developed in such a way that the guideway superstructures can be adjusted in the shortest possible time at the lowest possible cost in the case of building subsidence. The degrees of adjustment are to be prescribed specifically for the project. In the choice of gradation of the adjustment steps the admissible offsets between the guideway superstructures following /MSB AG-FW GEO/ are to be taken into account.

Values of ± 10 mm (at-grade guideway) up to ± 20 mm (elevated guideway with around 5m support height) can be used as guide values depending on the type of guideway in directions y and x. In direction z the guide value up to – 20 mm can be used.

(12) If the admissible value limits of the deformations and displacements are exceeded, a balance should be aimed for by adjusting the guideway supports. If this is not possible a simple exchange of the wearing parts must be guaranteed.

(13) If it is not possible to rule out actions by earthquakes or impact of crossing traffic on the guideway, then inadmissible displacement of the guideway superstructures must be prevented by suitable additional securing elements on the guideway supports.

(14) The position of moving guideway supports must be testable in direction x (e.g. automatic).

(15) The underside of the guideway support must lie above the upper side of the ground.

Guide value for the minimum distance of ground to underside of support: 20 cm

(16) In the case of direct connection of the guideway superstructures to the guideway substructures (e.g. in the case of direct casting of guideway plates and guideway substructures) the durability and safety is to be guaranteed by a robust and error tolerant design.

(17) For carrying out repairs to supports the guideway superstructures should not be raised more than 5mm. The location of presses for raising the guideway superstructures is to be defined and marked on the beam.

(18) Secondary measures for maintaining guideway supports such as removing windings are to be avoided.

(19) The maintenance (inspection and if appropriate the exchange of wearing parts) must be possible from the guideway superstructure where the guideway is raised (special vehicle).

Verification process

The overriding requirements indicated in chapter **0** concerning the guideway verification process are to be observed.

The following requirements are to be given particular attention:

(1) The friction coefficients accepted in the dimensioning of the guideway superstructures and substructures of the moving guideway supports are to be indicated by giving their functions and value limits.

(2) The friction coefficient values given for the guideway supports are to be proven. The speed of movement of the supports is to be taken into account in the theoretical estimation of the wear of the guideway support (verification of serviceability).

Handling, transport and assembly

(1) It is recommended to fit the guideway supports of discretely supported guideway beams to the guideway superstructures on site and to cast the anchoring of the supports in the framework of the fine positioning of the guideway superstructures in the recesses of the guideway substructures provided for this purpose.

(2) The supports are to be protected against damage when transporting the guideway superstructures.

(3) Fitting instructions for the securing of the guideway supports to the guideway superstructures and substructures are to be created.

Earth / lightning protection

General

In order to guarantee faultless and reliable operation, effective earth and potential balancing appliances are to be provided.

The leakage conductance from excess voltage resulting from lightning action on the vehicle is made over the functional levels of the guideway.

Along with the general instructions for the layout of earth and lightning protection appliances of DIN VDE 0100, DIN 18014, DIN VDE 0101 and DIN VDE 0185, the following requirements are to be observed.

Functional requirements

(1) For protection of personnel and protection against the effects of electrostatic charges as well as in regard to the electromagnetic compatibility (EMC) the electrical actions from:

- Lightning strikes,
- Potential differences and
- System related earth and fault currents of all components and modules of the guideway

are to be drawn off into the ground via an earth and lightning protection system of the guideway superstructure and substructure. All electrically conducting components and modules of the guideway are to be included in this.

(2) All electrical connections are to be constructed in such a way that they reliably meet the specified requirements in the project specific environmental conditions during the whole service life.

(3) For the guideway/vehicle interface the guideway is to be constructed in such a way that

- The earth of the vehicle in set down state
- The leakage conductance from excess voltage resulting from lightning actions on the vehicle

is assured over the function levels of the vehicle.

Design requirements

(1) The lateral guidance rails attached to the cantilever arms of the guideway superstructures and metallic sliding strips present if appropriate must be incorporated into the lightning protection system as a lightning current arrester of the lightning protection.

(2) Guideway equipment for which earth and lightning protection connections are to be provided in accordance with valid standards are to be integrated into the lightning protection system of the guideway superstructures.
The earthing cable of the motor winding is to be integrated into the earth and lightning protection system at the start and end of the beam and at both ends of the guideway beams. For guideway beam type III the distances between two connecting points along the length of the guideway must not exceed 30 m.
Note: Corresponding connection points on the earth/lightning protection system are to be taken into account as early as during the design of the beam.

(3) The earth/lightning protection system of the guideway superstructures is to be connected with the earth/lightning protection system of the guideway substructures. For this purpose the earth conductors of the guideway superstructures and substructures are to be made at external connecting points at each support point so that an electrically conductive connection can be made. For guideway beam type III this is to be provided at each first and last back up ring.

(4) For testing and measurement tasks, and also for external installations which are to be incorporated in the earth system, connecting points are to be provided in the lower area of the support connecting points on the earth/lightning protection system. The exact position and number of these connecting points is to be determined specifically for the project.

(5) The reinforcement steels with the function of conducting lightning currents are to be identified in the reinforcement plans.

(6) The reinforcement steels with the function of conducting lightning currents are to be connected to one another durably and with electrical conductivity in line with the generally recognised rules of engineering.

(7) The clearance spaces defined in /MSB AG-GESAMTSYS/ and /MSB AG-FW GEO/ are to be taken into account.

(8) The external joining and/or connecting points must be capable of being visually inspected without dismantling of panels (e.g. with the help of automatic image processing).

(9) All electrical connections are to be constructed in such a way that they reliably meet the specified requirements in the project specific environmental conditions during the whole service life.

(10) In the dimensioning, sufficient mechanical protection of the external electrical connection conductor must be guaranteed.

Verification process

The overriding requirements indicated in chapter **0** concerning the guideway verification process are to be observed.

The following requirements are to be given particular attention:

(1) The layout of the earth and lightning protection system is to be carried out appropriately in line with the state of technology and documented (dimensioning and construction/design).

(2) The suitability of the planned measures is to be tested by the appropriate board of control and their expert if appropriate.

(3) For the planning of the construction, verification of compatibility with the complete system is to be provided.

(4) Following manufacture of the guideway, the earth resistance of the guideway substructures (foundation earth electrode) and the transit resistance between the guideway superstructures and guideway substructures is to be measured and recorded with random samples and in agreement with the board of control.

Handling, transport and assembly

(1) Electrical connections between the guideway superstructures and the guideway substructures are to be made on site.

(2) The accessibility of the connecting points is to be taken into account in the design layout.

(3) Pre-fabricated connecting leads are recommended.

Beam gap covers

General

The horizontal gap between consecutive guideway beams are to be closed in accordance with chapter 7.3 (21) as this gap can lead to inadmissible aerodynamic loads for the vehicle (variations in pressure in the sub nose area).

Subsequently the system technical requirements for the required beam gap cover are specified.

Functional requirements

(1) The fluctuations in pressure between the upper side of the guideway and the bottom of it when crossing beam gaps with the vehicle are to be reduced / prevented.

Design requirements

The design requirements of the beam gap covers are:

(1) Appropriate choice of material and connections;

(2) Appropriate choice of corrosion protection;

(3) Consideration of the movements of the guideway (temperature and substructure deformations);

(4) Robust and error tolerant design of all components and modules;

(5) Minimisation of maintenance expenditure;

(6) Optimisation of ease of inspection;

(7) Minimisation of possible negative effects on aerodynamics and noise;

(8) Consideration of vibrations of the guideway;

(9) Consideration of possible mechanical and functional repercussions on the guideway;

(10) Possible installation spaces are to be prescribed specifically for the design;

(11) Exclusions of incursions on clearance space through failure of parts;

(12) Minimisation of collections of depressions;

(13) Consideration of aerodynamic actions from the vehicle crossing (pressure/suction);

(16) The upper side of the guideway superstructure should be made level.

Verification process

The overriding requirements indicated in chapter **0** concerning the guideway verification process are to be observed.

Handling, transport and assembly

Where there are particular requirements of assembly and handling, these are to be prescribed in an assembly and acceptance instruction. Other add ons.

General

All additional modules/components which are secured to the guideway superstructure or guideway substructure and were not covered in the previous chapters of guideway equipment are categorised under the term "Other add ons".

Examples of these other extensions are:

(1) Appliances for maintenance (e.g. fixed ladders and protective bars);

(2) Temporary add ons for testing of new modules/components;

(3) Appliances for evacuation of passengers.

Functional requirements

(1) The add ons must be made in such a way that they meet all requirements reliably in the project specific operating and environmental conditions during the service life demanded.

(2) The add ons must be made in such a way that they do not have any inadmissible effects on the operation.

(3) The specific functional requirements on the modules and components of the other add ons are to be defined individually.

Design layout

The design layout of the add ons is to be formed dependent on the specific requirements with the following general factors being taken into consideration:

(1) Appropriate choice of material and connections;

(2) Appropriate choice of corrosion protection;

(3) Robust and error tolerant design;

(4) Minimisation of maintenance expenditure;

(5) Minimisation of possible negative effects on aerodynamics and noise;

(6) Consideration of vibrations of the guideway as a result of dynamic load actions from operation and the environment;

(7) Consideration of possible mechanical and functional repercussions on the guideway;

(8) Consideration of possible plastic and elastical deformations of the guideway;

(9) Consideration of possible repercussions on the whole system (e.g. radio system);

(10) Possible installation spaces, geometry and admissible tolerances in the area of the guideway are to be prescribed specifically for the project;

(11) Incursions on clearance space as a result of failure of parts are to be ruled out in the design.

Verification process

The overriding requirements indicated in chapter **0** concerning the guideway verification process are generally to be observed.

The following requirements are to be given particular attention:

(1) For all designs verification of compatibility with the complete system must be given.

(2) Dependent on the type and design of the other add ons, further requirements of the verification process are to be taken into account where appropriate.

(3) The load assumptions and serviceability are to be proved by measurements both in the development of prototypes and in the commissioning of the system realised.

Handling, transport and assembly

(1) The other add ons are to be handled and fitted appropriately.

(2) Where there are particular requirements of fitting and handling, these are to be prescribed in a fitting and acceptance instruction.

Track switching equipment

General

The general designs/types of track switching equipment are shown in figure 110.

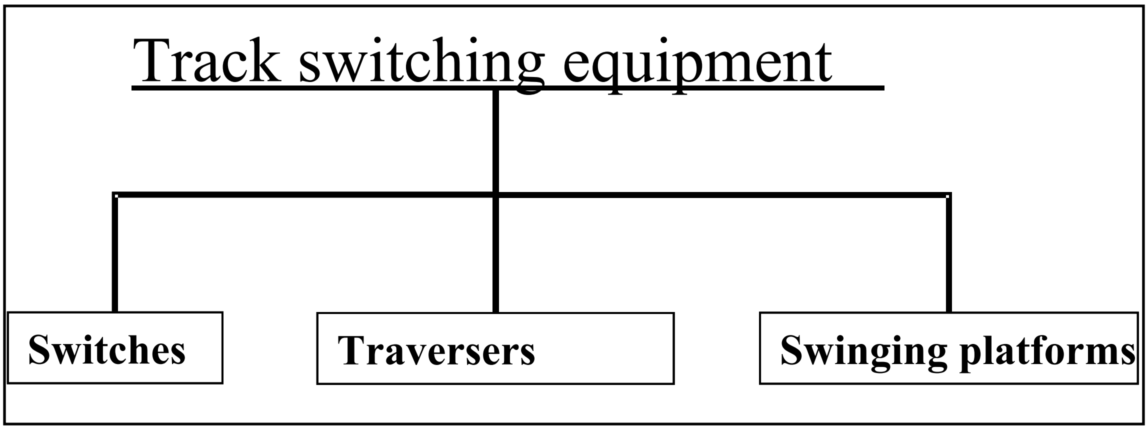

Figure 110: Designs/types of track switching equipment

The use of the individual types of track switching equipment is dependent on the operational requirements.

These are divided into

(1) *Track switching equipment which does not require an interruption to the journey (switches and transfer connections as combinations of switches) and*

(2) Track switching equipment which requires an interruption to the journey (transfer tables, swinging platform),

.

Switches in a turning off position can be ridden over at various speeds depending on the geometry (bending line) (normal arrangement: Slow travel switch and quick travel switch, see /MSB AG-FW TRAS/). Transfer connections which make the switch to a track which runs parallel possible can be realised through a combination of switches (see /MSB AG-FW TRAS/).The track switching equipment is normally made up of the following principal groups:

- *Guideway superstructure (e.g. bendable supports with horizontal beams and abutments);*
- *Positioning elements (normally electro mechanical propulsion systems);*
- *Locking devices;*
- *Air gap bypasses;*
- *Sensor technology and control;*
- *Energy supply;*
- *Switchgear areas;*
- *Guideway equipment.*

Functional requirements

The following functional requirements are to be taken into account with regard to the operational safety (incorporation into the operational control systems) and availability:

(1) The track switching equipment must make a secure, reliable switch of track possible for vehicles and special vehicles.

(2) *The information about the status "track switching equipment can be travelled over safely" is needed by the operational control systems BLT for testing.*

For this purpose the track switching equipment must make the required signals available for the systems control technology.

(3) After reaching a secure end position the track switching equipment must retain its safe end position regardless of failures in the sensor technology, monitoring or energy supply.

(4) The design of the track switching equipment must ensure that it is not possible to leave the secured end position without clearance by the systems control technology.

(5) The failure of an individual electrical, electronic or electromechanical assembly in positioning or locking devices, control, monitoring or current supply must remain without effect on the ability to adjust and the correct message about the condition (safe end position) and the position of the track switching equipment on the systems control technology.

(6) The correct message about the condition (safe end position) and the position of the track switching equipment (e.g. straight ahead position) must come to the systems control technology in the case of failure of an individual mechanical assembly too.

(7) A diagnostic device for online diagnosis is to be integrated.

(8) A device for adjustment of the track switching equipment on site is to be provided (on site adjustment operation).

Design requirements

(1) The interchange of the design is to be taken into account back in the planning phase if the service life of the track switching equipment does not correspond to the service life of the section of line.

(2) The time cost for the exchange of modules/components of the track switching equipment must correspond to the operational boundary conditions. Prescriptions regarding this must occur in a project specific way.

(3) The project specific adjustment times to be prescribed must be taken into account in the dimensioning of the propulsion elements.

(4) The control and monitoring must make it impossible for the support safety and serviceability of the track switching equipment or their components and modules to be affected adversely as a result of incorrect function of individual actuating drives (e.g. through monitoring of synchronised operation). The actions from the incorrect function are to be included in the verification process of the track switching equipment.

(5) The devices for adjusting and locking of the track switching equipment are to be constructed with robust and error tolerant modules which are as low maintenance as possible.

(6) An interruption free supply of current is to be guaranteed for the securing of the track switching equipment.

(7) All modules/components are to be developed/integrated in such a way that the maintenance expenditure is kept to a minimum.

(8) In order to achieve high availability of the track switching equipment, functional redundancy of the propulsion systems is to be attained.

(9) The guideway substructures of at-grade track switching equipment consist of foundation with elements for supporting and locking the horizontal beams.

(10) The guideway substructures of elevated track change devices consist of foundation, supports and support head plates with elements for supporting and locking the horizontal beams.

(11) The static system of track switching equipment is to be defined dependent on the static and system technical requirements (e.g. bending line). The prescription of the static system requires proof of the compatibility with the complete system.

(12) The routing technical requirements of the track switching equipment are set down in /MSB AG-FW TRAS/.

(13) The requirements of the geometry of the function levels are set down in /MSB AG-FW GEO/.

(14) Mountings are to be equipped with stop/anti derail devices and bolts for removal of the supporting forces and these devices are to keep the track switching equipment reliably in the required position while taking all actions from operation and environment into account.

(15) Short guideway elements (abutment; $L \geq 1{,}032$ m) are to be used as intermediate elements between the moving guideway superstructures of the track switching equipment and the guideway superstructures of the connecting guideway or the moving end of connecting track switching equipment. The modules for locking and if appropriate gap filling are to be integrated into these abutments.

(16) The most robust possible products are to the used for the modules and components of the track switching equipment.

(17) In order to guarantee fault free winter operation, snow and ice sensitive control equipment is to be heated and protected against collection and compression of snow where appropriate.

(18) Rain water is generally to be drained off in such a way that icing up between moving parts can be ruled out.

(19) The structure of the control of the track switching equipment and the structure of the interfaces for securing the track switching equipment are to be defined project specifically in agreement with the operational control systems. Suitable installation spaces are to be provided.

(20) The control and monitoring of the control and locking equipment (for coming to the position given by the systems control technology) usually occurs at the instigation of the systems control technology). A device for manual adjustment of the track switching equipment is to be provided.

(21) Buildings (if appropriate areas in existing buildings) which are to be as uniform as possible are to provided very close to the track switching equipment for the control, safety and current supply devices.

These buildings form part of the periphery of the track.

(22) For returning of the cable of the long stator winding from the mobile to the fixed switch end, suitable holding fixtures are to be provided.

(23) It is recommended that there is a possibility of illuminating track switching equipment. For elevated track change devices the fitting of a work surface (e.g. grating) under the continuous girders can be effective. Both help to speed up maintenance measures during breaks in operation.

(24) The compatibility of the horizontal gap developing at the mobile switch end (to the adjacent guideway) with the requirements of the complete system is to be proved.

Verification process

The overriding requirements indicated in chapter **0** concerning the guideway verification process are generally to be observed.

The following requirements are to be given particular attention:

(1) Particular attention in the testing and commissioning of track switching equipment must be aimed at the proof of incorporation of the track switching equipment into the systems control technology.

(2) The adherence of the required transition times for each installed track switching device is to be proved.

(3) The frequency of adjustment to be taken as a basis for the dimensioning is to be prescribed specifically for the project.

(4) Instructions for the required reliability of the modules/components (e.g. MTBF values) must occur in a project specific way.

(5) The electrical power required for operation of the track switching equipment is to be established in a project specific way for the dimensioning of the energy supply.

(6) In track switching equipment, verification of the correct position of the maglev specific guideway equipment for each possible operating condition which may be observed (e.g. branching off or straight ahead positions at switches) must be provided.

Handling, transport and assembly

(1) For the appropriate transport and error free assembly of the track switching equipment instructions are to be created.

Special structures

Tunnels

General

The standards for tunnels are to be taken from /MSB AG-GESAMTSYS/

Primary load bearing elements

General

Under the term „primary load bearing element" all structures are included which hold the guideway super-structure as an interim construction in the place of the usual guideway substructures and whose loads drain off via its own foundation into the ground. Generally primary load bearing elements are used in order to bridge large spans (e.g. valley bridges).

Functional requirements

(1) The functional requirements of the primary load bearing elements correspond to the requirements of the guideway substructures (see chapter **(2)**).

(2) In addition the consideration of location and/or project specific requirements for holding individual modules of the line periphery may be required.

Design requirements

(1) The required holding of elements/modules of the other guideway equipment or line periphery is to be prescribed in a project specific way with verification of compatibility with the complete system.

(2) The necessity of providing gangplanks for the evacuation of people and other rescue devices is to be prescribed individually as a function of the project specific safety and operating design.

(3) For primary support elements in two stage or multi stage construction the fixed bearing is to be arranged in the central primary support element area.

(4) With large spans the gaps which occur at the crossing to the next guideway are to be defined in such a way by measures which are to be defined in a project specific way that the value limits given in /MSB AG-FW BEM/ und /MSB AG-FW GEO/ are not exceeded. Essentially here the temperature related shifts and/or deformations on the primary load bearing element in x and y direction and the various settlements in direction z with regard to the subsequent guideway are to be taken into account.

(5) The project specific requirements for winter service are to be adhered to (e.g. falling snow when clearing intersection areas).

Verification process

The overriding requirements indicated in chapter **0** concerning the guideway verification process are generally to be observed.

The following requirements are to be given particular attention:

(1) The dynamic behaviour of the primary load bearing element is to be verified.

(2) Settlements, expansion gaps and changes in incline at the crossing to the next guideway are to be shown.

(3) The requirements and serviceability are to be proved by measurements on commissioning the system achieved. The scope is to be agreed with the inspectorate.

(4) The theoretical assumptions applied for the calculations of the deviations in the geometry of the function levels (between primary load bearing element and subsequent guideway) resulting from different structure temperatures are to be verified metrologically.

Handling, transport and assembly

For appropriate transport and error free fitting of the individual components and modules on the primary load bearing element, project specific instructions are to be created.

Edge of line

General

The edge of the line includes

(1) system technically required small structural appliances which are used in the environment close to the route (e.g. radio mast, power houses) and

(2) other required structures which follow the guideway in their position (e.g. noise insulation wall, visual protection, deviation protection etc).

The edge of the line also includes e.g.:

- *Power houses of the propulsion system;*
- *power houses of the track change devices;*
- *radio masts;*
- *cable channels;*
- *enclosures;*
- *impact protection structures;*
- *noise protection structures;*
- *sight protection structures;*
- *supporting walls, troughs.*

Functional requirements

The functional requirements of the appliances of the edge of the track result from their tasks and are thus individually different.

The appliances must however all be made in such a way that they

(1) reliably meet all requirements during the required service life at project specific operating and environmental conditions (such as e.g. the requirements as a result of aerodynamic actions, vibrations, consideration of the natural vibration behaviour) and

(2) have no inadmissible effects on operation.

Design requirements

(1) The design requirements of the modules/components at the edge of the track are to be prescribed specifically for the project.

(2) For components at the edge of the track, verification of compatibility with the complete system is to be given.

This also relates to the arrangement of the components and modules in planning in particular.

Verification process

(1) The verification for the appliances at the edge of the track are to be made in line with the state of technology with possible maglev railway specific actions being taken into account.

(2) The overriding requirements indicated in chapter **0** concerning the guideway verification process are generally to be observed.

Handling, transport and assembly

(1) For the individual appliances at the edge of the track, instructions for handling, transport and assembly are to be created if this is not yet prescribed in the design planning. This can be done without in the case of reliable ancillary components/modules.

Quality management and quality assurance

General

A comprehensive quality assurance is required in all phases from the planning up to the manufacture and use of the guideway in order to able to assure adherence to the guideway standards.

These phases are:

- *Development;*
- *Planning (outline/design planning of the routing and structures);*
- *Verification process (design and qualification);*
- *Manufacture (production, equipment, transport and assembly);*
- *Commissioning and testing;*
- *Maintenance (inspection, servicing, repair).*

The measures for assuring the required quality of the guideway are to be set down in a comprehensive quality management system (QS) – following DIN ISO 9000ff. This system must take all aspects of quality assurance into account and is to be agreed by the supplier with the responsible inspection bodies directly after the start of the project (e.g. in the form of test specifications, test instructions or work instructions).

The supplier/manufacturer must use quality management and quality assurance to ensure that

(1) adherence to the system technical and safety technical requirements is assured, verified and documented in terms of development and manufacture. The aim of the quality assurance is to ensure and document the adherence to the minimum requirements by testing the required verifications. This is the prerequisite for the orderly integration of the guideway subsystem into the complete system.

(2) the relevant quality documentation is made available for his scope of supply.

(3) the project dependent quality risks are analysed and suitable measures are prescribed individually.

The analysis should occur before the start of the project and in coordination between the subsystems (guideway, vehicle, propulsion/energy supply and systems control technology)and the responsible inspectorate and building manager. For this all interfaces of the guideway subsystem are to be balanced with those of the other subsystems.

(4) an assessment and if appropriate an adaptation of the prescribed measures is carried out at intervals to be prescribed (e.g. at the end of individual project phases) or when unexpected circumstances arise.

(5) the results of the quality assurance are documented in a suitable form (test reports, result records etc), comprehensibly archived and made available in a suitable form for maintenance and later use.

(6) the use of the guideway can take place in line with the project specific requirements.

In detail it is recommended that

(1) all required standards are specified.

(2) the required design regulations and methods are stated and matched to the project engineering and technologies.

(3) Methods, processes and tools are prescribed and used in order to prove that all standards were verified (e.g. through analysis, examination, testing, design review, audit).

(4) there is a prescribed qualification standard for each module/component which makes it possible to show that the unit is laid out and designed in such a way that it reliably fulfils all project specific standards for operation and environment.

(5) the design is producible and repeatable and the resultant product can be verified and used within the operational limits given.

(6) appropriate monitoring measures for acquiring components, materials, software and hardware elements and services are taken.

(7) Manufacture, integration, testing and maintenance are demonstrably carried out in such a way that the end product matches the valid configuration.

(8) a monitoring system for non conformities is introduced and maintained so that they can be followed up systematically and their recurrence can be prevented.

(9) quality notes are made and analysed in order to record and report trends punctually for preventative and corrective measures.

(10) all required testing equipment and tools for checking, measuring and testing the modules/components are available and they are regularly calibrated in order to assure their accuracy.

(11) Processes and instructions for marking, separating, handling, packing, preserving, storing and transporting of all modules/components are introduced.

Verification of the guideway with regard to compatibility to the complete system

The verification of compatibility of the components and modules of the guideway to the complete system must be planned and carried out in a project specific way.

The responsibility for this lies with the supplier of the guideway or the respective component or module.

The verification helps to assure serviceability (availability, ability to maintain, functionality) of the respective component/module for use within the complete system and also assures the function of the complete system when using the respective component/module.

The verification of compatibility with the complete system includes testing of adherence to the system technical minimum requirements

(1) of development and design documents.

(2) for the routing (dynamic handling test, geometrical routing test, test of the distribution of supports and linked to this the maglev specific guideway equipment).

(3) for project specific planning and design documents including the planned arrangement of the guideway equipment and edge of the track.

(4) for manufacturing and assembly processes.

(5) for the modules and components realised for the guideway.

(6) for the measurements to be defined project specifically (e.g. noise, ride comfort, aerodynamics, vibrations, interaction of guideway/vehicle).

For the testing of adherence to the system technical minimum requirements on modules and components which have been completed, the following verifications must be provided at the very least:

(7) Verification of quality assurance in the factory (e.g. geometrical checking of guideway beams);

(8) Verification of carrying out the interim inspection of the guideway following fine positioning as a prerequisite for clearance for use with guideway bound special vehicles (and the subsequent on site installation of the guideway equipment);

The interim inspection of the guideway must include the following at the very least:

- the establishment of positive results of the quality tests of the materials or components in the framework of the building design;
- a visual test which includes components which are hard to access with emphasis placed on the supporting and load discharging components and modules (e.g. supports, cantilever arm);
- the documentation of the test and all deviations established from the desired state.

(9) Verification of the carrying out of the final system technical inspection of the guideway following completed installation of the guideway equipment as a prerequisite for clearance for riding with vehicles;

The final system technical inspection must include the following at the very least:

- the establishment and documentation of the rectification of all shortcomings and damage and deviations from the planning documents;
- the geodesic three dimensional recording of the space curve of the routing with deviations from the desired state (if this has not occurred in connection with the assembly);
- the geodesic three dimensional recording of the position of the foundations (if this has not occurred in connection with the assembly);
- the verification of adherence to the system technical minimum requirements (in accordance with /MSB AG-FW ÜBG/ and /MSB AG-FW GEO/);
- the documentation of the test and all deviations established from the desired state;
- the documentation of the results of an examination which may be repeated after elimination of deviations.

The final system technical inspection serves to establish the "zero condition" (condition of the guideway before commissioning). This condition is the basis for the assessment of the effects of all changes which occur later.

Following this test and following commissioning of the vehicles, the reference runs of the automated measurement systems must be carried out within a short period of time and these must be assigned to the geodesic measurement data.

The measures demanded in this chapter are required from a system technical viewpoint. They form part of the total acceptance test.

In the course of creating the components, tests and inspections carried out can be assessed as part of the building supervisory acceptance if it can be assumed that there have not been any significant changes in the meantime.

Documentation

General

The documentation of the guideway includes:

(1) technical documents of the guideway components and modules;

(2) documentation of the project specific boundary conditions;

(3) technical documents on construction (including quality assurance documentation);

(4) Documentation for guideway maintenance.

Verification process for modules / components

(1) The stability verification (supporting stability, proof of material fatigue), serviceability verification and the associated drawings are to be stated with the generally recognised rules of engineering being taken into consideration. For electronic data processing supported verification of stability the “guideline for stating and testing of electronic data processing supported stability verification” /Ri–EDV–AP–2001/ applies.

Project specific requirements

The project specific boundary conditions (requirements and instructions) for the guideway are to be prescribed in a project specification for the guideway.

This specification is to contain at least the following:

(1) project specific supplementation of the guideway design basis;

(2) project specific system technical guideway equipment list;

(3) Maintenance plan/programme for the guideway with an interface to the overriding maintenance plan/programme of the complete system;

(4) Definitions for guideway equipment (position and coding of the reference rails, position and arrangement of the stator packs and arrangement of the motor winding, definition of the areas with external on-board energy supply);

(5) Definition of the stopping places;

(6) Creation of a top and limiting velocity from guideway dimensioning;

(7) Examinations of the actions from the environment (e.g. of snow and ice on the minimum gradient height and/or crossings of the infrastructure).

Technical documents for construction

The technical documents for construction must contain design documents and verification of modules/components of the guideway and neighbouring structures (graphic representation of the component with corresponding uniformity, serviceability verification, verification of dynamic strength etc) and also the following in particular:

(1) Documents for appliances on the edge of the track and structures on the edge of the track (with regard to the adherence to system technical requirements);

(2) Documents on transitions between special structures/special designs and the standard guideway (with regard to the adherence to the system technical requirements);

(3) Documents on interfaces of the guideway with stations and stops (to assure adherence to the system technical requirements);

(4) Documents for design of the complete lightning protection and earth system including all inaccessible cables and connections within the guideway superstructures and substructures;

(5) Quality assurance programmes of the guideway manufacturer to realise a guideway (procedure to ensure that the system technical and safety technical requirements are adhered to);

(6) results of quality assurance in the factory (e.g. geometrical checking of guideway beams in the factory);

(7) results of fine positioning;

(8) Routing (layout, gradients, banking);

(9) Maintenance programmes for the individual components and modules of the guideway;

(10) Documents about add ons on the guideway in the project specific system technical guideway equipment list.

System technical guideway equipment list

In the framework of the design planning a system technical guideway equipment list is to be created.

This document is to contain at least the following information in rising kilometres for each track:

- Track data (space curve, ranges, radius, banking, gradient height over ground etc);
- Substructures (with component numbering, location reference to space curve, and information about special structures, track switching equipment and mass spring systems);
- Beams (with component numbering, location reference to space curve, information on the exact system length of the beam and support arrangement);
- Stator pack arrangement (for each beam with information about the nominal gap on the beam crossing, type indication of the used stator packs and complemented with module arrangement if appropriate);
- phase related position of the motor winding (in relation to the use of the stator packs) and definition of the cable entries and exits (in relation to the substructures);
- the guideway modules of the location system with location reference to the position of the motor winding (e.g. arrangement and coding of the support reference strips);
- Stopping place areas;

- Areas with external on-board energy supply (with definition of the cable structures on the substructures).

The system technical guideway equipment list should be complemented with additional information for the edge of the track in a project specific way (such as e.g. radio aerials, cable routings, protective structures etc).

Documents for maintenance

see /MSB AG-FW IH/

Annex I-A Maximum dimensions for guideway superstructures

In the following figures the maximum dimensions for guideway superstructures of the standard guideway types I, II and III are given. These dimensions are to be taken into account in the development of new guideway superstructures along with the requirements for clearance following Figure 106.

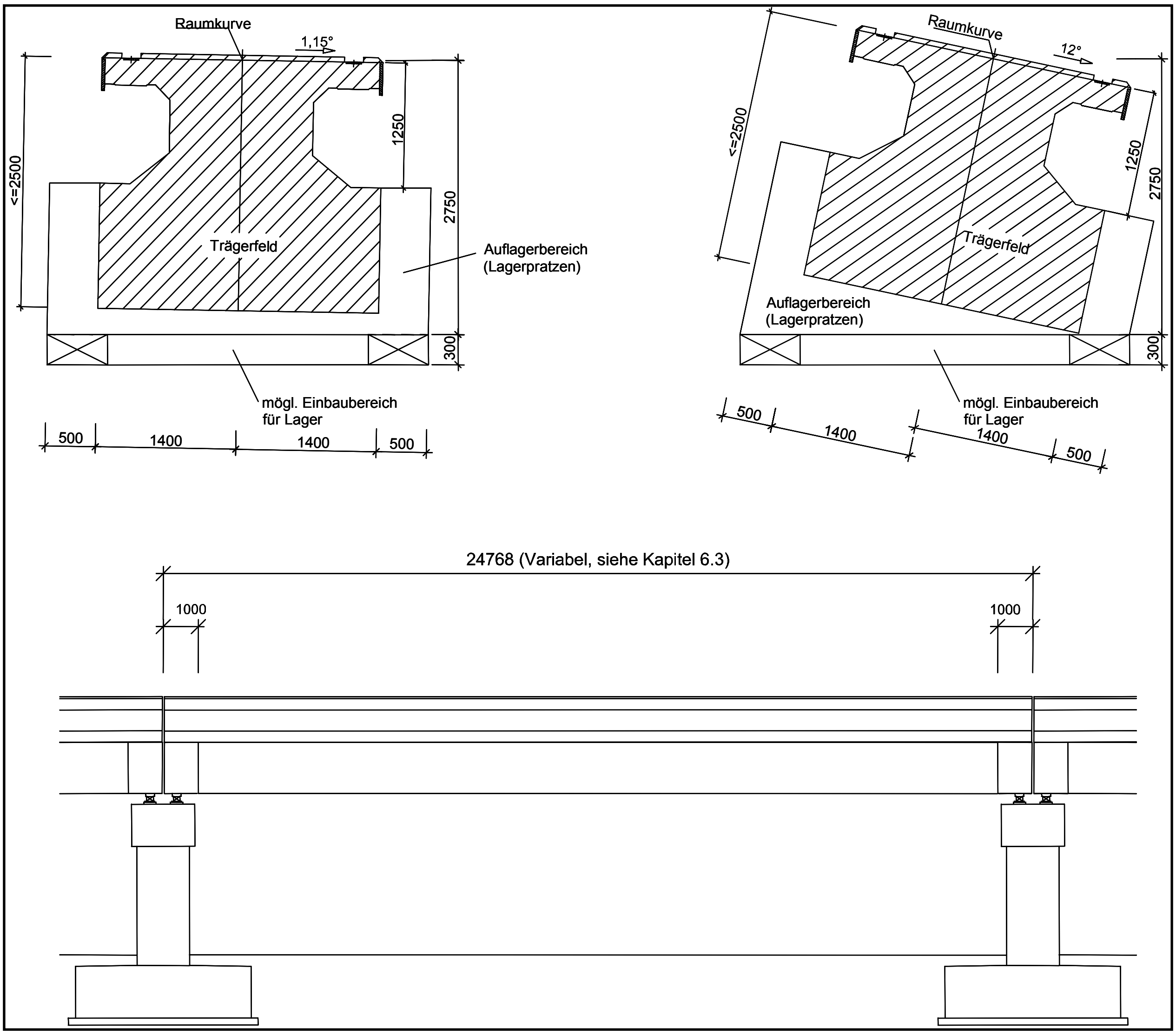

Figure 111: Maximum sectional dimension for standard guideway type I (example)

Raumkurve	Space curve
Trägerfeld	Beam field
Auflagerbereich (Lagerpratzen)	Support area (support paws)
Mögl. Einbaubereich für Lager	Possible installation area for supports
(Variabel, siehe Kapitel 6.3)	(Variable, see chapter 6.3)

Figure 112: Maximum sectional dimension for standard guideway type II (example)

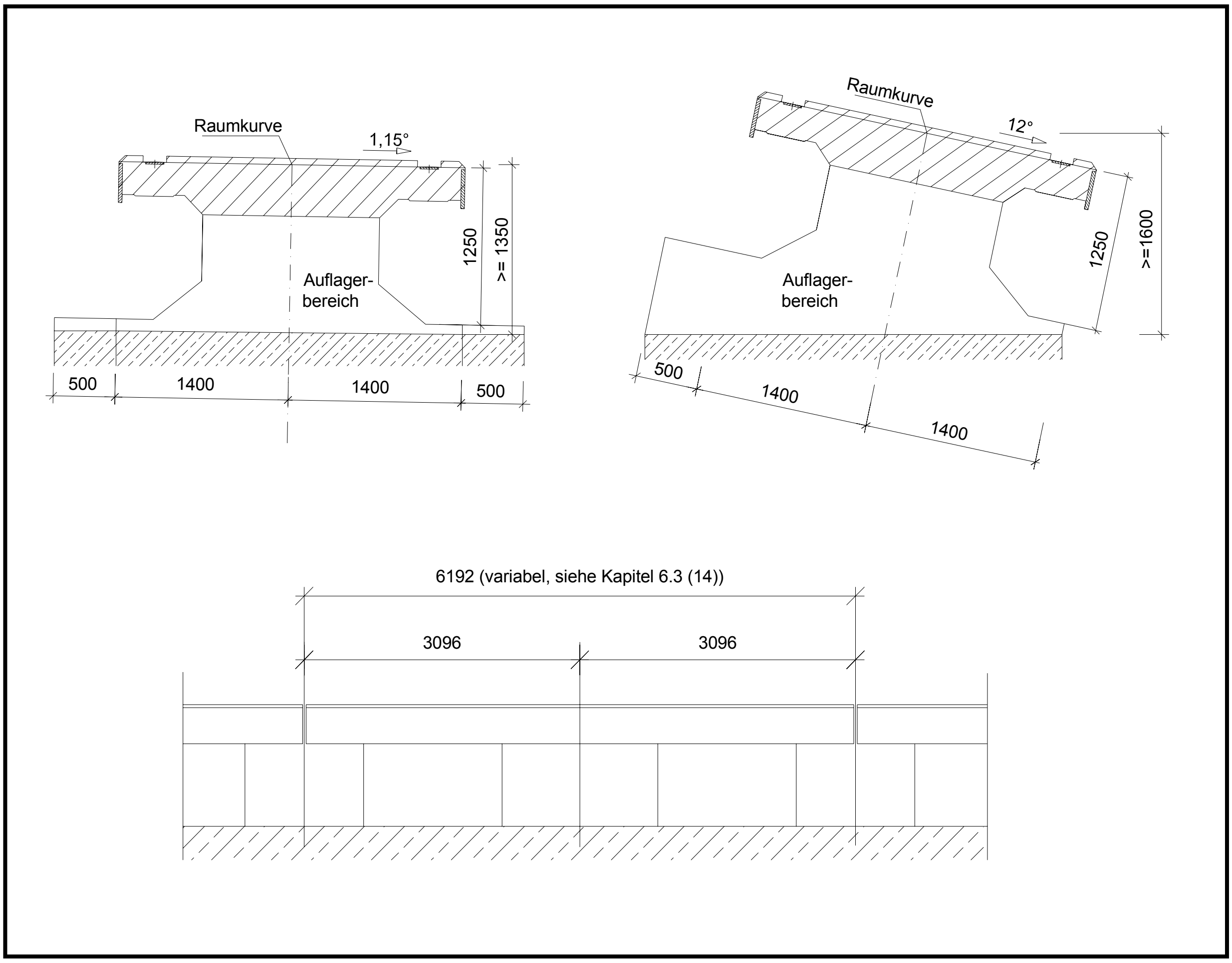

Figure 113: Maximum sectional dimension for standard guideway type III (example)

Raumkurve	Space curve
Auflagerbereich (Lagerpratzen)	Support area (support paws)

(Variabel, siehe Kapitel 6.3)	(Variable, see chapter 6.3)

Annex I-B Arrangement of the maglev train specific guideway equipment (informative)

In figure 114 the arrangement of the maglev specific guideway equipment on the guideway beam is shown as an example.

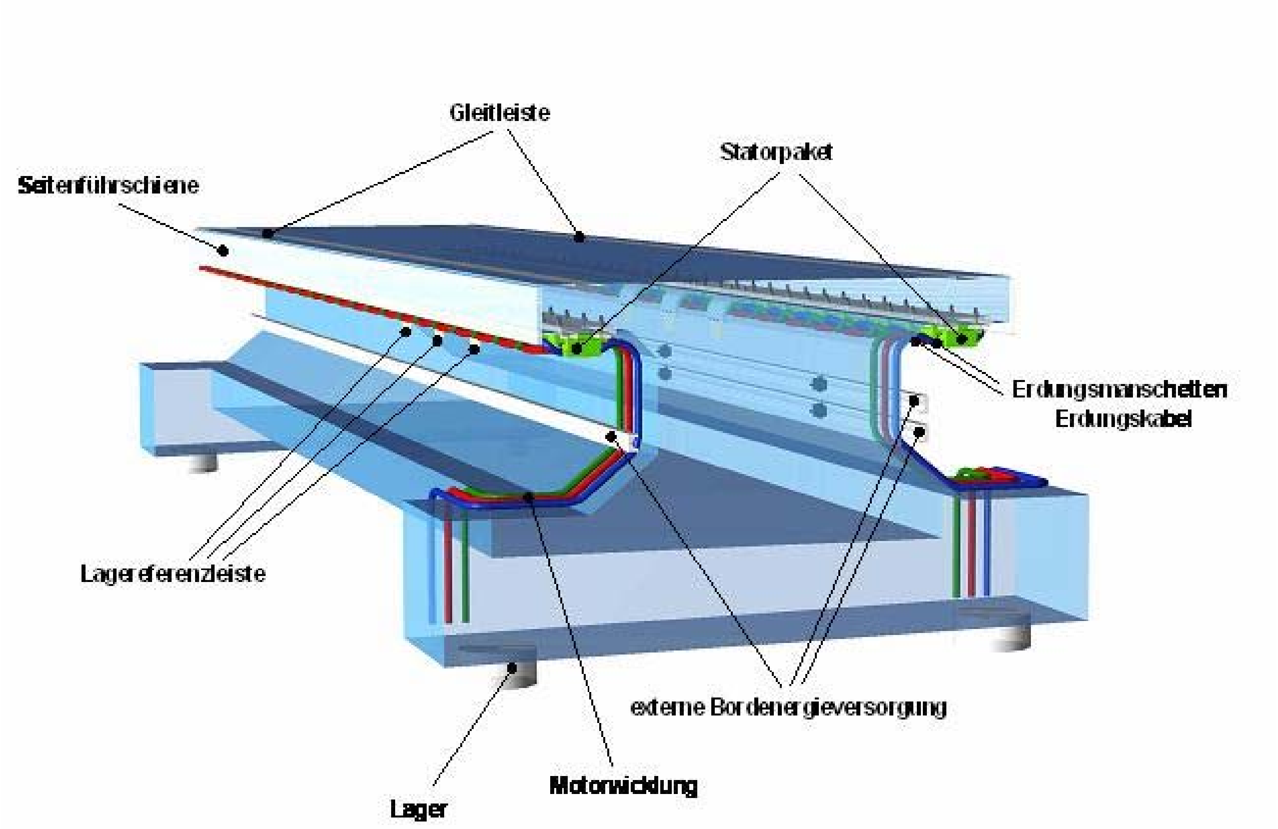

Figure 114: Arrangement of the maglev train specific guideway equipment on the guideway beam

Seitenführschiene	Lateral guidance rail
Gleitleiste	Sliding strip
Statorpaket	Stator pack
Erdungsmanschetten	Earth sleeves
Erdungskabel	Earth cable
Externe Bordenergieversorgung	External on-board energy supply
Motorwicklung	Motor winding

Lagereferenzleiste	Position reference rail
Lager	support

Annex I-C Stator pack and motor winding (informative)

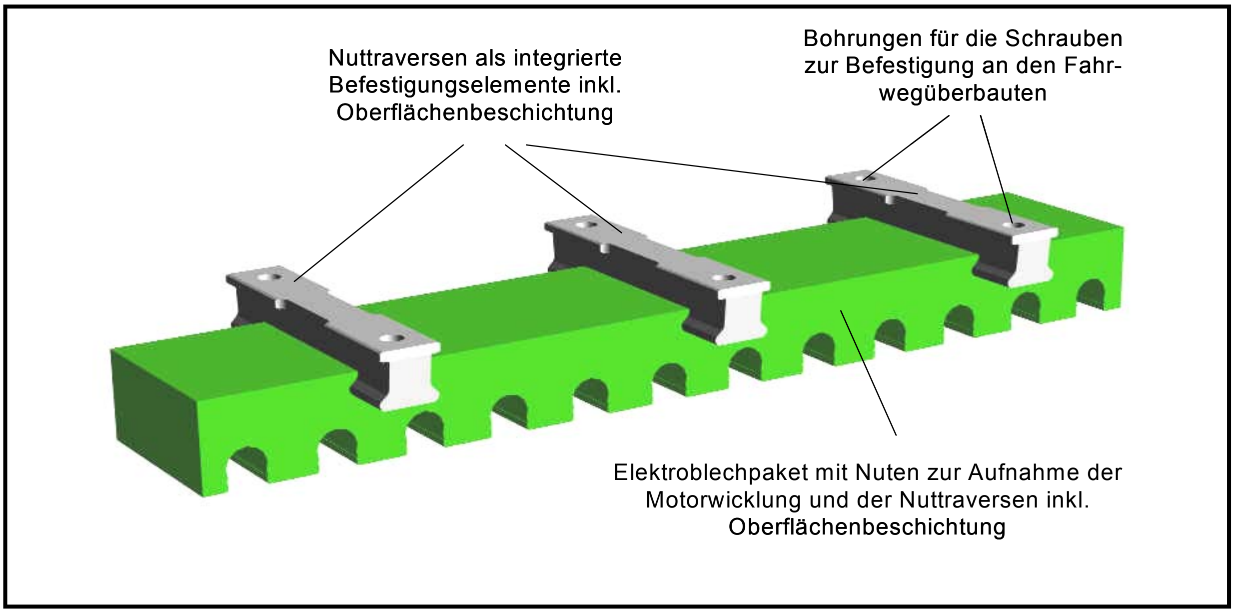

Figure 115: Example of a completed stator pack

Nuttraversen als integrierte Befestigungselemente inkl. Oberflächenbeschichtung	Groove cross beams as integrated securing elements including surface coating
Bohrungen für die Schrauben zur Befestigung an den Fahrwegüberbauten	Bores for the bolts for securing to the guideway superstructure
Elektroblechpaket mit Nuten zur Aufnahme der Motorwicklung und der Nuttraversen inkl. Oberflächen beschichtung	Electro laminated core with slots for accepting the motor winding and the groove cross beams including surface coating

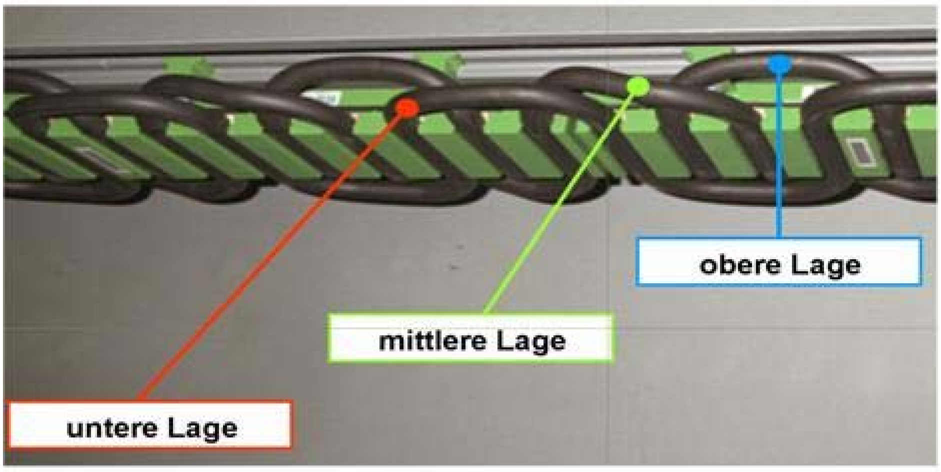

Figure 116: Example of a 3 phase motor winding

Untere Lage	Lower position
Mittlere Lage	Middle position
Obere Lage	Upper position

Annex I-D Diverse redundant securings for stator packs (examples)

In the following figures examples for diverse redundant securings for stator packs are shown. The solutions shown (figure 117 and figure 118) are used in prototypes of the Transrapid test facility in Emsland (TVE) and in the Shanghai stretch.

The primary fixing in these solutions consists of a pre-tensioned bolt (primary fixing) The redundancy consists of the grooves by the cantilever arm and the cantilever arms of the groove cross beams by the stator pack. If bolts fail the stator pack settles on the grooves by the cantilever arm. The play between the cantilever arms of the groove cross beams and the surfaces of the fixings by the beams is such that automatic detection in accordance with "design basis guideway part III" /MSB AG-FW GEO/ and "design basis guideway part IV" /MSB AG-FW IH/ is possible.

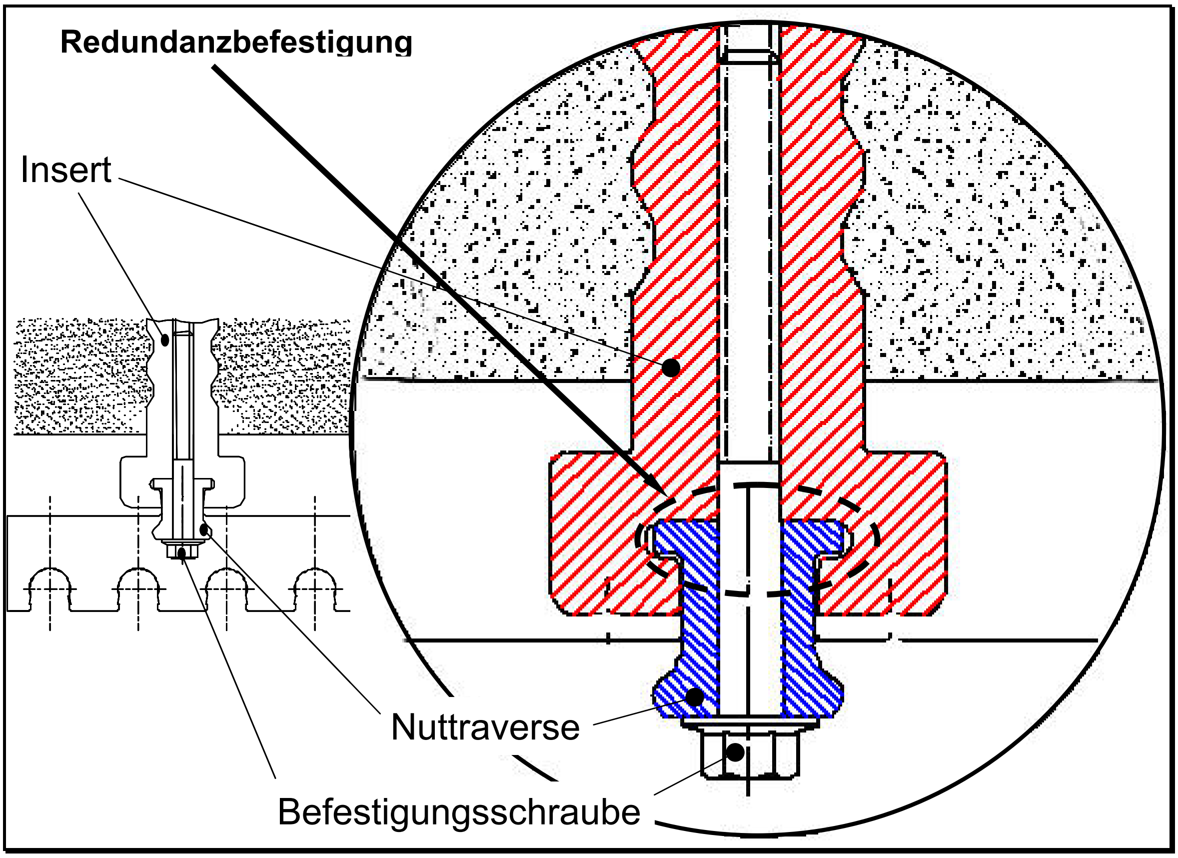

Figure 117: Example of a diverse redundant stator pack fixing on a concrete cantilever arm

Insert	insert
Redundanzbefestigung	Redundancy securing attachment
Nuttraverse	Grooved crossbeam
Befestigungsschraube	Securing bolt

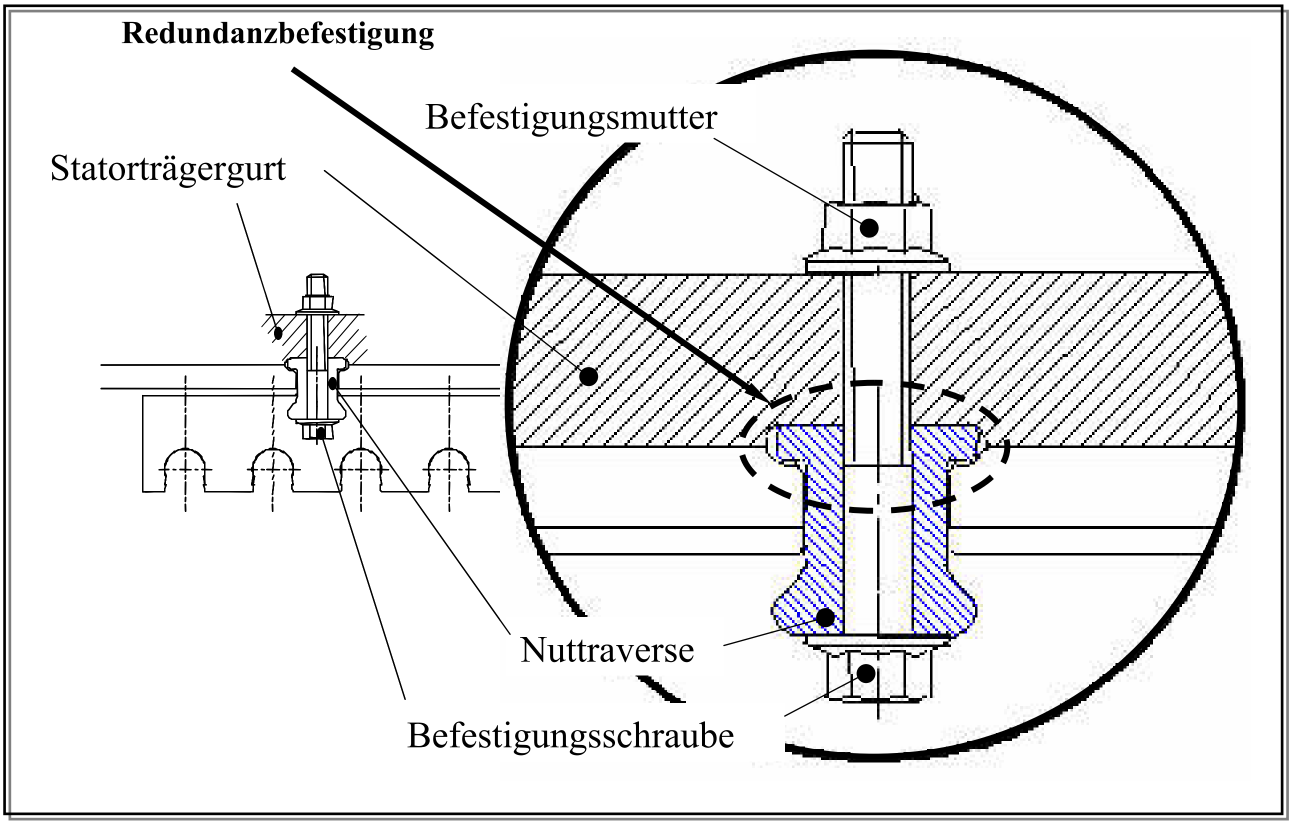

Figure 118: Example of a diverse redundant stator pack fixing on a steel cantilever arm

Redundanzbefestigung	Redundancy securing attachment
Befestigungsmutter	Securing nut
Nuttraverse	Grooved cross beam
Befestigungsschraube	Securing bolt
Statorträgergurt	Stator support belt

Annex I-E Support systems of guideway superstructures

In figure 119 examples of possible support systems on single and two span beams are given.

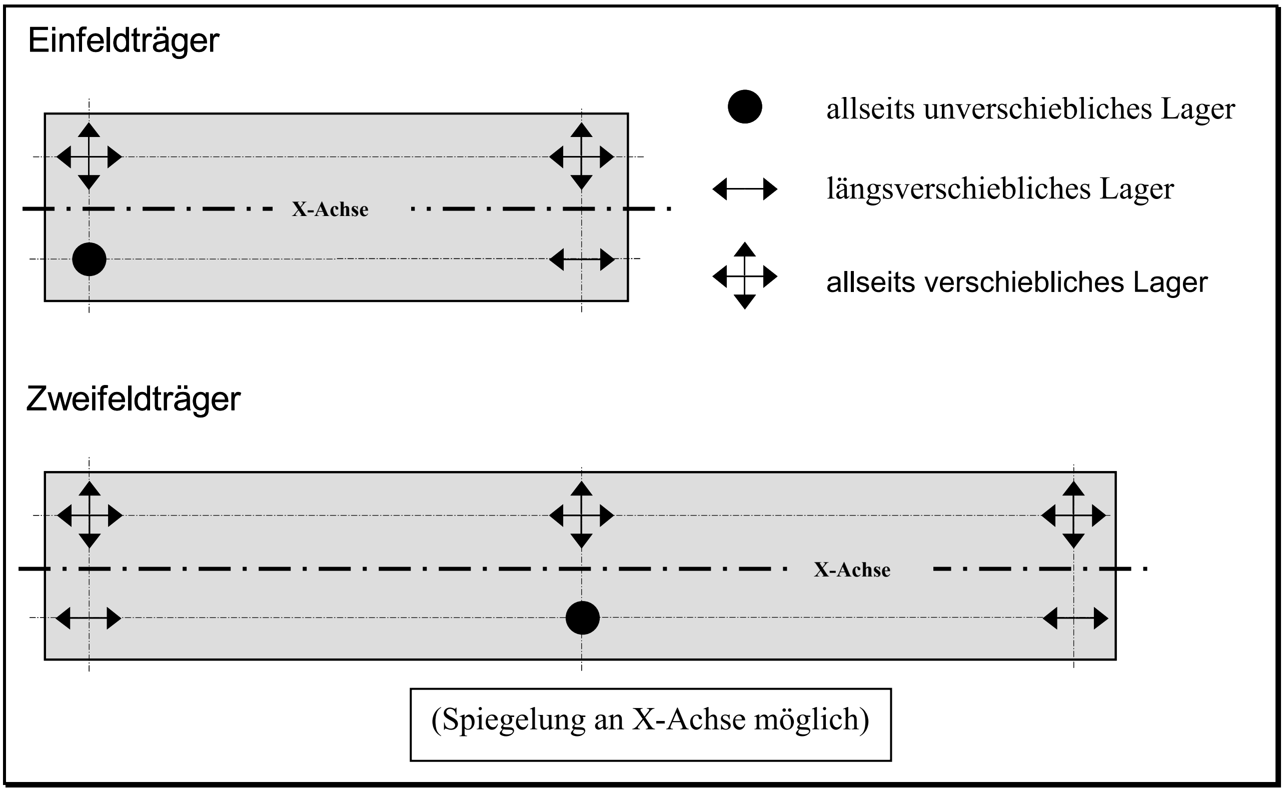

Figure 119: Exemplary support arrangement for single and two span beam systems

Einfeldträger	Single span beam
Zweifeldträger	Twin span beam
Allseits unverschiebliches Lager	Support fixed on all sides
Längsverschiebliches Lager	Support which can be moved longitudinally
Allseits verschiebliches Lager	Support which can be moved in all directions
Spiegelung an x-Achse möglich	Mirroring to x-axis possible

Maglev
Design principles

Guideway
Part II
Design

Distributor

This document was cleared by the guideway Technical Committee for publication.

Revisions

Date of release: 15.02.2007, White paper, Guideway Technical Committee.

Table of contents

General

Purpose of the document and area of application

(1) The system specific fundamentals described in this design basis for the design and verification process of the maglev guideway (including building structures close to the lines[12]) are independent of the project.[13]

(2) These fundamentals are to be used as dimensioning instructions in the sense of a calculating instruction for the guideway (see also /MSB AG-FW ÜBG/).

(3) These fundamentals have the general system requirements in /MSB AG-GESAMTSYS/ as a basis and also the overriding requirements of the guideway /MSB AG-FW ÜBG/.

(4) Any available potential regarding a special layout for e.g. higher transport capacity[14] is not taken into account here. For this the required structural verifications are to be provided in each individual case in agreement with the responsible inspectorate.

(5) The setting down of the system specific requirements for the guideway (e.g. value limits of the deformations) is based mainly on the experiences with proven guideway structural methods so far.

(6) For new types of construction the unlimited practicability of these standards is to be checked. If appropriate suitable standards are to be set in agreement with the responsible inspectorate.

(7) The system specific fundamentals for laying out maglev guideways include information about:

- the documents to be used;
- the description of the actions to be taken into account;
- the characteristic and representative values of the actions;
- the geometry (actions images and weak points) of the actions;
- the fundamentals for proof of the dynamic behaviour of the guideway;
- the instructions for the verification process of the support safety, serviceability and material fatigue with the associated standards and value limits;

(8) The fundamentals for establishing the characteristic and representative values of the actions are included in /MSB AG-GESAMTSYS/ as overriding.

(9) All components and modules of the guideway, also those for which no information for layout is given in this design basis, are to be dimensioned and proven following the generally accepted rules of engineering in agreement with the responsible inspectorate.

(10) For the following components and modules of the maglev specific guideway equipment, project and style specific additional requirements of their verification processes are to be set down:

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[12] In so far as system specific actions are to be taken into account (e.g. aerodynamic actions).

[13] Applies for applications as regional transport and long distance transport in Germany following /MSB AG-GESAMTSYS/. Project dependent boundary conditions like local climatic (wind, temperature etc), geological relations (earthquake, ground etc) and operational requirements are to be correspondingly set down project specifically.

[14] Increase e.g. through increasing the payload or increase of the section number (n>10).

- Long stator winding including securing attachment;
- Guideway equipment for recording the guideway position including securing attachment;
- Guideway equipment for external on-board energy supply including securing attachment;

(11) The guideway must be made in such a way following the MbBO[15] or other comparable, national regulations that it satisfies the requirements of safety and order. These requirements are met if the guideway meets the MbBO regulations or, if these do not contain the relevant regulations, the generally recognised rules of engineering (see § 3 paragraph (1) of the MbBO).

(12) The design is to be carried out in such a way on the basis of the following information that the stability and serviceability is economically and environmentally assured during the required period of use. The design is to be formed in such a way that the required maintenance cost for guaranteeing these requirements is minimised (for standards for this see /MSB AG-FW ÜBG/).

(13) If at least the same safety is proved as when observing the generally recognised rules of engineering, then a deviation from the generally recognised rules can be made. Verification of at least equal safety is to be provided to the responsible inspectorate (for this see § 3 paragraph (2) of the MbBO).

(14) All deviations from the standards of this document require the agreement of the responsible inspectorate and verification of the compatibility within the complete system and to the relevant subsystems by the supplier.

(15) This design basis applies for a maglev railway in accordance with the General Maglev System Act /AMbG/.

Design fundamentals

(16) This document forms part of documentation for maglev trains made up of various design fundamentals. The document tree is presented in figure 1 /MSB AG-GESAMTSYS/.

(17) The overriding documents for the design basis for the whole system and its annexes apply uniformly for the whole documentation:

- Maglev design principles for the complete system, doc nr: 50630, /MSB AG-GESAMTSYS/
- Annex 1: Maglev abbreviations and definitions, doc nr: 67536, /MSB AG-ABK&DEF/
- Annex 2: Maglev laws, regulations, standards and guidelines, doc nr: 67539, /MSB AG-NORM&RILI/
- Annex 3: Maglev environment, Doc.-Nr: 67285, /MSB AG-UMWELT/
- Annex 4: Maglev rules for operation and maintenance, doc nr: 69061, /MSB AG-BTR/
- Annex 5: Maglev noise, Doc.-Nr: 72963, /MSB AG-SCHALL/

Abbreviations and definitions

(18) The abbreviations and definitions given in /MSB AG-ABK&DEF/ apply.

[15] Applies for application in Germany.

Laws, regulations, standards and guidelines

(1) The laws, regulations, standards and guidelines shown in /MSB AG-NORM&RILI/ must be observed.

(2) The normative documents shown in /MSB AG-NORM&RILI/ contain arrangements which become a part of the Maglev design principles through reference in the design principles.

(3) For dated normative documents in /MSB AG-NORM&RILI/, later changes or revisions of these publications do not apply. For undated references the last edition of the normative document referred to applies.

(4) The status of the standards and guidelines to be taken into account in a Maglev project must be set down bindingly in a project specific way.

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Labelling and liability

(1) All numerical values contained in this design basis (e.g. characteristic values of the actions from the vehicle, dimensions etc) are based on the table of the system characteristic values contained in /MSB AG-GESAMTSYS/ or describe typical designs. In this table the size indications are divided into system constants/system value limits and project specific variable characteristic values.

(2) For each application project it must be checked whether the information contained in this document on typical designs is appropriate.

(3) The project specific variable values to be applied are to be documented in a project specific specification of the values to be applied in every case.

(4) In the creation of this document the regulations in accordance with /DIN 820/ were largely applied.

(5) In the following chapters
• the requirements are shown in standard script and the
• explanations and examples in *italics*

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References

(1) Maglev design principles

/MSB AG-GESAMTSYS/ Maglev design principles, complete system

Doc.-Nr. 50630

/MSB AG-ABK&DEF/ Maglev design principles, complete system,
enclosure 1: Maglev abbreviations and definitions

Doc.-Nr. 67536

/MSB AG-NORM&RILI/ Maglev design principles, complete system,
enclosure 2: Maglev laws, regulations, standards and guidelines

Doc.-Nr. 67539

/MSB AG-FW ÜBG/ Maglev design principles, guideway
Part I: Overriding requirements

Doc.-Nr. 57284

/MSB AG-FW GEO/ Maglev design principles, guideway
Part III: Geometry

Doc.-Nr. 41727

/MSB AG-FW TRAS/ Maglev design principles, guideway
Part IV: Routeing

Doc.-Nr. 60640

/MSB AG-FW VERM/ Maglev design principles, guideway
Part V: Measurement

Doc.-Nr. 60641

/MSB AG-FW IH/ Maglev design principles, guideway
Part VI: Maintenance

Doc.-Nr. 63842

(2) Other references

•

/R 1/ Mangerig; Zapfe: WEP Project 28 - Studie zum temperaturoptimierten Einfeld-Fahrwegträger im Weiterentwicklungsprogramm Magnetschwebebahntechnologie - September 2002
(Study on the temperature optimised single span guideway beam in the further development plan of magnetic levitating railway technology – September 2002)

/R 2/ Lutzenberger, S.; Lutzens J.: Grundsatzuntersuchungen zur Bestimmung des vertikalen globalen Schwingbeiwert $\varphi_{Bg,z}$ von Transrapid Fahrwegträgern, Endbericht, Statisches System Einfeldträger mit $L_{St} = L_{Sys}$ = 24,768 m. Im Auftrag der Transrapid International GmbH, 2005.
(Examinations of principles for determining the vertical global swing coefficient **###**$_{Bg,z}$ of Transrapid guideway beams, final report, static system single span beam with $L_{St} = L_{Sys}$ = 24,768 m. On behalf of the Transrapid International GmBH, 2005.)

/R 3/ Lutzenberger, S.; Lutzens J.: Grundsatzuntersuchungen zur Bestimmung des vertikalen globalen Schwingbeiwert $\varphi_{Bg,z}$ von Transrapid Fahrwegträgern, Endbericht, Statisches System Einfeldträger mit $L_{St} = L_{Sys}$ = 12,384 m. Im Auftrag der Transrapid International GmbH, 2006.
(Examinations of principles for determining the vertical global swing coefficient **###**$_{Bg,z}$ of Transrapid guideway beams, final report, static system single span beams with $L_{St} = L_{Sys}$ = 12,384 m. On behalf of the Transrapid International GmBH, 2006.)

/R 4/ Lutzenberger, S.; Lutzens J.: Weiterführende Grundsatzuntersuchungen zur Bestimmung des vertikalen globalen Schwingbeiwert $\varphi_{Bg,z}$ von Transrapid Fahrwegträgern, Endbericht, Statisches System Einfeldträger mit $L_{St} = L_{Sys}$ = 24,768 m. Im Auftrag der Transrapid International GmbH, 2006.
(Further examinations of principles for determining the vertical global swing coefficient of **###** $_{Bg,z}$ Transrapid guideway beams, final report static system single span beam with $L_{St} = L_{Sys}$ = 24,768 m. On behalf of the Transrapid International GmBH, 2006.2)

Design situations

General

(19) *Subsequently the maglev railway specific design situations for rating of the guideway which are to be taken into account are given.*

(20) *Details of the combination possibilities of actions for the vehicles are given in chapter 0 and in the chapters 0 and 0*

Vehicle related design situations

Frequent design situations

(1) The frequent design situations of the vehicle contain all vehicle related situations without losses or faults of modules. They are subsequently summarised and are to be taken into account in the verification process.

(2) Raising and setting down of the vehicle at v_{Fzg} = 0 km/h (including short time of hovering for a period of around 30 s) ⇒ 0;

(3) vehicles alongside one another in track sections provided for this purpose (stations with $|\alpha| \leq 3°$ and $|s| \leq 0.5\%$);

(4) maximum delay on a track and maximum acceleration on the other track at each point of the guideway with opposite direction of travel (in this way travel operation is also covered in the same direction as parallel operation);

(5) Layout of the individual tracks (e.g. for double track guideways) for both directions of travel;

(6) Vehicles with n =2… 10 sections (≈ 50 m ... 250m) are to be taken into account regardless of the project;

(7) The weight of the vehicles without or with payload (vehicle weight) from /MSB AG-GESAMTSYS/ (see also chapter ⇒ 0);

(8) Travel in a straight direction with dips or hills or curved travel with dips or hills for the operating conditions “stationary operation”, “accelerate” and “delay” respectively including airstream and dynamic lateral forces [16] ⇒ 0 ... 0;

(9) Operation with stationary and gusty wind ⇒ 0;

(10) Passing by structures close to the line and other structures ⇒ (54);

(11) Travel through tunnel with “tunnel entry”, “travel in tunnel” and tunnel exit” ⇒ (50);

(12) Meeting of trains with opposite directions of travel at each point of the guideway ⇒ 0;

Infrequent and accidental design situations

(1) The subsequent vehicle related rating situations result from losses or faults of modules and are – related to individual guideway elements- as a rule to be regarded as infrequent or accidental situations.

(2) Worst-Case-Halt following /MSB AG-GESAMTSYS/: standing or adjacent vehicles or slow travelling vehicles at each point of the guideway outside the stopping points provided (the speed of travel is less than the layout speed for frequent design situations set down which is dependent on the project and routing);

[16] Also contains the crossing of non-continuous and continuous deviations (offsets and "waves").

(3) Standing or adjacent vehicles outside stations in sections of track provided for this purpose (operational stopping points and defined areas of track connected with platform areas following /MSB AG-GESAMTSYS/) with $|\alpha| \leq 12°$ and $|s| \leq 0.5\%$ (with a possibility of icing) and $|s| \leq 5\%$ (without a possibility of icing);

(4) Setting down of the whole vehicle on the support skids at $v_{Fzg} > 0$ km/h ⇒ **0**;

(5) Braking with the vehicle's own safe brake (for travelling straight and through curves, dips or hills) following failure of the long stator propulsion or other faults following /MSB AG-GESAMTSYS/ (in an extremely small number of cases at the same time in the same direction)
⇒ (8);

(6) Switching off or failure of magnets ⇒ 0 ... 0;

(7) Use of the regulation braking system (propulsion) and safe brake at the same time;

(8) Varied propulsion (acceleration/deceleration) on both sides of a track outside areas of motor section switching during the alternating step method⇒ **0**;

(9) "Falling out of step" of the propulsion (slip/oscillation)
⇒ covered by the dynamic forces in 0;

(10) Braking through short circuit winding of danger points (e.g. at the connection area of platforms at end stations or before track change installations) ⇒ covered by (8);

(11) One sided setting down of the vehicle ⇒ **0**;

(12) Touching/activation of magnets ⇒ **0**;

Guideway related design situations

(1) Following /MSB AG-FW ÜBG/ it is required that no unexpected guideway related failures/faults occur through the layout and maintenance of the guideway (safe for service life; safe life) which can lead to increased actions.

(2) The actions/loads as a consequence of possible failures/faults on the guideway (e.g. modified load removal for activated redundancies) are to be taken into account.

Environment related design situations

(1) Environment related operating situations with actions as a consequence of wind (on vehicle and guideway), temperature and earthquake are to be taken into account in line with the project specific requirements

(2) If higher actions occur in comparison to the value limits of actions from the environment set down in /MSB AG-GESAMTSYS/ then these are to be correspondingly taken into account.

Surrounding area related design situations

(1) Project specific conditions of the surroundings such as e.g. crossing lines of traffic are to be taken into account.

Velocities and acceleration

Value limits of the travelling speeds

(1) In the layout of the guideway the project specific location dependent guideway speed limit $v_{Fzg,FW,grenz}$ (x) and the project specific location dependent guideway highest speed $v_{Fzg,FW,höchst}$ (x) are to be taken into account following /MSB AG-GESAMTSYS/. The maglev train specific maximum values for this are:

- max location dependent guideway speed limit : max $v_{Fzg,FW,grenz}$ (x) $\leq$ 530 km/h;
- max location dependent guideway highest speed : max $v_{Fzg,FW,grenz}$ (x) $\leq$ 500 km/h;

(2) The location dependent guideway speed limit $v_{Fzg,FW,grenz}$ (x) defines the location dependent course of the maximum admissible speed of a marked out stretch derived from the maximum actions applied in the rating of the guideway as a consequence of infrequent or accidental design situations.

(3) *The location dependent guideway highest speed $v_{Fzg,FW,grenz}$ (x) defines the location dependent course of the maximum admissible speed of a marked out stretch derived from the maximum actions applied in the rating of the guideway of frequent situations.*

(4) The local guideway speed may be exceeded in individual cases under certain boundary conditions for demonstration and qualification purposes (e.g. limitation of the admissible wind speed). For this a special project specific proof is necessary and this is to be approved by the responsible inspectorate.

(5) The local maximum speed max $v_{Fzg,häufig}$ (x) may not exceed the guideway highest speed as a frequent design situation under consideration of all speed tolerances and the local marking out.

(6) *The local minimum speed min $v_{Fzg,häufig}$ (x) may not be dropped below under consideration of all speed tolerances and the project dependent comfort requirements.*

(7) *The local maximum and minimum speeds result project specifically on the basis of the actual travel profile.*

(8) There are few situations where the local minimum speed $v_{Fzg,häufig}$ (x) can be dropped below or the local maximum speed max $v_{Fzg,häufig}$ (x) can be exceeded($v_{Fzg,selten}$ (x) < min $v_{Fzg,häufig}$ (x) or. $v_{Fzg,selten}$ (x) > max $v_{Fzg,häufig}$ (x)).

Acceleration value limits

(1) The acceleration value limits for frequent and infrequent design situations are to be taken from the following table 91.

<table>
<tr><th>Direction</th><th>Designation</th><th>Value Limits</th></tr>
<tr><td>x</td><td>Acceleration and braking</td><td>$- 1.5\ m/s^2 \leq \mathbf{a_x} \leq + 1.5\ m/s^2$</td></tr>
<tr><td>y</td><td>free lateral acceleration</td><td>$- 1.5\ m/s^2 \leq \mathbf{a_y} \leq + 1.5\ m/s^2$</td></tr>
<tr><td>z</td><td>normal acceleration (incl. g = 9.81 m/s²)</td><td>$+ 9.21\ m/s^2 \leq \mathbf{a_z} \leq + 11.01\ m/s^2$
(from g - 0.6 m/s² or
g + 1.2 m/s²)</td></tr>
<tr><td colspan="3">Accelerations which deviate from this are to be taken into account in the following design situations:
a) With points the maximum free lateral acceleration is to be applied with a_y = 2.0 m/s² if no project specific deviating setting occurs.
b) For a vehicle which is in α = 12° banking (v_{Fzg} = 0 km/h) there results a free lateral acceleration of a_y = -2.04 m/s² for example or a_y = -2.70 m/s² at α = 16° (Q11g).
c) Increasing of the longitudinal acceleration for error functions of the propulsion (Q11h) and when using the “safe brake” (Q11f)</td></tr>
</table>

Table 91 – Value limits of the accelerations in x-,y and z-direction

Actions on the guideway

Arrangement of the actions

(1) *The actions (F) to be taken into account are divided into permanent (G), variable (Q) and accidental actions (A) in the following tables following /EN 1990/. The basis for the actions is /MSB AG-GESAMTSYS/. If appropriate project specific additions are necessary and deletions are admissible.*

(2) *The variable actions are divided into frequent (normally: frequency > 1/week) and infrequent (normally: frequency < 1/year) effects.*

Permanent actions

Definition:

A permanent action (G) following /EN 1990/ is an actions which is required to apply during the complete service life and the change in size over time of which is negligible or in which the change up to attaining a particular value limit always takes place in the same direction evenly.

Nr.	Permanent actions	Chapter
G1	Permanent weight of the components	0
G2	Planned pre-tension/force	(3)
G3	Creeping and shrinkage (e.g. of the concrete)	(6)
G4	Constant water compressive forces	(8)
G5	Possible ground movements	(9)
G6	Constant earth pressure	0

Table 92 – Permanent actions

Variable actions

<u>Definition:</u>

A variable action (Q) is an action following /EN 1990/ the change in size over time of which is not negligible or in which the change does not always take place in the same direction.

Nr.	Actions	Chapter
<u>Frequent actions</u>		
Q1	Inertia forces including dynamics from vehicle self-weight	0
Q2	Inertia forces including dynamics from payload	0
Q3	Unequal distribution of the vehicle weight in x direction	0
Q4	Unequal distribution of the vehicle weight in x direction	(19)
Q5	Travel dynamics (dynamic forces from the track)	0
Q6	Reactive forces in narrow radii	0
Q7a	Aerodynamic forces from meeting of trains	0
Q7b	Aerodynamic forces from tunnel travel	(50)
Q7c	Aerodynamic forces on building structures close to the track	(54)
Q8a	Actions from prevailing wind: Uplift	(59)
Q8b	Actions from prevailing wind: Pressure/suction	0
Q9a	Lateral forces as a consequence of wind from environment	0
Q9b	Uplift as a consequence of wind from environment	0
Q10	Temperature as a result of propulsion	0
<u>Infrequent actions</u>		
Q11a	Increased vehicle weight	0
Q11b	Failure of a support magnet control system	0
Q11c	Dual failure of a support magnet control circuit	0
Q11d	Failure of a guidance magnet control system	0
Q11e	Dual failure of a guidance magnet control circuit	0
Q11f	Use of the vehicle “safe brake”	(8)
Q11g	Velocity deviation	**0**
Q11h	Propulsion system failure	**0**
Q11i	Actions resulting from a windings short circuit	**0**
Q11j	Activating/contact with magnets (Q11j)	**0**
Q11k	Raising of support skids, which are frozen on the sliding surface	**0**
Q11l	Increase in vehicle weight due to snow	**0**

Table 93 – Variable (frequent/infrequent) actions from the vehicle

Nr.	Actions	Chapter
Q30	Actions from maintenance	**0**
Q50a	Environmental temperature: Thermal fluctuations	**0**
Q50b	Environmental temperature: Linear temperature differences	**0**
Q50c	Environmental temperature: Uneven heating of components	**0**
Q51	Wind on the supporting structure	**0**
Q52	Snow and ice loads	**0**
Q53	Variable water pressure forces	**0**
Q54	Wind load on construction stages	□
Q55	Maintenance conditions	**0**
Q56	Construction conditions	**0**
Q57a	Track switching equipment: Elastical bending of switches	**0**
Q57b	Track switching equipment: Inertia forces from shifting	**0**
Q58	Displacement resistance of bearings	**0**
Q59	Failure of supporting structure elements	**0**
Q60	Lateral earth pressure from variable actions	**0**

Table 94 – Other variable actions

Accidental actions

Definition:

Following /EN 1990/ an accidental action (A) is an action which is usually for a short period but of considerable significance and which can however occur with no great probability during the planned service life of the supporting element.

Nr.	Actions	Chapter
Actions from the vehicle		
A1	Actions as a result of loading gauge violations	**0**
A2	Safety wind on vehicle (v=0 km/h)	**0**
Other accidental actions		
A3	Maintenance	**0**
A4	Safety wind on supporting element	**0**
A5	Possible ground movements	**0**
A6	Impact of track guided vehicles	**0**
A7	Impact of road vehicles	**0**
A8	Ice jam, thermal ice pressure, impact from watercraft	**0**
A9	Earthquake	**0**

Table 95 – Accidental actions

Combination of the actions

(1) *The whole of the design values for the verification of reliability of the supporting structure for a boundary conditions with the simultaneousness of its occurrence being taken into account is referred to as a combination of actions following /EN 1990/.*

(2) The actions are to be combined in such a way with the possibilities given in the following table 96 that unfavourable requirements for the rating result.

(3) The reduction and combination factors indicated in the following chapters may be applied taking into account the fact that certain actions with sufficient probability do not occur simultaneously with their maximum sizes.

Actions		**Actions situations 1)**	
constant actions G following tab 2.		with	-
Actions from the vehicle			
Q1	Vehicle self weight	max	min
Q2	Payload 2)	max	min
Q3	Unequal distribution of the vehicle self weight in x and y direction	3)	
Q4			
Q5	dynamic lateral forces from guidance dynamics 4)	with	without
Q6	Reactive forces in narrow radii 5)	with	-
Q7	aerodynamic lateral forces 6)	with	without
Q8	Actions from prevailing wind 6)	with	without
Q10	Temperature as a result of propulsion	with	without
Q11	Infrequent actions	with	without
Actions from the environment			
Q9	Wind action on vehicle 6)	with	without
Q50	Temperature from environment	with	without
Q51	Wind on supporting structure	with	without
Q52	Snow and ice loads	with	without
Q53	Variable water compressive forces	with	without
Q60	Earth pressure from variable actions	with	without
other actions			
Q30	Actions from maintenance 7)	with	without
Q55	Maintenance conditions 8)	with	without
Q57a	Elast. deformation of the bendable switches	with	without
Q58	Support-shifting resistances	with	without
Q59	Failure of load support elements	with	without

Observations:

For 1) incl. Following operating conditions:
- travelling vehicle (min v, max v)
- standing vehicle
setting down vehicle
levitating vehicle
track situations (α, s, R_H, $R_{K,W}$)

For 2)
A proven partial payload may be used for proof of the operating stability (see chap 0).

For 3)
see chap 0

For 4)
as a result of guideway deformations and guideway tolerances

For 5)
dependent on the radius in the x-y-plane

For 6)
dependent on the travelling speed

For 7)
see chap 0
For 8)
see chap **0**

Table 96 – Typical action situations for formation of the decisive combinations

Power transferring interfaces vehicle - guide-way

General

(1) *The power transferring interfaces vehicle – guideway (see figure 120)*

- *Support magnet – long stator,*
- *Guidance magnet – lateral guidance rails*
- *Braking magnet – lateral guidance rails and*
- *Support skid – sliding strip*

are described in the following chapters.

(2) *The basis for this is the designs set down in /MSB AG-GESAMTSYS/. Apart from these interfaces it is generally only aerodynamic forces (pressure/suction) which are transferred to the guideway.*

(3) *In addition forces can be transferred in the area of other guideway equipment elements (e.g. external on board energy supply) and these are to be set down for the individual case.*

(4) The inertia forces from special vehicles are usually guided to the guideway via the above interfaces.

(5) *The geometry of the guideway interface modules is set down in /MSB AG-FW ÜBG/ and /MSB AG-FW GEO/. In addition the system specific measurements and dimensions which describe the power transferring interfaces between vehicle and guideway are given for typical designs.*

(6) Further information on the interfaces is compiled in chapter ***0****with the description of the load figures.*

(7) *In the Annex of chapter* ***0****the vehicle actions on the guideway are assigned to the individual interfaces in* ***Error! Reference source not found.***

(8) The support magnet lengths are to be used as reference sizes for the establishment of the requirements:

- End sections: $L_{ES} = L_{TM\text{-}B,\ ES} = 23{,}753$ m
- Middle sections: $L_{MS} = L_{TM\text{-}B,\ MS} = 24{,}768$ m

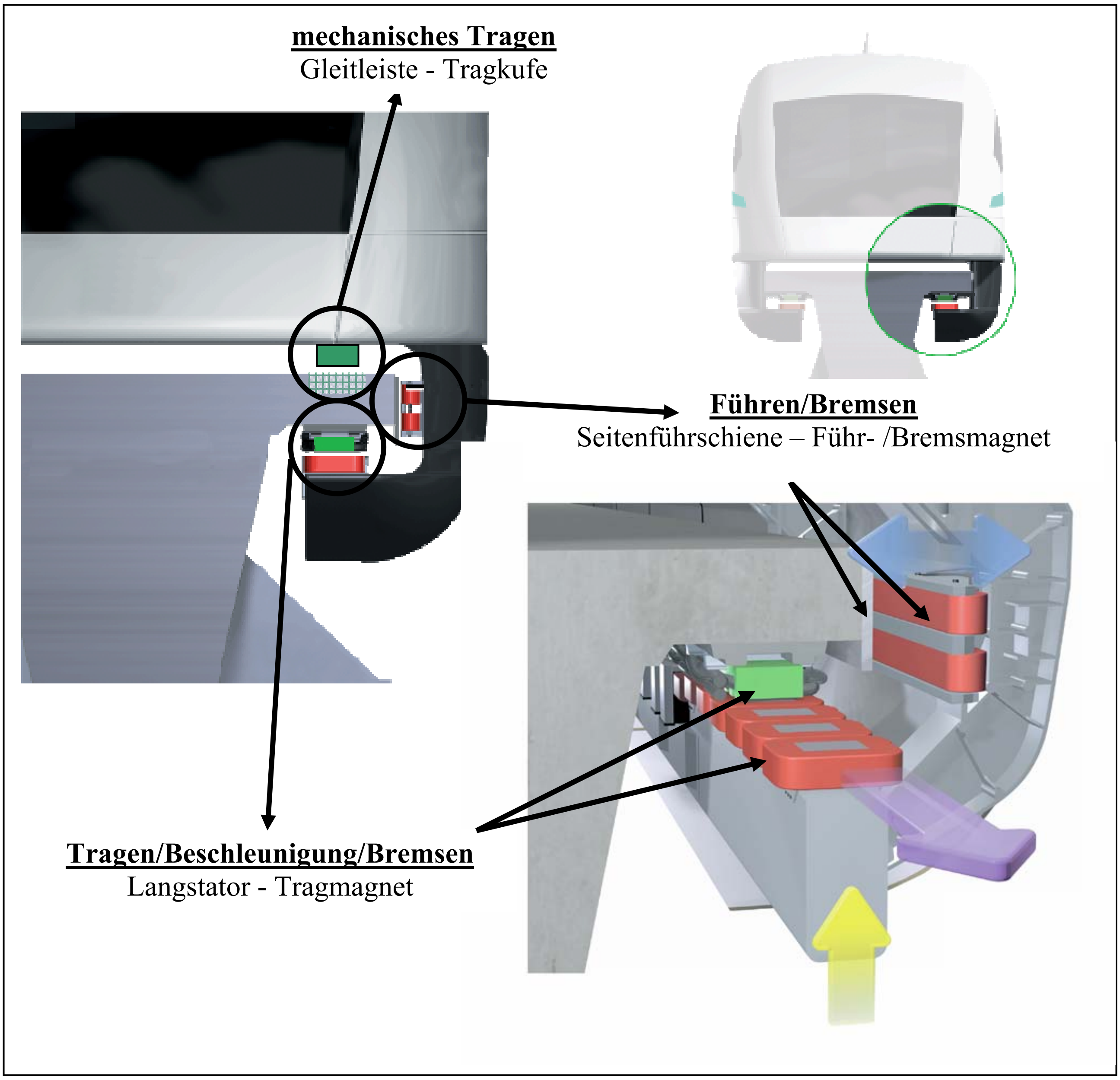

Figure 120 – Interfaces vehicle-guideway

Mechanisches Tragen	Mechanical support
Gleitleiste-Tragkufe	Sliding strip – support skid
Führen/Bremsen	Guidance/braking
Seitenführschiene – Führ -/Bremsmagnet	Lateral guidance rail – guidance/braking magnet
Tragen/Beschleunigung/Bremsen	Support/acceleration/braking
Langstator -Tragmagnet	Long stator – support magnet

Designation and numbering of the partial magnets

(1) The designation and numbering of the partial magnets for supporting TMT and guiding FMT is to be taken from figure 121 for the end and middle sections.

(2) In this the left (le) and right (ri) vehicle/guideway side must be distinguished between.

(3) *The current state of technology for vehicles means that the partial magnets FMT 1 for guiding and FMT 16 are not present because no section crossing guidance magnets are available.*

(4) The partial magnets for support TMT(1) and TMT(16) of the end sections correspond to the lengthening of the nose or tail magnets.

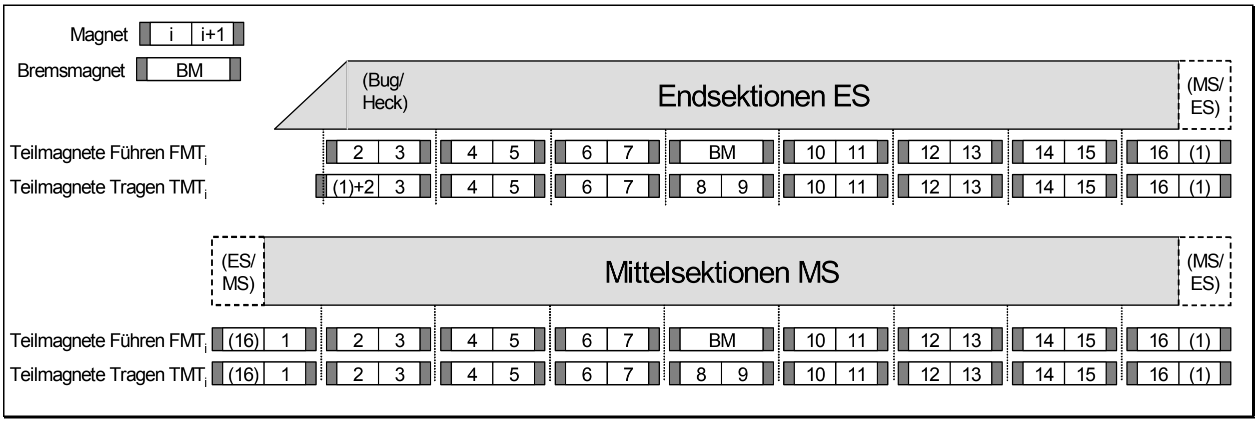

Figure 121 – Designation of the partial magnets (supporting and guidance)

Magnet	Magnet
Bremsmagnet	Braking magnet
Bug/Heck	Nose/tail
Endsektionen	End sections
Mittelsektionen	Middle sections
Teilmagnete Führen	Partial magnets guidance
Teilmagnete Tragen	Partial magnets support

Interface support magnet – long stator

Functions

(1) *–Only electromagnetic forces in the +z-direction and electromagnetic longitudinal forces in the ± x direction resulting from propulsion and braking are transferred via the support magnet-long stator interfaces (see figure 120) arranged on both sides of the guideway and vehicle.*

(2) *If a partial magnet fails the neighbouring magnet takes over the forces of the failed magnet as a rule (Q11b). If a neighbouring partial magnet fails the assigned support skid takes over the forces of the failed partial magnets (Q11c).*

Geometry

(1) *The geometry of the support magnets and the power transferring components of the support magnets (pole bodies) is presented in figure 122.*

(2) *In the sense of this design basis the length of the vehicle corresponds to the length covered by the support magnet L_{TM-B}. The length of a section covered by the support magnet L_{TM-B} results from the sum of the system lengths of the available support magnets $L_{sys,TM}$. The length covered by the support magnets L_{TM-B} for vehicles with n-sections ($n \geq 2$) with the length covered by the support magnets for end and middle sections taken into account amounts to:* $L_{TM-B} = 2 \cdot L_{TM-B,ES} + (n-2) \cdot L_{TM-B,MS}$

(3) *The regulating support magnets have 10 main and 2 end poles (exception: typical design of the nose and tail magnets with 2 additional main poles).*

(4) *The system length of the regulation support magnets amounts to 3096mm (exception: typical design of the nose/tail support magnets: $L_{sys,TM}$ = 3629 mm).*

(5) *The smallest system unit with reference to support magnet force amounts to: $L_{sys,TMT}$ = 1548 mm = $L_{sys,TM}$ / 2*
(exception: typical design on nose/tail: $L_{sys,TMT,nose/tail}$ = 2081 mm).

(6) The dimensions given are to be applied for all ranges and radii of the guideway track.

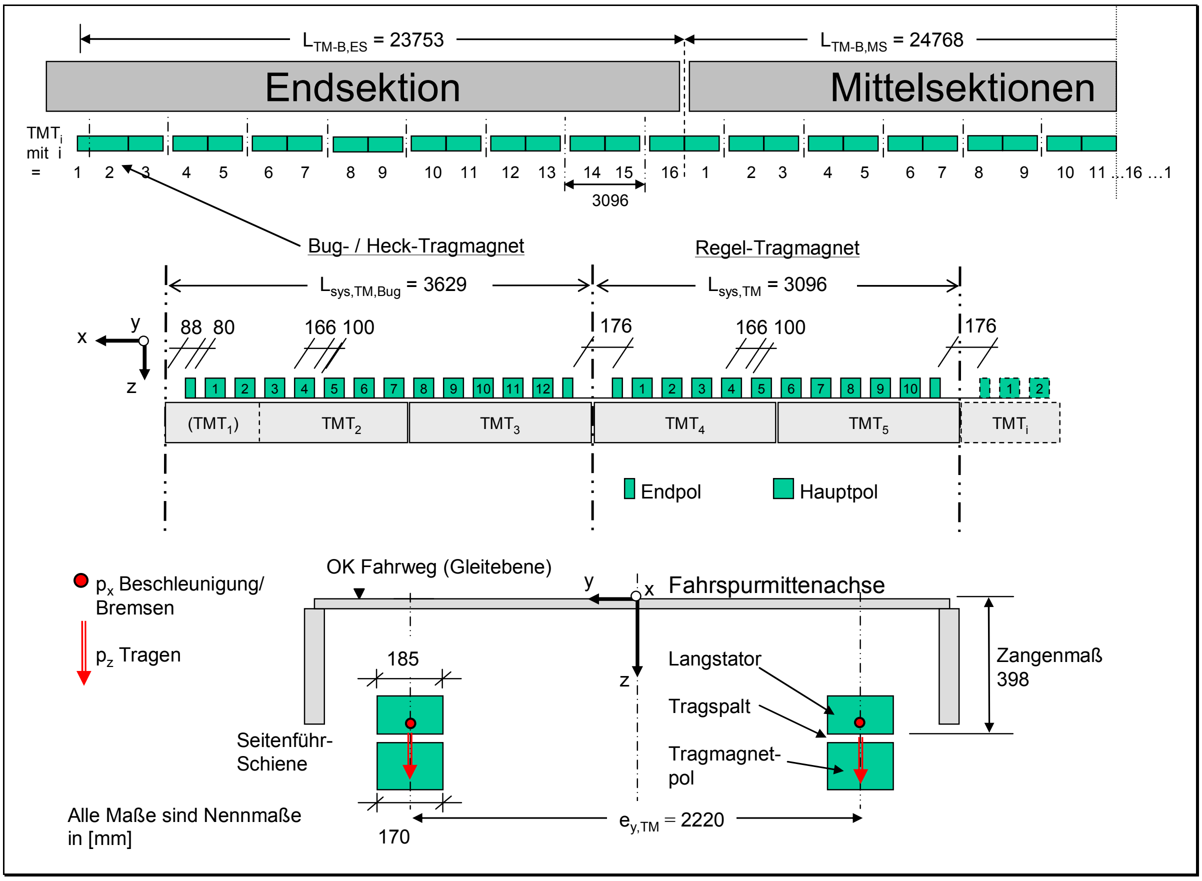

Figure 122 – Typical geometry of the actions support magnet – long stator

Endsektion	End section
Mittelsektionen	Middle sections
Bug -/Heck-Tragmagnet	Nose -/tail-support magnet

Regel-Tragmagnet	Regulation-support magnet
Beschleunigung/Bremsen	Acceleration/braking
Tragen	Support
Fahrweg	Guideway
Gleitebene	Sliding surface
Fahrspurmittenachse	Track central axis
Seitenführschiene	Lateral guidance rail
Langstator	Long stator
Tragspalt	Support gap
Tragmagnet -pol	Support magnet -pole
Zangenmass	Grip measurement
Alle Masse sind Nennmasse in (mm)	All measurements are nominal measurements in (mm)

Interface guidance magnet – lateral guidance rails

Functions

(1) *Electromagnetic tractive forces in y direction are transferred from the actions in y-direction via the guidance magnet-lateral guidance rails interface arranged on the both guideway and vehicle (see figure 123).*

(2) *In infrequent situations (e.g. failed magnetic regulating circuits for guiding(Q11d, Q11e)or with unfavourable overlapping of extreme actions) local mechanical tractive forces are exerted in y-direction and frictional forces in +x direction.*

Geometry

(1) *The magnetic and mechanical forces are transferred via 2 or 4 longitudinal pole strips (Pl) onto the lateral guidance rails (see figure 123). In the longitudinal direction gaps of 46 mm (2.23 mm) are present every 3096m (guidance magnet system length $L_{sys,FM}$ = 3,096 m). The force transferring pole-strip length amounts to $L_{PL,FM}$ = 3,050 m or $L_{PL,FMT}$ = 1,525 m. The arrangement of the guidance magnets and guidance magnet poles or partial magnets over the length of the vehicle is variable. A typical arrangement of the individual guidance magnets is presented in figure 123.*

(2) *The mechanical forces for double failure of neighbouring guidance magnet circuits are transferred to the ends of the guidance magnets via the start strips onto the guideway ($b_{z,AL}$ = 283 mm; $b_{x,AL}$ = 5 mm; see Figure 123)*

(3) For establishing the actions as a consequence of friction, typical friction coefficients between guidance magnet and lateral guidance rails are to be taken from table 97.

(4) The lengths covered by the guidance magnets $L_{FM-B,ES}$ and $L_{FM-B,MS}$ can be derived from figure 124.

(5) The dimensions are to be applied for all ranges and radii of the guideway track.

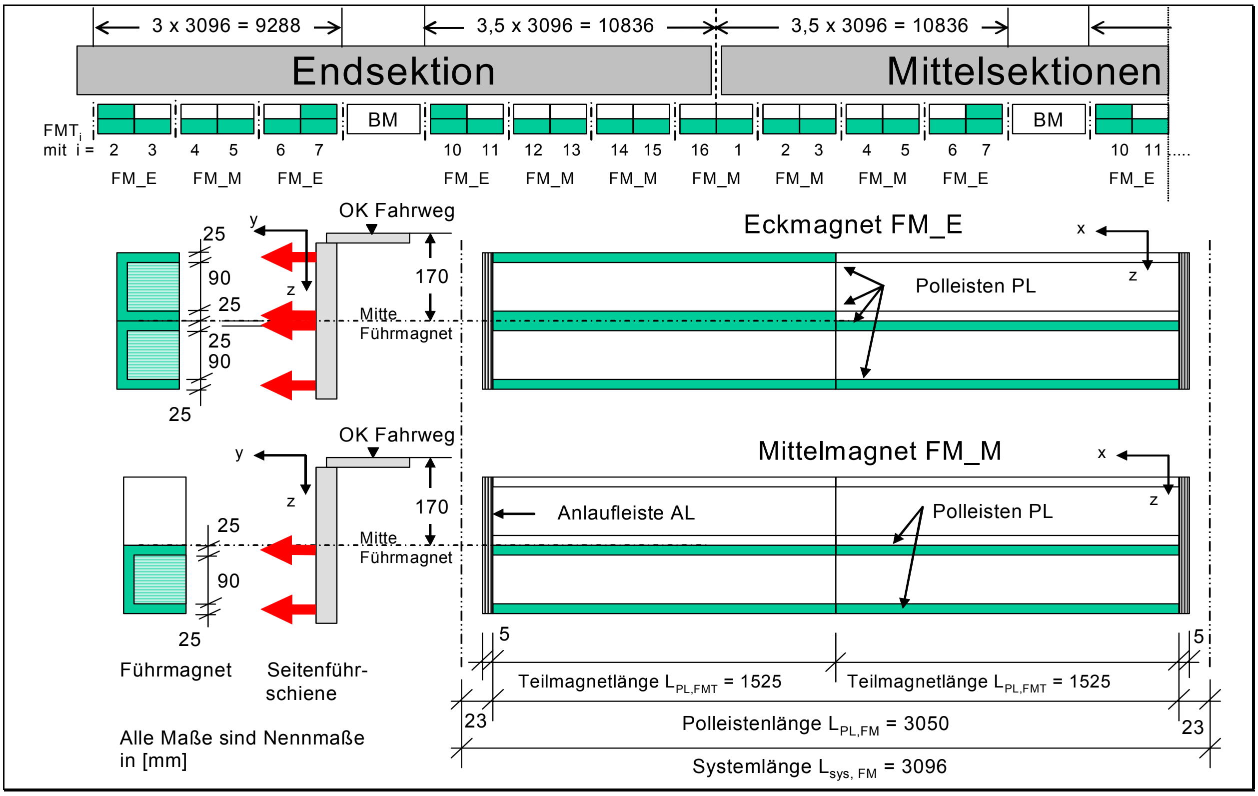

Figure 123 – Typical geometry of the actions support magnet – lateral guidance rails

Endsektion	End section
Mittelsektionen	Middle sections
Eckmagnet	Corner magnet
Fahrweg	Guideway
Führmagnet	Guidance magnet
Polleisten	Pole strips
Mittelmagnet	Middle magnet
Anlaufleiste	Start up strip
Seitenführschiene	Lateral guidance rail
Alle Masse sind Nennmasse in (mm)	All measurements are nominal measurements in (mm)
Teilmagnetlänge	Partial magnet length
Polleistenlänge	Pole strip length
Systemlänge	System length

Interface braking magnet – lateral guidance rails

Functions

(1) *If the long stator motor fails electromagnetic tractive forces in y- direction and longitudinal forces in +x direction and also mechanical frictional forces in +x direction for set braking magnets are transferred via the interface braking magnet-lateral guidance rails (see figure 124) on both the guideway and vehicle.*

Geometry

(1) *A typical arrangement of the braking magnets in x-direction and the typical geometry of the load transmitting pole bodies is given in figure 124.*

(2) *The centre to centre distance of the braking magnets in x-direction amounts to $e_{x,BM}$ = 24,768 m.*

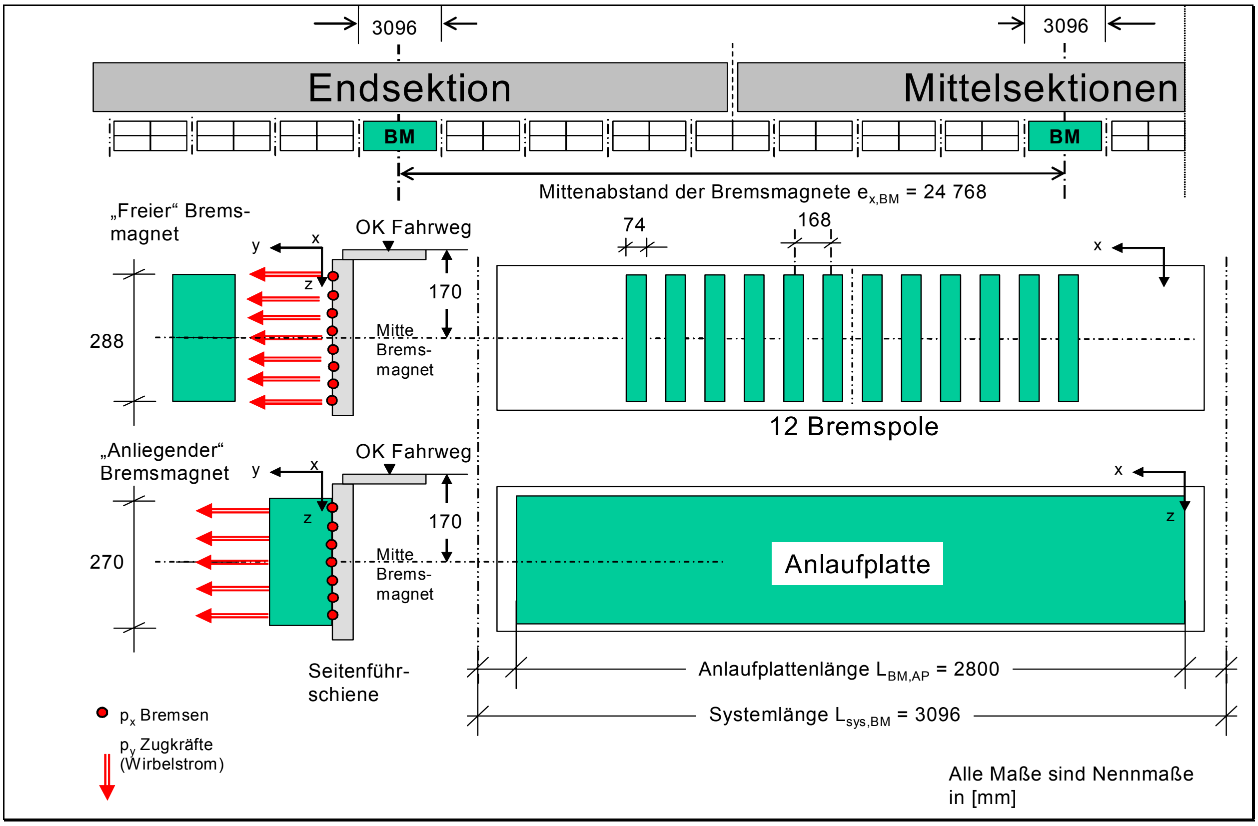

Figure 124 – Typical geometry of the actions braking magnet – lateral guidance rails

Endsektion	End section
Mittelsektionen	Middle sections
Mittenabstand der Bremsmagnete	Middle distance of the braking magnets
Freier Bremsmagnet	Free braking magnet
Anliegender Bremsmagnet	Close braking magnet

Fahrweg	Guideway
Bremspole	Braking poles
Anlaufplatte	Axial buffer disk
Anlaufplattenlänge	Axial buffer disk length
Systemlänge	System length
Alle Masse sind Nennmasse in (mm)	All measurements are nominal measurements in (mm)
Seitenführschiene	Lateral guidance rails
Bremsen	Brakes
Zugkräfte (Wirbelstrom)	Tractive forces (eddy current)

(3) The maximum friction coefficients μ_{BM-SFS} between the braking magnet and lateral guidance rails to be applied as a function of the travel speed are to be taken from table 97.

	Adhesive friction	Dynamic friction							
v_{Fzg} [km/h]	0	$v \rightarrow 0$	10	20	30	50	100	200	> 300
μ_{BM-SFS} [-]	0.50	0.30	0.25	0.22	0.20	0.18	0.14	0.12	0.10

Table 97 – Typical frictional coefficients braking magnet – lateral guidance rails (dry guideway)

Interface support skid – sliding strip

Functions

(1) *–Forces in the z and friction in the ±x and ±y direction are transferred via the support skid-sliding strips interfaces arranged on both sides of the guideway and vehicle (see figure 125)* (normally at v_{Fzg} = 0 km/h, in infrequent design situations at $v_{Fzg} \geq 0$ km/h).

(2) The process for establishing the actions to be taken into account is described in the subsequent chapters.

(3) The maximum friction coefficients μ_{TK-GL} to be applied as a function of the travel velocity between support skid and sliding strip are to be taken from table 98 to establish the actions in x-direction as a consequence of friction.

	Adhesive friction	Dynamic friction							
v_{Fzg} [km/h]	0	$v \to 0$	10	20	30	50	100	200	> 300
μ_{TK-GL}[-]	0.50 *	0.30 **	0.24	0.21	0.20	0.18	0.14	0.12	0.10
* Coefficient for taking into account the adhesive friction ** The max. friction coefficient for $v_{Fzg} \to 0$ km/h is to be tested project specifically.									

Table 98 – Typical frictional coefficients support skid – sliding strip (dry guideway)

Geometry

(1) A typical arrangement of the support skids on the vehicle with the typical dimensions of the support skids is presented in figure 125.

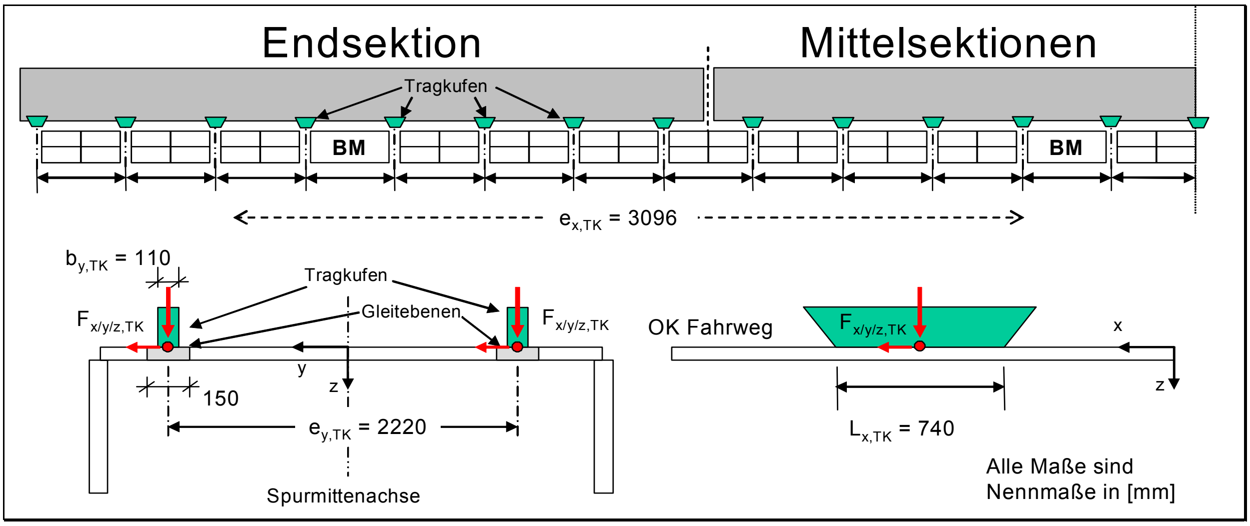

Figure 125 – Typical geometry of the actions support skid – sliding strip

Endsektion	End section
Mittelsektionen	Middle sections
Tragkufen	Support skids

Gleitebenen	Sliding strips
Fahrweg	Guideway
Spurmittenachse	Track central axis
Alle Masse sind Nennmasse in (mm)	All measurements are nominal measurements in (mm)

Other interfaces

(1) The interfaces to the components of the external on board energy supply and to the components for recording the vehicle position (location) are described in /MSB AG-FW ÜBG/.

(2) The characteristic values of the actions are to be set down specifically for the project and the design.

Dynamic step up of requirements

General

(1) As a consequence of the transient actions on the guideway, oscillations/vibrations occur as a rule which lead to a rise in the static guideway requirements (dynamic step up) such as to radiation of sound and solid base noise (vibrations).

Influence quantities on the dynamic step up

General

(1) The parameters and characteristic values described subsequently influence the dynamic behaviour and the dynamic reaction of the guideway when a vehicle travels over and thus the size of the dynamic step ups.

Influence quantities of the guideway

(1) Characteristic frequencies and forms of the guideway structure
The dynamic behaviour of the guideway and its ability to be stimulated is determined decisively by the associated characteristic frequencies and forms along the function planes and by the load arrangement. *Global and local characteristic frequencies and forms depend on the mass, torsional rigidity, the static systems and the support conditions of the designs.*

(2) Damping characteristics of the guideway structure
The guideway characteristics of the guideway significantly influence the size of the dynamic step ups with harmonic stimulation above all. *The damping characteristics are dependent on the materials used and the design characteristics of the structure. The most accurate possible of the respective damping characteristics of the guideway is required for a mathematical establishment of the dynamic requirements.*

(3) Accuracy of position of the function planes
The greater the geometrical deviations from the ideal guideway position (e.g. positional inaccuracies of the long stator, offset at end of beam) are, the greater the dynamic step ups of the requirements expected (for admissible deviations in position see */MSB AG-FW GEO)*.

Influence quantities of the vehicle

(1) Load image of the vehicle and geometrical regularities contained in it
The load image of the vehicle is decisive for the size of the dynamic step up for intermittent load. *Possible vehicle excitation frequencies result from the geometrical regularities in the load arrangement and in the development of the support magnets/magnetic poles as a function of the travel speed.*

(2) Travel speed of the vehicle
Significantly increased oscillations of the guideway beams can occur as a function of the travel speed. *Dynamic step ups are mainly to be expected at resonant travel speeds, at high travel speeds (intermittent load) and at low travel speed (slow travel/hovering).*

(3) Dynamic characteristics of the vehicle
All factors which the time variability of the magnetic forces influence (e.g. gap distance) have an effect on the dynamic step up of the guideway requirements.

Influential excitation mechanisms

(1) The influential system specific mechanisms and their influence quantities are shown subsequently.

Excitation mechanism I

(1) *Intermittent load of the guideway through crossing of the vehicle:*
For vehicle lengths, guideway geometries and travel velocities present the size of the dynamic load increases with the travel speed. This effect can be relevant for high travel speeds in particular.

Excitation mechanism II

(1) *Geometrical regularities of the vehicle (length of the support magnet L_{TM}; section length of the vehicle $L_{ES/MS}$) lead to a periodic excitation of the guideway, the frequency of which is dependent on the travel velocity. Stepped up guideway oscillations can result from this. The harmonic excitation of the guideway can also lead to vibrations in the ground.*

(2) *The decisive wavelengths of the action result from the geometry and arrangement of the vehicle actions (e.g. support magnets and support magnet poles or guidance magnets and guidance magnet poles). Typical wavelengths for the actions in z-direction are e.g. $\lambda_i = L_\lambda / i \cdot$ with i = 1; 2 … and L_λ = 3,096 m; 24,768 m; 49,536 m.*

(3) With the help of equation (1) the associated speed dependent excitation frequencies can be calculated.

$$f_{Anregung} = v_{Fzg} / \lambda_i \ [Hz] \qquad (1)$$

(4) A large number of exciter frequencies thus result for the guideway which can lead to resonant dynamic step ups in the area of guideway natural frequencies (for this see chapter 0 (4)).

Excitation mechanism III

(1) *Periodic fluctuations in the magnetic forces transferred from the vehicle to the guideway through the tooth/slot development of the long stator.*

(2) As a consequence of the low dimensions these mainly have an effect on structures with short influential lengths and at low travel velocities and lead to a periodic exciting of the guideway, the frequency of which depends on the travel velocity.

Excitation mechanism IV

(1) *Vehicle vibrations can cause periodic fluctuations of the vehicle loads. Possible causes of an exciting of vibration of the vehicle are subsequently described.*

(2) *Parameter excited oscillation of the vehicle (exciter mechanism IV.a):*
As a consequence of a regular, final length of the guideway beams, the rigidity of the guideway under the support magnets can change periodically (e.g. support area, beam field). If an excitation frequency resulting from the travel velocity and the support distance of the guideway beams is close to the natural frequency of the vehicle or the guideway, this can lead to stepped up vibrations of the vehicle and thus also the guideway.

(3) *Excitations from the roughness of the track (excitation mechanism IV.b):*
Deviations of the function planes from the ideal position (e.g. position inaccuracies of the stator packs or displacements on the beam joints) lead to a dynamic exciting of the vehicle during crossing and thus to vehicle vibrations which again have a retrospective effect on the guideway as a consequence.

Excitation mechanism V

(1) Dynamic effects from the regulation of the vehicle and thus in the coupling of the vehicle to the guideway can lead to strongly stepped up vibrations especially during slow travel/hovering and especially in the area of natural frequencies of the guideway structure.

(2) The associated exchange forces can be limited by measurements on e.g. prototype vehicles.

Excitation mechanism VI

(1) Excitations as a result of infrequent actions such as e.g. fault of propulsion regulation of the long stator linear motor (slip, swing), regulated setting down of the vehicle when using the safe brake or starting up a support magnet on the stator pack.

Damping characteristics

(1) With regard to a reduction of dynamic step ups it is recommended to use designs/construction methods with a high degree of natural damping.

(2) The damping measurements following EN 1991-2:2003 Tab. 6.6 or experimentally established damping values may be used if these can be proved as representative for the respective case of application and are agreed with the responsible inspectorate.

(3) If damping measurements following (2) are not available, the values given in table 99 can be used for the dynamic tests as a conservative damping measurement D in % of the critical damping (damping factor).

Beam/component from	Conservative damping measurement D [%]
welded steel structures	0.3
screwed steel structures	0.4 .. 0.6 (dependent on the design)
Ferro concrete	0.6
Pre-stressed concrete	0.6
Steel bonding	0.6
Ground	project specific

Table 99 – damping measurements D in % of the critical damping

Establishment of the dynamic requirements

General

(1) The general requirements for furnishing proof of dynamic actions are to be taken from

- DIN specialised report 101 chap. -6.4; Annex H;
- DIN 1055-100, chap. 5.4
- Eurocodes (e.g. EN 1990 - chap. 4.1.5; chap. 5.1.3 and EN 1991-2 - chap. 6.4)

(2) In establishing the dynamic requirements all actions from the travelling operation and if appropriate the environment (wind, earthquake) are to be taken into account with their special characteristics.

(3) The local increase as a consequence of the magnet regulation is to be taken into account in line with chapter 0.

(4) In the mathematical determination of dynamic requirements while using suitable calculation programmes, the information in chapter 0 is to be taken into account

(5) Dynamic actions may be accepted as quasi-permanent actions in so far as vibration coefficients are available and agreed with the responsible inspectorate.

(6) For verification of the serviceability of the guideway with regard to its vibration behaviour, the requirements for system compatibility of vibration amplitudes contained in chapter **Error! Reference source not found.** is to be taken into account.

(7) Dynamic requirements in the resonance area are to be demonstrably limited through suitable measures (e.g. damping by oscillation/vibration dampers) in such a way that the serviceability, the support safety and operating stability can be proven for the project specific service life required with the resonance requirements being taken into account.

(8) The theoretical assumptions and calculation results are to be verified through measurement of the dynamic requirements following /MSB AG-FW ÜBG/.

Dynamic step ups as a consequence of magnet regulation

Time variability of the magnet forces

(1) *In order to adhere to the required air gap at the support magnet/long stator and guidance magnet/lateral guidance rail interfaces, the magnetic forces are regulated in line with the local and temporary gap ratios (see reliable guideway tolerances following /MSB AG-FW GEO/.*

(2) The time variability (dynamic) of the magnetic forces (reaction forces as a consequence of position tolerances of the long stator and the lateral guidance rails, slip, oscillation) which results from this is to be taken into account for local proofs in the interface area (support magnet-long stator, guidance magnet-lateral guidance rails) for respectively one partial magnet for support or guidance (see chapter 7.3 and 9.3).

(3) For the verification process the following step up coefficients φ_{Rl} are to be applied:

$$\min \varphi_{Rl,x/y/z} = 0.8 \quad \text{and} \quad \max \varphi_{Rl,x/y/z} = 1.2$$

(4) The higher value limits of the static actions indicated in chapter 9 are to be used as capacity limits of the support and guidance magnets. The step ups $\max\varphi_{Rl,x/y/z}$ are already included in this.

Excitation of characteristic forms through the magnet regulation

(1) During slow travel and hovering in particular characteristic forms of guideway elements can be excited by variable magnetic forces as a consequence of the gap regulation. The requirements and deformations as a consequence of these excitations are to be proved.

(2) The type/method of the verification process is to be agreed with the responsible inspectorate.

(3) *Possibilities for the verification process are:*

- *Theoretical verification process through dynamic FEM calculations e.g. through response analysis; (the excitation forces and associated frequency areas are to be set down in agreement with the responsible inspectorate in a project specific way.)*
- *If no values are set down in agreement with the responsible inspectorate, excitation forces as in harmonic varying forces in the characteristic frequencies of the beam with maximum power amplitudes of $\Delta p_z = \Delta p_y = \pm 1$ kN/m can be assumed for estimation of the dynamic step ups. Here the frequency range of 0 to 30 Hz is decisive.*
- *Measurement of the dynamic deformations and requirements of a prototype beam with simultaneous verification of the system behaviour;*
- *Checking of guideway elements in the test stand;*

(4) In addition to a mathematical verification, an inspection of the guideway designs through test technical checking of the dynamic behaviour and measurement of the dynamic requirements for slow crossing and hovering is required.

Dynamic step ups as a consequence of mobile operation

Mathematical establishment of the dynamic requirements

(1) In the mathematical establishment of the dynamic requirements to be proven, the load arrangements of chapter **0** are to be applied. In addition the influence quantities and excitation mechanisms described above are to be taken into account.

(2) The models for the guideway structures are to be chosen in such a way that geometry, rigidity, support ratios and distributions of mass and the dynamic characteristics (natural frequency, characteristic forms, damping) can be represented sufficiently realistically. The structures are to be portrayed via suitable methods such as e.g. the finite elements method. The parameters of the guideway beams are to be varied in their whole (or project specific) band width. The damping is to be estimated conservatively following chapter 0. The influence of the guideway substructure and guideway foundation is also to be recorded in the calculation of the dynamic requirements as far as this is necessary. The examination of the global reaction of the guideway beam can normally occur with models.

(3) The depiction of the periodic excitation from the slot-tooth development of the long stator can occur through an increased (reduced) power transfer of the magnetic forces with location equality with the teeth (grooves) of the long stator. Here it is to be assumed that the total power transfer occurs over the teeth of the long stator.

(4) The actions from the vehicle must depict the characteristics of the vehicle sufficiently accurately (e.g. geometry of the support/guidance magnets). In particular the decisive excitation mechanism must be covered by the assumptions.

(5) For known natural frequencies of the guideway, the travel speeds at which a resonant excitation of the guideway construction is to be expected can be determined by equation (1).

(6) The information contained in chapter 0 is to be taken into account for consideration of the dynamic step ups as a consequence of the magnet regulation at low travel speeds and when hovering.

(7) If models for other dynamic actions (e.g. wind, earthquake) are used, these must depict the size, position, direction and course, positional and time variability, frequency of repetition and excitation frequencies of the individual parts of the action sufficiently accurately.

(8) For carrying out of the dynamic simulation calculation a time integration function is to be chosen which guarantees sufficient result quality. The size of the time step is to be chosen sufficiently finely.

(9) The simulation calculations are to be carried out up to maximum design speed for a sufficient number of speeds (e.g. with a speed pattern of Δv_{Fzg} = 1 m/s). The speed ranges in which the excitation frequencies of the vehicle coincide with the natural frequencies of the guideway are to be given particular examination. Here the extension of the period of the time integration process for establishing resonance speed is to be taken into account.

Establishment of the dynamic requirements with the help of vibration coefficients

General

(1) *As a rule the effect of the non resting actions on the guideway can be established by quasi-permanent verification as the actions are multiplied with vibration coefficients φ.*

(2) The vibration coefficients are to cover the decisive effects of the excitation as a function of the damping here.

(3) The dynamic step ups can as a rule be established by global vibration coefficients φ_{Bg} and local vibration coefficients φ_{Bl}:

- *The global vibration coefficients φ_{Bg} refer to the requirements in the main support direction (x-, y- and z- direction) of the guideway beams and are also to be taken into account in the layout of the substructure.*
- *In the immediate area of the interfaces between the vehicle and guideway locally greater dynamic step ups result as a function of the local design boundary conditions (rigidity and damping ratios) and the load arrangements of the actions (geometry and frequency) and these are to be taken into account through local vibration coefficients φ_{Bl}. Local vibration coefficients are thus to be taken into account in e.g. the cantilever arm area of discretely supported guideway beams and for short guideway elements such as e.g. guideway plates.*

(4) The time variability of the magnetic forces is taken into account through the local vibration coefficients given in chapter 0.

(5) With reference to the serviceability of the guideway a maximum vibration coefficient of 1.5 is to be aimed for as the upper limit for the dynamic step up of the requirements.

(6) The vibration coefficients can be established mathematically or experimentally taking into account the notes given in the subsequent sections.

Mathematically established vibration coefficients

(1) Design dependent vibration coefficients can be derived from mathematically determined dynamic requirements. These can be used for the dimensioning of the guideway elements if the assumptions made are confirmed by the responsible inspectorate. Notes on the mathematical establishment of dynamic requirements (instructions and boundary conditions) are compiled in chapter 0 for this purpose.

(2) *For single span beam systems with typical support scopes, exemplary rating figures for the global vibration coefficient $\varphi_{Bg,z}$ for actions in a vertical direction as a function of the damping in accordance with table 1 and the vehicle length (2,4,6 and 10 sections) are given independent of design and explained with reference to their application limits. As long as there are no more precise findings, no vibration coefficients smaller than $\varphi_{Bg,z}$ and $\varphi_{Bg,z,WSE}$ may be used for horizontal actions and for effective torsion moments in accordance with Annex II-B.*

(3) As long as there are no more accurate findings or own mathematical examinations, no vibration coefficients smaller than for single span beam systems should be used for twin span beam systems with the same support scope.

Test technical proven vibration coefficients

(1) *The use of test technically established and proven vibration coefficients is admissible as long as the following boundary conditions are met:*

- *The design of the guideway beam to be proven is similar to guideway designs already verified (rigidity, mass per unit area, support scopes, support systems).*
- *The operational boundary conditions of the test technical furnishing of proof (vehicle geometry and equipment and also operating and track parameters) cover the project specific requirements.*
- *The travel speeds resulting from equation (1) in which a resonant excitation of the guideway design is to be expected are covered by the tests.*

(2) *The current state of knowledge regarding the test technically proven vibration coefficients and the associated boundary conditions can be requested from the responsible inspectorate.*

Limitation of the dynamic step ups

(1) The dynamic response of the guideway is to be limited by suitable measures such as e.g. by increasing the damping (e.g. use of vibration dampers) in case:

- the admissible deformations following section 10.3 are exceeded,
- the required period of use cannot be attained as a consequence of dynamic step up of the requirements and/or
- the behaviour of the linked system vehicle/guideway is not system compatible.

Characteristic values of the actions

Permanent actions

Self-weight(G1)

(1) The self-weights of the components are to be determined following the relevant standards and regulations.

(2) For the maglev railway specific equipment components the following values are to be assumed:

- Long stator including motor winding, earth and securing attachment : 1.4 kN/m [17])
- Lateral guidance rails, sliding strips : [18])
- Components of the external on board energy supply including securing attachment : 0.25 kN/m
- Supplement for other add on parts : 0.10 kN/m

(3) The above actions from the individual components of the maglev railway specific guideway equipment are to be proven by measurement of weight.

Planned pre-tension / force (G2)

(4) *The pre tension for pre-stressed concrete is a permanent action. For practical reasons it may however be treated differently (see EN 1992). Force in the sense of G2 can for example be a forced deformation of beam through its weight or pretensioning against a support.*

(5) *Pre-tension can be created by pre-stressing elements, anchorings (e.g. on guideway plates), change of the support conditions, pre-loading or other measures,*

(6) Planned pre-tension and force are to be taken into account.

Creeping and shrinkage of the concrete (G3)

(7) Creeping and relaxation are action dependent and are thus to be assigned to the creating action combinations.

(8) The actions from creeping and shrinkage may be taken into account if the requirements become more favourable. They must be taken into account if the requirements become less favourable as a result.

Constant water compressive forces (G4)

(9) The actions from constant hydraulic pressure are to be taken into account following the relevant regulations and standards.

[17] per side of the guideway beam;

[18] The self-weights of the lateral guidance rails and sliding strips are to be established in accordance with the general requirements (dimensions and materials) from /MSB AG-FW ALLG/ under consideration of the respective design layout.

Probable ground movements (G5)

Guideway superstructure

(1) The values of the probable ground movements to be applied for rating of the guideway superstructure correspond to the value limits of the admissible deformations of the guideway substructure (see chapter **Error! Reference source not found.**). These values are to be applied in every unfavourable position.

(2) In an individual case (e.g. for flow through systems with short support scopes) the probable ground movements to be applied may however be reduced in agreement with the responsible inspectorate and on proof of the compatibility to the vehicle. In this way it is to be guaranteed through maintenance that the guideway is adjusted before exceeding the reduced values.

(3) Before reaching the system value limits of the subsidence (established in the verification of serviceability) the supports are to be adjusted. If this system value limit is applied as a possible ground movement, γ_Q = 1.0 may be applied for the guideway superstructure (see also ENV 1991-3: C2.3).

Guideway substructure

(10) The guideway substructure is to be formed in such a way that the probable ground movements can be balanced by adjustment of the supports of the guideway superstructure in each case (see also /MSB AG-FW ÜBG/, chapter 10.2.2).

(11) The support positions following adjustment of the supports are to be taken into account in the guideway verification process (weak points of the support forces).

Earth pressure (G6)

(12) The earth pressure is to be established and proved following the generally recognised rules of engineering.

Variable actions

Variable actions as a consequence of the vehicle

Coordinate system of the actions

(21) *The following actions refer to the Cartesian coordinates system presented in figure 126.*

(22) For this see also/MSB AG-FW TRAS/, /MSB AG-FW VERM/.

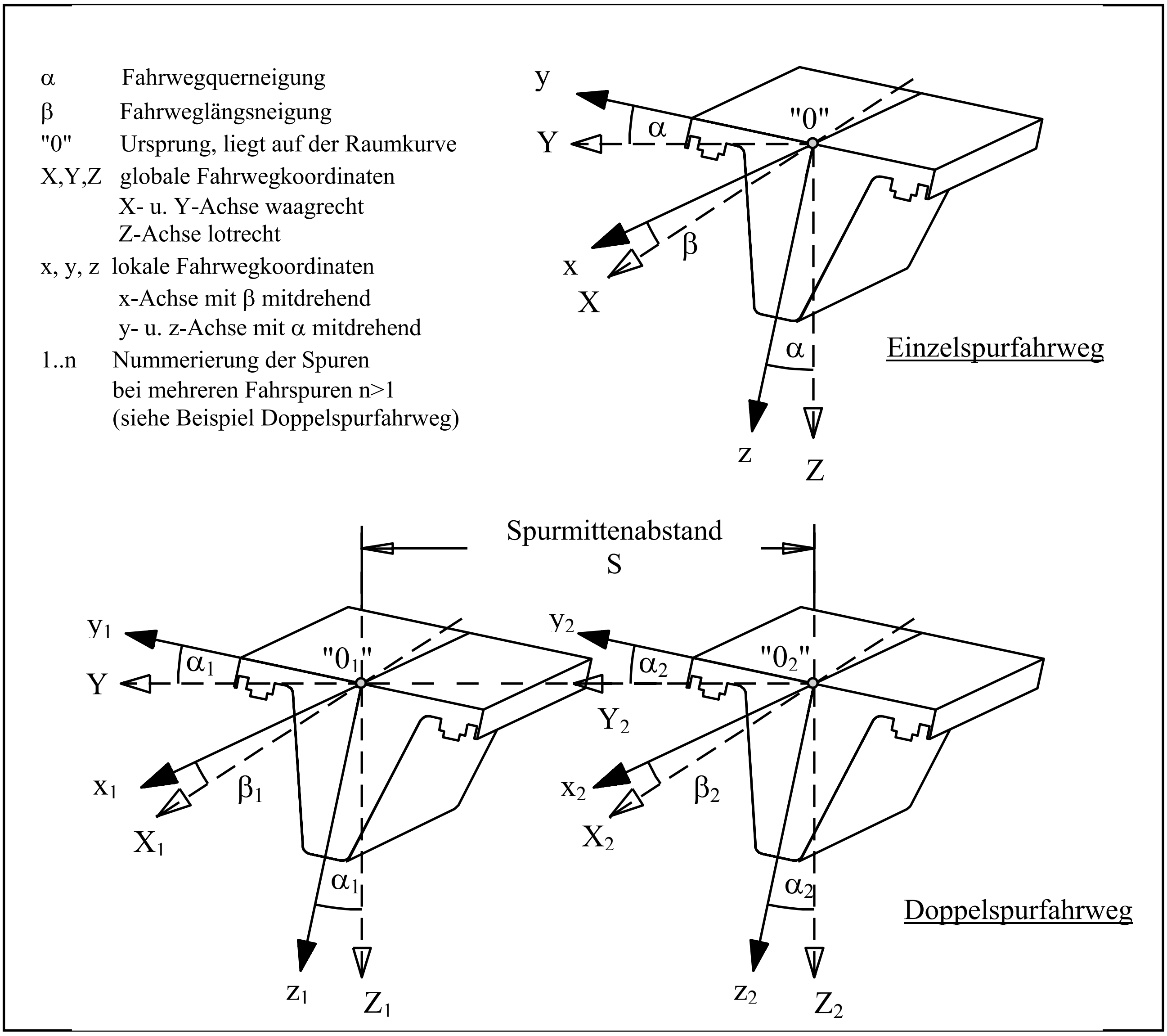

Figure 126 – Coordinate system of the actions

Fahrwegquerneigung	Guideway transverse inclination
Fahrweglängsneigung	Guideway lengthways inclination
Ursprung, liegt auf der Raumkurve	Origin, lies on the space curve

Globale Fahrwegkoordinaten X- u. Y-Achse waagrecht Z-Achse lotrecht	Global guideway coordinates X and Y axis horizontal Z-axis perpendicular
Lokale Fahrwegkoordinaten x-Achse mit β mitdrehend y-u.z Achse mit α mitdrehend	Local guideway coordinates –axis with β rotating in same direction
Nummerierung der Spuren bei meheren Fahrspuren n>1 (siehe Beispiel Doppelspurfahrweg)	Numbering of the tracks for several tracks n>1 (see example double track guideway)
Einzelspurfahrweg	Single track guideway
Spurmittenabstand	Track centre distance
Doppelspurfahrweg	Double track guideway

Vehicle weight (self-weight and payload) (Q1, Q2)

(13) As a static action as a consequence of vehicle weight (vehicle self-weight and payload) the inertia forces $\overline{p}_Z$ following table 100 are to be applied for the dimensioning of the guideway following /MSB AG-GESAMTSYS/.

(14) The track loads provided for the vehicle weight are averaged across the support magnet occupation length L_{TM-B} (see figure 122). For the design of the guideway the local actions about the vehicle length are to be determined from these average track loads while applying the equations and tables indicated in the subsequent chapters.

(15)

(16) A possible unequal distribution of the payloads in x- and y- direction (Q3, Q4) is to be taken into account in accordance with the chapters 0 and 0.

(17) *The use of the average track loads or own simplifications of the subsequent load arrangements is admissible if it is proved that the requirements established through the simplification are on the safe side.*

Designation	Averaged, static track load [kN/m]	Frequency *
Vehicle self weight EG (minimum vehicle weight)	$\overline{p}_{Z,EG} = 21{,}0$ **	-
medium vehicle weight MG (for normal load)	$\overline{p}_{Z,MG} = 26{,}0$ ***	80 %
admissible vehicle weight ZG (for maximum load)	$\overline{p}_{Z,ZG} = 29{,}0$ ***	20 %
maximum vehicle weight HG (e.g. in the case of fire, evacuation of a section) ****	$\overline{p}_{Z,HG} = 31{,}0$	-
Observations:		

*	The frequencies indicated are to be tested for each product and adapted if appropriate.
**	For the use of lighter vehicles a reduced track load for the vehicle self weight can be set down project specifically (e.g. light goods vehicle with $\overline{p}_{Z,EG} = 19{,}0$ kN/m).
***	For proof of fatigue a vehicle weight MG* = $\overline{p}$ can be applied more simply in place of the actions from the middle vehicle weight MG (80%) and the admissible vehicle weight ZG (205)
****	The classification of the maximum vehicle weight HG is to be set down project specifically as frequent, infrequent or unusual action. As a rule the maximum vehicle weight is to be assumed as an unusual action.

Table 100 – Typical mean, static actions from the vehicle weight

Centre of gravity of the vehicle

Position of the vehicle centre of gravity in x-direction (Q3)

(18) *The centre of gravity of the vehicle weight can shift through uneven distribution of the payload and the vehicle self weight in x-direction (Q3). This uneven distribution is passed on over the vehicle structure (e.g. distribution of the loads over air spring systems) to the support and guidance magnets and is taken into account in the subsequent tables of actions (e.g. table 105).*

(19) With vehicles for goods transport it is to be assured through a project specific loading instruction that an uneven loading in x-direction does not lead to load distributions more unfavourable than those indicated in table 105.

Position of the vehicle centre of gravity in y-direction (Q4)

(20) *The centre of gravity of the vehicle weight can be shifted in the y-direction (Q4) through uneven distribution of the payload. This shifting of the centre of gravity is negligible when including the track loads in Table 100.*

(21) With vehicles for goods transport it is to be assured through a project specific loading instruction by the operator that there is no uneven loading in y-direction.

Position of the vehicle centre of gravity in z-direction

(1) The highest position of the vehicle centre of gravity above the level of the sliding strips amounts to:

- minimum vehicle weight $s_{z,EG}$ = - 600 mm;
- medium vehicle weight $s_{z,MG}$ = - 700 mm;
- admissible vehicle weight $s_{z,ZG}$ = - 850 mm;
- maximum vehicle weight $s_{z,HG}$ = - 950 mm;
  These centre of gravity positions are to be taken account of with the inertia forces in x- and y- direction.

Frequent variable actions (Q1...Q10)

General

(2) *The connection between the track parameters, the speed of travel and the acceleration is defined through the following relations:*

- *acceleration a_x (x) in x-direction from starting up and braking*

$|a_x(x)| \leq 1{,}5\ m/s^2 a_x(x)| \leq 1{,}5\ m/s^2$ (2)

- *Free lateral acceleration a_y (x) in y-direction*

$$a_y(x) = \frac{v(x)^2}{|R_H(x)|} \cdot \cos\alpha(x) \cdot \cos^2\beta(x) - \left(g \cdot \cos\beta(x) + \frac{v(x)^2}{-R_{V,K/W}(x)}\right) \cdot \sin\alpha(x) \quad (3)$$

- *Normal acceleration a_z (x) in z-direction*

$$a_z(x) = \frac{v(x)^2}{|R_H(x)|} \cdot \sin\alpha(x) \cdot \cos^2\beta(x) + \left(g \cdot \cos\beta(x) + \frac{v(x)^2}{-R_{V,K/W}(x)}\right) \cdot \cos\alpha(x) \quad (4)$$

with:

$a_x(x)$, $a_y(x)$, $a_z(x)$	[m/s²]	in direction of the local coordinate axes, location dependent accelerations;
v(x)	[m/s]	Location dependent speed of travel;
R_H (x)	[m]	Location dependent horizontal radius of the space curve in the ground plan;
R_V (x)	[m]	Location dependent vertical radius of the space curve in the gradient with
		$R_{V,K}$: Peak (+) and $R_{V,W}$: Depression (-);
α(x)	[°]	Location dependent angle of rotation of the guideway round the x-axis (guideway banking);
β(x)	[°]	Location dependent angle of rotation of the guideway round the y-axis (guideway longitudinal gradient);

(3) *The connection between actions F, acceleration a and vehicle mass m is given by Newton's law:*

$$F = m \cdot a \quad (5)$$

(4) *The connection between accelerations and track parameters is presented in figure 127. The possibility of overlapping of track elements is limited by the $R_{x,z}$ –criterion given in /MSB AG-FW TRAS/. The value limits of possible combinations are compiled in Annex II-C.*

(5) *The maximum possible guideway actions are set down by the limitation of the admissible accelerations following chapter 0. The acceleration values can deviate downwards project specifically limitation of the admissible accelerations).*

(6) The equations (3) and (4) also apply for the standing vehicle.

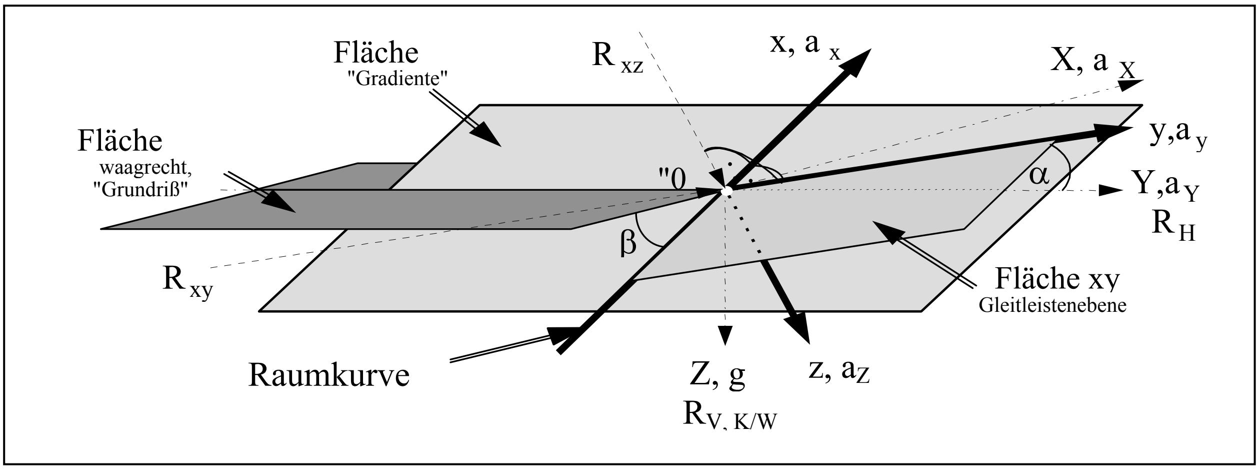

Figure 127 – Connection between accelerations and track parameters

Fläche	Surface
Gradiente	Gradient
Waagrecht "Grundriss"	Horizontal "layout"
Raumkurve	Space curve
Gleitleistenebene	Sliding strip surface

Actions as a consequence of braking and accelerating (Q1/Q2)

z, a_z

(22) The thrust in each route section and the max. permissible longitudinal force resulting from ma a_x according to Table 91 is to be set as a frequently variable action in the x-direction.

(23) *The force in x-direction is location dependent and takes into account acceleration stretches (starting up and braking), inertia stretches, incline, fall and the aerodynamic travel resistance (incl. headwind).*

(24) A force of 110 Kn/middle section with reference to the vehicle weight is to be taken into account as limit force in x-direction in frequent design situations (see also table 101 line 3).

(25) The actions to be taken into account as a consequence of propulsion (braking/accelerating) are to be taken from table 101 for max a_x = 1.5 m/s² for the various vehicle weights.

Static actions max $p_{x,Schub}$ for frequent rating situations from:

1	minimum vehicle weight	$\max p_{x,Q1/Q2,EG} = \overline{p}_{Z,EG} / g \cdot \max a_x = 3.2$ kN/m
2	medium vehicle weight	$\max p_{x,Q1/Q2,MG} = \overline{p}_{Z,MG} / g \cdot \max a_x = 4.0$ kN/m
3	admissible vehicle weight	$\max p_{x,Q1/Q2,ZG} = \overline{p}_{Z,ZG} / g \cdot \max a_x = 4.5$ kN/m (value limit)
4	maximum vehicle weight	$\max p_{x,Q1/Q2,HG} = \max p_{x,Q1/Q2,ZG} = 4.5$ kN/m (value limit)

Table 101 – Maximum forces in x-direction from propulsion and braking

(26) As a rating the value the action $p_{x,Q1/Q2}$ following (6) is to be applied.

$$p_{x,Q1/Q2} = \max p_{x,Q1/Q2} \qquad (6)$$

(27) In the area outside of motor section switching the following is to be applied:

$$p_{x,links} = p_{x,rechts} = 0,5 \cdot p_x \qquad (7)$$

(28) During the alternating step method (ASM) 73% of the installed braking or propulsion force or the above limit value is to be discharged via a beam side in the area of motor section switches. For these areas the following is to be applied:

$$p_{x,links} = 0 \quad \text{and} \quad p_{x,rechts} = 0{,}73 \cdot p_x \tag{8}$$

$$\text{bzw.} \quad p_{x,links} = 0{,}73 \cdot p_x \quad \text{and} \quad p_{x,rechts} = 0 \tag{9}$$

(29) *As a consequence of the centre of gravity distance in the z-direction a moment round the y-axis results when braking and accelerating which leads to a load in z-direction (see chapter 0).*

(30) Additional actions on the lateral guidance rails result through the single side introduction of the actions following equation (8) and (9). The associated partial magnet forces are to be taken into account in accordance with chapter 0.

(31) Component dynamics and control dynamics following chapter 0 are to be taken into account.

Actions in y-direction

General

(32) The guidance magnet forces' points of attack are to be derived from the interface descriptions in chapter 0 (figure 123) and the load arrangements in **0**.

Guidance magnet initial loading

(1) For directional control, guidance magnet forces (tractive forces) are transferred to both sides of the guideway via the interface guidance magnets-lateral guidance rails ("guidance magnet initial loading"). As "inner forces" they do not create any reactive forces in the beam supports and they act like a prestressing force. The maximum guidance magnet initial load is to be applied with $p_{y,Vor}$ = 3.6 kN/m.

(2) The lateral pre load is to be transferred to the other actions in y-direction. The procedure in the transfer is presented in figure 128.

(3) Component dynamics and control dynamics following chapter 0 are to be taken into account.

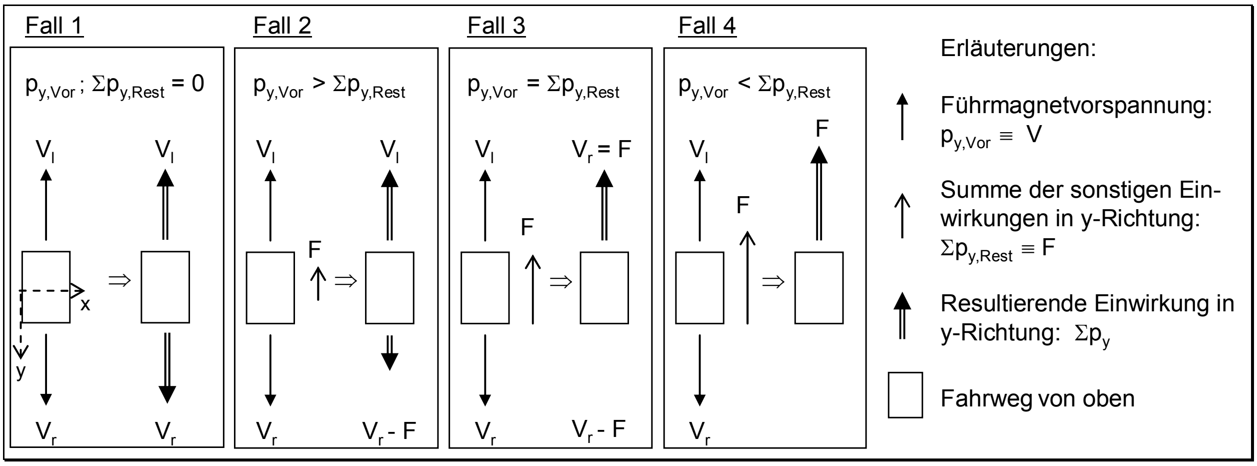

Figure 128 – Transfers with the guidance magnet pre loading

Erläuterungen	Notes

Führmagnetvorspannung	Guidance magnet pre loading
Summe der sonstigen Einwirkungen in y-Richtung	Sum of the other actions in y-direction
Resultierende Einwirkung in y-Richtung	Resultant action in y-direction
Fahrweg von oben	Guideway from above

Free lateral acceleration (Q1, Q2)

(33) The free lateral acceleration a_y (centrifugal force) is to applied in accordance with equation (3) and equation (5) as a further variable action in y-direction as a consequence of the vehicle

(34) The static actions to be applied are to be established for the individual partial magnets guiding FMT_i from equation (10)

(35) Component dynamics and control dynamics following chapter 0 are to be taken into account.

(36) The distribution of the guidance magnet forces along the length of the vehicle corresponding to the guidance magnet occupation (see figure 123) is to be taken as a percentage via the factors $k_{y,ay,i}$ from Table 102.

$$p_{y,ay,FMT_i,EG/MG/ZG/HG} = \overline{p}_{Z,EG/MG/ZG/HG} \cdot \frac{L_{ES/MS}}{L_{FMT}} \cdot \frac{a_y}{g} \cdot \frac{k_{y,ay,i}}{100} \quad \text{in [kN/m]} \qquad (10)$$

(37) As a consequence of the centre of gravity distance of the vehicle (see chapter 0) and the centrifugal force $p_{y,ay}$ there results a rail moment round the x-axis which is passed on into the guideway via the support magnets. The actions from the free lateral acceleration $\pm p_{z,ay,FMTi}$ are to be established with the help of the equation (11) and table 102 with z_{FM} = 0,17 m for the individual partial support magnets $TMT_{i.}$

$$\pm\ p_{z,ay,TMT_i,EG/MG/ZG/HG} = \overline{p}_{Z,EG/MG/ZG/HG} \cdot \frac{L_{ES/MS}}{L_{TMT_i}} \cdot \frac{a_y}{g} \cdot \frac{\pm k_{z,ay,i}}{100} \cdot \frac{\left(|s_Z| + z_{FM}\right)}{e_{y,TM}} \qquad (11)$$

$$\text{in [kN/m]}$$

FMT_i TMT_i	End sections															
	(1) *	2	3	4	5	6	7	BM		10	11	12	13	14	15	16
$k_{y,ay,i}$ [%]	-	*7*	*7*	*8*	*7*	*8*	*11*	-	-	*11*	*8*	*7*	*9*	*8*	*5*	*4*
$k_{y,ay,i}$ [%]	*5*		*10*	*6*	*6*	*6*	*7*	*9*	*8*	*6*	*6*	*6*	*6*	*5*	*7*	*7*
FMT_i TMT_i	Middle sections															
	1	2	3	4	5	6	7	BM		10	11	12	13	14	15	16
$k_{y,ay,i}$ [%]	*4*	*5*	*7*	*8*	*7*	*8*	*11*	-	-	*11*	*8*	*7*	*8*	*7*	*5*	*4*
$k_{y,ay,i}$ [%]	*7*	*7*	*5*	*6*	*5*	*5*	*7*	*8*	*8*	*7*	*5*	*5*	*6*	*5*	*7*	*7*
* TMT_1 conforms as typical extension of TMT_2 (see figure 122).																

Table 102 – Typical distribution of the magnetic forces from a_y over the length of the vehicle

Lateral forces from the guidance dynamics (Q5)

(38) Dynamic lateral forces SK for taking into account the guidance dynamics as a result of global guideway tolerances of the lateral guidance rails are to be applied according to the following relationship:

$$\pm p_{y,SK} = \pm\left(1+\frac{v_{Fzg}\ [km/h]}{500\ [km/h]}\right) \quad \text{in } [kN/m] \qquad (12)$$

(39) For set down vehicle with $v_{Fzg} = 0$, $p_{y,SK} = 0$ is to be applied.

(40) *The action $p_{y,SK}$ is a dynamic action and thus contains the global component dynamics.*

(41) Local component dynamics and control dynamics following chapter 0 are to be taken into account.

Reactive forces with small horizontal radii R_H (Q6)

(42) With small horizontal radii local reactive forces determined by the vehicle geometry are to be transferred in y-direction to the other actions from the guidance magnets.

(43) The characteristic reactive forces to be applied for the corresponding horizontal radii are to be taken from table 103. As an addition to this the distribution of the actions is presented in figure 129.

(44) Component dynamics and control dynamics following chapter 0 are to be taken into account.

$p_{y,ZWG,i}$ [kN/m]	End sections		Middle sections	
	R_H = 350 m	R_H = 1000 m	R_H = 350 m	R_H = 1000 m
$p_{y,ZWG,1}$	-	-	18.0	7
$p_{y,ZWG,2}$	21.0	7	0	0
$p_{y,ZWG,3}$	0	0	0	0
$p_{y,ZWG,4}$	1.0	0	6.0	0
$p_{y,ZWG,5}$	2.0	0	1.0	0
$p_{y,ZWG,6}$	-4.5	0	-5	-1
$p_{y,ZWG,7}$	-21.0	-7	-21.0	-6
BM	-	-	-	-
$p_{y,ZWG,10}$	-21.0	-7	-21.0	-6
$p_{y,ZWG,11}$	-4.5	0	-5	-1
$p_{y,ZWG,12}$	1.0	0	1.0	0
$p_{y,ZWG,13}$	7.0	0	6.0	0
$p_{y,ZWG,14}$	0	0	0	0
$p_{y,ZWG,15}$	1.0	0	1.0	0
$p_{y,ZWG,16}$	18.0	7	18.0	7
Interim values may interpolated or extrapolated in a linear way.				

Table 103 – Typical reactive forces $p_{y,ZWG,i}$ for small horizontal radii

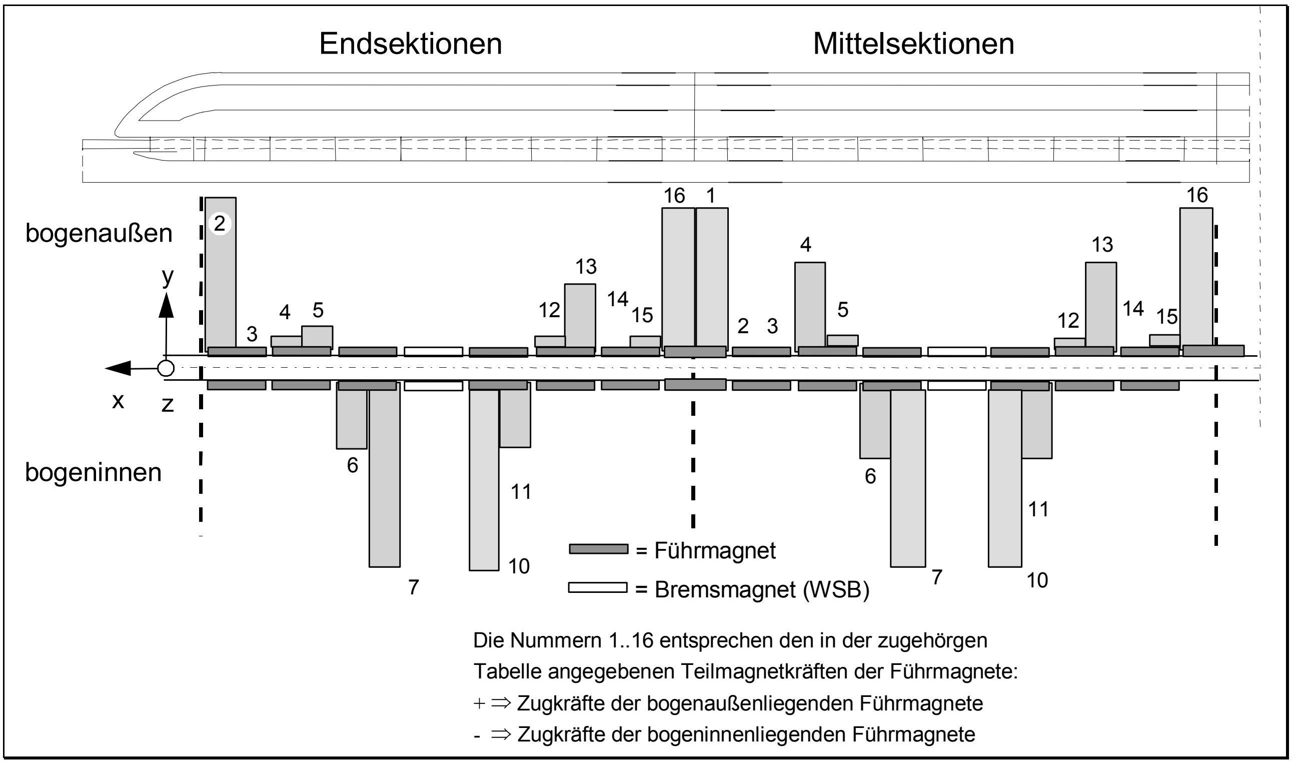

Figure 129 – Typical distribution of the reactive forces in tight horizontal radii R_H

bogenaussen	Outside of curve
bogeninnen	Inside of curve
Endsektionen	End sections
Mittelsektionen	Middle sections
Führmagnet	Guidance magnet
Bremsmagnet	Braking magnet
Die Nummern 1..16 entsprechen den in der zugehörigen Tabelle angegebenen Teilmagnetkräfte der Führmagnete:	The numbers 1..16 correspond to the part magnet forces of the guidance magnets in the associated table:
Zugkräfte der bogenaussenliegenden Führmagnete	Tractive forces of the guidance magnets on the out-side of the curve
Zugkräfte der bogeninnenenliegenden Führmagnete	Tractive forces of the guidance magnets on the in-side of the curve

Guidance magnet forces from one sided propulsion

(7) The moment round the z-axis from one sided propulsion (e.g. following chapter 0 change over step process) is introduced to the guideway via the guidance magnets.

(1) The actions to be applied are to be determined with equation (13) and table 104 for the guidance magnets shown in figure 121, whereby the existing acceleration $a_{x,WSV}$ at point (x) of the guideway is to be applied.

$$p_{y,a_{x,WSV},FMT_i,EG/MG/ZG/HG} = \frac{vorh\ a_{x,WSV}(x)}{0,73 \cdot a_{x,max}} \cdot \frac{\overline{p}_{Z,EG/MG/ZG/HG}}{\overline{p}_{Z,ZG}} \cdot p_{y,a_{x,WSV},i,ZG} \qquad (13)$$

in [kN/m]

Whereby max a_x = + 1.5 m/s² or – 1.5 m/s², $a_{x,WSV}(x) \leq 0.73 \cdot \max a_x$

and $p_{y,axWSV,i,ZG}$ from table 104;

(2) *As a consequence of the mechanical linking of the magnets guidance magnet forces can work as tractive forces on the right (r)and left (l) side of the beam simultaneously (see figure 130).*

(3) Component dynamics and control dynamics following chapter 0 are to be taken into account.

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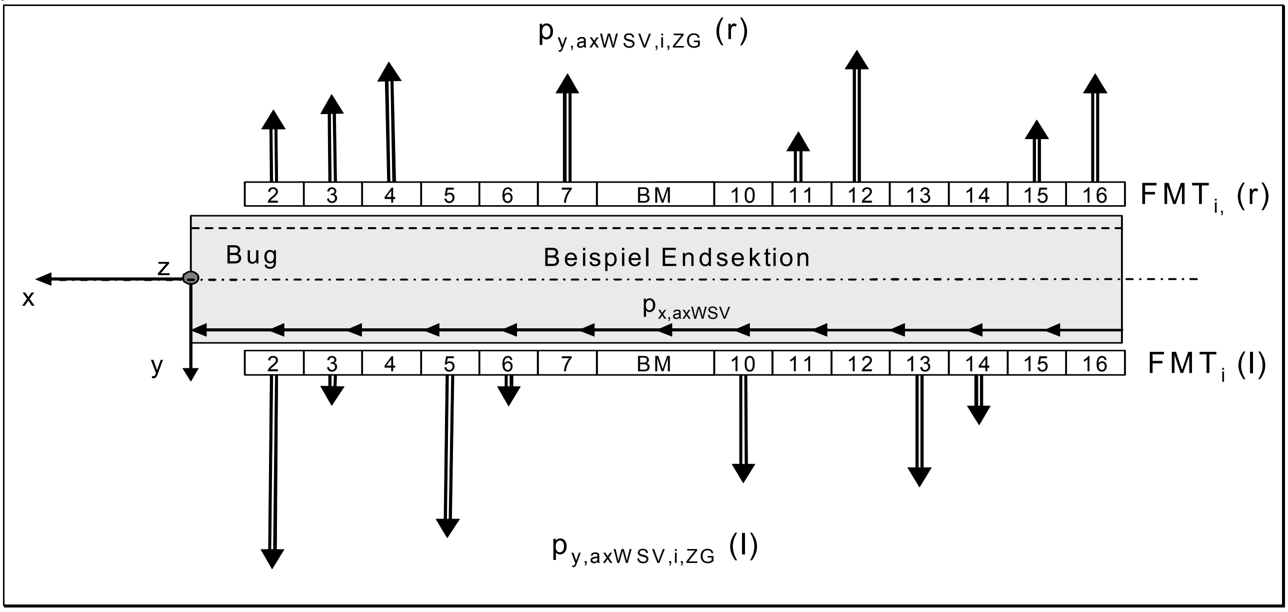


Figure 130 – Typical distribution of the guidance magnets from $a_{x,WSV}$

Bug	Nose
Besipiel Endsektion	Example end section

FMT_i in [kN/m]	End sections														
	-	2	3	4	5	6	7	BM		10	11	12	13	14	15	16
$p_{y,axWSV,i,ZG}$ (r)	-	2.2	3.7	4.7	0	0	4.5	-	-	0	1.1	5.6	0	0	1.4	4.4

$p_{y,axWSV,i,ZG}$ (l)	-	8.5	0.5	0	6.2	0.5	0	-	-	4.6	0	0	4.8	1.1	0	0
FMT_i in [kN/m]	Middle sections															
	1	2	3	4	5	6	7	BM		10	11	12	13	14	15	16
$p_{y,axWSV,i,ZG}$ (r)	0	0	1.7	4.3	0	0	4.7	-	-	0	1.1	5.8	0	0	1.4	4.4
$p_{y,axWSV,i,ZG}$ (l)	5	0.8	0	0	6.2	0.6	0	-	-	4.8	0	0	4.9	1.1	0	0
The actions listed in this table take into account the permissible vehicle weight according to Table 100 and the max. permissible braking/propulsion acceleration according to Table 91. The force balance of the end sections is not balanced (transfer of a remaining force over the section coupling).																

Table 104 – Typical distribution of the guidance magnets from $a_{x,WSV}$

Actions in z-direction (Q1.. Q3)

Acceleration in z-direction

(4) The actions from the vehicle weight as a consequence of a_z (see equation (4)) in z-direction are to be established with the help of the subsequent equations (14) and (15) and the distribution given in table 105 over the vehicle length (see chapter 0).

$$p_{z,a_z,EG/MG/ZG/HG} = \overline{p}_{Z,EG/MG/ZG/HG} \cdot \frac{a_z}{g} \quad \text{in [kN/m]} \qquad (14)$$

(5) The limit values for a_z are to be taken from Table 91.

(6) For the individual partial magnets TMT_i according to figure 121 the corresponding forces are to be determined according to equation (15). In the distribution of the partial magnet actions the unequal distribution through the factors $k_{z,az,i}$ (see table 105) as a consequence of vehicle centre of gravity position in x-direction is included following chapter 0.

$$p_{z,az,TMT_i,EG/MG/ZG/HG} = 0{,}5 \cdot \overline{p}_{Z,EG/MG/ZG/HG} \cdot \frac{L_{ES/MS}}{L_{TMT_i}} \cdot \frac{a_z}{g} \cdot \frac{k_{z,az,i}}{100} \quad \text{in [kN/m]} \qquad (15)$$

(7) Component dynamics and control dynamics following chapter 0 are to be taken into account.

TMT_i	End sections															
	1 *	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$k_{z,az,i}$ [%]	10	10	5	7	7	7	7	7	7	7	6	6	6	6	6	6
TMT_i	Middle sections															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$k_{z,az,i}$ [%]	6	6	6	6	6	6	7	7	7	7	6	6	6	6	6	6
* TMT_1 conforms as typical extension of TMT_2 (see figure 122).																

Table 105 – Typical distribution of the guidance magnet forces from a_z over the length of the vehicle

Acceleration and braking

(1) The pitching moments of the carriage body round the y-axis as a consequence of the centre of gravity distance in z-direction (see chapter 0) while braking and accelerating are to be taken into account in accordance with the load arrangement (loading and unloading) in accordance with figure 131 (circuits of air suspension connection) (here see also the force distribution from the tilting of the support-guidance structure following chapter 0).

(2) This load arrangement is to the unfavourably transferred to the static guideway load following chapter 0.

(3) Component dynamics and control dynamics following chapter 0 are to be taken into account.

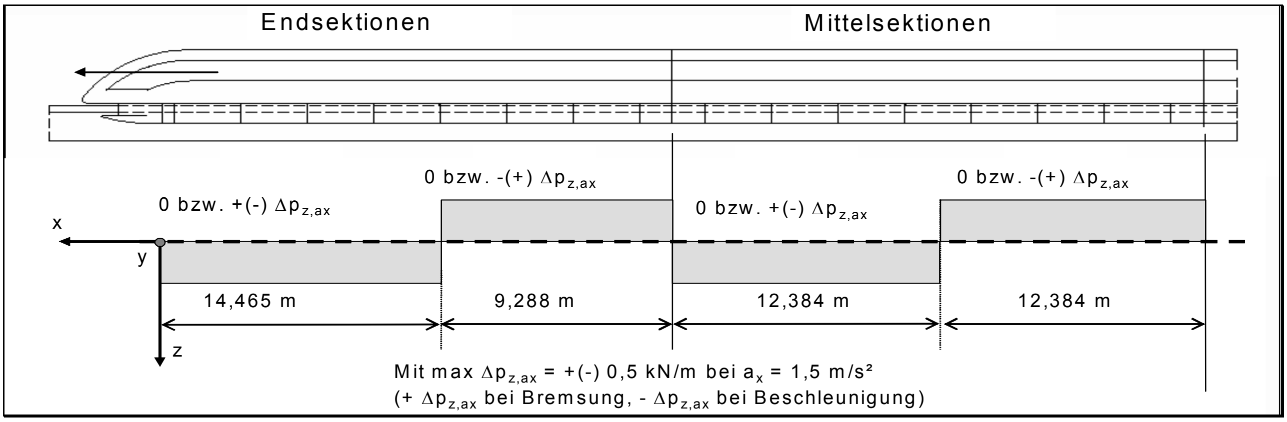


Figure 131- Typical additional loads in z-direction as a consequence of braking/accelerating

Endsektionen	End sections
Mittelsektionen	Middle sections
Mit max	With max
Bei Bremsung	For braking
Bei Beschleunigung	For acceleration

Special operating situations

Regulated setting down of the vehicle at v = 0 km/h (Q1, Q2)

(45) With regulated setting down in stations and operating structures dynamic actions are created on the guideway via the support skids. The static action from a support skid is to be established in the following way:

$$F_{z,TK,j/j+1} = (p_{z,az,TMT_j} + p_{z,az,TMT_{j+1}}) \cdot L_{sys,TMT}; \quad \text{in [kN]} \tag{16}$$

with $p_{z,az,TMT}$ from equation (15) and j = 1, 3, 5, 7, 9, 11, 13, 15

(46) Component dynamics and control dynamics following chapter 0 are to be taken into account.

(47) The time function of the regulated setting down to be taken into account is to be taken from figure 135 in chapter (8)

(48) The forces which occur as a consequence of guideway longitudinal and crossways tilting as a consequence of the friction coefficient μ (see table 98) for a support skid $F_{x/y,TK}$ in x- and/or y-direction which are limited by the maximum forces max $F_{x/y,TK}$ dependent on the friction coefficient are to be applied following equation (17) and (18).

$$F_{y,TK} = F_{z,TK} \cdot \frac{a_y}{a_z} \quad \text{whereby} \quad \max F_{y,TK} = \mu \cdot F_{z,TK}; \quad \text{in [kN]} \tag{17}$$

and

$$F_{x,TK} = F_{z,TK} \cdot \frac{a_x}{a_z} \quad \text{whereby} \quad \max F_{x,TK} = \mu \cdot F_{z,TK}; \quad \text{in [kN]} \tag{18}$$

Set down vehicle (Q1, Q2)

(49) *The actions from the operating condition "set down vehicle" are covered by the actions from the regulated setting down process (see chapter 0).*

Levitating vehicle and hovering (Q1, Q2)

(1) The magnetic forces analogous to the previous chapter are to be applied.

(2) Component dynamics and control dynamics following chapter 0 are to be taken into account. In this a possible excitation of natural frequencies of the guideway is to be observed through the magnet regulation above all (see chapter 0).

Aerodynamic actions from the vehicle (Q7, Q8)

Meeting of trains (Q7a)

(50) *Additional guidance magnet forces as a consequence of a meeting of trains may be ignored on adherence to the track centre distances stipulated.*

Tunnel travel (Q7b)

(51) Direct actions from the vehicle
A reduced space (tunnel cross section) for the displacement of the air results through the tunnel. The values indicated in table 107 for pressure and suction are to be applied with a 10% increase.

(52) Indirect actions as a consequence of the variability of the all-round pressure of the surrounding area
A change in pressure from 5500 Pa only effects the pressure tight closed cavities (e.g. cavity boxes of guideway beams which are sealed through welding). This action is not to be transferred with the increased pressure/suction value. It is recommended, in guideway areas in which corresponding changes in pressure are possible not to use pressure tight guideway designs.

(53) Indirect actions as a consequence of reflected blast/suction waves
Actions as a consequence of reflected blast/suction waves are negligible.

(54) Unequal pressure distribution / air buffeting
The characteristic values of possible actions as a consequence of unequal pressure distribution and air buffeting are to be set down project specifically with the available boundary conditions (tunnel cross section, tunnel length, travel speed) being taken into consideration.

Actions on structures close to track/tunnels (Q7c)

(55) The actions on structures close to the track are to be taken from EN 1991-2 chapter 6.6 with the vehicle width being taken into account. Here the width of the track vehicle is to be applied with 3.07m and the width of the maglev vehicle with 3.70 m.

(56) The values for higher speeds are to be extrapolated in proportion to the squares of the speed.

(57) The factor k_1 from EN 1991-2 chapter 6.6 for consideration of a favourable aerodynamic form is to be applied with $k_1 = 0.6$ (streamlined vehicle)

(58) Further coefficients are to be taken into account in line with EN 1991-2 chapter 6.6.

(59) Dynamic step ups through excitation of natural forms are to be proven.

Impulse (Q8a)

(60) The forces in table 106 in z- direction analogous to figure 133 are to be applied for the nose/tail sections as a function of the travel speed v.

v	$p_{z,A,1}$	$p_{z,A,2}$
[km/h]	[kN/m]	[kN/m]
0	0	0
200	-0.8	0.5
300	-1.8	1.2
400	-3.2	2.1
500	-5.0	3.2

Table 106 – Typical impulse forces nose/tail section

(61) For the middle sections the following impulse forces are to be applied continuously:

$$p_{z,A,3}(v) = \frac{p_{z,A,1}(v)}{3} \quad \text{in [kN/m]} \tag{19}$$

(62) The impulse forces are only to be applied when they operate unfavourably.

(63) The impulse forces reduce the vertical loads. In verification of the positional stability the minimum vibration coefficient (e.g.$1/\varphi_{z,Bg}$) is to be taken into account.

(64) The actions Q8a and Q9b are not to be applied simultaneously.

(65) Q8a is to be taken into account as an action effective against fatigue.

Direct pressure/suction action on the guideway (Q8b)

(66) *Pressure and suction forces act on the guideway in the immediate vicinity of the vehicle. These are dependent on the travelling speed and the respective location of the guideway cross section.*

(67) On the upper side of the guideway a pressure/suction load in line with the distribution shown in figure 1323 is to be applied. The associated action quantities for v = 500 km/h (530 km/h) are to be taken from table 107.

(68) The values for other travelling speeds are to be established quadratically with the speed interpolated.

v	$q_{D/S,OG,1}$	$q_{D/S,OG,2}$	$q_{D/S,OG,3}$
0 km/h	0 kN/m²	0 kN/m²	0 kN/m²
500 km/h	+ 14 kN/m²	- 7 kN/m²	+ 7 kN/m²
530 km/h	+ 16 kN/m²	- 8 kN/m²	+ 8 kN/m²

Table 107 – Typical pressure - (+) and suction forces (-) on the upper side of the guideway

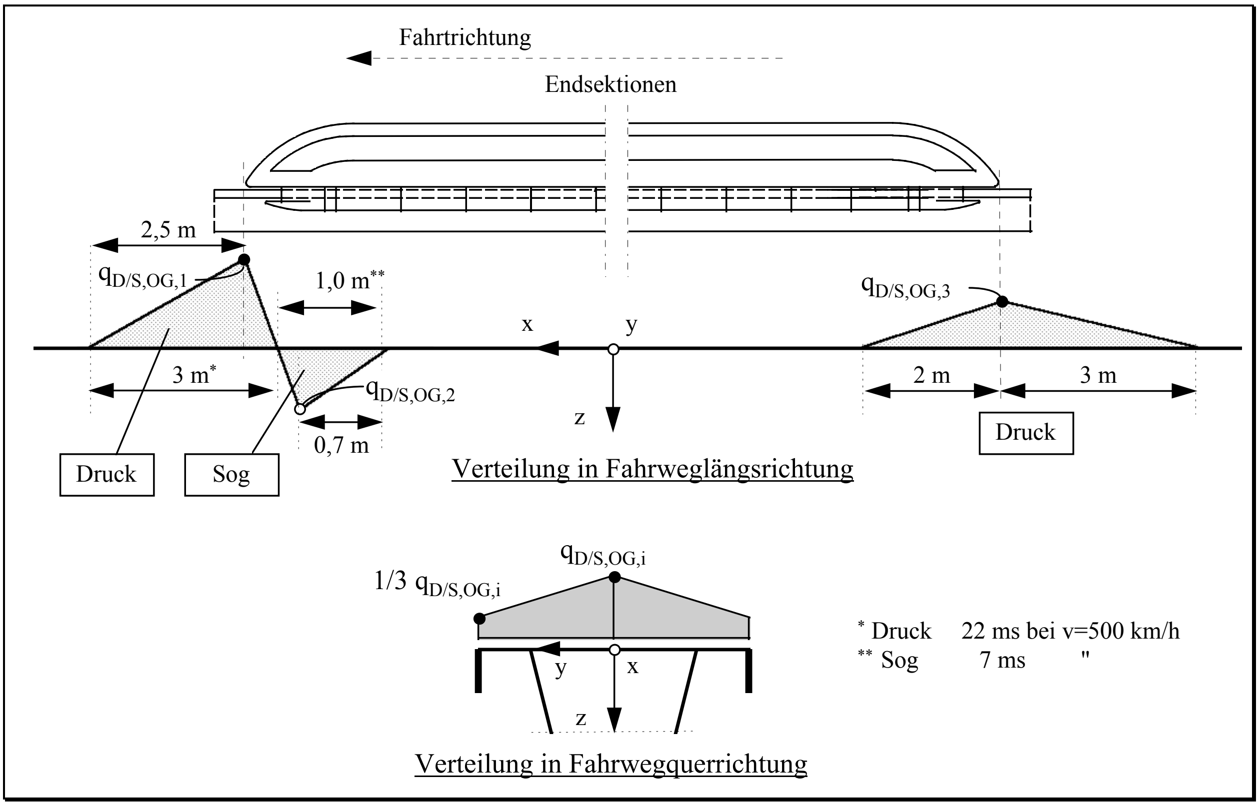


Figure 132 – Typical distribution of the pressure/suction action on the upper side of the guideway

Fahrtrichtung	Direction of travel
Endsektionen	End sections
Verteilung in Fahrweglängsrichtung	Distribution in guideway longitudinal direction
Druck	Pressure
Sog	Suction
Verteilung in Fahrwegquerrichtung	Distribution in guideway transverse direction

(69) If required the pressure/suction actions for other points on the guideway beam are to be specially established whereby the diagram shown in figure 6 from /DIN Fachbericht 101/ for pressure load when a vehicle travels by is to be used.

(70) Component dynamics are to be taken into account following chapter 0.

Wind on the vehicle (Q9)

General

(71) *Subsequently the actions to be taken into account as a consequence of wind on stationary and moving vehicles are given (basis is /MSB AG-UMWELT/).*

(72) *Wind can bring about lateral forces and y-direction and moments via the weak point of the resulting wind power round the x- and z- axis and impulse forces in z-direction.*

(73) *The sizes and the weak points of the actions as a consequence of wind on the vehicle are dependent on the:*

- *Travel speed v_{Fzg}*
- *Wind speed $v_{W,b}$ or $v_{W,m}$*
- *Geometry of the vehicle (c-value)*

(74) *The travel speed and the wind speed which occurs are dependent on the project and the location.*

Action as a consequence of side wind on the vehicle (Q9a)

(75) As a basis for the wind speeds to be taken into account in the layout of the guideway the following rounded nominal gust wind speeds (5 sec.-mean value) $v_{b,10}$ at $h_{W,Gelände}$ = 10 m, which occur once per year are to be assumed.

- Wind zone I $v_{W,b,10}$ = 27 m/s
- Wind zone II [19] $v_{W,b,10}$ = 30 m/s
- Wind zone III $v_{W,b,10}$ = 34 m/s
- Wind zone IV $v_{W,b,10}$ = 38 m/s

(76) *Opposite the ground speed $v_{W,m,10}$ (10 min-mean value in 10m height and in 10 years) with a wind speed$v_{W,m,10}$ = 25 m/s for the wind zone II, there results a gust factor of 1.44 (e.g. wind zone II: (30 m/s)² / (25 m/s)² = 1.44).* This factor covers a possible dynamic step up of the guideway requirement from the wind on the vehicle at constant wind (10 min mean value; ground speed).

(77) Nominal gust wind speeds with different heights h_W (in m) over land surface are to be calculated with the help of equation (20) and z_W= approx 1.3m and rounded up to whole numbers.

$$\frac{v_{W,b,h_W}}{v_{W,b,10}} = \left(\frac{h_W}{10\ m}\right)^{0,11} \quad \text{with } h_W = h_{G,\,Gelände} + z_W \quad \text{in [m/s]} \qquad (20)$$

(78) As a consequence of the distance of the resultant force of the wind force in z-direction a track moment is effective round the axis. The pair of forces which results from this in z-direction is introduced to the guideway via the support magnets and is to be taken into account.

[19] Decisive wind zone of the guideway regulation dimensioning for German applications.

(79) The guidance and support magnet forces to be applied are to be taken from the tables contained in Annex II-E (Tables 118 to 136) for various travel speeds and wind speeds (see e.g. table 108). The forces for deviating travel speeds are to be established through linear interpolation for v_{Fzg} < 500 km/h For travel speeds v_{Fzg}> 500 km/h the forces are to be established through extrapolation in proportion to the squares of the travel speeds.

Wind speeds at $h_{G,Gelände} \leq 4.0$ m in wind zone				wind speed at $4{,}0\ m < h_{G,Gelände} \leq 13.0$ m in wind zone				wind speed at $13{,}0\ m < h_{G,Gelände} \leq 20.0$ m in wind zone			
I	II	III	IV	I	II	III	IV	I	II	III	IV
25	28	32	36	28	31	36	40	29	33	37	42

Table 108 – Wind speeds [m/s] with relevant guideway heights

Aerodynamic impulse as a consequence of wind (Q9b)

(80) The impulse forces for side wind are dependent on the travel speed and the wind speed and are to be applied in line with table 109.

(81) The associated geometry is to be assumed in accordance with figure 24.

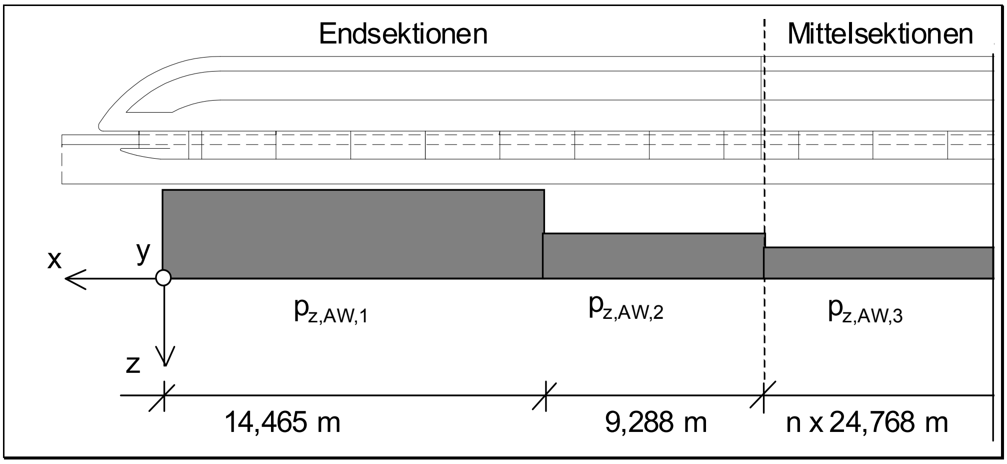


Figure 133 – Typical load arrangement for the aerodynamic propulsion

Endsektionen	End sections
Mittelsektionen	Middle sections

(82) The impulse forces reduce the vertical loads and are only to be applied when they operate unfavourably.

(83) For the middle sections the following impulse forces are to be applied continuously:

$$p_{z,AW,3}(v) = \frac{p_{z,AW,1}(v)}{3} \quad \text{in [kN/m]} \qquad (21)$$

(84) For the rear section the aerodynamic impulse forces are smaller than for the nose section. Therefore the values of the nose section can also be applied safely for the rear section.

(85) The actions as a consequence of Q8a and Q9b are not to be taken into account at the same time as the action Q9b contains the action Q8a.

v_W [m/s]	v_{Fzg} = 0 km/h		v_{Fzg} = 200 km/h		v_{Fzg} = 300 km/h		v_{Fzg} = 400 km/h		v_{Fzg} = 500 km/h		v_{Fzg} = 530 km/h	
	$p_{z,AW,1}$	$p_{z,AW,2}$	$p_{z,AW,1}$	$p_{z,AW,2}$	$p_{z,AW,1}$	$p_{z,AW,2}$	$p_{z,AW,1}$	$p_{z,AW,2}$	$p_{z,AW,1}$	$p_{z,AW,2}$	$p_{z,AW.1}$	$p_{z,AW.2}$
40	-2.4	-1.5	-7.5	-9.6	-8.1	-8.9	-9.0	-6.9	-10.2	-5.1	-10.6	-4.5
39	-2.3	-1.4	-7.2	-9.2	-7.8	-8.3	-8.6	-6.4	-9.8	-4.6	-10.2	-4.1
38	-2.2	-1.4	-6.9	-8.7	-7.4	-7.8	-8.3	-5.9	-9.5	-4.2	-9.9	-3.7
37	-2.1	-1.3	-6.6	-8.3	-7.1	-7.2	-8.0	-5.4	-9.2	-3.7	-9.6	-3.3
36	-2.0	-1.2	-6.3	-7.9	-6.8	-6.7	-7.7	-4.9	-8.9	-3.3	-9.2	-2.9
35	-1.9	-1.1	-6.0	-7.5	-6.5	-6.2	-7.4	-4.5	-8.6	-2.9	-8.9	-2.5
34	-1.8	-1.1	-5.7	-7.1	-6.2	-5.7	-7.1	-4.1	-8.2	-2.6	-8.6	-2.2
33	-1.6	-1.0	-5.4	-6.7	-5.9	-5.2	-6.8	-3.6	-7.9	-2.2	-8.3	-1.8
32	-1.6	-1.0	-5.1	-6.3	-5.6	-4.8	-6.5	-3.2	-7.6	-1.9	-8.0	-1.5
31	-1.5	-0.9	-4.8	-5.8	-5.3	-4.3	-6.2	-2.9	-7.4	-1.6	-7.7	-1.3
30	-1.4	-0.8	-4.5	-5.3	-5.1	-3.9	-6.0	-2.5	-7.1	-1.3	-7.4	-1.0
29	-1.3	-0.8	-4.2	-4.9	-4.8	-3.5	-5.7	-2.2	-6.8	-1.1	-7.2	-0.7
28	-1.2	-0.7	-4.0	-4.5	-4.6	-3.1	-5.5	-1.9	-6.5	-0.8	-6.9	-0.5
27	-1.1	-0.7	-3.7	-4.1	-4.3	-2.8	-5.2	-1.6	-6.3	-0.6	-6.7	-0.3
26	-1.0	-0.6	-3.5	-3.7	-4.1	-2.4	-5.0	-1.3	-6.0	-0.4	-6.4	-0.1
25	-0.9	-0.6	-3.2	-3.3	-3.9	-2.1	-4.8	-1.1	-5.8	-0.2	-6.2	0.1
24	-0.9	-0.5	-3.0	-3.0	-3.7	-1.8	-4.5	-0.8	-5.6	0	-5.9	0.3
23	-0.8	-0.5	-2.8	-2.6	-3.5	-1.6	-4.3	-0.6	-5.4	0.2	-5.7	0.4
22	-0.7	-0.5	-2.6	-2.3	-3.3	-1.3	-4.1	-0.4	-5.1	0.3	-5.5	0.6
21	-0.7	-0.4	-2.4	-2.0	-3.1	-1.1	-3.9	-0.3	-4.9	0.5	-5.3	0.7
20	-0.6	-0.4	-2.2	-1.7	-2.9	-0.8	-3.7	-0.1	-4.8	0.6	-5.1	0.8
19	-0.5	-0.3	-2.1	-1.5	-2.7	-0.7	-3.5	0	-4.6	0.7	-4.9	0.9
18	-0.5	-0.3	-1.9	-1.2	-2.6	-0.5	-3.4	0.2	-4.4	0.8	-4.8	1.0
17	-0.4	-0.3	-1.8	-1.0	-2.4	-0.3	-3.2	-0.3	-4.3	0.9	-4.6	1.1
16	-0.4	-0.2	-1.6	-0.8	-2.2	-0.2	-3.0	0.4	-4.1	1.0	-4.5	1.2
15	-0.3	-0.2	-1.5	-0.6	-2.1	-0.1	-2.9	0.5	-4.0	1.1	-4.4	1.3
14	-0.3	-0.2	-1.4	-0.5	-2.0	0	-2.8	0.6	-3.9	1.2	-4.3	1.4
13	-0.3	-0.2	-1.2	-1.3	-1.8	0.1	-2.7	0.6	-3.8	1.3	-4.2	1.5
12	-0.2	-0.1	-1.1	-1.2	-1.7	0.2	-2.6	0.7	-3.7	1.3	-4.2	1.6
11	-0.2	-0.1	-1.0	-0.1	-1.6	0.3	-2.5	0.8	-3.7	1.4	-4.1	1.7
10	-0.2	-0.1	-0.9	0	-1.5	0.3	-2.4	0.8	-3.7	1.5	-4.1	1.8

Table 109 – Typical side wind determined impulse forces of the nose section

Wind with unfavourable aerodynamic influences

(86) In the area of tunnel exits and entrances, on valley bridges and for other unfavourable dynamic influences higher actions are to be taken into account project specifically.

(87) The actions from possible higher wind speeds in the entrance and exit area of tunnels and on valley bridges are to be limited in such a way (e.g. through wind protection measures) that the actions indicated in chapters 0 and 0 are not exceeded. In addition aerodynamic influences such as e.g. exposed positions are to be taken into account in line with the regulations of the standards and directions.

Thermal action as a consequence of propulsion (Q10)

(88) Between the stator packs of the long stator and the beam cantilever arm a maximum temperature difference of max $\Delta T_{Antrieb}$ = 15 K
is to be taken into account.[20]

(89) The temperature difference is caused by the propulsion and is to be transferred with the temperature difference from the environment. For this action a vibration cycle of max SS($\Delta T_{Antrieb}$) = 2 SS/Tag is to be assumed. The vibration cycles take into account 2 phases with compressed travel operation (morning and evening).

[20] Should the actions in x-direction only be transferred into the cantilever arm of the guideway beams through friction in the connecting contacts of the stator pack securing attachment (e.g. pre-stressed screw connection), then there results maximum power from the maximum pre-stressing force and the maximum friction coefficient as a consequence of propulsion and environment from temperature action.

Infrequent variable actions (Q11a...Q11k)

General

(90) Subsequent infrequent actions from the vehicle are to be taken into account with regard to the safety level analogous to the frequent variable actions if

- no guideway inspection is to be carried out immediately following start of the action and/or
- a statement of the start of the action is not assured and thus an inspection cannot be carried out.

(91) If a safety risk through e.g. redundant elements or moving of the load etc can be ruled out, then a reduction of the partial safety factors may occur in agreement with the responsible inspectorate for taking into account the small probability of the infrequent actions occurring.

(92) In the formation of combinations in line with chapter **0** The infrequent actions are to be applied as guiding actions with γ_F = 1,35.

(93) Dynamic step ups following chapter 0 are to be taken into account in each of the subsequent actions if nothing expressly to the contrary is indicated.

Exceeding of payload (Q11a)

(94) *A possible exceeding of the payload during unusual operating systems such as fire with evacuation in neighbouring sections is covered by the maximum vehicle weight.*

Failure of a support magnet circuit (Q11b)

(95) With the failure of a magnet regulating circuit for support MRET the proportionate supporting force of the failed partial magnet is passed on into the guideway through the neighbouring partial magnet of the neighbouring support magnet.

(96) The following maximum magnetic actions (limit capacity of the support magnets[21]) is to be applied for local proofs for these neighbouring support magnets on a length of $L_{sys,TMT}$ = 1,548 m

- in z-direction: max $p_{z,TMT,Q11b}$ = 45,0 kN/m
- in x-direction: max $p_{x,TMT,Q11b}$ = ± 4,0 kN/m

(97) The regulating factor is to be applied with φ_{Rl} =1,0.

(98) The associated load arrangement is to be taken from Figure 149.

(99) *For global proofs replacement loads may be applied in place of the above value limits of the support magnet forces which result from the global actions following chapter 0.*

[21] The capacity limit is derived from the maximum half magnet force which results from the most unfavourable vehicle action combination (incl. fail situations) on the most unfavourable position of the vehicle.

Failure of neighbouring support magnet circuits (Q11c)

(1) When regulating circuits of neighbouring support magnets fail, the assigned support skid stops on the sliding strip. The maximum local actions from the support skid (incl. local component dynamics) are to be applied

- Impact load max $F_{z,TK,Stoß}$ = 100 kN
- quasi-static load max $F_{z,TK,stat}$ = 50 kN

.

(2) *The maximum value is limited to 100kN by the vehicle for the most unfavourable situation. The dynamic effects can be proved e.g. with the help of the force time course following figure 134.*

(3) The associated power in x-direction from the above impact force and the maximum friction coefficients following table 98 is to be applied as follows:

- from impact force (with $\mu_{TK\text{-}GL}$ = 0,30) max $F_{x,TK,Stoß}$ = 30 kN
- from quasi-static load (with $\mu_{TK\text{-}GL,Haft}$ = 0,50) max $F_{x,TK,stat}$ = 25 kN

(4) The friction coefficient may be reduced with the minimum location dependent travel speed following table 98 being taken into account.

(5) As a consequence of friction between support skid and sliding plane the support skid heats up. The maximum amount of heat stored in the sliding surfaces of the support skid amounts to 650kJ. With a stopping vehicle this leads to heating of the sliding strip/sliding plane in the area of the support skid. The resultant temperature increase is to be established dependent on the design.

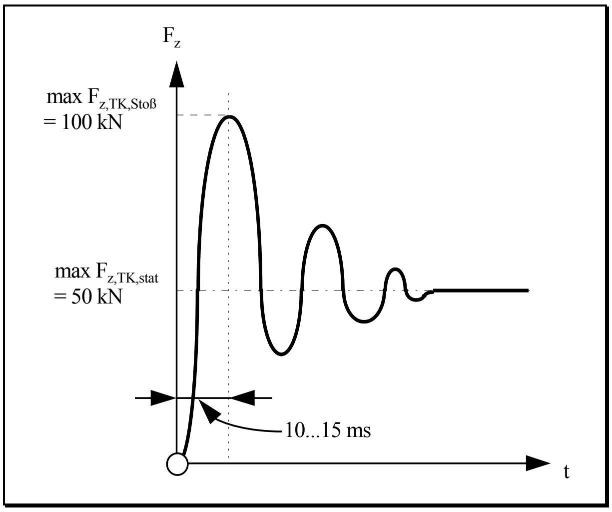


Figure 134 – Typical force-time course of the dynamic support skid force

(6) The local deformations as a consequence of the impact load are to be established. The verification of compatibility to the vehicle is to be shown for the deformations to be expected.

(7) The surface loads are to be established as follows with the dimensions in figure 125 being taken into account:

$$\max q_{z,TK} = \max F_{z,TK} / (L_{TK} \cdot b_{TK}) \max q_{z,TK} = \max F_{z,TK} / (L_{TK} \cdot b_{TK}) \quad (22)$$

$$\max q_{x,TK} = \mu \cdot \max F_{z,TK} / (L_{TK} \cdot b_{TK}) \max q_{x,TK} = \mu \cdot \max F_{z,TK} / (L_{TK} \cdot b_{TK}) \quad (23)$$

(8) For global proofs replacement loads may be applied in place of the above value limits of the support skid forces which result from the global actions following chapter 0.

Failure of a guidance magnet circuit (Q11d)

(1) *With failure of a magnet regulating circuit for guidance MREF the proportionate guidance force of the failed partial magnet (see load arrangement) is transferred from the neighbouring partial magnet of the neighbouring guidance magnet.*

(2) For local proofs the following maximum magnetic forces in y-direction are to be applied for this action (limit capacity of the guidance magnets):

- max $p_{y,FMT}$ = 16 kN/m for guidance magnets with magnetic poles below
- max $p_{y,FMT}$ = 32 kN/m for guidance magnets with magnetic poles below and above

(3) The associated load arrangement is to be taken from Figure 152 (chapter **0**)

(4) For global proofs replacement loads may be applied in place of the above value limits of the guidance magnet forces which result from the global actions following chapter 0.

Failure of neighbouring support magnet circuits (Q11e)

(1) *With failure of both magnet regulating circuits on one levitating framework the start strips of the guidance magnets opposite transfer the proportionate guidance forces to the lateral guidance rails mechanically (compressive force).*

(2) The maximum local impact force on the lateral guidance rails (incl. local component dynamics) is to be applied as follows for local proofs:

- max $F_{y,FM,Q11e1}$ = 63 kN (with γ_F =1,35) without wind
- max $F_{y,FM,Q11e2}$ = 115 kN (with γ_F =1,00) [22] with wind (v_W = 25 m/s)

(3) The action $F_{y,FM,Q11e2}$ is to be classified as "accidental action" with reference to the probability of occurrence.

(4) The associated maximum power in x-direction is to be established from the above impact force and the maximum friction coefficient of $\mu_{FM,SFS}$ = 0,3 at v ⇒ 0 km/h as follows:

$$\max F_{x,FM} = \mu_{FM\_SFS} \cdot \max F_{y,FM} \qquad (24)$$

(5) The coefficient of friction may be reduced, taking into consideration the local minimum operating velocity in accordance with Tabelle 97 .

(6) The geometry of the action is to be taken from Figure 153.

(7) The temperature increase as a consequence of mechanical guiding (start up) is covered by the action from the safe brake.

(8) For global proofs replacement loads may be applied in place of the above value limits of the start up forces of the guidance magnet which result from the global actions following chapter 0.

[22] If the serviceability and safety are not affected inadmissibly, local plastic deformations with the application of max $F_{y1FMQ11e2}$ can be permitted in agreement with the responsible inspectorate.

•

Use of the vehicle "safe brake" (Q11f)

Rule

If the braking system (long stator motor) fails, the vehicle safe brake is activated (for the geometry and positioning of the braking magnets on the vehicle see Figure 124). The braking process is divided into two sections according to the actions on the guideway (see Figure 137):

- *Section I: Non-contact application of the eddy-current braking force ("free" braking magnet)*
- *Section II: Applying the braking magnets to the lateral guidance rails*

In the case of an empty vehicle, the braking forces may be reduced in accordance with the lower mass in the ratio of the dead weight of the vehicle to its permitted total weight (see chapter **0**).

For section I ($\approx$200 km/h $\leq v_{Veh} \leq$ 530 km/h) the following actions must be taken into account:

Non-contact application of the eddy-current braking force $F_{x,BM,}$, whereby the magnetic force increases as the velocity decreases:

$$\max F_{x,BM,I} = 63 \text{ kN/section} \ \ldots \approx 85 \text{ kN/section}$$ [23]

The accompanying magnetic tensile force $p_{y,BM,I}$ on the lateral guidance rails, which takes effect as an "inner force" similar to the prestressing force of the guidance magnet, taking into account the tolerances and range, amounts to:

$\max p_{y,BM,I} \leq$ 37.5 kN/m

For the support magnets near the eddy-current brakes, an uneven distribution of the support magnet force of around 30% must be set, as shown in Figure 148. This combination must also be considered in the following braking section II.

In section II (0 km/h < v_{Fzg} < $\approx$200 km/h) the following actions must be taken into account:

At v_{Fzg} < $\approx$200 km/h the braking magnets are applied to the lateral guidance rails. The amount of acting frictional force in the x-direction, together with the decreasing magnetic braking force is limited to a maximum braking force, max $F_{x,BM,II}$ of:

$\max F_{x,BM,II} \leq$ 110 kN/section

The maximum tensile force in the y-direction max $p_{y,BM,II}$ is: max $p_{y,BM,II}$ = 37.5 kN/m

Compressive force does not occur in the y-direction. When using max $p_{y,BM,II}$, φ_{RI} = 1.0 can be used.

At v_{Veh} = 5 km/h the set-down command comes into force and the vehicle is set down on the guideway in a controlled manner. As the support skids are lowered onto the sliding surfaces, the vehicle's velocity v_{Fzg} = 0 km/h. The support skids' strength can be determined in a similar manner to that in chapter **0**, taking the corresponding vibration coefficient into consideration. The time function of the controlled set down of the vehicle is shown in Figure 135. This must be taken into account when verifying the dynamics in the x- and z-directions.

The increase in temperature on the lateral guidance rails caused by the braking magnets must be set at $\Delta T_{BM\_SFS} \leq$ 8 K for a 10 section vehicle. This temperature increase must be superimposed with the environmental thermal actions in accordance with chapter 0.

The load arrangement for the braking magnets must be taken from Figure 154.

As with braking and acceleration via the long stator, the overturning moment occurs around the y-axle when the "safe brake" is applied. The resulting z-force distribution must be taken into account.

[23] Intermediate values may be added linearly.

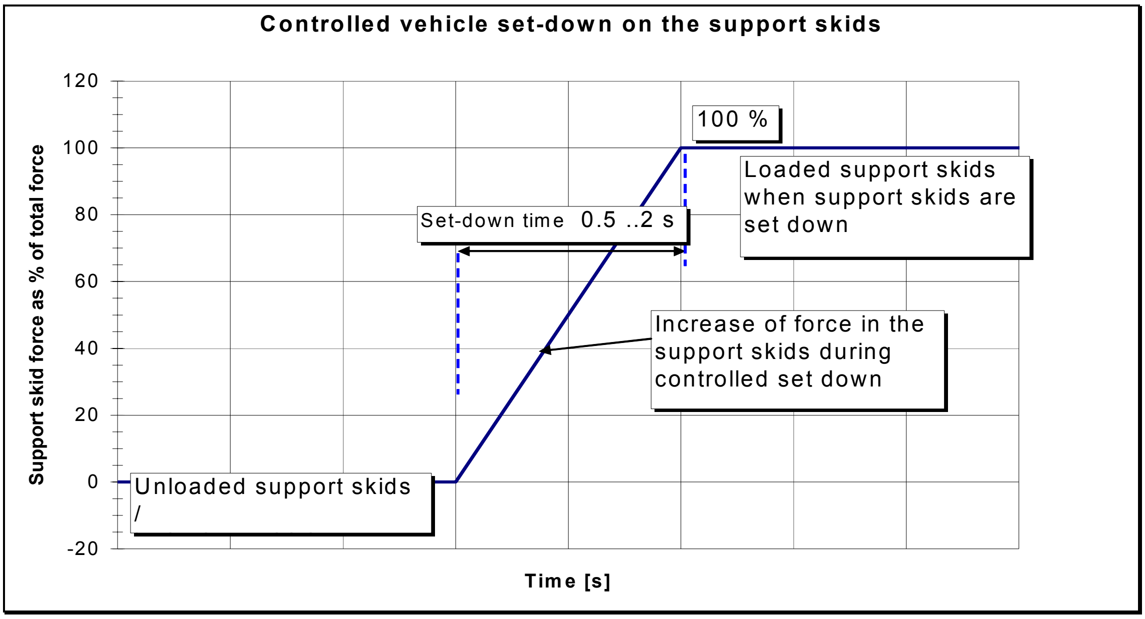


Figure 135 – Typical, simplified time function of controlled vehicle set down

Special cases

When the braking power of the braking magnets (see Figure 137: line 1), the slide $v_{Veh} \Rightarrow 0$ of a vehicle with permitted weight placed on the support skids (see Figure 137: area v_{veh} < 10 km/h) and γ_Q = 1.0 is exceeded, this must be considered as an accidental design situation.

For these special cases, when designing the guideway observe the time lapse provided in the following Figure 136 for the acceleration a_x during the transition from sliding to static friction.

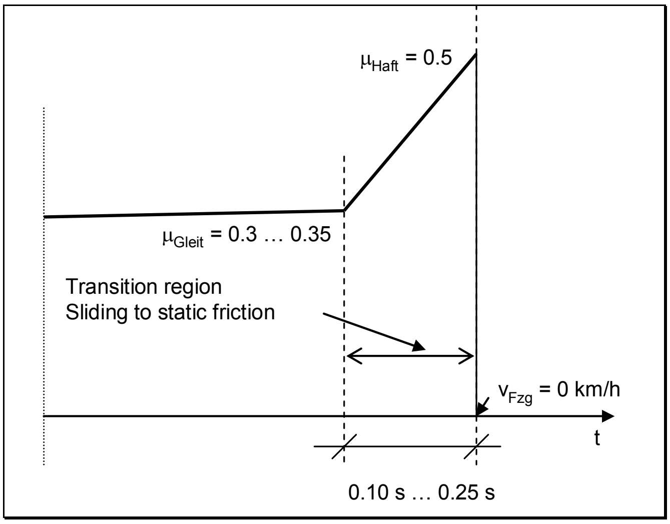


Figure 136 - Typical acceleration time function for sliding on the support skids

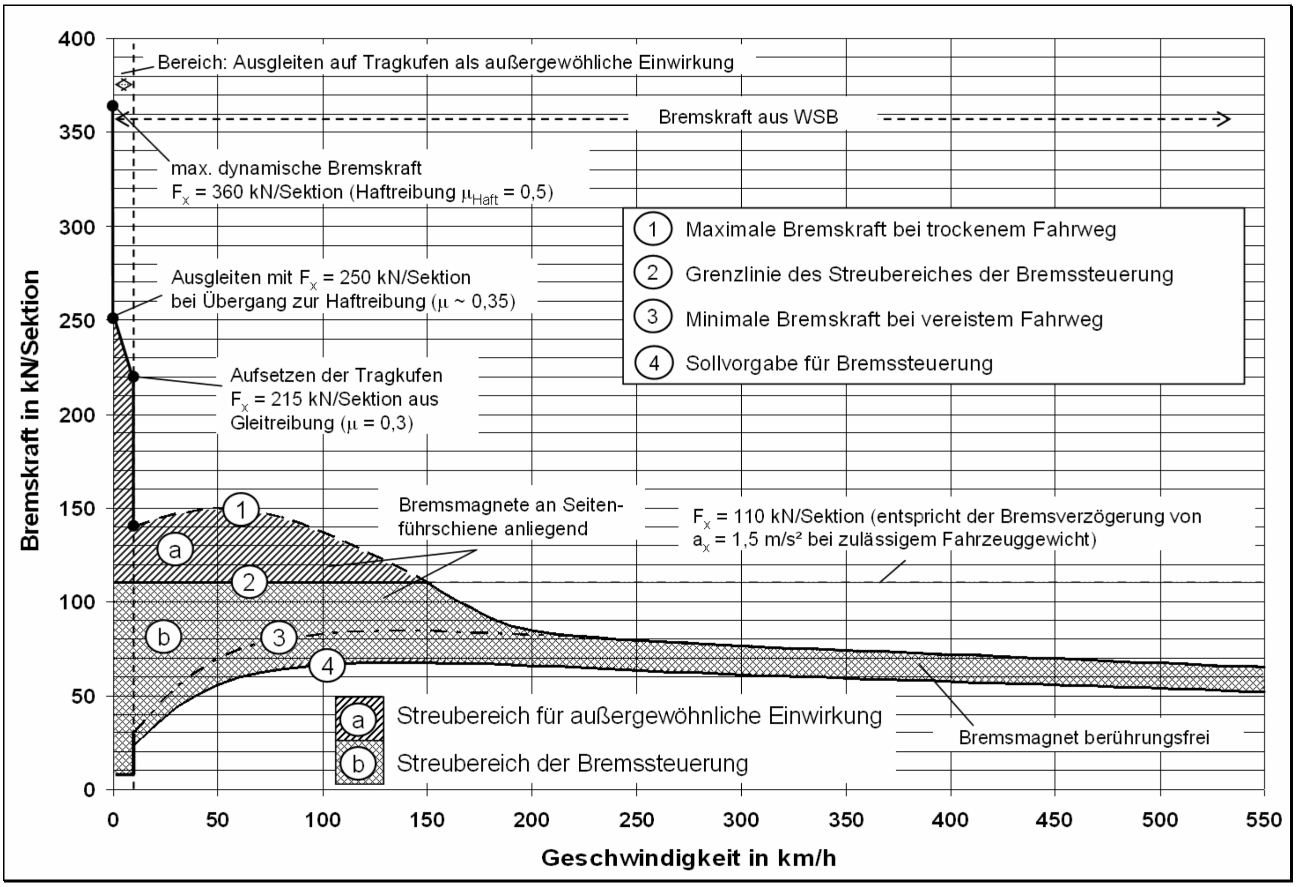


Figure 137 - "Safe brake" braking force progression

Bereich: Ausgleiten auf Tragkufen als außergewöhnliche Einwirkung	Area: Sliding on support skids as accidental action
Bremskraft aus WSB	Braking force from WSB
Max. dynamischer Bremskraft Fx = 360 Kn/Sektion (Haftreibung)	Max. dynamic braking force Fx = 360 Kn/section (static friction)
Maximale Bremskraft bei trockenem Fahrweg	Maximum braking force on a dry guideway
Grenzlinie des Streubereiches der Bremssteuerung	Limit of the range of dispersion of the braking control
Minimale Bremskraft bei vereistem Fahrweg	Minimum braking force on icy guideway
Sollvorgabe für Bremsteuerung	Target values for braking control
Ausgleiten mit Fx = 250 kN/Sektion bei Übergang zur Haftreibung	Sliding at Fx = 250 Kn/section during transition to static friction
Aufsetzen der Tragkufen Fx = 215 kN/Sektion aus Gleit-reibung	Setting down of the support skids Fx = 215 Kn/section from sliding friction
Bremsmagnete an Seitenführschiene anliegend	Braking magnet placed on lateral guidance rail
Fx = 110 Kn/Sektion (entspricht der Bremsverzögerung	Fx = 110 Kn/section (corresponds to brake retardation

von Ax = 1.5 m/s² bei zulässigem Fahrzeuggewicht)	of Ax = 1.5 m/s² with permissible vehicle weight)
Streubereich für außergewöhnliche Einwirkung	Range of dispersion for accidental action
Streubereich der Bremssteuerung	Range of dispersion of the braking control
Bremsmagnet berührungsfrei	Contactless braking magnet
Geschwindigkeit in km/h	Velocity in km/h
Bremskraft in kN/Sektion	Braking force in kN/section

Velocity deviations (Q11g)

Actions resulting from velocity deviations (e.g. stationary vehicles outside stations or slow moving vehicles on 12° guideway transverse gradients ($a_y \Rightarrow 2.04$ m/s²)) must be regarded as infrequent variable actions in comparison to frequent variable actions (for more information regarding this see chapter **0**).

Propulsion system failure (Q11h)

One-sided propulsion system failure

The "one-sided propulsion system failure" malfunction must be considered as described and covered in chapter **0** (actions relating to motor section switching during the alternating step method).

Other propulsion system malfunctions

In the case of unfavourable side-selective unequal distribution 0.73/0.27, a maximum thrust of $F_{x,Q11h1,HG}$ = 185 kN/middle section should be taken into account[24]. This results in the following forces on each side of the guideway:

max $p_{x,\ Q11h1,\ HG,\ right/left}$ = 0.73 · 185 kN / 24.768 m = 5.5 kN/m

min $p_{x,\ Q11h1,HG,\ left/right}$ = 0.27 · 185 kN / 24.768 m = 2.0 kN/m (without dynamic force)

When there are equally effective, maximum resulting actions in the x-direction on both guideway sides in the event of malfunction, take into consideration the following force: $p_{x,Q11h2}$ = 250 kN / middle section = 250 kN / 24.768 m = approx. 10.0 kN/m

A typical (simplified) function of the action dependent on velocity and vehicle length (number of sections) as a result of propulsion system malfunction is shown as an example on Figure 138. In the case of project independent verification, the specified reduction must be applied.

With regard to probability of occurrence, the action $p_{x,Q11h2}$ must be considered unusual (γ_Q = 1.0).

Whether it is necessary to consider these actions and the scale of the reduction depends on the project and must always be confirmed on a case by case basis.

Forces resulting from pitching moments must be taken into consideration as in chapter **0**

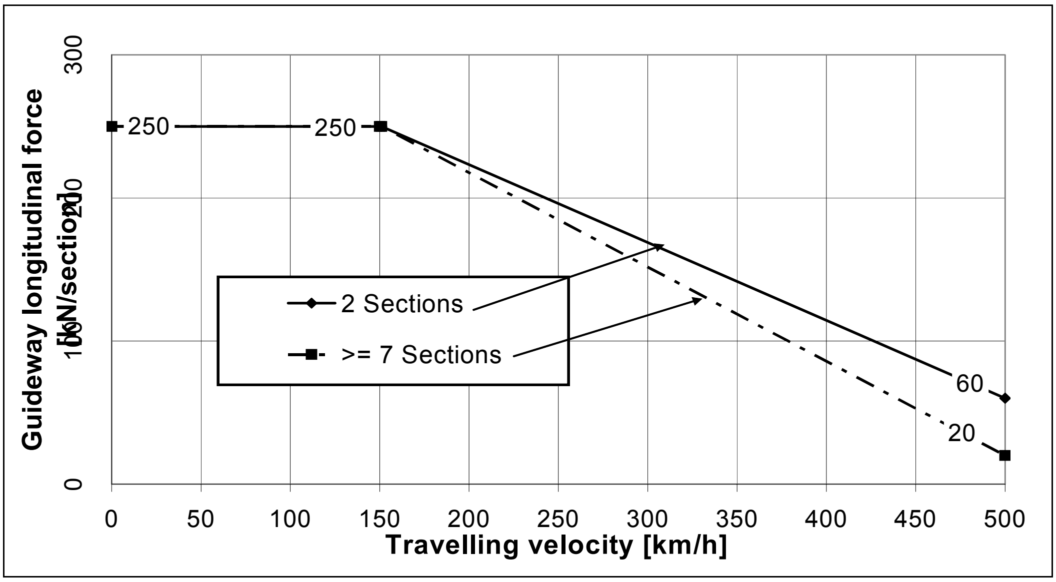


Figure 138 - Velocity function of the x-forces as a result of propulsion system malfunction

One-sided set-down of the vehicle (Q11i)

General

[24] The actions for the other vehicle weights are: $F_{x,Q11h1,ZG}$ = 180 kN/middle section, $F_{x,Q11h1,MG}$ = 170 kN/middle section and max $F_{x,Q11h1,EG}$ = 150 kN/middle section

In the event of a short circuit of the long stator winding, the two following design situations must be considered with regard to the actions on the guideway.

Design situation 1

There is a short circuit on the windings, the vehicle is above the location of the short circuit, which is near to the winding star point (motor section switching) and the velocity is v ≥ 25 km/h. This results in the vehicle being set-down on one side on the sliding surface of the guideway beams. The support skids come into contact with the gliding strips one after the other. The side of the vehicle opposite the short circuit continues to levitate.

Taking the vehicle weight into consideration, the unilateral section loads $q_{z,set}$ and $q_{z,fun}$ will be as follows:

- Set down side:

$$q_{z,Q11i,set.} = 0.5 \cdot \text{stat } p_z \cdot a_z /g \quad (25)$$

- "functional" (levitating) side:

$$q_{z,Q11i,fun.} = 0.5 \cdot \text{stat } p_z \cdot a_z / g \quad (26)$$

Other actions (e.g. centrifugal force) must be superimposed according to chapter **0**. The skid forces on the set down side must be calculated using $e_{x,SS}$ = support skid centre distance, as follows:

$$F_{z,SS,Q11i} = q_{z,Q11i,set} \cdot e_{x,SS} \quad (27)$$

The velocity-dependent coefficient of friction can be found in Table 98.

An additional vibration coefficient of max. $\varphi_{B,z,Q11i} = 1.8$ must be taken into account for the set down side. Determine the vibration coefficient in the z-direction with a min. of $\varphi_{B,z,Q11i} = 0.9$ for the functioning opposite side.

The effect from the propulsion system may be positive (braking), negative (acceleration) or zero in accordance with chapter **0**.

The different forces in the x-direction on both the functional and set down side cause a moment to act on the z-axle. This moment ensures that the forces on the lateral guidance rails (y-direction) are balanced. The guidance magnet forces act in a similar manner to that described in chapter **0**. The remaining actions in the y-direction must be determined in a similar way to the frequent actions.

Only take into account the combination that has the vehicle weight as the leading variable action.

Design situation 2

The short circuit location is not near the cable winding star point or the vehicle has travelled over an already existing short circuit.

This design situation has an effect on the short circuit side on the support magnet/long stator interface braking force, which is globally covered by the x-forces from a) and locally covered by the x-forces from Q11b.

Activating/contact with magnets (Q11j)

Support magnets

The vehicle-side minimum gap monitoring prevents a force-induced activation of the support magnets on the stator packs.

Potential activation due to interference as a result of unfavourable boundary conditions (guideway tolerances, state of motion and load status of the support magnet) is covered by the actions listed in chapter 0.

Guidance magnets

If the ultimate bearing capacity of the guidance magnets is exceeded as described in chapter **0**, this may lead to contact with the guidance magnets positioned opposite.

Actions caused by contact with guidance magnets are described in chapter **0** "Failure of neighbouring support magnet circuits (Q11e)".

Raising frozen support skids (Q11k)

The tension and thrust created by releasing a frozen support skid is transferred to the supporting structure via the gliding strips.

The maximum actions caused by raising frozen support skids are applied locally using the following forces:

- Tension in z-direction $F_{z,Q11k}$ = 50.0 kN / skid
- Thrust in x-direction $F_{z,Q11k}$ = 25.0 kN / skid

It is unwise to assume that the locally assigned support magnets on the frozen support skid do not receive any of the force (see chapter **0**).

Increase in vehicle weight due to snow (Q11l)

Take into account that snow accumulation on the vehicle increases the section load, using the following values:

- $\Delta p_{Z,EG,Q11l(1)} = 1.6$ kN/m → infrequent
- $\Delta p_{Z,EG,Q11l(2)} = 3.2$ kN/m → accidental

The frequency of occurrence and the characteristic values to be applied must be determined on an individual basis (see also /MSB AG-FW IH/; reference carrier, monitoring).

The centroidal distance of the snow accumulation in the z-direction must be set at $s_{z,Q11l}$ = 400 mm.

Actions resulting from maintenance (Q30)

Action effects including potential dynamic step-ups resulting from maintenance (incl. the associated special vehicles, devices and payloads) must not be measured.

Environmental temperature (Q50)

General

/DIN technical report 101/chapter V describes the rules and procedures for the determination of thermal actions on bridges, including their sections. The characteristic values of the actions, as far as they are applicable to the guideway elements of the high-speed Maglev system, can be taken from there. It does not include application-dependent thermal actions.

The following will be referred to:

- *Thermal fluctuation: a regular change in the centroidal temperature of all components (see /DIN technical report 101/chapter V, 6.3.1.3)*
- *Linear temperature difference: linear thermal gradient between opposite edges of components (see /DIN technical report 101/chapter V, 6.3.1.4)*
- *Uneven heating of components: a jump (thermal difference) between the centroidal temperature of individual components, which are not joined together and/or are made of different types of material (see /DIN technical report 101/chapter V, 6.3.1.6)*

The thermal expansion coefficient for the components must be taken from /DIN technical report 101/.

Thermal fluctuations in the guideway superstructure (Q50a)

If the min. and max. outside air temperature cannot be determined more exactly, then the typical values given in Table 110 (column 1) can be used for central European projects. These refer to outside air temperatures between –24°C and +37°C over a period of 50 years.

When calculating the bearing play and (expansion) joints increase the values in Table 110 by 25%.

The possibility of reducing the actions described in Table 110 must be agreed upon on an individual basis with the responsible inspectorate.

Linear temperature difference (Q50b)

General

The temperature differences that need to be taken into account are, among other things, dependent on the condition of the surface, the geometry and climatic conditions.

The following symbols apply to the subsequent threshold values:

ΔT_M *linear temperature difference* $T_o - T_u$ *or* $T_l - T_r$
T_o *Top chord temperature*
T_u *Bottom chord temperature*
T_l *Temperature of the left edge of the load-bearing cross section*
T_r *Temperature of the right edge of the load-bearing cross section*
(For full cross sections use the values on the cross section edge for T_o *and* T_u*.)*

Guideway superstructure

Characteristic values for linear temperature differences for various types of bridge superstructure and varying bridge surface thicknesses can be found in /DIN technical report 101/chapter V, 6.3.1.4. These values are upper limit values for the linear temperature differences for typical examples of the bridge geometry of roads and railway bridges.

The following guidelines must also be considered for the high-speed Maglev system's guideway beams:

- Guideway type I and II
  For discretely supported guideway beams, the characteristic values provided in Table 110 (column 2) can be used, if their cross section and surface is similar. Check the suitability of these values for each individual case with the responsible inspectorate.
- Guideway type III and other guideway designs
  For guideway plate systems and other guideway constructions that are not covered by the values provided in Table 110, then the values are to be agreed upon with the responsible inspectorate (if necessary by theoretical investigation on the basis of calculation simulations).
- Guideways in tunnels
  In the case of guideways in tunnels, there is generally no need to apply a temperature difference as a result of environmental factors.
- Track switching equipment
  see Table 110

To ensure an optimal guideway position in peak periods, (this is to be determined on an individual project basis), when determining the supporting theoretical position, take into account an expected linear temperature difference T_0 - T_U for this period, during the determination of the theoretical pre-curve. This temperature difference results in an optimal guideway position (i.e. the guideway position corresponds to the guideway gradient when the vehicle is on it).

For cross sections not covered in Table 110, hypotheses for the temperature scales must be determined in cooperation with the responsible inspectorate with reference to Table 100 and any other experience or findings. If necessary, these hypotheses must be proven by measurements.

Guideway substructures

Environmental thermal actions for guideway substructures can be found in /DIN technical report 101/chapter V, 6.3.2.

Uneven heating of components due to environmental factors (Q50c)

Set $\Delta T = \pm 15$ K as the temperature difference between steel and concrete parts for the cases described in /DIN technical report 101/chapter 6.3.1.6.

With steel and concrete components that are connected by an entire surface (e.g. LGR or SS on concrete girders) use temperature differences of $\Delta T = \pm 10$ K when lower temperatures have not been verified.

The uneven heating mentioned above is to be superimposed on components, whose temperature increases as a result of traffic.

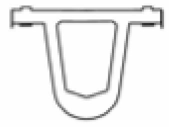
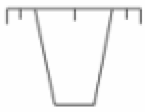
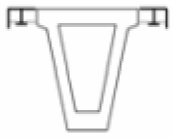
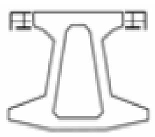
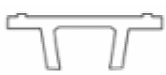
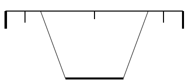
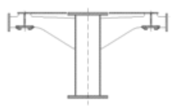
Construction method	Cross section	Thermal fluctuation T_N	Linear temperature difference $\Delta T_{z,My}$ vertical [K]	Linear temperature difference $\Delta T_{y,Mz}$ lateral [K]
		1	2	3
Concrete construction (Height: 2 m)		$-15\ °C \leq T_N \leq 35\ °C$	$-5 \leq \Delta T_{z,My} \leq 17$	$-10 \leq \Delta T_{y,Mz} \leq 10$
Steel construction (Height: 2 m)		$-20\ °C \leq T_N \leq 50\ °C$	$-5 \leq \Delta T_{z,My} \leq 25$	$-17 \leq \Delta T_{y,Mz} \leq 17$
Hybrid construction I (Height: 2 m)		$-15\ °C \leq T_N \leq 35\ °C$	$-5 \leq \Delta T_{z,My} \leq 15$	$-10 \leq \Delta T_{y,Mz} \leq 10$ *
Hybrid construction II (Height: 2.2 m)		$-15\ °C \leq T_N \leq 35\ °C$	$-5 \leq \Delta T_{z,My} \leq 10$	$-10 \leq \Delta T_{y,Mz} \leq 10$ *
Concrete construction (Height: 1 m)		$-15\ °C \leq T_N \leq 35\ °C$	$-5 \leq \Delta T_{z,My} \leq 17$	$-5 \leq \Delta T_{y,Mz} \leq 5$
Steel construction (Height: 1 m)		$-20\ °C \leq T_N \leq 50\ °C$	$-8 \leq \Delta T_{z,My} \leq 25$	$-13 \leq \Delta T_{y,Mz} \leq 13$
Flexible steel (bendable girder WxH: 0.45 m x 1.5 m)		$-20\ °C \leq T_N \leq 50\ °C$	$-10 \leq \Delta T_{z,My} \leq 20$	$-10 \leq \Delta T_{y,Mz} \leq 10$
The characteristic values provided for the thermal actions were determined according to the information given in /DIN technical report 101/, the theoretical calculation results in /R 1/ and the measurement results from TVE. * on the supporting concrete cross section				

Table 110 - thermal fluctuations and linear temperature differences

Effect of wind on the supporting structure (Q51)

Effect of both wind and traffic on the supporting structure (Q51)

Assess wind actions in conjunction with traffic on the supporting structure as described in /DIN technical report 101/.

It is assumed that the guideway is not susceptible to vibration with regard to wind actions, otherwise more exact verification is required.

Assume the wind direction is horizontal.

In the case of double track guideways, measure the individual tracks for the full wind load from both directions.

In the case of wind and traffic acting on the supporting structure, only the area of the guideway not covered by the vehicle is used as the wind exposed surface.

The dynamic pressure to be considered for the nominal wind gust velocity $v_{b,10}$ (5 second average, once a year) in wind zones I, II,III and IV for various gradients across ground must be taken from Table 111.

Form factors and other factors for determining the size of the action on the supporting structure caused by wind must be taken from the existing regulations of the relevant structure.

Gradient height $h_{G,ground}$	WZ I v_W [m/s]	WZ I $q_{W,supporting\ structure}$ [kN/m²]	WZ II v_W [m/s]	WZ II $q_{W,supporting\ structure}$ [kN/m²]	WZ II v_W [m/s]	WZ II $q_{W,supporting\ structure}$ [kN/m²]	WZ IV v_W [m/s]	WZ IV $q_{W,supporting\ structure}$ [kN/m²]
≤ 4.0 m	25	0.40	28	0.50	32	0.65	36	0.80
> 4.0 m … 13.0 m	28	0.50	31	0.60	36	0.80	40	1.00
> 13.0 m … 20.0 m	29	0.55	33	0.70	37	0.85	42	1.10

Table 111 - dynamic pressure $q_{W,supporting\ structure}$ on the supporting structure

Effect of wind without traffic on the supporting structure (Q51)

Verify wind actions without traffic on the supporting structure in accordance with the /DIN technical report 101/.

It is assumed that the guideway is not susceptible to vibration with regard to wind actions, otherwise more exact verification is required.

Snow and ice loads (Q52)

With traffic:
The assumed snow depth with traffic is 10 cm. Take into account an area load of q_{snow} = 0.5 kN/m², this corresponds to assuming a unit weight of 5 kN/m³ (wet snow).

Without traffic:
For snow without traffic use the values in /DIN technical report 101/. For the guideway beams, this action combination is covered by traffic actions.

Variable water pressure forces (Q53)

- Variable water pressure forces must be taken into account as appropriate for local circumstances.

Wind load in construction stages (Q54)

Wind actions in construction stages must be regarded as variable actions on the basis of /DIN technical report 101/.

Maintenance conditions (Q55)

Actions resulting from maintenance conditions or similar conditions (e.g. due to raising the supporting structure to replace bearings and bearing parts) must be taken into account.

Construction stages (Q56)

Actions as a result of construction and assembly stages must be considered when dimensioning the supporting structure.

In order the take into account the actions as a result of the assembly of the stator packs and the long stator winding, the following actions must be applied locally for the verification of the stator packs and their attachment to the guideway structure:

dyn pz = - 5.0 kN/m

dyn px = 5.0 kN/m

Actions on track switching equipment (Q57)

Elastic bending of deflection switches (Q57a)

Calculate the flexural tensile stresses from forced bending of the deflection switches and the adjustment forces using the elastic deflection curve of the relevant switch.

Actions resulting from the propulsion system (Q57b)

Take into consideration actions resulting from the inertia, friction and asynchronism of the location of the track switching equipment drive system (deflection switches, travelling platforms).

Displacement resistance of bearings (Q58)

Actions from bearing friction must be considered in accordance with the legal construction regulations.

Failure of supporting structure elements (Q59)

It must be verified that the guideway will remain fit for traffic for a defined amount of time in the event of failure of the supporting structure elements.

The measures required for this (e.g. redundancy) and the verification process must be agreed upon with the responsible inspectorate.

Lateral earth pressure from variable actions (Q60)

- Lateral earth pressure from variable actions must be considered in accordance with the generally accepted technical rules and standards.

Accidental actions

General

The strategies and regulations for protecting the structural works of the guideway from identifiable and non-identifiable accidental actions can be found in the appropriate standards and regulations (e.g. EN 1991).

Accidental actions resulting from the vehicle

Actions as a result of loading gauge violations (A1)

Provided that the measures on how to avoid loading gauge violations described in /MSB AG-GESAMTSYS/ are taken into account, actions as a result of loading gauge violation by the vehicle do not need to be explored.

Safety wind load on the vehicle (A2)

An additional stability verification taking into account the hundred year wind ("safety wind load") must be carried out for the operating situation "guideway with stationary vehicle". The safety wind load on the vehicle must be applied using the following nominal wind gust velocities $v_{b,10}$ (5 second average) at a height of 10 m and a probability of occurrence of once every 100 years:

- Wind zone I $v_{b,10}$ = 36 m/s
- Wind zone II $v_{b,10}$ = 40 m/s
- Wind zone III $v_{b,10}$ = 46 m/s
- Wind zone IV $v_{b,10}$ = 52 m/s

The buoyancy forces on the vehicle that result from the wind velocity must be taken from Table 112. The actions must be determined in accordance with chapter **0**.

The guidance magnet forces $p_{y,SW,FMTi}$ and the accompanying forces from the moment around the x-axle must be determined in a similar manner to that described in chapter **0** and annex II-E.

Actions in kN/m		Gradient height $h_{G,ground} \leq 4.0$ m	Gradient height $4.0 \text{ m} < h_{G,ground} \leq 13.0$ m	Gradient height $13.0 \text{ m} < h_{G,ground} \leq 20.0$ m
Wind zone I	$p_{z,SA,1}$	-1.8	-1.9	-2.2
	$p_{z,SA,2}$	-1.1	-1.1	-1.4
Wind zone II	$p_{z,SA,1}$	-2.2	-2.3	-2.7
	$p_{z,SA,2}$	-1.4	-1.4	-1.7
Wind zone III	$p_{z,SA,1}$	-2.8	-3.1	-3.6
	$p_{z,SA,2}$	-1.7	-1.9	-2.3
Wind zone IV	$p_{z,SA,1}$	-3.6	-3.9	-4.6
	$p_{z,SA,2}$	-2.3	-2.4	-2.8

Table 112 - Typical actions from vehicle buoyancy as a result of safety wind load

Accidental actions resulting from maintenance (A3)

Action effects from maintenance do not have to verified for the vehicle.

In accordance with /MSB AG-FW ÜBG/, all special vehicles, devices and payloads required for maintenance must be dimensioned so that action effects resulting from maintenance are covered by the Maglev vehicle action effects.

Safety wind load on the supporting structure (A4)

Apply the wind actions according to /DIN technical report 101/ annex N.2 as the actions as a result of the safety wind load (SW) on the supporting structure.

Possible foundation movements (A5)

Possible foundation movements must be taken into consideration in accordance with the generally accepted technical rules and standards and the local guideway circumstances with regard to stability and serviceability (see chapter 0).

Impact

General

If necessary, project specific additional verification must be carried out for the structural works of the guideway taking into account accidental actions as a result of an impact.

Potential measures to prevent impact and/or required verification for the consideration of impact on columns and pillars can be found in existing regulations (e.g. /DIN technical report 101/).

Apply a vehicle impact load of at least 500 kN in the most unfavourable direction for all columns and pillars e.g. even in areas in agricultural use. The load acts horizontally 1.25 m above the ground and must be regarded as an accidental action. A dual-layer reinforcement design and a shattering layer are not necessary.

For all situations, the application of measures selected to prevent impact and/or required verification for the consideration of impact with guideway beams must be carried out in accordance with the generally accepted technical rules and standards and agreed upon with the responsible inspectorate.

Annex B of the prEN 199117:2005 contains advice on planning and implementing risk analysis.

Impact of track-guided vehicles (A6)

The requirements that must be considered regarding the impact of track-guided vehicles (railroad cars) must be agreed upon with the responsible inspectorate.

The /DIN technical report 101/, the prEN 199117:2005, section 4.4 and the accompanying national attachment contain information on verifying accidental actions resulting from impacts.

Road vehicle impact (A7)

Accidental actions as a result of road vehicle impact on supporting substructures and guideway superstructures must be considered on the basis of EN 1991-1-7, section 4.3.

For personal safety, the guideway supports must also be measured for the following simultaneously acting, resultant forces, in order to verify stability in the event of a road vehicle impact on guideway beams:

Resultant force in y-direction: $F_{Y,impact,bearing}$ = 1000 kN;

Resultant force in z-direction: $F_{Z,impact,bearing}$ = -300 kN;

Set the response time of the resultant forces at 60 ms.

The resultant forces apply to discretely supported guideway beams made of steel and concrete with design characteristics (stiffness, area density) similar to the TVE guideway beams.

The transferability of the resultant forces to other boundary conditions (guideway and vehicle data) or signs of deviating resultant forces must be verified for the responsible inspectorate.

Observe the permissible deformations for accidental actions as a result of impact on columns and guideway beams according to chapter **0**.

Ice jam, thermal ice pressure, impact from watercraft (A8)

The actions and verification processes to apply for each individual case must be agreed upon with the responsible inspectorate.

Accidental actions resulting from ship collisions must be taken from EN 1991-1-7, section 4.6.

Earthquakes (A9)

As a general rule, the design conditions according to the applicable technical construction regulations and the generally accepted technical rules and standards (e.g. according to Eurocode EN 1998 "Design of structures for earthquake resistance") can be used.

If in doubt, consult the responsible inspectorate as to which earthquake actions are to be taken into account.

Vehicle load arrangements

General

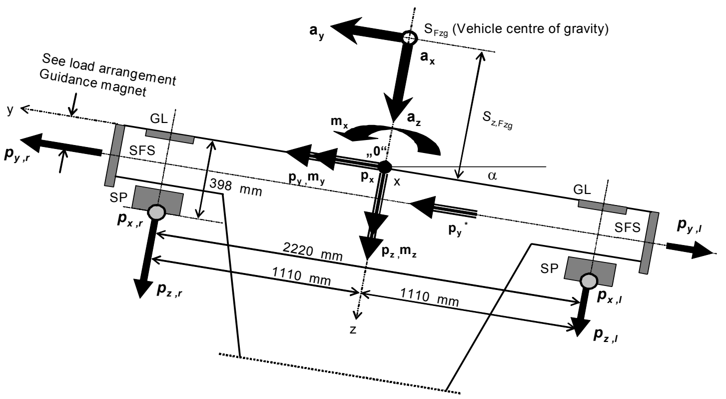
The following load arrangements must be applied according to the size of the structure being examined for global and/or local verifications of the vehicle.

Global load arrangements

Inertia forces

The load arrangements for the vehicle-side inertia forces (incl. dynamic lateral loads and constraint forces) in the x-, y- and z-direction must be taken from Figure 139, Figure 143 and Figure 144 in accordance with chapter **0**

The global actions p^*, p_x, p_y, p_z and m_x, m_y and m_z resulting from the vehicle give rise to the interface forces p_x, p_y, p_z, F_x, F_y, and F_z.



p_y^* : Dynamic lateral forces and constraint forces

- In the x-direction, take into account the magnet array lengths in accordance with chapter **0**

Figure 139 - Global load arrangement for the levitating vehicle

The distribution of the inertia forces resulting from a_z and a_y across the length of the vehicle is shown on the following illustrations.

Determine the individual magnitudes using the equations provided.

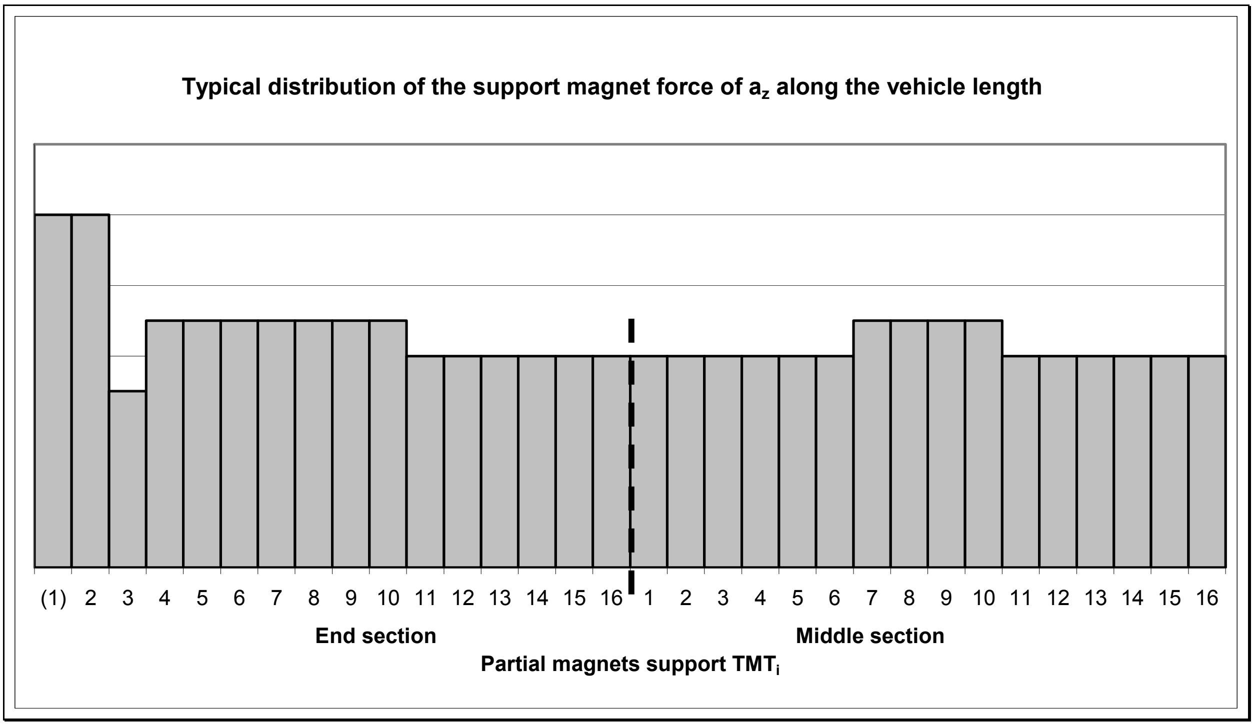


Figure 140 - Typical load arrangement for the force distribution of $p_{z,az}$ according to equation **(15)**

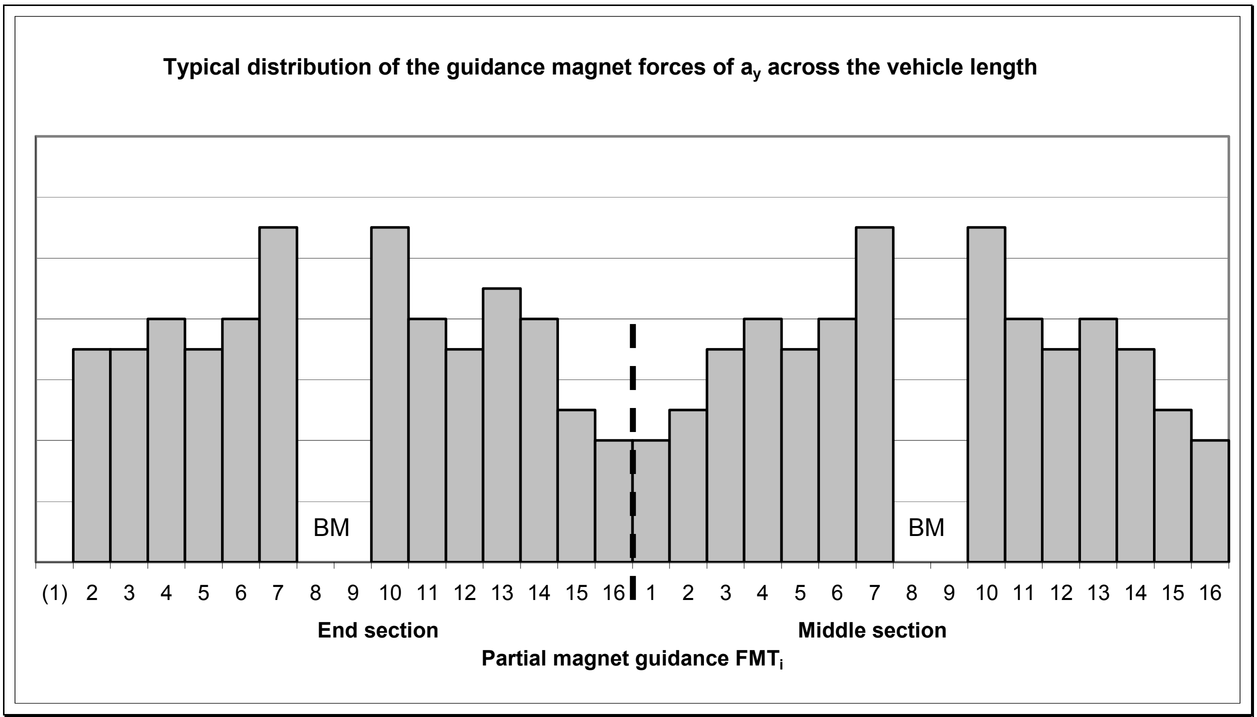


Figure 141 - Typical load arrangement for the force distribution of $p_{y,ay}$ according to equation

$$p_{y,ay,FMT_i,EG/MG/ZG/HG} = \overline{p}_{Z,EG/MG/ZG/HG} \cdot \frac{L_{ES/MS}}{L_{FMT}} \cdot \frac{a_y}{g} \cdot \frac{k_{y,ay,i}}{100} \quad \text{in [kN/m]}$$

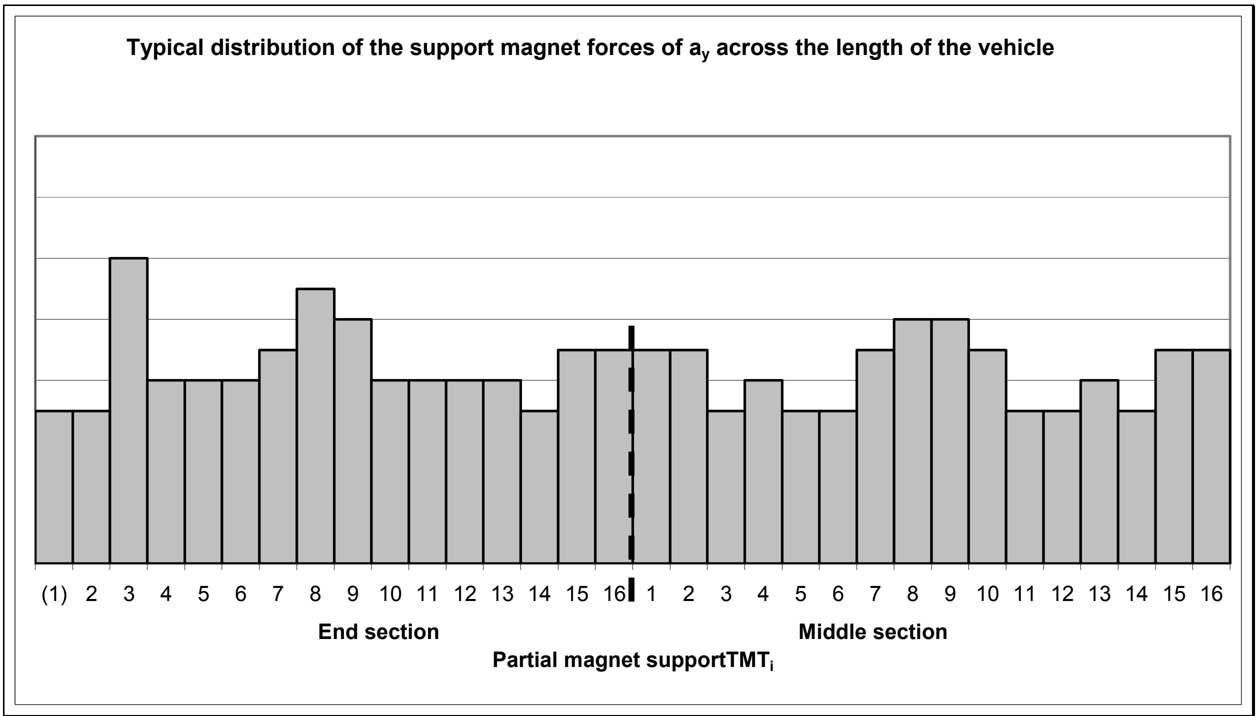
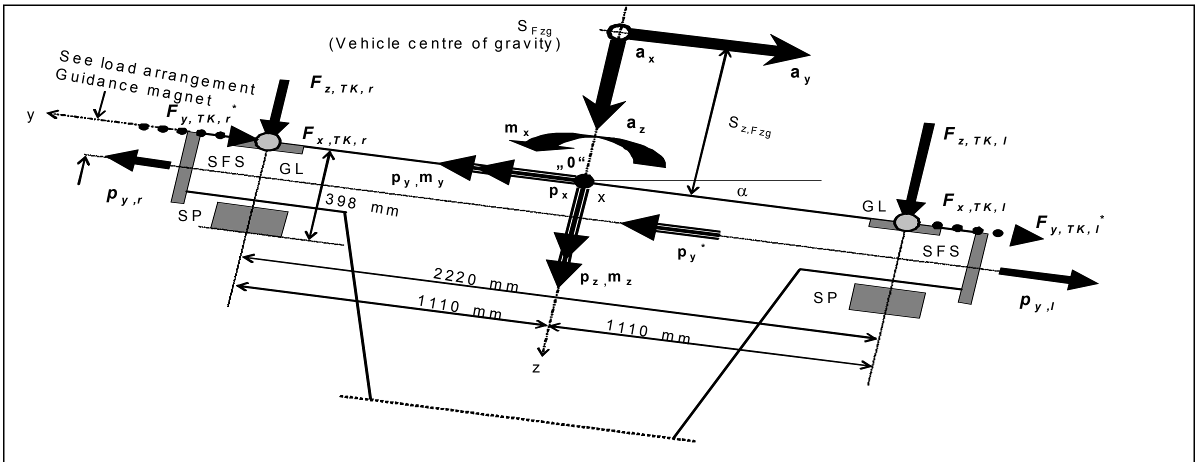
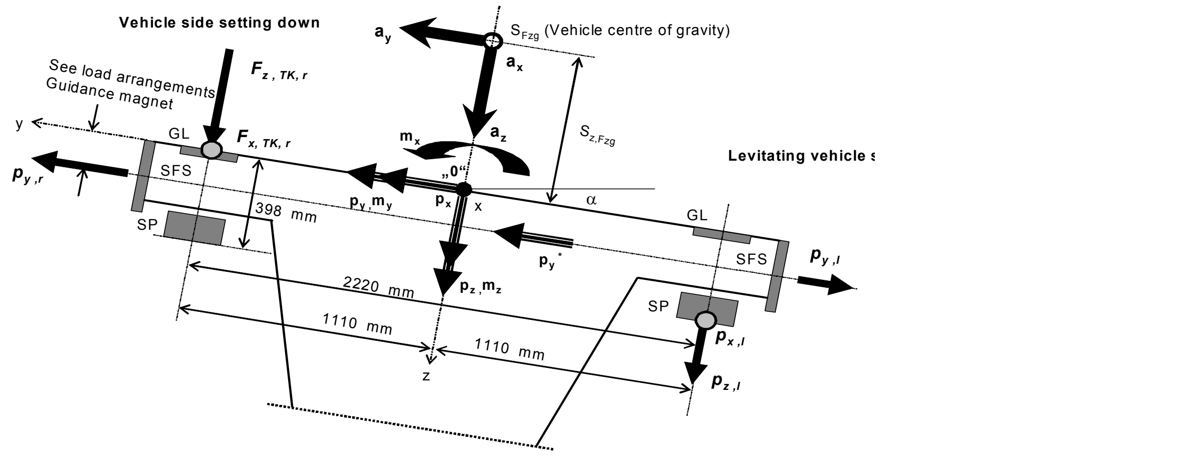


Figure 142 - Typical load arrangement for the force distribution of $p_{z,ay}$ according to equation **(11)**



- p_y^* : Dynamic lateral forces and constraint forces
- In the x-direction, take into account the magnet array lengths in accordance with chapter **0**
- $F_{y,\ TK,r/l}$ * act only when the guidance magnets are deactivated $p_{y,\ r} = p_{y,\ l} = 0$

Figure 143 - Global load arrangement for the levitating vehicle / stationary vehicle



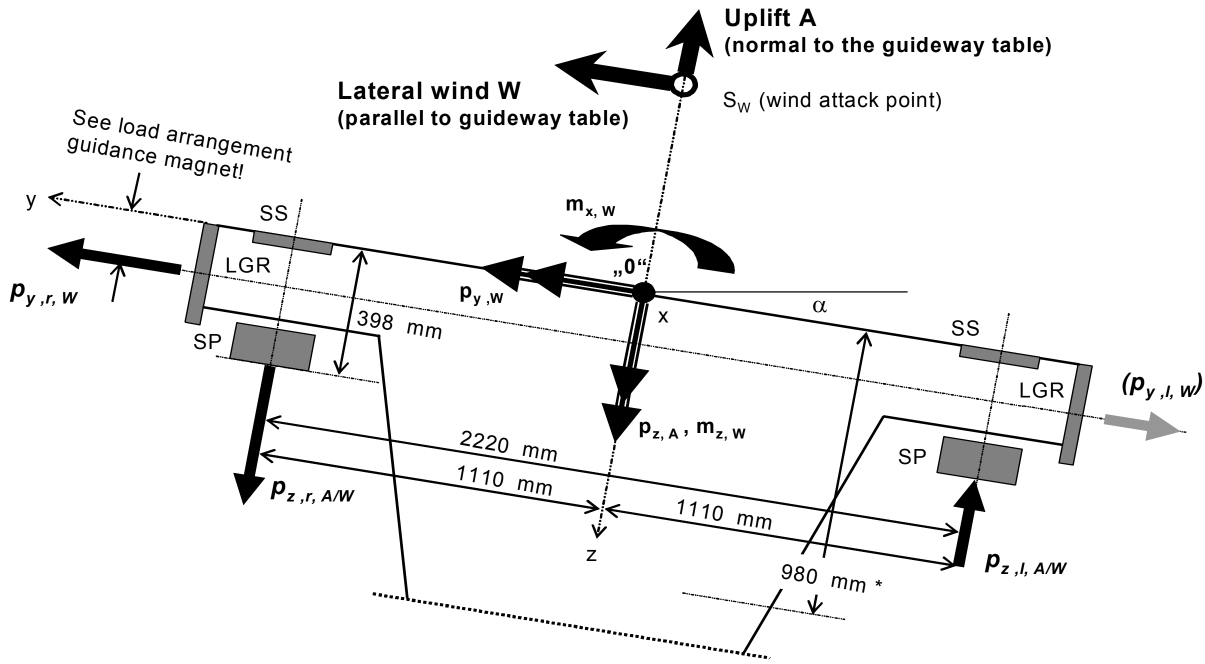
- p_y^* : Dynamic lateral forces and constraint forces
- In the x-direction, take into account the magnet array lengths in accordance with chapter **0**

Figure 144 - Global load arrangement for the design situation Q11i

Wind on the vehicle

The load arrangement for actions as a result of "wind on the vehicle" and "buoyancy" according to chapter **0** must be taken from Figure 145.

The global actions p^*, p_x, p_y, p_z and m_x, m_y und m_z resulting from the vehicle give rise to the interface forces p_x, p_y, p_z, F_x, F_y, und F_z.



- In the x-direction, take into account the magnet array lengths in accordance with chapter **0** and the wind force distribution in accordance with chapter **0**
- * height of the guideway beams, independent of the vehicle

Figure 145 - Global load arrangement "wind" and "buoyancy" on levitating vehicle

The global load arrangement for actions resulting from "wind on the vehicle" and "buoyancy" must be determined for the infrequent operating situation "one-sided set down of the vehicle as a result of a short circuit at the windings" as shown on Figure 144.

Figure 143 applies mutatis mutandis to the set down vehicle.

The following illustrations show the distributions of the support and guidance magnet forces as a result of cross wind along the length of the vehicle. Determine the individual intensities using the equations provided.

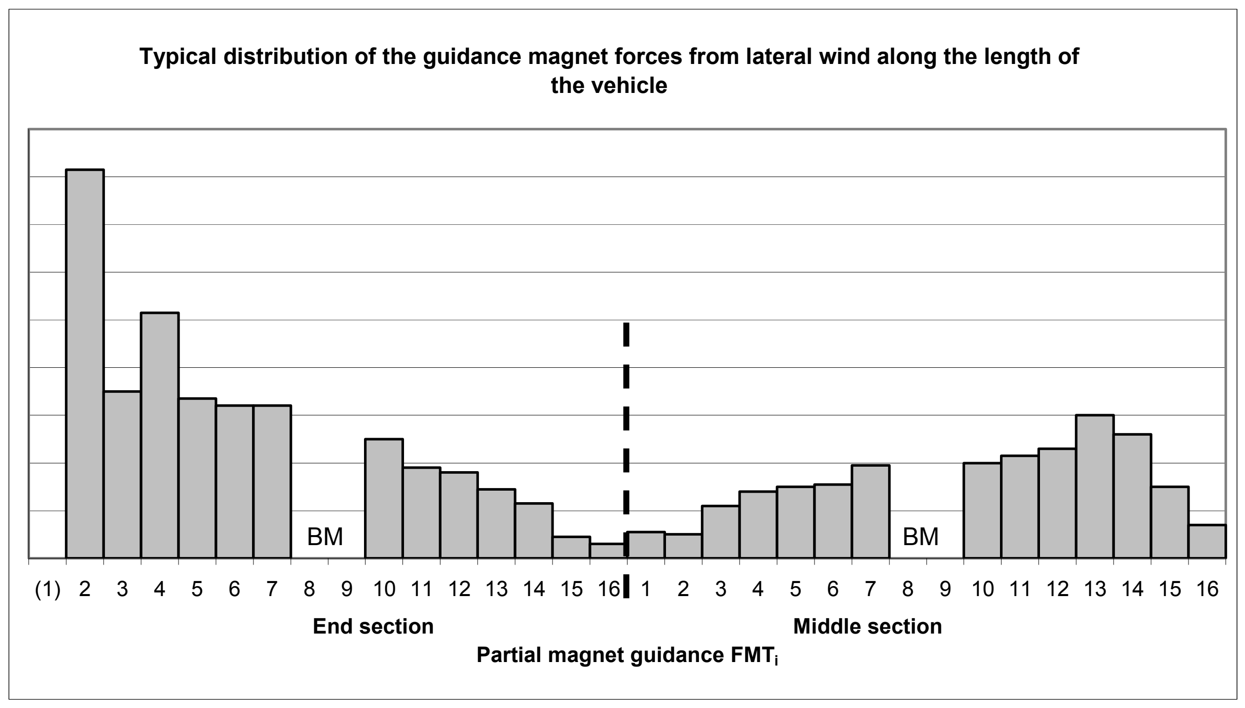


Figure 146 - Typical load arrangement for $p_{y,W}$ with v_W = 25 m/s and v_{Fzg} = 500 km/h

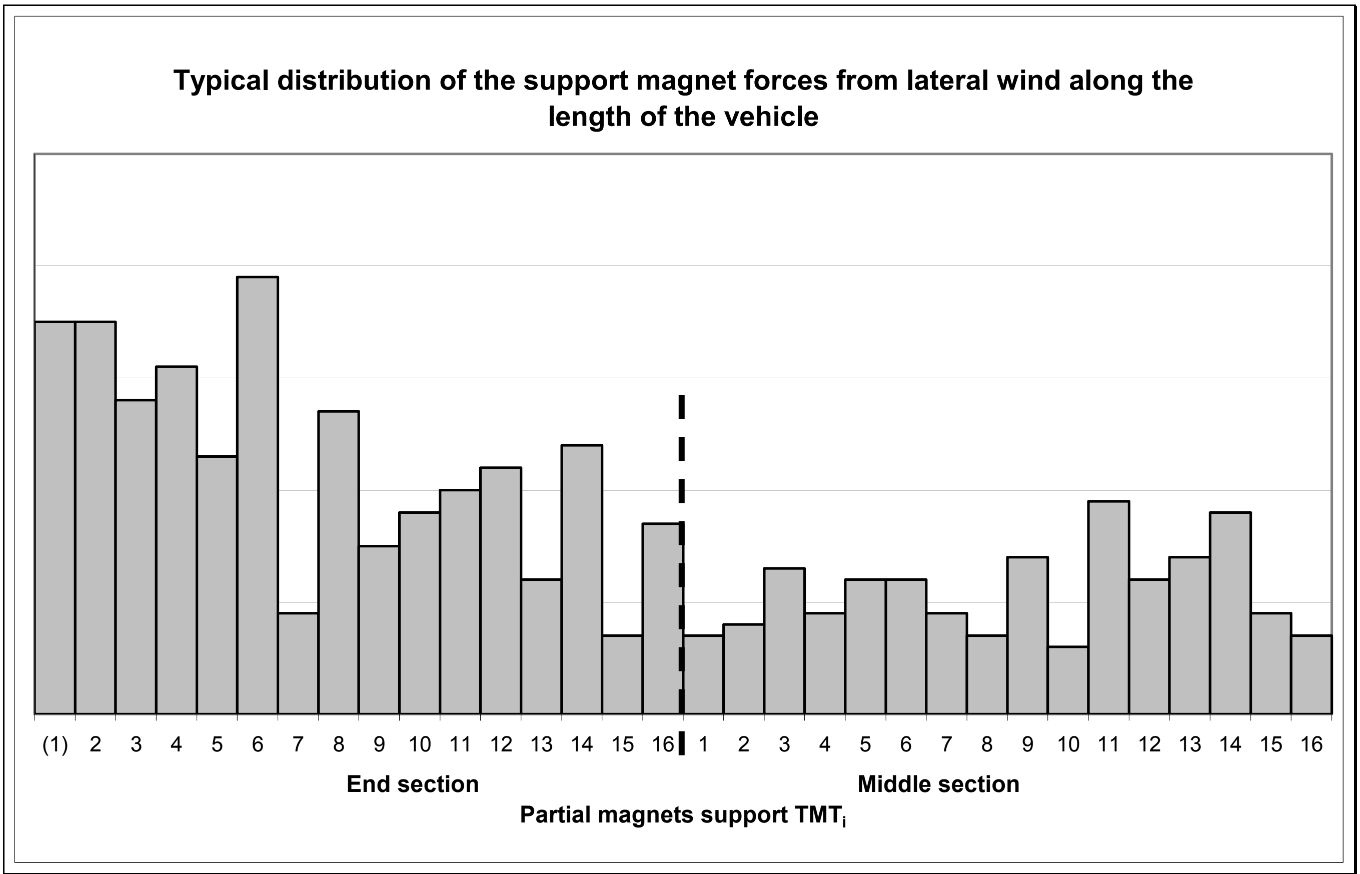


Figure 147 - Typical load arrangement for $p_{z,W}$ with v_W = 25 m/s and v_{Fzg} = 500 km/h

Local load arrangements

Support magnet / long stator interface (stator pack)

Actions from frequent design situations (Q1...Q10)

For frequently variable design situations, calculate the local interface forces from the vehicle taking into account the relevant position of the potential vehicle-side combination groups and those resulting from global actions.

For local verification, the control dynamic factor must also be taken into account for the structural dynamics (see chapter **0**). The minimum unit length is 1.548 m (partial magnet length). The maximum actions must be increased or reduced for 2 adjacent partial magnets, taking the total loading into account.

In the case of simultaneous transfer of forces along the long stator in the x-direction with max. thrust, an additional force redistribution of max. of 30% (see Figure 148) from the inclination of the support magnets must be taken into consideration. In the case of lower thrust, this redistribution must be linearly reduced according to the existing thrust force.

The action geometry (see Figure 148) must be superimposed as most unfavourable with the actions on the lateral guidance rails/guidance magnet interfaces.

The load arrangement can also be used for global verification, i.e. the total of the forces remains the same.

The following figures show a control support magnet. The first and last magnets on a vehicle (nose and tail magnets) may have two additional poles (see also Figure 122).

Information for determining the pole forces incl. 30 % redistribution: See annex chapter **0**;

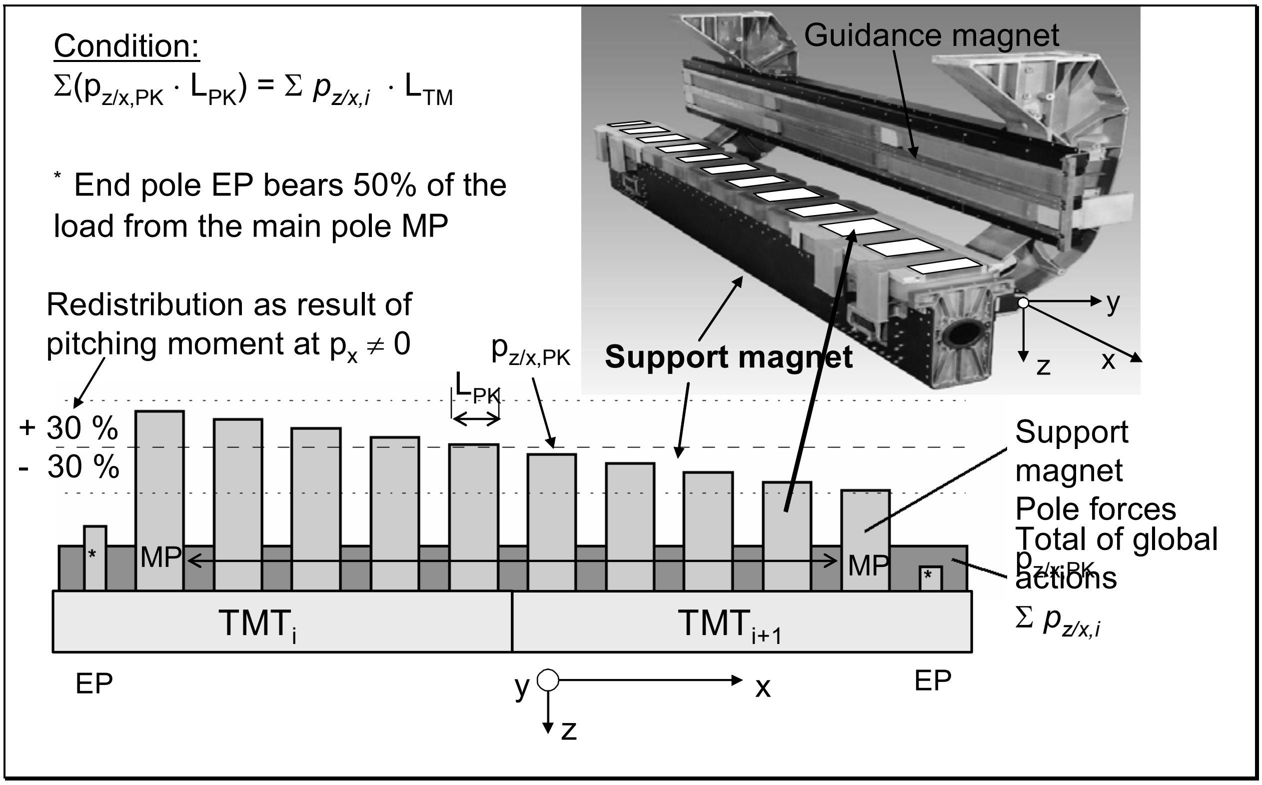


Figure 148 - Typical load arrangement for the support magnet during operation without technical failure

Actions from infrequent design situations

Failure of a support magnet control system (Q11b)

The action geometry for the failure of a support magnet control system must be taken from Figure 149. The corresponding action must be applied locally as a maximum value.

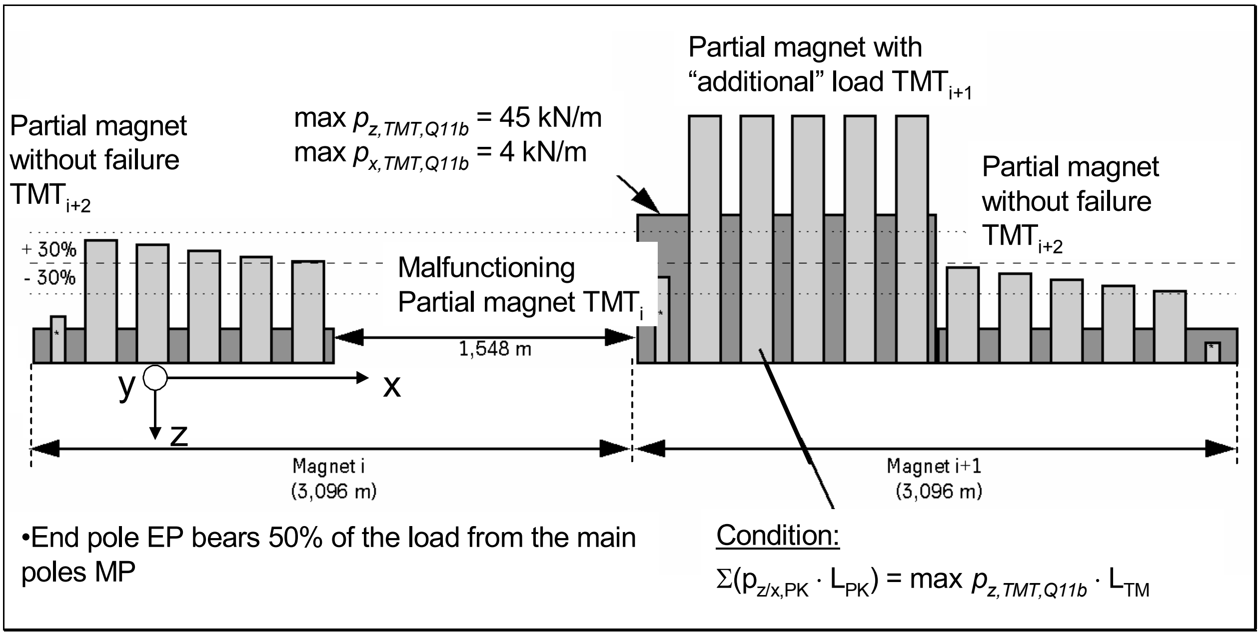


Figure 149 - Typical load arrangement for the failure of a support magnet control system (Q11b)

Dual failure of support magnet control systems (Q11c)

The dual failure of the support magnet control systems on a levitation frame results in an action from the levitation frame's support skid (see 0).

Other infrequent design situations (Q11a, Q11d to Q11i)

The design situations Q11a, Q11d to Q11i must be handled according to Figure 148.

Local component dynamic

See chapter **0**.

Guidance magnets – lateral guidance rails interface

Actions from frequent design situations (Q1...Q10)

For frequently variable design situations, calculate the local interface forces from the vehicle taking into consideration the relevant position of the potential vehicle-side combination groups and those resulting from global actions. Make sure that the guidance forces can only be transferred by magnetic force.

For local verification, the control dynamic factor must also be taken into account for the structural dynamics (see chapter **0**). the actions must be increased or reduced for a max. of 2 adjacent partial magnets, taking the total loading into account.

The action geometry (see chapter 0) must be superimposed as most unfavourable with the actions on the long stator/support magnet interface.

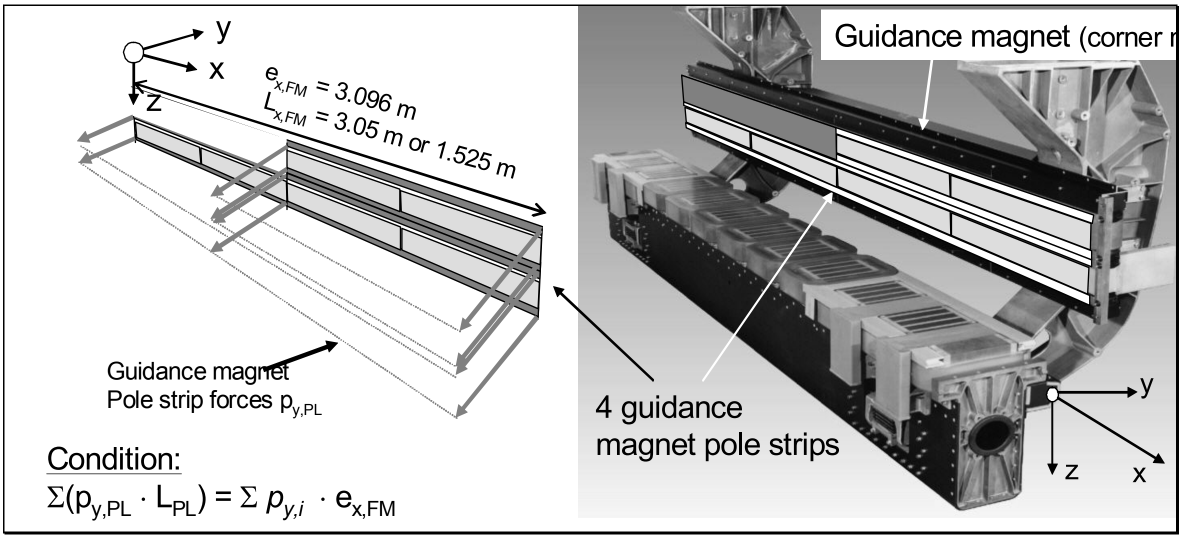


Figure 150 - Typical load arrangement of a guidance magnet (corner magnet)c

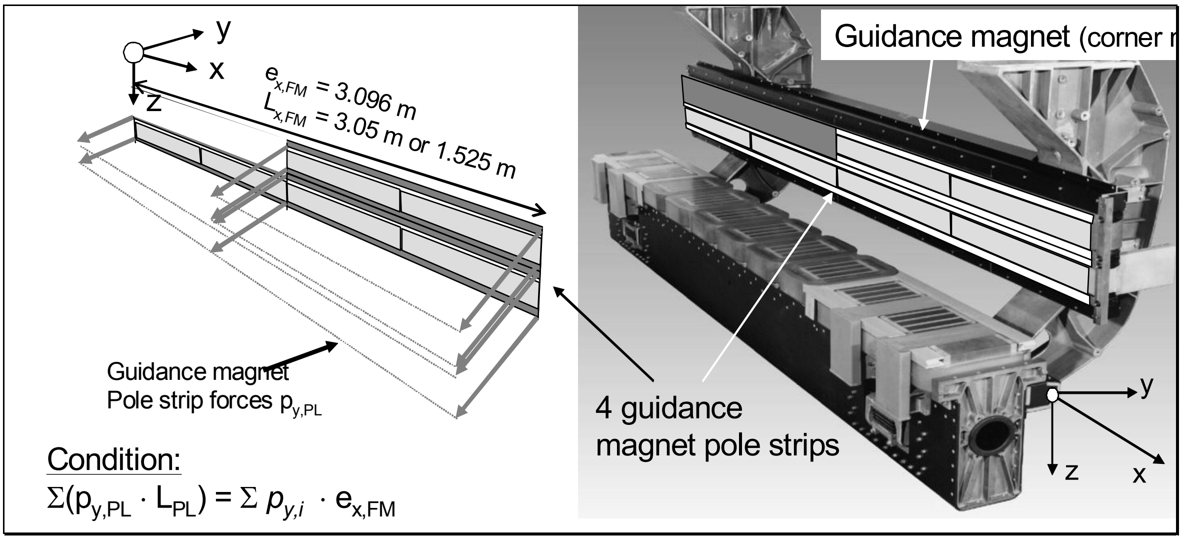


Figure 151 - Typical load arrangement of a guidance magnet (middle magnet)

Actions from infrequent design situations

Failure of a guidance magnet control system (Q11d)

The action geometry for the failure of a guidance magnet control system (MREF) must be taken from Figure 152.

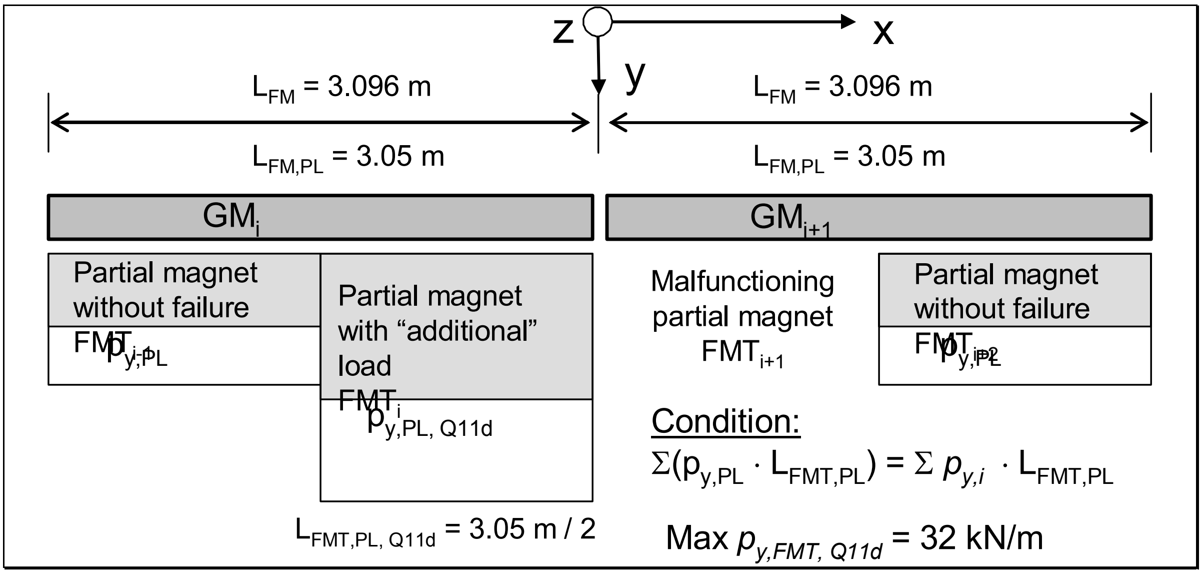


Figure 152 - Typical load arrangement for the failure of a guidance magnet control system (Q11d)

Dual failure of guidance magnet control systems (Q11e)

The failure of two adjacent guidance magnet control systems results in an action from the guidance magnets positioned opposite (activation of guidance magnets).

The action geometry for this local action must be taken from Figure 153.

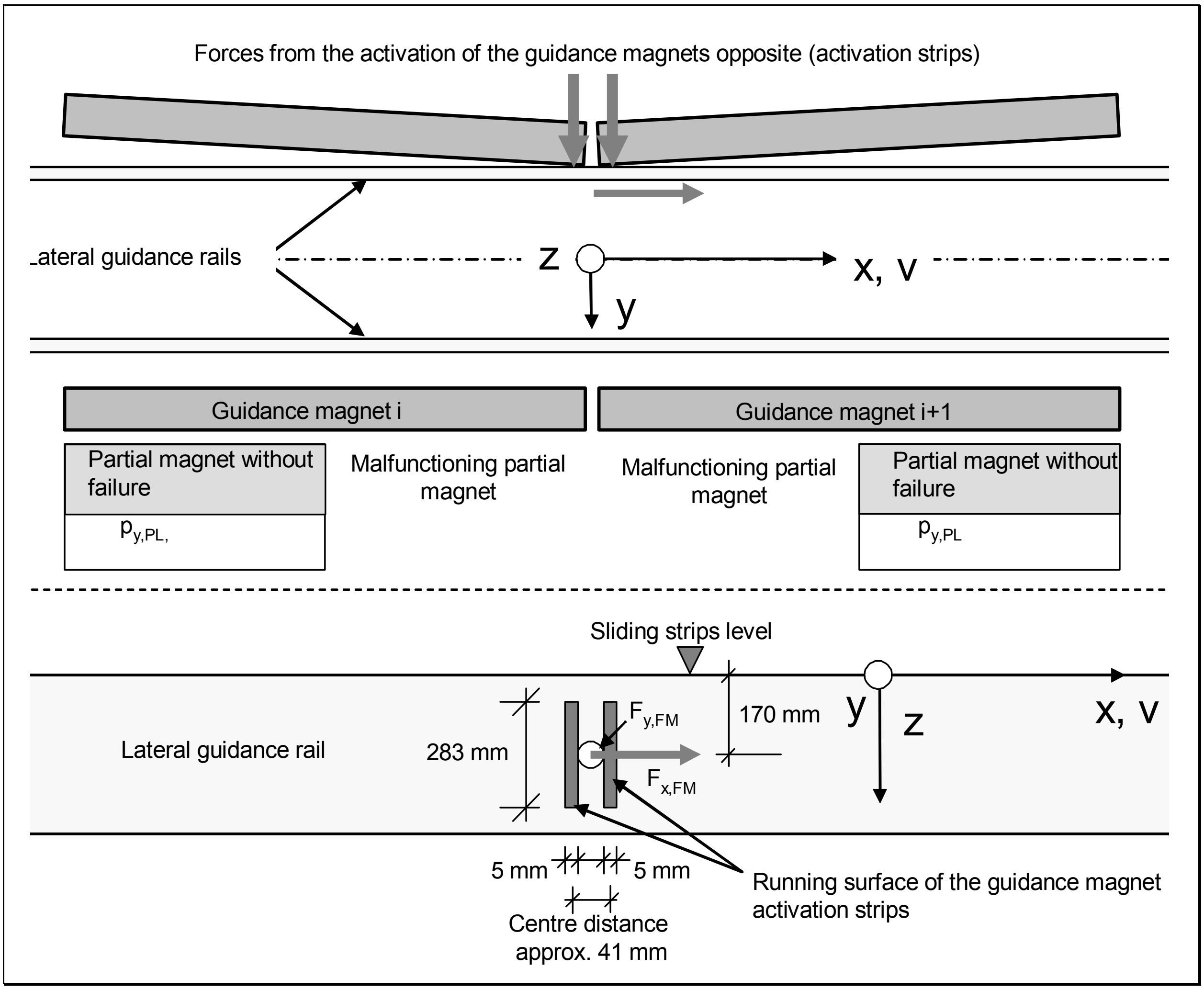


Figure 153 - Typical load arrangement in the event of dual failure of the guidance magnet control systems (Q11e)

Local component dynamic

For the actions as a result of the dual failure of guidance magnet control systems (activation of the guidance magnets) according to chapter **0** an additional dynamic scaling factor to account for a local, design-dependent component dynamic must not be applied, as the maximum dynamic loads of a potential dynamic are already taken into account.

Braking magnet / lateral guidance rails interface

Infrequent design situations (Q11f)

The action geometry for the actions from the non-contact or adjoining braking magnets must be taken from Figure 154.

The braking magnet actions must be superimposed as infrequent variable actions, with the corresponding actions from the support/guidance systems taking into account the conditions in **0** and **0** (see also (8)).

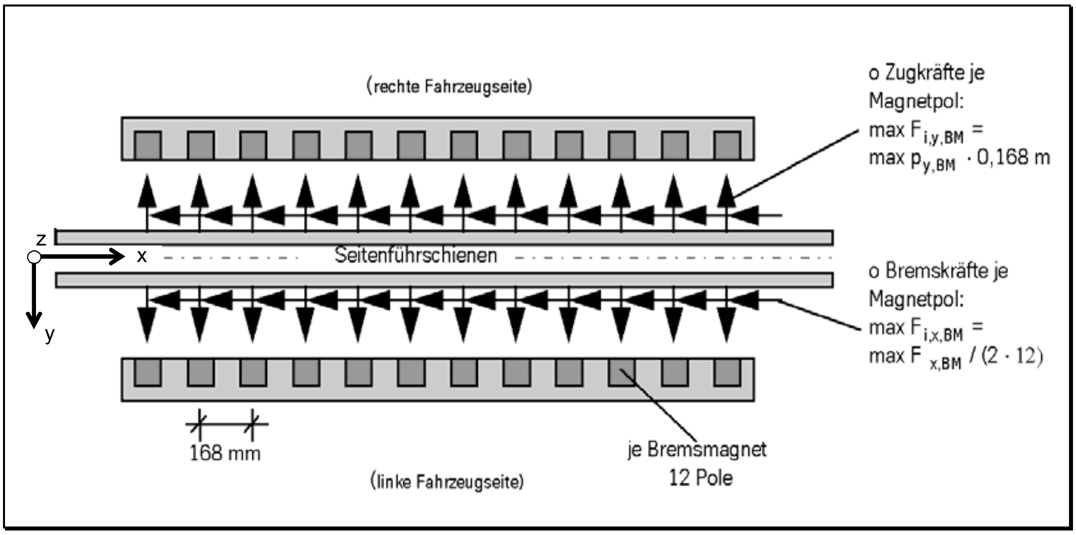


Figure 154 - Typical load arrangement for the braking magnets (non-contact or adjacent)

Rechte Fahrzeugseite	Right-hand side of the vehicle
Seitenführschienen	Lateral guidance rails
Zugkräfte je Magnetpol	Tensile force for each magnet pole
Bremskräfte je Magnetpol	Braking force for each magnet pole
Je Bremsmagnet 12 Pole	12 poles per braking magnet
Linke Fahrzeugseite	Left-hand side of the vehicle
Abgesetzte Tragkufe	Set down support skid

Local component dynamic

See chapter **0**.

Support skid / gliding strip interface

Actions from frequent design situations (Q1...Q10)

The support skids' load arrangement as a result of actions in frequent design situations (stationary vehicle being set down or stationary set down vehicle) must be taken from Figure 155 (see also chapter 0).

All actions from the vehicle are transferred to the guideway via the support skids.

Actions from infrequent design situations

Dual failure of support magnet control systems (Q11c)

Apply the max. impact force given in chapter **0** as the action from the support skid. Assume that the 2 partial support magnets (TMT_i and TMT_{i+1}) directly assigned to the support skid, are inactive.

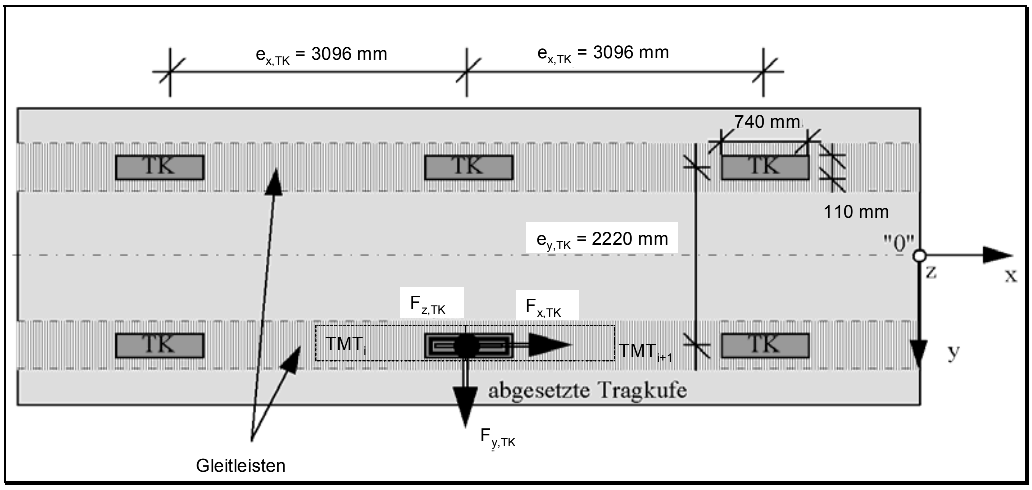


Figure 155 - Typical load arrangement of support skids

Gleitleisten	Sliding srtip
abgesetzte Tragkufe	Set down support skid

Use of the vehicle "safe brake" (Q11f)

For the design situation "vehicle being set down" "safe brake" apply the load arrangements shown in Figure 155 and Figure 143.

One-sided set down of the vehicle (Q11i)

For the design situation "one-sided set down of the vehicle", the skids arranged on one side of the vehicle bear the load (see also Figure 144).

Local component dynamic

An additional dynamic scaling factor to take into account a local design-dependent component dynamic does not need to be applied for the infrequent design situation "dual failure of support magnet control systems", as the max. dynamic loads from the support skid are already taken into account.

Other interfaces

Action and load arrangement guidelines for other vehicle/guideway interfaces (e.g. external on-board energy supply) must be determined individually for each project. These guidelines must be approved for use by the responsible inspectorate.

Verification

General

Verification requirements are defined in detail, for example, in /EN 1990/ and DIN 1055 Part 100.

As a rule, the following must be verified:

Verification of the ultimate limit states

- Verification of the capacity of the components, cross sections and joints to withstand stress (tension verification)
- Verification of the stability of the supporting structure
- Verification of stability
- Verification of material fatigue (verification of the service strength by cumulative damage or verification of damage-equivalent stress variation range)

Verification for serviceability limit states

- Verification of deformation limit values specific to the high-speed Maglev system
- Verification of dynamic effects
- Verification of limit values specific to the building material

If the rules regarding applicability to the high-speed Maglev system guideway are not clear, then they must be determined in agreement with the responsible inspectorate.

To carry out the verification specified above, on the basis of the actions put together in this design principles document taking into account project-specific information on the significant operating and geometric parameters for the sections to be verified, it is recommended that action tables are created (in simplified form if necessary). These tables can be created according to the verification process to individually assemble the significant combinations of actions. They must be approved by the responsible inspectorate as part of the verification audit.

The safety and serviceability of the guideway must be preserved during the planned (project-specific) period of use by specific maintenance measures that are appropriate for the guideway construction.

The following general observations regarding actions must be considered during verification:

- The inertia forces must be calculated by taking into consideration the permissible accelerations and velocities (min v_{Fzg}, max v_{Fzg}).
- The dead weight of the vehicle given in chapter **0** for the middle and end sections takes into account goods and passenger vehicles.
- Allow for dynamic step-ups of the actions. Dynamic factors and dynamic lateral forces do not need to be applied when v_{Fzg} = 0 km/h. However, the control dynamic must always be considered.
- Actions resulting from interdependent causes must be applied together.
- Within the braking profile provided for the vehicle-side "safe brake" the actions must be classed as infrequent. With regard to the braking process, setting down at $v_{Fzg} \leq 5$ km/h must be only considered an infrequent event in defined sections (restricted area at and in front of the stopping place).
- Setting down at $v_{Fzg} > 5$ km/h with skidding of the set down vehicle on any area of the guideway must be considered an accidental design situation (Worst-Case-Halt).
- Actions arising from maintenance must be considered and verified if necessary (see also /MSB AG-FW ÜBG/). If necessary, potential actions arising from guideway maintenance must be classed as variable or accidental actions according to the probability of them occurring.
- For the verification of shared guideway substructures for double track guideways, a shadow factor may be applied for cross wind actions on the 2nd track (see EN 1991-1-4).

In agreement with the responsible inspectorate the safety factors can be adjusted to account for the low probability of occurrence of infrequent operating situations. Depending on the probability of occurrence and the expected results, an inspection of the guideway is not necessarily required.

Simplification of the actions and/or load arrangements is permissible if it is clear or proven that the simplifications are on the safe side.

Verification of the ultimate limit states

General

Verification must be carried out for the actions resulting from the line routeing and operating parameters (e.g. for straight guideway beams $a_y = 0$) within the limits laid down by the MbBO and with the limits provided for the vehicle weight, accelerations and other actions.

To verify the ultimate limit states, the design parameters for the decisive loading cases/design situations must be determined from the actions by a combination of the simultaneously occurring actions.

The combination rules can be found in /EN 1990/ chapter 6.4.3. If it is not clear which is the leading action, consider each variable action in turn as the leading variable action. Combinations for designing accidental situations are based either on an explicit accidental action or applied to the situation (condition) according to an accidental event.

Combinations may be simplified. However, it must be verified that simplified combinations are on the safe side in comparison to the standard combinations.

Partial safety factors of the actions

The partial safety factors of the actions for the verification of the ultimate limit states must be taken from Table 113.

When forming the loading cases or combinations, apply the representative and characteristic values of the actions in accordance with the Eurocodes and the notes for Table 113 with the appropriate partial safety factors.

The partial safety factors of the actions cover, in accordance with DIN 1055 part 100,

- *The possibility of unfavourable deviations of the actions (magnitude and distribution of the actions),*
- *The possibility of inaccurate model assumptions for the actions and*
- *Uncertainty in the determination of the effects.*

The partial safety factors are assigned to the following actions:

- *Permanent* actions ⇒ γ_G
- *Variable actions (frequent and infrequent)* ⇒ γ_Q
- Accidental *actions* ⇒ γ_A

For the accidental actions (A), the safety margins given in Table 113 are permissible under acceptance of sectional damage.

If the result is relatively low local action effects, then a check must be carried out to see whether small adjustments to the system or the geometry of the actions will result in larger action effects or vice versa. If necessary, additional buffers for the action effects must be provided.

Partial safety factors γ		Effect	Symbol	Situations * G/Q	A	
Permanent actions **G1… G6:**	See Eurocodes and DIN technical report					
Variable actions from the vehicle						
Q1...Q6	Inertia forces from permissible and maximum vehicle weight, constraint forces, lead dynamic	unfavourable	γ_{Qi}	1.35	1	1)
		favourable	γ_{Qi}	1.0 / 0	0	
Q7...Q8	Aerodynamic actions from v_{Veh}	unfavourable	γ_{Qi}	1.35	1	1)
		favourable	γ_{Qi}	0	0	
Q9	Aerodynamic actions from wind on the vehicle	unfavourable	γ_{Qi}	1.5	1	1)
		favourable	γ_{Qi}	0	0	
Q10	Temperature as a result of propulsion system	unfavourable	γ_{Qi}	1.35	1	1)
		favourable	γ_{Qi}	0	0	
Q11	Actions resulting from technical failure or malfunction	unfavourable	γ_{Qi}	1.35	0	2)
		favourable	γ_{Qi}	0	0	
Other variable actions						
Q30	Actions resulting from maintenance	unfavourable	γ_{Qi}	1.5	1	2)
		favourable	γ_{Qi}	0	0	
Q50 ... Q60	o general	unfavourable	γ_{Qi}	1.5	1	3)
		favourable	γ_{Qi}	0	0	
	o with verified limit values	unfavourable	γ_{Qi}	1.35	1	
		favourable	γ_{Qi}	0	0	
Accidental actions						
A1...A9	General		γ_{Ai}		1	4)
* G/Q: Permanent and variable situations; A: Accidental situations						
Table continues overleaf.						

Table 91 - Partial safety factors of the actions

Table cont.: Partial safety factors of the actions

Notes

1) Taking limit values from actions resulting from the vehicle into consideration (e.g. vehicle dead weight, payloads, permissible accelerations), which have been determined in accordance with current regulations, a partial safety value of γ_{Qi} = 1.35 can be applied on agreement with the responsible inspectorate . The classification of the possible vehicle weight conditions according to Table 100 must also be observed.
2) The vehicle-side actions resulting from technical failure or malfunction relating to individual guideway elements (e.g. guideway beams) are rare or very rare events. Due to their low probability of occurrence they should be regarded as predominantly static actions. Superimposing several such actions in accordance with Table 93 is not required. In agreement with the responsible inspectorate the partial safety factor can be reduced, if necessary, to account for the low probability of them occurring.
   There is no need to superimpose the vehicle-side actions from infrequent design situations Q11 (a...k) with accidental actions A1...A9 due to their low probability of occurrence.
3) If the environmental thermal actions are determined by secure measurements, a lower value, which must be determined in agreement with the responsible inspectorate (e.g. γQ50 = 1.35), may be used instead of γ_{Q50} = 1.50. When superimposing the snow/ice loads given in 0 (limit value taking into account the space between the vehicle and guideway) with traffic loads, a value of γ_{Q50} = 1.00 may be used.
4) Whether it is necessary to form accidental design situations taking into account actions from maintenance must be checked from case to case and agreed upon with the responsible inspectorate.

Combination values

When forming combinations of actions according to the combination rules provided in /EN 1990/, the combination factors ψ compiled in the following tables must be used to take into account the simultaneity and probability of occurrence of the actions, whilst observing the accompanying notes.

The combination factors of the variable actions are arranged into the following groups based on the probability of occurrence of the actions:

- *For variable actions* ⇒ ψ_0
- *For infrequent actions (1/year)* ⇒ $\psi_{1'}$
- *For frequent actions (1/week)* ⇒ ψ_1
- *For quasi-permanent* actions ⇒ ψ_2

Combination factors ψ		ψ_0	ψ_1'	ψ_1	ψ_2	Notes
Actions resulting from the vehicle						
Q1/Q2	Dynamic inertia forces from the vehicle weight	1	1	1	1	
Q3/Q4	Uneven distribution of the payload	1	1	1	0	
Q5	Lead dynamic (dyn. lateral forces)	1	1	1	1	
Q6	Constraint forces in tight radii	1	1	1	1	
Q7	Aerodynamic lateral forces	1	1	1	0	
Q8	Airstream actions	1	1	1	1	
Q9	Wind actions on the vehicle	0.6	0.6	0.5	0	4)
Q10	Temperature as a result of propulsion system	1	1	1	1	
Q11a..k	Actions resulting from technical failure or malfunction	1	0	0	0	5) 6)
Q111	Increase in vehicle weight due to snow	0.7	0.2	0.2	0	
Other variable actions						
Q30	Actions from maintenance					1)
Q50	Environment temperature	0.6	0.8	0.6	0.5	4) 5) 7) 8)
Q51	Wind on the supporting structure	0.6	0.6	0.5	0	4)
Q52	Snow and ice loads	0.7	0.2	0.2	0	
Q53	Variable water pressure forces					2)
Q54	Wind load on construction stages					2)
Q55	Maintenance conditions					2)
Q56	Construction stages					2)
Q57	Actions from track switching equipment	1.0	1.0	1.0	1.0	
Q58	Displacement resistance of bearings					2)
Q59	Failure of supporting structure elements					2) 3)
Q60	Lateral earth pressure from variable actions					2)
Table continues overleaf.						

Table 92 - Combination factors ψ_i of actions

Table cont.: Combination factors ψ_i of actions

Notes

1) The combination factors for actions resulting from maintenance must be determined individually and agreed upon with the responsible inspectorate.
2) The combination factors for the respective actions can either be taken from /EN 1990/ or the appropriate rules, standards and regulations or determined on a individual basis in agreement with the responsible inspectorate.
3) The loss of, for example, a screw connection or other component must be considered a permanent action if it cannot be guaranteed that it will be repaired immediately.
4) When using Q9 and Q51 as the leading variable action, a combination factor of ψ_0 = 0.5 can be set for Q50b+c, and vice versa.
5) When thermal actions resulting from braking magnet BM, support skids SS and mechanical guidance elements MGE, are superimposed with environmental thermal actions, the environmental uneven heating (Q50c) between different components can be reduced to half the value.
6) Due to the low probability of occurrence, the combination factors ψ_1 or ψ_1 can be used with the remaining actions in Q11a, Q11b, Q11c, Q11d, Q11e, Q11g, Q11i (case 1), Q11j , Q11k as leading variable actions for forming the combinations of actions. The actions Q11a..k do not need to be applied simultaneously. If the action Q11l must specifically be considered for a project, combine Q11l(1) as opposed to Q11l(2) with the remaining Q11 actions.
7) Maximum temperature differences between the upper and bottom chord of the beam and maximum temperature difference between the left and right sides of the beam must not be considered simultaneously with their maximum values. When superimposing temperature differences, one of the two temperature differences should be reduced by 1/3.
8) When superimposing the beam temperature difference in accordance with chapter 0 with actions as a result of traffic, apply the appropriate value for ΔT in accordance with Table 110.
9) For the verification of the serviceability limit state do not apply the actions from Q11a .. Q11k.

Proof of the performance capability limit states

General

(1) *The limit values relating to guideway deformation and the regulations concerning the furnishing of proof which are specific to high-speed maglev systems are indicated below. These reflect current experience levels and, when observed, generally result in guideways which are fit for their purpose, i.e. guideways which are in keeping with the system.*

(2) *Permitted deformations, offsets, displacements and gap changes are defined as follows in relation to the functional areas comprising stator level, lateral guide rail level and slider level, as well as in relation to the position of the space curve in the three directions according to the local coordinate system:*

- *permitted long- or short-wave deformations in the support structures (e.g. global girder deflection) which are the result of actions*
- *permitted displacements in the functional areas at the girder joint and in the girder section which are the result of actions*
- *permitted elastic and plastic deformations in the guideway substructures (long-wave alteration in the position of the functional areas)*

(3) *In addition to the static deformations resulting from the actions of vehicles, the dynamic behaviour (vibrational behaviour) influences the performance capability of the guideway. Specifications in this regard are given in Chapter 10.3.5.*

(4) *The combinations of effects regarding the performance capability limit states are generally laid down by means of the equations defined in EN 1990.*

(5) The general combination factors shall be taken from Table 114.

(6) In addition, the load model, effects and combinations of effects which are specific to high-speed maglev systems shall be taken into consideration in accordance with the following sections.

(7) The effects arising from Q11a to Q11k shall not be specified.

(8) In addition to these requirements which are specific to high-speed maglev systems, the corresponding provisions adopted by the building inspectorate concerning proof of performance capability shall be taken into consideration (e.g. the limiting of compressive strains and crack widths in the concrete construction).

(9) If the following chapters or Annex (Chapter 11.4) do not stipulate any applicable requirements in relation to limit values and combinations of effects which are specific to high-speed maglev systems as proof of performance capability, proof of the vehicle's compatibility must be furnished in relation to the accepted limit values and combinations.

(10) In each individual case, proof of the vehicle's compatibility must be furnished as proof of the performance capability of construction methods and structural forms not qualified previously.

Global deformations in discretely mounted guideway superstructures

General

(1) *As regards the deformation limit values below, a maximum free lateral acceleration of $a_y = \pm 1.5\ m/s^2$ is taken as a basis.*

(2) In the case of discretely mounted support structures, proof of global deformations in functional areas may generally be furnished in the form of proof of the centre of gravity displacement of the support structures, provided functional area deformation is negligibly small compared with the amount of deformation in the support structure.

(3) As regards the static proofs of deflections in the y and z directions given below, maximum dynamic cambers of 20% in the z direction and 40% in the y direction form the basis for permitted deflections. If dynamic tests establish greater dynamic cambers, static deflections must be reduced to the extent that the permitted deformations specified below are not exceeded, taking into account the existing dynamic camber.

(4) Proof must be furnished in a particular case as to the extent to which static deflection may be increased in the case of smaller dynamic cambers.

Deformations in the z direction

Effects resulting from the vehicle

General

(1) Proof of permitted deflection in the z direction must be furnished for all routing scenarios, girder constructions and static systems under the following girder loads (see Chapter 8.2.1.2):

$p_{z,fz} = \overline{p}_{z,ZG} = 29$ kN/m

(2) As regards the static systems indicated below, consideration must be given to the following limit values as regards deformation in the z direction. Generally speaking, the span of the support structures L_{St} shall be used as the reference length when furnishing proof of the global deformations in guideway superstructures. Depending on the support structure mounting conditions, L_{St} may differ for the y and z directions.

(3) The permitted deformations indicated correspond to a tangential torsion at the end of the girder of ϑ_y = 0.0008 rad.

(4) Permitted girder deformation progression (e.g. maximum deflection) in the case of girders with sudden changes in rigidity shall be specified in a particular case.

(5) When determining the load-free design precurvature of the support structures in the z direction in accordance with the Guideway design principles for high-speed maglev systems - Part III: Geometry, the actual maximum deflection under the effect of the mean vehicle weight $\overline{p}_{z,MG}$ = 26 kN/m shall be specified as the load for all girder sections.

Simple beam N = 1

(1) Maximum permitted deflection in the midspan of the simple beam:

$$\max f_{z,Fzg} \leq L_{St} / 4000 \quad (28)$$

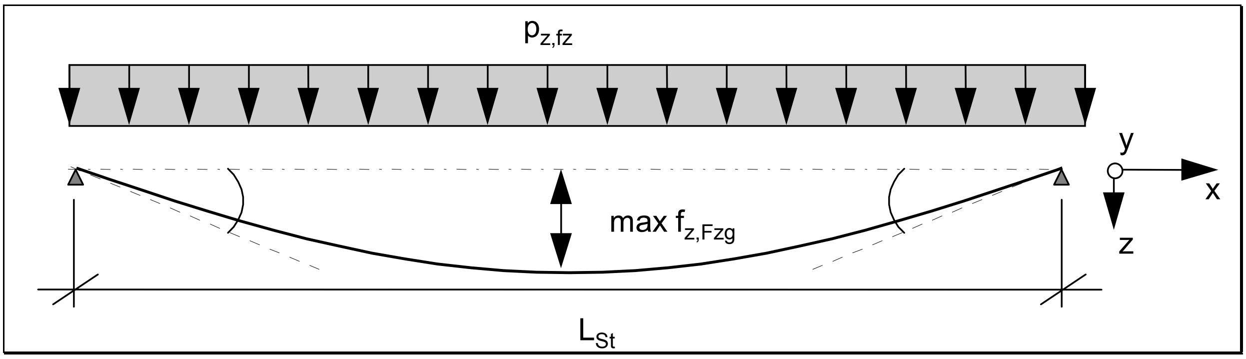


Fig. 156 - Permitted deformation in the z direction caused by a vehicle in the case of simple beams

Two-span beams with the same spans N = 2

(1) Maximum permitted deflection in the girder section where $x_{max\ fz} = 0.421 \cdot L_{St}$, in which connection, both girder sections are subjected to loads:

$$\max f_{z,Fzg} \leq L_{St} / 4800 \quad (29)$$

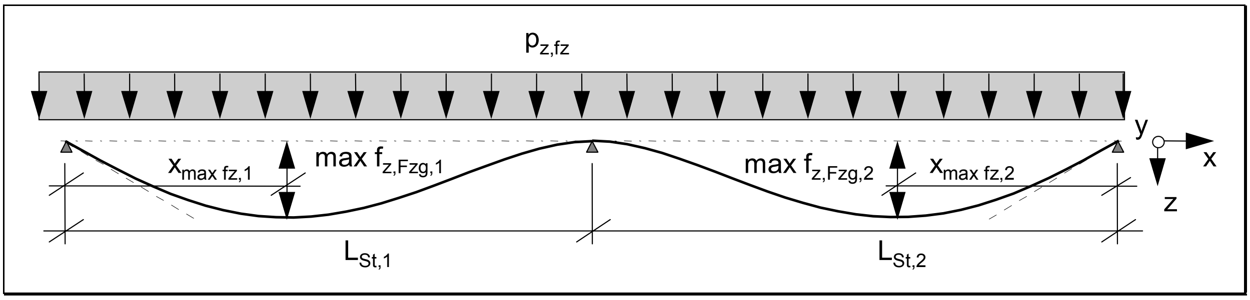


Fig. 157 - Deflection in the z direction in the case of two-span beams with the same spans

Two-span beams with unequal spans

(1) The cross-sectional values for the girder sections shall be chosen such that, when both sections are subjected to loads, the requirements pertaining to two-span beams with the same spans (see Chapter 10.3.2.2.1.3) are observed in relation to each section.

Multiple span girders N > 2

(1) The cross-sectional values for girders with more than two sections shall be chosen such that when all the sections are subjected to loads, the following requirements are observed:

- Edge sections: limit value the same as with two-span beams
- Internal sections: limit value the same as with simple beams

Temperate differential

(1) Deformations resulting from differences in temperature between the top and bottom booms may not exceed the following limit values (also refer in this regard to Chapter 8.2.3.3).

(2) If a temperature differential ΔT_0 is already taken into consideration when stipulating the load-free design precurvature (e.g. ΔT_0 = 7 K, i.e. the theoretical position which is not subject to a load is adjusted with a temperature differential of 7 K), this nominal temperature differential may be taken into account accordingly when proving deformations as a result of a temperature differential as per Chapter 8.2.3.3.2.

Simple beam N = 1

$t_o > t_u$: $\max f_{z,\Delta T} = L_{St} / 6500$ (30)

$t_o < t_u$: $\max f_{z,\Delta T} = + L_{St} / 5400$ (31)

Two-span beams with the same spans N = 2

$t_o > t_u$: $\max f_{z,\Delta T} = L_{St} / 8000$ (32)

$t_o < t_u$: $\max f_{z,\Delta T} = + L_{St} / 6500$ (33)

Two-span beams with unequal spans

(1) The cross-sectional values for the girder sections shall be chosen such that, when specifying ΔT in both sections, the requirements pertaining to two-span beams with the same spans (see Chapter 10.3.2.2.2.2) are observed in relation to each section.

Multiple span girders N > 2

(1) The cross-sectional values for girders with more than two sections shall be chosen such that when specifying ΔT in all sections, the following requirements are observed:

- Edge sections: limit value the same as with two-span beams
- Internal sections: limit value the same as with simple beams

Deformations specific to the building material

(1) Long-wave deviations from the support structure theoretical position as a result of properties which are specific to the building materials (e.g. creeping/shrinkage of the concrete) shall be estimated for the requisite period of use using approved calculation methods.

(2) The calculated values shall be incorporated within the permitted tolerance band for long-wave deviation which is laid down in the Guideway design principles for high-speed maglev systems - Part III: Geometry.

Deformations in the y direction

Effects resulting from the vehicle

General

(1) Proof of permitted deflection in the y direction must be furnished for all routing scenarios, girder constructions and static systems under the following girder loads:

$p_{y,fy} = \overline{p}_{z,ZG} \cdot \max a_y / g = 29\ kN/m \cdot 1.5\ m/s^2 / 9.81\ m/s^2 = 4.5\ kN/m$

(2) Permitted girder deformations relate to girders which have constant rigidity. As regards support structures with different girder rigidities (e.g. sudden changes in rigidity), the permitted deformation progression shall be specified in a particular case.

Simple beam N = 1

(1) Maximum permitted deflection in the y direction as per fig. 156 in the midspan:

$$\max f_{y,Fzg} \leq \left| L_{St} / 15000 \right| \quad (34)$$

Two-span beams with the same spans N = 2

(1) Maximum permitted deflection in the y direction as per fig. 157 in the girder section where x = 0.421· L_{St}:

$$\max f_{y,Fzg} \leq \left| L_{St} / 18000 \right| \quad (35)$$

Two-span beams with unequal spans N = 2

(1) The cross-sectional values for the girder sections shall be chosen such that, when both sections are subjected to loads, the requirements pertaining to two-span beams with the same spans (see Chapter 10.3.2.3.1.3) are observed in relation to each section.

Multiple span girders N > 2

(1) The cross-sectional values for girders with more than two sections shall be chosen such that when all the sections are subjected to loads, the following requirements are observed:

- Edge sections: limit value the same as with two-span beams
- Internal sections: limit value the same as with simple beams

Temperate differential

General

(1) Deformations resulting from differences in temperature between the left and right sides of the support structure girder should not exceed the following limit values (also refer in this regard to Chapter 8.2.3.3).

Simple beam N = 1

$$\max f_{y,\Delta T} = \pm L_{St} / 5800 \quad (36)$$

Two-span beams with the same spans N = 2

$$\max f_{y,\Delta T} = \pm L_{St} / 6960 \quad (37)$$

Two-span beams with unequal spans N = 2

(1) The cross-sectional values for the girder sections shall be chosen such that the requirements pertaining to two-span beams with the same spans (see Chapter 10.3.2.3.2.3) are observed in relation to each section.

Multiple span girders N > 2

(1) The cross-sectional values for girders with more than two sections shall be chosen such that the following requirements are observed:

- Edge sections: limit value the same as with two-span beams
- Internal sections: limit value the same as with simple beams

Deformations specific to the building material

(1) Long-wave deviations from the support structure theoretical position as a result of properties which are specific to the building materials (e.g. creeping/shrinkage of the concrete) shall be estimated for the requisite period of use using approved calculation methods.

(2) The calculated values shall be incorporated within the permitted tolerance band for long-wave deviation which is laid down in the Guideway design principles for high-speed maglev systems - Part III: Geometry.

Wind

(1) Additional support structure deformations as a result of wind are compatible with the system when observing the requirements mentioned in Chapters 10.3.2.3.1 and 10.3.2.3.2 pertaining to rigidity and maximum wind speeds (see Q9) in wind zone II up to a height of $h_{G,Ground}$ = 20 m (see Table 108), taking into account note 7 to Table 113. Proof of deformation as a result of wind is therefore not required.

(2) With higher wind speeds, the data contained in Chapter 8.2.1.4.7 must be taken into account. System compatibility shall be examined in this instance.

Deformations in the x direction

Traffic

(1) The permitted gap changes between the support structures must be observed (see Chapter 10.3.7).

(2) Gap changes in the x direction may also be caused, for instance, by support structure deformations in the area of the x solid bearing (e.g. crosswise bending of support brackets or as a result of elastic deformation of the bearings themselves).

Temperature

(1) The permitted gap changes between the support structures must be observed (see Chapter 10.3.7).

Creeping and shrinkage

(1) The permitted gap changes between the support structures must be observed (see Chapter 10.3.7).

Wind

(1) Support structure deformations in the x direction as a result of wind are not definitive.

Deformation as a result of torsion around the x axis

(1) On account of the gap between the centre of gravity of the vehicle and the shear centre of the guideway in the y and z directions, torsion in the girder cross-section around the x-axis arises as a result of effects in the y and z directions.

(2) Torsion brings about displacement of the functional areas in the y and z directions. The level of displacement in the y direction is negligible.

(3) In simplified terms, displacement of the functional areas in the z direction as a result of torsion is limited by the following rules:

a) The calculated deformation $f_{z,rot,x}$ of the stator level in the z direction as a result of torsion may exceed the permitted deformation in the z direction due to vertical effects (see Chapter 10.3.2.2.1) at any point by a maximum of 20% of the permitted deformation as per Chapter 10.3.2.2.1.

b) If the calculated, actual static deformation as a result of vertical effects is smaller than the limit value as per Chapter 10.3.2.2.1, deformation as a result of torsion may be no more than 50% of the limit value as per Chapter 10.3.2.2.1, in which connection the limit as per a) may not be exceeded.

c) The static line load stat $p_{y,fy}$ = 4.5 kN/m as per Chapter 10.3.2.3.1 shall be specified as an action in the vehicle's centre of gravity.

Permitted local support structure deformations

(1) Local guideway superstructure deformations should not result in the respective assemblies being positioned in areas where they are not allowed (contact freedom).

(2) Limit values for the allowable positions of the lateral guide rails, sliding rails and the longitudinal stator are laid down in the Principles concerning the overall system design of high-speed maglev systems and the Guideway design principles for high-speed maglev systems - Part III: Geometry.

(3) As regards the stator level, a maximum offset of 4 mm in the z direction between two stator plates is permitted temporarily in a particular case (e.g. with an "activated" redundant attachment).

(4) As regards support structures whose functional areas comprising the lateral guide rail level and slider level are interrupted in a grid smaller than 6.192 m, the limit values specified below do not generally apply to offsets. To this end, construction-dependent limit values shall be laid down, providing evidence of the vehicle's compatibility.

Permitted deformations in guideway plates

(1) Given the small spans of guideway plates (approx. 6 m), as regards the guideway plates, the displacement criteria between the individual plates are generally definitive (see Chapter 10.3.6).

(2) Since guideway plates are generally repeatedly mounted in a statically indeterminate manner on continuous strip foundations, an overall deformation assessment of the plates / foundation system is necessary in an individual case.

Dynamic deformations when stimulating inherent frequencies

(1) As a result of vehicles stimulating the guideway itself, dynamic oscillation amplitudes may be generated in the functional levels which may result in minimal magnet disconnections (also refer to Chapter 7.4 in this regard).

(2) *Magnet disconnections are not anticipated when these oscillation amplitudes are limited to a maximum of $\pm$ 3 mm.*

(3) System compatibility must be verified in each case by means of tests.

Permitted offsets in the functional levels

Variable effects to be specified

(1) Q1 ÷ Q60 (minus Q11) or the effects indicated in Chapters 10.3.6.2 and 10.3.6.3 where γ_i = 1.0, combination factors ψ_i as per Table 114 and combinations of effects as per EN 1990.

(2) The limit values below apply irrespective of the type and design of the guideway substructures, i.e. also in the case of separate substructures along girder joints.

Permitted offsets in the stator and slider levels

(1) as a result of a live load in the x direction (braking force) as per Chapter 8.2.1.2 (Q1+Q2) arising from the elastic deformation of the guideway substructures:

permitted $\Delta V_{z,1}$ = 0.4 mm

(2) as a result of a live load as per Chapter 8.2.1.4 (Q1+Q2) arising from the elastic deformation of the guideway superstructures, the guideway bearings and the guideway substructures:

permitted $\Delta V_{z,2}$ = 0.6 mm

(3) as a result of the plastic deformation of the guideway substructures:

permitted $\Delta V_{z,3}$ = 0.5 mm

Permitted offsets in the lateral guide rail level

(1) as a result of a live load in the y direction as per Chapter 8.2.1.2 (Q1+Q2) arising from elastic beam bending and as a result of the elastic and plastic deformation of the substructures (subsoil settlement, plastic creeping and shrinkage deformations):

permitted $\Delta V_{y,1}$ = 0.3 mm

Proof of the gap in the x direction along girder joints

Variable effects to be specified

(1) Q1 ÷ Q60 (as a Q11 effect, only Q11(f) is to be specified) or the effects indicated in Chapter 10.3.7.2 where γ_i = 1.0, combination factors ψ_i as per Table 114 and combinations of effects as per EN 1990.

Control gaps

Elastic gap changes as a result of traffic

(1) The following values must be considered as limit values for the gap change in the x direction along the functional areas as a result of elastic deformation of the guideway substructures and support structures (deviation from the guideway support locations in the longitudinal direction as per the Principles concerning the overall system design of high-speed maglev systems):

a) periodically by driving and braking as a frequently occurring operational situation: max. $\Delta S_{x,Q1/Q2}$ = 10 mm

b) in the case of uncommon and unusual operational situations: max. $\Delta S_{x,Q11/A}$ = 20 mm

Limit values for the gap in the x direction

(1) Proof of the maximum gap width max S_x shall be furnished by ΔT_r with proof of the minimum gap width *min* S_x furnished by ΔT_f.

(2) min/max S_x as per the Guideway design principles for high-speed maglev systems - Part III: Geometry

(3) A minimum gap of 5 mm between the function components shall be guaranteed, where necessary, by suitable structural measures (e.g. axial force buffer).

Proof of freedom from shear

(1) With ΔT_N, proof must be furnished that the support structures are free from shear in accordance with Chapter 8.2.3.2. If proof cannot be furnished, shear forces must be taken into account.

Special gaps

(1) In the case of interrupted long stator winding, larger gaps are permitted (refer to the Guideway design principles for high-speed maglev systems - Part III: Geometry, for the limit values) in relation to gauge change devices, transition structures in the case of guideways on primary supporting frameworks, etc.

Elastic and plastic deformation in substructures

General

(1) As a result of elastic and plastic deformations in the guideway substructures (e.g. supports, foundations, subsoil), angles η result along the support structure support sites (see figs. 158 - 160) in the functional areas which are specific to high-speed maglev systems. These angles along the functional areas are limited in all coordinate directions by means of the definition of permitted guideway substructure deformations which is dependent on the system length.

(2) When the permissible deviations in the positions of guideway substructures are exceeded (= probable subsoil movements), readjustment of the guideway bearings is necessary for ensuring system compatibility.

(3) Generally speaking, the system length of the girder sections for the direction under consideration each time shall be used as the reference length L_{Sys}. Depending on the support structure mounting conditions, L_{Sys} may differ for the y and z directions. In the case of supports along which support structures with unequal system lengths ($L_{Sys,1} \neq L_{Sys,2}$) rest, the mean of the two system widths shall be specified for determining permitted substructure deformation.

(4) Substructure deformation is limited by the stipulations of the following chapters. These limits involve differential deformations, i.e. positional deviations between the individual mounting points. With regard to clearance, proof must also be furnished of the absolute deformations in relation to the space curve. Proof must also be furnished for uncommon design situations.

(5) To determine substructure deformations, the combinations of effects as per the equations in Chapter 10.3.1 shall be applied.

(6) In this regard, the partial safety coefficients as regards the characteristic values of the effects shall be specified at $\gamma_i = 1.0$.

Substructure deformation in the x direction

(1) Elastic and plastic substructure deformation in the x direction shall be limited in such a way that the limit values indicated in Chapter 10.3.7 (e.g. freedom from shear) are observed.

Substructure deformation in the y direction

Plastic substructure deformation

(1) The following limit values for guideway substructure deformation in the y direction must be observed by both simple beams and multiple span girders:

- Supports with girder joints: $\Delta y_{St,1,plas} = \pm L_{Sys} / 6000$ (38)
- King posts in the case of multiple span girders: $\Delta y_{St,2,plas} = \pm L_{Sys} / 4500$ (39)

(2) When the limit value is exceeded, the support structure mounting must be readjusted.

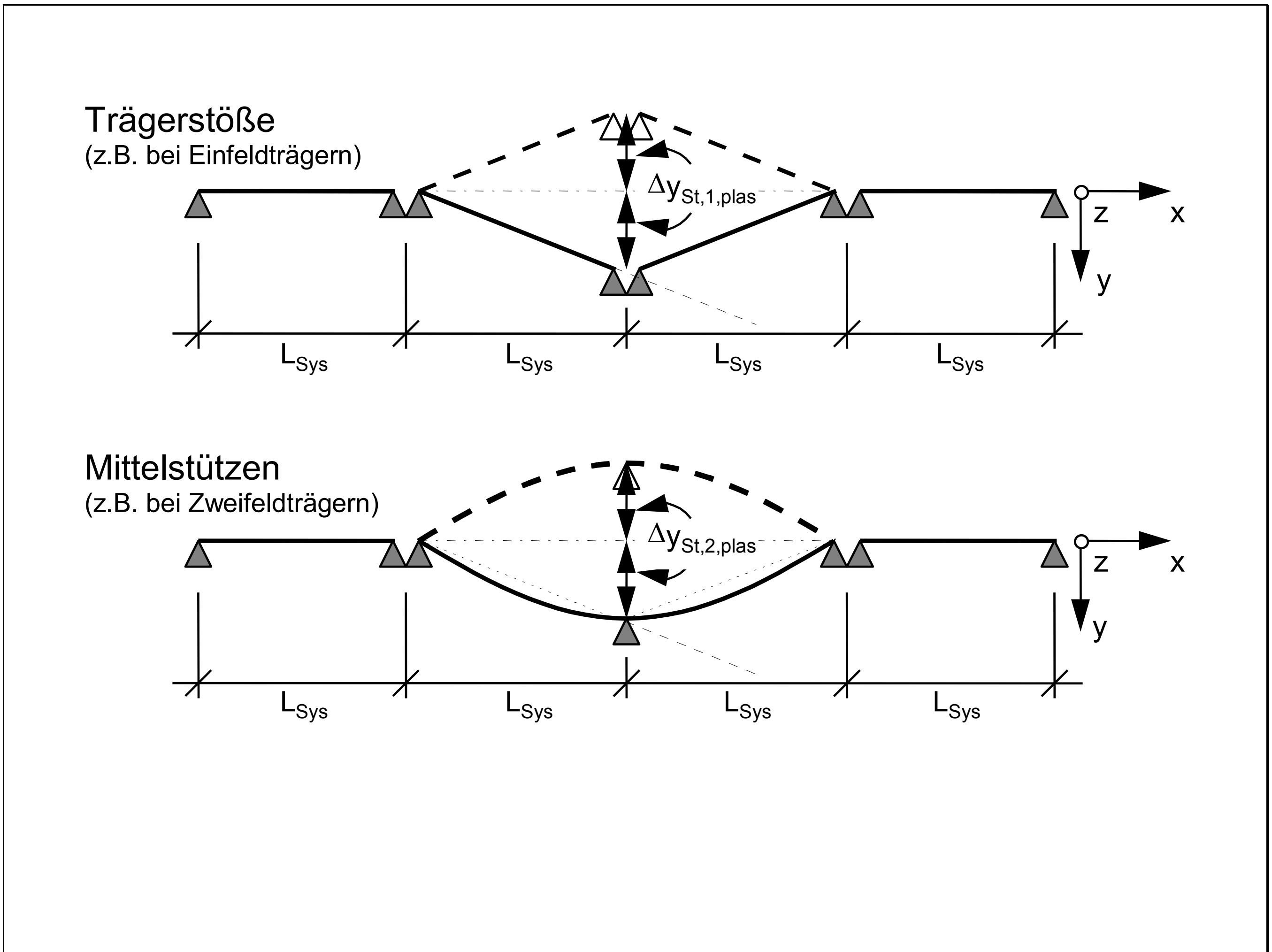


Fig. 158 - Plastic substructure deformation in the y direction (example)

[Key to diagram:
Tragerstöße (z.B. bei Einfeldträgern) = girder joints (e.g. in the case of simple beams)
Mittelstützen (z.B. bei Zweifeldträgern) = king posts (e.g. in the case of two-span beams)]

Elastic substructure deformation

(1) The following limit values must be observed as regards the elastic deformation of substructures in the y direction as a result of the variable effects Q1 ÷ Q10 and Q50 ÷ Q60:

- Supports with girder joints: $\Delta y_{St,1,elas} = \pm L_{Sys} \cdot (0.0013 - 1/6000) \cdot k$ (40)
- King posts in the case of multiple span girders: $\Delta y_{St,2,elas} = \pm L_{Sys} \cdot (0{,}0015 - 1/4500) \cdot k$ (41)

where $k = h_{G,Ground}$ [m]/ 20 m, $h_{G,Ground} \geq 3$ m and $k \leq 1$

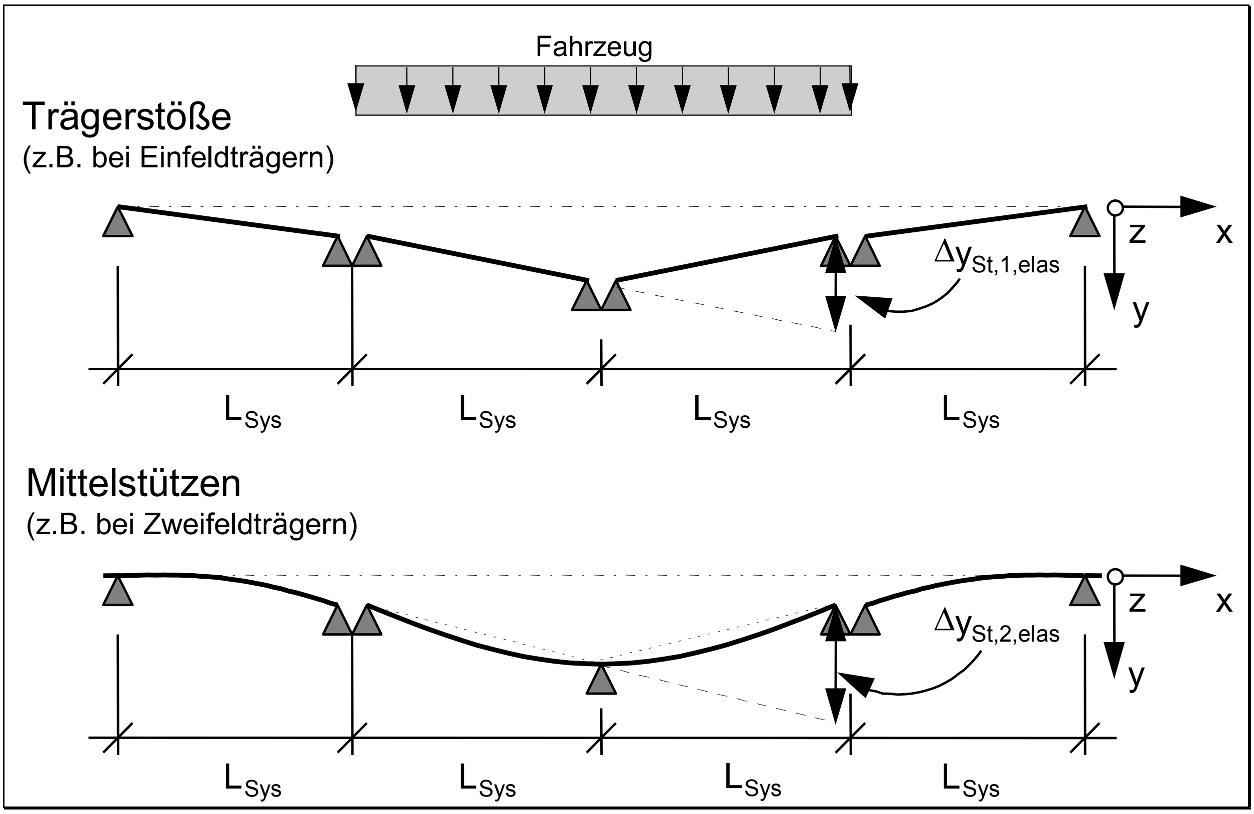


Fig. 159 - Elastic substructure deformation in the y direction (example 1)

[Key to diagram:
Fahrzeug = vehicle
Tragerstöße (z.B. bei Einfeldträgern) = girder joints (e.g. in the case of simple beams)
Mittelstützen (z.B. bei Zweifeldträgern) = king posts (e.g. in the case of two-span beams)]

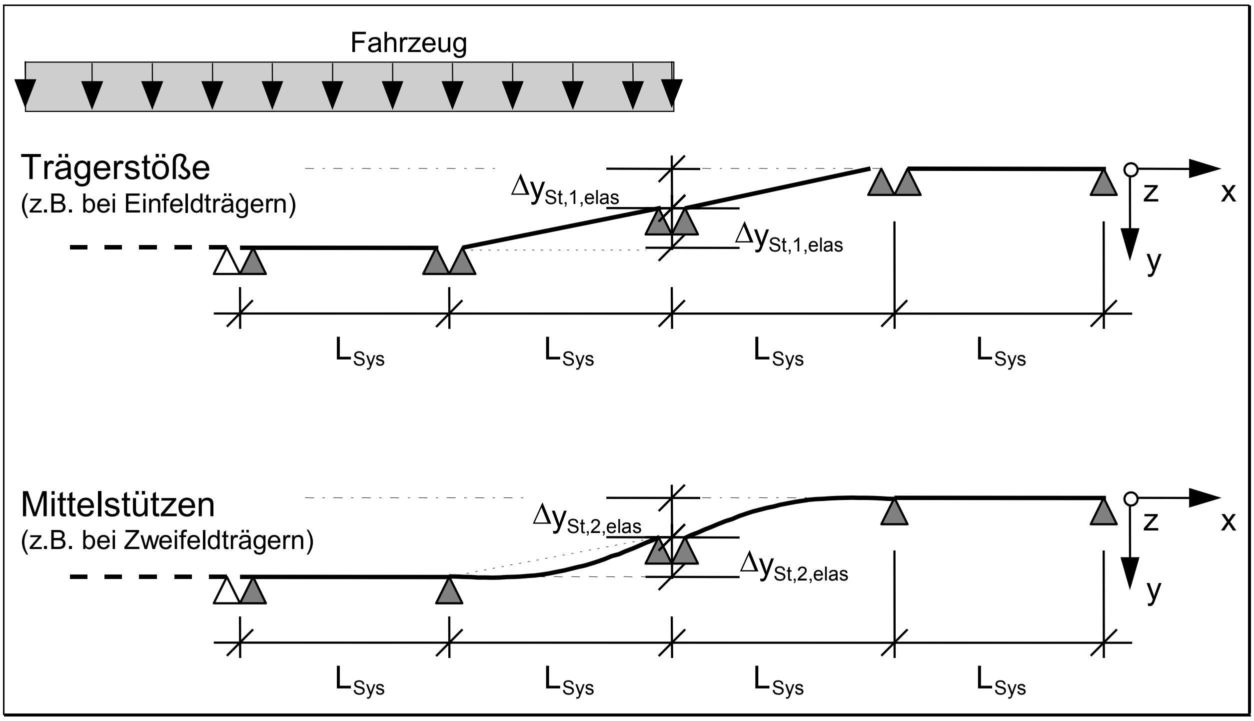


Fig. 160 - Elastic substructure deformation in the y direction (example 2)

[Key to diagram:
Fahrzeug = vehicle
Tragerstößе (z.B. bei Einfeldträgern) = girder joints (e.g. in the case of simple beams)
Mittelstützen (z.B. bei Zweifeldträgern) = king posts (e.g. in the case of two-span beams)]

Substructure deformation in the z direction

Plastic substructure deformation

(1) The following limit values for plastic substructure deformation in the z direction (representation similar to fig. 158) must be observed by both simple beams and multiple span girders:

- Supports with girder joints: $\Delta z_{St,1,plas} = \pm L_{Sys} / 6000$ (42)
- King posts in the case of multiple span girders: $\Delta_{zSt,2,plas} = \pm L_{Sys} / 4500$ (43)

(2) When the limit value is exceeded, the support structure mounting must be readjusted.

Elastic substructure deformation

(1) The following limit values must be observed as regards the elastic deformation of substructures in the z direction as a result of the variable effects Q1 ÷ Q10 and Q50 ÷ Q60 (representation similar to figs. 159 and 160):

- Supports with girder joints: $\Delta z_{St,1,elas} = \pm L_{Sys} / 6000$ (44)
- King posts in the case of multiple span girders: $\Delta z_{St,2,elas} = \pm L_{Sys} / 4500$ (45)

Deformation of continuous strip foundations

(1) An assessment of the deformation of continuous strip foundations (e.g. the guideway plate) shall be conducted in a particular case. As a rule in this regard, the limiting of permitted offsets at the functional levels (stator, lateral guide and slider levels) is decisive (see Chapter 10.3.6).

(2) The equations and figures from Chapter 10.3.8 are not applicable here.

Primary supporting framework deformation

(1) The permitted deformation of primary supporting frameworks (e.g. viaducts with “laid” support structures of low-lying/ground level design) shall be limited such that the abovementioned requirements pertaining to

- the end tangent angle of rotation ϑ (see figs. 156 and 157),
- the gap dimensions and
- offsets

are satisfied.

(2) Following agreement with the competent supervisory authority, taking into account the framework condition whereby the guideway position on the primary supporting framework corresponds to the standard camber of 100%, as regards primary supporting frameworks, the limit values for supporting framework deflection in the z direction as set out in Chapter 10.3.2.2.1 may be doubled where justified in exceptional circumstances (i.e. unstressed, 100% camber, 100% deflection under a load).

(3) Proof must be furnished of the compatibility of primary supporting frameworks in relation to the vehicle.

Deformations in the event of collisions on the guideway

(1) If a collision on the guideway is to be considered in accordance with Chapter 8.3.6, the offsets which remain between the "functional levels" (stator levels, lateral guide rail levels) along girder joints following a collision involving supports or support structures should not exceed 3 mm.

Metal fatigue

General

(1) The general principles concerning the furnishing of proof of structural durability/fatigue evaluation (fatigue classes with the associated stress-number line, partial safety coefficients of the resistance side, etc.) shall be taken from EN 1990 and the respective standards and guidelines, as well as other permitted regulations and the Guideway design principles for high-speed maglev systems - Part I: Principle requirements.

(2) Selected parameters which are dependent on the structure shall be substantiated when proof is furnished.

Framework conditions which are specific to high-speed maglev systems

(1) Unless otherwise stipulated in relation to a specific project, the following typical formulations apply to the proofs concerning metal fatigue:

- vehicle weights Q1…Q4 and the appurtenant frequencies as per Chapter 8.2.1.2
- 130 journeys per traffic lane per day (basis: approx. 20 hours/day with 6 journeys/hour)
- a service life of 80 years (365 days/year)
- free lateral acceleration a_y = - 0.5 m/s² … 1.5 m/s²
- vertical acceleration (incl. g) a_z = 9.21 m/s² …11.01 m/s²
- load in the x direction as per Table 101 with the option of a project-specific grading of the longitudinal forces based on the propulsion design for a project-specific design (of the guideway substructures, for instance)
- taking into account the dynamics as per Chapter 7.4
- taking into account the pertinent global/local load scenarios
- allowing for the travel dynamics (dynamic lateral forces) and constraint forces
- allowing for a head wind
- taking into consideration the numerous variable environmental effect values[25]
- taking into account the bending load of the points arising from the adjustment procedure to the branch positions
- with increased vehicle weight as a result of snow (the frequency and size of the load shall be stipulated in relation to the particular project)
- disregarding the effects of uncommon operational situations
- disregarding unusual influences

(2) As regards the local support components at the points of intersection between the longitudinal stator and the levitation magnet and the lateral guide rail and the guidance magnet, the conditions specified in Chapters 10.4.3 and 10.4.4 apply.

Point of intersection between the longitudinal stator and the levitation magnet

- the project-dependent design of the building components and assemblies as per Chapter 10.4.2;
- consideration of the levitation magnet pole division as per Chapter 7.3;
- where the building components and assemblies are designed independent of the project, the action limit values must be taken into consideration.
- allowing for the structural and control dynamics;[26]

Point of intersection between the lateral guide rail and the guidance magnet

- the project-dependent design of the building components and assemblies as per Chapter 10.4.2;
- the smallest device for considering the control dynamics is the part magnet (1525 mm). Interruptions in the pole terminal strips in the x direction between two adjacent guidance magnets and within the guidance magnets are negligible;
- where the building components and assemblies are designed independent of the project, the action limit values must be taken into consideration;
- allowing for the structural and control dynamics;[27]

Annex

Annex II-A: Allocation of the effects at the points of intersection

No.	Effects resulting from the vehicle/drive	SE	SFE	GLE	Comments
Common design situations					
Q1	Forces of gravity, incl. dynamics arising from a vehicle's own weight	x	x	x	
Q2	Forces of gravity, incl. dynamics arising from the live load	x	x	x	
Q3	Unequal distribution of the vehicle weight in the x direction	x	x	x	
Q4	Unequal distribution of the vehicle weight in the y direction	x		x	
Q5	Travel dynamics (dynamic forces arising from tracking)		x		
Q6	Constraint forces in narrow radii		x		
Q7a	Aerodynamic forces arising from train crossings		x		
Q7b	Aerodynamic forces arising from journeys through tunnels	(x)	(x)	(x)	
Q7c	Aerodynamic forces on structural works situated close to the guideway				
Q8a	Effects of the head wind: lift	x			
Q8b	Effects of the head wind: pressure/pull	(x)	(x)	(x)	
Q9a	Lateral forces as a result of atmospheric wind	x	x	x	
Q9b	Lift as a result of atmospheric wind	x			
Q10	Temperature as a result of propulsion	x			
Uncommon design situations					
Q11a	Increased vehicle weight	x	x	x	
Q11b	Failure of a magnet control circuit, support	x			
Q11c	Double failure of magnet control circuits, support			x	
Q11d	Failure of a magnet control circuit, guidance		x		
Q11e	Double failure of magnet control circuits, guidance		x		
Q11f	Use of the "secure brake"	x	x	x	
Q11g	Speed fluctuations	x	x	(x)	
Q11h	Propulsion mechanism malfunction	x	(x)		
Q11i	Effects as a result of a motor short circuit	x		x	
Q11j	Magnet start up	x			
Q11k	Lifting up skid pads frozen to the guideway			x	
Q11l	Increased vehicle weight as a result of snow in the vehicle	x	x	x	
Unusual effects (analogous)					

Table 115 - Assignment of effects to the functional levels

[Key to table:
SE = stator level
SFE = lateral guide rail level

GLE = slider level]

Annex II-B: Calculated vibration coefficients

General

(1) *The examples of the vibration coefficient diagrams given below include the global vibration coefficient $\varphi_{Bg,z}$ or $\varphi_{Bg,z,WSE}$ for simple beams with spans L_{St} = 12.384 m and L_{St} = 24.768 m. This coefficient is not dependent on the structural design or the construction method. In this regard, the vibration coefficients indicate the dynamic camber as a result of the effects of the moved vehicle in the z direction.*

(2) *Using the example of the loads E in the centre of the girder (e.g. deflection, internal forces, stresses), the diagrams below show how the load develops over time in principle as a result of a vehicle passing over and the associated assessment variables.*

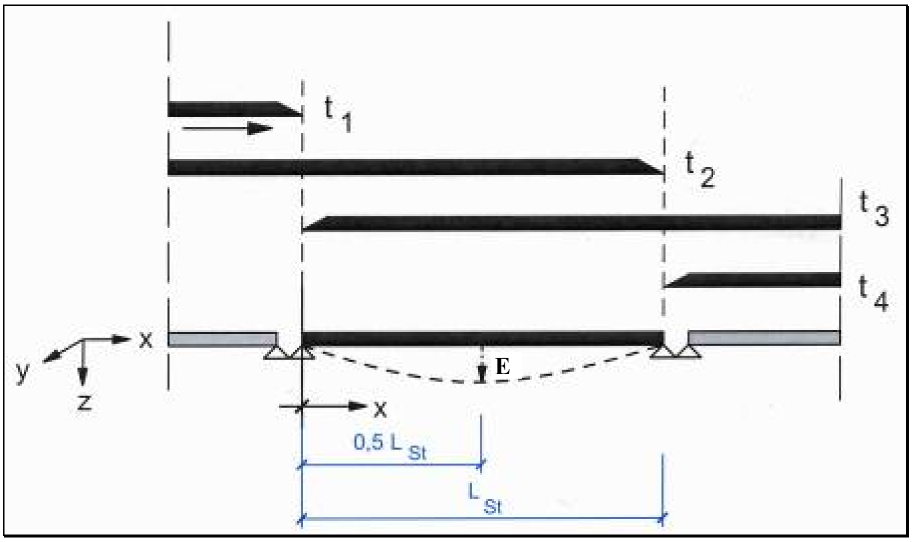


Fig. 161 - Passage of the vehicle along the simple beam with the assessment variable w in the midspan

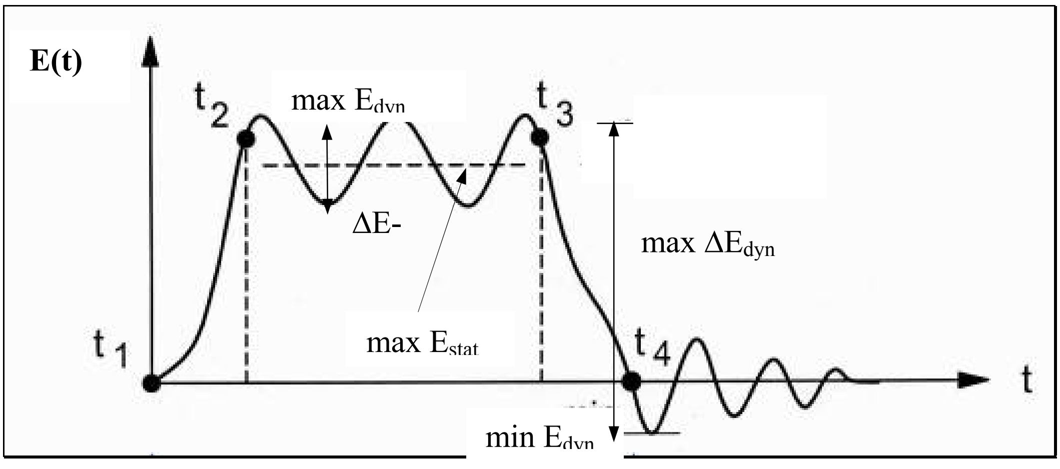


Fig. 162 - Load development over time as a result of a vehicle passing along the simple beam

(3) *Idealised mathematical models form the basis of the diagrams. These diagrams consider the dynamic cambers as a result of period and harmonic stimulations ("Impact" and "Resonance"); cf. in this regard R2, R3 and R4.*

(4) *The following parameters form the basis of the diagrams:*

- *Span, simple beam, where:* L_{St} = 12.384 m and L_{St} = 24.768 m
- *Vehicle lengths:* 2; 4; 6; 10 sections
- *Damping factor D:* 0%; 0.3%; 0.6%; 1.6%
- *Vehicle load scenarios:* as per Chapter 9

(5) *The following assessment variables are also covered by the diagrams:*

- *Deflection* max/min w_{dyn}
- *Bending moment* max/min $M_{y,dyn}$
- *Shearing load* max/min $V_{z,dyn}$

(6) *The diagrams were prepared in relation to furnishing the following proof:*

- *The vibration coefficient for furnishing proof of performance capability and loadbearing capacity*

$$\varphi_{Bg,z} = \frac{\max E_{dyn}}{\max E_{stat}}$$

- *The vibration coefficient for furnishing proof of metal fatigue for determining the maximum load amplitude:*

$$\varphi_{Bg,z,WSE} = \frac{\left(\max E_{dyn} - \min E_{dyn}\right)}{\max E_{stat}}$$

(7) *The vibration coefficients are read off using the non-dimensional value k in the diagrams. The value k is established as follows depending on the span L_{St}, the speed of the vehicle v_{Fzg} and the first vertical natural bending frequency $f_{z,1}$ of the support structure:*

$$k = \frac{L_{St}}{v_{Fzg}} \cdot f_{z,1}$$

Area of application

(1) *When using vibration coefficient diagrams (figs. 164 to 179), the following area of application must be considered:*

- *a span which is approximately equal to the system length $L_{St} \approx L_{Sys}$;*
- *girder-like, rigidly supported simple beams with an approximately constant weight per unit area μ and flexural strength EI;*
- *with an approximately rigid connection ($GA_V \to \infty$);*
- *specification of the damping (damping factor D = 0%; 0.3%; 0.6%; 1.6%);*
  (for values in-between, the next smallest damping factor should conservatively be specified.)
- *vehicle load scenarios as per Chapter 9;*
- *magnet end poles of the levitation magnets shall carry at least 25% of the main magnet pole loads;*
- *calculation only for vertical components of the effects arising from the vehicle, globally in the z direction;*
- *application to deflection w, the bending moment M_y and the shearing load V_z;*
- *the diagrams do not generally apply to vehicle speeds where the vehicle - guideway interaction as a result of magnet control must be considered (low vehicle speeds v_{Fzg} < 50 m/s), and especially not to stationary vehicles v_{Fzg} = 0 m/s.*

(2) *The vibration coefficients for metal fatigue $\varphi_{Bg,z,WSE}$ assist in determining the maximum load amplitude $\max \Delta E_{dyn} = \varphi_{Bg,z,WSE} \cdot \max E_{stat} = \max E_{dyn} - \min E_{dyn}$, which shall only be specified once per vehicle crossing.*

When specifying a single-stage unit, it must be examined whether the existing double amplitudes of the load progression are below the cut-off limit as a result of vibrations ΔE_{dyn}. This is satisfied as long as the following applies to ΔE_{dyn}:

$$\Delta E_{dyn} = 2 \cdot \gamma_{Fl} \cdot \max E_{stat} \cdot (\varphi_{Bg,z} - 1) < \Delta E_{cut-off-limit} / \gamma_{Mf} .$$

If this condition is not satisfied, and for materials or fatigue details without a "cut off limit" area, these oscillation amplitudes must also be considered in the metal fatigue proofs.

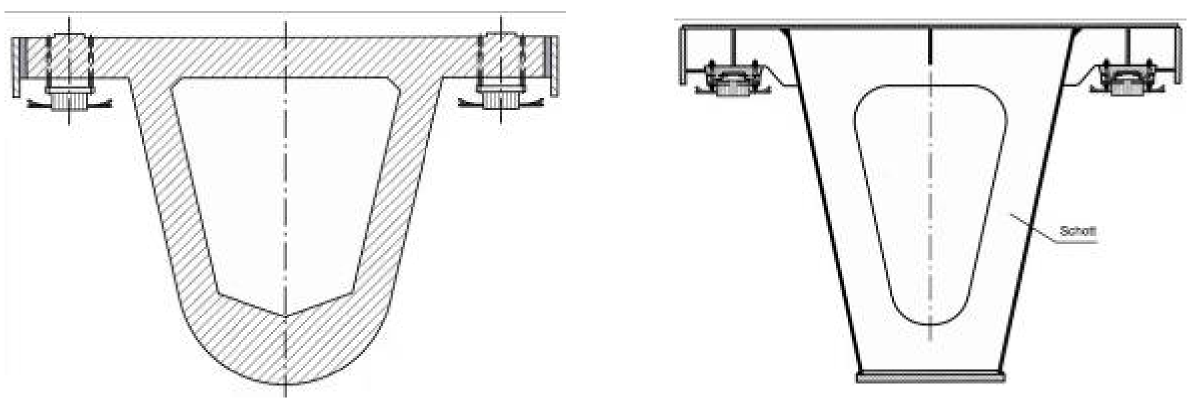
Examples of application

(1) *To illustrate the application of the vibration coefficient diagrams, examples are cited below of type I support structures which are constructed in concrete or steel.*

(2) *The following parameters form the basis of the examples:*

- *cross-sections in the panel area as per fig. 163;*
- *data concerning the rigidity EI and the weight per unit area μ from R1;*
- *simple beams with a span of L_{St} = 24.768 m;*
- *a damping factor of D = 0.6% for prestressed concrete girders;*
- *a damping factor of D = 0.3% for welded steel girders;*
- *a vehicle length consisting of 4 sections;*
- *max v_{Fzg} = 450 km/h = 125 m/s;*

Type I, concrete construction | Type I, steel construction



EI_y = 18800 MNm^2, μ = 3900 kg/m | EI_y = 23200 MNm^2, μ = 2000 kg/m

Fig. 163 - Support structures for the example of application - cross-sections in the panel area

[Key to diagram:
Schott = bulkhead]

(3) *Determining the k values for reading off the global vibration coefficients from the diagrams*

- *As regards the Type 1 concrete construction support structure:*

$$f_{z,1} = \frac{\pi}{2 \cdot 24{,}768^2} \cdot \sqrt{\frac{1{,}88 \cdot 10^{10}}{3900}} = 5{,}62\,\text{Hz} \quad \rightarrow \quad k = \frac{L_{St} \cdot f_{z,1}}{v_{Fzg}} = \frac{24{,}768 \cdot 5{,}62}{125} = 1{,}11$$

⇒ *from fig. 174:* $\varphi_{Bg,z} = 1{,}15 + 1{,}0 \cdot (1{,}4 - k) = 1{,}44$

⇒ *from fig. 175:* $\varphi_{Bg,z,WSE} = 1{,}8$

- *As regards the Type 1 steel construction support structure:*

$$f_{z,1} = \frac{\pi}{2 \cdot 24{,}768^2} \cdot \sqrt{\frac{2{,}32 \cdot 10^{10}}{2000}} = 8{,}72\,\text{Hz} \quad \rightarrow \quad k = \frac{24{,}768 \cdot 8{,}72}{125} = 1{,}73$$

⇒ *from fig. 174:* $\varphi_{Bg,z} = 1{,}15$

⇒ *from fig. 175:* $\varphi_{Bg,z,WSE} = 1{,}3$

(4) *When choosing the damping factor, Chapter 7.4.3 must be taken into consideration.*

(5) *The actual (measured) natural frequencies may deviate from the natural frequencies which have been calculated. The other results shall then be adapted accordingly.*

Examples of vibration coefficient diagrams

General

(1) *The following diagrams present examples of the vibration coefficients $\varphi_{Bg,z}$ and $\varphi_{Bg,z,WSE}$ in relation to the spans and vehicle lengths listed in Table 116.*

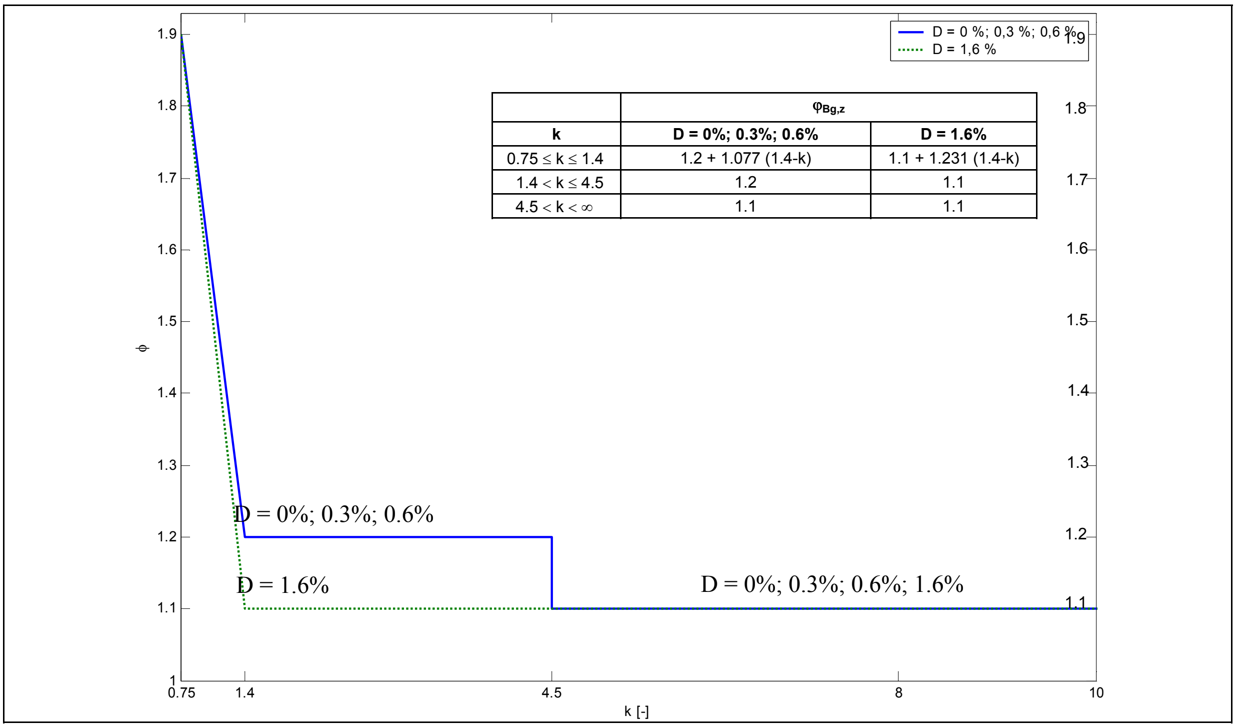
(2) *As a result of the investigations in R2, R3 and R4, vibration coefficient calculation lines were determined in relation to different areas of k and the damping values analysed which take into account the dynamic cambers as a result of period and harmonic stimulation following a vehicle crossing.*

Span	Vehicle length	Page
L_{St} = 12.384 m	2 sections	Figs. 164 and 165
	4 sections	Figs. 166 and 167
	6 sections	Figs. 168 and 169
	10 sections	Figs. 170 and 171
L_{St} = 24.768 m	2 sections	Figs. 172 and 173
	4 sections	Figs. 174 and 175
	6 sections	Figs. 176 and 177
	10 sections	Figs. 178 and 179

Table 116 - Spans and vehicle lengths of the vibration coefficient diagrams provided by way of example

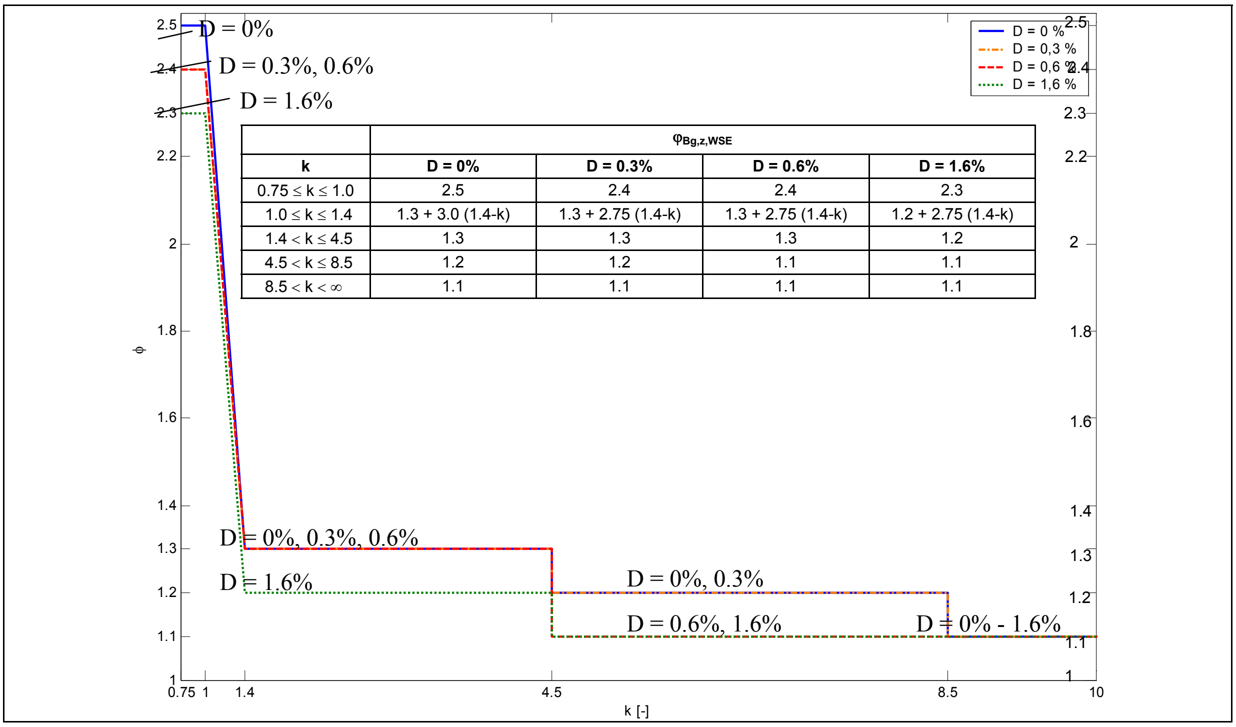
Vibration coefficient diagrams for simple beams where L_{St} = 12.384 m

Vibration coefficients for 2-section vehicles



	$\varphi_{Bg,z}$	
k	**D = 0%; 0.3%; 0.6%**	**D = 1.6%**
0.75 ≤ k ≤ 1.4	1.2 + 1.077 (1.4-k)	1.1 + 1.231 (1.4-k)
1.4 < k ≤ 4.5	1.2	1.1
4.5 < k < ∞	1.1	1.1

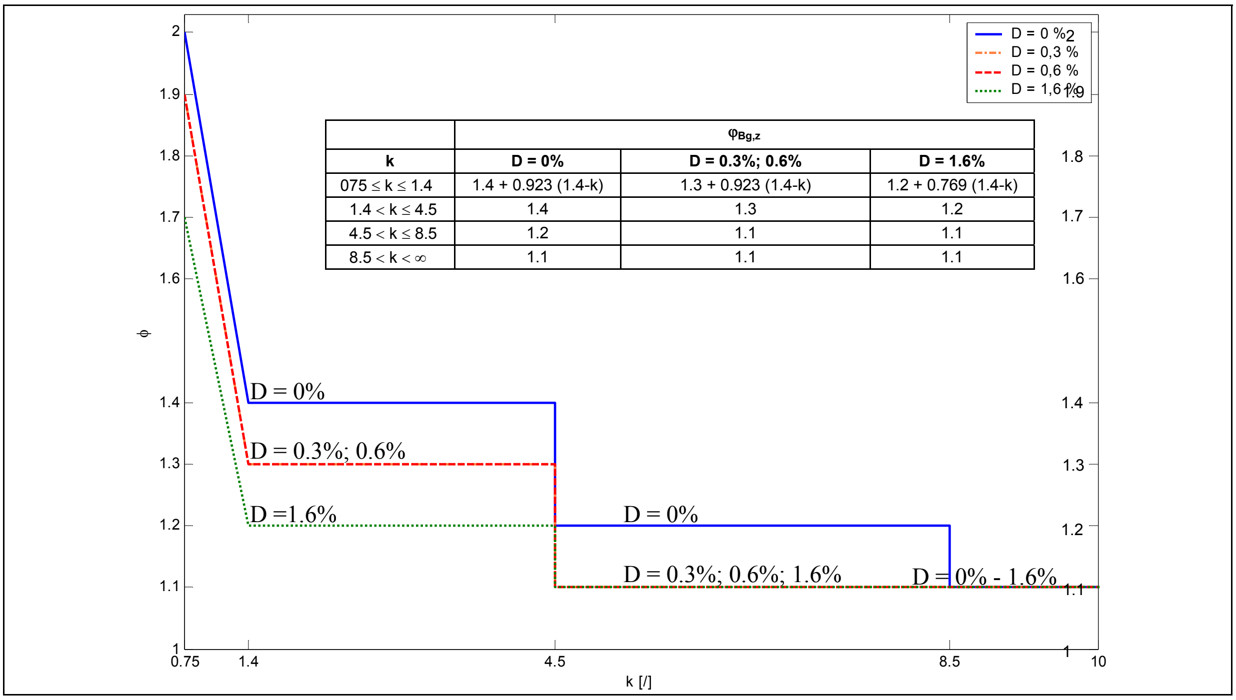
Fig. 164 - $\varphi_{Bg,z}$ for simple beams where L_{St} = 12.384 m - 2-section vehicle



	$\varphi_{Bg,z,WSE}$			
k	**D = 0%**	**D = 0.3%**	**D = 0.6%**	**D = 1.6%**
0.75 ≤ k ≤ 1.0	2.5	2.4	2.4	2.3
1.0 ≤ k ≤ 1.4	1.3 + 3.0 (1.4-k)	1.3 + 2.75 (1.4-k)	1.3 + 2.75 (1.4-k)	1.2 + 2.75 (1.4-k)
1.4 < k ≤ 4.5	1.3	1.3	1.3	1.2
4.5 < k ≤ 8.5	1.2	1.2	1.1	1.1
8.5 < k < ∞	1.1	1.1	1.1	1.1

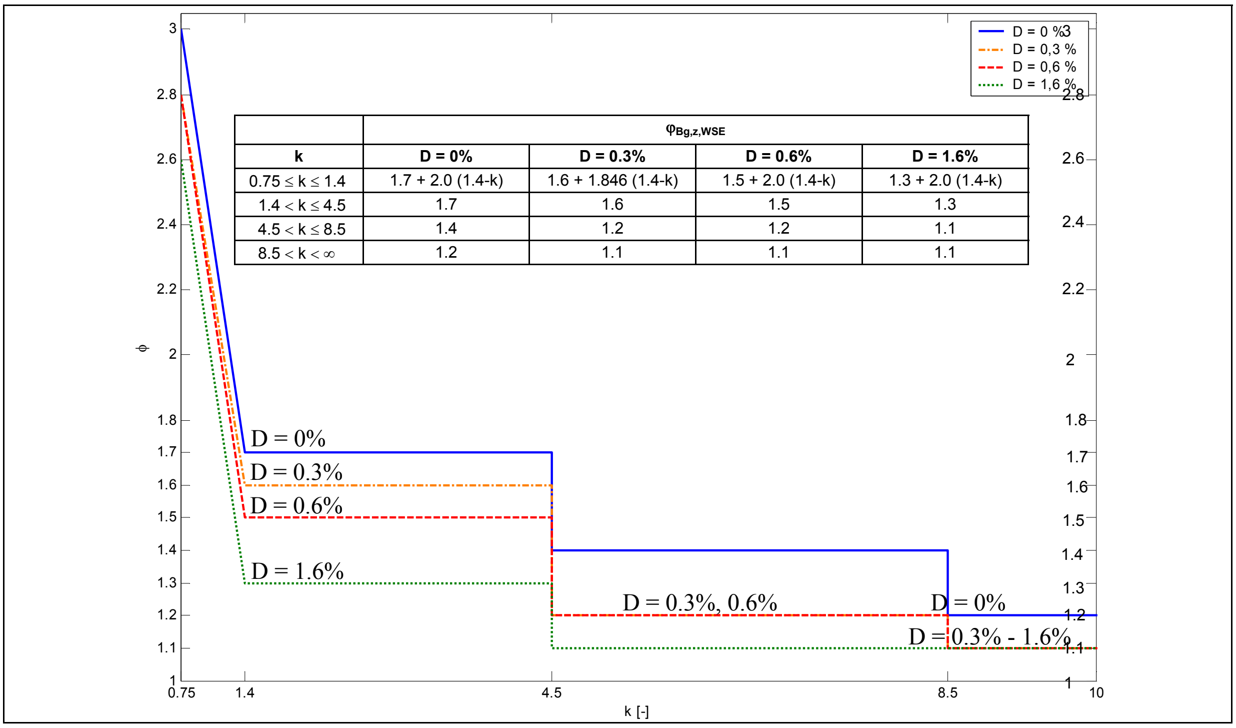
Fig. 165 - $\varphi_{Bg,z,WSE}$ for simple beams where L_{St} = 12.384 m - 2-section vehicle

Vibration coefficients for 4-section vehicles



k	$\varphi_{Bg,z}$		
	D = 0%	D = 0.3%; 0.6%	D = 1.6%
075 ≤ k ≤ 1.4	1.4 + 0.923 (1.4-k)	1.3 + 0.923 (1.4-k)	1.2 + 0.769 (1.4-k)
1.4 < k ≤ 4.5	1.4	1.3	1.2
4.5 < k ≤ 8.5	1.2	1.1	1.1
8.5 < k < ∞	1.1	1.1	1.1

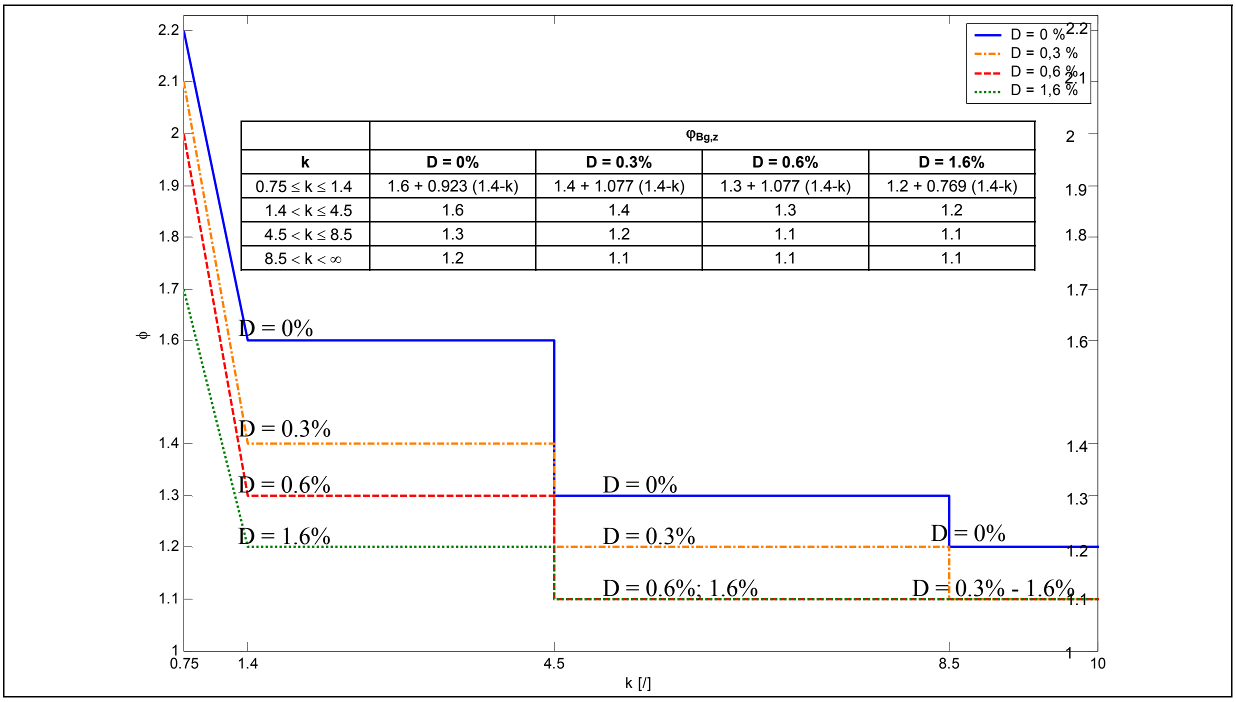
Fig. 166 - $\varphi_{Bg,z}$ for simple beams where L_{St} = 12.384 m - 4-section vehicle



k	$\varphi_{Bg,z,WSE}$			
	D = 0%	D = 0.3%	D = 0.6%	D = 1.6%
0.75 ≤ k ≤ 1.4	1.7 + 2.0 (1.4-k)	1.6 + 1.846 (1.4-k)	1.5 + 2.0 (1.4-k)	1.3 + 2.0 (1.4-k)
1.4 < k ≤ 4.5	1.7	1.6	1.5	1.3
4.5 < k ≤ 8.5	1.4	1.2	1.2	1.1
8.5 < k < ∞	1.2	1.1	1.1	1.1

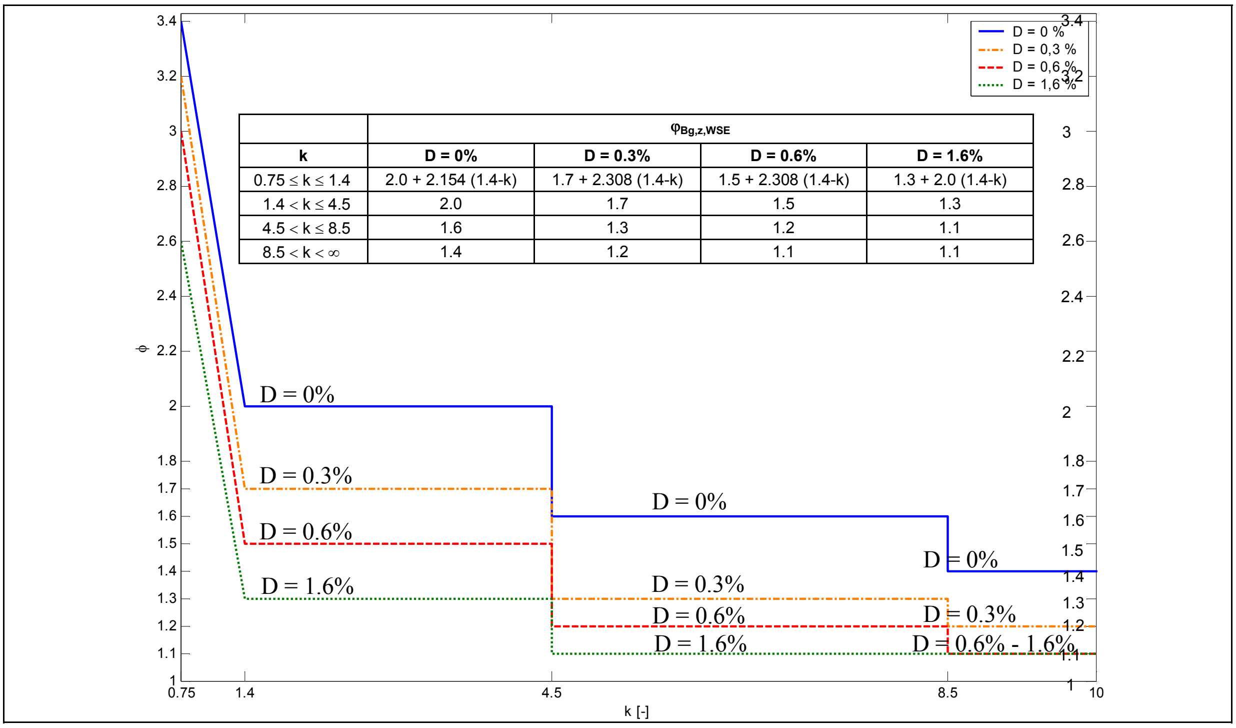
Fig. 167 - $\varphi_{Bg,z, WSE}$ for simple beams where L_{St} = 12.384 m - 4-section vehicle

Vibration coefficients for 6-section vehicles



k	$\varphi_{Bg,z}$ D = 0%	D = 0.3%	D = 0.6%	D = 1.6%
0.75 ≤ k ≤ 1.4	1.6 + 0.923 (1.4-k)	1.4 + 1.077 (1.4-k)	1.3 + 1.077 (1.4-k)	1.2 + 0.769 (1.4-k)
1.4 < k ≤ 4.5	1.6	1.4	1.3	1.2
4.5 < k ≤ 8.5	1.3	1.2	1.1	1.1
8.5 < k < ∞	1.2	1.1	1.1	1.1

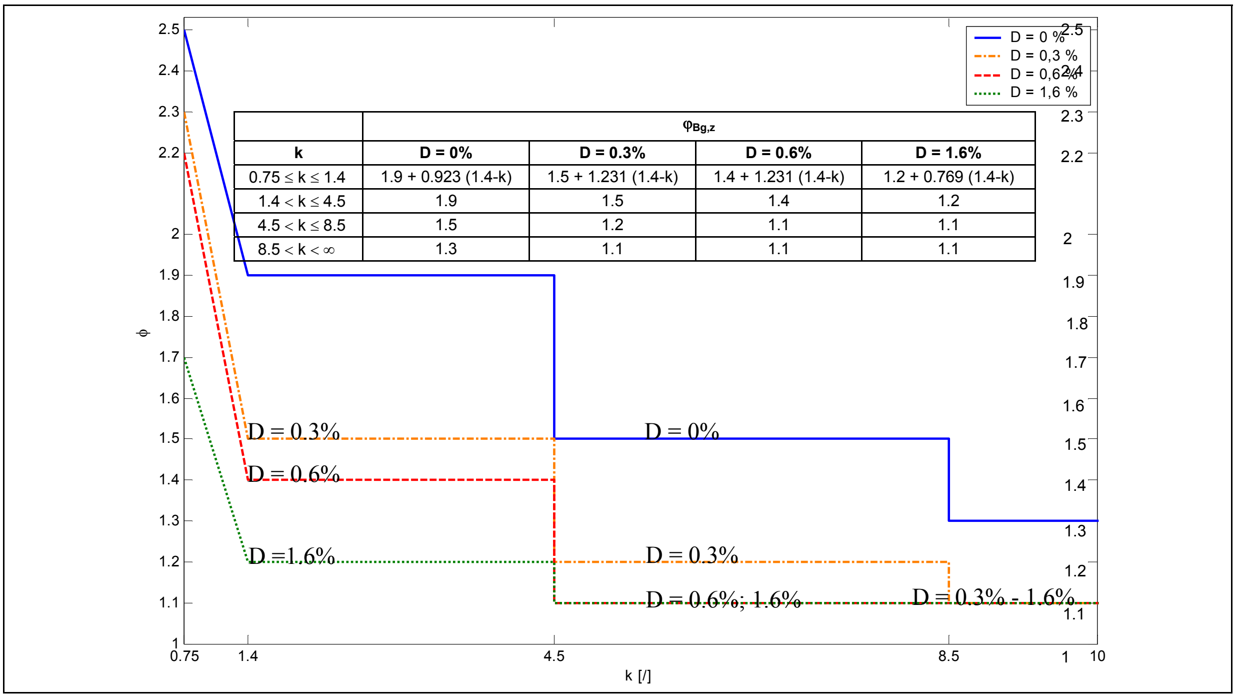
Fig. 168 - $\varphi_{Bg,z}$ for simple beams where L_{St} = 12.384 m - 6-section vehicle



k	$\varphi_{Bg,z,WSE}$ D = 0%	D = 0.3%	D = 0.6%	D = 1.6%
0.75 ≤ k ≤ 1.4	2.0 + 2.154 (1.4-k)	1.7 + 2.308 (1.4-k)	1.5 + 2.308 (1.4-k)	1.3 + 2.0 (1.4-k)
1.4 < k ≤ 4.5	2.0	1.7	1.5	1.3
4.5 < k ≤ 8.5	1.6	1.3	1.2	1.1
8.5 < k < ∞	1.4	1.2	1.1	1.1

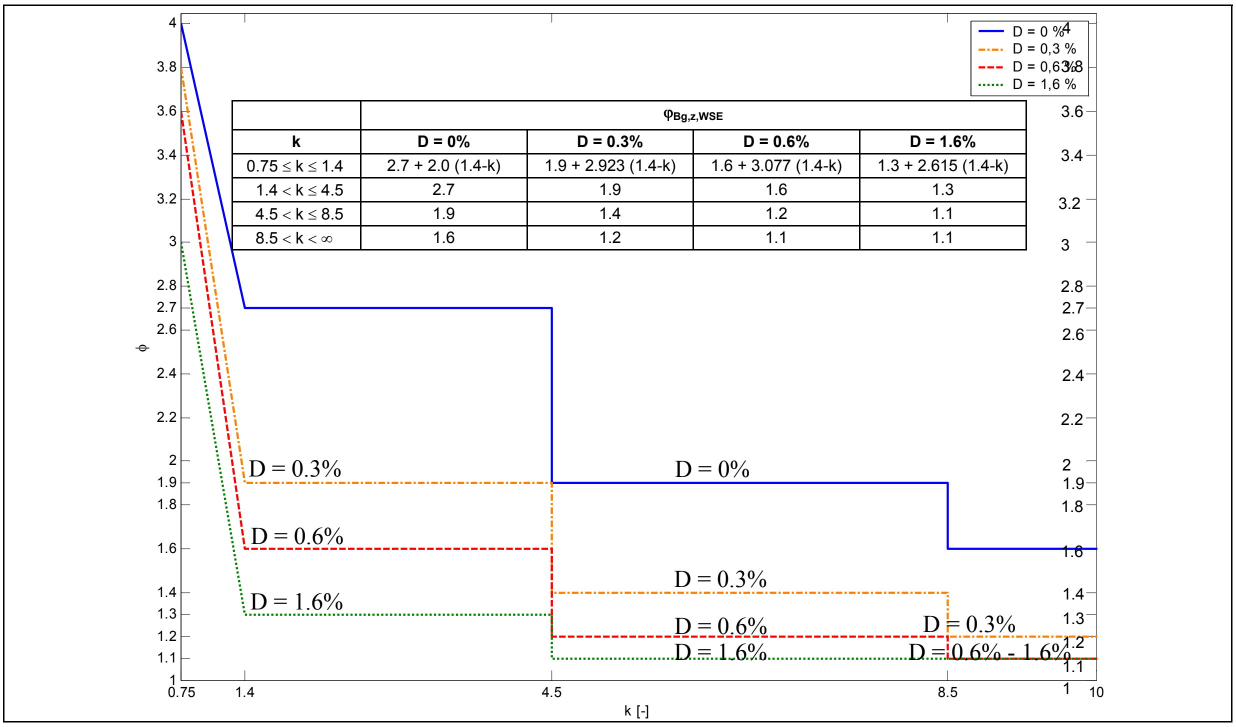
Fig. 169 - $\varphi_{Bg,z,WSE}$ for simple beams where L_{St} = 12.384 m - 6-section vehicle

Vibration coefficients for 10-section vehicles



k	$\varphi_{Bg,z}$ D = 0%	D = 0.3%	D = 0.6%	D = 1.6%
0.75 ≤ k ≤ 1.4	1.9 + 0.923 (1.4-k)	1.5 + 1.231 (1.4-k)	1.4 + 1.231 (1.4-k)	1.2 + 0.769 (1.4-k)
1.4 < k ≤ 4.5	1.9	1.5	1.4	1.2
4.5 < k ≤ 8.5	1.5	1.2	1.1	1.1
8.5 < k < ∞	1.3	1.1	1.1	1.1

Fig. 170 - $\varphi_{Bg,z}$ for simple beams where L_{St} = 12.384 m - 10-section vehicle

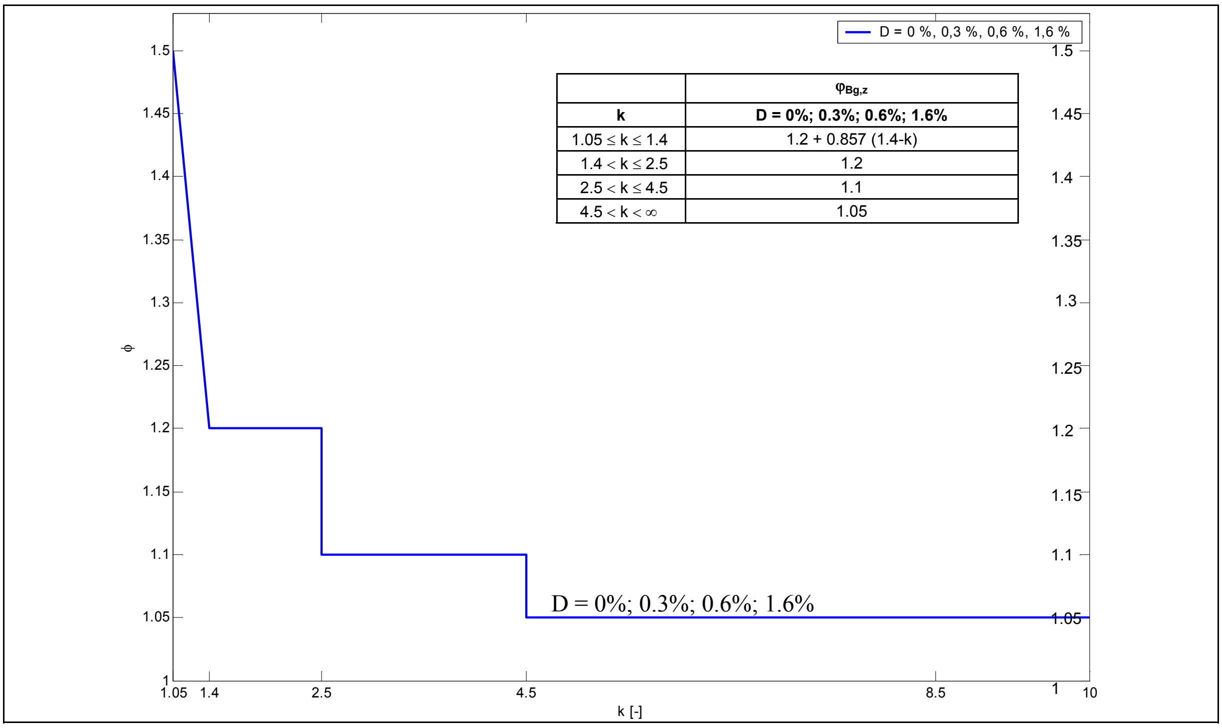


k	$\varphi_{Bg,z,WSE}$ D = 0%	D = 0.3%	D = 0.6%	D = 1.6%
0.75 ≤ k ≤ 1.4	2.7 + 2.0 (1.4-k)	1.9 + 2.923 (1.4-k)	1.6 + 3.077 (1.4-k)	1.3 + 2.615 (1.4-k)
1.4 < k ≤ 4.5	2.7	1.9	1.6	1.3
4.5 < k ≤ 8.5	1.9	1.4	1.2	1.1
8.5 < k < ∞	1.6	1.2	1.1	1.1

Fig. 171 - $\varphi_{Bg,z,WSE}$ for simple beams where L_{St} = 12.384 m - 10-section vehicle

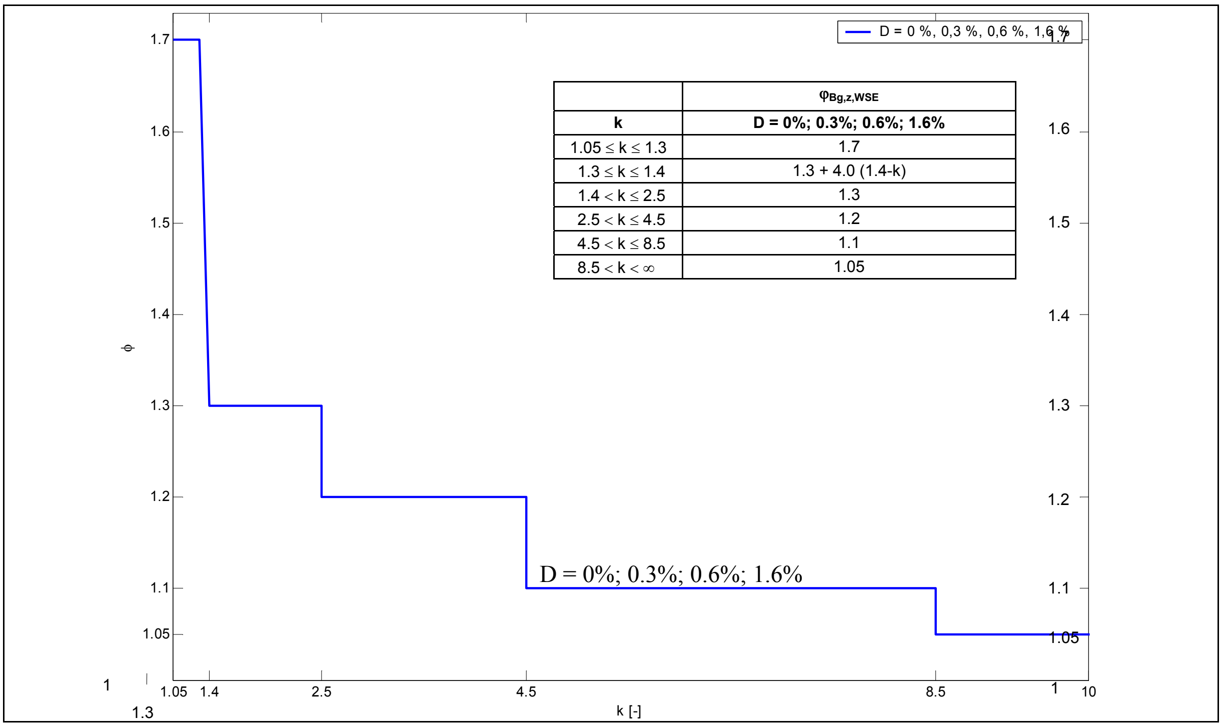
Vibration coefficient diagrams for simple beams where L_{St} = 24.768 m

Vibration coefficients for 2-section vehicles



k	$\varphi_{Bg,z}$ D = 0%; 0.3%; 0.6%; 1.6%
1.05 ≤ k ≤ 1.4	1.2 + 0.857 (1.4-k)
1.4 < k ≤ 2.5	1.2
2.5 < k ≤ 4.5	1.1
4.5 < k < ∞	1.05

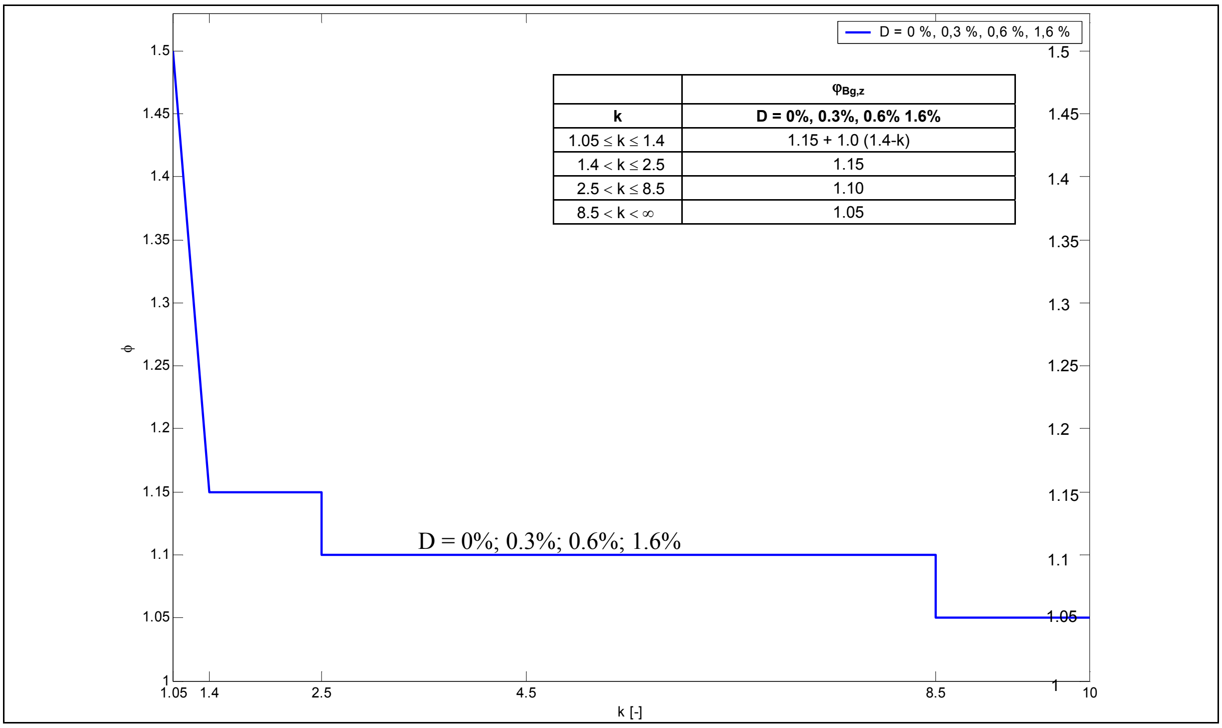
Fig. 172 - $\varphi_{Bg,z}$ for simple beams where L_{St} = 24.768 m - 2-section vehicle



k	$\varphi_{Bg,z,WSE}$ D = 0%; 0.3%; 0.6%; 1.6%
1.05 ≤ k ≤ 1.3	1.7
1.3 ≤ k ≤ 1.4	1.3 + 4.0 (1.4-k)
1.4 < k ≤ 2.5	1.3
2.5 < k ≤ 4.5	1.2
4.5 < k ≤ 8.5	1.1
8.5 < k < ∞	1.05

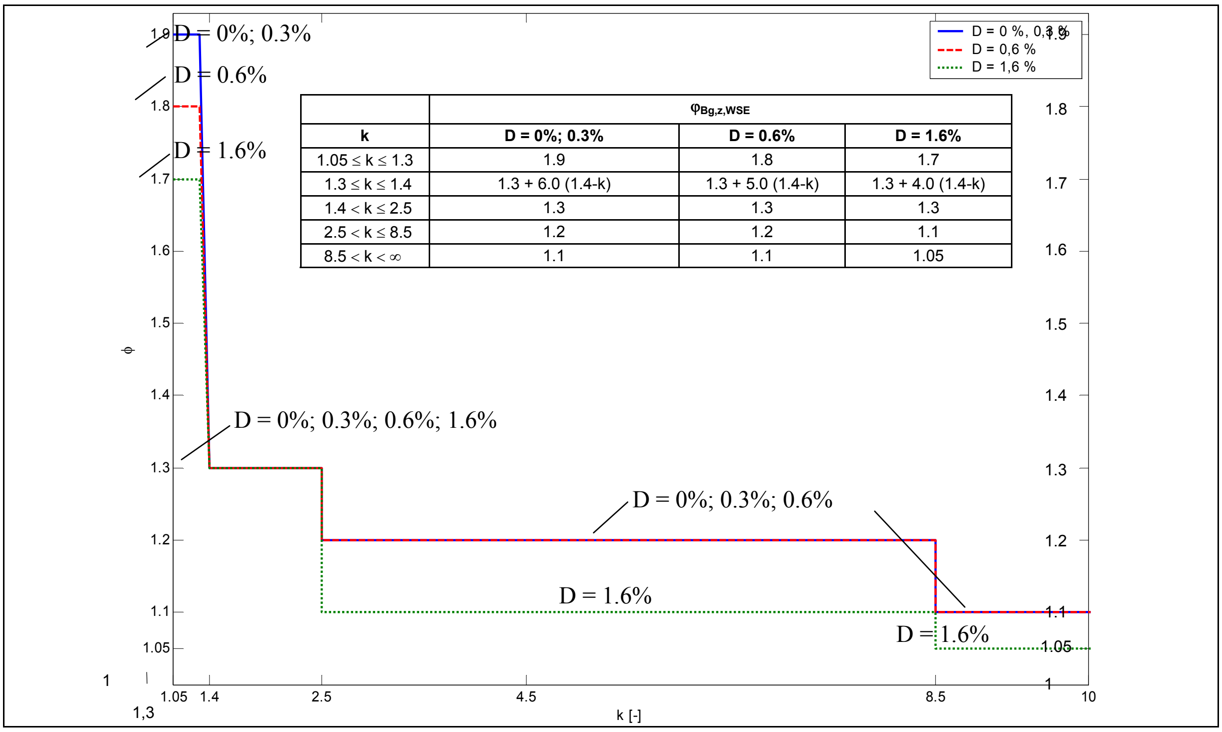
Fig. 173 - $\varphi_{Bg,z,\ WSE}$ for simple beams where L_{St} = 24.768 m - 2-section vehicle

Vibration coefficients for 4-section vehicles



k	$\varphi_{Bg,z}$ D = 0%, 0.3%, 0.6% 1.6%
1.05 ≤ k ≤ 1.4	1.15 + 1.0 (1.4-k)
1.4 < k ≤ 2.5	1.15
2.5 < k ≤ 8.5	1.10
8.5 < k < ∞	1.05

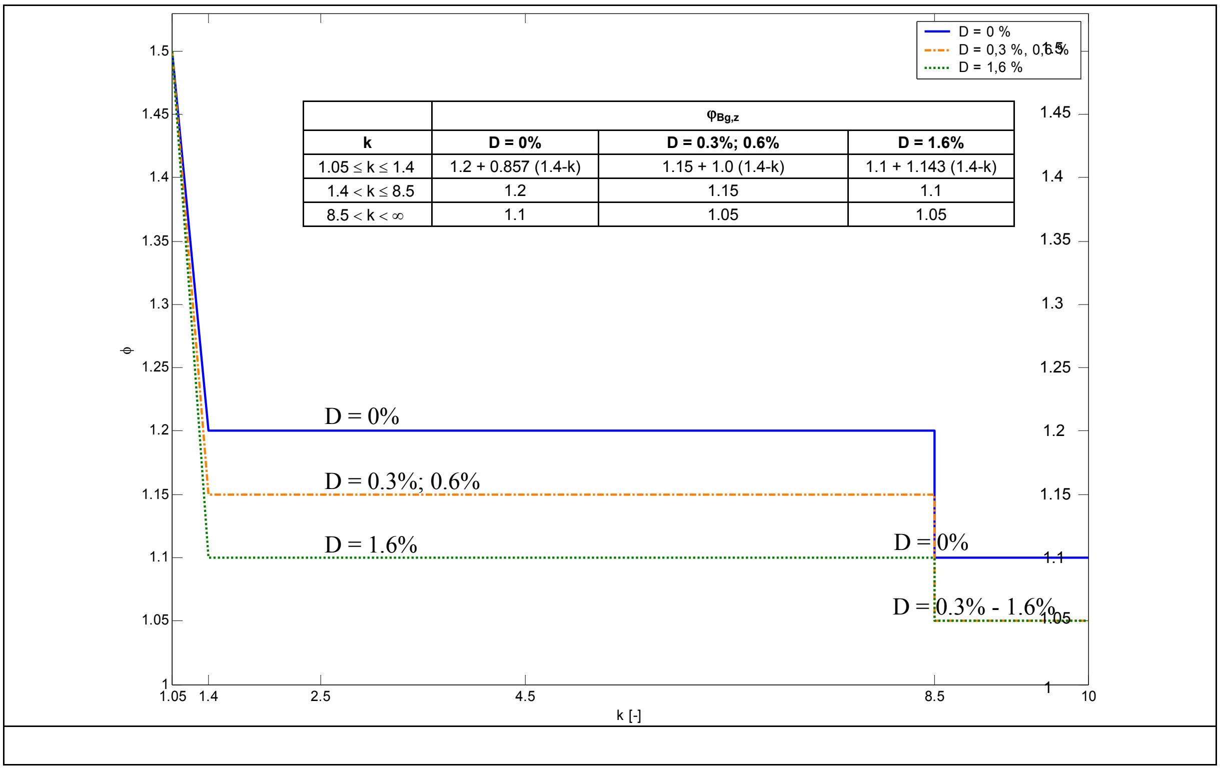
Fig. 174 - $\varphi_{Bg,z}$ for simple beams where L_{St} = 24.768 m - 4-section vehicle



k	$\varphi_{Bg,z,WSE}$ D = 0%; 0.3%	D = 0.6%	D = 1.6%
1.05 ≤ k ≤ 1.3	1.9	1.8	1.7
1.3 ≤ k ≤ 1.4	1.3 + 6.0 (1.4-k)	1.3 + 5.0 (1.4-k)	1.3 + 4.0 (1.4-k)
1.4 < k ≤ 2.5	1.3	1.3	1.3
2.5 < k ≤ 8.5	1.2	1.2	1.1
8.5 < k < ∞	1.1	1.1	1.05

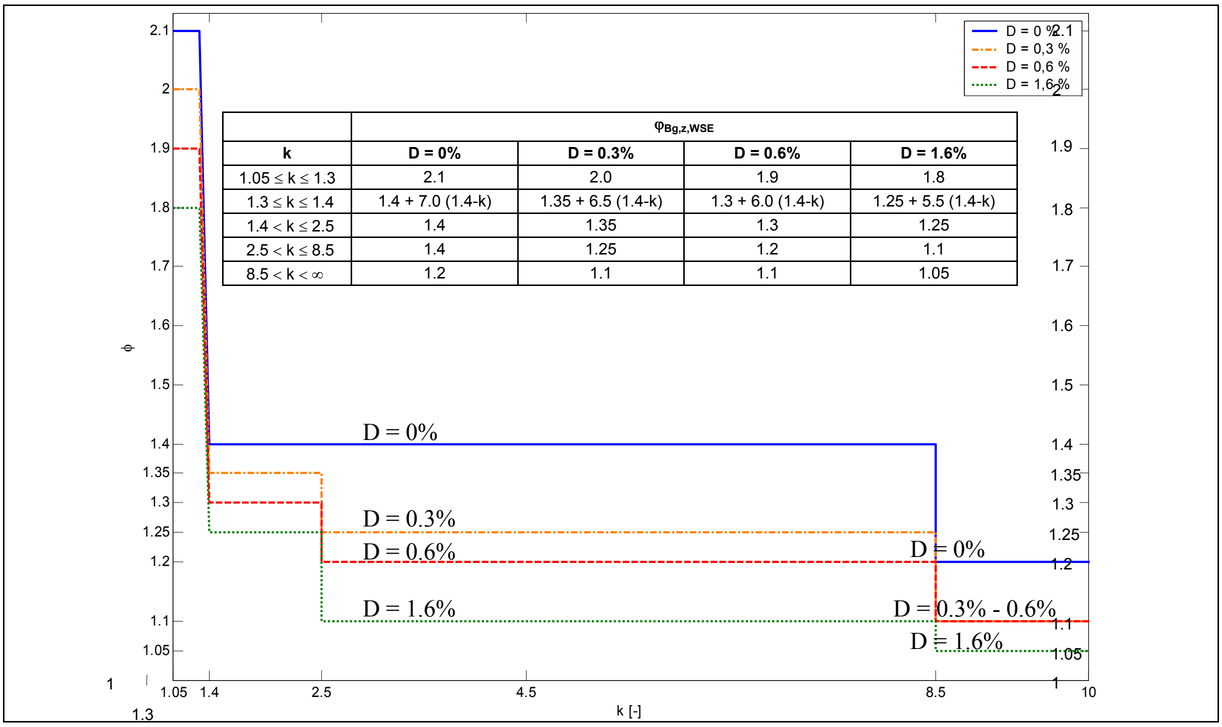
Fig. 175 - $\varphi_{Bg,z,\,WSE}$ for simple beams where L_{St} = 24.768 m - 4-section vehicle

Vibration coefficients for 6-section vehicles



k	$\varphi_{Bg,z}$ D = 0%	D = 0.3%; 0.6%	D = 1.6%
1.05 ≤ k ≤ 1.4	1.2 + 0.857 (1.4-k)	1.15 + 1.0 (1.4-k)	1.1 + 1.143 (1.4-k)
1.4 < k ≤ 8.5	1.2	1.15	1.1
8.5 < k < ∞	1.1	1.05	1.05

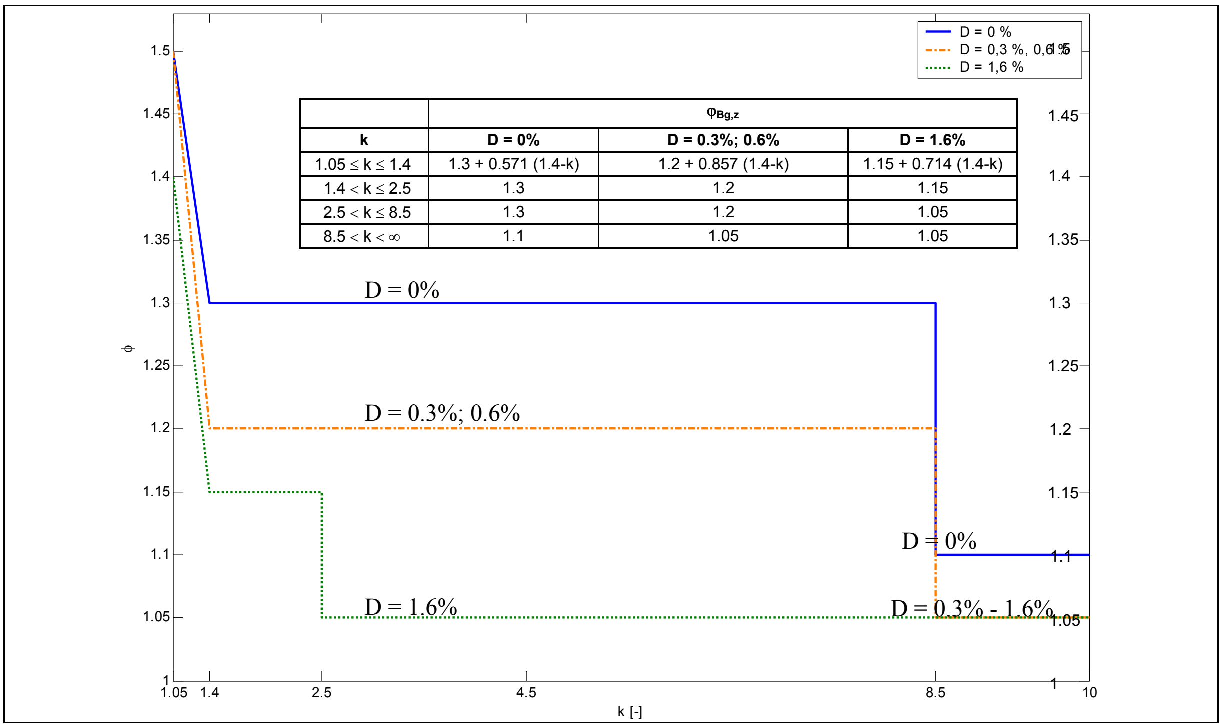
Fig. 176 - $\varphi_{Bg,z}$ for simple beams where L_{St} = 24.768 m - 6-section vehicle



k	$\varphi_{Bg,z,WSE}$ D = 0%	D = 0.3%	D = 0.6%	D = 1.6%
1.05 ≤ k ≤ 1.3	2.1	2.0	1.9	1.8
1.3 ≤ k ≤ 1.4	1.4 + 7.0 (1.4-k)	1.35 + 6.5 (1.4-k)	1.3 + 6.0 (1.4-k)	1.25 + 5.5 (1.4-k)
1.4 < k ≤ 2.5	1.4	1.35	1.3	1.25
2.5 < k ≤ 8.5	1.4	1.25	1.2	1.1
8.5 < k < ∞	1.2	1.1	1.1	1.05

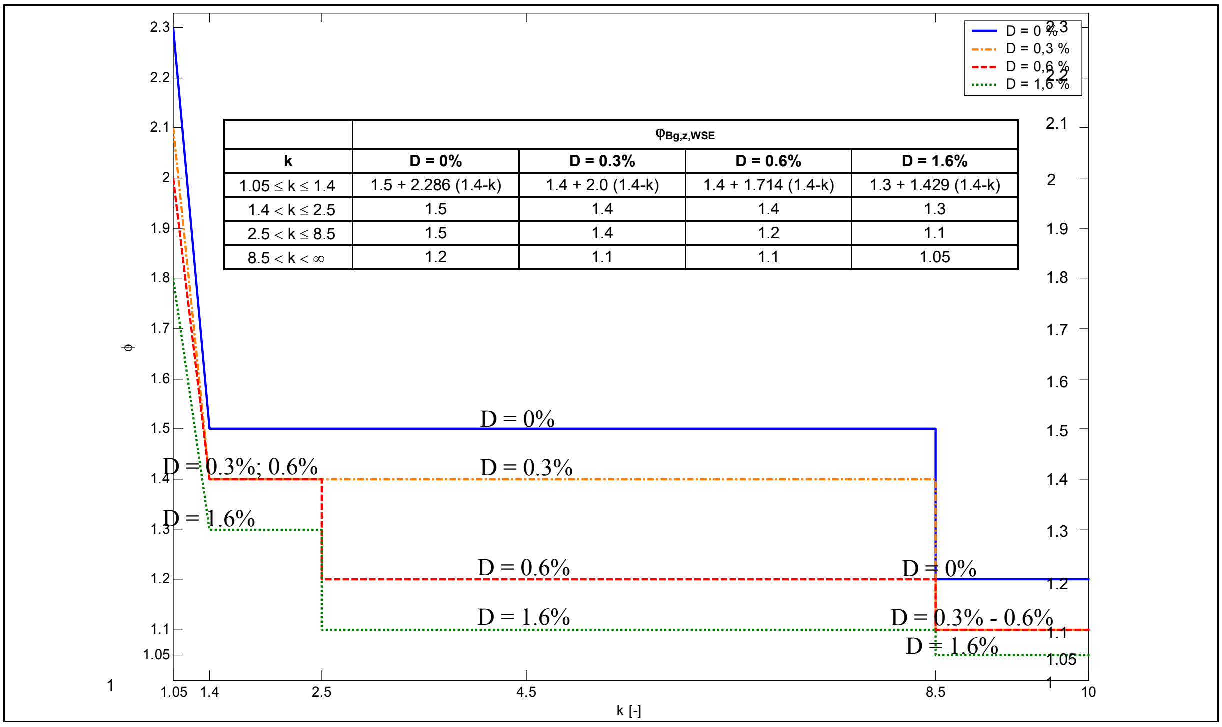
Fig. 177 - $\varphi_{Bg,z,\,WSE}$ for simple beams where L_{St} = 24.768 m - 6-section vehicle

Vibration coefficients for 10-section vehicles



k	$\varphi_{Bg,z}$ D = 0%	D = 0.3%; 0.6%	D = 1.6%
1.05 ≤ k ≤ 1.4	1.3 + 0.571 (1.4-k)	1.2 + 0.857 (1.4-k)	1.15 + 0.714 (1.4-k)
1.4 < k ≤ 2.5	1.3	1.2	1.15
2.5 < k ≤ 8.5	1.3	1.2	1.05
8.5 < k < ∞	1.1	1.05	1.05

Fig. 178 - $\varphi_{Bg,z}$ for simple beams where L_{St} = 24.768 m - 10-section vehicle



k	$\varphi_{Bg,z,WSE}$ D = 0%	D = 0.3%	D = 0.6%	D = 1.6%
1.05 ≤ k ≤ 1.4	1.5 + 2.286 (1.4-k)	1.4 + 2.0 (1.4-k)	1.4 + 1.714 (1.4-k)	1.3 + 1.429 (1.4-k)
1.4 < k ≤ 2.5	1.5	1.4	1.4	1.3
2.5 < k ≤ 8.5	1.5	1.4	1.2	1.1
8.5 < k < ∞	1.2	1.1	1.1	1.05

Fig. 179 - $\varphi_{Bg,z,WSE}$ for simple beams where L_{St} = 24.768 m - 10-section vehicle

Annex II-C: Limit values for routing elements

According to Chapter 4.1.7 of the Guideway design principles for high-speed maglev systems - Part IV: Routing, the combination of the routing elements - horizontal radius R_H, vertical radius R_V and the lateral incline of the guideway α - is limited by the $R_{x,z}$ criterion. In this regard, the limit value $R_{x,z}$ is also dependent on the guideway distortion $\Delta\alpha$. Table 117 gives examples of combination possibilities for routing parameter limit values.

The longitudinal incline (slope, gradient) is set at s = 0% in Table 117.

$R_{x,z,min}$ = 530 m where the distortion $\Delta\alpha$ = 0°/m		
Lateral incline α	Horizontal radius R_H	Vertical radius $R_{V,(K/W)}$
0°	350 m	$R_{V,W} \leq$ - 530 m
		$R_{V,K} \geq$ 530 m
12°	350 m	$R_{V,W} \leq$ - 756 m
		$R_{V,K} \geq$ 530 m
	5050 m	$R_{V,W} \leq$ - 530 m
		$R_{V,K} \geq$ 554 m
$R_{x,z,min}$ = 1100 m where the distortion $\Delta\alpha$ = 0.1°/m		
0°	350 m	$R_{V,W} \leq$ - 1100 m
		$R_{V,K} \geq$ 1100 m
12°	350 m	$R_{V,W} \leq$ - 3105 m
		$R_{V,K} \geq$ 651 m

Table 117 - Limit values for combinations of routing elements

Annex II-D: General limit values relating to deformation

The tables of general limit values relating to deformation are in the process of being drawn up. The deformation limit values to be specified shall be coordinated with the competent supervisory authority, where necessary, until the report is complete.

Annex II-E: Tables of the magnetic forces as a result of cross-winds (Q9a)

The following tables indicate the appurtenant guidance and levitation magnet forces of the advancing end and middle sections for vehicle speeds of 0 km/h, 200 km/h, 300 km/h, 400 km/h and 500 km/h and crosswind speeds of 10 m/s up to 40 m/s. The forces for speeds of travel in between these values, for instance, shall be determined in relation to a specific project by interpolation/extrapolation.

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
40	-	37.1	13.6	19.5	14.1	13.6	13.8	-	-	11.0	8.1	7.5	6.1	4.9	1.8	1.3
39	-	35.5	13.1	18.9	13.6	13.0	13.3	-	-	10.5	7.8	7.2	5.9	4.7	1.8	1.2
38	-	33.9	12.7	18.2	13.0	12.5	12.7	-	-	10.1	7.5	6.9	5.7	4.5	1.7	1.2
37	-	32.4	12.2	17.6	12.5	12.0	12.2	-	-	9.7	7.2	6.7	5.4	4.3	1.6	1.1
36	-	30.9	11.7	16.9	12.0	11.5	11.6	-	-	9.2	6.9	6.4	5.2	4.2	1.6	1.1
35	-	29.4	11.3	16.3	11.4	11.0	11.1	-	-	8.8	6.6	6.1	5.0	4.0	1.5	1.0
34	-	27.9	10.8	15.6	10.9	10.5	10.6	-	-	8.4	6.3	5.8	4.7	3.8	1.5	1.0
33	-	26.5	10.4	15.0	10.4	10.0	10.1	-	-	8.0	6.0	5.6	4.5	3.6	1.4	0.9
32	-	25.1	9.9	14.4	9.9	9.5	9.6	-	-	7.6	5.7	5.3	4.3	3.4	1.3	0.9
31	-	23.8	9.5	13.8	9.4	9.0	9.1	-	-	7.2	5.4	5.1	4.1	3.3	1.3	0.9
30	-	22.5	9.1	13.2	9.0	8.6	8.6	-	-	6.8	5.1	4.8	3.9	3.1	1.2	0.8
29	-	21.2	8.6	12.6	8.5	8.1	8.2	-	-	6.4	4.9	4.6	3.7	2.9	1.2	0.8
28	-	19.9	8.2	12.0	8.0	7.7	7.7	-	-	6.1	4.6	4.3	3.5	2.8	1.1	0.7
27	-	18.7	7.8	11.4	7.6	7.3	7.3	-	-	5.7	4.3	4.1	3.3	2.6	1.0	0.7
26	-	17.5	7.4	10.8	7.1	6.8	6.8	-	-	5.4	4.1	3.9	3.1	2.5	1.0	0.7
25	-	16.3	7.0	10.3	6.7	6.4	6.4	-	-	5.0	3.8	3.6	2.9	2.3	0.9	0.6

v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)														
	(1) 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	7.4	5.6	6.8	4.7	8.3	2.0	5.6	3.2	3.8	4.2	4.8	2.6	5.0	1.4	3.7
39	7.1	5.4	6.5	4.5	8.0	1.9	5.4	3.1	3.6	4.0	4.6	2.5	4.8	1.4	3.6
38	6.8	5.2	6.3	4.4	7.7	1.8	5.2	3.0	3.5	3.9	4.4	2.4	4.6	1.3	3.4
37	6.5	5.0	6.0	4.2	7.4	1.8	5.0	2.8	3.3	3.7	4.2	2.3	4.4	1.3	3.3
36	6.3	4.8	5.7	4.0	7.1	1.7	4.7	2.7	3.2	3.5	4.0	2.2	4.2	1.2	3.1
35	6.0	4.6	5.5	3.8	6.7	1.6	4.5	2.6	3.1	3.4	3.9	2.1	4.1	1.2	3.0
34	5.7	4.4	5.2	3.7	6.4	1.5	4.3	2.5	2.9	3.2	3.7	2.0	3.9	1.1	2.9
33	5.4	4.2	5.0	3.5	6.1	1.5	4.1	2.3	2.8	3.1	3.5	1.9	3.7	1.1	2.7
32	5.2	4.0	4.7	3.3	5.8	1.4	3.9	2.2	2.6	2.9	3.3	1.8	3.5	1.0	2.6
31	4.9	3.8	4.5	3.2	5.6	1.3	3.7	2.1	2.5	2.8	3.2	1.7	3.3	1.0	2.5
30	4.7	3.6	4.2	3.0	5.3	1.2	3.6	2.0	2.4	2.7	3.0	1.6	3.2	0.9	2.3
29	4.4	3.5	4.0	2.9	5.0	1.2	3.4	1.9	2.2	2.5	2.8	1.5	3.0	0.9	2.2
28	4.2	3.3	3.8	2.7	4.7	1.1	3.2	1.8	2.1	2.4	2.7	1.4	2.8	0.8	2.1
27	3.9	3.1	3.6	2.5	4.5	1.0	3.0	1.7	2.0	2.2	2.5	1.4	2.7	0.8	2.0
26	3.7	2.9	3.4	2.4	4.2	1.0	2.8	1.6	1.9	2.1	2.4	1.3	2.5	0.7	1.9
25	3.5	2.8	3.1	2.3	3.9	0.9	2.7	1.5	1.8	2.0	2.2	1.2	2.4	0.7	1.7

Table 118 - Magnetic forces as a result of cross-winds: end section, v_{Fzg} = 500 km/h, v_W = 25 .. 40 m/s

v_W [m/s]	**Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]**															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
25	-	16.3	7.0	10.3	6.7	6.4	6.4	-	-	5.0	3.8	3.6	2.9	2.3	0.9	0.6
24	-	15.2	6.6	9.7	6.3	6.0	6.0	-	-	4.7	3.6	3.4	2.7	2.2	0.9	0.6
23	-	14.1	6.2	9.2	5.9	5.6	5.6	-	-	4.4	3.4	3.2	2.5	2.0	0.8	0.5
22	-	13.1	5.8	8.6	5.5	5.2	5.2	-	-	4.1	3.1	3.0	2.3	1.9	0.8	0.5
21	-	12.0	5.5	8.1	5.1	4.9	4.8	-	-	3.8	2.9	2.8	2.2	1.8	0.7	0.5
20	-	11.1	5.1	7.6	4.7	4.5	4.4	-	-	3.5	2.7	2.6	2.0	1.6	0.7	0.4
19	-	10.1	4.7	7.0	4.4	4.1	4.1	-	-	3.2	2.5	2.4	1.9	1.5	0.6	0.4
18	-	9.2	4.4	6.5	4.0	3.8	3.7	-	-	2.9	2.3	2.2	1.7	1.4	0.6	0.4
17	-	8.3	4.0	6.1	3.7	3.5	3.4	-	-	2.6	2.1	2.0	1.5	1.2	0.5	0.3
16	-	7.5	3.7	5.6	3.3	3.2	3.1	-	-	2.4	1.9	1.8	1.4	1.1	0.5	0.3
15	-	6.7	3.4	5.1	3.0	2.8	2.8	-	-	2.1	1.7	1.7	1.3	1.0	0.4	0.3
14	-	5.9	3.1	4.6	2.7	2.5	2.5	-	-	1.9	1.5	1.5	1.1	0.9	0.4	0.3
13	-	5.2	2.8	4.2	2.4	2.3	2.2	-	-	1.7	1.4	1.3	1.0	0.8	0.4	0.2
12	-	4.5	2.5	3.8	2.1	2.0	1.9	-	-	1.5	1.2	1.2	0.9	0.7	0.3	0.2
11	-	3.9	2.2	3.3	1.8	1.7	1.7	-	-	1.3	1.0	1.0	0.8	0.6	0.3	0.2
10	-	3.3	1.9	2.9	1.6	1.5	1.4	-	-	1.1	0.9	0.9	0.7	0.5	0.2	0.2
v_W [m/s]	**Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m]** (+/-)															
	(1)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
25	3.5		2.8	3.1	2.3	3.9	0.9	2.7	1.5	1.8	2.0	2.2	1.2	2.4	0.7	1.7
24	3.3		2.6	2.9	2.1	3.7	0.9	2.5	1.4	1.6	1.9	2.1	1.1	2.2	0.6	1.6
23	3.0		2.4	2.7	2.0	3.5	0.8	2.3	1.3	1.5	1.7	2.0	1.1	2.1	0.6	1.5
22	2.8		2.3	2.5	1.8	3.2	0.7	2.2	1.2	1.4	1.6	1.8	1.0	1.9	0.6	1.4
21	2.6		2.1	2.4	1.7	3.0	0.7	2.0	1.1	1.3	1.5	1.7	0.9	1.8	0.5	1.3
20	2.4		2.0	2.2	1.6	2.8	0.6	1.9	1.0	1.2	1.4	1.6	0.8	1.6	0.5	1.2
19	2.2		1.8	2.0	1.5	2.5	0.6	1.7	0.9	1.1	1.3	1.4	0.8	1.5	0.4	1.1
18	2.0		1.7	1.8	1.3	2.3	0.5	1.6	0.9	1.0	1.2	1.3	0.7	1.4	0.4	1.0
17	1.9		1.5	1.7	1.2	2.1	0.5	1.4	0.8	0.9	1.1	1.2	0.6	1.3	0.4	0.9
16	1.7		1.4	1.5	1.1	1.9	0.4	1.3	0.7	0.8	1.0	1.1	0.6	1.1	0.3	0.9
15	1.5		1.3	1.4	1.0	1.7	0.4	1.2	0.6	0.8	0.9	1.0	0.5	1.0	0.3	0.8
14	1.4		1.2	1.2	0.9	1.6	0.4	1.1	0.6	0.7	0.8	0.9	0.5	0.9	0.3	0.7
13	1.2		1.0	1.1	0.8	1.4	0.3	0.9	0.5	0.6	0.7	0.8	0.4	0.8	0.2	0.6
12	1.1		0.9	0.9	0.7	1.2	0.3	0.8	0.4	0.5	0.6	0.7	0.4	0.7	0.2	0.5
11	0.9		0.8	0.8	0.6	1.1	0.2	0.7	0.4	0.5	0.5	0.6	0.3	0.6	0.2	0.5
10	0.8		0.7	0.7	0.5	0.9	0.2	0.6	0.3	0.4	0.5	0.5	0.3	0.5	0.2	0.4

Table 119 - Magnetic forces as a result of cross-winds: end section, v_{Fzg} = 500 km/h, v_W = 10 .. 25 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
40	2.4	1.8	4.4	6.0	6.2	6.4	8.1	-	-	9.6	9.5	9.8	12.6	10.7	6.1	2.6
39	2.3	1.7	4.3	5.7	5.9	6.2	7.8	-	-	9.1	9.1	9.4	12.1	10.3	5.9	2.5
38	2.2	1.7	4.1	5.5	5.7	5.9	7.5	-	-	8.7	8.7	9.0	11.6	9.9	5.6	2.4
37	2.1	1.6	4.0	5.3	5.5	5.7	7.2	-	-	8.3	8.3	8.7	11.1	9.5	5.4	2.3
36	2.0	1.6	3.8	5.1	5.2	5.5	6.9	-	-	7.9	7.9	8.3	10.7	9.1	5.2	2.2
35	1.9	1.5	3.6	4.8	5.0	5.2	6.6	-	-	7.5	7.5	7.9	10.2	8.7	5.0	2.2
34	1.8	1.5	3.5	4.6	4.8	5.0	6.3	-	-	7.1	7.2	7.6	9.7	8.3	4.8	2.1
33	1.7	1.4	3.3	4.4	4.6	4.8	6.0	-	-	6.7	6.8	7.2	9.3	8.0	4.6	2.0
32	1.6	1.3	3.2	4.2	4.4	4.5	5.7	-	-	6.3	6.5	6.9	8.9	7.6	4.3	1.9
31	1.5	1.3	3.0	4.0	4.2	4.3	5.4	-	-	6.0	6.1	6.5	8.4	7.2	4.1	1.8
30	1.5	1.2	2.9	3.8	4.0	4.1	5.2	-	-	5.6	5.8	6.2	8.0	6.9	3.9	1.8
29	1.4	1.2	2.7	3.6	3.8	3.9	4.9	-	-	5.3	5.5	5.9	7.6	6.5	3.7	1.7
28	1.3	1.1	2.6	3.4	3.6	3.7	4.6	-	-	4.9	5.2	5.6	7.2	6.2	3.5	1.6
27	1.2	1.1	2.5	3.2	3.4	3.5	4.4	-	-	4.6	4.8	5.2	6.8	5.8	3.4	1.5
26	1.1	1.0	2.3	3.0	3.2	3.3	4.1	-	-	4.3	4.5	4.9	6.4	5.5	3.2	1.5
25	1.1	1.0	2.2	2.8	3.0	3.1	3.9	-	-	4.0	4.3	4.6	6.0	5.2	3.0	1.4
v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	1.5	1.6	2.7	1.8	2.5	2.6	1.9	2.1	2.7	1.3	3.9	2.6	3.0	3.9	1.8	1.5
39	1.4	1.6	2.6	1.8	2.4	2.5	1.8	2.0	2.6	1.3	3.8	2.5	2.8	3.8	1.8	1.4
38	1.3	1.5	2.5	1.7	2.3	2.4	1.8	1.8	2.5	1.2	3.6	2.4	2.7	3.6	1.7	1.3
37	1.3	1.4	2.3	1.6	2.2	2.3	1.7	1.7	2.4	1.1	3.5	2.3	2.6	3.5	1.6	1.3
36	1.2	1.4	2.2	1.5	2.1	2.2	1.6	1.6	2.3	1.1	3.3	2.2	2.5	3.3	1.5	1.2
35	1.2	1.3	2.1	1.5	2.0	2.1	1.5	1.5	2.2	1.0	3.2	2.1	2.4	3.2	1.5	1.2
34	1.1	1.3	2.1	1.4	1.9	2.0	1.5	1.4	2.1	1.0	3.0	2.0	2.3	3.0	1.4	1.1
33	1.1	1.2	2.0	1.3	1.8	1.9	1.4	1.3	2.0	1.0	2.9	1.9	2.2	2.9	1.3	1.1
32	1.0	1.1	1.9	1.3	1.7	1.8	1.3	1.2	2.0	0.9	2.8	1.8	2.1	2.7	1.3	1.0
31	1.0	1.1	1.8	1.2	1.7	1.7	1.3	1.1	1.9	0.9	2.6	1.7	2.0	2.6	1.2	1.0
30	0.9	1.0	1.7	1.2	1.6	1.6	1.2	1.1	1.8	0.8	2.5	1.6	1.9	2.5	1.2	0.9
29	0.9	1.0	1.6	1.1	1.5	1.5	1.1	1.0	1.7	0.8	2.4	1.5	1.8	2.3	1.1	0.9
28	0.8	0.9	1.5	1.0	1.4	1.5	1.1	0.9	1.6	0.7	2.3	1.4	1.7	2.2	1.0	0.8
27	0.8	0.9	1.4	1.0	1.3	1.4	1.0	0.8	1.5	0.7	2.1	1.4	1.6	2.1	1.0	0.8
26	0.7	0.8	1.3	0.9	1.2	1.3	0.9	0.8	1.4	0.6	2.0	1.3	1.5	2.0	0.9	0.7
25	0.7	0.8	1.3	0.9	1.2	1.2	0.9	0.7	1.4	0.6	1.9	1.2	1.4	1.8	0.9	0.7

Table 120 - Magnetic forces as a result of cross-winds: middle section, v_{Fzg} = 500 km/h, v_W = 25 .. 40 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
25	1.1	1.0	2.2	2.8	3.0	3.1	3.9	-	-	4.0	4.3	4.6	6.0	5.2	3.0	1.4
24	1.0	0.9	2.1	2.7	2.8	2.9	3.6	-	-	3.7	4.0	4.3	5.7	4.9	2.8	1.3
23	0.9	0.9	1.9	2.5	2.6	2.7	3.4	-	-	3.4	3.7	4.1	5.3	4.5	2.6	1.2
22	0.9	0.8	1.8	2.3	2.5	2.5	3.1	-	-	3.2	3.4	3.8	4.9	4.2	2.5	1.2
21	0.8	0.8	1.7	2.2	2.3	2.4	2.9	-	-	2.9	3.2	3.5	4.6	3.9	2.3	1.1
20	0.7	0.7	1.6	2.0	2.1	2.2	2.7	-	-	2.7	2.9	3.3	4.3	3.7	2.1	1.0
19	0.7	0.7	1.5	1.8	2.0	2.0	2.5	-	-	2.4	2.7	3.0	3.9	3.4	2.0	1.0
18	0.6	0.6	1.3	1.7	1.8	1.9	2.3	-	-	2.2	2.4	2.8	3.6	3.1	1.8	0.9
17	0.6	0.6	1.2	1.5	1.7	1.7	2.1	-	-	2.0	2.2	2.5	3.3	2.8	1.7	0.8
16	0.5	0.6	1.1	1.4	1.5	1.5	1.9	-	-	1.8	2.0	2.3	3.0	2.6	1.5	0.8
15	0.4	0.5	1.0	1.3	1.4	1.4	1.7	-	-	1.6	1.8	2.1	2.7	2.3	1.4	0.7
14	0.4	0.5	0.9	1.1	1.2	1.3	1.5	-	-	1.4	1.6	1.8	2.4	2.1	1.2	0.6
13	0.4	0.4	0.8	1.0	1.1	1.1	1.4	-	-	1.2	1.4	1.6	2.2	1.9	1.1	0.6
12	0.3	0.4	0.7	0.9	1.0	1.0	1.2	-	-	1.0	1.2	1.4	1.9	1.7	1.0	0.5
11	0.3	0.3	0.6	0.8	0.8	0.9	1.0	-	-	0.9	1.0	1.3	1.7	1.4	0.9	0.5
10	0.2	0.3	0.6	0.7	0.7	0.7	0.9	-	-	0.7	0.9	1.1	1.4	1.2	0.7	0.4
v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
25	0.7	0.8	1.3	0.9	1.2	1.2	0.9	0.7	1.4	0.6	1.9	1.2	1.4	1.8	0.9	0.7
24	0.6	0.7	1.2	0.8	1.1	1.1	0.8	0.6	1.3	0.6	1.8	1.1	1.3	1.7	0.8	0.6
23	0.6	0.7	1.1	0.8	1.0	1.1	0.8	0.6	1.2	0.5	1.7	1.0	1.2	1.6	0.8	0.6
22	0.6	0.6	1.0	0.7	1.0	1.0	0.7	0.5	1.1	0.5	1.5	1.0	1.2	1.5	0.7	0.6
21	0.5	0.6	1.0	0.7	0.9	0.9	0.7	0.5	1.1	0.5	1.4	0.9	1.1	1.4	0.7	0.5
20	0.5	0.5	0.9	0.6	0.8	0.9	0.6	0.4	1.0	0.4	1.3	0.8	1.0	1.3	0.6	0.5
19	0.4	0.5	0.8	0.6	0.8	0.8	0.6	0.4	0.9	0.4	1.2	0.8	0.9	1.2	0.6	0.4
18	0.4	0.5	0.7	0.5	0.7	0.7	0.5	0.3	0.8	0.4	1.1	0.7	0.8	1.1	0.5	0.4
17	0.4	0.4	0.7	0.5	0.6	0.7	0.5	0.3	0.8	0.3	1.0	0.6	0.8	1.0	0.5	0.4
16	0.3	0.4	0.6	0.4	0.6	0.6	0.4	0.2	0.7	0.3	0.9	0.6	0.7	0.9	0.4	0.3
15	0.3	0.3	0.6	0.4	0.5	0.5	0.4	0.2	0.6	0.3	0.8	0.5	0.6	0.8	0.4	0.3
14	0.3	0.3	0.5	0.3	0.5	0.5	0.3	0.2	0.6	0.2	0.8	0.5	0.6	0.7	0.3	0.3
13	0.2	0.3	0.4	0.3	0.4	0.4	0.3	0.1	0.5	0.2	0.7	0.4	0.5	0.6	0.3	0.2
12	0.2	0.2	0.4	0.3	0.4	0.4	0.3	0.1	0.5	0.2	0.6	0.4	0.4	0.6	0.3	0.2
11	0.2	0.2	0.3	0.2	0.3	0.3	0.2	0.1	0.4	0.2	0.5	0.3	0.4	0.5	0.2	0.2
10	0.2	0.2	0.3	0.2	0.3	0.3	0.2	0.1	0.4	0.1	0.4	0.3	0.3	0.4	0.2	0.2

Table 121 - Magnetic forces as a result of cross-winds: middle section, v_{Fzg} = 500 km/h, v_W = 10 .. 25 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
40	-	27.9	13.4	18.6	13.2	12.7	12.9	-	-	10.2	7.6	7.1	5.6	4.6	1.9	1.0
39	-	26.7	12.9	18.0	12.7	12.2	12.4	-	-	9.8	7.3	6.8	5.4	4.4	1.8	0.9
38	-	25.5	12.4	17.4	12.2	11.7	11.9	-	-	9.4	7.0	6.5	5.2	4.2	1.8	0.9
37	-	24.4	11.9	16.7	11.7	11.2	11.4	-	-	9.0	6.7	6.3	5.0	4.0	1.7	0.9
36	-	23.3	11.4	16.1	11.2	10.7	10.9	-	-	8.6	6.4	6.0	4.7	3.9	1.6	0.8
35	-	22.2	11.0	15.5	10.7	10.3	10.4	-	-	8.2	6.1	5.7	4.5	3.7	1.6	0.8
34	-	21.1	10.5	14.9	10.2	9.8	9.9	-	-	7.8	5.9	5.5	4.3	3.5	1.5	0.8
33	-	20.0	10.0	14.3	9.7	9.3	9.4	-	-	7.4	5.6	5.3	4.1	3.3	1.4	0.7
32	-	19.0	9.6	13.7	9.3	8.9	9.0	-	-	7.0	5.3	5.0	3.9	3.2	1.4	0.7
31	-	18.0	9.2	13.1	8.8	8.5	8.5	-	-	6.7	5.1	4.8	3.7	3.0	1.3	0.7
30	-	17.0	8.7	12.6	8.4	8.0	8.1	-	-	6.3	4.8	4.5	3.5	2.9	1.3	0.6
29	-	16.1	8.3	12.0	7.9	7.6	7.6	-	-	6.0	4.6	4.3	3.3	2.7	1.2	0.6
28	-	15.1	7.9	11.4	7.5	7.2	7.2	-	-	5.6	4.3	4.1	3.2	2.6	1.1	0.6
27	-	14.2	7.5	10.9	7.1	6.8	6.8	-	-	5.3	4.1	3.9	3.0	2.4	1.1	0.5
26	-	13.3	7.0	10.3	6.7	6.4	6.4	-	-	5.0	3.8	3.6	2.8	2.3	1.0	0.5
25	-	12.5	6.6	9.8	6.3	6.0	6.0	-	-	4.7	3.6	3.4	2.6	2.1	1.0	0.5

v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)															
	(1)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	6.6		5.4	6.4	4.4	7.9	1.8	5.3	3.0	3.5	3.9	4.5	2.4	4.7	1.3	3.5
39	6.3		5.2	6.1	4.2	7.6	1.7	5.1	2.9	3.4	3.7	4.3	2.3	4.5	1.2	3.3
38	6.1		5.0	5.8	4.0	7.2	1.7	4.8	2.7	3.2	3.6	4.1	2.2	4.3	1.2	3.2
37	5.8		4.8	5.6	3.9	6.9	1.6	4.6	2.6	3.1	3.4	3.9	2.1	4.1	1.1	3.1
36	5.6		4.6	5.4	3.7	6.7	1.5	4.4	2.5	3.0	3.3	3.8	2.0	4.0	1.1	2.9
35	5.3		4.4	5.1	3.5	6.4	1.5	4.3	2.4	2.8	3.2	3.6	1.9	3.8	1.0	2.8
34	5.1		4.2	4.9	3.4	6.1	1.4	4.1	2.3	2.7	3.0	3.4	1.8	3.6	1.0	2.7
33	4.8		4.0	4.6	3.2	5.8	1.3	3.9	2.2	2.6	2.9	3.3	1.7	3.4	1.0	2.5
32	4.6		3.8	4.4	3.1	5.5	1.3	3.7	2.1	2.4	2.7	3.1	1.7	3.3	0.9	2.4
31	4.4		3.6	4.2	2.9	5.2	1.2	3.5	2.0	2.3	2.6	3.0	1.6	3.1	0.9	2.3
30	4.2		3.5	4.0	2.8	5.0	1.1	3.3	1.9	2.2	2.5	2.8	1.5	2.9	0.8	2.2
29	3.9		3.3	3.7	2.6	4.7	1.1	3.1	1.8	2.1	2.3	2.7	1.4	2.8	0.8	2.1
28	3.7		3.1	3.5	2.5	4.5	1.0	3.0	1.7	2.0	2.2	2.5	1.3	2.6	0.7	2.0
27	3.5		3.0	3.3	2.4	4.2	0.9	2.8	1.6	1.9	2.1	2.4	1.3	2.5	0.7	1.8
26	3.3		2.8	3.1	2.2	4.0	0.9	2.6	1.5	1.7	2.0	2.2	1.2	2.3	0.7	1.7
25	3.1		2.6	2.9	2.1	3.7	0.8	2.5	1.4	1.6	1.9	2.1	1.1	2.2	0.6	1.6

Table 122 - Magnetic forces as a result of cross-winds: end section, v_{Fzg} = 400 km/h, v_W = 25 .. 40 m/s

v_W [m/s]	**Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]**															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
25	-	12.5	6.6	9.8	6.3	6.0	6.0	-	-	4.7	3.6	3.4	2.6	2.1	1.0	0.5
24	-	11.6	6.3	9.2	5.9	5.6	5.6	-	-	4.3	3.4	3.2	2.5	2.0	0.9	0.4
23	-	10.8	5.9	8.7	5.5	5.3	5.2	-	-	4.0	3.2	3.0	2.3	1.9	0.9	0.4
22	-	10.0	5.5	8.2	5.1	4.9	4.8	-	-	3.8	2.9	2.8	2.1	1.7	0.8	0.4
21	-	9.2	5.1	7.7	4.8	4.6	4.5	-	-	3.5	2.7	2.6	2.0	1.6	0.7	0.4
20	-	8.5	4.8	7.2	4.4	4.2	4.1	-	-	3.2	2.5	2.4	1.8	1.5	0.7	0.3
19	-	7.8	4.4	6.7	4.1	3.9	3.8	-	-	2.9	2.3	2.2	1.7	1.4	0.6	0.3
18	-	7.1	4.1	6.2	3.7	3.6	3.5	-	-	2.7	2.1	2.1	1.6	1.3	0.6	0.3
17	-	6.4	3.7	5.8	3.4	3.3	3.2	-	-	2.4	1.9	1.9	1.4	1.2	0.6	0.3
16	-	5.8	3.4	5.3	3.1	3.0	2.9	-	-	2.2	1.8	1.7	1.3	1.0	0.5	0.2
15	-	5.2	3.1	4.9	2.8	2.7	2.6	-	-	2.0	1.6	1.6	1.2	0.9	0.5	0.2
14	-	4.6	2.8	4.4	2.5	2.4	2.3	-	-	1.8	1.4	1.4	1.0	0.8	0.4	0.2
13	-	4.1	2.5	4.0	2.2	2.1	2.0	-	-	1.6	1.3	1.2	0.9	0.8	0.4	0.2
12	-	3.5	2.2	3.6	2.0	1.9	1.8	-	-	1.4	1.1	1.1	0.8	0.7	0.3	0.2
11	-	3.1	2.0	3.2	1.7	1.6	1.6	-	-	1.2	1.0	1.0	0.7	0.6	0.3	0.1
10	-	2.6	1.7	2.8	1.5	1.4	1.3	-	-	1.0	0.8	0.8	0.6	0.5	0.3	0.1

v_W [m/s]	**Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m]** (+/-)														
	(1) 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
25	3.1	2.6	2.9	2.1	3.7	0.8	2.5	1.4	1.6	1.9	2.1	1.1	2.2	0.6	1.6
24	2.9	2.5	2.7	2.0	3.5	0.8	2.3	1.3	1.5	1.7	2.0	1.0	2.1	0.6	1.5
23	2.7	2.3	2.6	1.8	3.3	0.7	2.2	1.2	1.4	1.6	1.8	1.0	1.9	0.5	1.4
22	2.5	2.2	2.4	1.7	3.0	0.7	2.0	1.1	1.3	1.5	1.7	0.9	1.8	0.5	1.3
21	2.3	2.0	2.2	1.6	2.8	0.6	1.9	1.0	1.2	1.4	1.6	0.8	1.7	0.5	1.2
20	2.2	1.9	2.0	1.5	2.6	0.6	1.7	1.0	1.1	1.3	1.5	0.8	1.5	0.4	1.1
19	2.0	1.7	1.9	1.4	2.4	0.5	1.6	0.9	1.0	1.2	1.3	0.7	1.4	0.4	1.0
18	1.8	1.6	1.7	1.2	2.2	0.5	1.5	0.8	1.0	1.1	1.2	0.7	1.3	0.4	1.0
17	1.7	1.5	1.6	1.1	2.0	0.4	1.3	0.7	0.9	1.0	1.1	0.6	1.2	0.3	0.9
16	1.5	1.3	1.4	1.0	1.8	0.4	1.2	0.7	0.8	0.9	1.0	0.5	1.1	0.3	0.8
15	1.4	1.2	1.3	0.9	1.6	0.4	1.1	0.6	0.7	0.8	0.9	0.5	1.0	0.3	0.7
14	1.2	1.1	1.1	0.8	1.5	0.3	1.0	0.5	0.6	0.7	0.8	0.4	0.9	0.2	0.6
13	1.1	1.0	1.0	0.7	1.3	0.3	0.9	0.5	0.6	0.7	0.7	0.4	0.8	0.2	0.6
12	0.9	0.9	0.9	0.7	1.2	0.2	0.8	0.4	0.5	0.6	0.6	0.3	0.7	0.2	0.5
11	0.8	0.8	0.8	0.6	1.0	0.2	0.7	0.4	0.4	0.5	0.6	0.3	0.6	0.2	0.4
10	0.7	0.7	0.7	0.5	0.9	0.2	0.6	0.3	0.4	0.4	0.5	0.3	0.5	0.1	0.4

Table 123 - Magnetic forces as a result of cross-winds: end section, v_{Fzg} = 400 km/h, v_W = 10 .. 25 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
40	1.4	2.1	4.2	5.0	5.7	5.9	7.4	-	-	8.7	8.8	9.2	10.8	8.6	4.4	2.3
39	1.4	2.0	4.1	4.8	5.4	5.7	7.1	-	-	8.3	8.5	8.8	10.3	8.2	4.3	2.2
38	1.3	2.0	3.9	4.6	5.2	5.4	6.8	-	-	7.9	8.1	8.5	9.9	7.9	4.1	2.1
37	1.3	1.9	3.8	4.4	5.0	5.2	6.5	-	-	7.5	7.7	8.1	9.5	7.6	3.9	2.1
36	1.2	1.8	3.6	4.2	4.8	5.0	6.2	-	-	7.2	7.4	7.8	9.1	7.3	3.8	2.0
35	1.2	1.8	3.5	4.1	4.6	4.8	6.0	-	-	6.8	7.0	7.4	8.7	7.0	3.6	1.9
34	1.1	1.7	3.3	3.9	4.4	4.6	5.7	-	-	6.4	6.7	7.1	8.3	6.7	3.5	1.8
33	1.0	1.7	3.2	3.7	4.2	4.4	5.4	-	-	6.1	6.4	6.8	8.0	6.4	3.3	1.8
32	1.0	1.6	3.0	3.5	4.0	4.2	5.2	-	-	5.8	6.0	6.4	7.6	6.1	3.2	1.7
31	0.9	1.5	2.9	3.3	3.8	4.0	4.9	-	-	5.4	5.7	6.1	7.2	5.8	3.0	1.6
30	0.9	1.5	2.8	3.2	3.6	3.8	4.7	-	-	5.1	5.4	5.8	6.9	5.5	2.9	1.6
29	0.8	1.4	2.6	3.0	3.4	3.6	4.4	-	-	4.8	5.1	5.5	6.5	5.2	2.7	1.5
28	0.8	1.3	2.5	2.9	3.3	3.4	4.2	-	-	4.5	4.8	5.2	6.2	4.9	2.6	1.4
27	0.7	1.3	2.4	2.7	3.1	3.2	3.9	-	-	4.2	4.5	4.9	5.8	4.7	2.4	1.4
26	0.7	1.2	2.2	2.5	2.9	3.0	3.7	-	-	3.9	4.2	4.6	5.5	4.4	2.3	1.3
25	0.7	1.2	2.1	2.4	2.7	2.8	3.5	-	-	3.6	4.0	4.4	5.2	4.1	2.2	1.2

v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	1.3	1.5	2.4	1.7	2.3	2.3	1.8	1.9	2.5	1.2	3.6	2.4	2.7	3.7	1.8	1.3
39	1.3	1.4	2.3	1.6	2.2	2.3	1.7	1.8	2.4	1.2	3.5	2.3	2.6	3.5	1.7	1.3
38	1.2	1.4	2.2	1.6	2.1	2.2	1.6	1.7	2.3	1.1	3.3	2.2	2.5	3.4	1.6	1.2
37	1.2	1.3	2.1	1.5	2.0	2.1	1.6	1.6	2.2	1.1	3.2	2.1	2.4	3.2	1.6	1.2
36	1.1	1.3	2.0	1.4	1.9	2.0	1.5	1.5	2.2	1.0	3.1	2.0	2.3	3.1	1.5	1.1
35	1.1	1.2	2.0	1.4	1.9	1.9	1.4	1.4	2.1	1.0	2.9	1.9	2.2	2.9	1.4	1.1
34	1.0	1.2	1.9	1.3	1.8	1.8	1.4	1.3	2.0	0.9	2.8	1.8	2.1	2.8	1.4	1.0
33	1.0	1.1	1.8	1.2	1.7	1.7	1.3	1.2	1.9	0.9	2.7	1.8	2.0	2.7	1.3	1.0
32	0.9	1.1	1.7	1.2	1.6	1.6	1.2	1.1	1.8	0.8	2.5	1.7	1.9	2.6	1.2	0.9
31	0.9	1.0	1.6	1.1	1.5	1.6	1.2	1.0	1.7	0.8	2.4	1.6	1.8	2.4	1.2	0.9
30	0.8	0.9	1.5	1.1	1.4	1.5	1.1	1.0	1.6	0.8	2.3	1.5	1.7	2.3	1.1	0.8
29	0.8	0.9	1.5	1.0	1.4	1.4	1.0	0.9	1.6	0.7	2.2	1.4	1.6	2.2	1.1	0.8
28	0.7	0.8	1.4	1.0	1.3	1.3	1.0	0.8	1.5	0.7	2.1	1.3	1.6	2.1	1.0	0.7
27	0.7	0.8	1.3	0.9	1.2	1.3	0.9	0.8	1.4	0.6	1.9	1.3	1.5	1.9	0.9	0.7
26	0.7	0.8	1.2	0.9	1.1	1.2	0.9	0.7	1.3	0.6	1.8	1.2	1.4	1.8	0.9	0.7
25	0.6	0.7	1.1	0.8	1.1	1.1	0.8	0.6	1.3	0.6	1.7	1.1	1.3	1.7	0.8	0.6

Table 124 - Magnetic forces as a result of cross-winds: middle section, v_{Fzg} = 400 km/h, v_W = 25 .. 40 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
25	0.7	1.2	2.1	2.4	2.7	2.8	3.5	-	-	3.6	4.0	4.4	5.2	4.1	2.2	1.2
24	0.6	1.1	2.0	2.2	2.6	2.6	3.3	-	-	3.4	3.7	4.1	4.8	3.9	2.0	1.2
23	0.6	1.0	1.9	2.1	2.4	2.5	3.1	-	-	3.1	3.4	3.8	4.5	3.6	1.9	1.1
22	0.5	1.0	1.7	1.9	2.3	2.3	2.8	-	-	2.9	3.2	3.6	4.2	3.4	1.8	1.0
21	0.5	0.9	1.6	1.8	2.1	2.2	2.6	-	-	2.6	2.9	3.3	3.9	3.2	1.7	1.0
20	0.4	0.9	1.5	1.7	1.9	2.0	2.4	-	-	2.4	2.7	3.1	3.6	2.9	1.5	0.9
19	0.4	0.8	1.4	1.5	1.8	1.8	2.3	-	-	2.2	2.5	2.8	3.4	2.7	1.4	0.8
18	0.4	0.8	1.3	1.4	1.7	1.7	2.1	-	-	2.0	2.3	2.6	3.1	2.5	1.3	0.8
17	0.3	0.7	1.2	1.3	1.5	1.5	1.9	-	-	1.8	2.1	2.4	2.8	2.3	1.2	0.7
16	0.3	0.7	1.1	1.2	1.4	1.4	1.7	-	-	1.6	1.9	2.1	2.6	2.1	1.1	0.7
15	0.3	0.6	1.0	1.1	1.2	1.3	1.6	-	-	1.4	1.7	1.9	2.3	1.9	1.0	0.6
14	0.2	0.5	0.9	1.0	1.1	1.1	1.4	-	-	1.2	1.5	1.7	2.1	1.7	0.9	0.6
13	0.2	0.5	0.8	0.8	1.0	1.0	1.2	-	-	1.1	1.3	1.5	1.9	1.5	0.8	0.5
12	0.2	0.5	0.7	0.7	0.9	0.9	1.1	-	-	0.9	1.1	1.4	1.6	1.3	0.7	0.5
11	0.2	0.4	0.6	0.7	0.8	0.8	0.9	-	-	0.8	1.0	1.2	1.4	1.2	0.6	0.4
10	0.1	0.4	0.5	0.6	0.7	0.7	0.8	-	-	0.7	0.8	1.0	1.2	1.0	0.5	0.4

v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
25	0.6	0.7	1.1	0.8	1.1	1.1	0.8	0.6	1.3	0.6	1.7	1.1	1.3	1.7	0.8	0.6
24	0.6	0.7	1.1	0.8	1.0	1.0	0.8	0.6	1.2	0.5	1.6	1.0	1.2	1.6	0.8	0.6
23	0.5	0.6	1.0	0.7	0.9	1.0	0.7	0.5	1.1	0.5	1.5	1.0	1.1	1.5	0.7	0.5
22	0.5	0.6	0.9	0.7	0.9	0.9	0.7	0.5	1.0	0.5	1.4	0.9	1.1	1.4	0.7	0.5
21	0.5	0.5	0.9	0.6	0.8	0.8	0.6	0.4	1.0	0.4	1.3	0.8	1.0	1.3	0.6	0.5
20	0.4	0.5	0.8	0.6	0.8	0.8	0.6	0.4	0.9	0.4	1.2	0.8	0.9	1.2	0.6	0.4
19	0.4	0.5	0.7	0.5	0.7	0.7	0.5	0.3	0.8	0.4	1.1	0.7	0.8	1.1	0.5	0.4
18	0.4	0.4	0.7	0.5	0.6	0.7	0.5	0.3	0.8	0.3	1.0	0.7	0.8	1.0	0.5	0.4
17	0.3	0.4	0.6	0.4	0.6	0.6	0.4	0.3	0.7	0.3	0.9	0.6	0.7	0.9	0.4	0.3
16	0.3	0.3	0.6	0.4	0.5	0.6	0.4	0.2	0.7	0.3	0.9	0.5	0.6	0.8	0.4	0.3
15	0.3	0.3	0.5	0.4	0.5	0.5	0.3	0.2	0.6	0.2	0.8	0.5	0.6	0.8	0.4	0.3
14	0.2	0.3	0.5	0.3	0.4	0.4	0.3	0.2	0.5	0.2	0.7	0.4	0.5	0.7	0.3	0.2
13	0.2	0.2	0.4	0.3	0.4	0.4	0.3	0.1	0.5	0.2	0.6	0.4	0.5	0.6	0.3	0.2
12	0.2	0.2	0.4	0.3	0.3	0.3	0.2	0.1	0.4	0.2	0.5	0.3	0.4	0.5	0.3	0.2
11	0.2	0.2	0.3	0.2	0.3	0.3	0.2	0.1	0.4	0.1	0.5	0.3	0.4	0.5	0.2	0.2
10	0.1	0.2	0.3	0.2	0.2	0.3	0.2	0.1	0.3	0.1	0.4	0.3	0.3	0.4	0.2	0.1

Table 125 - Magnetic forces as a result of cross-winds: middle section, v_{Fzg} = 400 km/h, v_W = 10 .. 25 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
40	-	15.1	9.6	15.7	12.1	11.7	11.7	-	-	9.2	6.9	6.5	5.0	4.1	1.8	0.6
39	-	14.5	9.2	15.2	11.6	11.2	11.2	-	-	8.8	6.6	6.2	4.8	3.9	1.8	0.6
38	-	13.8	8.9	14.7	11.2	10.7	10.7	-	-	8.4	6.4	6.0	4.6	3.8	1.7	0.6
37	-	13.2	8.5	14.1	10.7	10.3	10.3	-	-	8.0	6.1	5.7	4.4	3.6	1.6	0.6
36	-	12.6	8.2	13.6	10.2	9.9	9.8	-	-	7.7	5.8	5.5	4.2	3.5	1.6	0.5
35	-	12.0	7.8	13.1	9.8	9.4	9.4	-	-	7.3	5.6	5.3	4.0	3.3	1.5	0.5
34	-	11.4	7.5	12.6	9.4	9.0	8.9	-	-	7.0	5.3	5.0	3.8	3.2	1.5	0.5
33	-	10.9	7.2	12.1	8.9	8.6	8.5	-	-	6.6	5.1	4.8	3.7	3.0	1.4	0.5
32	-	10.3	6.8	11.6	8.5	8.2	8.1	-	-	6.3	4.8	4.6	3.5	2.9	1.3	0.5
31	-	9.8	6.5	11.1	8.1	7.8	7.7	-	-	6.0	4.6	4.4	3.3	2.7	1.3	0.4
30	-	9.2	6.2	10.6	7.7	7.4	7.3	-	-	5.7	4.4	4.1	3.1	2.6	1.2	0.4
29	-	8.7	5.9	10.1	7.3	7.0	6.9	-	-	5.4	4.1	3.9	3.0	2.4	1.2	0.4
28	-	8.2	5.6	9.7	6.9	6.6	6.5	-	-	5.1	3.9	3.7	2.8	2.3	1.1	0.4
27	-	7.7	5.3	9.2	6.5	6.2	6.1	-	-	4.8	3.7	3.5	2.7	2.2	1.0	0.3
26	-	7.2	5.0	8.7	6.1	5.9	5.8	-	-	4.5	3.5	3.3	2.5	2.1	1.0	0.3
25	-	6.7	4.7	8.3	5.8	5.5	5.4	-	-	4.2	3.3	3.1	2.3	1.9	0.9	0.3

v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)														
	(1) 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	5.7	4.9	5.8	3.9	7.2	1.6	4.8	2.7	3.2	3.5	4.0	2.1	4.2	1.2	3.1
39	5.5	4.8	5.5	3.8	6.9	1.5	4.6	2.6	3.1	3.4	3.9	2.0	4.1	1.1	3.0
38	5.3	4.6	5.3	3.6	6.7	1.5	4.4	2.5	2.9	3.3	3.7	2.0	3.9	1.1	2.9
37	5.0	4.4	5.1	3.5	6.4	1.4	4.2	2.4	2.8	3.1	3.6	1.9	3.7	1.0	2.8
36	4.8	4.2	4.9	3.3	6.1	1.3	4.1	2.3	2.7	3.0	3.4	1.8	3.6	1.0	2.6
35	4.6	4.0	4.6	3.2	5.8	1.3	3.9	2.2	2.6	2.9	3.3	1.7	3.4	0.9	2.5
34	4.4	3.9	4.4	3.0	5.6	1.2	3.7	2.1	2.4	2.7	3.1	1.6	3.3	0.9	2.4
33	4.2	3.7	4.2	2.9	5.3	1.2	3.5	2.0	2.3	2.6	3.0	1.6	3.1	0.9	2.3
32	4.0	3.5	4.0	2.7	5.1	1.1	3.4	1.9	2.2	2.5	2.8	1.5	3.0	0.8	2.2
31	3.8	3.4	3.8	2.6	4.8	1.0	3.2	1.8	2.1	2.4	2.7	1.4	2.8	0.8	2.1
30	3.6	3.2	3.6	2.5	4.6	1.0	3.0	1.7	2.0	2.2	2.5	1.3	2.7	0.7	2.0
29	3.4	3.1	3.4	2.4	4.3	0.9	2.9	1.6	1.9	2.1	2.4	1.3	2.5	0.7	1.9
28	3.2	2.9	3.2	2.2	4.1	0.9	2.7	1.5	1.8	2.0	2.3	1.2	2.4	0.7	1.8
27	3.0	2.7	3.0	2.1	3.9	0.8	2.6	1.4	1.7	1.9	2.1	1.1	2.2	0.6	1.7
26	2.9	2.6	2.8	2.0	3.6	0.8	2.4	1.3	1.6	1.8	2.0	1.1	2.1	0.6	1.6
25	2.7	2.4	2.7	1.9	3.4	0.7	2.3	1.2	1.5	1.7	1.9	1.0	2.0	0.6	1.5

Table 126 - Magnetic forces as a result of cross-winds: end section, v_{Fzg} = 300 km/h, v_W = 25 .. 40 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
25	-	6.7	4.7	8.3	5.8	5.5	5.4	-	-	4.2	3.3	3.1	2.3	1.9	0.9	0.3
24	-	6.3	4.5	7.8	5.4	5.2	5.0	-	-	3.9	3.1	2.9	2.2	1.8	0.9	0.3
23	-	5.8	4.2	7.4	5.0	4.8	4.7	-	-	3.6	2.9	2.8	2.1	1.7	0.8	0.3
22	-	5.4	3.9	6.9	4.7	4.5	4.4	-	-	3.4	2.7	2.6	1.9	1.6	0.8	0.3
21	-	5.0	3.6	6.5	4.4	4.2	4.1	-	-	3.1	2.5	2.4	1.8	1.5	0.7	0.2
20	-	4.6	3.4	6.1	4.0	3.9	3.7	-	-	2.9	2.3	2.2	1.6	1.3	0.7	0.2
19	-	4.2	3.1	5.7	3.7	3.6	3.4	-	-	2.6	2.1	2.0	1.5	1.2	0.6	0.2
18	-	3.8	2.9	5.3	3.4	3.3	3.1	-	-	2.4	1.9	1.9	1.4	1.1	0.6	0.2
17	-	3.5	2.7	4.9	3.1	3.0	2.9	-	-	2.2	1.8	1.7	1.3	1.0	0.5	0.2
16	-	3.1	2.4	4.5	2.8	2.7	2.6	-	-	2.0	1.6	1.6	1.1	0.9	0.5	0.2
15	-	2.8	2.2	4.1	2.6	2.4	2.3	-	-	1.8	1.5	1.4	1.0	0.9	0.4	0.1
14	-	2.5	2.0	3.7	2.3	2.2	2.1	-	-	1.6	1.3	1.3	0.9	0.8	0.4	0.1
13	-	2.2	1.8	3.4	2.0	1.9	1.8	-	-	1.4	1.2	1.1	0.8	0.7	0.4	0.1
12	-	1.9	1.6	3.0	1.8	1.7	1.6	-	-	1.2	1.0	1.0	0.7	0.6	0.3	0.1
11	-	1.6	1.4	2.7	1.6	1.5	1.4	-	-	1.1	0.9	0.9	0.6	0.5	0.3	0.1
10	-	1.4	1.2	2.4	1.3	1.3	1.2	-	-	0.9	0.8	0.8	0.5	0.4	0.2	0.1

v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)															
	(1)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
25	2.7		2.4	2.7	1.9	3.4	0.7	2.3	1.2	1.5	1.7	1.9	1.0	2.0	0.6	1.5
24	2.5		2.3	2.5	1.7	3.2	0.7	2.1	1.2	1.4	1.6	1.8	0.9	1.9	0.5	1.4
23	2.3		2.2	2.3	1.6	3.0	0.6	2.0	1.1	1.3	1.5	1.7	0.9	1.7	0.5	1.3
22	2.2		2.0	2.2	1.5	2.8	0.6	1.8	1.0	1.2	1.4	1.5	0.8	1.6	0.5	1.2
21	2.0		1.9	2.0	1.4	2.6	0.5	1.7	0.9	1.1	1.3	1.4	0.8	1.5	0.4	1.1
20	1.9		1.7	1.8	1.3	2.4	0.5	1.6	0.9	1.0	1.2	1.3	0.7	1.4	0.4	1.0
19	1.7		1.6	1.7	1.2	2.2	0.5	1.5	0.8	0.9	1.1	1.2	0.6	1.3	0.4	0.9
18	1.6		1.5	1.6	1.1	2.0	0.4	1.3	0.7	0.9	1.0	1.1	0.6	1.2	0.3	0.9
17	1.4		1.4	1.4	1.0	1.8	0.4	1.2	0.7	0.8	0.9	1.0	0.5	1.1	0.3	0.8
16	1.3		1.2	1.3	0.9	1.7	0.4	1.1	0.6	0.7	0.8	0.9	0.5	1.0	0.3	0.7
15	1.2		1.1	1.1	0.8	1.5	0.3	1.0	0.5	0.6	0.8	0.8	0.4	0.9	0.2	0.6
14	1.1		1.0	1.0	0.7	1.4	0.3	0.9	0.5	0.6	0.7	0.7	0.4	0.8	0.2	0.6
13	0.9		0.9	0.9	0.7	1.2	0.2	0.8	0.4	0.5	0.6	0.7	0.4	0.7	0.2	0.5
12	0.8		0.8	0.8	0.6	1.1	0.2	0.7	0.4	0.4	0.5	0.6	0.3	0.6	0.2	0.4
11	0.7		0.7	0.7	0.5	0.9	0.2	0.6	0.3	0.4	0.5	0.5	0.3	0.5	0.2	0.4
10	0.6		0.6	0.6	0.4	0.8	0.2	0.5	0.3	0.3	0.4	0.4	0.2	0.5	0.1	0.3

Table 127 - Magnetic forces as a result of cross-winds: end section, v_{Fzg} = 300 km/h, v_W = 10 .. 25 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
40	1.8	1.7	3.3	4.9	5.0	5.2	6.6	-	-	7.8	8.0	8.3	10.2	8.7	4.6	2.6
39	1.8	1.6	3.2	4.7	4.8	5.0	6.3	-	-	7.4	7.6	8.0	9.8	8.3	4.4	2.6
38	1.7	1.6	3.0	4.5	4.6	4.8	6.1	-	-	7.1	7.3	7.7	9.4	8.0	4.2	2.5
37	1.6	1.5	2.9	4.3	4.4	4.6	5.8	-	-	6.7	7.0	7.4	9.1	7.7	4.0	2.4
36	1.5	1.5	2.8	4.1	4.2	4.4	5.6	-	-	6.4	6.7	7.0	8.7	7.4	3.9	2.3
35	1.5	1.4	2.7	4.0	4.1	4.2	5.3	-	-	6.1	6.3	6.7	8.3	7.0	3.7	2.2
34	1.4	1.4	2.6	3.8	3.9	4.0	5.1	-	-	5.8	6.0	6.4	7.9	6.7	3.6	2.1
33	1.3	1.3	2.5	3.6	3.7	3.9	4.9	-	-	5.4	5.7	6.1	7.6	6.4	3.4	2.0
32	1.3	1.3	2.4	3.4	3.5	3.7	4.6	-	-	5.1	5.4	5.8	7.2	6.1	3.2	2.0
31	1.2	1.2	2.2	3.3	3.4	3.5	4.4	-	-	4.8	5.2	5.6	6.9	5.8	3.1	1.9
30	1.1	1.2	2.1	3.1	3.2	3.3	4.2	-	-	4.6	4.9	5.3	6.5	5.5	2.9	1.8
29	1.1	1.1	2.0	2.9	3.0	3.2	4.0	-	-	4.3	4.6	5.0	6.2	5.3	2.8	1.7
28	1.0	1.1	1.9	2.8	2.9	3.0	3.7	-	-	4.0	4.3	4.7	5.9	5.0	2.7	1.6
27	0.9	1.0	1.8	2.6	2.7	2.8	3.5	-	-	3.8	4.1	4.5	5.5	4.7	2.5	1.6
26	0.9	1.0	1.7	2.5	2.6	2.7	3.3	-	-	3.5	3.8	4.2	5.2	4.4	2.4	1.5
25	0.8	0.9	1.6	2.3	2.4	2.5	3.1	-	-	3.3	3.6	3.9	4.9	4.2	2.2	1.4

v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	1.2	1.4	2.2	1.5	2.1	2.1	1.6	1.7	2.3	1.1	3.3	2.2	2.5	3.3	1.6	1.2
39	1.2	1.3	2.1	1.4	2.0	2.0	1.5	1.6	2.2	1.0	3.2	2.1	2.4	3.1	1.5	1.2
38	1.1	1.3	2.0	1.4	1.9	2.0	1.5	1.5	2.1	1.0	3.1	2.0	2.3	3.0	1.5	1.1
37	1.1	1.2	1.9	1.3	1.8	1.9	1.4	1.4	2.0	0.9	2.9	1.9	2.2	2.9	1.4	1.1
36	1.0	1.2	1.8	1.3	1.7	1.8	1.3	1.3	2.0	0.9	2.8	1.8	2.1	2.8	1.4	1.0
35	1.0	1.1	1.8	1.2	1.7	1.7	1.3	1.3	1.9	0.9	2.7	1.7	2.0	2.6	1.3	1.0
34	0.9	1.1	1.7	1.2	1.6	1.6	1.2	1.2	1.8	0.8	2.6	1.7	1.9	2.5	1.2	0.9
33	0.9	1.0	1.6	1.1	1.5	1.6	1.2	1.1	1.7	0.8	2.4	1.6	1.8	2.4	1.2	0.9
32	0.8	1.0	1.5	1.1	1.4	1.5	1.1	1.0	1.6	0.7	2.3	1.5	1.7	2.3	1.1	0.8
31	0.8	0.9	1.5	1.0	1.4	1.4	1.1	0.9	1.6	0.7	2.2	1.4	1.7	2.2	1.1	0.8
30	0.8	0.9	1.4	1.0	1.3	1.3	1.0	0.9	1.5	0.7	2.1	1.4	1.6	2.1	1.0	0.8
29	0.7	0.8	1.3	0.9	1.2	1.3	0.9	0.8	1.4	0.6	2.0	1.3	1.5	1.9	1.0	0.7
28	0.7	0.8	1.2	0.9	1.2	1.2	0.9	0.7	1.4	0.6	1.9	1.2	1.4	1.8	0.9	0.7
27	0.6	0.7	1.2	0.8	1.1	1.1	0.8	0.7	1.3	0.6	1.8	1.1	1.3	1.7	0.9	0.6
26	0.6	0.7	1.1	0.8	1.0	1.1	0.8	0.6	1.2	0.5	1.7	1.1	1.3	1.6	0.8	0.6
25	0.6	0.6	1.0	0.7	1.0	1.0	0.7	0.6	1.1	0.5	1.6	1.0	1.2	1.5	0.8	0.6

Table 128 - Magnetic forces as a result of cross-winds: middle section, v_{Fzg} = 300 km/h, v_W = 25 .. 40 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
25	0.8	0.9	1.6	2.3	2.4	2.5	3.1	-	-	3.3	3.6	3.9	4.9	4.2	2.2	1.4
24	0.8	0.9	1.5	2.2	2.3	2.3	2.9	-	-	3.0	3.3	3.7	4.6	3.9	2.1	1.3
23	0.7	0.8	1.4	2.0	2.1	2.2	2.7	-	-	2.8	3.1	3.5	4.3	3.7	2.0	1.3
22	0.7	0.8	1.3	1.9	2.0	2.0	2.6	-	-	2.6	2.9	3.2	4.0	3.4	1.8	1.2
21	0.6	0.7	1.3	1.8	1.8	1.9	2.4	-	-	2.4	2.7	3.0	3.7	3.2	1.7	1.1
20	0.6	0.7	1.2	1.6	1.7	1.8	2.2	-	-	2.2	2.4	2.8	3.5	3.0	1.6	1.0
19	0.5	0.7	1.1	1.5	1.6	1.6	2.0	-	-	2.0	2.2	2.5	3.2	2.7	1.5	1.0
18	0.5	0.6	1.0	1.4	1.5	1.5	1.9	-	-	1.8	2.0	2.3	2.9	2.5	1.4	0.9
17	0.4	0.6	0.9	1.3	1.3	1.4	1.7	-	-	1.6	1.9	2.1	2.7	2.3	1.2	0.8
16	0.4	0.5	0.8	1.2	1.2	1.2	1.5	-	-	1.4	1.7	1.9	2.4	2.1	1.1	0.8
15	0.3	0.5	0.8	1.0	1.1	1.1	1.4	-	-	1.3	1.5	1.8	2.2	1.9	1.0	0.7
14	0.3	0.4	0.7	0.9	1.0	1.0	1.2	-	-	1.1	1.3	1.6	2.0	1.7	0.9	0.7
13	0.3	0.4	0.6	0.8	0.9	0.9	1.1	-	-	1.0	1.2	1.4	1.8	1.5	0.8	0.6
12	0.2	0.4	0.5	0.7	0.8	0.8	1.0	-	-	0.8	1.0	1.2	1.6	1.3	0.7	0.5
11	0.2	0.3	0.5	0.6	0.7	0.7	0.8	-	-	0.7	0.9	1.1	1.4	1.2	0.6	0.5
10	0.2	0.3	0.4	0.5	0.6	0.6	0.7	-	-	0.6	0.8	0.9	1.2	1.0	0.6	0.4
v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
25	0.6	0.6	1.0	0.7	1.0	1.0	0.7	0.6	1.1	0.5	1.6	1.0	1.2	1.5	0.8	0.6
24	0.5	0.6	1.0	0.7	0.9	0.9	0.7	0.5	1.1	0.5	1.5	0.9	1.1	1.4	0.7	0.5
23	0.5	0.6	0.9	0.6	0.8	0.9	0.6	0.5	1.0	0.4	1.4	0.9	1.0	1.3	0.7	0.5
22	0.5	0.5	0.8	0.6	0.8	0.8	0.6	0.4	0.9	0.4	1.3	0.8	1.0	1.2	0.6	0.5
21	0.4	0.5	0.8	0.5	0.7	0.8	0.6	0.4	0.9	0.4	1.2	0.8	0.9	1.2	0.6	0.4
20	0.4	0.4	0.7	0.5	0.7	0.7	0.5	0.3	0.8	0.3	1.1	0.7	0.8	1.1	0.5	0.4
19	0.4	0.4	0.7	0.5	0.6	0.7	0.5	0.3	0.8	0.3	1.0	0.6	0.8	1.0	0.5	0.4
18	0.3	0.4	0.6	0.4	0.6	0.6	0.4	0.3	0.7	0.3	0.9	0.6	0.7	0.9	0.4	0.3
17	0.3	0.3	0.6	0.4	0.5	0.5	0.4	0.2	0.6	0.3	0.9	0.5	0.6	0.8	0.4	0.3
16	0.3	0.3	0.5	0.4	0.5	0.5	0.4	0.2	0.6	0.2	0.8	0.5	0.6	0.7	0.4	0.3
15	0.3	0.3	0.5	0.3	0.4	0.4	0.3	0.2	0.5	0.2	0.7	0.4	0.5	0.7	0.3	0.3
14	0.2	0.3	0.4	0.3	0.4	0.4	0.3	0.1	0.5	0.2	0.6	0.4	0.5	0.6	0.3	0.2
13	0.2	0.2	0.4	0.3	0.3	0.4	0.2	0.1	0.4	0.2	0.6	0.3	0.4	0.5	0.3	0.2
12	0.2	0.2	0.3	0.2	0.3	0.3	0.2	0.1	0.4	0.1	0.5	0.3	0.4	0.5	0.2	0.2
11	0.2	0.2	0.3	0.2	0.3	0.3	0.2	0.1	0.3	0.1	0.4	0.3	0.3	0.4	0.2	0.2
10	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.3	0.1	0.4	0.2	0.3	0.4	0.2	0.1

Table 129 - Magnetic forces as a result of cross-winds: middle section, v_{Fzg} = 300 km/h, v_W = 10 .. 25 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
40	-	11.7	8.3	12.2	10.3	10.0	9.9	-	-	11.0	8.1	7.5	6.1	4.9	1.8	1.3
39	-	11.3	8.0	11.8	9.9	9.6	9.5	-	-	10.5	7.8	7.2	5.9	4.7	1.8	1.2
38	-	10.8	7.7	11.4	9.5	9.2	9.1	-	-	10.1	7.5	6.9	5.7	4.5	1.7	1.2
37	-	10.4	7.4	11.0	9.1	8.9	8.7	-	-	9.7	7.2	6.7	5.4	4.3	1.6	1.1
36	-	10.0	7.1	10.6	8.7	8.5	8.3	-	-	9.2	6.9	6.4	5.2	4.2	1.6	1.1
35	-	9.6	6.8	10.2	8.4	8.1	7.9	-	-	8.8	6.6	6.1	5.0	4.0	1.5	1.0
34	-	9.1	6.5	9.8	8.0	7.7	7.6	-	-	8.4	6.3	5.8	4.7	3.8	1.5	1.0
33	-	8.7	6.2	9.4	7.6	7.4	7.2	-	-	8.0	6.0	5.6	4.5	3.6	1.4	0.9
32	-	8.3	5.9	9.0	7.3	7.0	6.8	-	-	7.6	5.7	5.3	4.3	3.4	1.3	0.9
31	-	7.9	5.6	8.6	6.9	6.7	6.5	-	-	7.2	5.4	5.1	4.1	3.3	1.3	0.9
30	-	7.5	5.4	8.2	6.6	6.3	6.2	-	-	6.8	5.1	4.8	3.9	3.1	1.2	0.8
29	-	7.2	5.1	7.9	6.2	6.0	5.8	-	-	6.4	4.9	4.6	3.7	2.9	1.2	0.8
28	-	6.8	4.8	7.5	5.9	5.7	5.5	-	-	6.1	4.6	4.3	3.5	2.8	1.1	0.7
27	-	6.4	4.6	7.1	5.5	5.4	5.2	-	-	5.7	4.3	4.1	3.3	2.6	1.0	0.7
26	-	6.1	4.3	6.8	5.2	5.1	4.9	-	-	5.4	4.1	3.9	3.1	2.5	1.0	0.7
25	-	5.7	4.1	6.4	4.9	4.7	4.6	-	-	5.0	3.8	3.6	2.9	2.3	0.9	0.6

v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)															
	(1)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	5.0		4.3	5.0	3.5	6.1	1.4	4.1	2.3	2.7	3.1	3.5	1.8	3.7	1.0	2.7
39	4.8		4.1	4.8	3.3	5.9	1.4	3.9	2.2	2.6	3.0	3.4	1.8	3.5	1.0	2.6
38	4.6		3.9	4.6	3.2	5.6	1.3	3.8	2.2	2.5	2.8	3.2	1.7	3.4	0.9	2.5
37	4.4		3.8	4.4	3.1	5.4	1.3	3.6	2.1	2.4	2.7	3.1	1.6	3.2	0.9	2.4
36	4.2		3.6	4.2	2.9	5.2	1.2	3.5	2.0	2.3	2.6	2.9	1.5	3.1	0.8	2.3
35	4.0		3.5	4.0	2.8	4.9	1.2	3.3	1.9	2.2	2.5	2.8	1.5	3.0	0.8	2.2
34	3.8		3.3	3.8	2.7	4.7	1.1	3.2	1.8	2.1	2.4	2.7	1.4	2.8	0.8	2.1
33	3.6		3.2	3.6	2.6	4.5	1.0	3.0	1.7	2.0	2.3	2.6	1.3	2.7	0.7	2.0
32	3.5		3.0	3.5	2.4	4.3	1.0	2.9	1.6	1.9	2.2	2.4	1.3	2.6	0.7	1.9
31	3.3		2.9	3.3	2.3	4.1	0.9	2.7	1.5	1.8	2.1	2.3	1.2	2.4	0.7	1.8
30	3.1		2.8	3.1	2.2	3.9	0.9	2.6	1.5	1.7	2.0	2.2	1.2	2.3	0.6	1.7
29	3.0		2.6	2.9	2.1	3.7	0.8	2.5	1.4	1.6	1.9	2.1	1.1	2.2	0.6	1.6
28	2.8		2.5	2.8	2.0	3.5	0.8	2.3	1.3	1.5	1.8	2.0	1.0	2.1	0.6	1.5
27	2.6		2.4	2.6	1.9	3.3	0.8	2.2	1.2	1.4	1.7	1.8	1.0	1.9	0.5	1.4
26	2.5		2.2	2.5	1.8	3.1	0.7	2.1	1.2	1.3	1.6	1.7	0.9	1.8	0.5	1.3
25	2.3		2.1	2.3	1.7	2.9	0.7	1.9	1.1	1.3	1.5	1.6	0.9	1.7	0.5	1.3

Table 130 - Magnetic forces as a result of cross-winds: end section, v_{Fzg} = 200 km/h, v_W = 25 .. 40 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
25	-	5.7	4.1	6.4	4.9	4.7	4.6	-	-	5.0	3.8	3.6	2.9	2.3	0.9	0.6
24	-	5.4	3.8	6.1	4.6	4.4	4.3	-	-	4.7	3.6	3.4	2.7	2.2	0.9	0.6
23	-	5.0	3.6	5.7	4.3	4.2	4.0	-	-	4.4	3.4	3.2	2.5	2.0	0.8	0.5
22	-	4.7	3.3	5.4	4.0	3.9	3.7	-	-	4.1	3.1	3.0	2.3	1.9	0.8	0.5
21	-	4.4	3.1	5.0	3.7	3.6	3.4	-	-	3.8	2.9	2.8	2.2	1.8	0.7	0.5
20	-	4.1	2.9	4.7	3.5	3.3	3.2	-	-	3.5	2.7	2.6	2.0	1.6	0.7	0.4
19	-	3.7	2.7	4.4	3.2	3.1	2.9	-	-	3.2	2.5	2.4	1.9	1.5	0.6	0.4
18	-	3.4	2.5	4.1	2.9	2.8	2.7	-	-	2.9	2.3	2.2	1.7	1.4	0.6	0.4
17	-	3.2	2.2	3.8	2.7	2.6	2.4	-	-	2.6	2.1	2.0	1.5	1.2	0.5	0.3
16	-	2.9	2.1	3.5	2.4	2.3	2.2	-	-	2.4	1.9	1.8	1.4	1.1	0.5	0.3
15	-	2.6	1.9	3.2	2.2	2.1	2.0	-	-	2.1	1.7	1.7	1.3	1.0	0.4	0.3
14	-	2.3	1.7	2.9	2.0	1.9	1.8	-	-	1.9	1.5	1.5	1.1	0.9	0.4	0.3
13	-	2.1	1.5	2.6	1.7	1.7	1.6	-	-	1.7	1.4	1.3	1.0	0.8	0.4	0.2
12	-	1.9	1.3	2.3	1.5	1.5	1.4	-	-	1.5	1.2	1.2	0.9	0.7	0.3	0.2
11	-	1.6	1.2	2.1	1.3	1.3	1.2	-	-	1.3	1.0	1.0	0.8	0.6	0.3	0.2
10	-	1.4	1.0	1.8	1.2	1.1	1.0	-	-	1.1	0.9	0.9	0.7	0.5	0.2	0.2
v_W [m/s]	**Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m]** (+/-)															
	(1)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
25	2.3		2.1	2.3	1.7	2.9	0.7	1.9	1.1	1.3	1.5	1.6	0.9	1.7	0.5	1.3
24	2.2		2.0	2.2	1.5	2.7	0.6	1.8	1.0	1.2	1.4	1.5	0.8	1.6	0.4	1.2
23	2.0		1.9	2.0	1.4	2.5	0.6	1.7	0.9	1.1	1.3	1.4	0.8	1.5	0.4	1.1
22	1.9		1.7	1.9	1.3	2.4	0.5	1.6	0.9	1.0	1.2	1.3	0.7	1.4	0.4	1.0
21	1.8		1.6	1.7	1.3	2.2	0.5	1.5	0.8	0.9	1.1	1.2	0.7	1.3	0.4	1.0
20	1.6		1.5	1.6	1.2	2.0	0.5	1.4	0.7	0.9	1.0	1.1	0.6	1.2	0.3	0.9
19	1.5		1.4	1.5	1.1	1.9	0.4	1.2	0.7	0.8	0.9	1.0	0.6	1.1	0.3	0.8
18	1.4		1.3	1.3	1.0	1.7	0.4	1.1	0.6	0.7	0.9	1.0	0.5	1.0	0.3	0.7
17	1.3		1.2	1.2	0.9	1.6	0.4	1.0	0.6	0.7	0.8	0.9	0.5	0.9	0.3	0.7
16	1.1		1.1	1.1	0.8	1.4	0.3	0.9	0.5	0.6	0.7	0.8	0.4	0.8	0.2	0.6
15	1.0		1.0	1.0	0.7	1.3	0.3	0.9	0.5	0.5	0.7	0.7	0.4	0.8	0.2	0.6
14	0.9		0.9	0.9	0.7	1.1	0.3	0.8	0.4	0.5	0.6	0.6	0.3	0.7	0.2	0.5
13	0.8		0.8	0.8	0.6	1.0	0.2	0.7	0.4	0.4	0.5	0.6	0.3	0.6	0.2	0.4
12	0.7		0.7	0.7	0.5	0.9	0.2	0.6	0.3	0.4	0.5	0.5	0.3	0.5	0.1	0.4
11	0.6		0.6	0.6	0.5	0.8	0.2	0.5	0.3	0.3	0.4	0.4	0.2	0.5	0.1	0.3
10	0.5		0.5	0.5	0.4	0.7	0.1	0.4	0.2	0.3	0.3	0.4	0.2	0.4	0.1	0.3

Table 131 - Magnetic forces as a result of cross-winds: end section, v_{Fzg} = 200 km/h, v_W = 10 .. 25 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
40	1.1	1.6	3.2	3.8	4.3	4.5	5.6	-	-	6.6	6.9	7.2	8.9	7.8	4.8	2.5
39	1.0	1.5	3.1	3.7	4.2	4.3	5.4	-	-	6.3	6.6	6.9	8.6	7.5	4.6	2.5
38	1.0	1.5	3.0	3.5	4.0	4.2	5.1	-	-	6.0	6.3	6.7	8.2	7.2	4.4	2.4
37	0.9	1.4	2.9	3.4	3.8	4.0	4.9	-	-	5.7	6.0	6.4	7.9	6.9	4.2	2.3
36	0.9	1.4	2.8	3.2	3.7	3.8	4.7	-	-	5.4	5.7	6.1	7.6	6.6	4.1	2.2
35	0.9	1.3	2.6	3.1	3.5	3.7	4.5	-	-	5.1	5.5	5.8	7.3	6.4	3.9	2.1
34	0.8	1.3	2.5	3.0	3.4	3.5	4.3	-	-	4.9	5.2	5.6	6.9	6.1	3.7	2.0
33	0.8	1.2	2.4	2.8	3.2	3.3	4.1	-	-	4.6	5.0	5.3	6.6	5.8	3.6	2.0
32	0.7	1.2	2.3	2.7	3.1	3.2	3.9	-	-	4.4	4.7	5.1	6.3	5.5	3.4	1.9
31	0.7	1.1	2.2	2.6	2.9	3.0	3.7	-	-	4.1	4.5	4.8	6.0	5.3	3.2	1.8
30	0.7	1.1	2.1	2.4	2.8	2.9	3.5	-	-	3.9	4.2	4.6	5.7	5.0	3.1	1.7
29	0.6	1.0	2.0	2.3	2.6	2.7	3.3	-	-	3.6	4.0	4.3	5.4	4.7	2.9	1.7
28	0.6	1.0	1.9	2.2	2.5	2.6	3.2	-	-	3.4	3.7	4.1	5.1	4.5	2.8	1.6
27	0.6	1.0	1.8	2.1	2.4	2.4	3.0	-	-	3.2	3.5	3.9	4.8	4.2	2.6	1.5
26	0.5	0.9	1.7	1.9	2.2	2.3	2.8	-	-	3.0	3.3	3.6	4.6	4.0	2.5	1.4
25	0.5	0.9	1.6	1.8	2.1	2.2	2.6	-	-	2.8	3.1	3.4	4.3	3.8	2.3	1.4

v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	1.0	1.2	1.9	1.3	1.8	1.8	1.4	1.5	2.0	0.9	2.9	1.8	2.2	2.8	1.4	1.0
39	1.0	1.1	1.8	1.3	1.7	1.8	1.3	1.4	1.9	0.9	2.8	1.8	2.1	2.7	1.3	1.0
38	0.9	1.1	1.7	1.2	1.6	1.7	1.3	1.3	1.8	0.8	2.7	1.7	2.0	2.6	1.3	0.9
37	0.9	1.0	1.7	1.2	1.6	1.6	1.2	1.2	1.8	0.8	2.6	1.6	1.9	2.5	1.2	0.9
36	0.9	1.0	1.6	1.1	1.5	1.5	1.2	1.2	1.7	0.8	2.4	1.5	1.9	2.3	1.2	0.9
35	0.8	1.0	1.5	1.1	1.4	1.5	1.1	1.1	1.6	0.7	2.3	1.5	1.8	2.2	1.1	0.8
34	0.8	0.9	1.5	1.0	1.4	1.4	1.1	1.0	1.6	0.7	2.2	1.4	1.7	2.1	1.1	0.8
33	0.8	0.9	1.4	1.0	1.3	1.3	1.0	0.9	1.5	0.7	2.1	1.3	1.6	2.0	1.0	0.8
32	0.7	0.8	1.3	0.9	1.2	1.3	1.0	0.9	1.4	0.6	2.0	1.3	1.5	1.9	1.0	0.7
31	0.7	0.8	1.3	0.9	1.2	1.2	0.9	0.8	1.4	0.6	1.9	1.2	1.5	1.8	0.9	0.7
30	0.6	0.7	1.2	0.8	1.1	1.2	0.9	0.8	1.3	0.6	1.8	1.2	1.4	1.7	0.9	0.6
29	0.6	0.7	1.1	0.8	1.1	1.1	0.8	0.7	1.2	0.5	1.7	1.1	1.3	1.7	0.8	0.6
28	0.6	0.7	1.1	0.8	1.0	1.0	0.8	0.6	1.2	0.5	1.7	1.0	1.3	1.6	0.8	0.6
27	0.5	0.6	1.0	0.7	0.9	1.0	0.7	0.6	1.1	0.5	1.6	1.0	1.2	1.5	0.7	0.5
26	0.5	0.6	0.9	0.7	0.9	0.9	0.7	0.5	1.0	0.4	1.5	0.9	1.1	1.4	0.7	0.5
25	0.5	0.6	0.9	0.6	0.8	0.9	0.6	0.5	1.0	0.4	1.4	0.9	1.0	1.3	0.6	0.5

Table 132 - Magnetic forces as a result of cross-winds: middle section, v_{Fzg} = 200 km/h, v_W = 25 .. 40 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
25	0.5	0.9	1.6	1.8	2.1	2.2	2.6	-	-	2.8	3.1	3.4	4.3	3.8	2.3	1.4
24	0.5	0.8	1.5	1.7	2.0	2.0	2.5	-	-	2.6	2.9	3.2	4.0	3.5	2.2	1.3
23	0.4	0.8	1.4	1.6	1.9	1.9	2.3	-	-	2.4	2.7	3.0	3.8	3.3	2.1	1.2
22	0.4	0.7	1.3	1.5	1.7	1.8	2.2	-	-	2.2	2.5	2.8	3.5	3.1	1.9	1.1
21	0.4	0.7	1.2	1.4	1.6	1.6	2.0	-	-	2.0	2.3	2.6	3.3	2.9	1.8	1.1
20	0.3	0.7	1.1	1.3	1.5	1.5	1.9	-	-	1.8	2.1	2.4	3.0	2.7	1.7	1.0
19	0.3	0.6	1.1	1.2	1.4	1.4	1.7	-	-	1.7	1.9	2.2	2.8	2.5	1.5	0.9
18	0.3	0.6	1.0	1.1	1.3	1.3	1.6	-	-	1.5	1.8	2.0	2.6	2.3	1.4	0.9
17	0.3	0.5	0.9	1.0	1.2	1.2	1.4	-	-	1.4	1.6	1.9	2.3	2.1	1.3	0.8
16	0.2	0.5	0.8	0.9	1.1	1.1	1.3	-	-	1.2	1.4	1.7	2.1	1.9	1.2	0.7
15	0.2	0.4	0.7	0.8	1.0	1.0	1.2	-	-	1.1	1.3	1.5	1.9	1.7	1.1	0.7
14	0.2	0.4	0.7	0.7	0.9	0.9	1.1	-	-	0.9	1.1	1.4	1.7	1.5	1.0	0.6
13	0.2	0.4	0.6	0.6	0.8	0.8	0.9	-	-	0.8	1.0	1.2	1.5	1.4	0.9	0.6
12	0.1	0.3	0.5	0.6	0.7	0.7	0.8	-	-	0.7	0.9	1.1	1.4	1.2	0.8	0.5
11	0.1	0.3	0.5	0.5	0.6	0.6	0.7	-	-	0.6	0.8	0.9	1.2	1.1	0.7	0.5
10	0.1	0.3	0.4	0.4	0.5	0.5	0.6	-	-	0.5	0.6	0.8	1.0	0.9	0.6	0.4

v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
25	0.5	0.6	0.9	0.6	0.8	0.9	0.6	0.5	1.0	0.4	1.4	0.9	1.0	1.3	0.6	0.5
24	0.5	0.5	0.8	0.6	0.8	0.8	0.6	0.4	0.9	0.4	1.3	0.8	1.0	1.2	0.6	0.5
23	0.4	0.5	0.8	0.6	0.7	0.8	0.6	0.4	0.9	0.4	1.2	0.7	0.9	1.1	0.6	0.4
22	0.4	0.5	0.7	0.5	0.7	0.7	0.5	0.4	0.8	0.3	1.1	0.7	0.9	1.1	0.5	0.4
21	0.4	0.4	0.7	0.5	0.6	0.7	0.5	0.3	0.8	0.3	1.1	0.6	0.8	1.0	0.5	0.4
20	0.3	0.4	0.6	0.4	0.6	0.6	0.4	0.3	0.7	0.3	1.0	0.6	0.7	0.9	0.5	0.3
19	0.3	0.4	0.6	0.4	0.5	0.6	0.4	0.3	0.7	0.3	0.9	0.5	0.7	0.8	0.4	0.3
18	0.3	0.3	0.5	0.4	0.5	0.5	0.4	0.2	0.6	0.2	0.8	0.5	0.6	0.8	0.4	0.3
17	0.3	0.3	0.5	0.3	0.5	0.5	0.3	0.2	0.6	0.2	0.8	0.5	0.6	0.7	0.3	0.3
16	0.2	0.3	0.4	0.3	0.4	0.4	0.3	0.2	0.5	0.2	0.7	0.4	0.5	0.6	0.3	0.2
15	0.2	0.2	0.4	0.3	0.4	0.4	0.3	0.1	0.5	0.2	0.6	0.4	0.5	0.6	0.3	0.2
14	0.2	0.2	0.4	0.3	0.3	0.3	0.2	0.1	0.4	0.2	0.6	0.3	0.4	0.5	0.3	0.2
13	0.2	0.2	0.3	0.2	0.3	0.3	0.2	0.1	0.4	0.1	0.5	0.3	0.4	0.5	0.2	0.2
12	0.2	0.2	0.3	0.2	0.3	0.3	0.2	0.1	0.3	0.1	0.4	0.3	0.3	0.4	0.2	0.2
11	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.3	0.1	0.4	0.2	0.3	0.3	0.2	0.1
10	0.1	0.1	0.2	0.1	0.2	0.2	0.1	0.1	0.3	0.1	0.3	0.2	0.2	0.3	0.1	0.1

Table 133 - Magnetic forces as a result of cross-winds: middle section, v_{Fzg} = 200 km/h, v_W = 10 .. 25 m/s

v_W [m/s]	Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
40	-	3.2	3.2	3.6	3.2	3.6	5.0	-	-	5.0	3.6	3.2	4.1	3.6	2.2	1.9
39	-	3.0	3.0	3.4	3.0	3.4	4.8	-	-	4.8	3.4	3.0	3.9	3.4	2.1	1.8
38	-	2.8	2.8	3.3	2.8	3.3	4.5	-	-	4.5	3.3	2.8	3.7	3.3	2.0	1.7
37	-	2.7	2.7	3.1	2.7	3.1	4.3	-	-	4.3	3.1	2.7	3.5	3.1	1.9	1.6
36	-	2.6	2.6	2.9	2.6	2.9	4.1	-	-	4.1	2.9	2.6	3.3	2.9	1.8	1.5
35	-	2.4	2.4	2.8	2.4	2.8	3.8	-	-	3.8	2.8	2.4	3.1	2.8	1.7	1.4
34	-	2.3	2.3	2.6	2.3	2.6	3.6	-	-	3.6	2.6	2.3	3.0	2.6	1.6	1.4
33	-	2.1	2.1	2.5	2.1	2.5	3.4	-	-	3.4	2.5	2.1	2.8	2.5	1.5	1.3
32	-	2.0	2.0	2.3	2.0	2.3	3.2	-	-	3.2	2.3	2.0	2.6	2.3	1.4	1.2
31	-	1.9	1.9	2.2	1.9	2.2	3.0	-	-	3.0	2.2	1.9	2.5	2.2	1.3	1.1
30	-	1.8	1.8	2.0	1.8	2.0	2.8	-	-	2.8	2.0	1.8	2.3	2.0	1.2	1.1
29	-	1.7	1.7	1.9	1.7	1.9	2.6	-	-	2.6	1.9	1.7	2.2	1.9	1.2	1.0
28	-	1.5	1.5	1.8	1.5	1.8	2.5	-	-	2.5	1.8	1.5	2.0	1.8	1.1	0.9
27	-	1.4	1.4	1.7	1.4	1.7	2.3	-	-	2.3	1.7	1.4	1.9	1.7	1.0	0.9
26	-	1.3	1.3	1.5	1.3	1.5	2.1	-	-	2.1	1.5	1.3	1.7	1.5	0.9	0.8
25	-	1.2	1.2	1.4	1.2	1.4	2.0	-	-	2.0	1.4	1.2	1.6	1.4	0.9	0.7

v_W [m/s]	Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m] (+/-)															
	(1)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	0.8		1.7	1.0	1.0	1.0	1.1	1.5	1.4	1.0	1.0	1.0	1.0	0.8	1.1	1.1
39	0.8		1.6	1.0	1.0	1.0	1.1	1.4	1.3	1.0	1.0	1.0	1.0	0.8	1.1	1.1
38	0.7		1.6	0.9	0.9	0.9	1.0	1.4	1.3	0.9	0.9	0.9	0.9	0.7	1.0	1.0
37	0.7		1.5	0.9	0.9	0.9	1.0	1.3	1.2	0.9	0.9	0.9	0.9	0.7	1.0	1.0
36	0.7		1.4	0.9	0.9	0.9	1.0	1.2	1.1	0.9	0.9	0.9	0.9	0.7	1.0	1.0
35	0.6		1.4	0.8	0.8	0.8	0.9	1.2	1.1	0.8	0.8	0.8	0.8	0.6	0.9	0.9
34	0.6		1.3	0.8	0.8	0.8	0.9	1.1	1.0	0.8	0.8	0.8	0.8	0.6	0.9	0.9
33	0.6		1.3	0.7	0.8	0.7	0.8	1.1	1.0	0.7	0.8	0.7	0.7	0.6	0.8	0.8
32	0.6		1.2	0.7	0.7	0.7	0.8	1.0	0.9	0.7	0.7	0.7	0.7	0.6	0.8	0.8
31	0.5		1.1	0.7	0.7	0.7	0.7	1.0	0.9	0.7	0.7	0.7	0.7	0.5	0.8	0.8
30	0.5		1.1	0.6	0.6	0.6	0.7	0.9	0.8	0.6	0.6	0.6	0.6	0.5	0.7	0.7
29	0.5		1.0	0.6	0.6	0.6	0.7	0.9	0.8	0.6	0.6	0.6	0.6	0.5	0.7	0.7
28	0.4		1.0	0.6	0.6	0.6	0.6	0.8	0.8	0.6	0.6	0.6	0.6	0.4	0.6	0.6
27	0.4		0.9	0.5	0.5	0.5	0.6	0.8	0.7	0.5	0.5	0.5	0.5	0.4	0.6	0.6
26	0.4		0.9	0.5	0.5	0.5	0.6	0.7	0.7	0.5	0.5	0.5	0.5	0.4	0.6	0.6
25	0.4		0.8	0.5	0.5	0.5	0.5	0.7	0.6	0.5	0.5	0.5	0.5	0.4	0.5	0.5

Table 134 - Magnetic forces as a result of cross-winds: end section, v_{Fzg} = 0 km/h, v_W = 25 .. 40 m/s

v_W [m/s]	**Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]**															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
25	-	1.2	1.2	1.4	1.2	1.4	2.0	-	-	2.0	1.4	1.2	1.6	1.4	0.9	0.7
24	-	1.1	1.1	1.3	1.1	1.3	1.8	-	-	1.8	1.3	1.1	1.5	1.3	0.8	0.7
23	-	1.0	1.0	1.2	1.0	1.2	1.7	-	-	1.7	1.2	1.0	1.4	1.2	0.7	0.6
22	-	1.0	1.0	1.1	1.0	1.1	1.5	-	-	1.5	1.1	1.0	1.2	1.1	0.7	0.6
21	-	0.9	0.9	1.0	0.9	1.0	1.4	-	-	1.4	1.0	0.9	1.1	1.0	0.6	0.5
20	-	0.8	0.8	0.9	0.8	0.9	1.3	-	-	1.3	0.9	0.8	1.0	0.9	0.6	0.5
19	-	0.7	0.7	0.8	0.7	0.8	1.1	-	-	1.1	0.8	0.7	0.9	0.8	0.5	0.4
18	-	0.6	0.6	0.7	0.6	0.7	1.0	-	-	1.0	0.7	0.6	0.8	0.7	0.4	0.4
17	-	0.6	0.6	0.7	0.6	0.7	0.9	-	-	0.9	0.7	0.6	0.7	0.7	0.4	0.3
16	-	0.5	0.5	0.6	0.5	0.6	0.8	-	-	0.8	0.6	0.5	0.7	0.6	0.4	0.3
15	-	0.4	0.4	0.5	0.4	0.5	0.7	-	-	0.7	0.5	0.4	0.6	0.5	0.3	0.3
14	-	0.4	0.4	0.4	0.4	0.4	0.6	-	-	0.6	0.4	0.4	0.5	0.4	0.3	0.2
13	-	0.3	0.3	0.4	0.3	0.4	0.5	-	-	0.5	0.4	0.3	0.4	0.4	0.2	0.2
12	-	0.3	0.3	0.3	0.3	0.3	0.5	-	-	0.5	0.3	0.3	0.4	0.3	0.2	0.2
11	-	0.2	0.2	0.3	0.2	0.3	0.4	-	-	0.4	0.3	0.2	0.3	0.3	0.2	0.1
10	-	0.2	0.2	0.2	0.2	0.2	0.3	-	-	0.3	0.2	0.2	0.3	0.2	0.1	0.1
v_W [m/s]	**Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m]** (+/-)															
	(1)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
25	0.4		0.8	0.5	0.5	0.5	0.5	0.7	0.6	0.5	0.5	0.5	0.5	0.4	0.5	0.5
24	0.3		0.8	0.4	0.5	0.5	0.5	0.7	0.6	0.4	0.5	0.4	0.4	0.3	0.5	0.5
23	0.3		0.7	0.4	0.4	0.4	0.5	0.6	0.5	0.4	0.4	0.4	0.4	0.3	0.5	0.5
22	0.3		0.7	0.4	0.4	0.4	0.4	0.6	0.5	0.4	0.4	0.4	0.4	0.3	0.4	0.4
21	0.3		0.6	0.4	0.4	0.4	0.4	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.4	0.4
20	0.3		0.6	0.3	0.3	0.3	0.4	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.4	0.4
19	0.2		0.6	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.3	0.3
18	0.2		0.5	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.3	0.3
17	0.2		0.5	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3
16	0.2		0.4	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.3	0.3
15	0.2		0.4	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
14	0.1		0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2
13	0.1		0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2
12	0.1		0.3	0.1	0.2	0.1	0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.2	0.2
11	0.1		0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
10	0.1		0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table 135 - Magnetic forces as a result of cross-winds: end section, v_{Fzg} = 0 km/h, v_W = 10 .. 25 m/s

v_W [m/s]	**Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]**															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
40	1.9	2.2	3.2	3.6	3.2	3.6	5.0	-	-	5.0	3.6	3.2	3.6	3.2	2.2	1.9
39	1.8	2.1	3.0	3.4	3.0	3.4	4.8	-	-	4.8	3.4	3.0	3.4	3.0	2.1	1.8
38	1.7	2.0	2.8	3.3	2.8	3.3	4.5	-	-	4.5	3.3	2.8	3.3	2.8	2.0	1.7
37	1.6	1.9	2.7	3.1	2.7	3.1	4.3	-	-	4.3	3.1	2.7	3.1	2.7	1.9	1.6
36	1.5	1.8	2.6	2.9	2.6	2.9	4.1	-	-	4.1	2.9	2.6	2.9	2.6	1.8	1.5
35	1.4	1.7	2.4	2.8	2.4	2.8	3.8	-	-	3.8	2.8	2.4	2.8	2.4	1.7	1.4
34	1.4	1.6	2.3	2.6	2.3	2.6	3.6	-	-	3.6	2.6	2.3	2.6	2.3	1.6	1.4
33	1.3	1.5	2.1	2.5	2.1	2.5	3.4	-	-	3.4	2.5	2.1	2.5	2.1	1.5	1.3
32	1.2	1.4	2.0	2.3	2.0	2.3	3.2	-	-	3.2	2.3	2.0	2.3	2.0	1.4	1.2
31	1.1	1.3	1.9	2.2	1.9	2.2	3.0	-	-	3.0	2.2	1.9	2.2	1.9	1.3	1.1
30	1.1	1.2	1.8	2.0	1.8	2.0	2.8	-	-	2.8	2.0	1.8	2.0	1.8	1.2	1.1
29	1.0	1.2	1.7	1.9	1.7	1.9	2.6	-	-	2.6	1.9	1.7	1.9	1.7	1.2	1.0
28	0.9	1.1	1.5	1.8	1.5	1.8	2.5	-	-	2.5	1.8	1.5	1.8	1.5	1.1	0.9
27	0.9	1.0	1.4	1.7	1.4	1.7	2.3	-	-	2.3	1.7	1.4	1.7	1.4	1.0	0.9
26	0.8	0.9	1.3	1.5	1.3	1.5	2.1	-	-	2.1	1.5	1.3	1.5	1.3	0.9	0.8
25	0.7	0.9	1.2	1.4	1.2	1.4	2.0	-	-	2.0	1.4	1.2	1.4	1.2	0.9	0.7
v_W [m/s]	**Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m]** (+/-)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
40	1.1	1.1	0.8	1.0	0.8	0.8	1.1	1.4	1.3	1.1	0.8	0.8	1.0	0.8	1.1	1.1
39	1.1	1.1	0.8	1.0	0.8	0.8	1.1	1.4	1.3	1.1	0.8	0.8	1.0	0.8	1.1	1.1
38	1.0	1.0	0.7	0.9	0.7	0.7	1.0	1.3	1.2	1.0	0.7	0.7	0.9	0.7	1.0	1.0
37	1.0	1.0	0.7	0.9	0.7	0.7	1.0	1.2	1.2	1.0	0.7	0.7	0.9	0.7	1.0	1.0
36	1.0	1.0	0.7	0.9	0.7	0.7	1.0	1.1	1.2	1.0	0.7	0.7	0.9	0.7	1.0	1.0
35	0.9	0.9	0.6	0.8	0.6	0.6	0.9	1.1	1.1	0.9	0.6	0.6	0.8	0.6	0.9	0.9
34	0.9	0.9	0.6	0.8	0.6	0.6	0.9	1.0	1.1	0.9	0.6	0.6	0.8	0.6	0.9	0.9
33	0.8	0.8	0.6	0.8	0.6	0.6	0.8	0.9	1.0	0.8	0.6	0.6	0.8	0.6	0.8	0.8
32	0.8	0.8	0.6	0.7	0.6	0.6	0.8	0.9	1.0	0.8	0.6	0.6	0.7	0.6	0.8	0.8
31	0.8	0.8	0.5	0.7	0.5	0.5	0.7	0.8	0.9	0.7	0.5	0.5	0.7	0.5	0.8	0.8
30	0.7	0.7	0.5	0.6	0.5	0.5	0.7	0.7	0.9	0.7	0.5	0.5	0.6	0.5	0.7	0.7
29	0.7	0.7	0.5	0.6	0.5	0.5	0.7	0.7	0.8	0.7	0.5	0.5	0.6	0.5	0.7	0.7
28	0.6	0.6	0.4	0.6	0.4	0.5	0.6	0.6	0.8	0.6	0.5	0.4	0.6	0.4	0.6	0.6
27	0.6	0.6	0.4	0.5	0.4	0.4	0.6	0.6	0.8	0.6	0.4	0.4	0.5	0.4	0.6	0.6
26	0.6	0.6	0.4	0.5	0.4	0.4	0.6	0.5	0.7	0.6	0.4	0.4	0.5	0.4	0.6	0.6
25	0.5	0.5	0.4	0.5	0.4	0.4	0.5	0.5	0.7	0.5	0.4	0.4	0.5	0.4	0.5	0.5

Table 136 - Magnetic forces as a result of cross-winds: middle section, v_{Fzg} = 0 km/h, v_W = 25 .. 40 m/s

v_W [m/s]	**Guidance magnet forces $p_{y,W,FMTi}$ in [kN/m]**															
	1	2	3	4	5	6	7	BM	BM	10	11	12	13	14	15	16
25	0.7	0.9	1.2	1.4	1.2	1.4	2.0	-	-	2.0	1.4	1.2	1.4	1.2	0.9	0.7
24	0.7	0.8	1.1	1.3	1.1	1.3	1.8	-	-	1.8	1.3	1.1	1.3	1.1	0.8	0.7
23	0.6	0.7	1.0	1.2	1.0	1.2	1.7	-	-	1.7	1.2	1.0	1.2	1.0	0.7	0.6
22	0.6	0.7	1.0	1.1	1.0	1.1	1.5	-	-	1.5	1.1	1.0	1.1	1.0	0.7	0.6
21	0.5	0.6	0.9	1.0	0.9	1.0	1.4	-	-	1.4	1.0	0.9	1.0	0.9	0.6	0.5
20	0.5	0.6	0.8	0.9	0.8	0.9	1.3	-	-	1.3	0.9	0.8	0.9	0.8	0.6	0.5
19	0.4	0.5	0.7	0.8	0.7	0.8	1.1	-	-	1.1	0.8	0.7	0.8	0.7	0.5	0.4
18	0.4	0.4	0.6	0.7	0.6	0.7	1.0	-	-	1.0	0.7	0.6	0.7	0.6	0.4	0.4
17	0.3	0.4	0.6	0.7	0.6	0.7	0.9	-	-	0.9	0.7	0.6	0.7	0.6	0.4	0.3
16	0.3	0.4	0.5	0.6	0.5	0.6	0.8	-	-	0.8	0.6	0.5	0.6	0.5	0.4	0.3
15	0.3	0.3	0.4	0.5	0.4	0.5	0.7	-	-	0.7	0.5	0.4	0.5	0.4	0.3	0.3
14	0.2	0.3	0.4	0.4	0.4	0.4	0.6	-	-	0.6	0.4	0.4	0.4	0.4	0.3	0.2
13	0.2	0.2	0.3	0.4	0.3	0.4	0.5	-	-	0.5	0.4	0.3	0.4	0.3	0.2	0.2
12	0.2	0.2	0.3	0.3	0.3	0.3	0.5	-	-	0.5	0.3	0.3	0.3	0.3	0.2	0.2
11	0.1	0.2	0.2	0.3	0.2	0.3	0.4	-	-	0.4	0.3	0.2	0.3	0.2	0.2	0.1
10	0.1	0.1	0.2	0.2	0.2	0.2	0.3	-	-	0.3	0.2	0.2	0.2	0.2	0.1	0.1
v_W [m/s]	**Levitation magnet forces $p_{z,W,TMTi}$ in [kN/m]** (+/-)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
25	0.5	0.5	0.4	0.5	0.4	0.4	0.5	0.5	0.7	0.5	0.4	0.4	0.5	0.4	0.5	0.5
24	0.5	0.5	0.4	0.5	0.3	0.4	0.5	0.4	0.6	0.5	0.4	0.3	0.5	0.3	0.5	0.5
23	0.5	0.5	0.3	0.4	0.3	0.3	0.5	0.4	0.6	0.5	0.3	0.3	0.4	0.3	0.5	0.5
22	0.4	0.4	0.3	0.4	0.3	0.3	0.4	0.4	0.6	0.4	0.3	0.3	0.4	0.3	0.4	0.4
21	0.4	0.4	0.3	0.4	0.3	0.3	0.4	0.3	0.5	0.4	0.3	0.3	0.4	0.3	0.4	0.4
20	0.4	0.4	0.3	0.3	0.3	0.3	0.4	0.3	0.5	0.4	0.3	0.3	0.3	0.3	0.4	0.4
19	0.3	0.3	0.2	0.3	0.2	0.2	0.3	0.2	0.5	0.3	0.2	0.2	0.3	0.2	0.3	0.3
18	0.3	0.3	0.2	0.3	0.2	0.2	0.3	0.2	0.4	0.3	0.2	0.2	0.3	0.2	0.3	0.3
17	0.3	0.3	0.2	0.3	0.2	0.2	0.3	0.2	0.4	0.3	0.2	0.2	0.3	0.2	0.3	0.3
16	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.3
15	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
14	0.2	0.2	0.1	0.2	0.1	0.2	0.2	0.1	0.3	0.2	0.2	0.1	0.2	0.1	0.2	0.2
13	0.2	0.2	0.1	0.2	0.1	0.1	0.2	0.1	0.3	0.2	0.1	0.1	0.2	0.1	0.2	0.2
12	0.2	0.2	0.1	0.2	0.1	0.1	0.2	0.1	0.2	0.2	0.1	0.1	0.2	0.1	0.2	0.2
11	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
10	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table 137 - Magnetic forces as a result of cross-winds: middle section, v_{Fzg} = 0 km/h, v_W = 10 .. 25 m/s

Annex II-F: Calculating the levitation magnet pole forces

<u>Without rearrangement for standard and front and rear-mounted levitation magnets</u> (see figs. 180 and 181)				Example	
1	Line load, part magnets i, i+1	$p_{z,az,EG/MG/ZG/HG,TMT_i}$ $p_{z,az,EG/MG/ZG/HG,TMT_{i+1}}$	from equation 15	10 5	kN/m
2	Levitation magnet terminal pole forces	$P_{z,EP,i/i+1}$	$0.5 \cdot p_{z,az,EG/MG/ZG/HG,TMT(i/i+1)} \cdot L_{sys,TMT(i/i+1)} / 5.5$ or $0.5 \cdot p_{z,az,EG/MG/ZG/HG,TMT(i/i+1)} \cdot L_{sys,TMT(i/i+1)} / 7.5$ *	1.41; 0.70 1.39 *	kN
3	Levitation magnet main pole forces	$P_{z,HP,i/i+1}$	$p_{z,az,EG/MG/ZG/HG,TMT(i/i+1)} \cdot L_{sys,TMT(i/i+1)} / 5.5$ or $p_{z,az,EG/MG/ZG/HG,TMT(i/i+1)} \cdot L_{sys,TMT(i/i+1)} / 7.5$ *	2.82; 1.40 2.77 *	kN
* with a front and rear-mounted levitation magnet					

Table 138 - Levitation magnet pole forces without rearrangement

<u>With 30% rearrangement for standard levitation magnets</u> (see fig. 180)				Example	
1	Line load, part magnets i, i+1	$p_{z,az,EG/MG/ZG/HG,TMT_i}$ $\geq$ $p_{z,az,EG/MG/ZG/HG,TMT_{i+1}}$	from equation 15	10 5	kN/m
2	Result of the uneven distribution TMT_i	$R_{TMTi,30\%}$	$p_{z,az,EG/MG/ZG/HG,TMT_i} \cdot 30\% \cdot L_{sys,TMT_i} / 2$	2.32	kN
3	Levitation magnet terminal pole force i	$P_{z,EP,30,i}$	$P_{z,EP,i} + R_{TMTi,30\%} \cdot 3 / 18$	1.79	kN
4	Levitation magnet main pole force 1,i	$P_{z,HP1,30,i}$	$P_{z,HP,i} + R_{TMTi,30\%} \cdot 5 / 18$	3.46	kN
5	Levitation magnet main pole force 2,i	$P_{z,HP2,30,i}$	$P_{z,HP,i} + R_{TMTi,30\%} \cdot 4 / 18$	3.33	kN
6	Levitation magnet main pole force 3,i	$P_{z,HP3,30,i}$	$P_{z,HP,i} + R_{TMTi,30\%} \cdot 3 / 18$	3.20	kN
7	Levitation magnet main pole force 4,i	$P_{z,HP4,30,i}$	$P_{z,HP,i} + R_{TMTi,30\%} \cdot 2 / 18$	3.07	kN
8	Levitation magnet main pole force 5,i	$P_{z,HP5,30,i}$	$P_{z,HP,i} + R_{TMTi,30\%} \cdot 1 / 18$	2.94	kN

9	Levitation magnet main pole force 6,i+1	$P_{z,HP6,30,i+1}$	$P_{z,HP,i+1}$ - $R_{TMTi,30\%}$ · 1 / 18	1.27	kN
10	Levitation magnet main pole force 7,i+1	$P_{z,HP7,30,i+1}$	$P_{z,HP,i+1}$ - $R_{TMTi,30\%}$ · 2 / 18	1.14	kN
11	Levitation magnet main pole force 8,i+1	$P_{z,HP8,30,i+1}$	$P_{z,HP,i+1}$ - $R_{TMTi,30\%}$ · 3 / 18	1.02	kN
12	Levitation magnet main pole force 9,i+1	$P_{z,HP9,30,i+1}$	$P_{z,HP,i+1}$ - $R_{TMTi,30\%}$ · 4 / 18	0.89	kN
13	Levitation magnet main pole force 10,i+1	$P_{z,HP10,30,i+1}$	$P_{z,HP,i+1}$ - $R_{TMTi,30\%}$ · 5 / 18	0.76	kN
14	Levitation magnet terminal pole force i+1	$P_{z,EP,30,i+1}$	$P_{z,EP,i+1}$ - $R_{TMTi,30\%}$ · 3 / 18	0.31	kN

Table 139 - Levitation magnet pole forces with 30% rearrangement (standard levitation magnet)

<u>With 30% rearrangement for front and rear-mounted levitation magnets</u> (see fig. 181)				Example	
1	Line load, part magnets i, i+1	$p_{z,az,EG/MG/ZG/HG,TMT_i} \geq p_{z,az,EG/MG/ZG/HG,TMT_{i+1}}$	from equation 15	10 5	kN/m
2	Result of the uneven distribution TMT_i	$R_{TMTi,30\%}$	$p_{z,az,EG/MG/ZG/HG,TMT_i} \cdot 30\% \cdot L_{sys,TMT,Bug/Heck} / 2$	3.12	kN
3	Levitation magnet terminal pole force i	$P_{z,EP,30,i}$	$P_{z,EP,i} + R_{TMTi,30\%} \cdot 4 / 32$	1.77	kN
4	Levitation magnet main pole force 1,i	$P_{z,HP1,30,i}$	$P_{z,HP,i} + R_{TMTi,30\%} \cdot 7 / 32$	3.45	kN
5	Levitation magnet main pole force 2,i	$P_{z,HP2,30,i}$	$P_{z,HP,i} + R_{TMTi,30\%} \cdot 6 / 32$	3.36	kN
6	Levitation magnet main pole force 3,i	$P_{z,HP3,30,i}$	$P_{z,HP,i} + R_{TMTi,30\%} \cdot 5 / 32$	3.26	kN
7	Levitation magnet main pole force 4,i	$P_{z,HP4,30,i}$	$P_{z,HP,i} + R_{TMTi,30\%} \cdot 4 / 32$	3.16	kN
8	Levitation magnet main pole force 5,i	$P_{z,HP5,30,i}$	$P_{z,HP,i} + R_{TMTi,30\%} \cdot 3 / 32$	3.06	kN
9	Levitation magnet main pole force 6,i	$P_{z,HP6,30,i}$	$P_{z,HP,i} + R_{TMTi,30\%} \cdot 2 / 32$	2.97	kN
10	Levitation magnet main pole force 7,i	$P_{z,HP7,30,i}$	$P_{z,HP,i} + R_{TMTi,30\%} \cdot 1 / 32$	2.87	kN
11	Levitation magnet main pole force 8,i+1	$P_{z,HP8,30,i+1}$	$P_{z,HP,i+1} - R_{TMTi,30\%} \cdot 1 / 18$	1.23	kN
12	Levitation magnet main pole force 9,i+1	$P_{z,HP9,30,i+1}$	$P_{z,HP,i+1} - R_{TMTi,30\%} \cdot 2 / 18$	1.06	kN
13	Levitation magnet main pole force 10,i+1	$P_{z,HP10,30,i+1}$	$P_{z,HP,i+1} - R_{TMTi,30\%} \cdot 3 / 18$	0.88	kN
14	Levitation magnet main pole force 11,i+1	$P_{z,HP11,30,i+1}$	$P_{z,HP,i+1} - R_{TMTi,30\%} \cdot 4 / 18$	0.71	kN
15	Levitation magnet main pole	$P_{z,HP12,30,i+1}$	$P_{z,HP,i+1} - R_{TMTi,30\%} \cdot 5 / 18$	0.54	kN

	force 12,i+1				
16	Levitation magnet terminal pole force i+1	$P_{z,EP,30,i+1}$	$P_{z,EP,i+1} - R_{TMTi,30\%} \cdot 3 / 18$	0.18	kN

Table 140 - Levitation magnet pole forces with 30% rearrangement (front and rear-mounted levitation magnets)

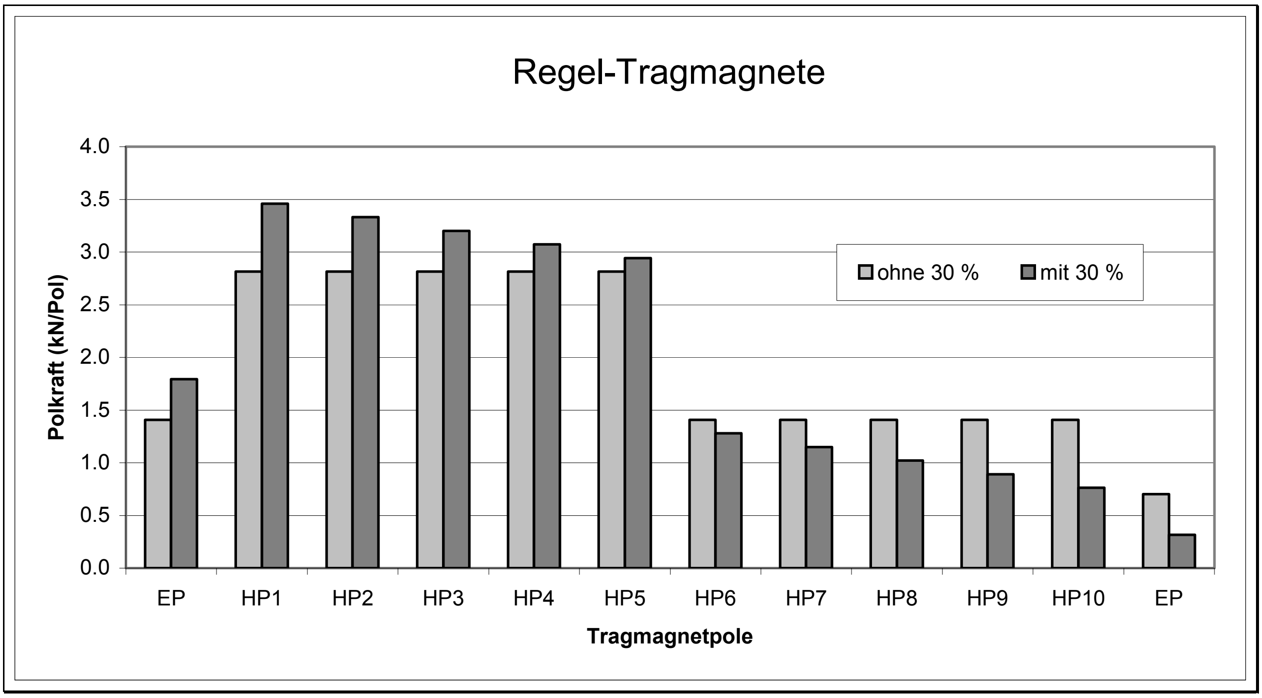


Fig. 180 - Levitation magnet pole forces; example of standard levitation magnets

[Key to diagram:
Regel-Tragmagnete = standard levitation magnets
ohne 30% = less 30%
mit 30% = plus 30%
Polkraft = pole force
Tragmagnetpole = levitation magnet poles]

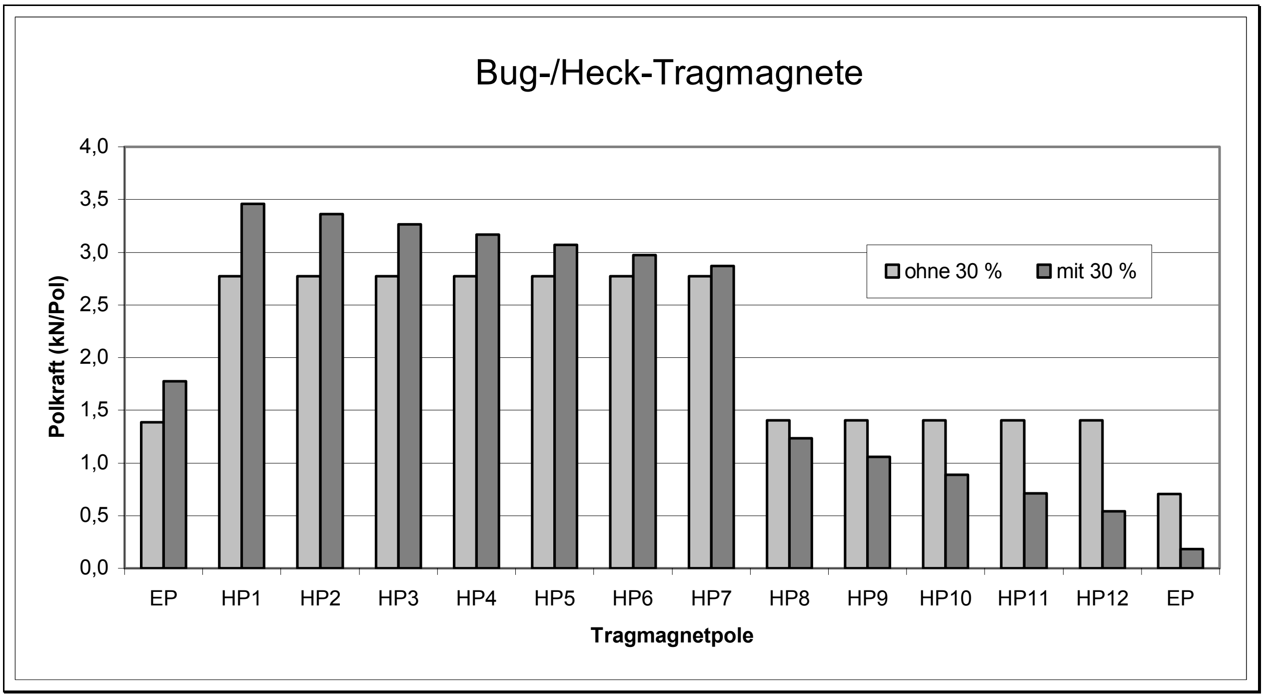


Fig. 181 - Levitation magnet pole forces; example of front and rear-mounted levitation magnets

[Key to diagram:
Bug-/Heck-Tragmagnete = front and rear-mounted levitation magnets
ohne 30% = less 30%
mit 30% = plus 30%
Polkraft = pole force
Tragmagnetpole = levitation magnet poles]

Principles for the design of high-speed maglev systems

Guideway
Part III
Geometry

Distributor

This document was released for publication by the Guideway Technical Committee.

Revision history

Date of release: 15.02.2007, White Paper published by the Guideway Technical Committee

Table of contents

List of diagrams

General

Object and area of application

This document sets out in detail the generally applicable technical requirements concerning the guideway geometry of the maglev train system.

These design principles apply to a maglev train in accordance with the General Maglev Systems' Act.

Document structure

These design principles set out in detail the geometric requirements pertaining to the functional levels of maglev train support structures.

Requirements concerning the precise positioning of the girders are set out in the Guideway design principles for high-speed maglev systems - Part IV: Surveying.
The explanatory notes concerning positional deviations, specifications and tolerances assist in a basic understanding of the construction of a maglev train guideway.

Based on the correlation between the individually stipulated limit values, taking into account the system as a whole, the limit values may be shifted in either direction. The requirements as per the Principles concerning the overall system design of high-speed maglev systems are included in the overall assessment in this regard.

The limit values indicated assist in observing the travel comfort offered by the system as a whole as well as its technical requirements.

Explanatory note concerning application

The document defines the permitted variations and positional deviations in the functional levels of the support structures which are to be observed in the equipped and precisely positioned states, without a live load, the only load coming from the girder's own weight.

In a further step, taking into account the envisaged manufacturing process, the manufacturing tolerances concerning guideway manufacture (the raw materials used in the guideway, its equipment and assembly) and maintenance shall be derived from this.

Unless expressly noted to the contrary, all data relates to a guideway under a project-specific reference temperature.

All data relates to the functional levels in the placed, coated state.

The stipulation of requirements in terms of guideway dimensions (e.g. limit values in terms of the permissible deviation, in combination with the guideway's deformation) is essentially based on experiences with guideways which have been tested previously and their interaction with magnetic trains which are driven under test and operational conditions.

The individual permitted variations partly produce overlaps during an overall tolerance assessment. With additional tolerance stipulations or those which are independent from one another, care must be taken that the respective individual tolerance is observed or that those stipulations with smaller tolerance values have priority.

If the document does not list permissible deviations of individual functional levels in terms of form and position, from the point of view of the system as a whole, there is no inducement to this end.

This case presupposes a manufacturing tolerance as per DIN ISO 2768-1 and DIN ISO 2768-2.

Principles for the design of high-speed maglev systems

This document is part of the documentation relating to high-speed maglev systems consisting of several design principles. The document tree is presented in fig. 1 of the Principles concerning the overall system design of high-speed maglev systems.

The primary overall system design documentation and its annexes apply in a uniform manner to the documentation as a whole:

- Principles concerning the overall system design of high-speed maglev systems, document number 50630, and its annexes:
  - Annex 1: Abbreviations and definitions, document number 67536 [Principles for the design of high-speed maglev systems - Abbreviations and definitions]
  - Annex 2: Acts, Orders, Standards and Guidelines, document number 67539 [Principles for the design of high-speed maglev systems - Standards and guidelines]
  - Annex 3: Environmental conditions, document number 67285 [Principles for the design of high-speed maglev systems - The environment]
  - Annex 4: Rules for operation (driving and maintenance), document number 69061 [Principles for the design of high-speed maglev systems - Driving and maintenance]
  - Annex 5: Sound, document number 72963 [Principles for the design of high-speed maglev systems - Sound]

Abbreviations and definitions

The abbreviations and definitions specified in the Principles for the design of high-speed maglev systems - Abbreviations and definitions - apply.

Acts, Orders, Standards and Guidelines

The normative documents listed in the Principles for the design of high-speed maglev systems - Standards and guidelines, contain stipulations which, by reference to the Principles for the design of high-speed maglev systems, become part of the same. Later amendments or revisions to these publications do not apply to dated, normative documents found in the Principles for the design of high-speed maglev systems - Standards and guidelines. Where references are not dated, the most recent version of the normative document referred to applies.

The status of the standards and guidelines to be taken into consideration in a maglev train project must be laid down in a binding manner specific to the project.

Indicating requirements and their binding nature

The provisions pursuant to DIN 820 were essentially applied when preparing this document.

In the chapters following and the annexes to this document,

- requirements are set out in standard type and
- explanatory notes, standard values and examples are set out in italics

(refer to the Guideway design principles for high-speed maglev systems - Part I: Principle requirements).

Clearances for built-in guideway fixtures

The placement clearances for guideway equipment which is specific to high-speed maglev systems are laid down below in figs. 182, 183 and 184 based on the Principles concerning the overall system design of high-speed maglev systems. In addition, the dimensions specified in the Annex of the Guideway design principles for high-speed maglev systems - Part I: Principle requirements, in relation to standard guideway types must be observed as standard gauges.

A definition of “clearance” is to be found in the Guideway design principles for high-speed maglev systems - Part IV: Alignment.

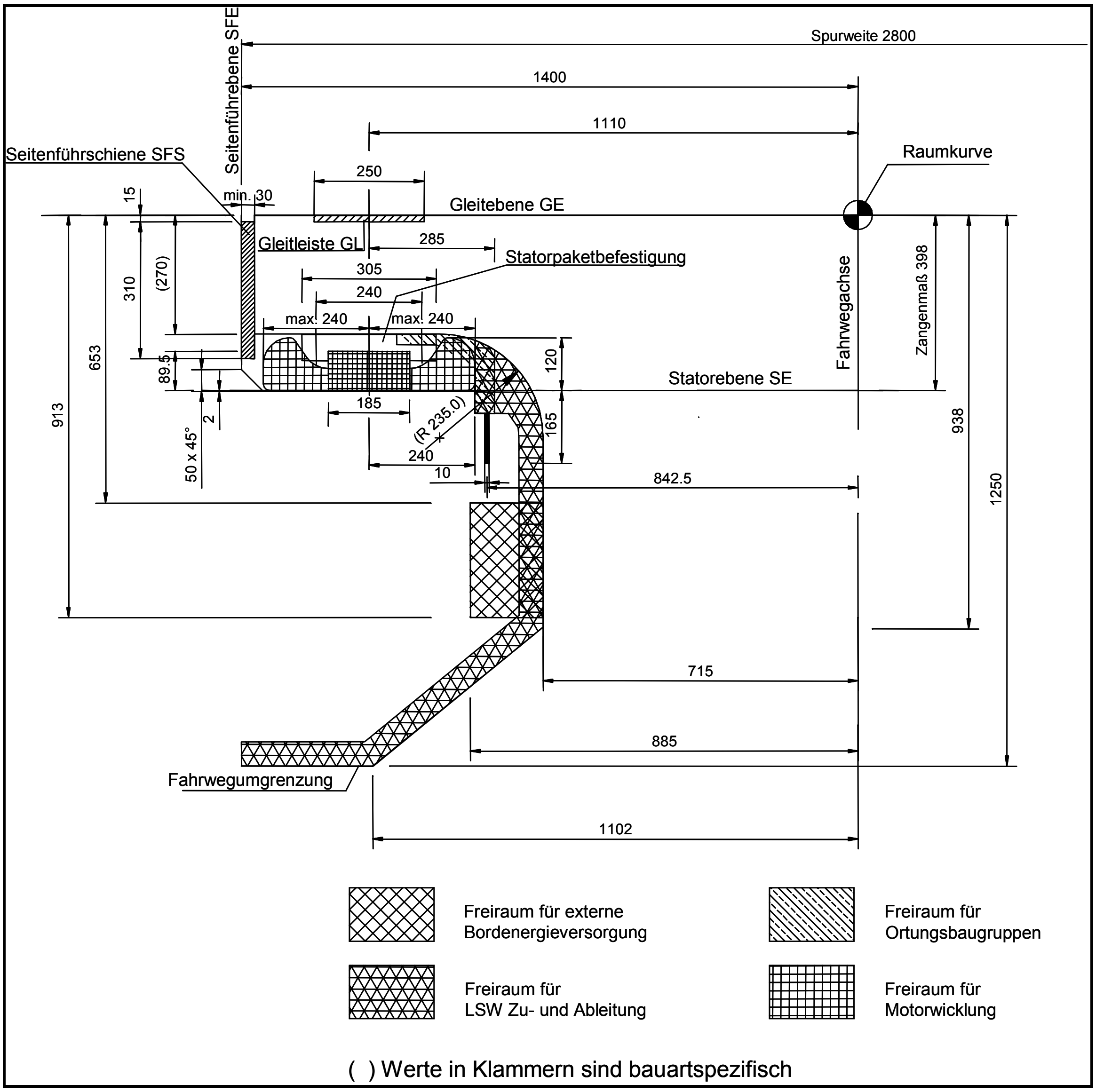


Fig. 182: Clearances for the guideway equipment which is specific to high-speed maglev systems and the support structures

[Key to diagram:
Spurweite = guideway gauge
Seitenführebene = lateral guide level

Seitenführschiene = lateral guide rail
Raumkurve = space curve
Gleitebene = slider level
Gleitleiste = slider strip
Statorpaketbefestigung = stator plate attachment
Fahrwegachse = guideway axis
Zangenmaß = hover clearance
Statorebene = stator level
Fahrwegumgrenzung = guideway boundary
Freiraum für externe Bordenergieversorgung = clearance for external inductive power supply
Freiraum für Ortungsbaugruppen = clearance for location-finding assemblies
Freiraum für LSW Zu- und Ableitung = clearance for LSW supply lines and offtakes
Freiraum für Motorwicklung = clearance for motor winding
Werte in Klammern sind bauartspezifisch = the values in brackets are specific to the design]

Explanatory notes to fig. 182:

1) *The guideway boundary line describes the maximum feasible wrap-around of the support structure, including its tolerances.*
2) *Design-specific deviations from the guideway boundary line are only permitted once they have been tested for compatibility with the system as a whole.*
3) *Provision is made for a clearance for securing the guideway equipment between that equipment which is specific to high-speed maglev systems and the support structures. The size of this clearance depends on the choice of mounting structure and requires a check confirming its compatibility with the system as a whole.*

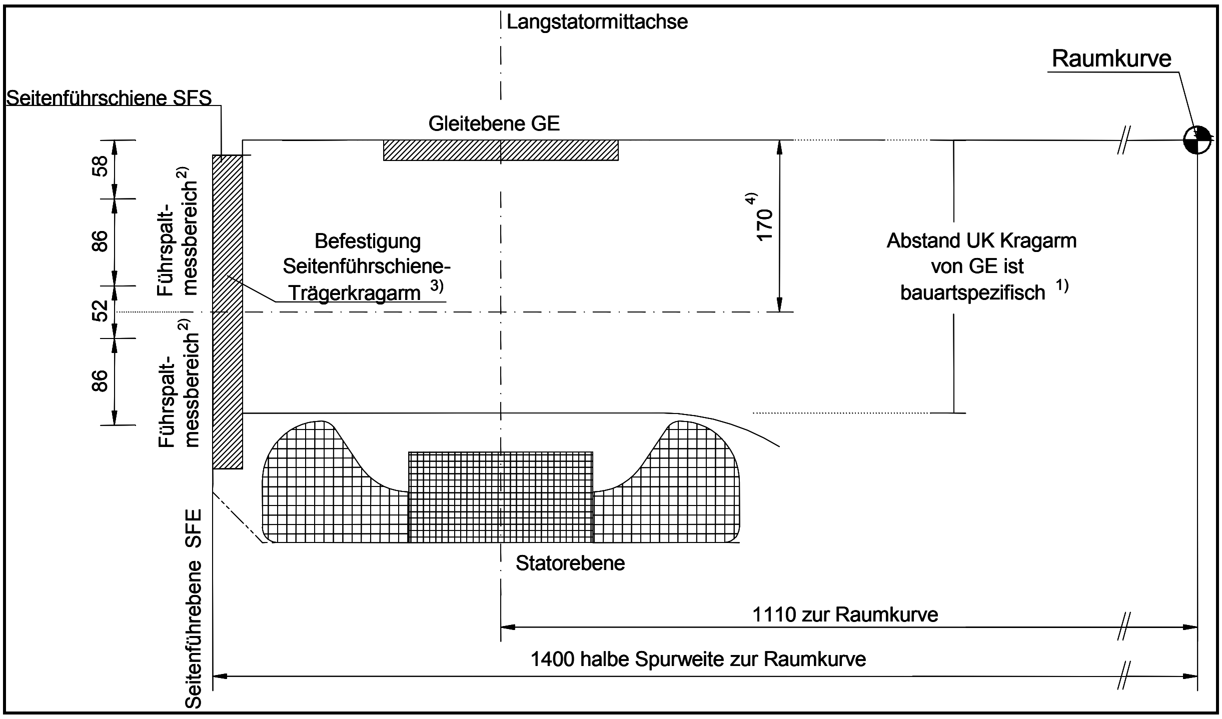


Fig. 183: Guide span position

[Key to diagram:
Langstatormittachse = centre axis of the longitudinal stator
Raumkurve = space curve
Seitenführschiene = lateral guide rail
Gleitebene = slider level
Führspaltmessbereich = guide span
Befestigung Seitenführschiene-Trägerkragarm = lateral guide rail girder jib boom attachment
Abstand UK Kragarm von GE ist bauartspezifisch = the distance between the bottom side of the jib boom and the slider level is specific to the design
Seitenführebene = lateral guide level
Statorebene = stator level
zur Raumkurve = in relation to the space curve
halbe Spurweite zur Raumkurve = half the guideway gauge in relation to the space curve]

Explanatory notes to fig. 183:

1) *The distance between the bottom side of the jib boom and the slider level is specific to the design and is established by the type of stator plate mounting and the motor winding housing.*
2) *The guide sensor areas depicted correspond to the position when the vehicle is hovering with a reference loadbearing gap of 10 mm.*
3) *The mounting for the lateral guide rails and the clearance which is required shall be stipulated in accordance with the particular design.*
4) *Centre point of the guidance magnets of the hovering vehicle with a reference loadbearing gap of 10 mm;*

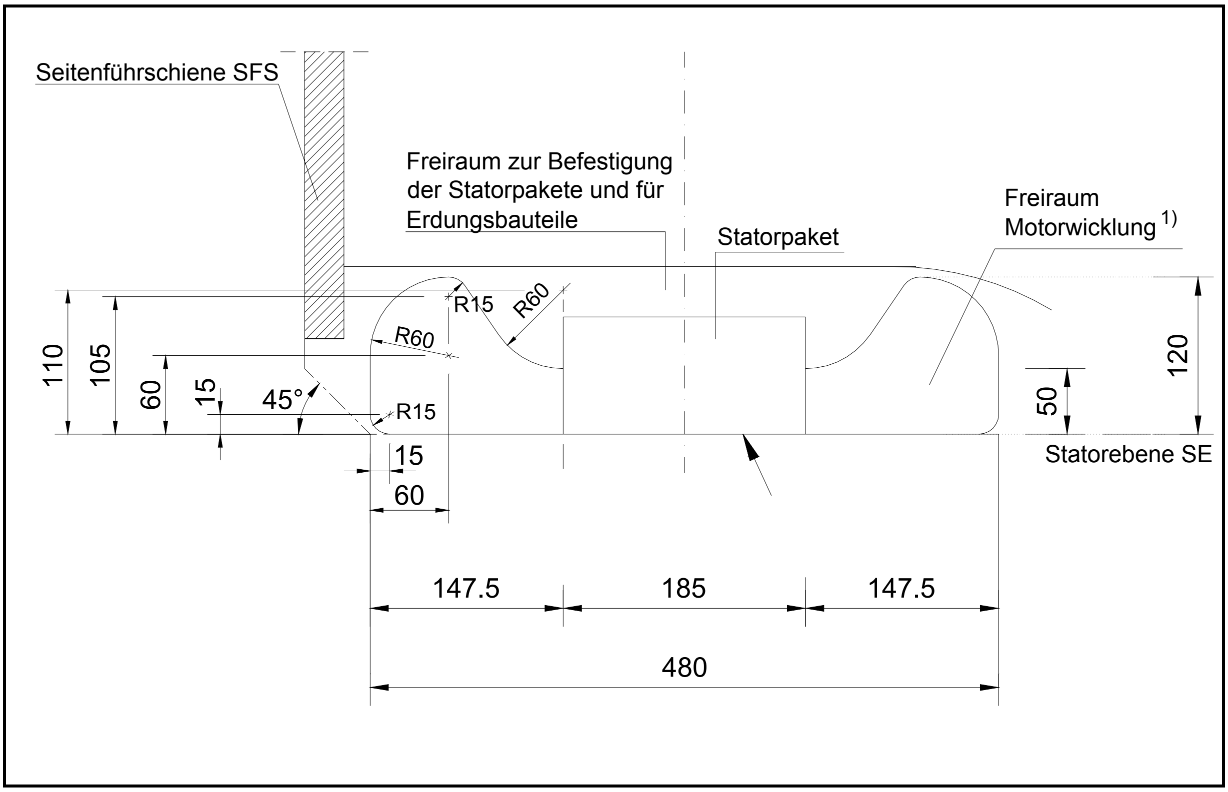


Fig. 184: Long stator winding housing

[Key to diagram:
Seitenführschiene = lateral guide rail
Freiraum zur Befestigung der Statorpakete und für Erdungsbauteile = clearance for attaching the stator plates and for earthing elements
Statorpaket = stator plate
Freiraum Motorwicklung = clearance for motor winding
Statorebene = stator level]

Explanatory notes to fig. 184:

1) *The motor winding housing depicted also takes into account the space required by the motor winding cable for the assembly process. The clearances required by the mounting device lie within the vehicle's gauge.*

Dimensional relationships, principal measuring points, reference planes and influencing variables

Functional levels and principal measuring point locations

The locations of the functional levels and the associated measuring points in the x, y and z directions are depicted in figs. 185, 186, 187 and 188.

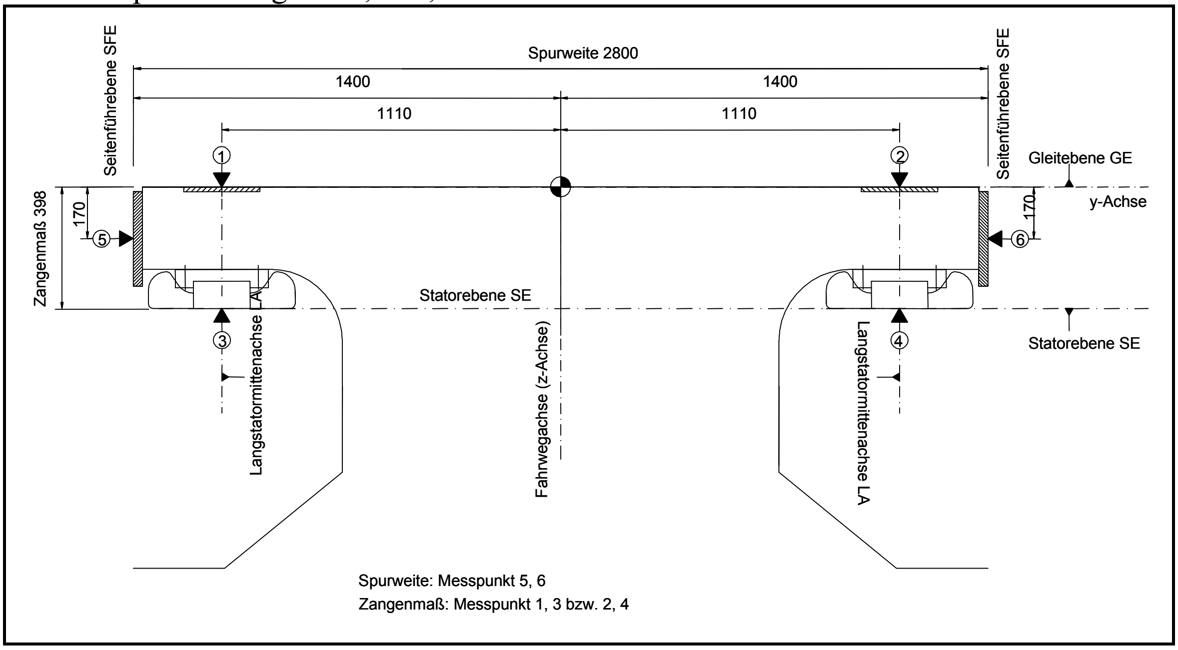


Fig. 185: Functional levels and principle measuring points in the y and z directions

[Key to diagram:
Spurweite = guideway gauge
Seitenführebene = lateral guide level
Gleitebene = slider level
Zangenmaß = hover clearance
y-Achse = y-axis
Statorebene = stator level
Langstatormittenachse = centre axis of the longitudinal stator
Fahrwegachse (z-Achse) = guideway axis (z-axis)
Spurweite: Messpunkt 5, 6 = guideway gauge: measuring points 5, 6
Zangenmaß: Messpunkt 1, 3 bzw. 2, 4 = hover clearance: measuring points 1, 3 or 2, 4]

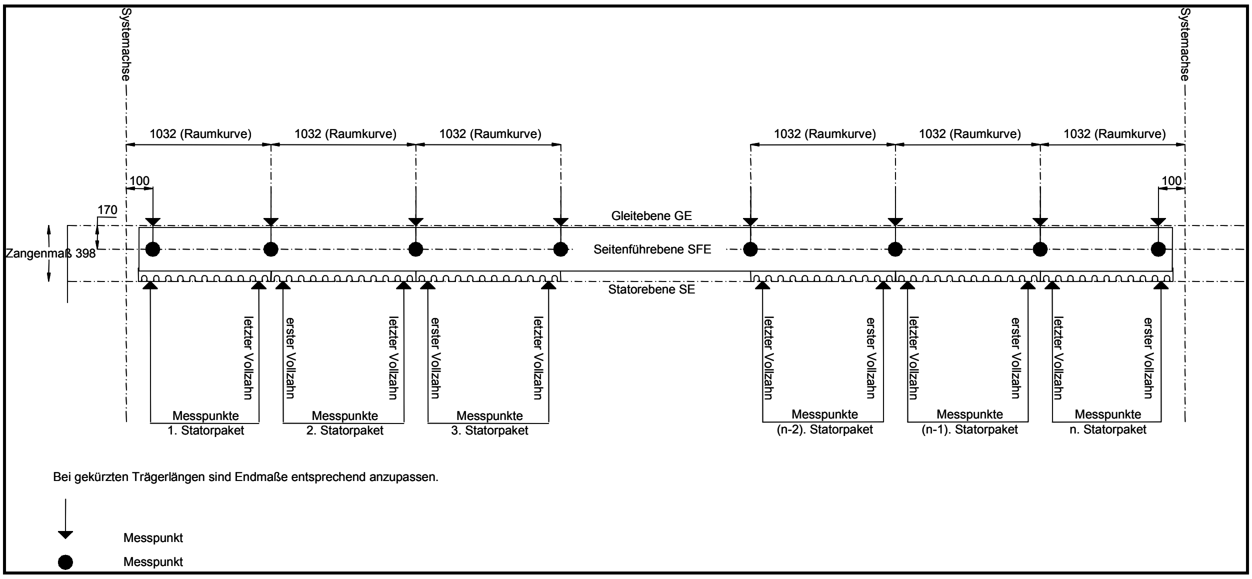


Fig. 186: Principal measuring points in the x and z directions

[Key to diagram:
Systemachse = system axis
Raumkurve = space curve
Zangenmaß = hover clearance
Gleitebene = slider level
Seitenführebene = lateral guide level
Statorebene = stator level
letzter Vollzahn = last full-depth tooth
erster Vollzahn = first full-depth tooth
Messpunkte = measuring points
Statorpaket = stator plate
Bei gekürzten Trägerlängen sind Endmaße entsprechend anzupassen = with shorter girder lengths, the final dimensions shall be adapted accordingly
Messpunkt = measuring point]

The principal measuring point locations in the x direction (refer to fig. 186 for the longitudinal direction) shall be selected such that a measured value for evaluation purposes is at least established within the system grid dimension of 1032 mm.

Where functional levels which have already been divided up are present, the gap dividing grid must be observed. In this instance, a measuring point shall be arranged on both sides of the gap.

The first measuring point at the beginning or end of the support structure shall be placed at a uniform distance of 100 mm from the system axis and should be durably marked.

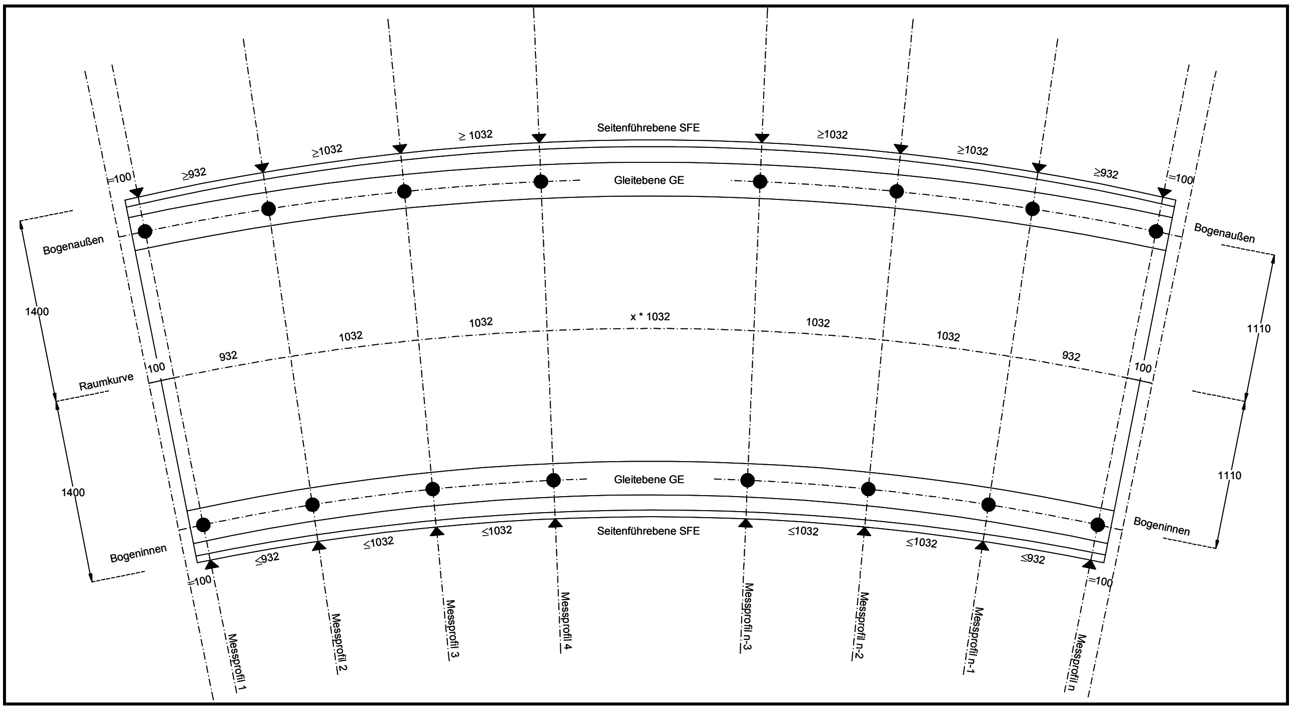


Fig. 187: Principal lateral guide and slider level measuring points

[Key to diagram:
Seitenführebene = lateral guide level
Gleitebene = slider level
Bogenaußen = outer side of the curve
Raumkurve = space curve
Bogeninnen = inner side of the curve
Messprofil = measuring profile]

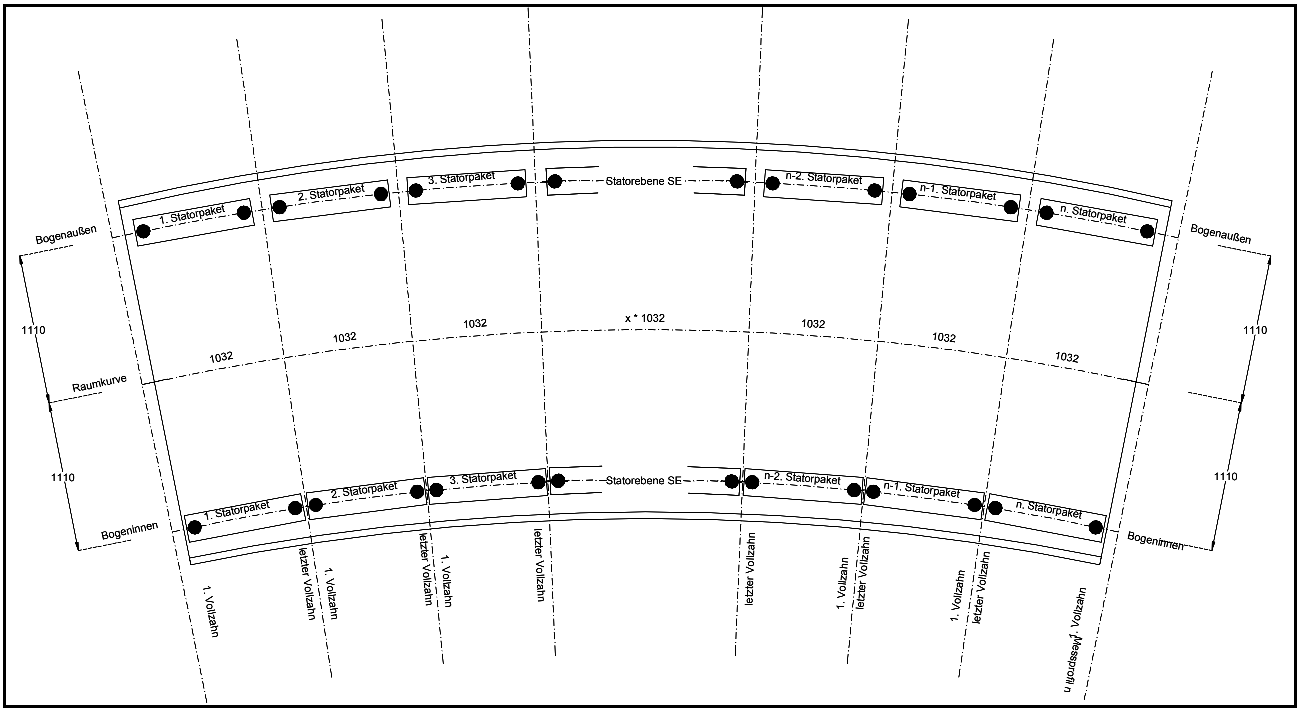


Fig. 188: Principal stator level measuring points

[Key to diagram:
Bogenaußen = outer side of the curve
Statorpaket = stator plate
Statorebene = stator level
Raumkurve = space curve
Bogeninnen = inner side of the curve
1. Vollzahn = first full-depth tooth
letzter Vollzahn = last full-depth tooth
Messprofil = measuring profile]

Requirements pertaining to principal measuring points and measured values

The measured values determined for the principal measuring points must allow a representative statement on the location of the functional level.

This means that measurement procedures and methods which are suitable for determining the measured value shall be applied which eliminate one-off influences on the measuring result (e.g. graduated edges, flaws in the material, local surface finishings, anomalies in the coating).

Coordinate systems

The tolerances given in the document relate to the coordinate axis designations

- y, x, z relate to the space curve coordinate system

  (girder-related sector of the space curve with a redefined zero point, see also Chapter 6.6), and

- Y, X, Z relate to the girder production coordinate system

  (machine-related production coordinate system taken into consideration in the design pre-curvature and production corrections which may be required).

Fig. 189 presents the correlations.

As regards work on the building site (staking out, constructing foundations, precise positioning of the guideway), the coordinates of the maglev train coordinate system are used.

(refer to the Guideway design principles for high-speed maglev systems - Part IV: Surveying regarding the x, y and z coordinates in the maglev train coordinate system)

The beginning and end coordinates of the support structures from the space curve coordinate system are transformed into the maglev train coordinate system at the same time via reference points.

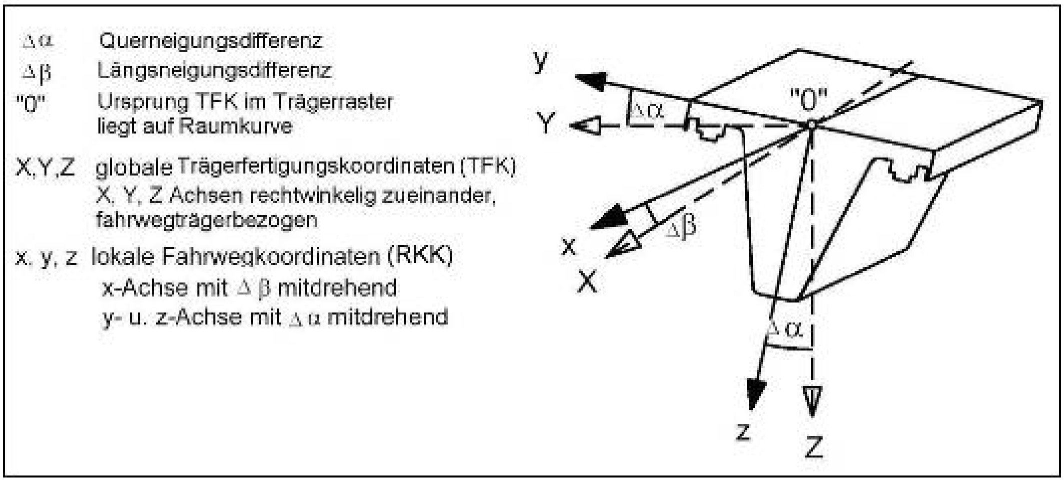


Fig. 189: Geometric correlation between the coordinate systems (girder production coordinate system and local guideway coordinates)

[Key to diagram:
Querneigungsdifferenz = lateral incline differential
Längsneigungsdifferenz = longitudinal gradient differential
Ursprung TFK im Trägerraster liegt auf Raumkurve = the zero point of the girder fabrication coordinates in the girder grid lies on the space curve
globale Trägerfertigungskoordinaten (TFK)
X, Y, Z Achsen rechtwinkelig zueinander, fahrwegträgerbezogen =
global girder production coordinates
X, Y, Z axes at right angles to one another, relative to the guideway
lokale Fahrwegkoordinaten (RKK)
x-Achse mit △ β mitdrehend
y- u. z-Achse mit △ α mitdrehend =
local guideway coordinates

x-axis with △ β rotating in the same direction
y- and Z-axes with △ α rotating in the same direction]

System and building component lengths

All measurements along the space curve which represent a multiple of 86 mm (this corresponds to a groove/tooth period according to the Principles concerning the overall system design of high-speed maglev systems) can be designated system lengths. Support structure lengths are specified when converting the route into system lengths.
Their actual length (building component length) depends on the design of the functional levels at the beginning and end of the support structure, as well as the horizontal and vertical radii (see fig. 190).

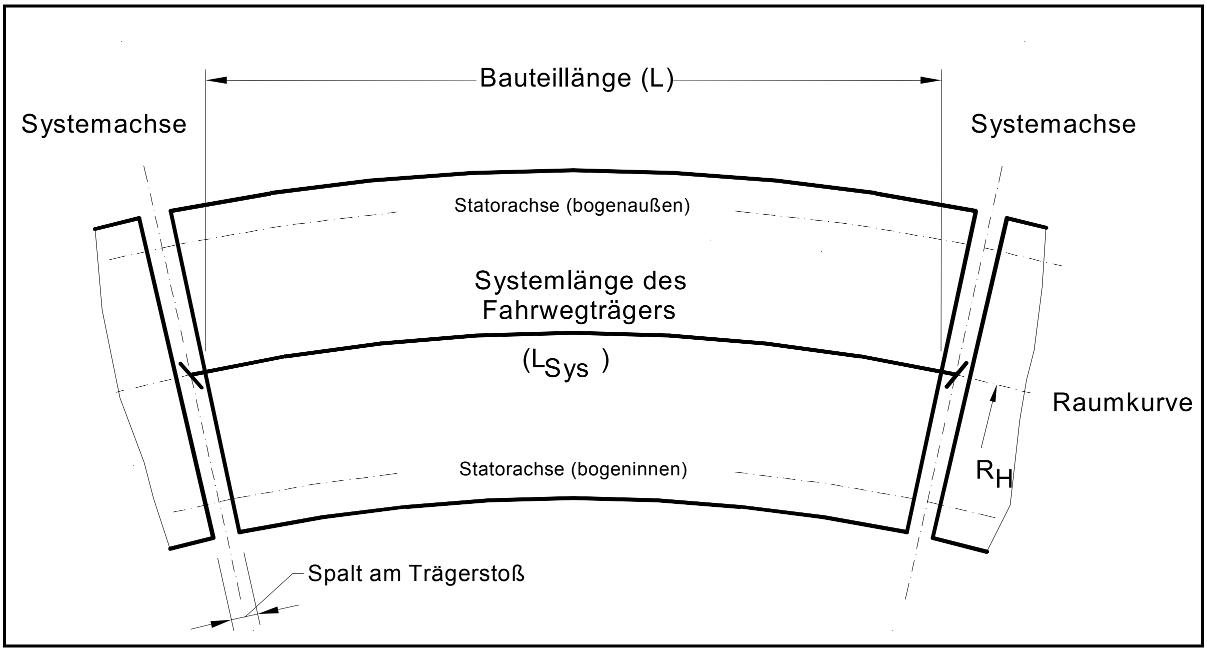


Fig. 190: Correlation between building component length and system length

[Key to diagram:
Bauteilänge = building component length
Systemachse = system axis
Statorachse (bogenaußen) = stator axis (outer side of the curve)
Systemlänge des Fahrwegträgers = system length of the support structure
Raumkurve = space curve
Statorachse (bogeninnen) = stator axis (inner side of the curve)
Spalt am Trägerstoß = opening in the girder joint]

Sign stipulations

The sign conventions facilitate a clear interpretation of the maglev train / guideway interface on the following basis:
When considered from the point of view of increasing chainage (positive x direction), a negative sign always indicates a deviation towards the space curve, while a positive sign points to a deviation away from the same curve or towards the outside. Regarding the guideway gauge, a negative sign therefore indicates a reduction, and a positive sign an increase, in the guideway gauge.

When applying the following equations, a clear direction of the deviation from the theoretical position is possible by means of the result sign. In the case of vibrations in elements, the displacement *shall be calculated by extrapolating measuring lines (each time from 2 measuring points) with the axes of intersection.*

- *Refer to fig. 191 for the sign convention for lateral guide level displacement:*

right side: $\Delta y = -y_i + y_{i+1}$ Equation 7

left side: $\Delta y = y_i - y_{i+1}$ Equation 8

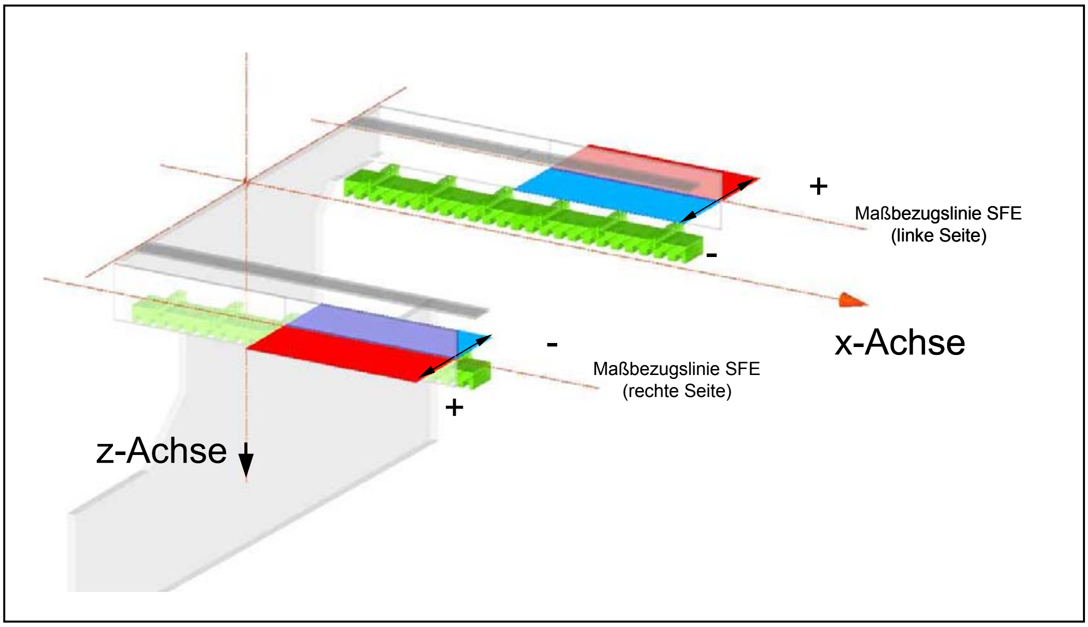


Fig. 191: Lateral guide level displacement, tolerance zone with sign allocation as per equations 7 and 8

[Key to diagram:
Maßbezugslinie SFE (linke Seite) = zero-datum line, lateral guide level (left side)
Maßbezugslinie SFE (rechte Seite) = zero-datum line, lateral guide level (right side)
x-Achse = x-axis
z-Achse = z-axis]

- Refer to fig. 192 for the sign convention for stator level displacement:

$\Delta z = -z_i + z_{i+1}$ Equation 9

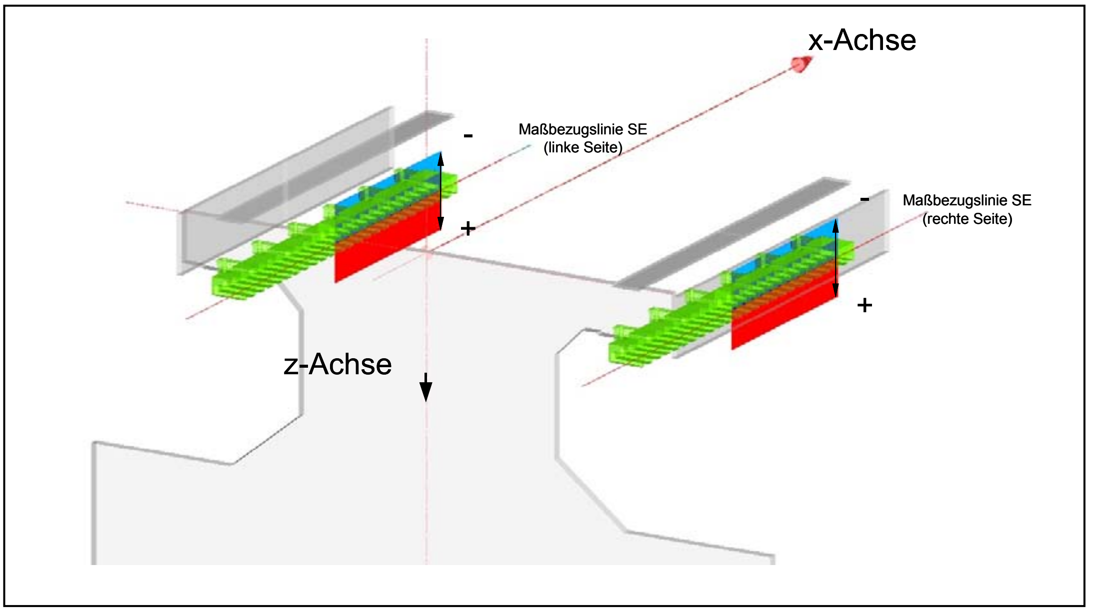


Fig. 192: Stator level displacement, tolerance zone with sign allocation as per equation 3

[Key to diagram:
Maßbezugslinie SE (linke Seite) = zero-datum line, stator level (left side)
Maßbezugslinie SE (rechte Seite) = zero-datum line, stator level (right side)
x-Achse = x-axis
z-Achse = z-axis]

- Refer to fig. 193 for the sign convention for slider level displacement:

$$\Delta z = z_i - z_{i+1}$$ Equation 10

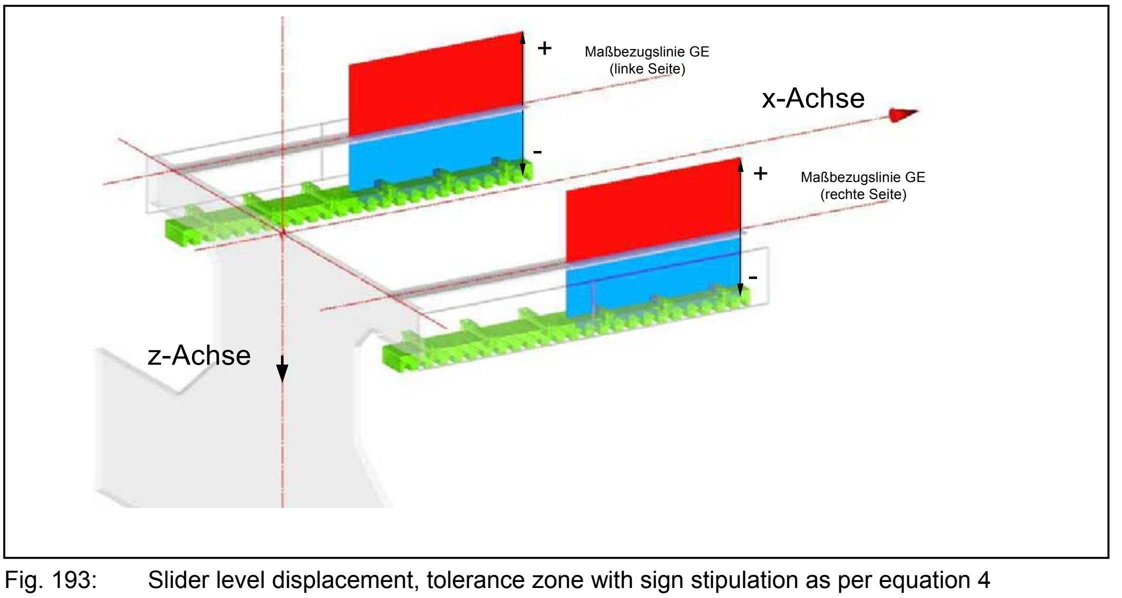


Fig. 193: Slider level displacement, tolerance zone with sign stipulation as per equation 4

[Key to diagram:
Maßbezugslinie GE (linke Seite) = zero-datum line, slider level (left side)
Maßbezugslinie GE (rechte Seite) = zero-datum line, slider level (right side)
x-Achse = x-axis
z-Achse = z-axis]

- *Refer to fig. 194 for the sign convention for altering the guideway gauge (S):*

$$\Delta y_s = -S_i + S_{i+1};\ S_i = \left|y_{i_1}\right| + \left|y_{i_2}\right|$$ Equation 11

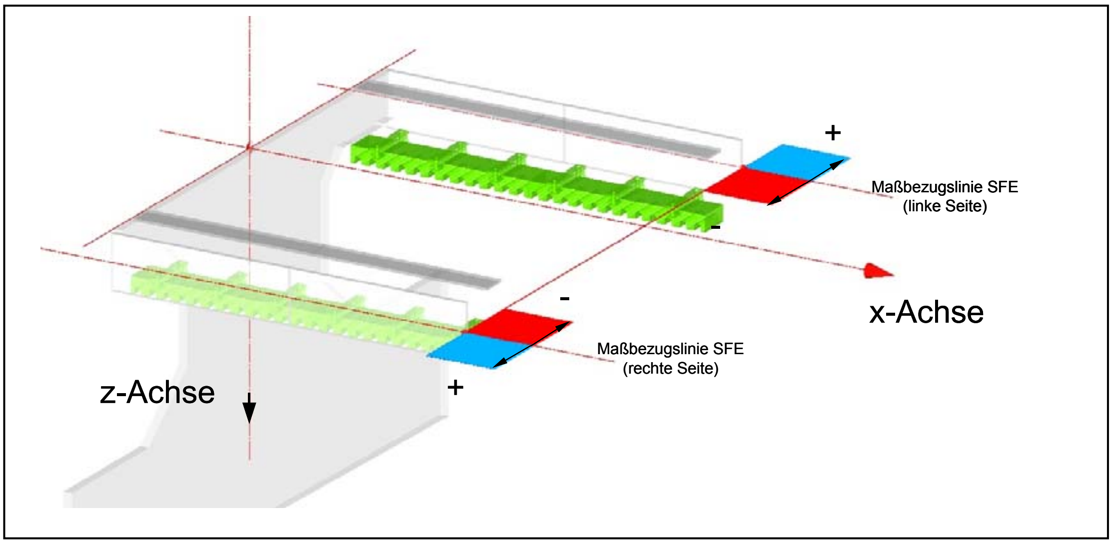


Fig. 194: Altering the guideway gauge, tolerance zones with sign stipulation as per equation 11

[Key to diagram:
Maßbezugslinie SFE (linke Seite) = zero-datum line, lateral guide level (left side)
Maßbezugslinie SFE (rechte Seite) = zero-datum line, lateral guide level (right side)
x-Achse = x-axis
z-Achse = z-axis]

- *The sign convention for the gradient-altering criterion of the lateral guide level within the girder, and at the girder joint and element transition, is extrapolated in accordance with equation 14 while observing the intervals between measuring points. Refer to fig. 195 for the graphic representation of the sign convention:*

right side:

$$NGK_{SFE} = 2 * \left[-y_i + \left(\frac{y_{i-1} + y_{i+1}}{2} \right) \right]$$ Equation 12

left side:

$$NGK_{SFE} = 2 * \left[y_i - \left(\frac{y_{i-1} + y_{i+1}}{2} \right) \right]$$ Equation 13

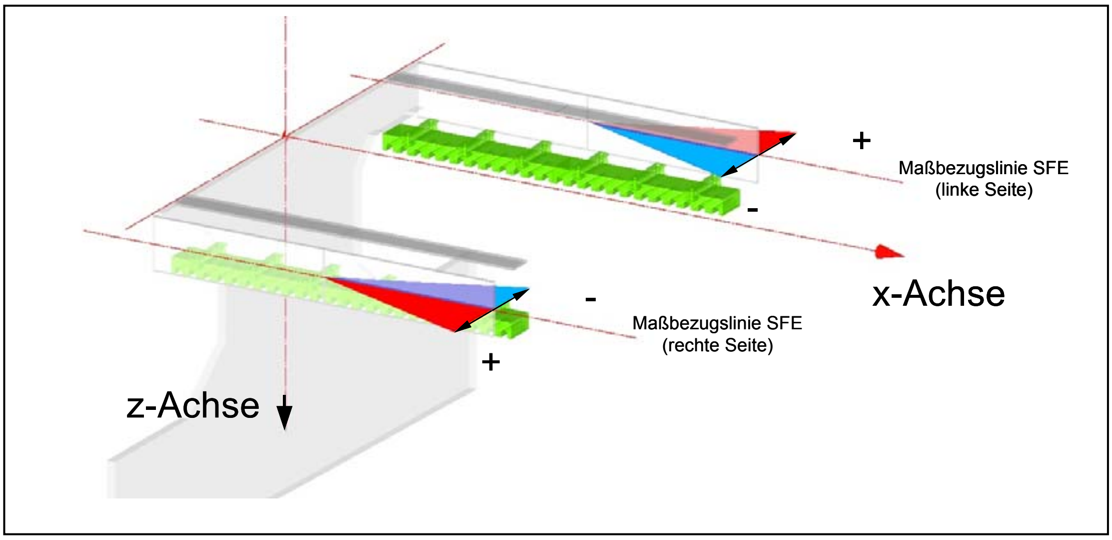


Fig. 195: Gradient-altering criterion of the lateral guide level, tolerance zones and sign stipulation as per equations 12 and 13

[Key to diagram:
Maßbezugslinie SFE (linke Seite) = zero-datum line, lateral guide level (left side)
Maßbezugslinie SFE (rechte Seite) = zero-datum line, lateral guide level (right side)
x-Achse = x-axis
z-Achse = z-axis]

- *The sign convention for the gradient-altering criterion of the stator level over four measuring points (first and last full-depth tooth of the stator plate numbered continuously (z_1, z_2, z_3 and z_4)).* Refer to fig. 196 for the graphic representation of the sign:

$$NGK_{SE} = \left[(z_1 - z_2) + (z_4 - z_3) \right] * \frac{1000}{860}$$ Equation 14

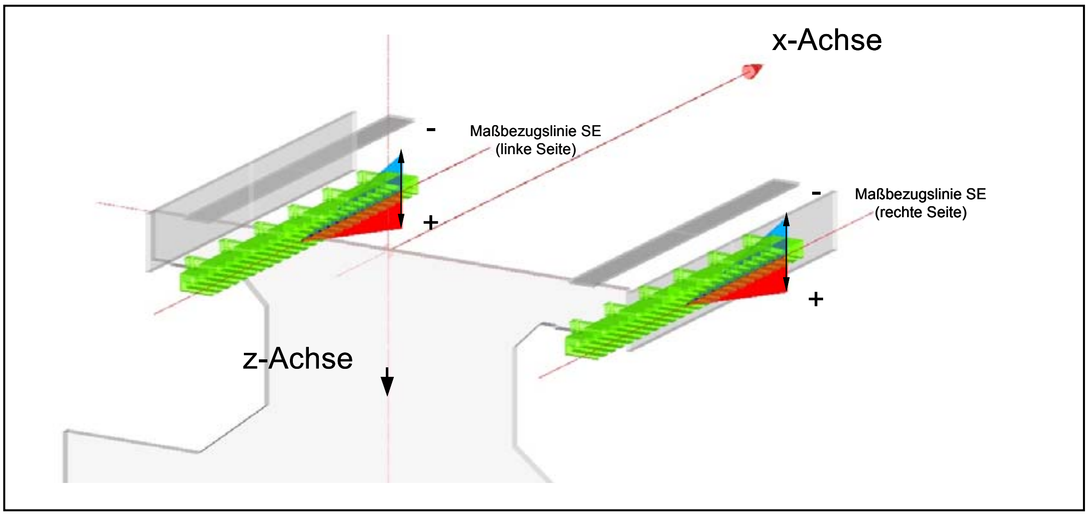


Fig. 196: Gradient-altering criterion of the stator level, tolerance zones with sign allocation as per equation 14

[Key to diagram:
Maßbezugslinie SE (linke Seite) = zero-datum line, stator level (left side)

Maßbezugslinie SE (rechte Seite) = zero-datum line, stator level (right side)
x-Achse = x-axis
z-Achse = z-axis]

- *Refer to fig. 197 for the sign convention for the gradient-altering criterion of the slider level:*

$$NGK_{GLE} = 2 * \left[z_i - \left(\frac{z_{i-1} + z_{i+1}}{2} \right) \right]$$ Equation 15

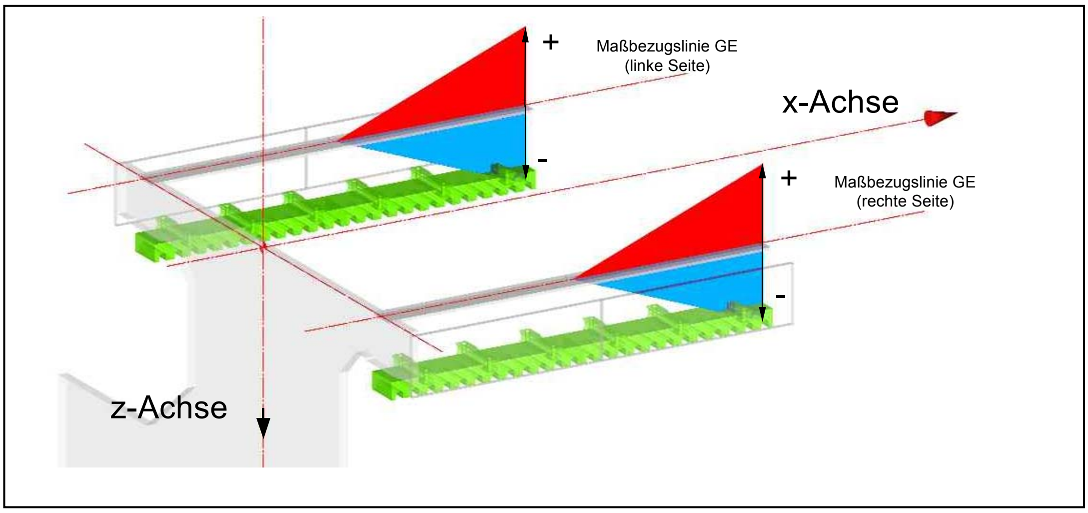


Fig. 197: Gradient-altering criterion of the slider level, tolerance zones with sign allocation as per equation 15

[Key to diagram:
Maßbezugslinie GE (linke Seite) = zero-datum line, slider level (left side)
Maßbezugslinie GE (rechte Seite) = zero-datum line, slider level (right side)
x-Achse = x-axis
z-Achse = z-axis]

Definitions and stipulations for tolerances and positional deviations

The tolerances and positional deviations described below relate exclusively to the girder production coordinate system.
Assuming a bearing arrangement, a distinction is drawn between simple beams, two-span beams and multiple span girders as well as gauge change devices.
When stipulating the tolerance zones, guideway plates are treated as simple beams.
In the diagrams which follow, the x-axis of the coordinate system mirrors the layout of the space curve.

Design precurvature

The design precurvature is designed to compensate the deflection of the support structure in the z direction as a result of the live load (mean vehicle weight under normal load conditions as per the Guideway design principles for high-speed maglev systems - Part II: Dimensioning) and also taking into account the project-specific prevailing temperature differentials in the guideway cross-section (change in temperature between the top and bottom booms) under operating conditions. In the case of concrete girders, where necessary, consideration must be given to the creep and shrinkage characteristics over the first 25-30 years (refer to the Guideway design principles for high-speed maglev systems - Part II: Dimensioning).

The aim as regards the guideway functional levels arranged in the z direction is that the reference surface is as flat as possible during operation. In this connection, the progression of the design precurvature generally relates to the position of the stator level under operating conditions (the theoretical position in the operating state corresponds in this connection to the progression of the space curve).
For determining the share of deformation to be taken into consideration as a result of the guideway temperature differential, a project-specific temperature change shall be stipulated (taking into account, inter alia, the design of the girder and the material used in its construction, the typical daytime temperature distribution within the girder and the gradient).
In the load-free theoretical position, for instance, during production (no live load, uniform building component temperature [$\Delta T = 0$ K], the building component temperature = the project-specific reference temperature), the functional levels arranged in the z direction (stator, slider levels) are therefore deflected upwards (see fig. 198, exception: refer to fig. 203 for stipulating the gauge change devices).

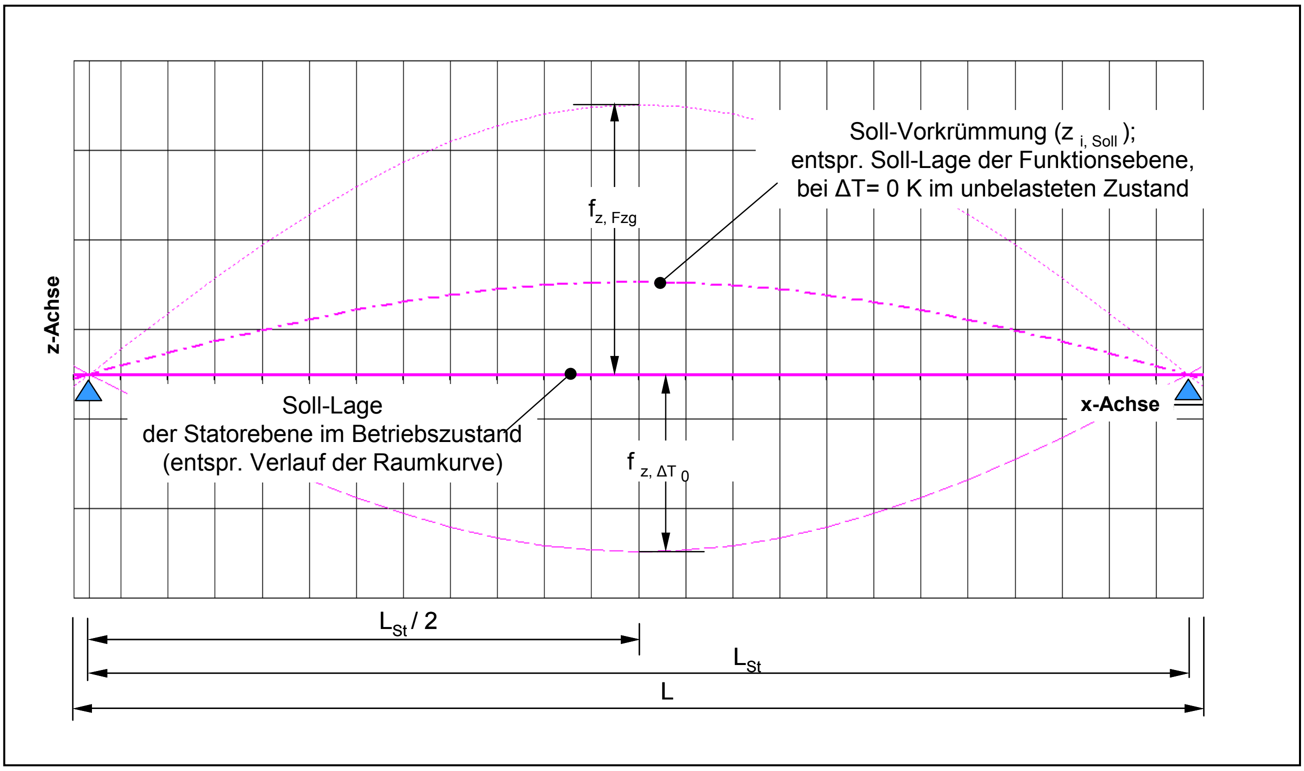


Fig. 198: Design precurvature and its proportions (the diagram does not take account of creep and shrinkage characteristics)

[Key to diagram:
Soll-Vorkrümmung ($z_{i / soll}$); entspr. Soll-Lage der Funktionsebene, bei △T= 0 K im unbelasteten Zustand = design precurvature ($z_{i / soll}$); corresponding to the theoretical position of the functional level, where △T = 0 K in the load-free state
Soll-Lage der Statorebene im Betriebszustand (entspr. Verlauf der Raumkurve) = theoretical position of the stator level in the operating state (corresponding to the progression of the space curve)
x-Achse = x-axis
z-Achse = z-axis]

Design precurvature in the case of simple beams

Between the girder supports, the progression of the design precurvature can be determined in the case of simple beams as per equation 16 (see also fig. 201).
To stipulate the progression of the design precurvature in the support structure areas from the support axes up to the beginning or end of the girder, tangents are laid at the design precurvature curve determined using support axis x values.

The progression of the design precurvature in relation to the z coordinates, by way of example:

$$z_{i,Soll} = z_{max} * \frac{384}{120} * \left(\frac{x_i}{L_{St}} - \frac{2 * x_i^3}{L_{St}^3} + \frac{x_i^4}{L_{St}^4} \right) \quad [mm]$$ Equation 16

Limit values for $z_{max} = f_{z,\,Fzg} - f_{z,\,\Delta T\,o}$ as per the Guideway design principles for high-speed maglev systems - Part II: Dimensioning

Design precurvature in the case of two-span beams

In the case of two-span beams with the same spans, the progression of the design precurvature can be determined for each span from the existing, calculated maximum deflection of the beam where both spans are subjected to loads depending on the length of the beam and its rigidity as per equation 17 (see also fig. 202).
The maximum deflection each time is 0.421* L_{St} viewed from the section support axis.
To stipulate the progression of the design precurvature in the areas of the guideway from the section support axes up to the beginning or end of the girder, tangents are laid at the design precurvature curve determined using support axis x values.
The progression of the design precurvature of two-span beams with unequal spans or different girder section rigidities shall be determined in the same way for every L_i.

The progression of the design precurvature in relation to the z coordinates, by way of example:

$$z_{i,Soll} = z_{max} * \frac{185}{48} * \left(\frac{x_i}{L_{St_i}} - \frac{3 * x_i^3}{L_{St_i}^3} + \frac{2 * x_i^4}{L_{St_i}^4} \right) \quad \text{[mm]}$$

Equation 17

Limit values for $z_{max} = f_{z,\,Fzg} - f_{z,\,\Delta T\,o}$ as per the Guideway design principles for high-speed maglev systems - Part II: Dimensioning

Design precurvature in the case of multiple span girders and gauge change devices

In the case of multiple span girders, a decision shall be reached on taking into account the design precurvature depending on the elastic line which is adjusted and the resulting deflections in the z direction and the end tangent angle at the beginning and end of the girder.
In the case of gauge change devices, as a rule, no design precurvature is taken into consideration.

Long-wave deviation

The definition of long-wave deviation is based, in principle, on the elastic line characteristic of the support structure to which a maximum permitted excursion ("deflection") is assigned in both directions (+/-) for each section under consideration.
The following stipulations are laid down as regards the upper and lower tolerance zone limits in terms of the long-wave deviation from the theoretical position (see also figs. 201, 202 and 203):

- In the case of simple and two-span beams, the x value of the maximum long-wave deviation is consistent with the x value of the maximum theoretical guideway deformation as a result of the impact of loads.
- In the case of simple and two-span beams, the progression from the maximum point to the beginning or end of the support structure may be described by equations 18 and 19 respectively.[28]
  As regards a design precurvature in the functional level which is to be taken into consideration, the limits can be determined in a simplified manner according to equation 20.
- In the case of simple and two-span beams, the functions of the theoretical elastic lines between the support locations are used as a basis for determining the tolerance band for long-

wave deviation. The beginning and end of the girder of the first or final section, as well as the support locations, shall be assigned the absolute value "0".

It is assumed that deviations from "0" which may occur during production at the support locations are compensated during assembly and precise positioning.

- Determining the progression of the precurvature in the case of multiple span girder systems (> 2 sections) does not constitute part of this document.

The actual location of the long-wave deviation (see fig. 199) may be determined from the continuous measured values, taking the functions to be assumed as a basis (see above), using Gauss' law of errors and the method of least squares, or by means of areal compensation.

The actual progression determined in this way as a function f(x) of the functional level considered, in conjunction with the superimposed tolerance zone of the short-wave deviation reflects the maximum possible deviations in terms of the continuous measured values from the actual location of the long-wave deviation.

The possible progression of the actual position of the long-wave deviation is limited in this regard by the long-wave deviation tolerance zone (see figs. 201, 202 and 203).

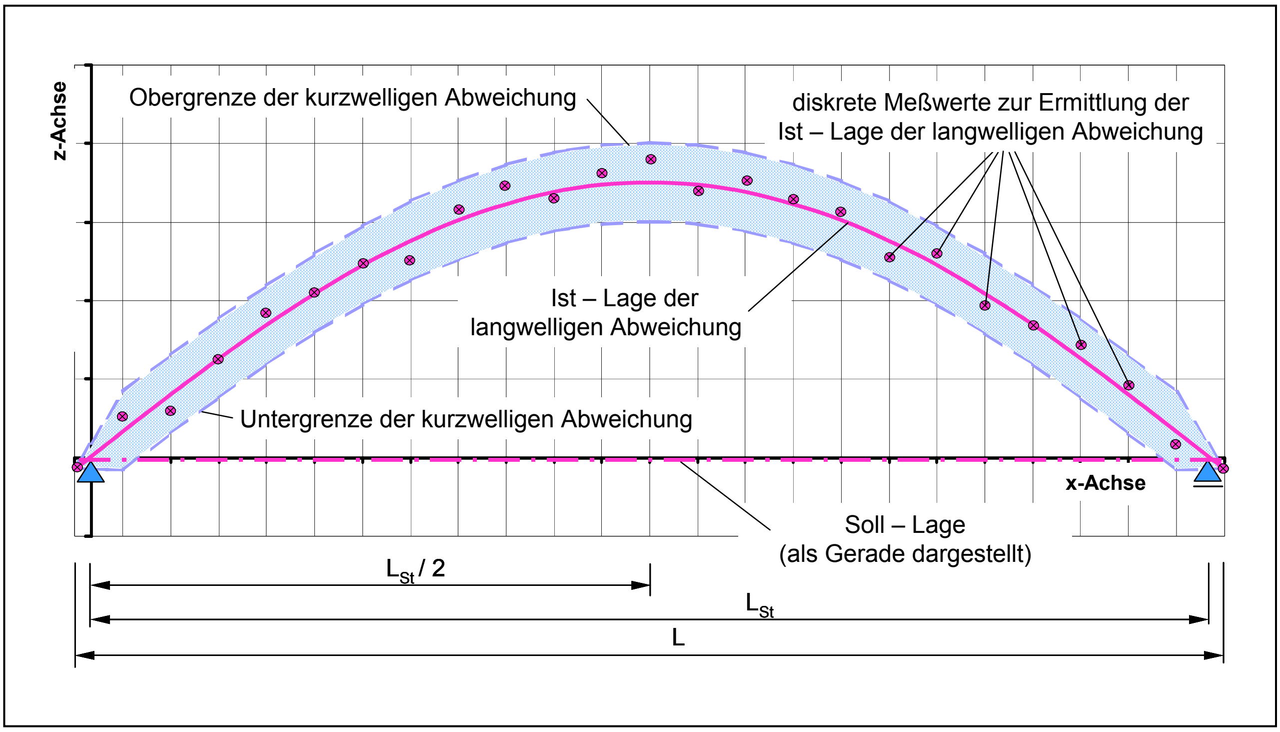


Fig. 199: Correlation between continuous measured values, the actual location of the long-wave deviation and the associated short-wave deviation limit values

[Key to diagram:
Obergrenze der kurzwelligen Abweichung = upper limit for short-wave deviation
diskrete Meßwerte zur Ermittlung der Ist-Lage der langwelligen Abweichung = continuous measured values for determining the actual position of the long-wave deviation
Ist-Lage der langwelligen Abweichung = actual position of the long-wave deviation
Untergrenze der kurzwelligen Abweichung = lower limit for short-wave deviation
Soll-Lage (als Gerade dargestellt) = theoretical position (portrayed as a straight line)
x-Achse = x-axis
z-Achse = z-axis]

When determining the long-wave deviation, the projected Δz_i of the gusset solution (Chapter 6.6.5) must be taken into consideration when using the continuous measured values.

Long-wave deviation in the case of simple beams

The diagrams and equations below relating to the long-wave deviation tolerance zone have been drawn up in relation to the z coordinates by way of example and can be applied, by analogy, to the y coordinates.

As regards simple beams, long-wave deviation progression as regards the tolerance zone is described by the following equation:

$$\Delta z_{i,Lw} = \pm \max \Delta z_{Lw} * \frac{384}{120} * \left(\frac{x_i}{L} - \frac{2 * x_i^3}{L^3} + \frac{x_i^4}{L^4} \right) \quad [\text{mm}]$$ Equation 18

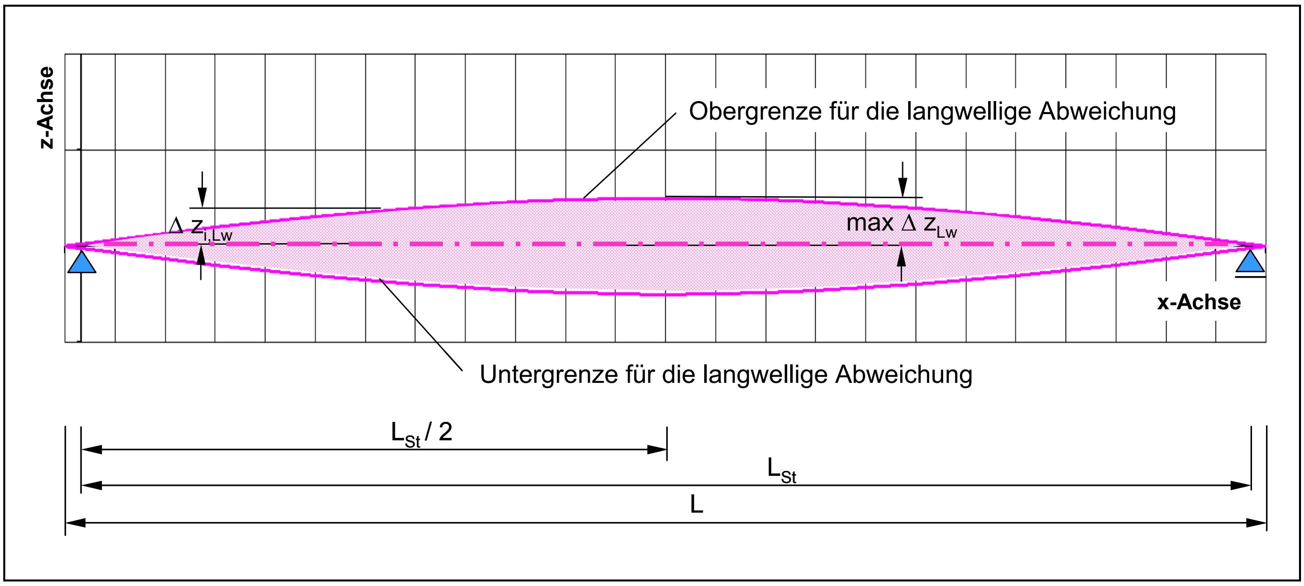


Fig. 200: The progression and position of the long-wave deviation tolerance zone in the case of simple beams without precurvature, using the example of the stator level

[Key to diagram:
Obergrenze für die langwellige Abweichung = upper limit for long-wave deviation
Untergrenze für die langwellige Abweichung = lower limit for long-wave deviation
x-Achse = x-axis
z-Achse = z-axis]

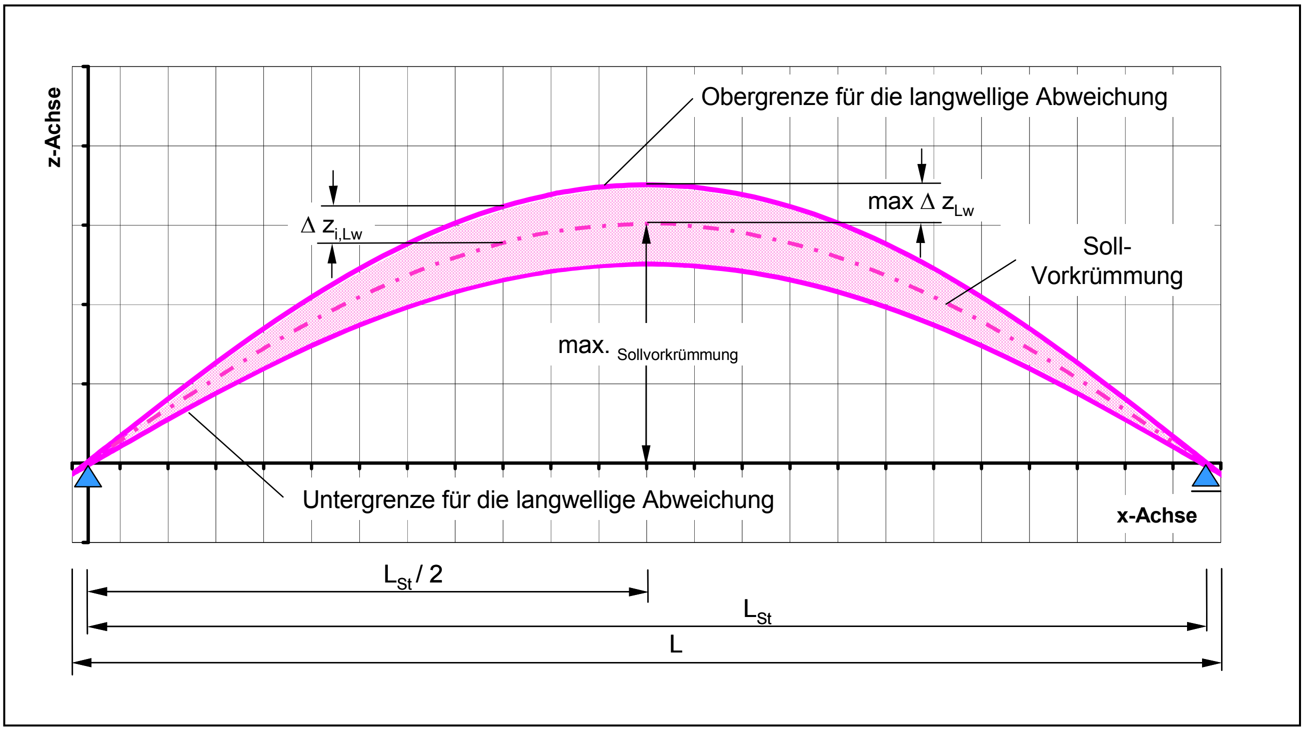


Fig. 201: The progression and position of the long-wave deviation tolerance zone in the case of simple beams with precurvature, using the example of the stator level

[Key to diagram:
Obergrenze für die langwellige Abweichung = upper limit for long-wave deviation
Soll-Vorkrümmung = design precurvature

max. Soll-Vorkrümmung = maximum design precurvature
Untergrenze für die langwellige Abweichung = lower limit for long-wave deviation
x-Achse = x-axis
z-Achse = z-axis]

Long-wave deviation in the case of two-span beams and multiple span girders as well as gauge change devices

The diagrams and equations below relating to the long-wave deviation tolerance zone have been drawn up in relation to the z coordinates by way of example and can be applied, by analogy, to the y coordinates.

As regards two-span beams, long-wave deviation progression as regards the tolerance zone in the area of the beginning or end of the girder as far as the centre support is described by the following equation:

$$\Delta z_{i,Lw} = \pm \max \Delta z_{Lw} * \frac{185}{48} * \left(\frac{x_i}{L_i} - \frac{3 * x_i^3}{L_i^3} + \frac{2 * x_i^4}{L_i^4} \right) \quad [mm]$$

Equation 19

The following equation is used for a simplified determination of the long-wave deviation tolerance zone in the case of bowed functional levels of simple and two-span beams between the beginning or end of the girder and the centre support:

$$\Delta z_{i,Lw} = \pm \frac{z_{i,Soll}}{\max z_{Soll}} \quad [mm]$$

Equation 20

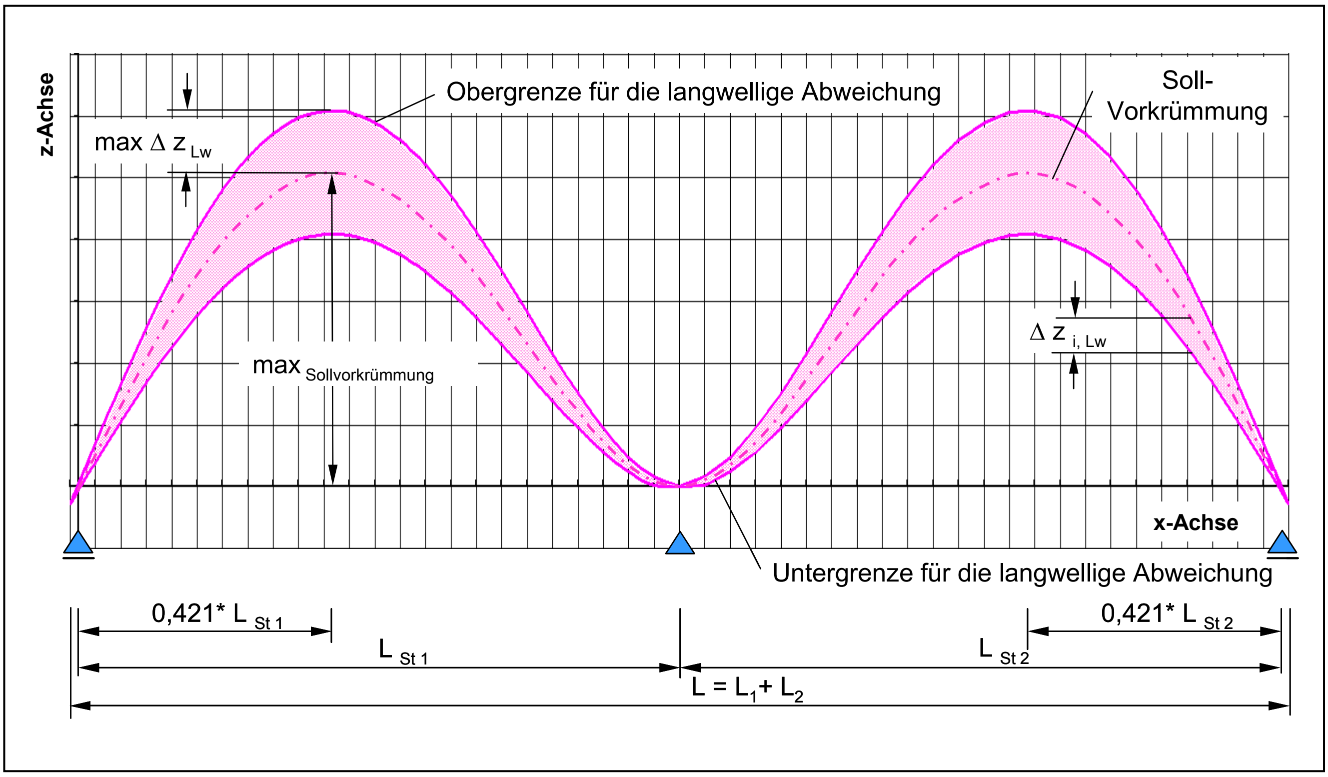


Fig. 202: The progression and position of the long-wave deviation tolerance zone in the case of two-span beams with precurvature, using the example of the stator level

[Key to diagram:
Obergrenze für die langwellige Abweichung = upper limit for long-wave deviation
Soll-Vorkrümmung = design precurvature
max. Soll-Vorkrümmung = maximum design precurvature

Untergrenze für die langwellige Abweichung = lower limit for long-wave deviation
x-Achse = x-axis
z-Achse = z-axis]

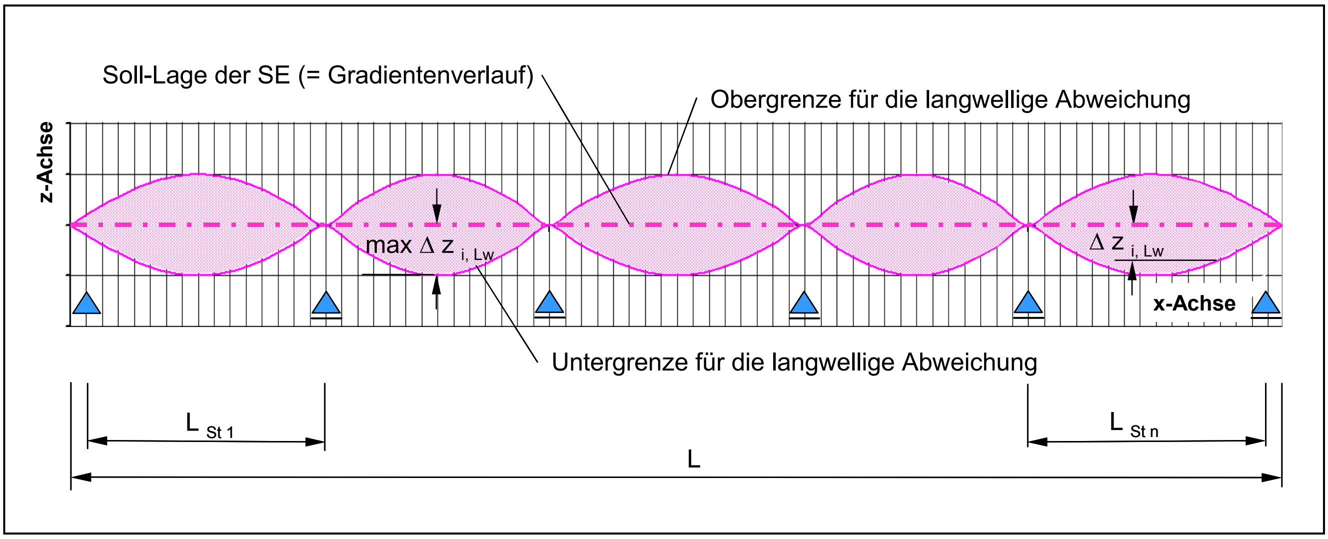


Fig. 203: The progression and position of the long-wave deviation tolerance zone using the example of the stator level of a gauge change device without design precurvature

[Key to diagram:
Soll-Lage der SE (= Gradientenverlauf) = theoretical position of the stator level (= progression of the gradient)
Obergrenze für die langwellige Abweichung = upper limit for long-wave deviation
Untergrenze für die langwellige Abweichung = lower limit for long-wave deviation
x-Achse = x-axis
z-Achse = z-axis]

Short-wave deviation

Short-wave deviation superimposes the actual location of the long-wave deviation. It comprises all tolerances as regards material, production and placement of those elements which determine the functional levels.

All absolute values at the local measurement points of the functional area, as well as all areas between the individual measurement points, must lie within its tolerance zone.

Up to the area of the immediate beginning and end of the girder, the tolerance width remains constant over the length of the support structure (see also figs. 204, 205 and 206).

The design at the beginning and end of the girder is characterised by the gradient-altering criterion which is permitted there (Chapter 6.6.5).

The diagrams below relating to short-wave deviation have been drawn up in relation to the z coordinates by way of example and can be applied, by analogy, to the y coordinates.

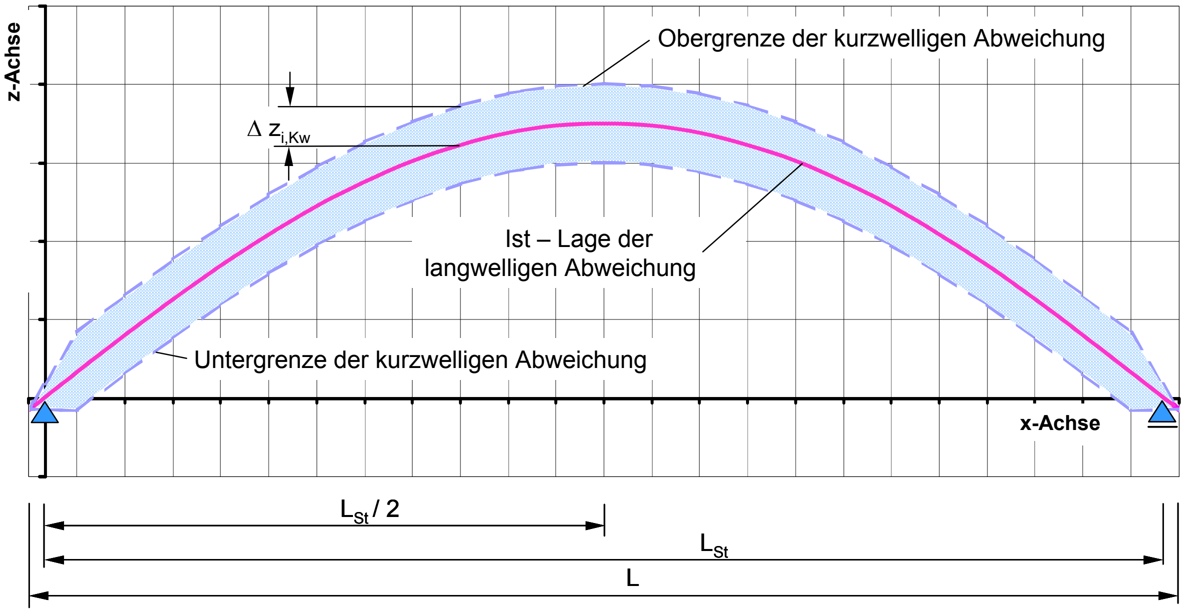


Fig. 204: Tolerance zone progression of the short-wave deviation in the case of simple beams with precurvature, using the example of the stator level

[Key to diagram:
Obergrenze der kurzwelligen Abweichung = upper limit for short-wave deviation
Ist-Lage der langwelligen Abweichung = actual position of the long-wave deviation
Untergrenze der kurzwelligen Abweichung = lower limit for short-wave deviation
x-Achse = x-axis
z-Achse = z-axis]

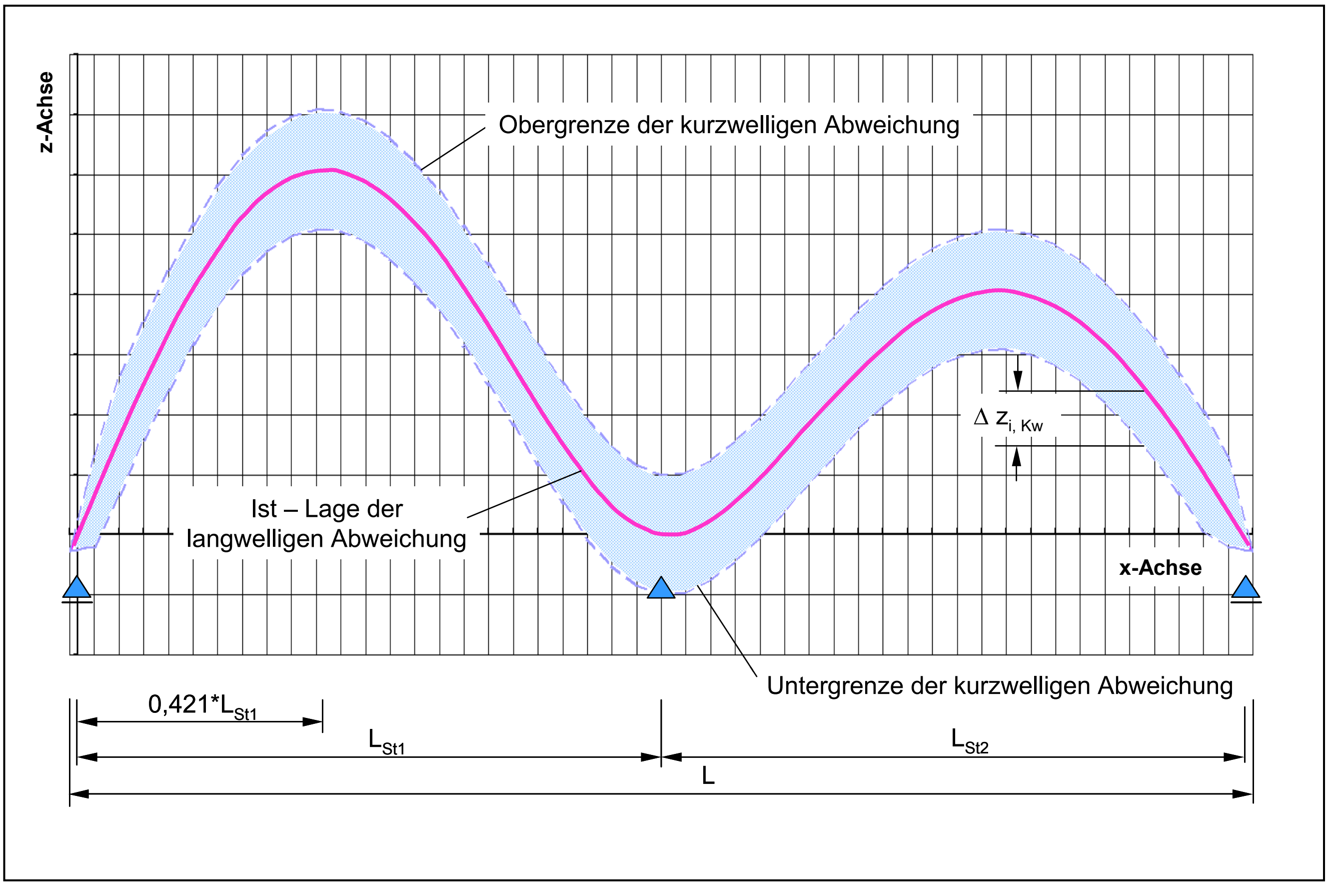


Fig. 205: Tolerance zone progression of the short-wave deviation in the case of two-span beams with design precurvature and reference to the actual location of the long-wave deviation, using the example of the stator level

[Key to diagram:
Obergrenze der kurzwelligen Abweichung = upper limit for short-wave deviation
Ist-Lage der langwelligen Abweichung = actual position of the long-wave deviation
Untergrenze der kurzwelligen Abweichung = lower limit for short-wave deviation
x-Achse = x-axis
z-Achse = z-axis]

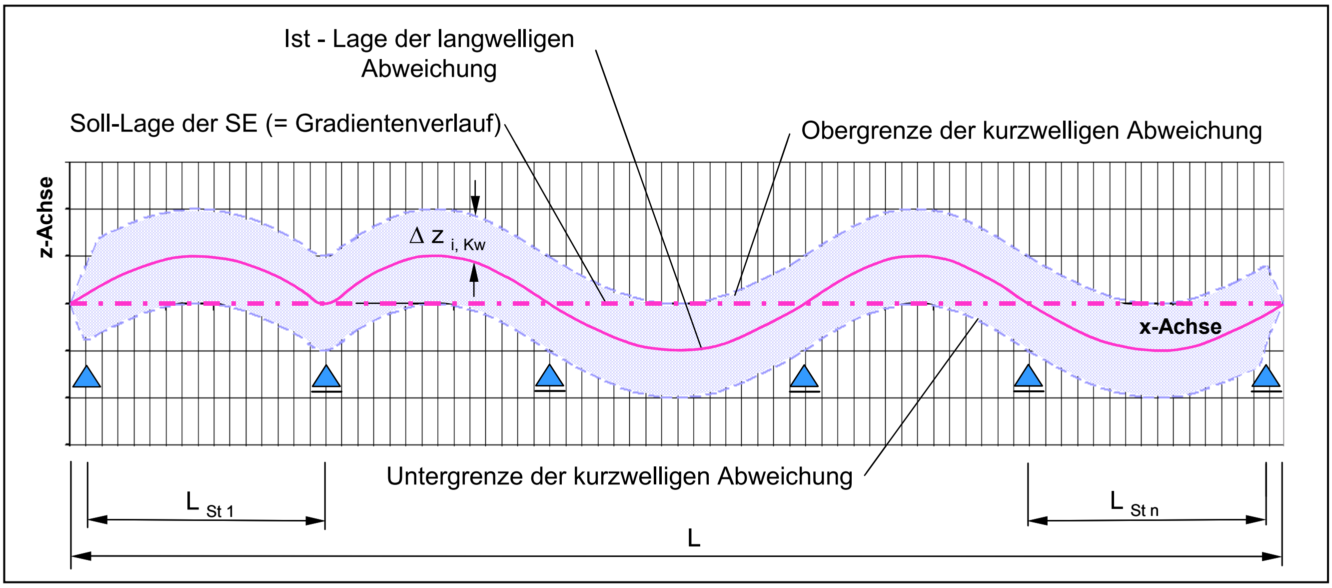


Fig. 206: Tolerance zone progression of the short-wave deviation of a gauge change device with reference to the actual location of the long-wave deviation, using the example of the stator level

[Key to diagram:
Ist-Lage der langwelligen Abweichung = actual position of the long-wave deviation
Soll-Lage der SE (= Gradientenverlauf) = theoretical position of the stator level (= progression of the gradient)
Obergrenze der kurzwelligen Abweichung = upper limit for short-wave deviation
Untergrenze der kurzwelligen Abweichung = lower limit for short-wave deviation
x-Achse = x-axis
z-Achse = z-axis]

Gradient-altering criterion

The angle deviation in mm, determined at the measurement points defined under point 6.1 of two adjacent 1 m long part elements of a functional level moving lengthwise along the guideway (x axis), constitutes the gradient-altering criterion.

When assessing the gradient-altering criterion, the following approach shall be assumed:

> *When examining tolerances, a gradient-altering criterion which is to be found in the girder may be regarded as constant depending on operation and temperature.*

However, the gradient-altering criterion at the girder transition has the following properties:

- *a fixed girder production portion which is determined by the portion from the design pre-curvature and the tolerance range definition of the short-wave deviation at the beginning or end of the girder,*
- *additionally, a variable portion which is dependent on the deformation of the girder under the effects of load and temperature at the place of installation during the period of operation.*

This means that, depending on the deformation characteristics of the girder, the tolerance zones for short-wave deviation at the beginning or end of the girder shall be stipulated in observance of the system-related contractual limit values (refer to the Principles concerning the overall system design of high-speed maglev systems).

As a rule, the permitted gradient-altering criterion at the beginning and end of the girder should not exceed half the permitted value in the support structure, relative to the theoretical position (taking account of the design precurvature).

Criteria concerned with altering the incline are determined in accordance with equation 21, see fig. 207.

The equation is presented using the z coordinates as an example

$$NGK_i = \left[\left(\frac{z_i - z_{i-1}}{L_1} \right) + \left(\frac{z_i - z_{i+1}}{L_2} \right) \right] \qquad \text{Equation 21}$$

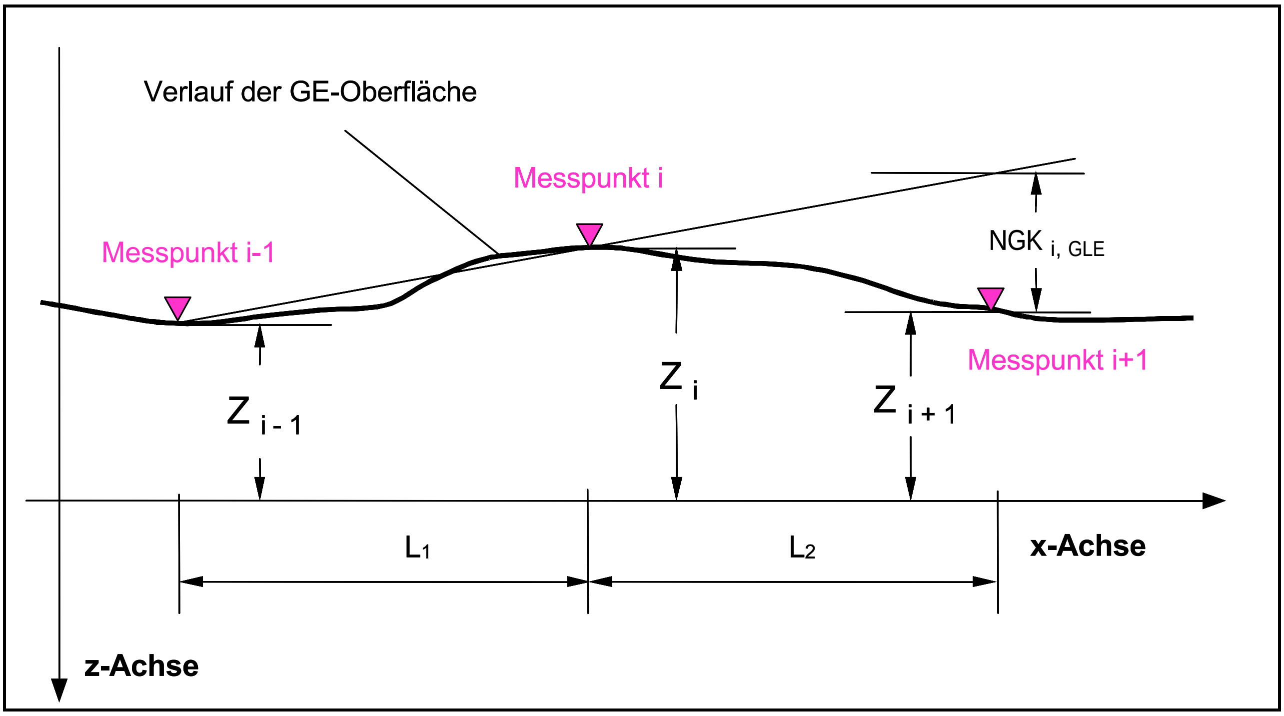


Fig. 207: Depiction of the gradient-altering criterion using the example of the slider level

[Key to diagram:
Verlauf der GE-Oberfläche = progression of the slider level surface
Messpunkt = measuring point
x-Achse = x-axis
z-Achse = z-axis]

Gusset solution

To adapt the short-wave deviation tolerance zone at the beginning and end of the girder with the aim of observing the gradient-altering criterion of the functional level (according to the Principles concerning the overall system design of high-speed maglev systems) under all operating conditions (the maximum actual temperature differential between the top and bottom booms of the girder; girder geometry with loaded and unloaded girders), the position of the functional level at the beginning and end of the girder can be optimised using the gusset solution. The x axis measurement points constitute the reference point (see fig. 185).

The gusset solution is currently only applied at the stator level, depending on the rigidity of the girder in the z direction.

The procedure, in principle, for stipulating the theoretical position is evident from fig. 208.

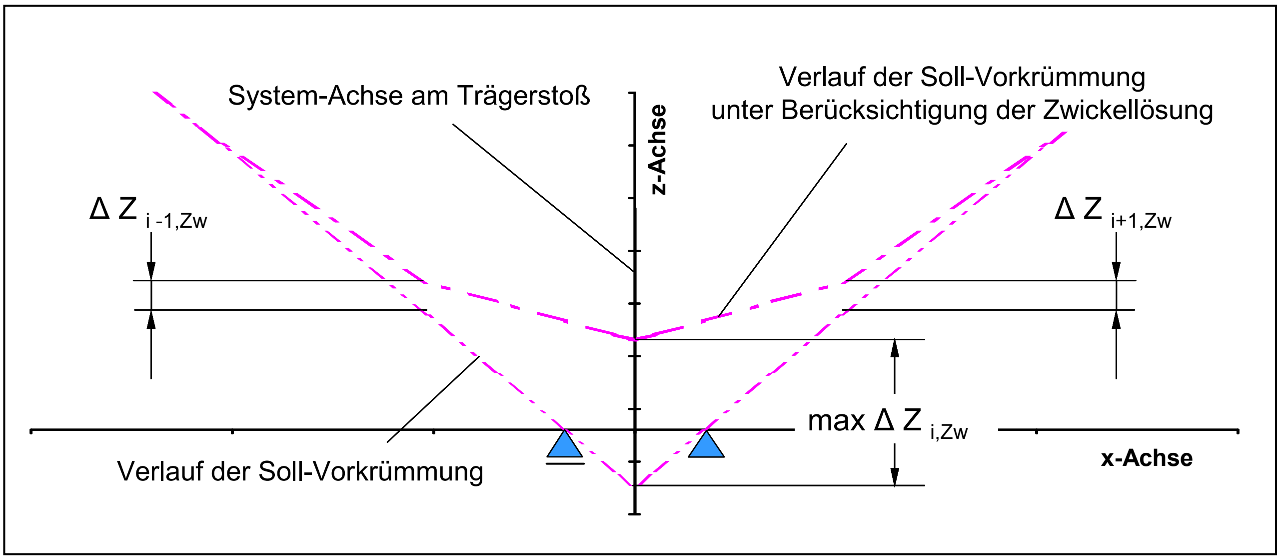


Fig. 208: Gusset solution design in the stator level

[Key to diagram:
System-Achse am Trägerstoß = system axis at the girder joint
Verlauf der Soll-Vorkrümmung unter Berücksichtigung der Zwickellösung = progression of the design precurvature, taking into account the gusset solution
Verlauf der Soll-Vorkrümmung = progression of the design precurvature
x-Achse = x-axis
z-Achse = z-axis]

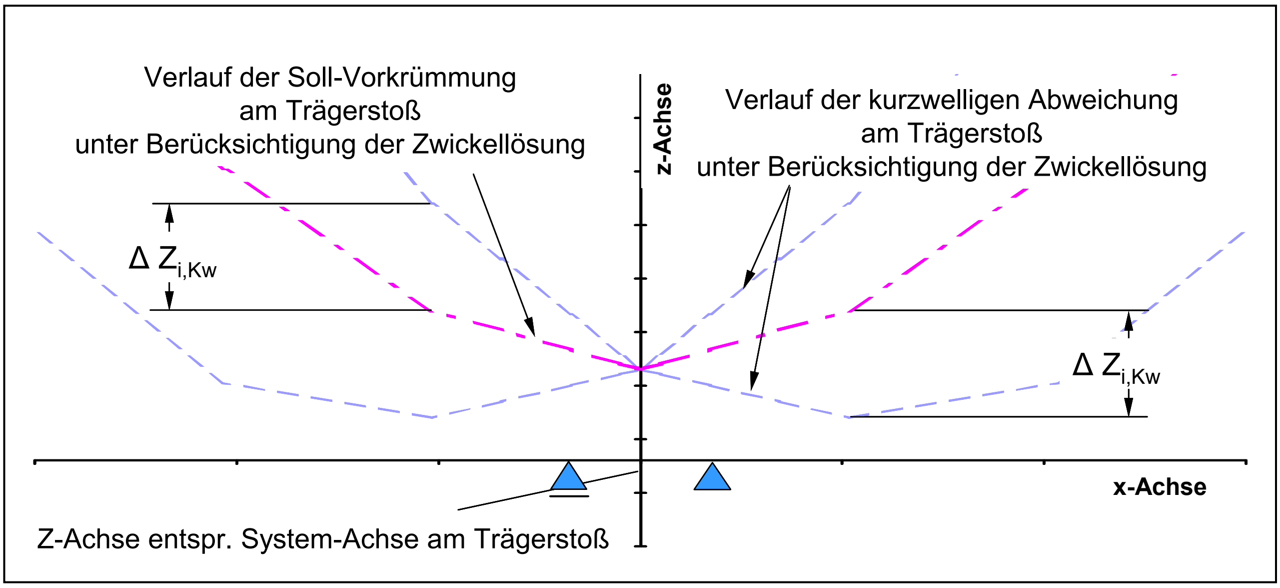


Fig. 209: Short-wave deviation progression of the stator level at the girder transition when applying the gusset solution

[Key to diagram:
Verlauf der Soll-Vorkrümmung am Trägerstoß, unter Berücksichtigung der Zwickellösung = progression of the design precurvature along the girder joint, taking into account the gusset solution

Verlauf der kurzwelligen Abweichung am Trägerstoß, unter Berücksichtigung der Zwickellösung = progression of the short-wave deviation along the girder joint, taking into account the gusset solution
Z-Achse entspr. System-Achse am Trägerstoß = z-axis corresponding to the system axis at the girder joint
x-Achse = x-axis
z-Achse = z-axis]

Giving consideration to the gusset solution at the time the girder is manufactured leads to a displacement of the short-wave deviation tolerance zone in the girder start and end area, see fig. 209.

Displacement

The difference between the absolute values of two adjacent functional level elements at the immediate transition is designated as displacement, see figs. 210 and 211.

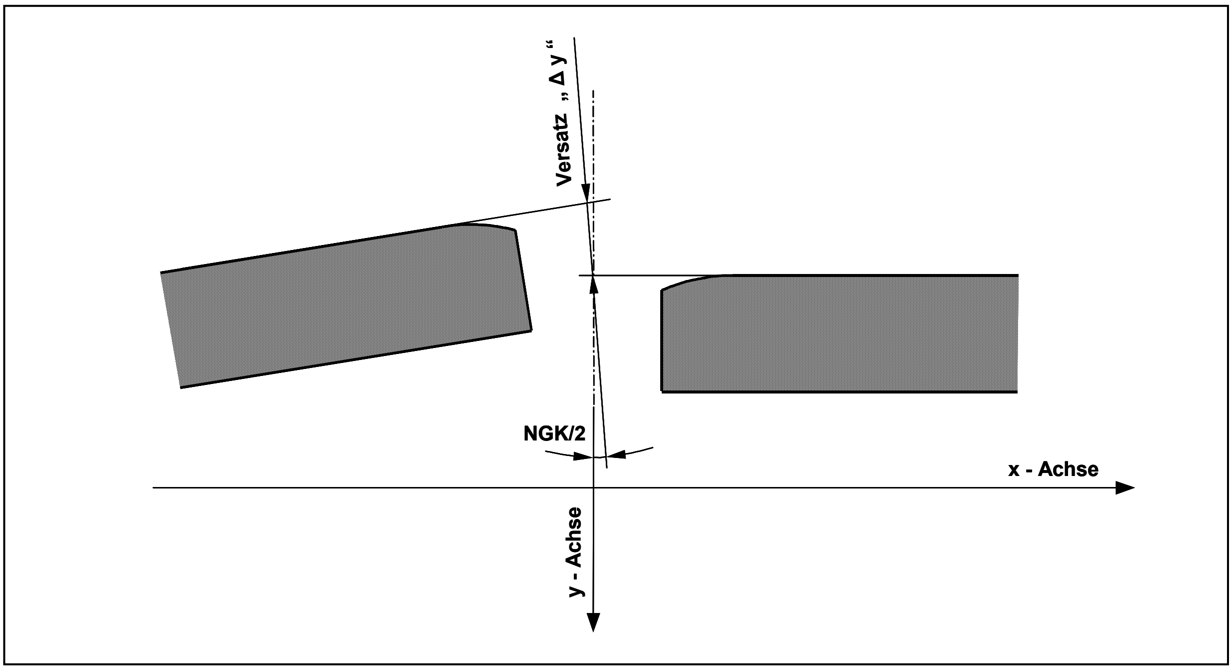


Fig. 210: Presentation of negative displacement at the lateral guide rail level with superimposed gradient-altering criterion

[Key to diagram:
Versatz = displacement
NGK = gradient-altering criterion
x-Achse = x-axis
y-Achse = y-axis]

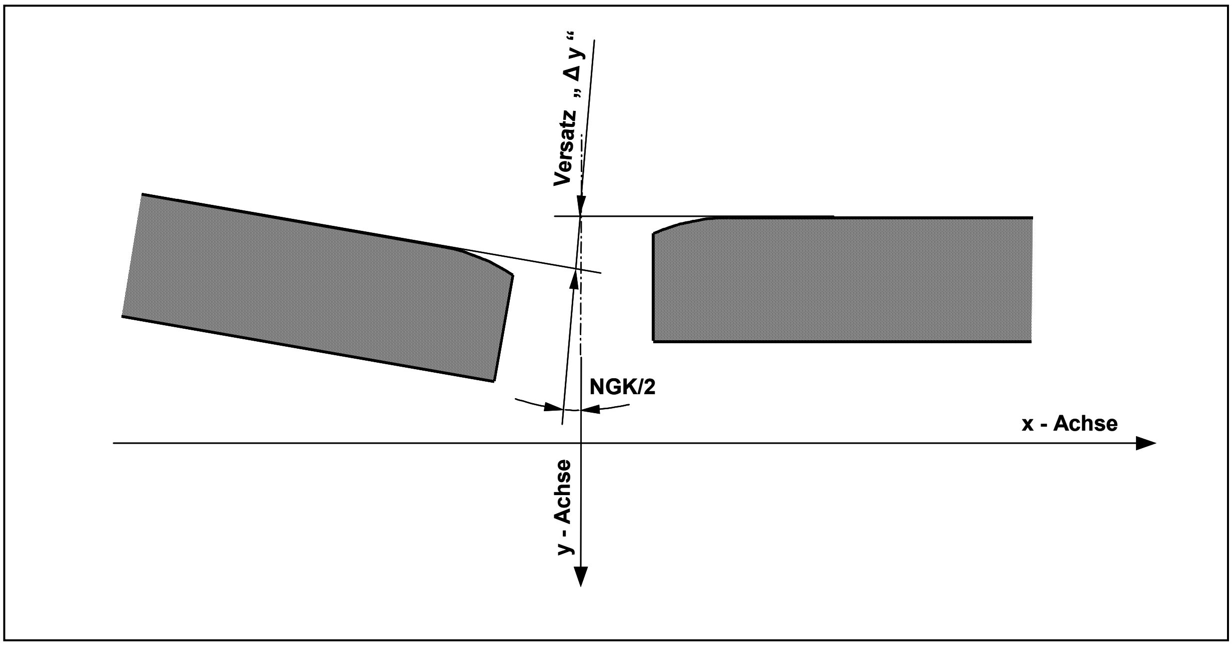


Fig. 211: Presentation of positive displacement at the lateral guide rail level with superimposed gradient-altering criterion

[Key to diagram:
Versatz = displacement
NGK = gradient-altering criterion
x-Achse = x-axis
y-Achse = y-axis]

Tilting

Functional level torsion at the measurement point (fig. 185) around the functional level longitudinal axis (x axis) is described as tilting.

Lateral incline tolerance

If a functional level or geometric parameter, such as the lateral incline of the guideway, is made up of two or more part areas (e.g. right and left stator levels), the lateral incline tolerance reflects the deviation in the mean actual locations (e.g. $z_{i,Ist}$) of the respective part areas at the same reference point x_i, from the theoretical position.

The lateral incline tolerance is only defined within the girder and comprises the actual progressions of the short-wave deviation tolerance range of the functional levels in question.

Superimposition of tolerances and positional deviations

The positional deviations and tolerances listed in the preceding chapters are defined in relation to the measurement point each time. Consequently, displacement which is considered, for instance, over the entire extension of the functional level in the y direction, is the sum of the displacement portions and the associated tilting portion (see fig. 212).

Gradient-altering criteria values only reflect the actual angle deviation of adjacent functional levels, excluding any additional displacements which may be present (see figs. 210 and 211).

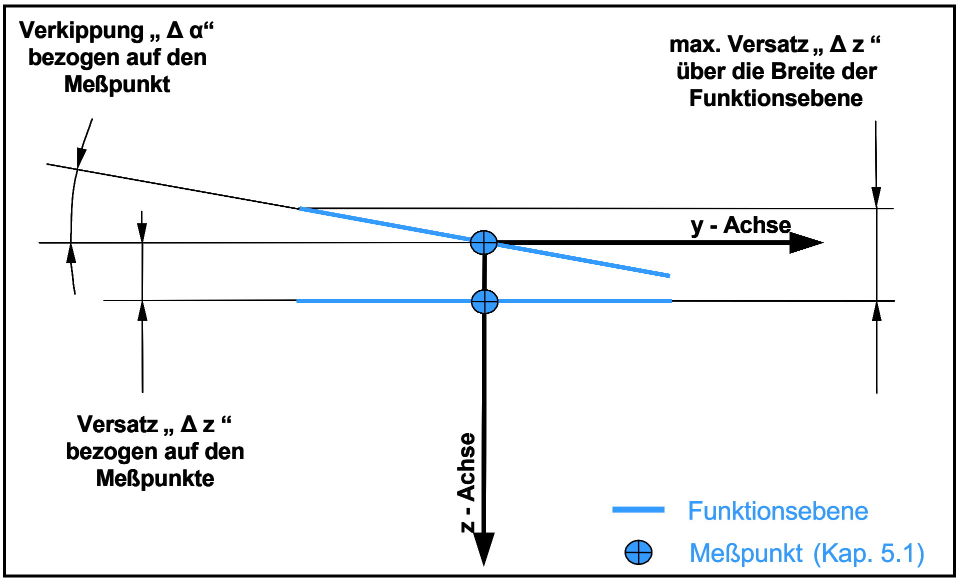


Fig. 212: Superimposition of displacement and tilting along the same adjacent functional levels (e.g. in the case of stator plates in the stator level)

[Key to diagram:
Verkippung “△α” bezogen auf den Meßpunkt = tilting “△α” relative to the measuring point
max. Versatz “△ z” über die Breite der Funktionsebene = maximum displacement “△ z” over the width of the functional level
Versatz “△ z” bezogen auf den Meßpunkt = displacement “△ z” relative to the measuring point
Funktionsebene = functional level
Meßpunkt (Kap. 5.1) = measuring point (chapter 5.1)
y-Achse = y-axis
z-Achse = z-axis]

The mutual influence exerted by the individual positional deviations and tolerances is presented in summary form in the following chapters in relation to the functional levels each time.

Permitted tolerance and positional deviations

Stator level tolerances and positional deviations

The mutual influence exerted by the individual stator level tolerances and positional deviations in the z coordinates is presented in the following overview (fig. 213).

The x and y coordinate correlations were not presented given their secondary importance.

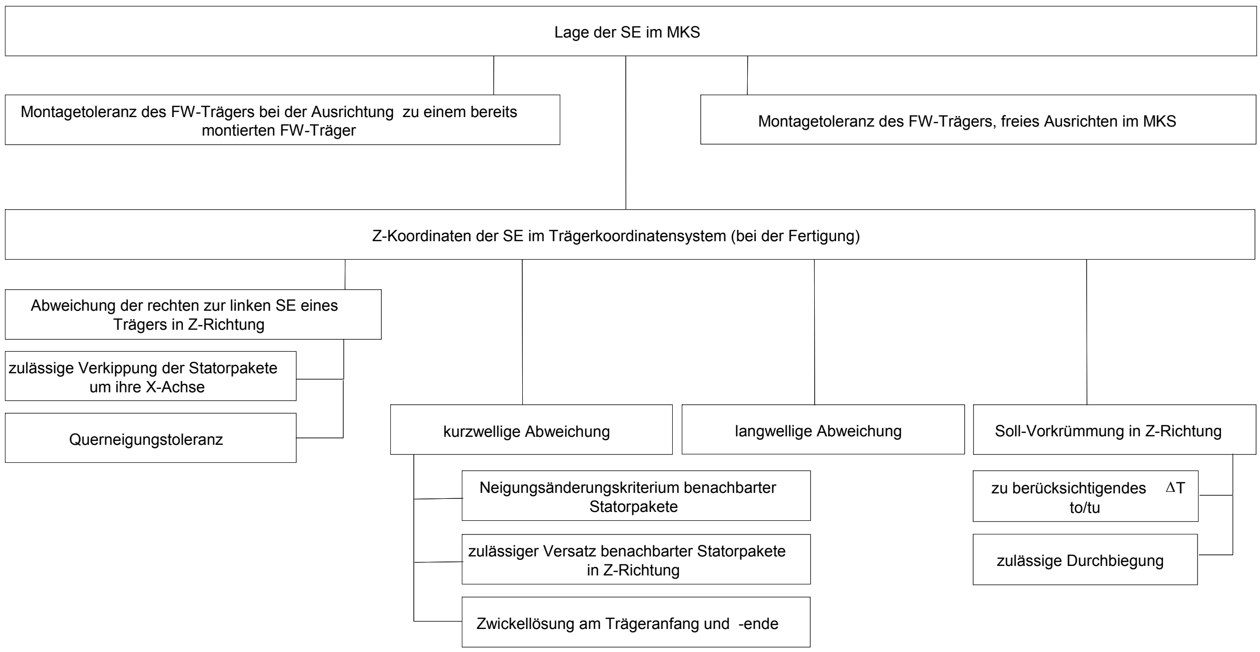


Fig. 213: Stator level tolerances and positional deviations and their mutual dependence

[Key to diagram:
Lage der SE im MKS = position of the stator level in the maglev train coordinate system
Montagetoleranz des FW-Trägers bei der Ausrichtung zu einem bereits montierten FW-Träger = assembly tolerance of the guideway girder in the case of alignment with a guideway girder which has already been installed
Montagetoleranz des FW-Trägers, freies Ausrichten im MKS = assembly tolerance of the guideway girder, free alignment in the maglev train coordinate system
Z-Koordinaten der SE im Trägerkoordinatensystem (bei der Fertigung) = z-coordinates of the stator level in the girder coordinate system (during production)
Abweichung der rechten zur linken SE eines Trägers in Z-Richtung = deviation between the right and left stator levels of a girder in the z direction
zulässige Verkippung der Statorpakete um ihre X-Achse = permitted tilting of the stator plates about its x-axis
Querneigungstoleranz = permitted variation in the lateral incline
kurzwellige Abweichung = short-wave deviation
langwellige Abweichung = long-wave deviation
Soll-Vorkrümmung in Z-Richtung = design precurvature in the z direction

Neigungsänderungskriterium benachbarter Statorpakete = gradient-altering criterion of adjacent stator plates
zu berücksichtigendes △ T to/tu = △ T to/tu to be considered
zulässiger Versatz benachbarter Statorpakete in Z-Richtung = permitted displacement in adjacent stator plates in the z direction
zulässige Durchbiegung = permitted bending
Zwickellösung am Trägeranfang und –ende = spandrel solution at the beginning and end of the girder]

Permitted positional deviation of the stator plates in the x direction

The theoretical position of the individual stator plates in the support structure and, consequently, their positioning in the x direction, are stipulated in relation to the project, taking into consideration the Principles concerning the overall system design of high-speed maglev systems.
Moreover, at the support structure crossovers, the envisaged position of the motor winding cable must be observed.
The manufacturing tolerances for incorporating the stator plates shall be selected in such a way that when observing the stipulations set out in the Guideway design principles for high-speed maglev systems - Part II: Dimensioning (guideway load and deformation), adjacent stator plates in the x direction shall remain free from contact. In the girder section, the mechanical gaps at the sides of the stator plates should be 0.5 to 2 mm.

Permitted positional deviation of the centre axis of the longitudinal stator in the y direction

The permitted positional deviation of the centre axis of the longitudinal stator (see fig. 185) in the y direction in relation to the theoretical position is uniformly

$$\Delta y_{\max} = \pm 2\,mm$$

Stator level tolerances in the z direction

Design precurvature

The theoretical progression between the support axes of simple and two-span beams can be determined in accordance with equations 16 or 17. Similar equations concerning deflection shall be used for multiple span elements. The deflection which is characteristic of the respective girder under a vehicle load shall be calculated as z_{max}.

The permitted deflection is determined in accordance with the Guideway design principles for high-speed maglev systems - Part II: Dimensioning.

When calculating the design precurvature, consideration must be given to the deformation in the girder as a result of the difference in temperature within the girder cross-section ΔT_{Be} according to the Guideway design principles for high-speed maglev systems - Part II: Dimensioning.

Long-wave deviation in the stator level

The long-wave deviation tolerance zone progression relative to the progression of the design precurvature is described as follows depending on the design of the girder:

Simple beams

$x_{Trägeranfang} < x_i < x_{Trägerende}$	$\Delta z_{i,Lw}$	$\Rightarrow$ equations 18 or 20

Two-span beams

$x_{Trägeranfang} \leq x_i \leq x_{L_1}$	$\Delta z_{i,Lw}$	$\Rightarrow$ equations 19 or 20
$x_{L_2} \leq x_i \leq x_{Trägerende}$	$\Delta z_{i,Lw}$	$\Rightarrow$ equations 19 or 20

When using equations 18 and 19 to determine the upper and lower limits

$$\max \Delta z_{Lw} = 1mm$$

shall be used.

Multiple span girders (gauge change devices)

$x_{Trägeranfang} \leq x_i \leq x_{L_1}$ $\Delta z_{i,Lw} \Rightarrow$ follows the mathematical description of the elastic line *

$x_{L_1} \leq x_i \leq x_{L_n}$ $\Delta z_{i,Lw} \Rightarrow$ follows the mathematical description of the elastic line *

$x_{L_n} \leq x_i \leq x_{Trägerende}$ $\Delta z_{i,Lw} \Rightarrow$ follows the mathematical description of the elastic line *

* see Chapter 6.6.2; $\max \Delta z_{i,Lw} = 1mm$ i = number of sections

Short-wave deviation in relation to the actual location of the stator level (long-wave deviation), tolerances at the girder joint

The short-wave deviation tolerance zone progression relative to the progression of the actual long-wave deviation is described by the following basic data in a standard manner for the simple beam and multiple span girder:

$x_{Trägeranfang}$; $x_{Trägerende}$ $\Delta z = 0$

$x_{Trägeranfang} < x_i < x_{0+n*1032}$; $x_{L-n*1032} < x_i < x_{Trägerende}$, n = 1, 2..* $\Delta z_i \leq \pm 1mm$

$x_{0+n*1032} < x_i < x_{L-n*1032}$ $\Delta z = \pm 1mm$

* n shall be stipulated in observance of the maximum permitted gradient-altering criterion

Gradient-altering criterion within the short-wave deviation

Within the short-wave deviation tolerance zone, to protect the proximity relation, a gradient-altering criterion of

$$NGK_{SE} \leq 1{,}5mm$$

must be observed in the stator level.

For determining the tolerance zone progression of the stator level at the beginning and end of the girder (girder transition), consideration must be given to the system-related limit values set out in the Principles concerning the overall system design of high-speed maglev systems and the permitted limit values from the Guideway design principles for high-speed maglev systems - Part II: Dimensioning.
Relative to the theoretical progression of the functional level, a gradient-altering criterion of

$$NGK_{SE,Anfang;Ende} \leq 0{,}75mm$$

shall be specified as a starting point.
As regards the gradient-altering criterion to be defined at these points for inspection and acceptance measurements, the measurement conditions and references must be specified unconditionally.

Permitted stator level displacements / tilting

The following tolerances relate to the measurement points according to fig. 185. In the x direction, the first and last full-depth tooth of the adjacent stator plates are used as the measurement point each time (see Chapter 6.1).

The tolerances are the same for all guideway designs.

- Displacements:
  within the girder $\left|\Delta z_{i_{max}}\right| = 0{,}4\,mm$

  at the girder joint $\left|\Delta z_{i_{max}}\right| = 0{,}6\,mm$

  Displacement at the girder joint in this regard is purely an assembly tolerance which is only adjusted following precise positioning of the girder.

  The maximum permitted displacement of the stator level in the event of the failure of the primary fixing device must be stipulated in relation to the specific project.
- tilting (relative to the measurement point in the centre axis of the longitudinal stator):

$$\Delta\alpha_{SE\ max} = \pm\arctan(0{,}2\,mm/92{,}5\,mm)$$

Stator level lateral incline tolerance

The lateral incline tolerance is only defined for simple and two-span beams.

$x_{Trägeranfang}$; $x_{Trägerende}$ $\Delta\alpha = 0°$ shall be set for calculation purposes

$x_{Trägeranfang} < x_i < x_{Trägerende}$ $\Delta\alpha_{max} = \pm\arctan(2\,mm/1110\,mm)$ *

* only permitted on condition that the tolerances are observed for each individual stator level to be considered.

Lateral guide rail level tolerances and positional deviations

The position of the two lateral guide levels is decisive as regards the horizontal alignment (guideway guidance) of the maglev train. Both levels are joined via the guideway gauge. The theoretical position in the girder production coordinate system is determined by the position of the guideway's centre axis.

The mutual influence exerted by the individual tolerances and positional deviations in the y coordinates is presented in the following overview (fig. 214).

The x and z coordinate correlations were not presented given their secondary importance.

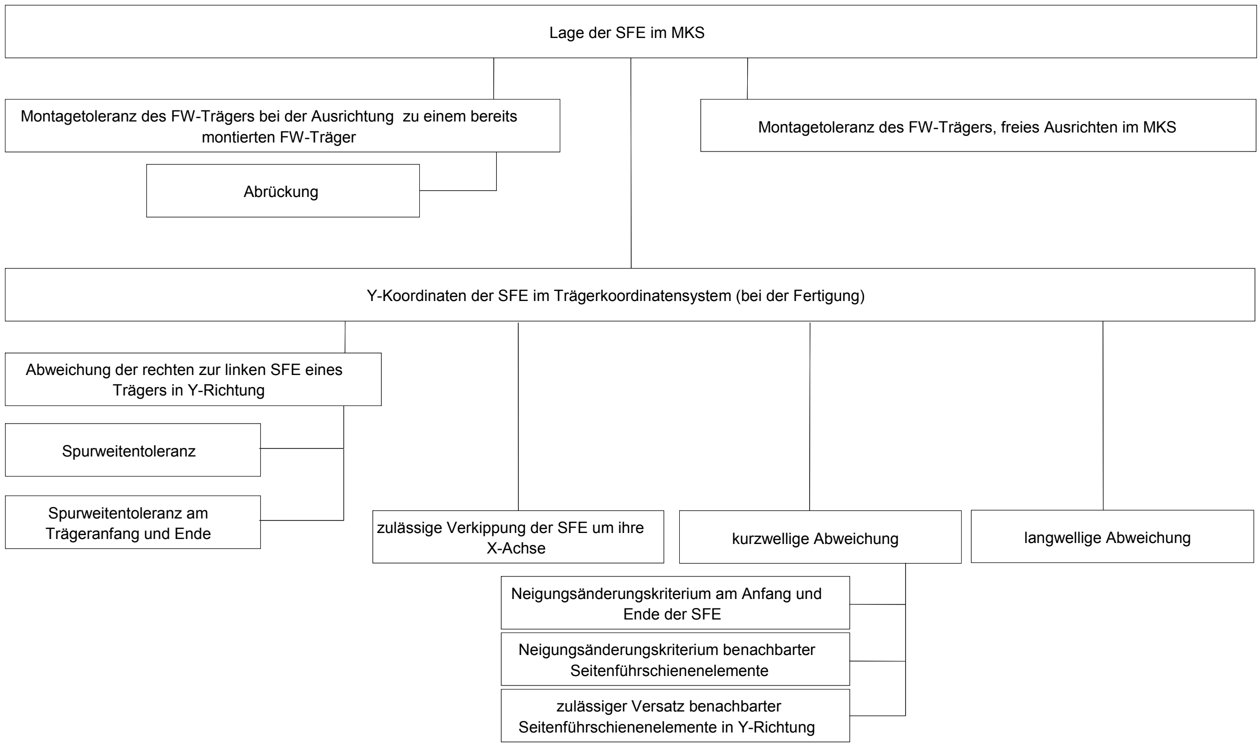


Fig. 214: Lateral guide level tolerances and positional deviations and their mutual dependence

[Key to diagram:
Lage der SFE im MKS = position of the lateral guide rail level in the maglev train coordinate system
Montagetoleranz des FW-Trägers bei der Ausrichtung zu einem bereits montierten FW-Träger = assembly tolerance of the guideway girder in the case of alignment with a guideway girder which has already been installed
Montagetoleranz des FW-Trägers, freies Ausrichten im MKS = assembly tolerance of the guideway girder, free alignment in the maglev train coordinate system
Abrückung = retraction
Y-Koordinaten der SFE im Trägerkoordinatensystem (bei der Fertigung) = Y coordinates of the lateral guide rail level in the girder coordinate system (during production)
Abweichung der rechten zur linken SFE eines Trägers in Y-Richtung = deviation between the right and left lateral guide rail levels of a girder in the Y direction
Spurweitentoleranz = guideway gauge tolerance
Spurweitentoleranz am Trägeranfang und Ende = guideway gauge tolerance at the beginning and end of the girder
zulässige Verkippung der SFE um ihre X-Achse = permitted tilting of the lateral guide rail level about its x-axis
kurzwellige Abweichung = short-wave deviation
langwellige Abweichung = long-wave deviation
Neigungsänderungskriterium am Anfang und Ende der SFE = gradient-altering criterion at the beginning and end of the lateral guide rail level
Neigungsänderungskriterium benachbarter Seitenführschienenelemente = gradient-altering criterion of adjacent lateral guide rail elements
zulässiger Versatz benachbarter Seitenführschienenelemente in Y-Richtung = permitted displacement in adjacent lateral guide rail elements in the Y direction]

Lateral guide rail level tolerances in the x direction

To determine the minimum gap at the support structure crossover, i.e. the gap to the system axis, the heat expansion of the guideway elements under the Guideway design principles for high-speed maglev systems - Part II: Dimensioning, the arrangement of the fixed and movable bearings and the permitted substructure deformation as per the Principles concerning the overall system design of high-speed maglev systems must be taken into consideration. The following standard values are specified:

The gap between the start or end of the element and the system axes are as follows:

Support structure (12 m ≤ system length ≤ 25 m) $\Delta x_{A,E} = 20\,mm$

Guideway plates (system length ≤ 6 m) $\Delta x_{A,E} = 10\,mm$

Intermediate parameters shall be explained in accordance with the introductory remarks.

For all support structure crossovers, the aim shall be to have girder joints of equal size at a defined reference temperature.

In the case of interruptions to the lateral guide rail level in the support structure which are the result of its design (e.g. with a modular design), the positional stability and form deviation of the lateral guide rail level attachment must be taken into consideration when determining the theoretical gap widths.

In the case of deflections, the required minimum gap between the lateral guide rail level elements is determined in accordance with equation 22, taking into account the deformations in the bending position.

$$\Delta x \geq L_M - L_M * \left(R_H - S/2\right)/R_H + 2 \qquad [mm]$$ Equation 22

A collision between like, adjacent functional level elements must be avoided.

The joints in the lateral guide rail level shall be designed in accordance with fig. 215.

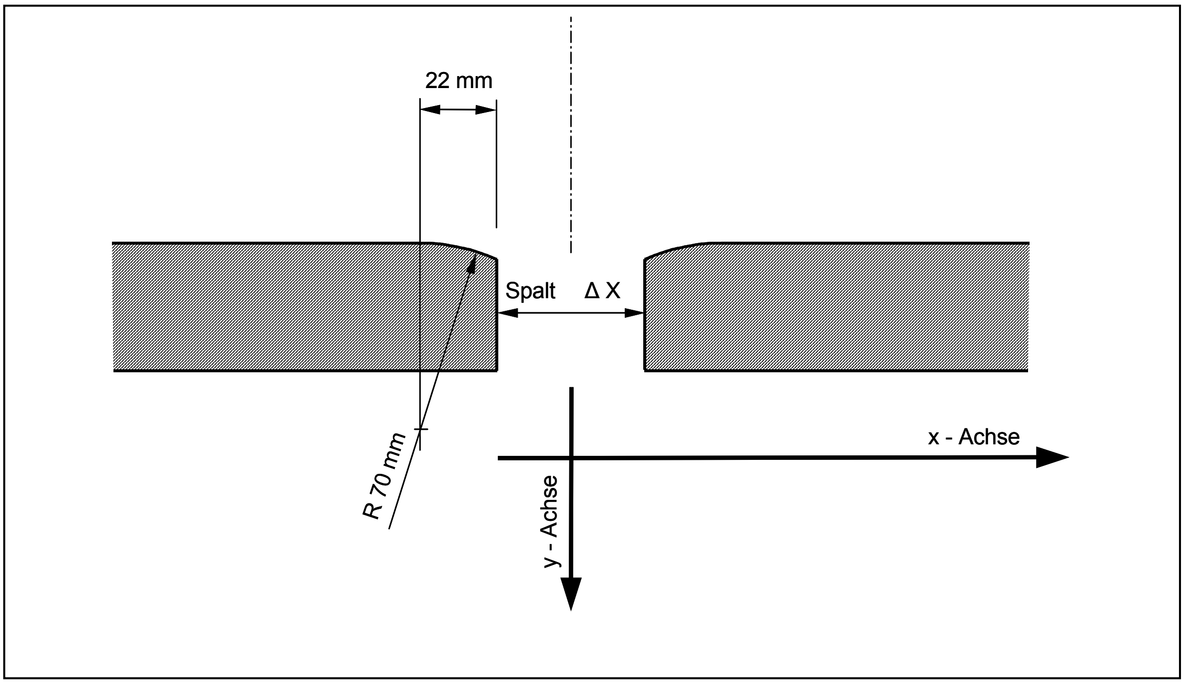


Fig. 215: Surface design of the lateral guide rail level at the girder joint or in the event of interruptions

[Key to diagram:
Spalt = opening
x-Achse = x-axis
y-Achse = y-axis]

Positional deviation of the lateral guide rail level in the y direction

Theoretical position

The theoretical position of the two lateral guide rail levels is specified by the routing. Long-wave deviation tolerance zone progression relates to these theoretical positions. The following data pertaining to long- and short-wave deviation relates to every individual lateral guide rail level. The compulsorily existing dependency of the actual positions of the two long-wave deviations is not taken into consideration with a view to observing the guideway gauge tolerance.

Possible deformation as a result of the vehicle load impact and temperature differences in the guideway are disregarded when determining the theoretical position of the lateral guide rail level.

Long-wave deviation in the lateral guide rail level

Long-wave deviation tolerance zone progression is described as follows depending on the design of the girder:

Simple beams

$x_{Trägeranfang} < x_i < x_{Trägerende}$ $\Delta y_{i,Lw}$ as per equation 18 *

$$* \quad L \leq 12384 \quad \max \Delta y_{Lw} = 1{,}0$$

$$L > 12384 \quad \max \Delta y_{Lw} = L * 2{,}0 / 24768$$

[mm]

Two-span beams

$x_{\text{Trägeranfang}} \le x_i \le L_1$ $\Delta y_{i,Lw}$ as per equation 19 *
$L_2 \le x_i \le x_{\text{Trägerende}}$ $\Delta y_{i,Lw}$ as per equation 19 **

$$\begin{aligned} * \quad & L_1 \le 12384 \quad \max \Delta y_{Lw} = 1{,}0 \\ & L_1 > 12384 \quad \max \Delta y_{Lw} = L_1 * 2{,}0 / 24768 \end{aligned} \quad \text{[mm]}$$

$$\begin{aligned} ** \quad & L_1 \le 12384 \quad \max \Delta y_{Lw} = 1{,}0 \\ & L_1 > 12384 \quad \max \Delta y_{Lw} = L_2 * 2{,}0 / 24768 \end{aligned} \quad \text{[mm]}$$

Multiple span girders (gauge change devices)

$x_{\text{Trägeranfang}} \le x_i \le L_1$ $\Delta y_{i,Lw}$ $\Rightarrow$ follows the mathematical description of the elastic line *
$L_2 < x_i < L_{n-1}$ $\Delta y_{i,Lw}$ $\Rightarrow$ follows the mathematical description of the elastic line *
$L_n \le x_i \le x_{\text{Trägerende}}$ $\Delta y_{i,Lw}$ $\Rightarrow$ follows the mathematical description of the elastic line *

$$\begin{aligned} * \quad & L_i \le 12384 \quad \max \Delta y_{Lw} = 1{,}0 \\ & L_i > 12384 \quad \max \Delta y_{Lw} = L_i * 2{,}0 / 24768 \end{aligned} \quad \text{[mm]}$$

i = 1,...n

see Chapter 6.6.2;

Short-wave deviation in relation to the actual location of the lateral guide rail level (long-wave deviation), tolerances at the girder joint

Short-wave deviation tolerance zone progression relative to the actual progression of the long-wave deviation is described by the following basic data in a standard manner for the simple beam and multiple span girder:

$x_{\text{Trägeranfang}}$; $x_{\text{Trägerende}}$ $\Delta y = 0$
$x_{\text{Trägeranfang}} < x_i < x_{0+n*1032}$;
$x_{L-n*1032} < x_i < x_{\text{Trägerende}}$ $n = 1{,}2... *$ $\Delta y_i \le \pm 2\text{mm}$
$x_{0+n*1032} < x_i < x_{L-n*1032}$ $\Delta y = \pm 2\text{mm}$

* n shall be stipulated in observance of the maximum permitted gradient-altering criterion

Within the short-wave deviation tolerance zone, the following proximity relation must be observed in the lateral guide rail level:

$$NGK_{SFE} \leq 2{,}0\,mm$$

For determining the tolerance zone progression of the lateral guide rail level at the beginning and end of the girder (girder transition), a gradient-altering criterion, relative to the theoretical position, of

$$NGK_{SFE,\,Anfang;Ende} \leq 1{,}0\,mm$$

shall be calculated.

The permitted limit values set out in the Guideway design principles for high-speed maglev systems - Part II: Dimensioning, must be observed in this regard.

As regards the gradient-altering criterion to be defined at these points for inspection and acceptance measurements, the measurement conditions must be specified.

Permitted lateral guide rail level displacements / tilting

The following tolerances relate to the measurement points according to fig. 185 and the stipulations concerning the choice of the pertinent x coordinates.

The tolerances listed below are the same for all types of guideway.

- Displacements: within the girder $\left|\Delta y_{i_{max}}\right| = 0{,}6\,mm$ *

  * the assumed segment length in this regard is 6 m,
  With different lengths, the value shall be taken from the diagram below:

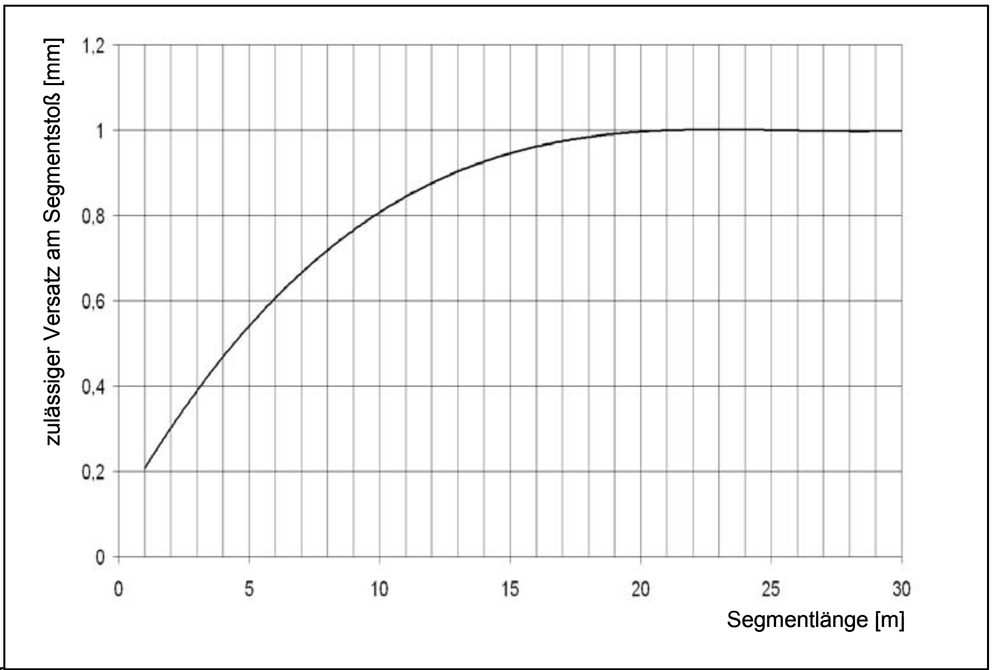


Fig. 216: Permitted displacements in the lateral guide rail level within a support structure depending on the segment lengths of the lateral guides

[Key to diagram:
zulässiger Versatz am Segmentstoß = permitted displacement at the segment joint
Segmentlänge = segment length]

at the girder joint $\left|\Delta y_{i_{max}}\right| = 1{,}0\,mm$

Displacement at the girder joint is adjusted following precise positioning of the girder and presupposes a guideway gauge tolerance of ± 1mm (see point 6.7.2.3).

- tilting (relative to the measurement point):

within the girder $\Delta\alpha_{SFE_{max}} = \pm\arctan(1{,}0\,mm / 155\,mm)$

inside, at lateral guide rail level joints $\Delta\alpha_{SFE_{max}} = \pm\arctan(0{,}7\,mm / 155\,mm)$

at the girder joint $\Delta\alpha_{SFE_{max}} = \pm\arctan(0{,}5\,mm / 155\,mm)$

Permitted guideway gauge tolerance

Changes in the guideway gauge as a result of a uniform change in the girder temperature in relation to the reference temperature (“temperature at the time of installation”) must be considered over and above the permitted tolerance.
The guideway gauge tolerance for all types of guideway is as follows:

within the support structure $\Delta S = \pm 2\,mm$

at the beginning/end of the support structure $\Delta S_{Anfang;Ende} = \pm 1mm$

Slider level tolerances and positional deviations

The slider level becomes the functional area when a maglev train sets off.
In terms of considerations regarding tolerance and positional deviation, its relationship with the actual progression of the stator level is given by means of the hover clearance. In other words, the actual long-wave deviation in the stator level shall be taken into consideration when determining the theoretical progression of the slider level (see fig. 219).
If a slider level reference to the theoretical position of the stator level is necessary for production-related reasons, when stipulating the slider level tolerance zone, inter alia, the two extremes in terms of long-wave stator level deviation must be taken into account.
The tolerance in terms of the hover clearance and data concerning the gradient-altering criterion limit values for the slider level must also be observed.
The mutual influence exerted by the individual tolerances and positional deviations in the z coordinates is presented in the following overview (fig. 217).
The x and y coordinate correlations were not presented given their secondary importance.

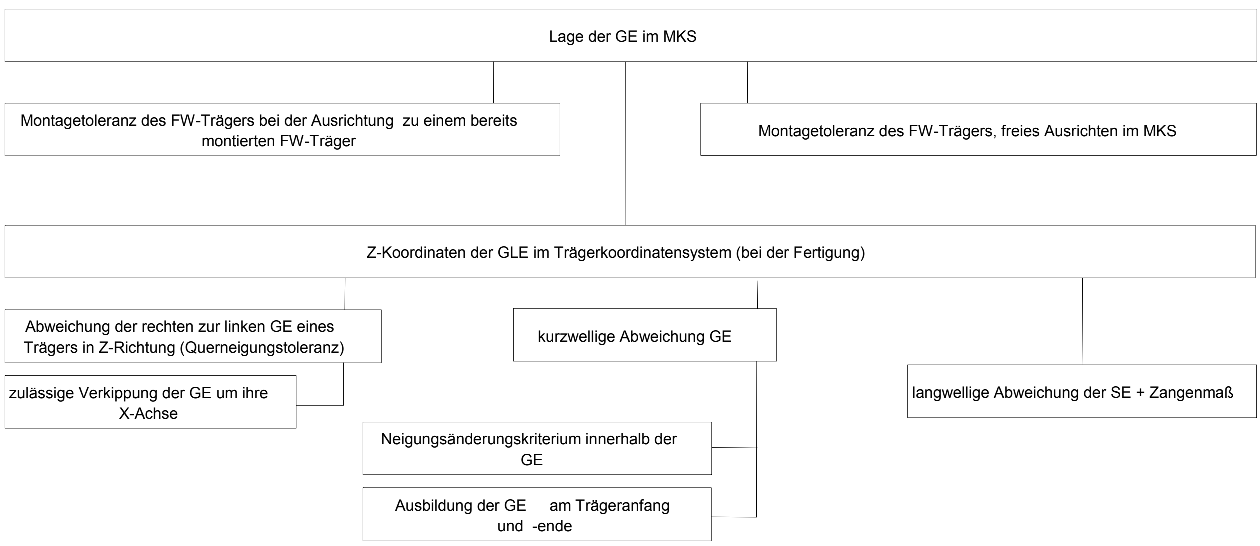


Fig. 217: Slider level tolerances and positional deviations in the z direction and their mutual dependence

[Key to diagram:
Lage der GE im MKS = position of the slider level in the maglev train coordinate system
Montagetoleranz des FW-Trägers bei der Ausrichtung zu einem bereits montierten FW-Träger = assembly tolerance of the guideway girder in the case of alignment with a guideway girder which has already been installed
Montagetoleranz des FW-Trägers, freies Ausrichten im MKS = assembly tolerance of the guideway girder, free alignment in the maglev train coordinate system
Z-Koordinaten der GLE im Trägerkoordinatensystem (bei der Fertigung) = z-coordinates of the slider level in the girder coordinate system (during production)
Abweichung der rechten zur linken GE eines Trägers in Z-Richtung (Querneigungstoleranz) = deviation between the right and left slider levels of a girder in the z direction (lateral incline tolerance)
kurzwellige Abweichung GE = short-wave deviation in the slider level
zulässige Verkippung der GE um ihre X-Achse = permitted tilting of the slider level about its x-axis
langwellige Abweichung der SE + Zangenmaß = long-wave deviation in the stator level + the hover clearance
Neigungsänderungskriterium innerhalb der GE = gradient-altering criterion within the slider level

Ausbildung der GE am Trägeranfang und –ende = slider level formation at the beginning and end of the gir-der]

Permitted slider level tolerances in the x direction

Permitted gap in the x direction within the sliding rail

The maximum permitted gap widths depending on their position in the guideway are defined in the Principles concerning the overall system design of high-speed maglev systems.

In the case of a one-piece slider level design over the entire length of the support structure, its heat expansion as set out in the Guideway design principles for high-speed maglev systems - Part II: Dimensioning, must be taken into consideration relative to the system axes at the beginning and end of the girder.

To determine the minimum gap, i.e. the distance from the beginning and end of the girder to the system axis, in the case of support structures, the arrangement of the fixed and movable bearings, as well as the permitted support deformation as per the Principles concerning the overall system design of high-speed maglev systems, must be taken into consideration.

The following standard values are specified:

The gap between the start or end of the girder and the system axes:

Support structure (12 m ≤ system length ≤ 25 m)	$\Delta x_{A,E} = 20\,mm$
Guideway plates (system length ≤ 6 m)	$\Delta x_{A,E} = 10\,mm$

The aim will be to achieve uniform girder joints at the reference temperature.

In the case of interruptions to the slider level which are the result of its design (e.g. with a modular design), the positional stability and form deviation of the slider level elements must be taken into consideration when determining the theoretical gap widths in the support structure.

In the case of points, the minimum gap which is required within the point between the slider level elements is determined in accordance with equation 22.

The number of gaps in the slider level is to be kept to a minimum (6.7.3.3.4).

A collision between like, adjacent functional level elements must be avoided.

The joints in the slider level shall be designed in accordance with fig. 218.

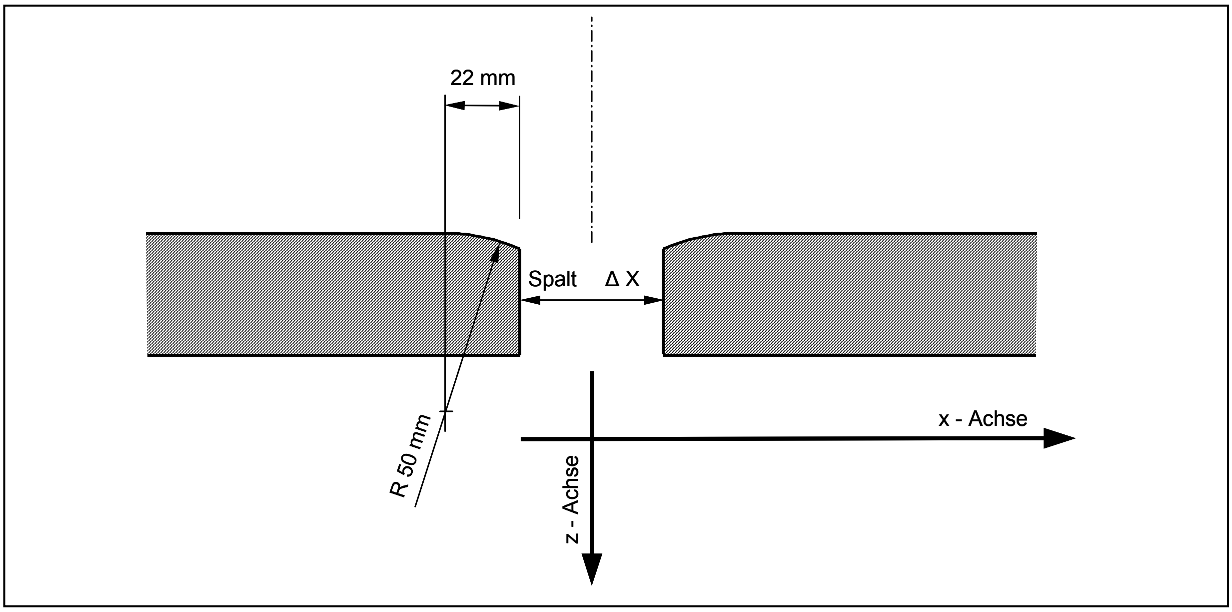


Fig. 218: Surface design of the slider level at the girder joint or in the event of interruptions

[Key to diagram:
Spalt = opening
x-Achse = x-axis
z-Achse = z-axis]

Permitted slider level tolerances in the Y direction

Relative to the centre axis of the longitudinal stator, the following uniform tolerance applies to all types of guideway from the beginning of the support structure to the end:

$$\Delta y = \pm 16 mm$$

Permitted slider level tolerances in the z direction

Theoretical position

The theoretical position of the slider level is stipulated in relation to the stator level by means of the hover clearance (-398 mm to the actual position of the stator level base).
As a basis for the actual position in this regard, the long-wave deviation progression, which is determined using the continuous stator level measured values, is used (see fig. 219).

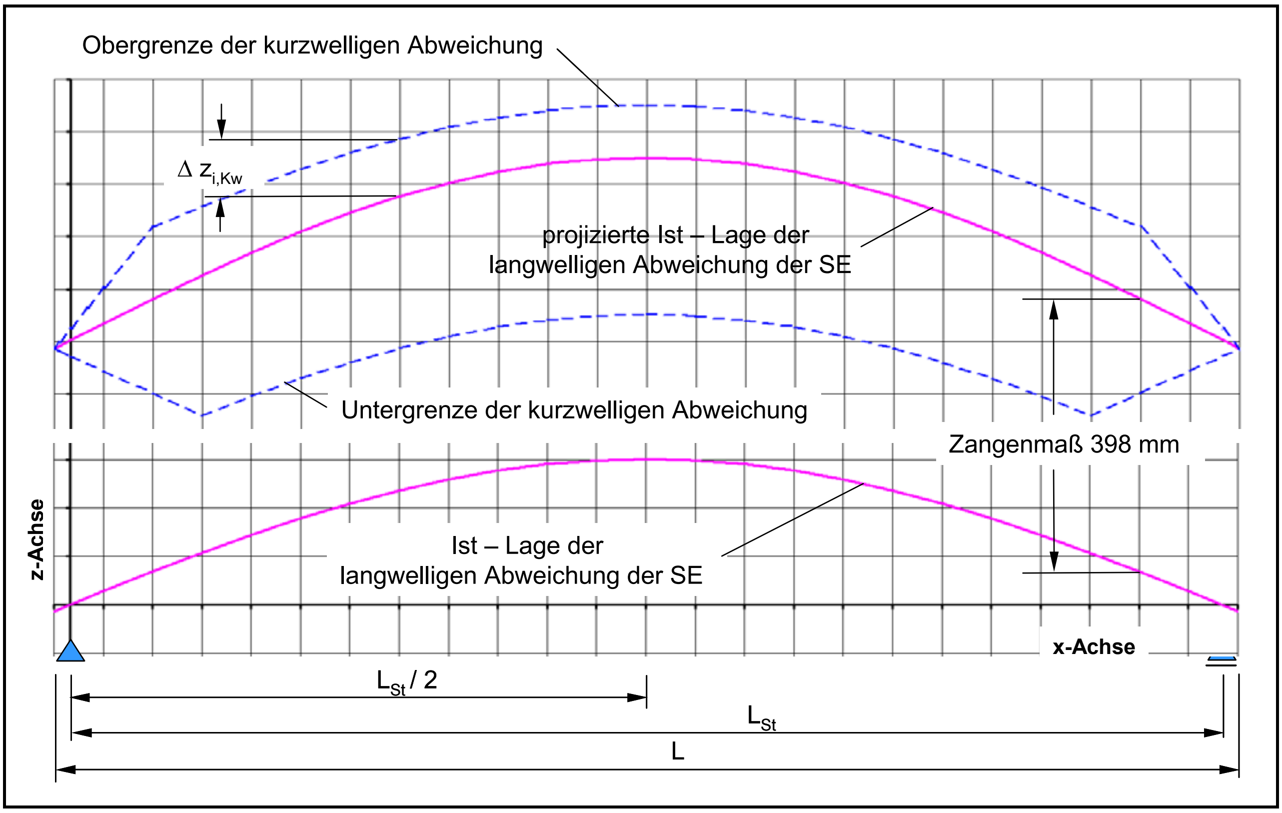


Fig. 219: The progression and position of the slider level's short-wave deviation using the example of a simple beam with precurvature

[Key to diagram:
Obergrenze der kurzwelligen Abweichung = upper limit for short-wave deviation
projizierte Ist-Lage der langwelligen Abweichung der SE = projected actual position of the long-wave deviation in the stator level
Untergrenze der kurzwelligen Abweichung = lower limit for the short-wave deviation
Zangenmaß = hover clearance
Ist-Lage der langwelligen Abweichung der SE = actual position of the long-wave deviation in the stator level
x-Achse = x-axis
z-Achse = z-axis]

The tolerances given below are valid for each slider level (right and left sides). A direct dependence on one another of the theoretical positions of the two slider levels is not envisaged.

Long-wave deviation in the slider level

The slider level tolerance range is determined by the actual long-wave progression of the stator level. For this purpose, the latter is displaced by the hover clearance.
A separate examination is dispensed with (see fig. 219).

Short-wave deviation in the slider level

The actual long-wave progression of the stator level is shifted upwards by the amount of the hover clearance.
The upper and lower limit range is superimposed on this, which is described in a uniform manner for all guideway types by the following basic data:

$$x_0 ; x_L \qquad \Delta z_i = \pm 0{,}4\,\text{mm}$$

$$x_0 < x_i < x_{0+n} ; x_{L-n} < x_i < x_L \quad n = 1{,}2 \ldots * \qquad -3\,\text{mm} \le \Delta z_i \le +5\,\text{mm}$$

$$x_{>n} < x_i < x_{<(L-n)} \qquad -3\,\text{mm} = \Delta z_i = +5\,\text{mm}$$

* n shall be stipulated in observance of the maximum permitted gradient-altering criterion

At each point, the criterion concerned with the gradient-altering criterion must also be observed (see 6.7.3.4).

Within the short-wave deviation tolerance zone, the following proximity relation must be observed in the slider level:

$$NGK_{GE} \le 3{,}0\,\text{mm}$$

For determining the tolerance range progression of the slider level at the beginning and end of the girder (girder transition), a gradient-altering criterion, relative to the theoretical position of the stator level, of

$$NGK_{GE,Anfang;Ende} \le 1{,}5\,\text{mm}$$

shall be applied.

The permitted limit values set out in the Guideway design principles for high-speed maglev systems - Part II: Dimensioning, must be observed in this regard.

Permitted slider level displacements / tilting

The following tolerances relate to the measurement points according to fig. 185 and the stipulations concerning the choice of the pertinent x coordinates.
The tolerances listed below are the same for all types of guideway.

- Displacements:

  within the girder $\left|\Delta z_{i_{max}}\right| = 0{,}2\text{mm}$ *

  * Depending on the frequency with which they occur, tolerances may be exceeded in contiguous guideway sections under the conditions presented in fig. 220:

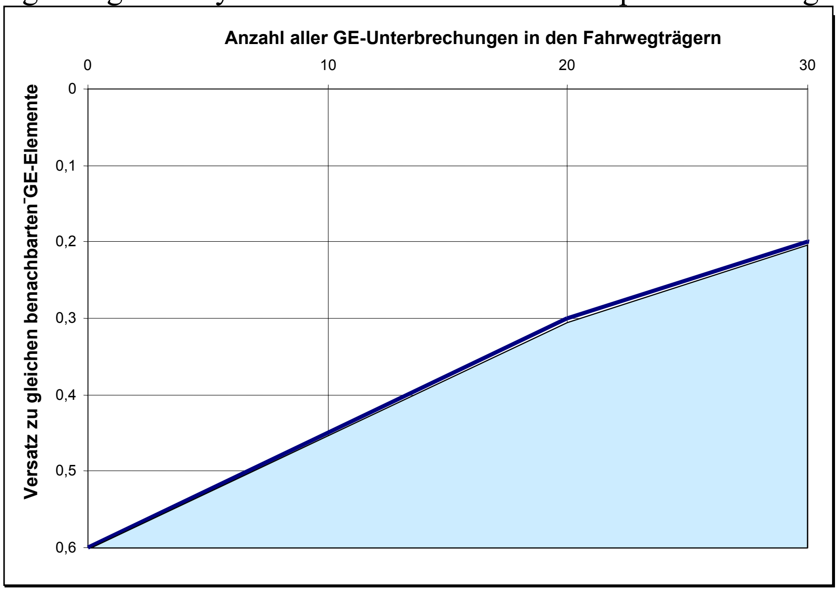


Fig. 220: Permitted displacements in the slider level within the support structure depending on their extent and the frequency with which they occur

[Key to diagram:
Anzahl aller GE-Unterbrechungen in den Fahrwegträgern = number of all the slider level interruptions in the support structures
Versatz zu gleichen benachbarten GE-Elemente = displacement in relation to similar adjacent slider level elements]

  at the girder joint $\left|\Delta z_{i_{max}}\right| = 0{,}6\,\text{mm}$

  The displacement at the girder joint comprises the tolerance width of the short-wave deviation for the slider level at the girder joint, the portion of tolerance relating to the hover clearance (Chapter 6.7.3.4) and the assembly tolerance.

- tilting (relative to the measurement point in the centre axis of the longitudinal stator):

$$\Delta\alpha_{GE_{max}} = \pm\arctan\left(0{,}5\text{mm}/75\text{mm}\right)$$

Hover clearance

The permitted hover clearance is established from a calculation of the permitted short-wave tolerances regarding the stator and slider levels (see Chapter 6.7.3.3.3 and fig. 219).

The following dimensions may be used as standard values for a punctual, geometric inspection using sample points without taking into account the long- and short-wave tolerances:

Nominal size:	*398 mm*
Standard value within the girder:	*from 393 mm to 401 mm*
Standard value at the beginning/end of the girder:	*from 397.6 mm to 398.4 mm*

Guideway assembly

The tolerances relating to precise positioning are specified in the Guideway design principles for high-speed maglev systems - Part IV: Surveying.

Geometric requirements pertaining to the calibrated guideway

Irrespective of the data provided previously, more stringent requirements are laid down in relation to the geometry of calibrated girders (guideway section within the central maintenance depot, assists in calibrating the maglev train). In this regard, the tolerances mentioned below in relation to the load-free girder are regarded as framework conditions for the time being:

As regards the stator level:

$\Delta z_{max} = \pm 1$ **mm**

where $L_{Sys} \geq 18m$ $|\Delta z_i| \leq \Delta z_{max}$

where $L_{Sys} < 18m$ $0{,}1mm < |\Delta z_i| < |\Delta z_{max}| * L_{Sys} / 18m$

As regards the lateral guide level:

$\Delta y_{max} = \pm 1$ **mm**

where $L_{Sys} \geq 18m$ $|\Delta y_i| \leq \Delta y_{max}$

where $L_{Sys} < 18m$ $0{,}1mm < |\Delta y_i| < |\Delta y_{max}| * L_{Sys} / 18m$

As regards the guideway gauge:

$\Delta S_{max} = \pm 0{,}5$ **mm**

where $L_{Sys} \geq 18m$ $|\Delta S_i| \leq \Delta S_{max}$

where $L_{Sys} < 18m$ $0{,}1mm < |\Delta S_i| < |\Delta S_{max}| * L_{Sys} / 18m$

As regards the hover clearance:

$\Delta Z_{max} = \pm 1$ **mm**

where $L_{Sys} \geq 18m$ $|\Delta Z_i| \leq \Delta Z_{max}$

where $L_{Sys} < 18m$ $0{,}1mm < |\Delta Z_i| < |\Delta Z_{max}| * L_{Sys} / 18m$

In addition, the following requirements pertaining to the rigidity of the girder apply:

Where the girder is subjected to a load comprising the weight of the vehicle (vehicle fully equipped), the following applies to the difference between the girder under load and the load-free girder in the z direction:

$\mathbf{\Delta z_{max} = 1\ mm}$

where $L_{Sys} \geq 18\,m$ $\quad |\Delta z_i| \leq \Delta z_{max}$

where $L_{Sys} < 18\,m$ $\quad 0{,}1mm < |\Delta z_i| < |\Delta z_{max}| * L_{Sys} / 18\,m$

With a lateral load of 0.3 g:

$\mathbf{\Delta y_{max} = 1\ mm}$

where $L_{Sys} \geq 18\,m$ $\quad |\Delta y_i| \leq \Delta y_{max}$

where $L_{Sys} < 18\,m$ $\quad 0{,}1mm < |\Delta y_i| < |\Delta y_{max}| * L_{Sys} / 18\,m$

Positional requirements relating to guideway ancillary devices and equipment items

Position of the motor winding

The clearance required for motor winding installation is defined in the Principles concerning the overall system design of high-speed maglev systems.

The motor winding shall be positioned such that the clearance is observed under all operating conditions.

The arrangement and location of the individual phases in relation to each other are defined in the Principles concerning the overall system design of high-speed maglev systems.

The distances between the meander of the motor winding and their x grids are determined by the chosen arrangement of the stator plates in the x direction. The basic meander grid is 258 mm.

Location of the positional reference guide rail

The clearance in the y and z directions which is required for installation of the positional reference guide rail is defined in the Principles concerning the overall system design of high-speed maglev systems.

The arrangement in the x direction is based on the position of the girder reference locations which is dependent on the actuation period.

Positional reference guide rails are secured to the guideway at the reference locations by means of special supports. The design of the supports and their attachment is defined in relation to the specific project.

The guideway reference locations are laid down in relation to the project with the drive design and the operational process control system.

Location of the external inductive power supply guideway-side assemblies

Location of the conductor rail guideway-side assemblies

The location of the conductor rails is laid down for individual sections of guideway in relation to the specific project.

The clearance in the y and z directions which is required for installation of the conductor rails is defined in the Principles concerning the overall system design of high-speed maglev systems.

The location, in principle, of the conductor rail supports is laid down in the Guideway design principles for high-speed maglev systems - Part I: Principle requirements.

Location of the inductive power transmission guideway-side assemblies

The inductive power transmission is currently still at the development stage. The requirements pertaining to this assembly are therefore added.

Temporarily, the project-independent requirements relating to "other guideway equipment assemblies" and project-specific stipulations apply.

Proofs

Building components and assemblies shall be measured within the framework of quality assurance following the production steps and variance comparisons carried out and documented.

The production documentation shall specify the date and the dimensions to be checked. The tolerance to be considered at the time of testing shall be determined in accordance with the overall tolerance assessment.

The fundamental requirements pertaining to quality assurance, building and acceptance shall be taken from the Guideway design principles for high-speed maglev systems - Part I: Principle requirements.

The approved measuring instruments and methods which are suitable for acceptance measurements shall be applied to prove observance of the tolerances in accordance with these design principles.

Annex III-A Stator plate attachment (support structure side)

The diagrams below (figs, 221, 222, 223 and 224) are examples of a solution for incorporating the stator plates along a continuous stator girder boom.

As an alternative, so called inserts are possible. The specified dimensions and tolerances apply to both variants.

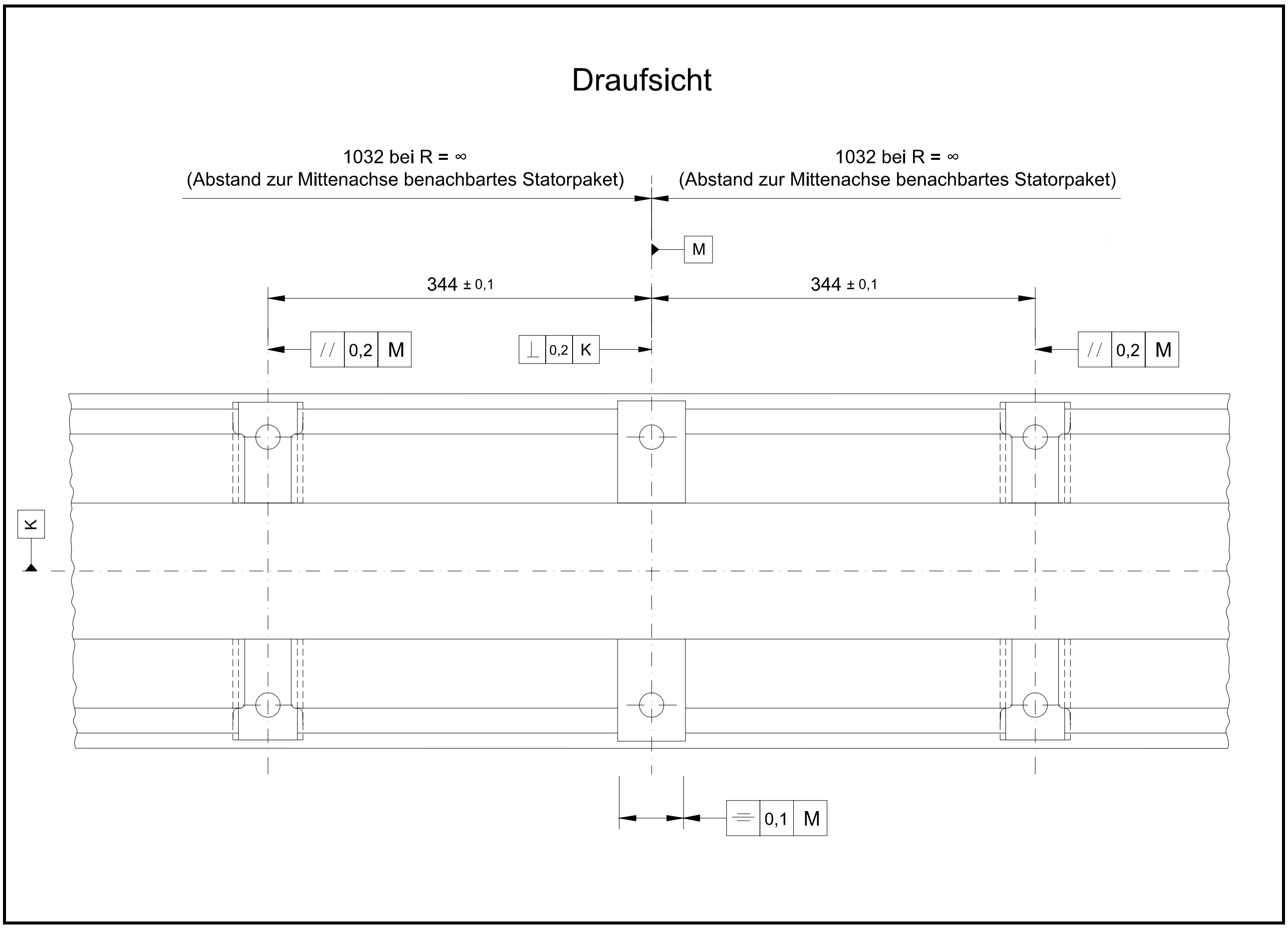


Fig. 221: Dimensions and tolerances for designing stator plate incorporation in a steel construction (top view)

[Key to diagram:
Draufsicht = top view
Abstand zur Mittenachse benachbartes Statorpaket = distance to the centre axis of the adjacent stator plate]

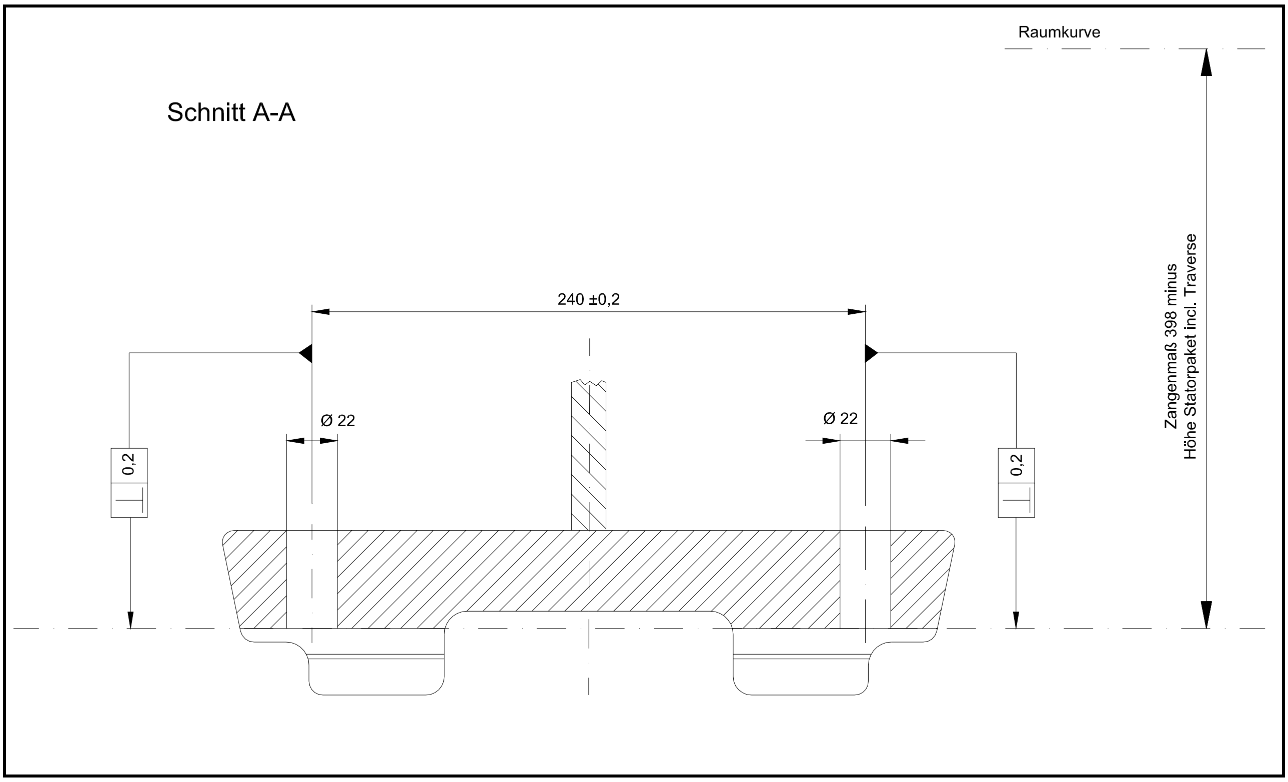


Fig. 222: Dimensions and tolerances for designing stator plate incorporation in a steel construction (cross-section)

[Key to diagram:
Raumkurve = space curve
Schnitt A-A = section A-A
Zangenmaß 398 minus Höhe Statorpaket incl. Traverse = hover clearance 398, minus the height of the stator plate, including the tie-bar]

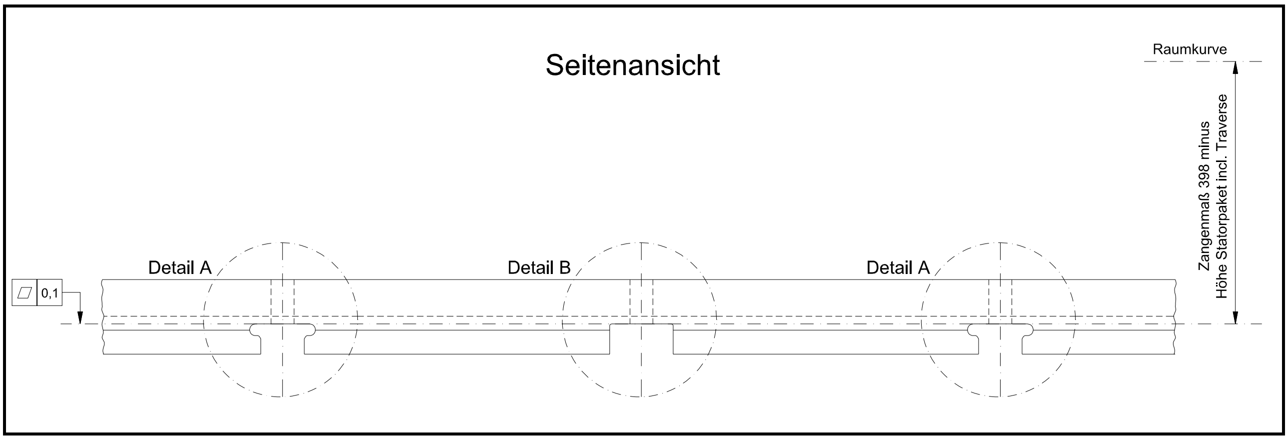


Fig. 223: Dimensions and tolerances for designing stator plate incorporation in a steel construction (side view)

[Key to diagram:
Raumkurve = space curve
Seitenansicht = side view
Zangenmaß 398 minus Höhe Statorpaket incl. Traverse = hover clearance 398, minus the height of the stator plate, including the tie-bar
Detail = detail]

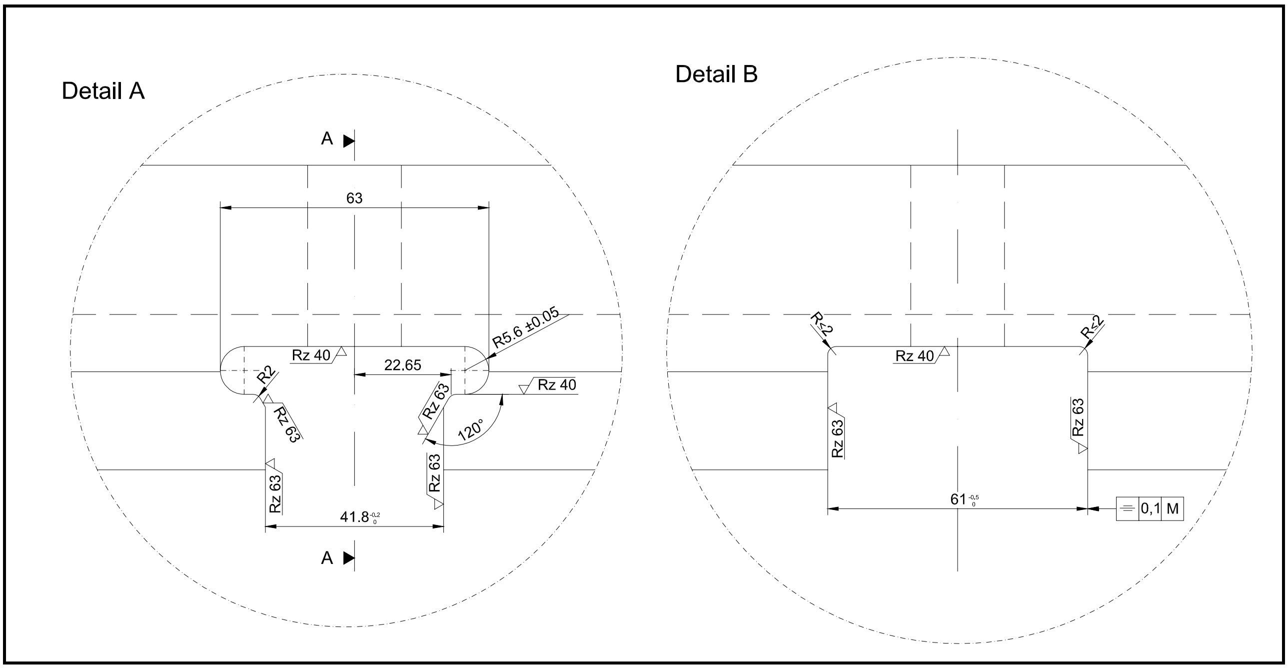


Fig. 224: Dimensions and tolerances for designing stator plate incorporation in a steel construction (details A and B)

[Key to diagram:
Detail = detail]

Annex III-B Stator plate fixing axes

The diagrams below (figs. 225, 226 and 227) are examples of stator plate fixing axes.

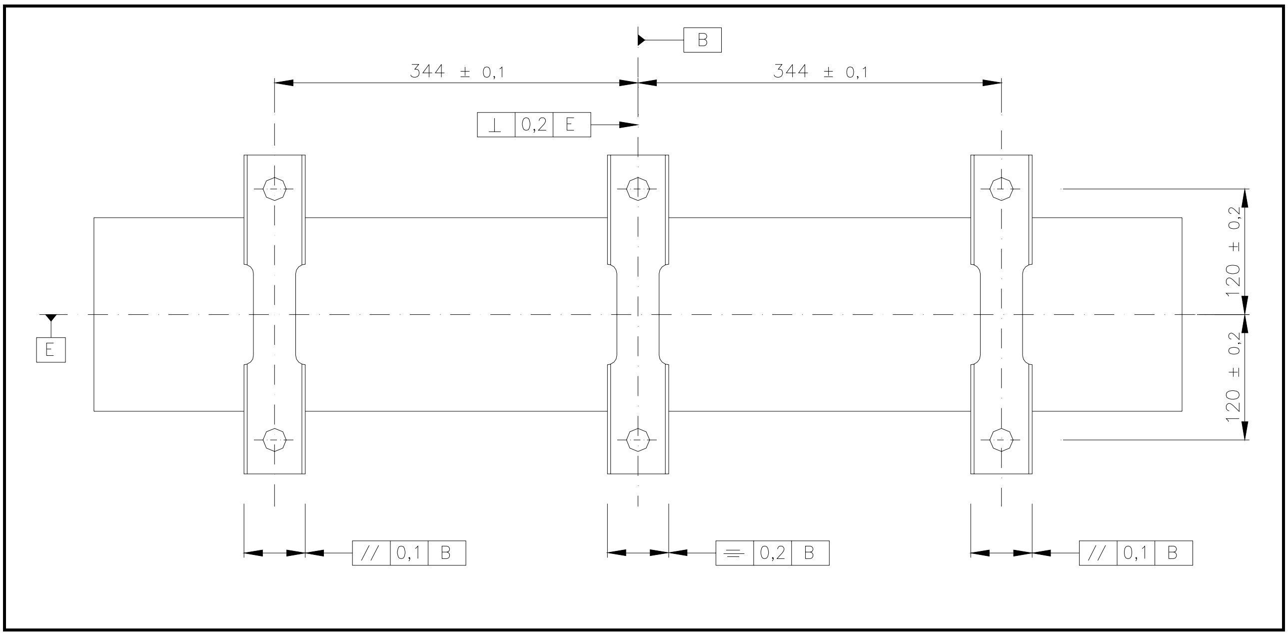


Fig. 225: Stator plate fixing axes (top view)

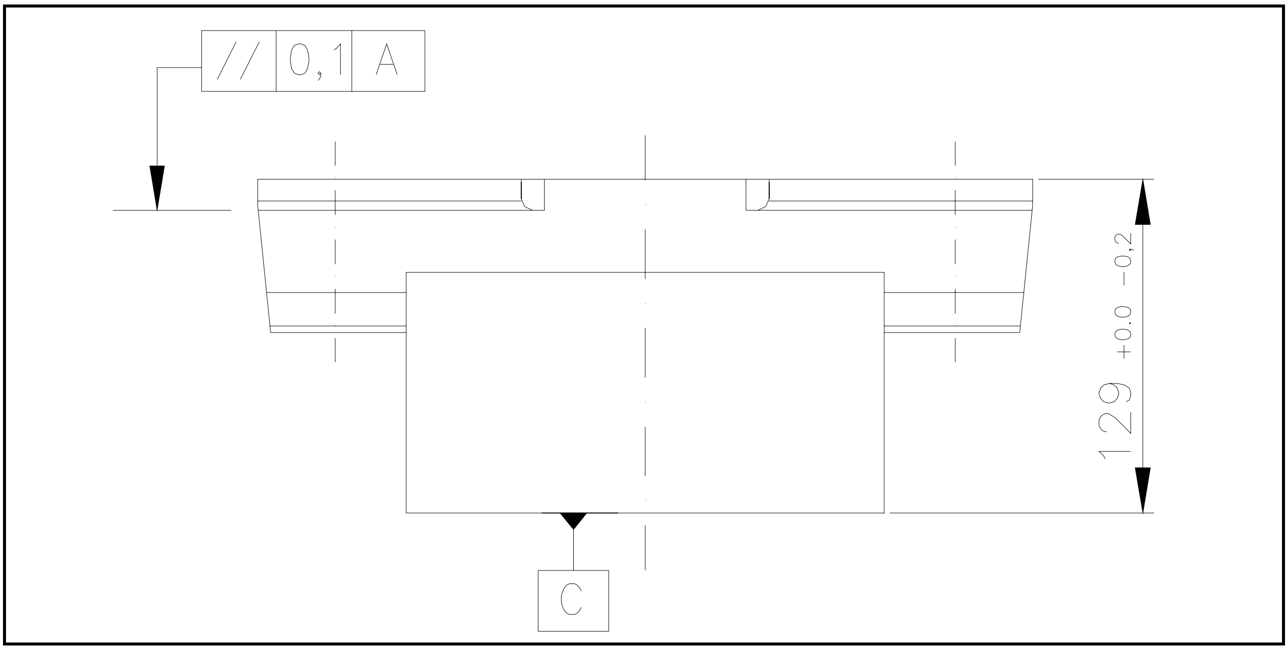


Fig. 226: Stator plate fixing axes (cross-section)

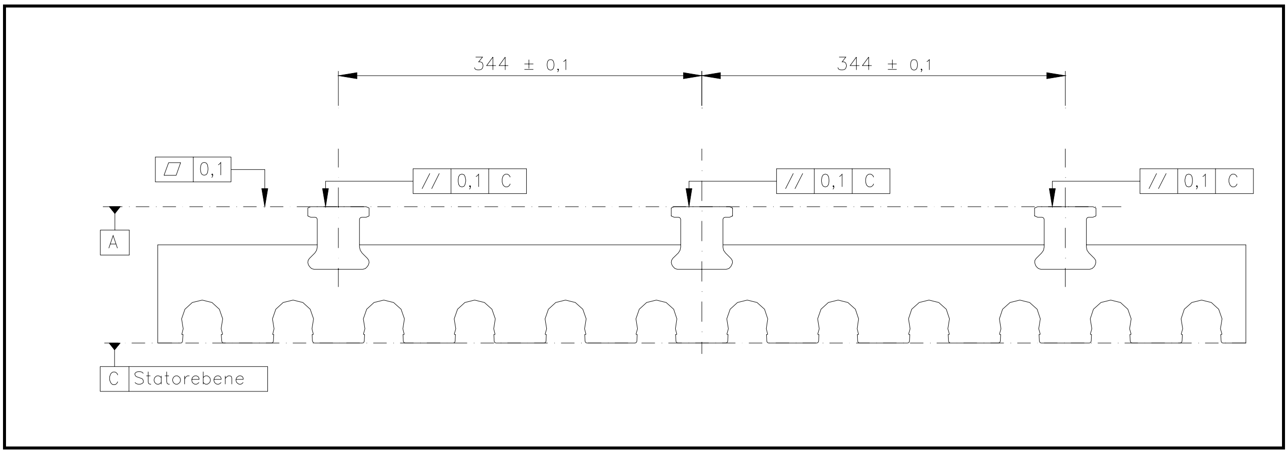


Fig. 227: Stator plate fixing axes (side view)

High-speed maglev systems
Design principles

Guideway
Part IV
Routing

Distributor

This document was released for publication by the Guideway Technical Committee.

Revision history

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List of diagrams

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General

Object and area of application

This document sets out in detail the generally applicable technical stipulations regarding the routing of guideways for high-speed maglev systems.
These design principles apply to a maglev train in accordance with the General Maglev Systems' Act.

Principles for the design of high-speed maglev systems

This document is part of the documentation relating to high-speed maglev systems consisting of several design principles. The document tree is presented in fig. 1 of the Principles concerning the overall system design of high-speed maglev systems.

The primary overall system design documentation and its annexes apply in a uniform manner to the documentation as a whole:

- Principles concerning the overall system design of high-speed maglev systems, document number 50630, and its annexes:
  - Annex 1: Abbreviations and definitions, document number 67536 [Principles for the design of high-speed maglev systems - Abbreviations and definitions]
  - Annex 2: Acts, Orders, Standards and Guidelines, document number 67539 [Principles for the design of high-speed maglev systems - Standards and guidelines]
  - Annex 3: Environmental conditions, document number 67285 [Principles for the design of high-speed maglev systems - The environment]
  - Annex 4: Rules for operation (driving and maintenance), document number 69061 [Principles for the design of high-speed maglev systems - Driving and maintenance]
  - Annex 5: Sound, document number 72963 [Principles for the design of high-speed maglev systems - Sound]

Abbreviations and definitions

The abbreviations and definitions specified in the Principles for the design of high-speed maglev systems - Abbreviations and definitions - apply.

Acts, Orders, Standards and Guidelines

The normative documents listed in the Principles for the design of high-speed maglev systems - Standards and guidelines, contain stipulations which, by reference to the Principles for the design of high-speed maglev systems, become part of the same. Later amendments or revisions to these publications do not apply to dated, normative documents found in the Principles for the design of high-speed maglev systems - Standards and guidelines. Where references are not dated, the most recent version of the normative document referred to applies.

The status of the standards and guidelines to be taken into consideration in a maglev train project must be laid down in a binding manner specific to the project.

Indicating requirements and their binding nature

The provisions pursuant to DIN 820 were essentially applied when preparing this document.

In the chapters following and the annexes to this document,

- requirements are set out in standard type and
- explanatory notes, standard values and examples are set out in *italics*

(refer to the Guideway design principles for high-speed maglev systems - Part I: Principle requirements).

Routing

General principles governing routing

Taking into account the technical options available, the routing should be chosen in such a way that during operation involving the theoretical path taken as a basis, economically optimum coordination is achieved between requirements in terms of travel dynamics, travel comfort, building and repair costs.

The ultimate aim is for the vehicle to be able to travel over long sections at a constant speed.

Other requirements which are relevant from the point of view of routing, for instance, environmental and sound insulation reasons, networking with other highways, aesthetic points of view and product design, may influence the planning of the line’s location and shall be included in relation to the specific project.

Guideway axis (space curve)

Guideway axes (space curves) consist of the three-dimensional superimposition of the horizontal and vertical plan alignment.

Guideway axes shall be provided with a clear designation. This should be numerical and comprise three digits.

In the case of multi-guideways, every guideway axis shall be routed separately.

Chainage

Based on the use of finished parts as a result of their system and design, chainage shall relate to the spatial termination of the guideway axis (space curve).

Horizontal and vertical plan alignment

Horizontal and vertical plan routing should be effected separately in the first instance.

The space curve established as a result of the superimposition of the horizontal and vertical plan alignment must fulfil all the requirements contained in this design principle.

Routing of the stretch as a whole shall be examined using the definitive, simulated actual paths to ensure that it fully satisfies the projected comfort limit values.

Inclusion of the routing design in calculations

Routing design should be carried out on the basis of general pans and gradient diagrams, together with their image systems.

The geometric and geodetic bases of the general pans and gradient diagrams shall be examined in terms of their applicability.

In terms of design-related follow-up work (stipulating the division of supports, bridge structures, points systems) and as regards subsequent staking, the graphic design shall be included in the maglev train coordinate system as set out in the Guideway design principles for high-speed maglev systems - Part IV: Surveying, according to location and elevation.

Existing constraining points shall be surveyed, coordinated and taken into consideration in the calculation.

Inclusion in calculations shall be effected in such a way that

- the progression of the line corresponds to the graphic representation given in the design plans to the standard degree of precision,
- strictly tangential transitions exist along the main points of the line,
- a steady progression exists in the curvature string and cross-fall string (the exception being the curvature string deflection and $v_{max} < 100$ km/h) and
- the three-dimensional x, y and z coordinates of all the main line points are determined using the corresponding chainages.

The calculations shall identify

- coordinates and elevations to four decimal places (1/10 mm) and
- data concerning angles to five decimal places.

Horizontal plan routing elements

Standard guideway

Horizontal plan routing elements are as follows:

- straight lines ($R_H = \infty$)
- arcs [of a circle] (R_H = constant)
- sinusoids (standard scenario, as a transition curve)
- clothoids (special scenario, as a transition curve)

Sinusoids should be used as transition curves.
In the case of sinusoids, curvature, cross-fall, unbalanced lateral acceleration and lateral jolts are established as a function of time and the distance travelled.

Clothoids in the form of transition curves can be used in the accelerating and braking areas at stations and in areas where there are no passengers (e.g. IHZ approaches). This only applies to sections of guideway on which the theoretical path speed does not exceed 100 km/h.
Subsequent use of that part of the guideway with a higher maximum speed (e.g. in the case of a network expansion and possible through passage at this station) should be assessed.

Cant gradients (S jolts) shall be routed as an element (continuous sinusoids).

The geometric characteristics of the sinusoids and clothoids and those concerning travel dynamics are presented below in figs. 228 and 229. The calculation of the minimum sinusoid and clothoid lengths is explained under point 6.2.4.

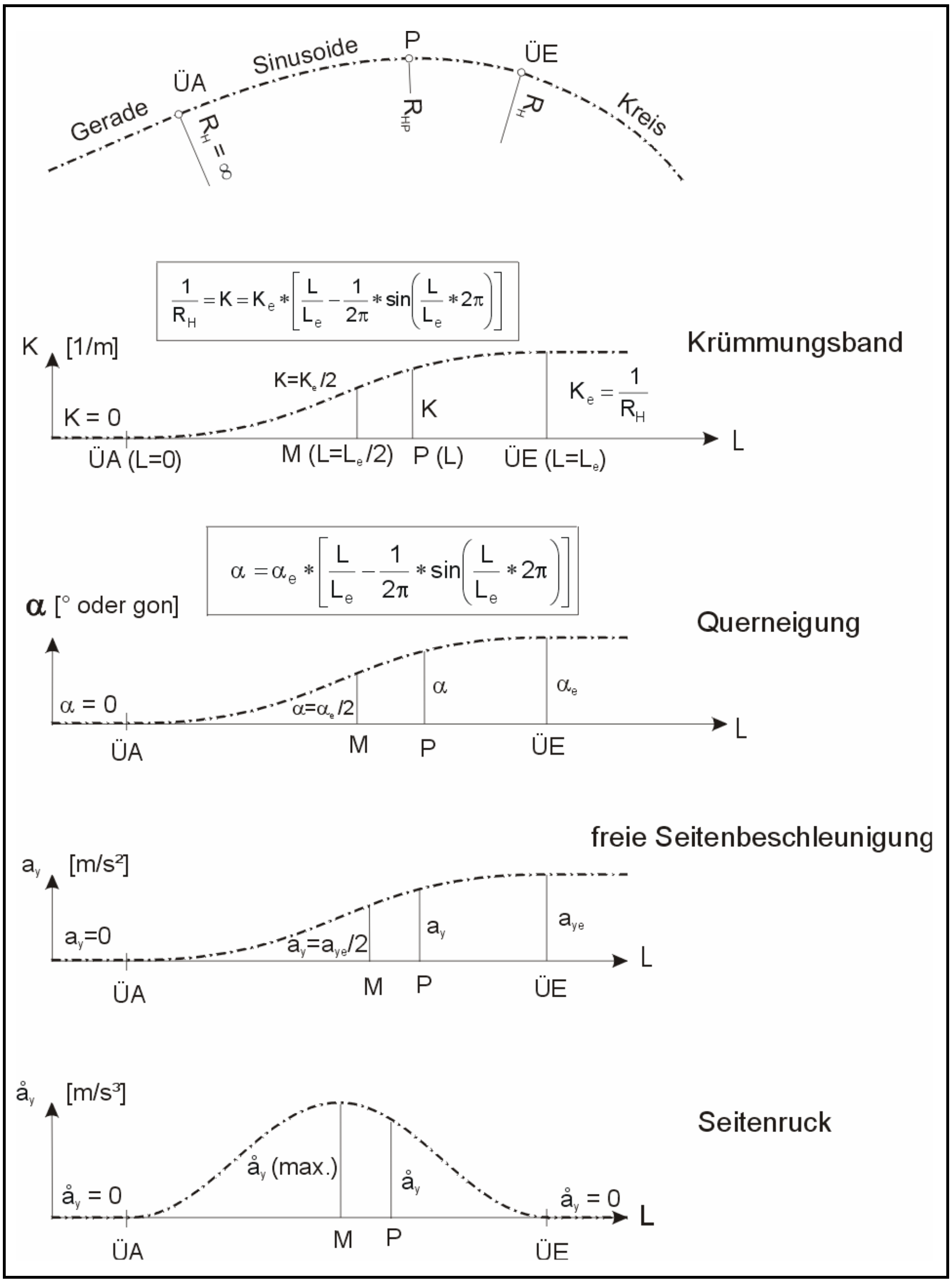


Fig. 228: Geometric characteristics of the sinusoids and those concerning travel dynamics

[Key to diagram:
Gerade = straight line
Sinusoide = sinusoid
Kreis = circle

Krümmungsband = curvature string
oder gon = or gon
Querneigung = lateral incline
freie Seitenbeschleunigung = free lateral acceleration
Seitenruck = lateral jolt]

The lateral incline has a sinusoidal structure in a similar way to the curvature.

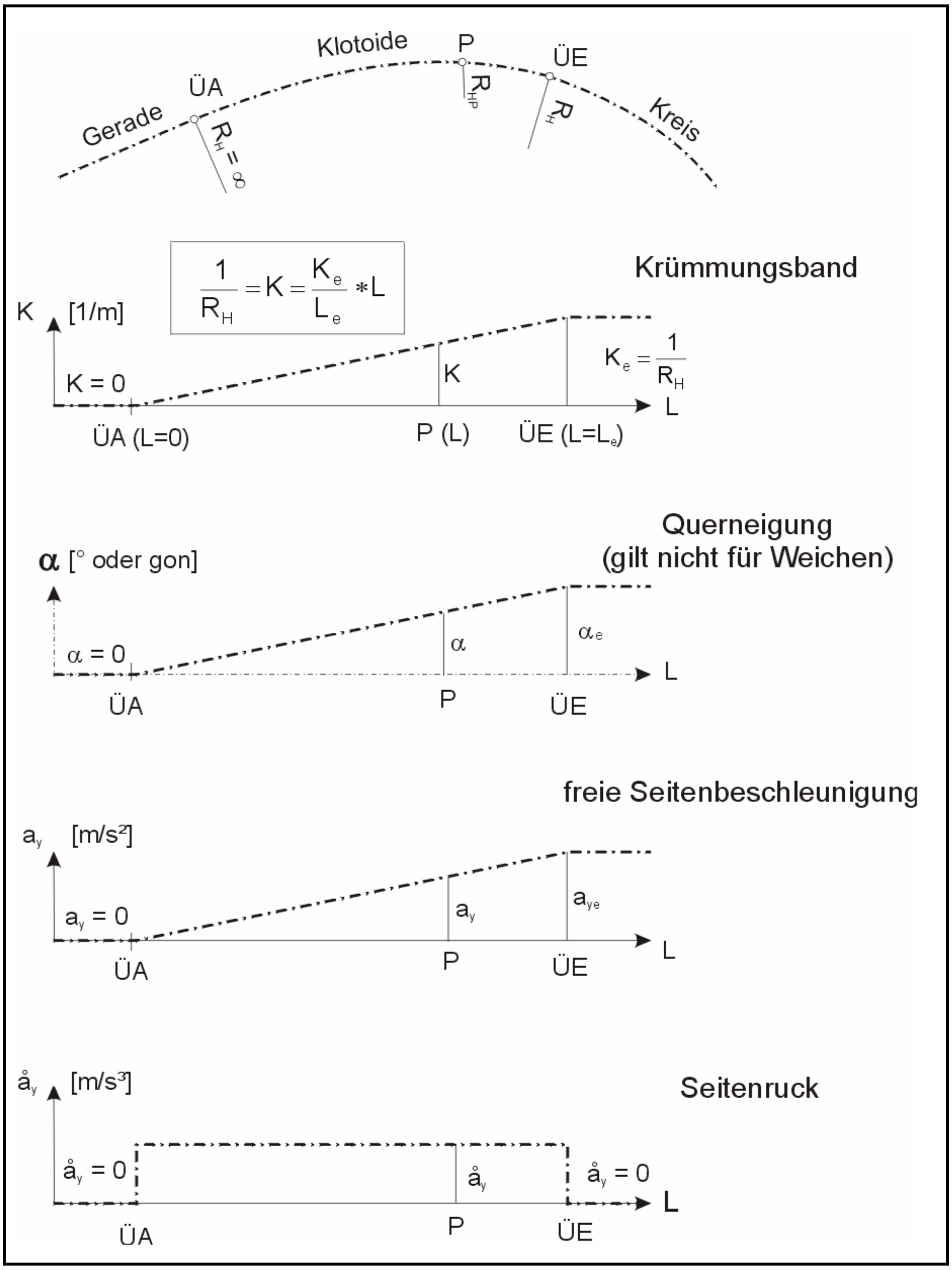


Fig. 229: Geometric characteristics of the clothoids and those concerning travel dynamics

[Key to diagram:
Gerade = straight line
Klotoide = clothoid
Kreis = circle

Krümmungsband = curvature string
oder gon = or gon
Querneigung (gilt nicht für Weichen) = lateral incline (does not apply to points)
freie Seitenbeschleunigung = free lateral acceleration
Seitenruck = lateral jolt]

Vertical plan routing elements

Standard guideway

The standard guideway vertical plan includes the following:

- straight lines ($R_V = \infty$)
- radii (arcs [of a circle], R_V = constant)
- clothoids (transition curve)

Between the straight lines and the radii, clothoids shall be engaged to prevent curvature jumps in the progression of the gradient (vertical jolt $\mathring{a}_z = \infty$).
The maximum permitted longitudinal gradient in the straight lines is laid down under point 6.1.1.

Points

Points should not be arranged in the area of vertical fillets. The maximum permitted longitudinal gradient in the straight lines is laid down under point 6.1.1.

Routing parameters

Geometric routing parameters

Explicitly identified special cases require authorisation.

Section 3(2) and Section 5(1)(2) of the Maglev Construction and Operation Ordinance apply to exemptions from these provisions.

Limit values for the longitudinal gradient of the guideway

The limit values for the longitudinal gradient of the guideway are listed in Table 141.

Place	**Area**	**Limit value**	**Stipulated by**
Open section of guideway outside stopping places		$\lvert s \rvert = 100$‰	Section 13(2) of the Maglev Construction and Operation Ordinance
Within stopping places	Platform area	$\lvert s \rvert = 5$‰	Section 13(2) of the Maglev Construction and Operation Ordinance
	Operational-related stopping places	$\lvert s \rvert = 100$‰ in accordance with the proof of the halting function	Section 13(2) of the Maglev Construction and Operation Ordinance
	Other operational stopping places	$\lvert s \rvert = 100$‰ in accordance with the proof of the halting function	Section 13(2) of the Maglev Construction and Operation Ordinance
	Stopping places for evacuation purposes	$\lvert s \rvert = 5$‰	Section 13(2) of the Maglev Construction and Operation Ordinance

Table 141: Longitudinal gradient of the guideway

Sign convention: + s = slope

- s = gradient

Limit values for the lateral incline of the guideway

The guideway levels shall be planned with a lateral incline to eliminate or reduce the unbalanced lateral acceleration which occurs when going round bends. The limit values are listed in Table 142.

The lateral incline is produced by rotating the guideway superstructures around the guideway axis which maintain their heights (gradients). Consequently, the vehicle's centre of gravity always maintains the same gap from the guideway axis. When stopping (at platforms or operational stopping places), the lateral incline causes acceleration towards the inside of the bend.

Place	Area	Limit value	Stipulated by
Open section of guideway outside stopping places		$\lvert\alpha\rvert$ = 12°	Section 13(3) of the Maglev Construction and Operation Ordinance
		$\lvert\alpha\rvert$ = 16° in special cases	Section 13(3) of the Maglev Construction and Operation Ordinance
Within stopping places	Platform area	$\lvert\alpha\rvert$ = 3.0° *	the system as a whole
	Operational-related stopping places	$\lvert\alpha\rvert$ = 6.0°	the system as a whole Corresponds to a_y = 1.0 m/s² (inside of the bend)
	Other operational stopping places	$\lvert\alpha\rvert$ = 12°	the system as a whole Corresponds to a_y = 2.0 m/s² (inside of the bend)
	Stopping places for evacuation purposes	$\lvert\alpha\rvert$ = 6.0°	the system as a whole Corresponds to a_y = 1.0 m/s² (inside of the bend)
Points		$\lvert\alpha\rvert$ = 0°	the system as a whole Upright or bending position (calculated where $\lvert s\rvert$ = 0 ‰)

Table 142: Lateral incline of the guideway

[*)] In Section 13(3) of the Maglev Construction and Operation Ordinance, the permitted lateral incline of a stationary vehicle in the platform area is limited to 3.4°. The maximum permitted lateral incline of 3.0° is laid down for system-related reasons.

The guideway should be drained via the top side of the guideway superstructures according to the Guideway design principles for high-speed maglev systems - Part I: Principle requirements.

The minimum lateral incline of the guideway is

$|\alpha| = 1.15°$ (corresponds to 2%).

(Areas where the direction of the lateral incline changes (e.g. S jolts) are exempt, along with parking and maintenance lanes, stations and points).

Sign convention: $+\alpha$ = clockwise rotation (viewed in the direction of the chainage)

$+\alpha$ = anti-clockwise rotation (viewed in the direction of the chainage)

Guideway distortion and the minimum permitted distortion length

The distortion section is the transition area between constant lateral incline sections.

The start and end points of distortion sections and transition curves in the case of horizontal plan routing should coincide with the position.

In a particular case, distortion sections can also be arranged in guideway sections with a constant horizontal plan curvature (also refer to the formula for calculating the lateral incline α where Le = the length of the distortion in point 5.2.1).

The progression of the distortion in the cross-fall string should be similar to the progression of the curvature in the horizontal plan routing.

When using sinusoids in the horizontal plan routing, the guideway distortion should be of sinusoidal design. However, if distortion coincides with a clothoid in the horizontal plan, the distortion shall be linear, i.e. with a uniform change in the lateral incline over the length of the element (see fig. 229).

	Distortion	**Stipulated by**
Maximum value	$\lvert \Delta\alpha_{max} \rvert$ = 0.10 °/m	the system as a whole (geometry of the vehicle)
Limit value according to the project-specific agreement	$\lvert \Delta\alpha_{max} \rvert$ = 0.15 °/m	the system as a whole (geometry of the vehicle)

The minimum permitted length of the distortion section is established from the maximum permitted distortion, the maximum lateral jolt (see 6.2.3.1) and the maximum vertical jolt (see 6.2.3.2 and 6.2.4).

Minimum permitted horizontal radius

As regards arc radii without unbalanced lateral acceleration, the following applies:

$$\mathbf{R_H} = \left| \frac{(v/3{,}6)^2 \cdot \cos\alpha \cdot \cos^2\beta}{\left(g \cdot \cos\beta + \frac{(v/3{,}6)^2}{-R_V} \right) \cdot \sin\alpha} \right| \qquad \mathbf{a_y = 0\ m/s^2} \qquad (1)$$

As regards arc radii with non-compensated, unbalanced lateral acceleration, the following applies:

$$\mathbf{R_H} = \left| \frac{(v/3{,}6)^2 \cdot \cos\alpha \cdot \cos^2\beta}{a_y + \left(g \cdot \cos\beta + \frac{(v/3{,}6)^2}{-R_V} \right) \cdot \sin\alpha} \right| \qquad \mathbf{a_y \le a_{y\,max}} \qquad (2)$$

Sign convention:	$+R_H$ = clockwise curve	(viewed in the direction of the chainage)
	$-R_H$ = anti-clockwise curve	(viewed in the direction of the chainage)

The limit values for a_y are listed under point 6.2.2.2. Consideration must also be given to the fact that the values for v, α, β and R_v may not remain constant over the entire arc of the circle but may alter with forward movement along the space curve. R_H is calculated using the above formulae for a single point on the space curve. Where a horizontal plan curvature is superimposed with a vertical fillet, the conditions pertaining to the $R_{x,z}$ criterion and the $R_{x,y}$ criterion must also be heeded (see point 6.1.6).

	Minimum permitted horizontal radius	**Stipulated by**
Limit value	$\lvert R_{H\,min} \rvert$ = 350 m	the system as a whole (geometry of the vehicle)

Fig. 230 below shows an example of the progression of the minimum permitted horizontal radius depending on the speed of the vehicle if stipulations in terms of travel dynamics are to be taken into consideration (see Chapter 6.2.2.2). In this example, a lateral incline of the guideway of 12° is assumed and the smallest horizontal radii are sought for an unbalanced lateral acceleration of 0.0 m/s² or 1.5 m/s².

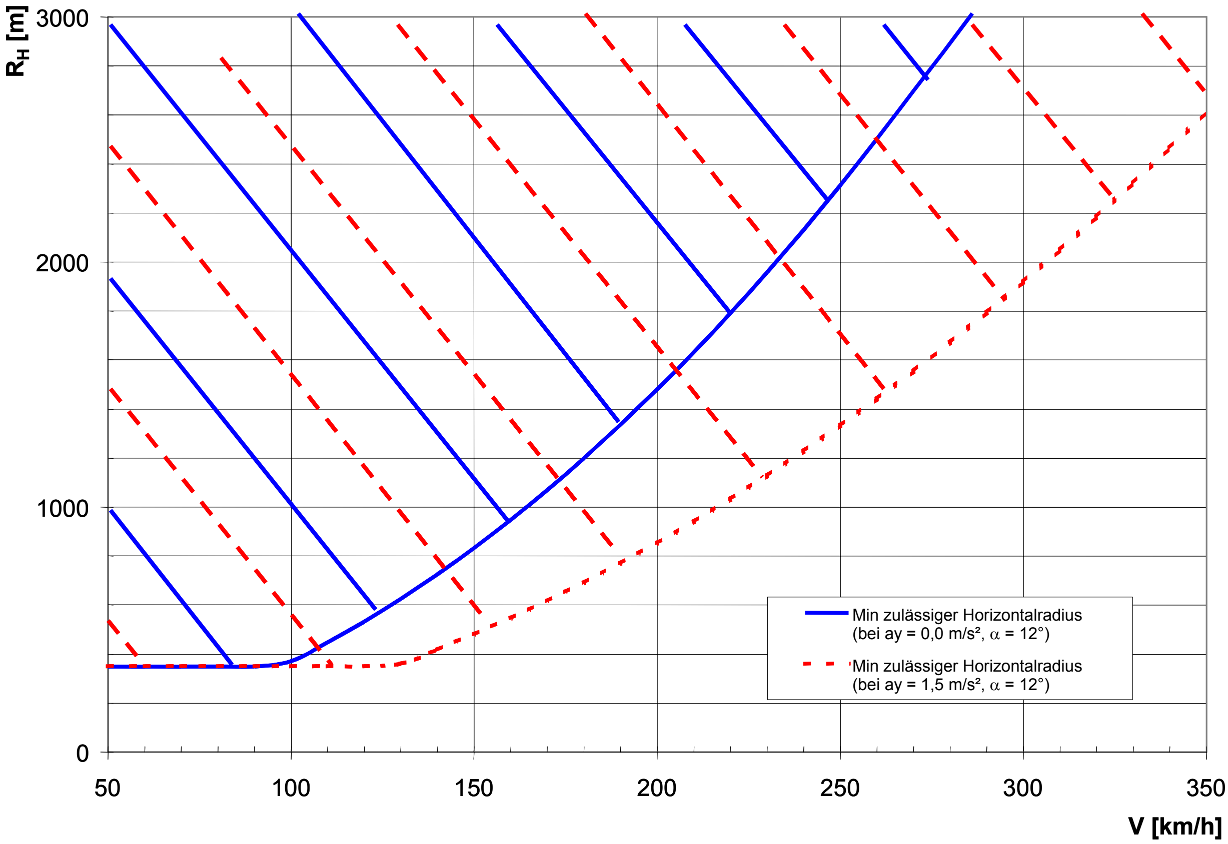


Fig. 230: Minimum permitted horizontal radius

[Key to diagram:
Min. zulässiger Horizontalradius (bei ay = ...) = minimum permitted horizontal radius (where ay = ...)]

Minimum permitted vertical radius

The radii chosen should be such that the standard acceleration which occurs is as low as possible.

Using the limit values for acceleration which are cited under point 6.2.1, the minimum fillet radii values are established as follows:

$$\mathbf{R}_{V\,min} = \left| \frac{\left(\frac{v}{3{,}6}\right)^2 \cdot \cos\alpha}{g \cdot (\cos\alpha \cdot \cos\beta - 1) + \left(\frac{v}{3{,}6}\right)^2 \cdot \frac{\sin\alpha \cdot \cos^2\beta}{R_H} - a_{z\,max}} \right| \qquad (3)$$

Sign convention: $+ R_V$ = peaks

$- R_V$ = troughs

Different limit values for $a_{z\,max}$ apply to peaks and troughs.
Here, too, a point on the space curve is calculated and consideration must be given to the possible change in v, α, β and R_H during the journey as a result of the radius when determining the result.

	Minimum permitted vertical radius	**Stipulated by**
Limit value	$\lvert R_{V\,min} \rvert$ = 530 m	the system as a whole (geometry of the vehicle)

Points should not be located in the area of vertical fillets.

The sign convention is required on account of using transition curves in the gradient calculation.

Fig. 231 below provides an example of the minimum permitted vertical diameter depending on the speed of the vehicle for the maximum standard acceleration which is permitted each time at peaks and in troughs. The stipulations concerning travel dynamics are used to calculate $R_{V\,min}$ according to equation (3) above.

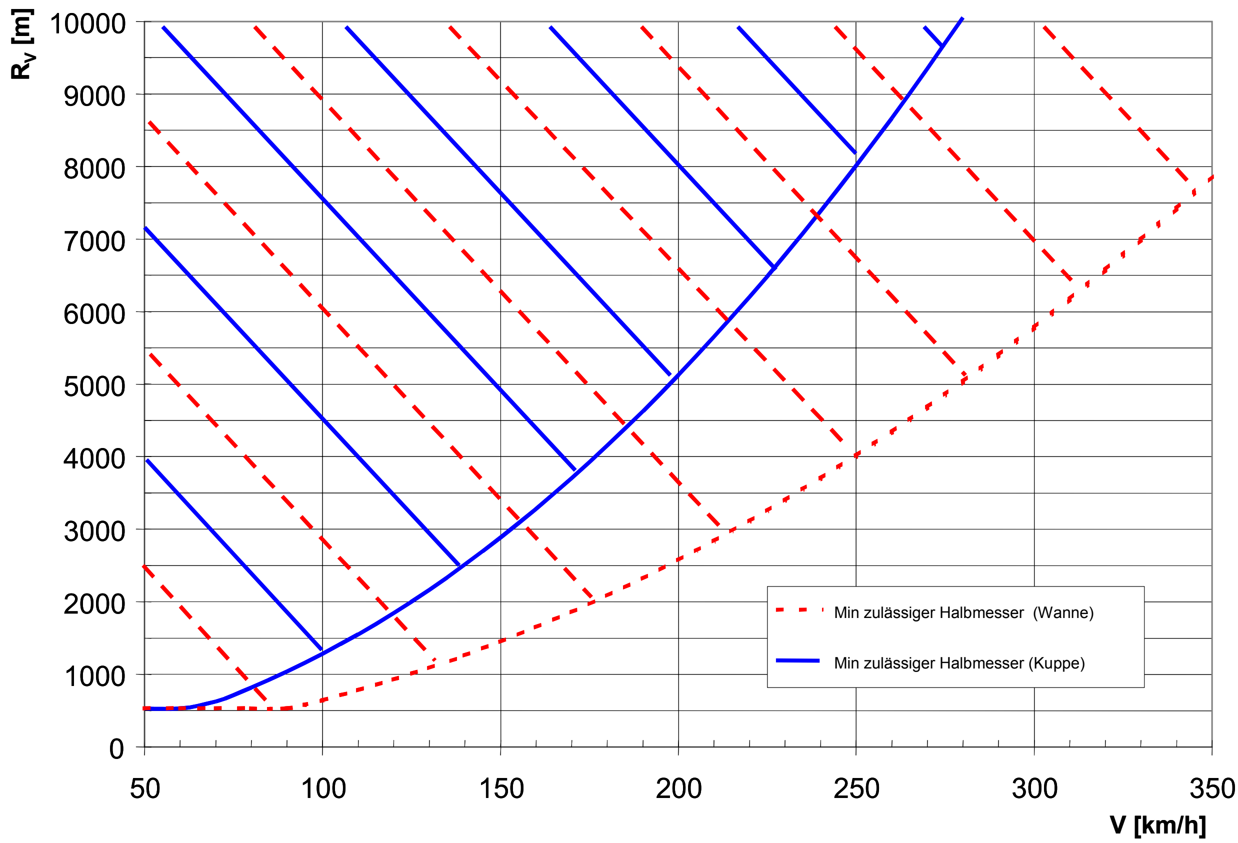


Fig. 231: Minimum permitted vertical radius

[Key to diagram:
Min. zulässiger Halbmesser (Wanne) = minimum permitted radius (trough)
Min. zulässiger Halbmesser (Kuppe) = minimum permitted radius (peak)]

$R_{x,z}$ criterion

When superimposing a gradient curvature (radius) with a horizontal curvature (radius), the $R_{x,z}$ criterion (spatial radius) must be heeded.

$$\frac{1}{R_{x,z}} = \left| \frac{\cos\alpha}{R_V} - \frac{\sin\alpha \cdot \cos^2\beta}{R_H} \right| \qquad (4)$$

Refer to Chapters 6.1.1 to 6.1.5 for the sign conventions of the parameters used.

	Minimum permitted Rx,z criterion	Stipulated by
Limit value	$\lvert R_{x,z\ min} \rvert$ = 530 m where $\Delta\alpha$ = 0.00 °/m	the system as a whole (geometry of the vehicle)

With additional superimposition involving distortion, the spatial radius depends on the distortion which exists locally.
The limit values laid down in Table 143 depend on the geometry of the vehicle which is specific to the particular project. (The Intermediate values must be determined by linear interpolation).

$\Delta\alpha$ [°/m]	0.00	0.01	0.02	0.03	0.04	0.05
$R_{x,z\ min}$ [m]	530	550	590	630	670	710

$\Delta\alpha$ [°/m]	0.06	0.07	0.08	0.09	0.10	0.11
$R_{x,z\ min}$ [m]	770	830	900	990	1100	1230

$\Delta\alpha$ [°/m]	0.12	0.13	0.14	0.15
$R_{x,z\ min}$ [m]	1410	1640	1950	2430

Table 143: Limit values for $R_{x,z}$ in the case of guideway distortion

$R_{x,y}$ criterion

When superimposing a gradient curvature (radius) with a horizontal curvature (radius), the $R_{x,y}$ criterion (spatial radius) must be heeded.

$$\frac{1}{R_{x,y}} = \left| \frac{\sin\alpha}{R_V} + \frac{\cos\alpha \cdot \cos^2\beta}{R_H} \right| \qquad (5)$$

Refer to Chapters 6.1.1 to 6.1.5 for the sign conventions of the parameters used.

	Minimum permitted $R_{x,y}$ criterion	**Stipulated by**
Limit value	$\lvert R_{x,y\ min} \rvert = 350$ m	the system as a whole (geometry of the vehicle)

The minimum permitted radius for the $R_{x,z}$ criterion shall be set at 530 m. On this basis, the limit value for the $R_{x,y}$ criterion of 350 m can also only be achieved by means of special routing geometries.

As regards possible superimposition involving distortion, project-specific regulations must be laid down depending on the geometry of the vehicle.

Driving dynamic specifications

Target line speed and permissible line speed

The target line speed is the local minimum, defined on the basis of the maximum running speed, the target speed from the point of view of ride comfort and further project specifications (see /MSB AG-ABK&DEF/ for diagram).
For the guideway dimensioning, the following upper limits are defined for the permissible speed for guideways and tunnels:

Line section	Permissible speed	Defined by
Open track	$v_{max} \leq 500$ km/h	Guideway (steady loads)
Tunnel sections (dependent upon cross-section)	$v_{max} \leq 500$ km/h	Guideway (steady loads)
Switches in straight position	$v_{max} \leq 500$ km/h	Guideway (steady loads)
Switches in turnout position	Model-specific	Guideway (steady loads)

Taking into account also the permissible speed for the vehicle (project-specific or /MSB AG-GESAMT/), the permissible speed for the line is determined from the above-mentioned permissible speeds.

The programmed speed is the minimum of target line speed and permissible line speed.

The actual driving profile required for the driving-dynamic simulations (see /MSB AG-ABK&DEF/ for diagram) is generated by additional drive simulations, in which the actual project-related performance of the drive is taken into account.

Accelerations

Depending upon their direction of action, the accelerations are divided into:

- Drive or braking acceleration a_x
- Uncompensated lateral acceleration a_y
- Normal acceleration (comfort value) a_z
- Normal case acceleration (acceleration due to gravity) g

The acceleration limit values for the uncompensated lateral acceleration and for the normal acceleration should be adhered to by the three-dimensional guideway axis (three-dimensional curve). The drive subsystem is responsible for adherence to the limit values for the drive or braking acceleration (see /MSB AG-ANT/).
For reasons of ride comfort, the lowest possible uncompensated lateral and normal acceleration values should be striven for by a suitable choice of route parameters. At switches, compensation for lateral acceleration is not possible since the guideway may not be tilted.
Figure 232 shows in cross-section a high-speed Maglev vehicle (viewed in direction of increasing kilometrage) upon which the acceleration in question acts with a positive sign.

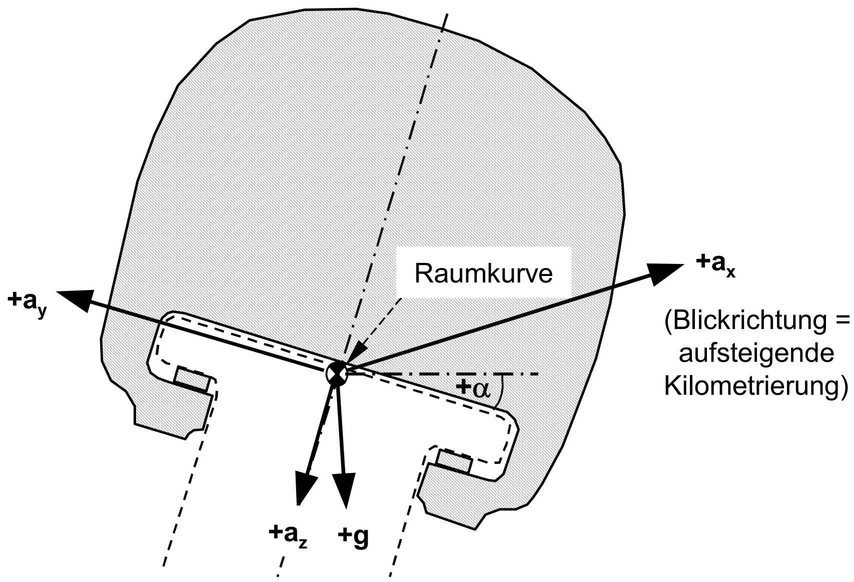


Figure 232: Sign of accelerations

Raumkurve	Three-dimensional curve
(Blickrichtung = …	(Viewing direction = rising kilometrage)

Drive and braking acceleration

The drive subsystem is responsible for adherence to the limit values for the drive / braking acceleration (see /MSB AG-ANT/).

Adherence to the limit values for the drive and braking acceleration should be checked at selected points, taking into consideration the predetermined maximum driving profile and the slope of the guideway resulting from the route study.

	Drive and braking acceleration	**Determined by**
Limit value	$\|a_{x\ max}\| = 1.5\ m/s^2$	MbBO

Comfort-determined maximum values (ride comfort) can be defined on a project-specific basis.

Uncompensated lateral acceleration

The uncompensated lateral acceleration is calculated as follows:

$$\mathbf{a_y} = \frac{(\mathbf{v}/\mathbf{3.6})^2}{\mathbf{R_H}} \cdot \mathbf{cos}\alpha \cdot \mathbf{cos}^2\beta - \left(\mathbf{g} \cdot \mathbf{cos}\beta + \frac{(\mathbf{v}/\mathbf{3.6})^2}{\mathbf{-R_V}} \right) \cdot \mathbf{sin}\alpha \qquad (6)$$

The sign of the calculated uncompensated lateral acceleration indicates the direction of the acceleration for the passenger:
In the case of a positive sign towards the left in direction of travel,
In the case of a negative sign towards the right in direction of travel.

Limit value	**Uncompensated lateral acceleration**	**Determined by**
For normal guideway	$\|a_{y\ max}\| = 1.5\ m/s^2$	MbBO (towards outside of curve)
For switches	$\|a_{y\ max}\| = 2.0\ m/s^2$	Complete system (dimensioning of switches)

Comfort-determined maximum values (ride comfort) can be defined on a project-specific basis.

If the speed of the vehicle is optimally adapted to the lateral tilt and the radius no lateral acceleration will occur ($a_y = 0$).
If the speed is higher, it acts towards the outside of the curve, i.e. upwards on the tilted surface of guideway as "excess acceleration".

If it is lower, it acts towards the inside of the curve, i.e. downwards on the tilted surface of the guideway as deficient acceleration (descending force).

The relationship of the current horizontal radius in the direction of travel, the associated direction of guideway lateral tilt and the sign of a_y from the calculation is shown in Table 144 for information.

	Right-hand curve and positive lateral tilt	***Left-hand curve and negative lateral tilt***
Route parameters in direction of travel	*R_H and α with positive sign (+)*	*R_H and α with negative sign (-)*
a_y with positive sign (+)	*Acceleration in direction of travel towards the left = excess acceleration*	*Acceleration in direction of travel towards the left = deficient acceleration*
a_y with negative sign (-)	*Acceleration in direction of travel towards the right = deficient acceleration*	*Acceleration in direction of travel towards the right = excess acceleration*

Table 144: Direction of excess and deficient acceleration

In the /MSB AG-FW BEM/, in deviation from these design principles, the direction of action of the free lateral acceleration is differentiated exclusively according to whether it is towards the inside or outside of curve. A negative sign in the /MSB AG-FW BEM/ always describes acceleration towards the inside of the curve (deficient acceleration) and a positive sign always describes an acceleration towards the outside of the curve (excess acceleration).

Normal acceleration (comfort value)

The normal acceleration (comfort value) resulting from the routing of the three-dimensional curve is calculated as follows:

$$\mathbf{a_z} = \frac{(v/3,6)^2}{\mathbf{R_H}} \cdot \sin\alpha \cdot \cos^2\beta + \left(\mathbf{g} \cdot \cos\beta + \frac{(v/3,6)^2}{\mathbf{-R_V}} \right) \cdot \cos\alpha - \mathbf{g} \tag{7}$$

The normal acceleration (comfort value) within a twisted line section (rotation about the three-dimensional curve) is found as follows:

$$\mathbf{a_z} = \pm \mathbf{b_G} \cdot 2\pi \cdot \frac{\alpha_e - \alpha_a}{\rho^\circ} \cdot \left(\frac{(v/3.6)}{\mathbf{L_e}} \right)^2 \cdot \sin\left(2\pi \cdot \frac{\mathbf{L}}{\mathbf{L_e}} \right) \tag{8}$$

The extreme values of the above-mentioned normal acceleration (comfort value) are as follows when $L = L_e / 4$ and $L = 3\ L_e / 4$:

$$\mathbf{a_z} = \pm \mathbf{b_G} \cdot 2\pi \cdot \frac{\alpha_e - \alpha_a}{\rho^\circ} \cdot \left(\frac{(v/3.6)}{\mathbf{L_e}} \right)^2 \tag{9}$$

The normal acceleration resulting from the twist acts with the opposing sign on the right-hand and left-hand side of the vehicle. In the addition of the two above-mentioned normal accelerations the least favourable case should always be calculated, i.e. the sign of the second component should be selected according to the normal acceleration components from the route in front view.

Limit value	**Normal acceleration**	**Determined by**
For humps	$a_{z\ max} = -0.6\ m/s^2$	Complete system (dimensioning of guideway), recommendation of MbBO
For valleys	$a_{z\ max} = +1.2\ m/s^2$	Complete system (dimensioning of guideway), recommendation of MbBO

Comfort-determined maximum values (ride comfort) can be defined on a project-specific basis.

Jerks

Jerks are differential changes in the acceleration per unit time.

The jerks are calculated based upon the three-dimensional guideway axis (three-dimensional curve).

Transition curves should be routed so that the maximum values for the jerks (differential changes in acceleration per unit time) are not exceeded.

The jerks are divided as follows depending upon direction of action:

- Lateral jerk $\mathring{a}_y$
- Vertical jerk $\mathring{a}_z$
- Longitudinal jerk $\mathring{a}_x$
- Omnidirectional jerk (not at switches) $\mathring{a}_o$

The lowest possible jerk values increase the subjective ride enjoyment of the passengers (good ride comfort). This can be achieved for example by extending the transition curve in the ground plan.

The formulae listed below for the calculation of the jerk values are only applicable if the path of the curve and twist sections are the same. If no analogous path is available, adherence to the limit values should be checked at selected points.

Lateral jerk

The lateral jerk is calculated as follows:

- For clotoids

$$\mathring{a}_y = \frac{\Delta a_y}{L_K} \cdot \frac{v}{3.6} \qquad (10)$$

- For sinusoids (for the maximum value)

$$\mathring{a}_y = 2 \cdot \frac{\Delta a_y}{L_S} \cdot \frac{v}{3.6} \qquad (11)$$

Maximum value	Lateral jerk	Determined by
In principle	$\lvert\mathring{a}_{y\ max}\rvert = 0.5\ m/s^3$	Complete system (ride comfort)
Exceptions, e.g. for vicinity of stations	$\lvert\mathring{a}_{y\ max}\rvert = 1.0\ m/s^3$	Complete system (ride comfort)
For switches (turnout position)	$\lvert\mathring{a}_{y\ max}\rvert = 2.0\ m/s^3$	Complete system (ride comfort)

To the extent that standing passengers can be expected on a regular basis in the regional service when the high-speed Maglev system is used, lower permissible lateral jerk values should be defined for the negotiation of switches, on a project-specific basis.

Vertical jerk

The vertical jerk is calculated as follows:

$$\mathring{a}_z = \frac{\Delta a_z}{L_K} \cdot \frac{v}{3.6} \quad (12)$$

The vertical jerk component within a twistroad (rotation about the three-dimensional curve) is as follows:

$$\mathring{a}_z = \pm b_G \cdot 4\pi^2 \cdot \frac{\alpha_e - \alpha_a}{\rho^\circ} \cdot \left(\frac{(v/3.6)}{L_e} \right)^3 \cdot \cos\left(2\pi \cdot \frac{L}{L_e} \right) \quad (13)$$

The extreme values of the above-mentioned vertical jerk component are as follows where L = 0, L = L_e / 2 and L = L_e:

$$\mathring{a}_z = \pm b_G \cdot 4\pi^2 \cdot \frac{\alpha_e - \alpha_a}{\rho^\circ} \cdot \left(\frac{(v/3.6)}{L_e} \right)^3 \quad (14)$$

The vertical jerk component resulting from the twist acts with an opposing sign on the right-hand and left-hand sides of the vehicle. In the addition of the two above-mentioned vertical jerk components the least favourable case should always be used for the calculation, i.e. the sign of the second component should be selected according to that of the vertical jerk component from the routing of the three-dimensional curve.

Maximum value	Vertical jerk	Determined by
In principle	$\|\mathring{a}_{z\ max}\| = 0.5\ m/s^3$	Complete system (ride comfort)
Exceptions, e.g. for the vicinity of stations	$\|\mathring{a}_{z\ max}\| = 1.0\ m/s^3$	Complete system (ride comfort)

Special cases with increased vertical jerk are permissible after testing for compatibility in the individual case.

Longitudinal jerk

The longitudinal jerk is not primarily dependent upon the path of the three-dimensional curve but upon the path of speed.

The operator requirements of longitudinal jerk should be adhered to by the driving profile.

Omnidirectional jerk

The spatial superposition of longitudinal jerk, lateral jerk and vertical jerk yield the omnidirectional jerk.

This is calculated as follows:

$$\mathring{a}_o = \sqrt{\mathring{a}_x^2 + \mathring{a}_y^2 + \mathring{a}_z^2} \qquad (15)$$

Maximum value	Omnidirectional jerk	Determined by
In principle	$|\mathring{a}_{o\ max}| = 1.0$ m/s³	Complete system (ride comfort)

Special cases with increased omnidirectional jerk are permissible after testing for compatibility in the individual case.

No maximum value for omnidirectional jerk is specified for switches (turnout position).

Minimum length of sinusoid

In the route path the sinusoids in question (including in s-twist amongst others) are defined by the length L and the radii R_{Ha} or R_{He}, whereby a radius can also be $R_H = \infty$ (straight).

The minimum length is found from the criteria of the maximum lateral jerk, the maximum permissible twist or the maximum vertical jerk using the formulae listed below, whereby the greatest length is always definitive.

$$L_{S\,min} = \left| 2 \cdot \frac{a_{y,e} \cdot SGN(R_{H,e}) - a_{y,a} \cdot SGN(R_{H,a})}{\mathring{a}_{y\,max}} \cdot \frac{v}{3.6} \right| \qquad (16)$$

$$L_{S\,min} = \left| 2 \cdot \frac{\alpha_e - \alpha_a}{\Delta\alpha_{max}} \right| \qquad (17)$$

$$L_{S\,min} = \sqrt[3]{\left(v/3.6\right)^3 \cdot b_G \cdot 4\pi^2 \cdot \frac{|\alpha_e - \alpha_a|}{\rho^\circ \cdot \mathring{a}_{z\,max}}} \qquad (18)$$

The listed formulae for the calculation of the minimum length of the sinusoids only apply if curve and twistroads have identical start and end points along the guideway axis. If no identical path e-xists, particular care should be taken that the limit values are adhered to.

In the event of the superposition of twists with vertical transitions, adherence to the limit values should be checked at selected points, since the vertical jerk component from the three-dimensional curve is not taken into consideration in the above-mentioned formula (see 0).).

Minimum length of clotoid

In the layout of the line the clotoids in question are defined by the radius (R_H) or the radius (R_V) of the following arc and the length L of the transition curve. L should be selected such that the maximum lateral or vertical jerk is not exceeded. The minimum length is found from the formulae listed below:

In the ground plan (in the standard guideway only for switches or at route obstacles where V < 100 km/h)

$$\mathbf{L}_{\mathbf{K\,min}} = \left| \frac{\Delta \mathbf{a}_{\mathbf{y}}}{\mathring{\mathbf{a}}_{y\,max}} \cdot \frac{\mathbf{v}}{\mathbf{3.6}} \right| \qquad (19)$$

In the vertical plan

$$\mathbf{L}_{\mathbf{K\,min}} = \left| \frac{\Delta \mathbf{a}_{\mathbf{z}}}{\mathring{a}_{z\,max}} \cdot \frac{\mathbf{v}}{\mathbf{3.6}} \right| \qquad (20)$$

In the case of the superposition of twists with vertical transitions, particular care should be taken that the limit values are adhered to, since in the above-mentioned formula the vertical jerk component from the twist is not taken into account (see 0).

Comfort criteria in relation to the overall journey time for the routed section

For the routing, not only should the specification of the individual route elements and their combination be checked from a system-technical point of view, the criteria of ride comfort should also be taken into account. In this connection, the overall sequence of route elements and their effect upon the passenger are important. In what follows the dimensioning and evaluation of the comfort of a planned route section are shown based upon the line layout and the envisaged maximum driving profile for this, independently of the vehicle and the passenger behaviour.

The effective value of accelerations (RMS value) is drawn upon as an evaluation criterion for the assessment of ride comfort. This value is found using the equation (21):

$$\mathbf{a}_{\mathbf{eff}} = \mathbf{a}_{\mathbf{rms}} = \sqrt{\frac{1}{T}\int_0^T a^2(t)\,dt} \qquad (21)$$

where a(t) = acceleration amplitude at point in time t

and T = overall journey time (complete section length)

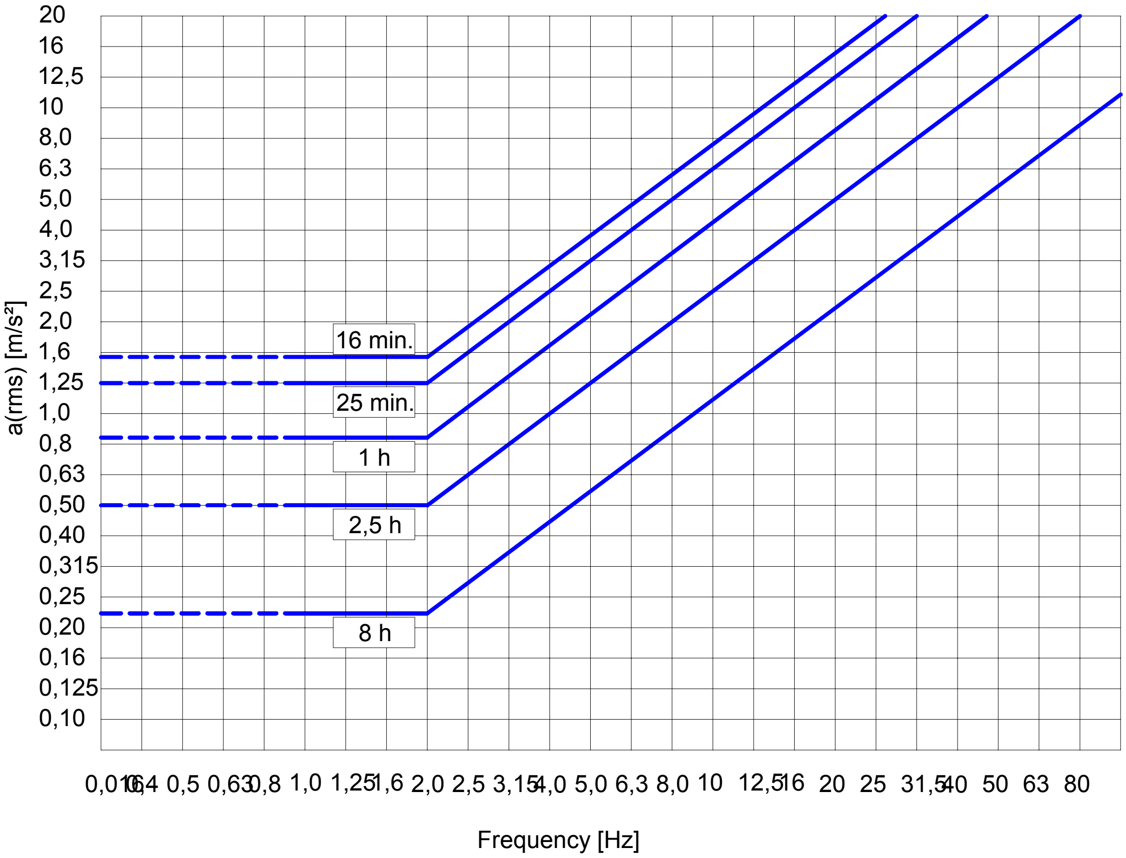
For the route design the following requirements are defined:

For the ground plan routing

- The effective value of uncompensated lateral acceleration must lie below the (sometimes extrapolated) limit values shown in the diagram “Ride comfort for longitudinal and lateral acceleration”. This diagram is shown in Figure 232.
- The action time corresponds to the overall journey time.
- A minimum length for the ground plan elements ‘straight line’ and ‘circle’ is not necessary for the consideration of the effective value.

For vertical plan routing

- The effective value of the normal acceleration must lie below the limit vales shown in the diagram “Ride comfort for normal acceleration”, for example to avoid kinetosis effects (travel sickness) this should be 20% below the limit value. This diagram is shown in Figure 234.
- The action time corresponds with the overall journey time.
- The periodic arrangement of transitions over an extended route section should be avoided.
- A minimum length for the vertical plan elements ‘straight line’ and ‘radius’ is not necessary.



Acceleration limits as a function of the frequency and action time

Figure 233: Ride comfort for longitudinal and lateral acceleration (according to ISO 2631)

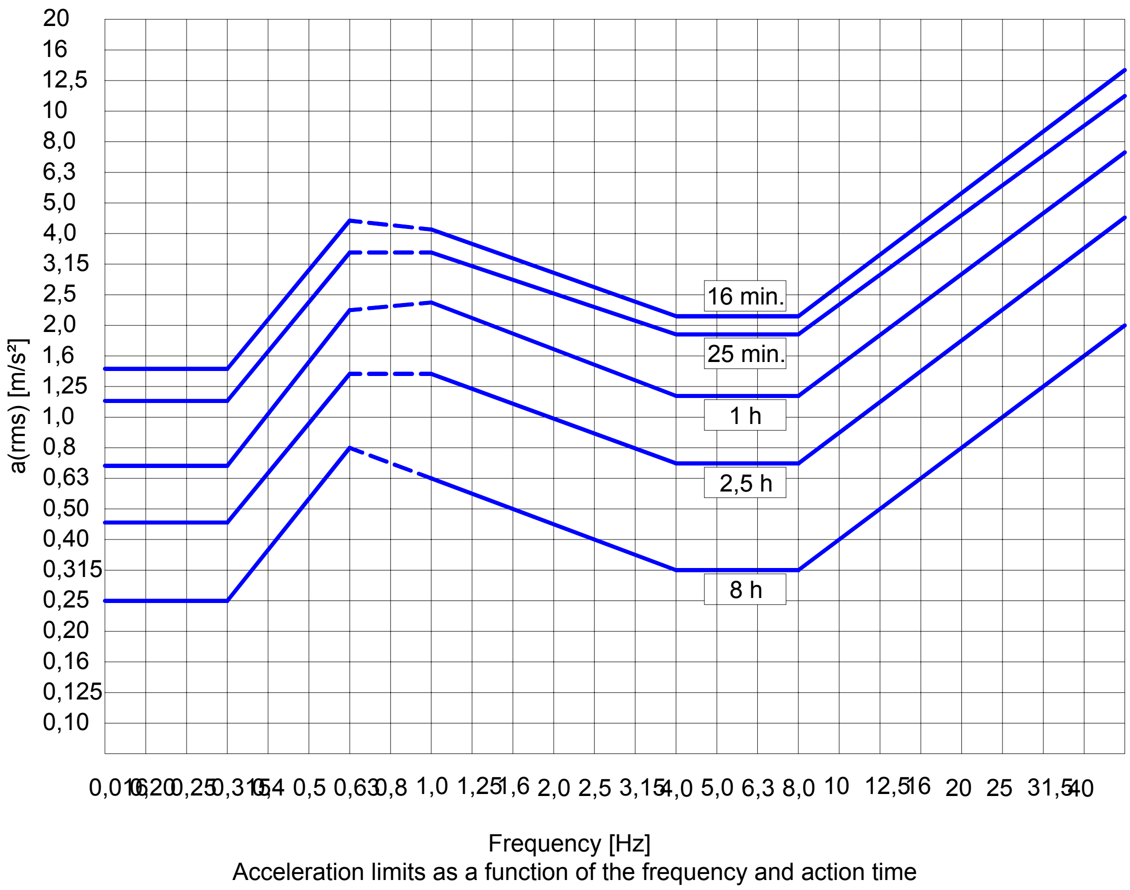


Figure 234: Ride comfort – normal acceleration (according to ISO 2631)

Support division and field widths

Single track guideway

After the determination of the three-dimensional curve path the field widths preferred from a technical and economic point of view for further planning should be considered. The support divisions relate to the defined field widths (/MSB AG-FW ÜBG/) and are assigned to the three-dimensional curve.

The field widths are determined on a project-specific basis.

Shorter field widths can also be used at route obstacles. It is possible to reduce the field width by an integer multiple of a groove / tooth period (86 mm). The calculation of the system lengths of guideway beams is performed using the following formula:

$$L = n \times 1032 - m \times 86 \qquad (22)$$

where $m \leq 4$ (number of reductions)

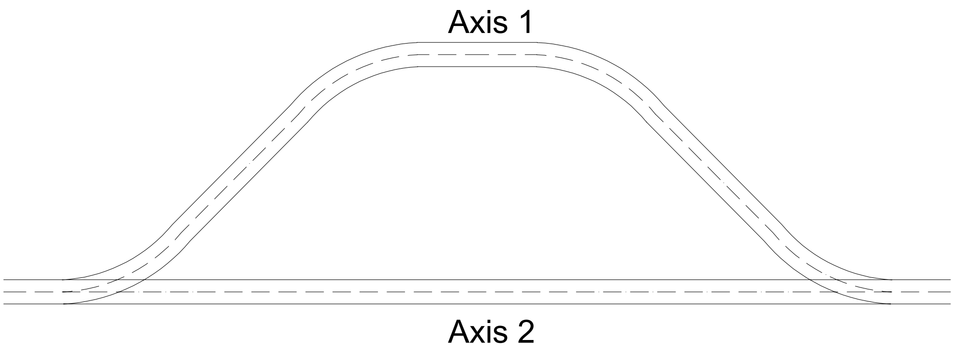
Double or multiple track guideway

In the case of the support division for double / multiple guideways, reduced field widths (/MSB AG-FW ÜBG, 7.1) can also be used in order to achieve an approximately radial arrangement of the support heads. Track switching equipment connect routing axis sections.

The spatial lengths of these routing axis sections between line changing devices must be an integer multiple of a drive period (516 mm).

These routing axis sections can be shortened by an integer multiple of a groove / tooth period (86 mm).

Figure 235 shows as an example two routing axes that run from a common start point in a track switching device to a common end point in a track switching device and the spatial lengths of which must comply with the stated condition.



Length of axis 1: a * 1032 + n * 86 [mm]
Length of axis 2: b * 1032 + n * 86 [mm]

Figure 235: Three-dimensional curve lengths in the case of multiple track guideway

In the case of geometric constraints the deviations of individual routing axis sections (< 516 mm) from the am/ condition can be uniformly distributed among the field widths within this routing axis section.

As a guide value for planning, a maximum 6.5 mm extension or up to 0.5 mm reduction can be used for a field width of 24.7680 m.

Guideway pitch and clearance

Guideway pitch

In the routing of parallel lines at least the guideway pitches described in Table 2 (in relation to the design speed Ve) should be adhered to.

In addition, there is a differentiation between the minimum guideway pitch due to the lateral tilt (α) and the horizontal radius (R_H) used to avoid the intersection of clearances in category 1 (Ve ≤ 300 km/h).

This rule applies only for lateral tilts up to a maximum of 12° and where the three-dimensional curve heights (gradients) are the same for adjacent tracks. If the gradient heights are not the same the clearances of both tracks should be investigated with regard to a possible intersection and the guideway pitch S modified accordingly.

Category	Design speed v_e [km/h]	Lateral tilt α [°]	Horizontal radius R_H [m]	Guideway pitch S [m]
1	$v_e \leq 300$			4.40
		α > 10°		4.50
		5° < α ≤ 10°	$R_H \leq 3500$	
2	$300 < v_e \leq 400$			4.80
3	$400 < v_e \leq 500$			5.10

Table 145: Guideway pitch

Accuracy

The guideway pitch should be adhered to 2 decimal places (in accordance with /MbBO/).

Non-parallelism of sinusoids

In the routing of parallel lines, sinusoids cannot be routed such that they are precisely geometrically parallel.
The deviations are included in the space requirement for positional deviations and tolerances of the guideways in relation to the three-dimensional curve and need not be taken into account here.

Clearance and gauges

The figures from the /MbBO/ were used as the basis for Figures 9 to 13 and supplemented by the lateral tilt area.

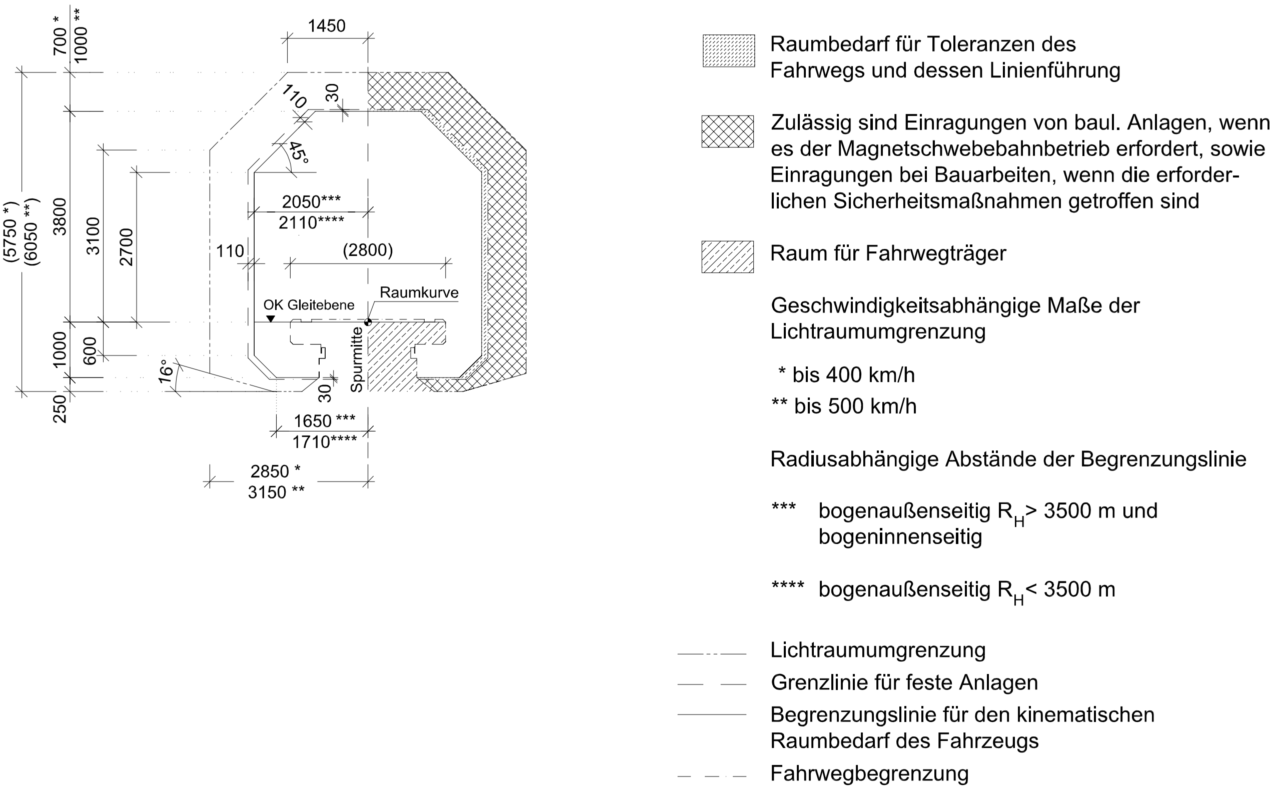


Figure 236: Clearance and gauges of the Maglev system single track guideway, α = 0°

Raumbedarf für Toleranzen des Fahrweg…	Space requirement for tolerances of the guideway and its line layout
Zulässig sind Einragungen ..	The protrusion of structures is permissible if required by the operation of the high-speed Maglev system, and protrusions in the case of construction work, if the required safety measures are taken
Raum für Fahrwegträger	Space for guideway beams
Geschwindigkeitsabhängige Maße …	Speed-dependent dimensions of the clearance gauge
bis	up to
Radiusabhängige Abstände …	Radius-dependent spacing of gauges

bogenaußenseitig	Outside of curve
und	and
bogeninnenseitig	Inside of curve
Lichtraumbegrenzung	Clearance limit
Grenzlinie für feste Anlagen	Boundary for fixed structures
Begrenzungslinie für den kinematischen Raumbedarf des Fahrzeugs	Gauge for the kinematic space requirement of the vehicle
Fahrwegbegrenzung	Guideway limit

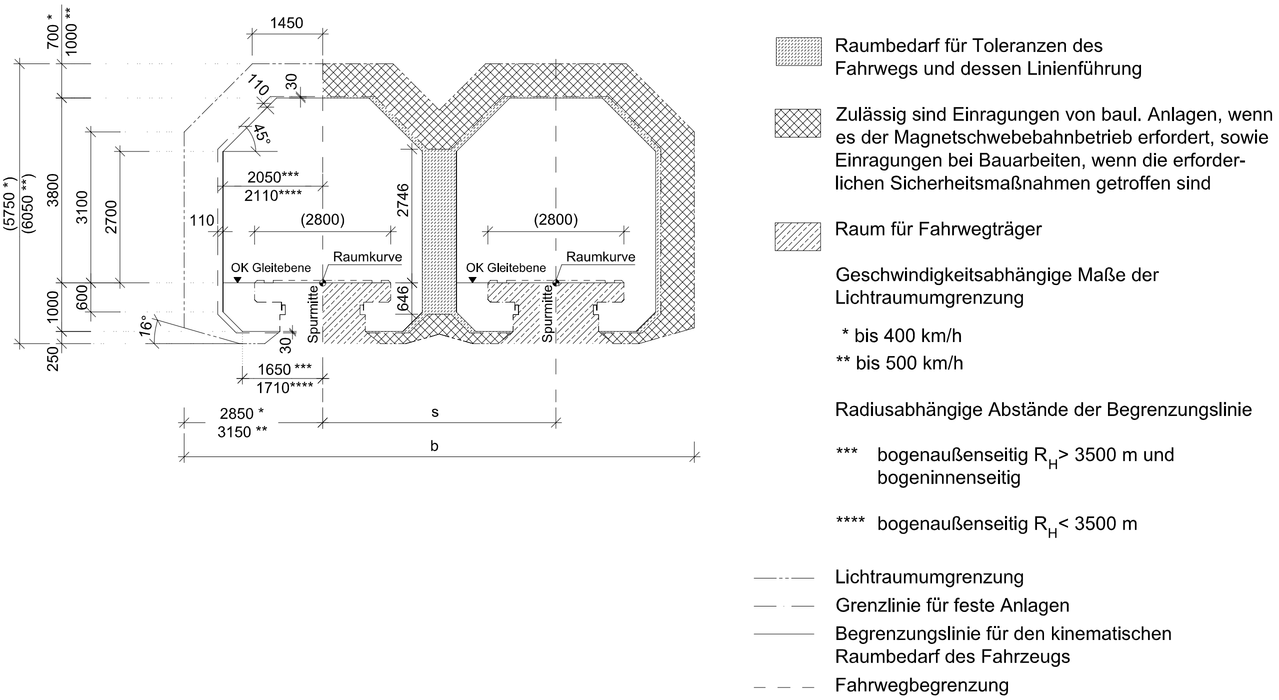
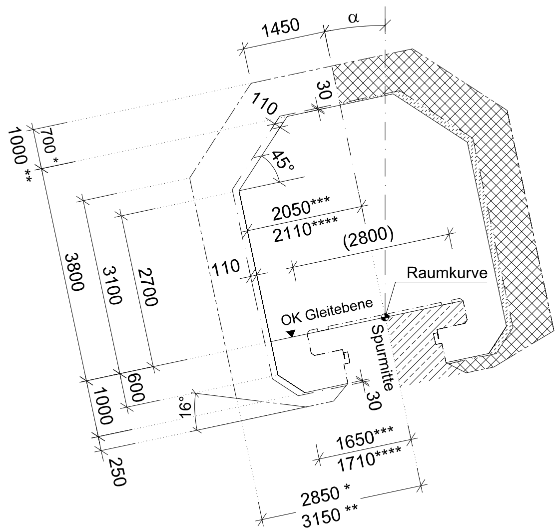


Figure 237: Clearance and gauges of the Maglev system double track guideway, α = 0°

Raumbedarf für Toleranzen des Fahrweg…	Space requirement for tolerances of the guideway and its line layout
Zulässig sind Einragungen ..	The protrusion of structures is permissible if required by the operation of the high-speed Maglev system, and protrusions in the case of construction work, if the required safety measures are taken

Raum für Fahrwegträger	Space for guideway beams
Geschwindigkeitsabhängige Maße …	Speed-dependent dimensions of the clearance gauge
bis	up to
Radiusabhängige Abstände …	Radius-dependent spacing of gauges
bogenaußenseitig	Outside of curve
und	and
bogeninnenseitig	Inside of curve
Lichtraumbegrenzung	Clearance limit
Grenzlinie für feste Anlagen	Boundary for fixed structures
Begrenzungslinie für den kinematischen Raumbedarf des Fahrzeugs	Gauge for the kinematic space requirement of the vehicle
Fahrwegbegrenzung	Guideway limit



Raumbedarf für Toleranzen des Fahrwegs und dessen Linienführung

Zulässig sind Einragungen von baul. Anlagen, wenn es der Magnetschwebebahnbetrieb erfordert, sowie Einragungen bei Bauarbeiten, wenn die erforderlichen Sicherheitsmaßnahmen getroffen sind

Raum für Fahrwegträger

Geschwindigkeitsabhängige Maße der Lichtraumumgrenzung

* bis 400 km/h
** bis 500 km/h

Radiusabhängige Abstände der Begrenzungslinie

*** bogenaußenseitig R_H> 3500 m und bogeninnenseitig

**** bogenaußenseitig R_H< 3500 m

Lichtraumumgrenzung
Grenzlinie für feste Anlagen
Begrenzungslinie für den kinematischen Raumbedarf des Fahrzeugs
Fahrwegbegrenzung

Figure 238: Clearance and gauges of the Maglev system single track guideway, α <= 12°

Raumbedarf für Toleranzen des Fahrweg…	Space requirement for tolerances of the guideway and its line layout
Zulässig sind Einragungen ..	The protrusion of structures is permissible if required by the operation of the high-speed Maglev system, and protrusions in the case of construction work, if the required safety measures are taken
Raum für Fahrwegträger	Space for guideway beams
Geschwindigkeitsabhängige Maße …	Speed-dependent dimensions of the clearance gauge
bis	up to
Radiusabhängige Abstände …	Radius-dependent spacing of gauges
bogenaußenseitig	Outside of curve
und	and
bogeninnenseitig	Inside of curve
Lichtraumbegrenzung	Clearance limit
Grenzlinie für feste Anlagen	Boundary for fixed structures
Begrenzungslinie für den kinematischen Raumbedarf des Fahrzeugs	Gauge for the kinematic space requirement of the vehicle
Fahrwegbegrenzung	Guideway limit

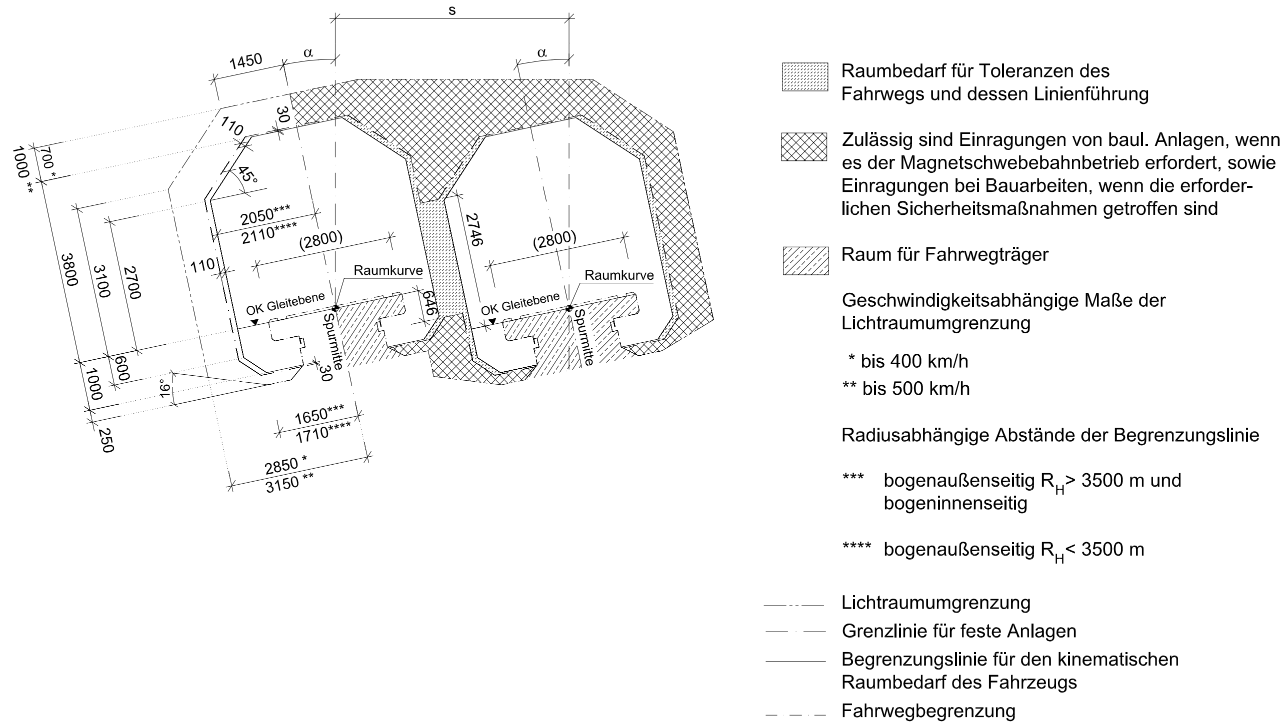
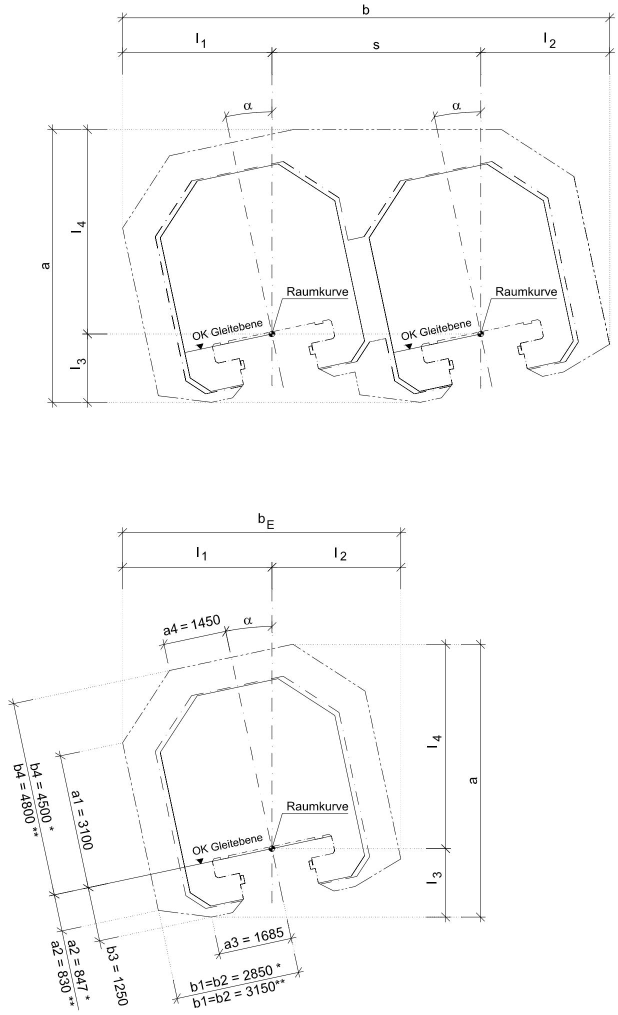


Figure 239: Clearance and gauges for the Maglev system double track guideway, α ≤ 12°

Raumbedarf für Toleranzen des Fahrweg…	Space requirement for tolerances of the guideway and its line layout
Zulässig sind Einragungen ..	The protrusion of structures is permissible if required by the operation of the high-speed Maglev system, and protrusions in the case of construction work, if the required safety measures are taken
Raum für Fahrwegträger	Space for guideway beams
Geschwindigkeitsabhängige Maße …	Speed-dependent dimensions of the clearance gauge
bis	up to
Radiusabhängige Abstände …	Radius-dependent spacing of gauges
bogenaußenseitig	Outside of curve
und	and
bogeninnenseitig	Inside of curve
Lichtraumbegrenzung	Clearance limit

Grenzlinie für feste Anlagen	Boundary for fixed structures
Begrenzungslinie für den kinematischen Raumbedarf des Fahrzeugs	Gauge for the kinematic space requirement of the vehicle
Fahrwegbegrenzung	Guideway limit



Berechnung der Breite des Streckenquerschnitts für Doppelspur (b) und Einzelspur (b_E) sowie der Höhe des Streckenquerschnitts(a)in Abhängigkeit der Querneigung (α):

$l_i = b_i + \Delta_i$ i = 1, 2, 3, 4

$\Delta_i = \sqrt{a_i^2 + b_i^2} \times \cos[\arctan(\frac{a_i}{b_i}) - \alpha] - b_i$

$b = l_1 + s + l_2$

$b = l_1 + l_2$

$a = l_3 + l_4$

Geschwindigkeitsabhängige Abmessungen des Spurmittenabstandes (s)

s = 4400 mm bis 300 km/h

s = 4800 mm bis 400 km/h

s = 5100 mm bis 500 km/h

Geschwindigkeitsabhängige Maße der Lichtraumumgrenzung

* bis 400 km/h

** bis 500 km/h

—··— Lichtraumumgrenzung

— — Grenzlinie für feste Anlagen

—— Begrenzungslinie für den kinematischen Raumbedarf des Fahrzeugs

— · — Fahrwegbegrenzung

Figure 240: Clearance of the Maglev system in relation to α ≤ 12°

Berechnung der Breite ...	Calculation of the width of the route cross-section for double track (b) and single track (b_E) as well as the height of the route cross-section (a) in relation to the lateral tilt (α)
Geschwindigkeitsabhängige Maße …	Speed-dependent dimensions of the clearance gauge
bis	up to

Lichtraumbegrenzung	Clearance limit
Grenzlinie für feste Anlagen	Boundary for fixed structures
Begrenzungslinie für den kinematischen Raumbedarf des Fahrzeugs	Gauge for the kinematic space requirement of the vehicle
Fahrwegbegrenzung	Guideway limit

Track switching equipment

General

Figure 241 shows the current variants of track switching equipment.

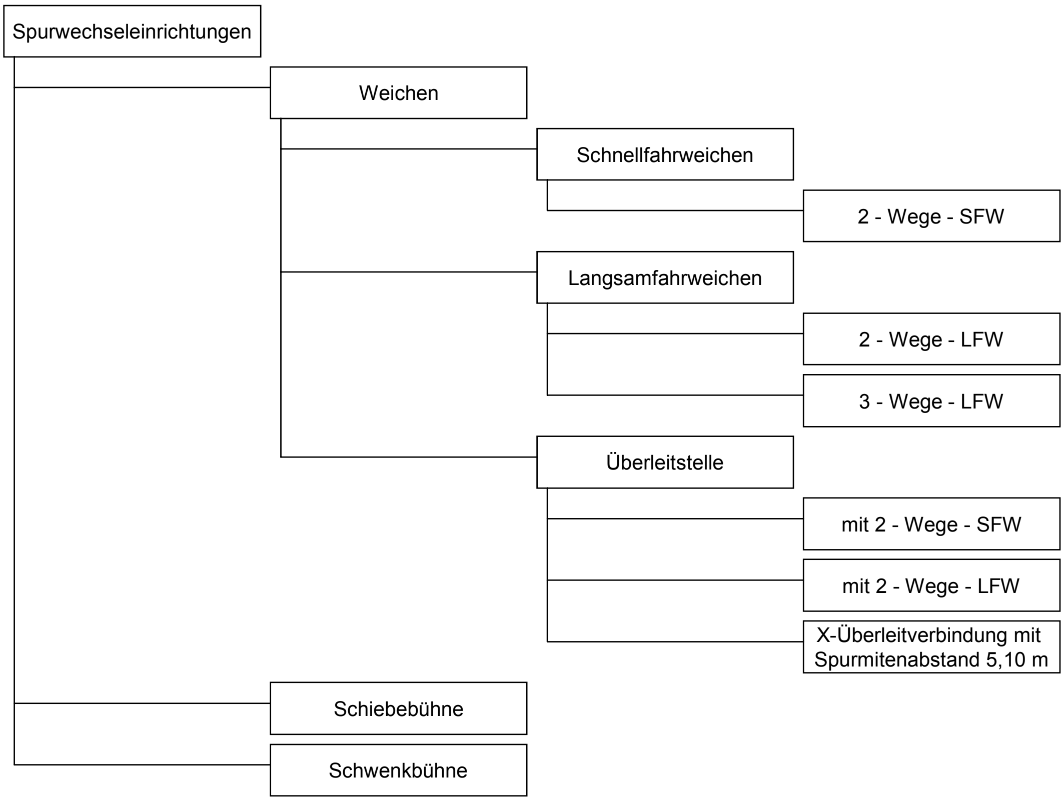


Figure 241: Classification of track switching devices

Spurwechseleinrichtungen	Line changing devices
Weichen	Switches
Schnellfahrweichen	High-speed switches
2-Wege SFW	2-way HSS
Langsamfahrweiche	Low-speed switches
2-Wege LFW	2-way LSS
3-Wege LFW	3-way LSS
Überleitstelle	Cross-over

mit 2-Wege SFW	With 2-way HSS
mit 2-Wege LFW	With 2-way LSS
X-Überleitverbindung mit Spurmittenabstand 5.10 m	X-connection with guideway pitch 5.10 m
Schiebebühne	Travelling platform
Schwenkbühne	Swinging platform

Switches

General

The following principles should be observed for the layout of switches:

- The entire switch support can be bent from the straight position to the turnout position.
- *In the ground plan the geometric sequence is as follows: straight-clotoid-circle-clotoid-straight. This sequence largely approximates the bending line of the switch support. Figure 11 shows the elements of the curve band of a switch in the turnout position.*
- *For reasons of comfort it is recommended that a straight section (RH = ∞) be included in the layout of the turnout track behind a switch for the travel time of 2 seconds. This recommendation does not apply for connections, since in this case a second switch is negotiated immediately after the first.*
- *In the gradient only the radius $R_V = \infty$ is permissible.*
- The planned lateral tilt of the switch is 0°.
- The planned longitudinal tilt of the switch is up to 100 ‰. *If a longitudinal tilt not equal to 0 ‰ is used route elements not mathematically defined in the ground plan of the turnout position occur.*

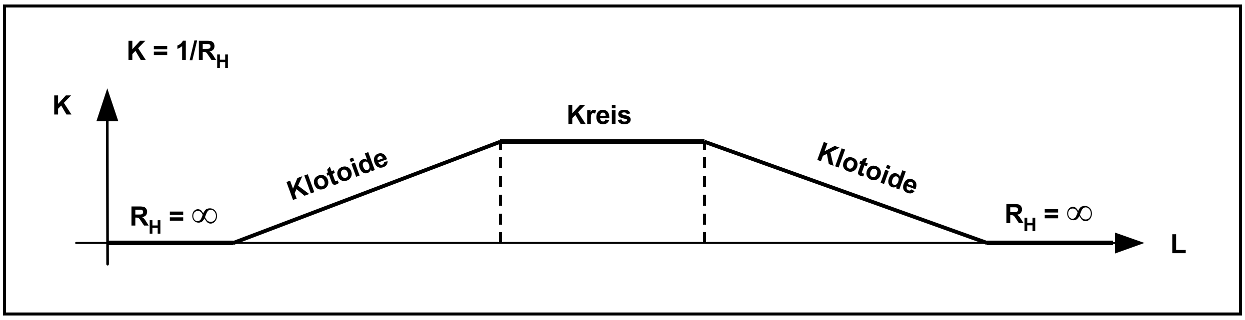


Figure 242: Curve band for switch

Klotoide	Clotoid
Kreis	Circle

Design examples of switch

Currently known design examples are shown below. Further switches can be defined on a project-specific basis.
The design examples include the geometric sequence of the route elements and a table containing the permissible speeds and the resulting lateral acceleration and lateral jerk values.
The title "medium-section / long-section application" and "regional application" arose due to the vehicle design (sitting passengers / standing passengers).
The values for the "regional application" should be taken as a recommendation.
The recommendations given in the following tables for regional applications are based upon comfort investigations focussing upon standing passengers.
Connections consist of 2 bendable switches and a locking device.
X-connections consist of 4 bendable switches, the guideway pitch is 5.100 m. In the turnout position it is necessary to set even the non-negotiated bendable switch in the turnout position, as otherwise the gauge for fixed installations would be exceeded (Chapter 0).

High-speed switch

The route elements of the high-speed switch are shown in Figure 12 in ground-plan form and not to scale, and are listed in Table 3.
The driving dynamic values for this switch are listed in Table 4.

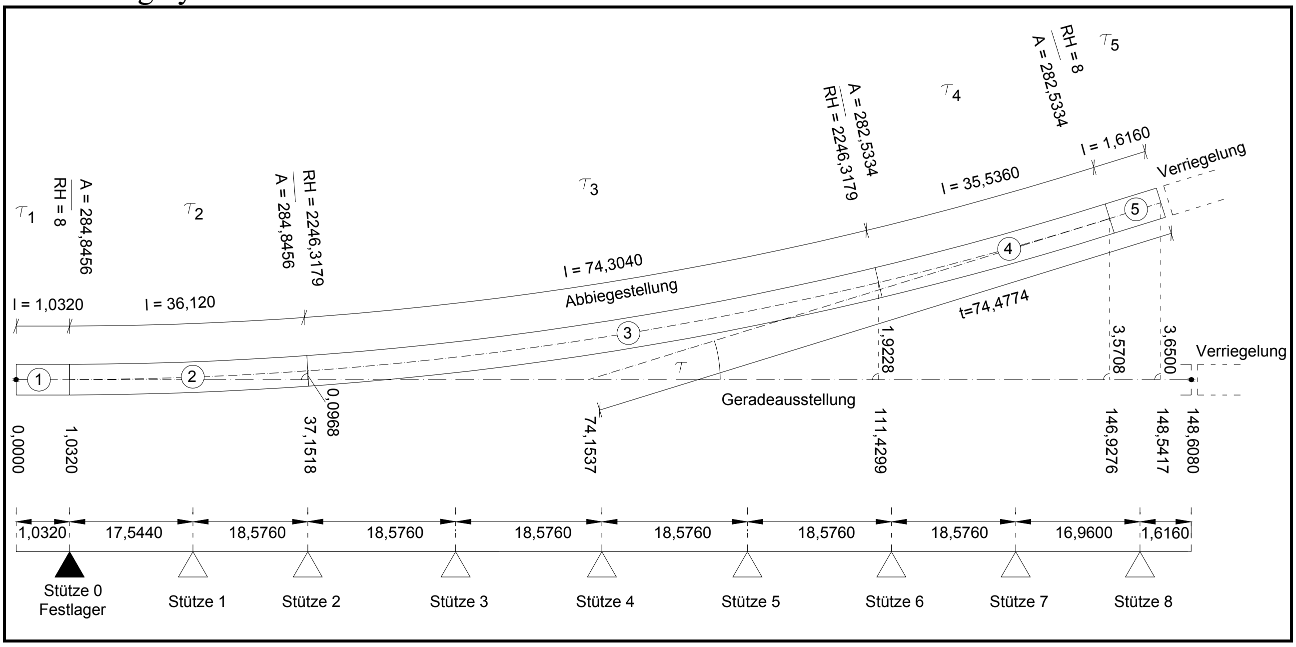


Figure 243: Route elements for high-speed switch (design example)

Verriegelung	Lock
Abbiegestellung	Turnout position
Geradeausstellung	Straight position
Stütze	Support
Festlager	Fixed bearing

No.	Element	Length [m]	Radius [m]	Abscissa [m]	Ordinate [m]	τ [gon]	τ [°]
	WA			0.0000	0.0000	0,00000	0,00000
1	Straight	1.0320		1.0320	0.0000	0,00000	0,00000
2	Clotoid	36.1200		37.1518	0.0968	0,51183	0,46065
3	Arc	74.3040	-2246.3179	111.4299	1.9228	2,10582	1,89524
4	Clotoid	35.5360		146.9276	3.5708	0,50356	0,45320
5	Straight	1.6160		148.5417	3.6500	0,00000	0,00000
∑		148.6080				3.12121	2.80909

Table 146: Route parameters for high-speed switch (design example)

Variable		Medium section application / Long section application		Regional application (Recommendation)	
Permissible speed straight position	v_{max}	500	[km/h]	500	[km/h]

Permissible speed turnout position	v_{max}	195	[km/h]	155	[km/h]
Uncompensated lateral acceleration	a_y	1.31	[m/s²]	0.83	[m/s²]
Lateral jerk (1st / 2nd clotoid)	$å_y$	1.96 / 1.99	[m/s³]	0.98 / 1.00	[m/s³]

Table 147: Driving dynamic values for high-speed switch (design example)

Low-speed switch

The route elements of the low-speed switch are shown in Figure 13 in ground plan form and not to scale, and are listed in Table 5.
The driving dynamic values for this switch are listed in Table 6.

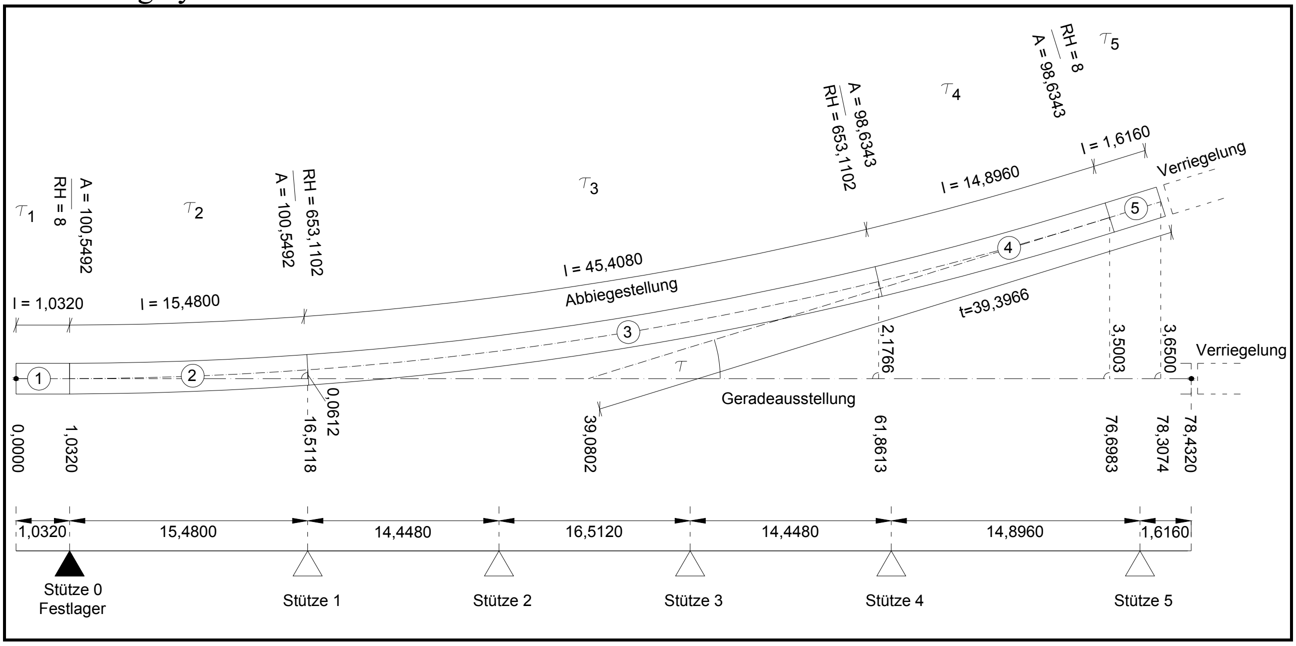


Figure 244: Route elements for 2-way low-speed switch (design example)

Verriegelung	Lock
Abbiegestellung	Turnout position
Geradeausstellung	Straight position
Stütze	Support
Festlager	Fixed bearing

No.	Element	Length [m]	Radius [m]	Abscissa [m]	Ordinate [m]	τ [gon]	τ [°]
	WA			0.0000	0.0000	0.00000	0,00000
1	Straight	1.0320		1.0320	0.0000	0.00000	0,00000
2	Clotoid	15.4800		16.5118	0.0612	0.75446	0,67901
3	Arc	45.4080	-653.1102	61.8613	2.1766	4.42615	3,98354
4	Clotoid	14.8960		76.6983	3.5003	0.72599	0,65339
5	Straight	1.6160		78.3074	3.6500	0.00000	0,00000
∑		78.4320				5.90660	5.31594

Table 148: Route parameters for 2-way low-speed switch (design example)

Size		Medium section application / Long section application	Regional application (Recommendation)

Permissible speed straight position	v_{max}	500	[km/h]	500	[km/h]
Permissible speed turnout position	v_{max}	97	[km/h]	77	[km/h]
Uncompensated lateral acceleration	a_y	1.10	[m/s²]	0.69	[m/s²]
Lateral jerk (1^{st} / 2^{nd} clotoid)	$\mathring{a}_y$	1.91 / 1.98	[m/s^3]	0.95 / 0.99	[m/s^3]

Table 149: Driving dynamic values of the 2-way low-speed switch (design example)

The geometric dimensions of the 3-way low-speed switch correspond to those of the 2-way low-speed switch (see Figure 244 and Table 148) with the straight direction as the axis of symmetry. Figure 245 shows the position variants.

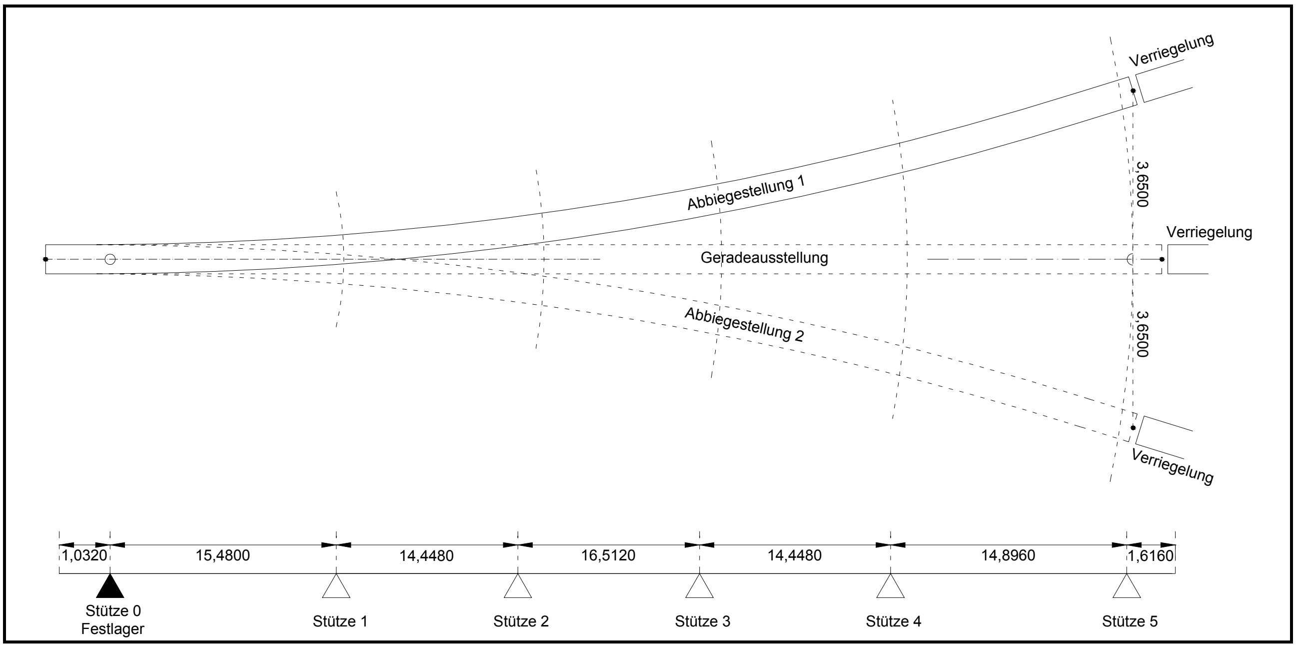


Figure 245: Position variants of the 3-way low-speed switch (design example)

Verriegelung	Lock
Abbiegestellung	Turnout position
Geradeausstellung	Straight position
Stütze	Support
Festlager	Fixed bearing

Connection with high-speed switch

Connections between tracks running in parallel are produced by the combination of several bendable switches.
Figure 246 shows the sequence of route elements for a connection with high-speed switches, depiction is not to scale, Table 150 shows the route elements.
Table 151 contains the driving dynamic values for this connection.

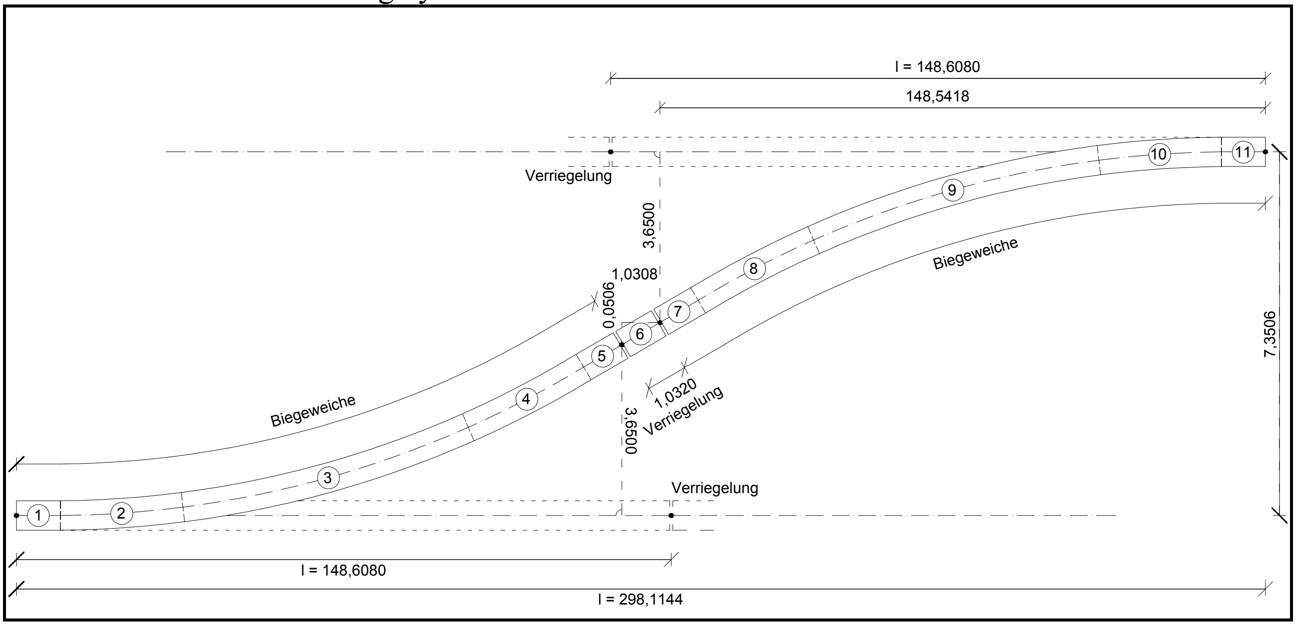


Figure 246: Route elements for the connection with high-speed switches (design example)

Verriegelung	Lock
Biegeweiche	Bendable switch

No.	Element	Length [m]	Radius [m]	Abscissa [m]	Ordinate [m]	τ [gon]	τ [°]
	WA			0.0000	0.0000	0,00000	0,00000
1	Straight	0.5000		0.5000	0.0000	0,00000	0,00000
2	Clotoid	36.6520		37.1518	0.0992	0,51687	0,46518
3	Arc	74.3040	-2257.1800	111.4300	1.9252	2,09569	1,88612
4	Clotoid	36.0680		147.4591	3.5969	0,50863	0,45777
5	Straight	1.0840		148.5418	3.6500	0,00000	0,00000
6	Straight	0.5000		149.5726	3.7006	0,00000	0,00000
7	Straight	1.0840		150.6553	3.7537	0,00000	0,00000
8	Clotoid	36.0680		186.6844	5.4254	-0,50863	-0,45777
9	Arc	74.3040	+2257.1800	260.9626	7.2514	-2,09569	-1,88612
10	Clotoid	36.6520		297.6144	7.3506	-0,51687	-0,46518
11	Straight	0.5000		298.1144	7.3506	0,00000	0,00000
∑		298.248				0.00000	0.00000

Table 150: Route parameters for the connection with high-speed switches (design example)

Variable		Medium section application / Long section application		Regional application (Recommendation)	
Permissible speed straight position	v_{max}	500	[km/h]	500	[km/h]
Permissible speed turnout position	v_{max}	196	[km/h]	124	[km/h]
Uncompensated lateral acceleration	a_y	1.31	[m/s²]	0.53	[m/s²]
Lateral jerk (1st / 2nd clotoid)	$\mathring{a}_y$	1.95 / 1.98	[m/s^3]	0.49 / 0.50	[m/s^3]

Table 151: Driving dynamic values of the connection with high-speed switches (design example)

Connection with low-speed switch

Figure 247 shows the routing sequence for a connection with low-speed switches, depiction is not to scale, Table 152 shows the route elements.
Table 153 contains the driving dynamic values for this connection.

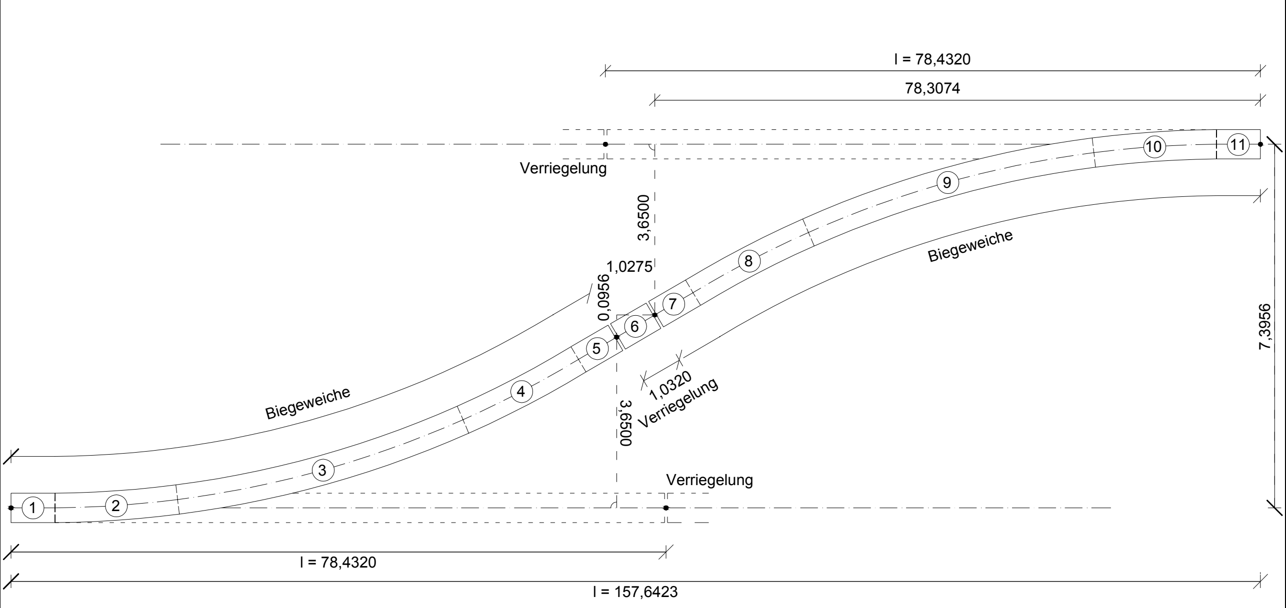


Figure 247: Route elements of the connection with low-speed switches (design example)

No.	Element	Length [m]	Radius [m]	Abscissa [m]	Ordinate [m]	τ [gon]	τ [°]
	WA			0.0000	0.0000	0,00000	0,00000
1	Straight	1.0320		1.0320	0.0000	0,00000	0,00000
2	Clotoid	15.4800		16.5118	0.0612	0,75446	0,67901
3	Arc	45.4080	-653.1102	61.8613	2.1766	4,42615	3,98354
4	Clotoid	14.8960		76.6983	3.5003	0,72599	0,65339
5	Straight	1.6160		78.3074	3.6500	0,00000	0,00000
6	Straight	1.0320		79.3349	3.7456	0,00000	0,00000
7	Straight	1.6160		80.9440	3.8953	0,00000	0,00000
8	Clotoid	14.8960		95.7810	5.2190	-0.72599	-0,65339
9	Arc	45.4080	+653.1102	141.1305	7.3345	-4.42615	3,98354
10	Clotoid	15.4800		156.6103	7.3956	-0.75446	-0,67901
11	Straight	1.0320		157.6423	7.3956	0.00000	0,00000
∑		157.8960				0.00000	0.00000

Table 152: Route parameters of the connection with low-speed switches (design example)

Variable		Medium section application / Long section application		Regional application (Recommendation)	
Permissible speed straight position	v_{max}	500	[km/h]	500	[km/h]
Permissible speed turnout position	v_{max}	97	[km/h]	61	[km/h]
Uncompensated lateral acceleration	a_y	1.10	[m/s²]	0.44	[m/s²]
Lateral jerk (1st / 2nd clotoid)	$\dot{a}_y$	1.91 / 1.98	[m/s³]	0.47 / 0.49	[m/s³]

Table 153: Driving dynamic values of the connection with low-speed switches (design example)

X-connection with low-speed switches for a guideway pitch of 5.10 m

The arrangement of low-speed switches into an X-connection with a guideway pitch of 5.10 m can be routed as a space saving variant (Figure 248, Table 154, Table 155).
The open ends of the straight tracks must be turned outwards at the connection in order to maintain the required clearances.

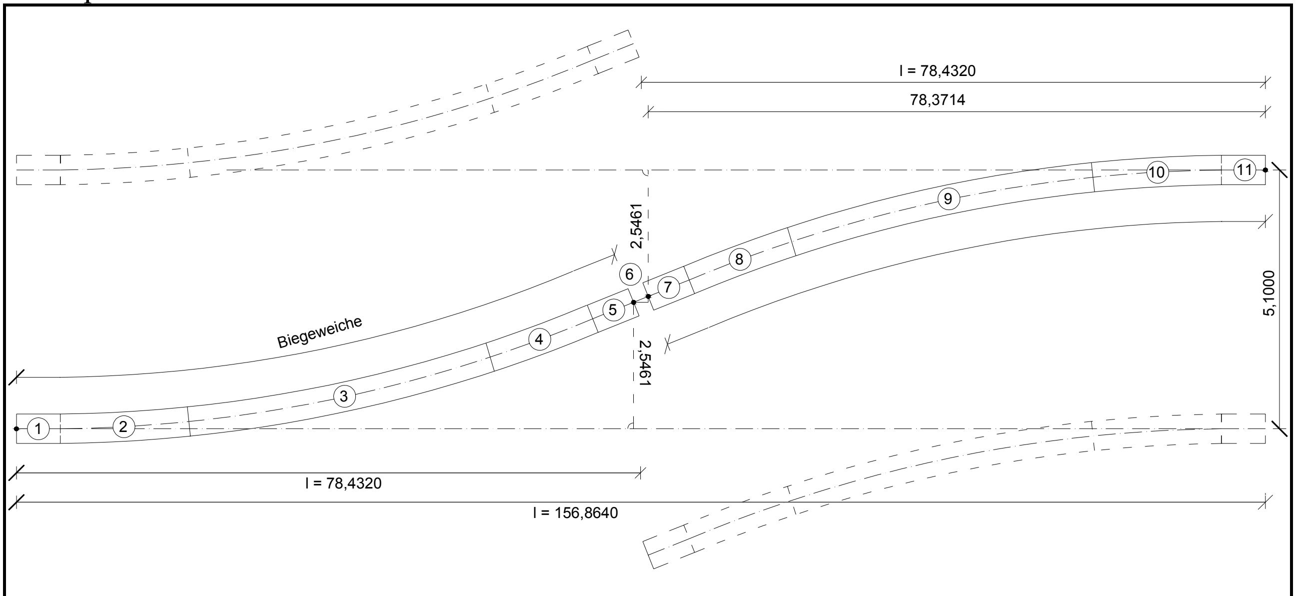


Figure 148: X-connection with low-speed switches (guideway pitch 5.10 m) (design example)

No.	Element	Length [m]	Radius [m]	Abscissa [m]	Ordinate [m]	τ [gon]	τ [°]
	WA			0,0000	0,0000	0.00000	0.00000
1	Straight	1.0320		1.0320	0.0000	0.00000	0.00000
2	Clotoid	15.4800		16.5119	0.0426	0.52604	0.47344
3	Arc	45.4080	-936.7000	61.8915	1.5181	3.08612	2.77751
4	Clotoid	14.8960		76.7588	2.4416	0.50619	0.45557
5	Straight	1.6160		78.3714	2.5461	0.00000	0.00000
6	geom. gap	0.1216		78.4926	2.5539	0.00000	0.00000
7	Straight	1.6160		80.1053	2.6584	0.00000	0.00000
8	Clotoid	14.8960		94.9726	3.5820	-0.50619	-0.45557
9	Arc	45.4080	+936.7000	140.3521	5.0574	-3.08612	-2.77751
10	Clotoid	15.4800		155.8320	5.1000	-0.52604	-0.47344
11	Straight	1.0320		156.8640	5.1000	0.00000	0.00000

∑	157.8960		0.00000	0.00000

Table 154: Route parameters of the X-connection with low-speed switches (guideway pitch 5.10 m) (design example)

Variable		Medium section application / Long section application		Regional application (Recommendation)	
Permissible speed straight position	v_{max}	500	[km/h]	500	[km/h]
Permissible speed turnout position	v_{max}	109	[km/h]	69	[km/h]
Uncompensated lateral acceleration	a_y	1.98	[m/s²]	0.39	[m/s²]
Lateral jerk (1st / 2nd clotoid)	$\mathring{a}_y$	1.91 / 1.98	[m/s³]	0.47 / 0.50	[m/s³]

Table 155: Driving dynamic values of the X-connection with low-speed switches (guideway pitch 5.10 m) (design example)

Travelling platform and swinging platform

The travelling platform (Figure 249) and the swinging platform (Figure 250) are routed as straight track ($R_H = \infty$) in the ground plan.

In the gradient path, depiction as hump or valley is possible.

The travelling platform and the swinging platform are moved while the vehicle is stationary. According to Chapter **Error! Reference source not found.** slopes should not be used.

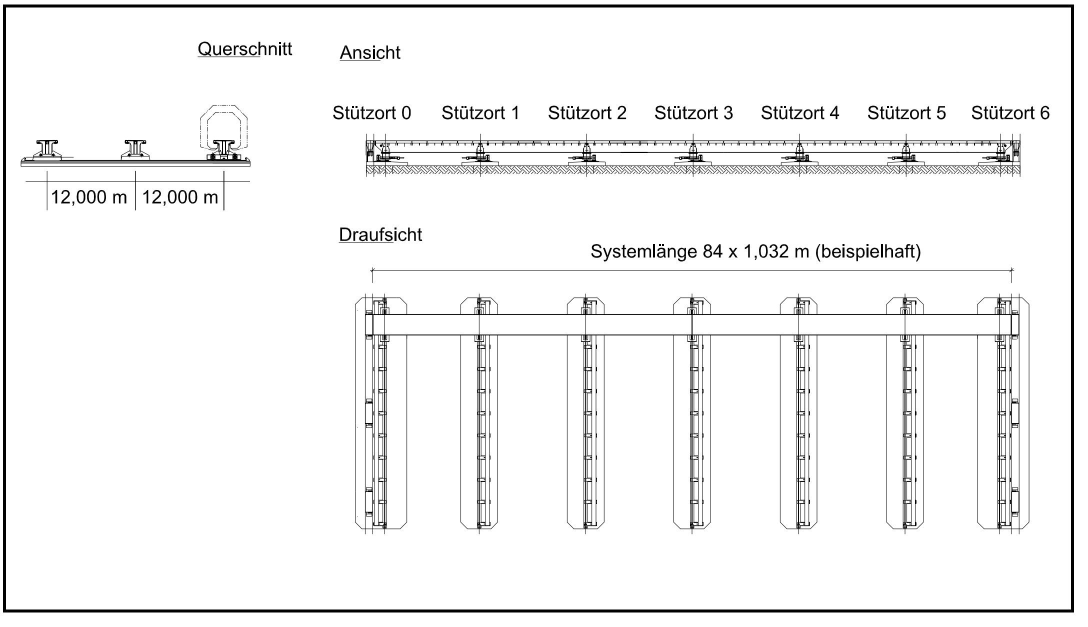


Figure 249: Travelling platform (example)

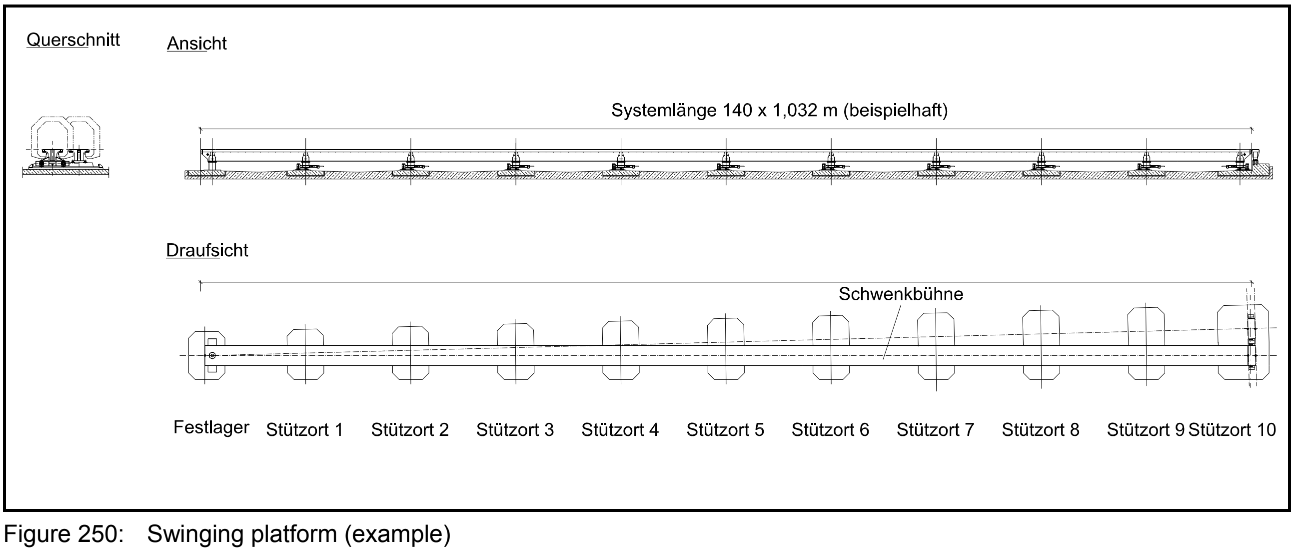


Figure 250: Swinging platform (example)

Operations facilities

Operations facilities such as stations or maintenance facilities will be designed on a project-specific basis.

They are therefore not part of these design principles for the layout of high-speed Maglev guideways.

The routing limit values given in this document however also apply for the operations facilities.

Within operations facilities, clotoids in the form of transition curves can be used as route elements in the ground plan under the above-mentioned conditions.

If a platform is planned between the guideways of a laterally tilted double track, the height difference between the entry levels should be compensated by parallel height adjustment of the gradients, so that the platform can run horizontally in the transverse direction.

High-speed Maglev System
Design Principles

Guideway
Part V
Surveying

Distributor

This document was released for publication by the ‘Guideway’ committee of experts.

Overview of revisions

Date of release: 15.02.2007, currently valid version, ‘Guideway’ committee of experts.

Table of Contents

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General

Purpose and field of application

This document specifies the requirements for the surveying of high-speed Maglev systems. The network of fixed points (position and height) to be created from it forms the basis for the planning, construction and the monitoring based on surveying technology during the maintenance of high-speed Maglev guideways.

These design principles apply independently of projects and serve as the basis for further surveying and calculation concepts.

Supplementary to this, to improve clarity in this document, explanations and justifications will be provided regarding the surveying and calculation procedures.

These design principles apply for a high-speed Maglev system in accordance with the Allgemeinem Magnetschwebebahngesetzt /AMbG/ (General Magnetic Levitation Systems Act).

High-speed Maglev system – design principles

This document is part of the documentation for high-speed Maglev systems consisting of several design principles. The document tree is shown in Figure 1 /MSB AG-GESAMTSYS/.

The higher-level document Design principles, complete system and its appendices apply consistently for the entire documentation:

- High-speed Maglev system – design principles, complete system, doc. no.: 50630, /MSB AG-GESAMTSYS/ with the appendices:
  - Annex 1: Abbreviations and definitions, doc. no.: 67536, /MSB AG-ABK&DEF/
  - Annex 2: Laws, regulations, standards and directives, doc. no.: 67539, /MSB AG-NORM&RILI/
  - Annex 3: Environmental conditions, doc. no.: 67285, /MSB AG-UMWELT/
  - Annex 4: Rules for operation (train service and maintenance), doc. no.: 69061, /MSB AG-BTR&IH/
  - Annex 5: Noise, doc. no.: 72963, /MSB AG-SCHALL/

Abbreviations and definitions

The abbreviations and definitions set down in /MSB AG-ABK&DEF/ apply.

Laws, regulations, standards and directives

The normative documents listed in /MSB AG-NORM&RILI/ contain statements that become part of the design principles for high-speed Maglev systems by reference to them in the design principles for high-speed Maglev systems. In the case of dated normative documents in /MSB AG-NORM&RILI/ subsequent changes or revisions to these publications do not apply. In the case of undated references the latest edition of the normative document in question applies.

The version of the standards and directives to be observed in a high-speed Maglev system project must be stated in binding terms on a project-specific basis.

Identification and binding nature of requirements

When this document was drawn up the rules in accordance with /DIN 820/ were in the main applied.
In the sections that follow and in the appendices of this document

- requirements are given in standard type and
- explanations, guide values and examples are given in italics

(see /MSB AG-FW ÜBG/).

Co-ordinate system

In the first instance, the existing official maps based upon national co-ordinate systems can be used as the technical basis for planning high-speed Maglev projects.

For the detailed routing of the three-dimensional curves of the guideways in question including the spacing of supports and beams (/MSB AG-FW TRAS/) and for the realisation of the structure a standardised, low-stress and structure-related geodetic reference system should be created.

Despite ongoing improvements in the national network with regard to homogeneity and accuracy, which have been achieved by satellite measuring technology, existing fixed point fields – determined by locality and history – still exhibit various shortcomings, for example

- *different projection properties,*
- *differences in up-to-dateness,*
- *inadequate quality (accuracy), stability, density and configuration.*

National co-ordinate systems

In surveying the co-ordinate systems for position and height are separated based upon the different calculation surfaces (rotational ellipsoid or quasigeoid).

The height relates to the quasigeoid, a level surface at the height of the average sea level, at which all perpendiculars are vertical.

For the position system, conformal (i.e. differentially isogonal) projections are primarily used of the surface of the earth for the calculation or map plan in question, which is approximated by a rotational ellipsoid.

The co-ordinate system used in surveying can generally not be used for the further measurements due to projection distortions and inhomogeneities due to different observation procedures, differences in up-to-dateness and grid voltages (e.g. deformations). These influences are superimposed upon one another and can lead to a loss of accuracy in the guideway surveying that is intolerable for the high-speed Maglev system.

Information on the projection and scale distortion is given in Annex A for the Gauß-Krüger projection system and in Annex B for the ETRS89/UTM projection system.

High-speed Maglev co-ordinate system (MCS)

For the detailed routing and realisation of the structure, a network of fixed points that fulfils the specific requirements should be planned, marked out, geodetically determined, calculated and maintained in a high-speed Maglev co-ordinate system (MCS). (Chapter 0).

Beam production co-ordinate system (BPC)

The planning, production and approval of guideway beams takes place within the beam production co-ordinate system specified for each beam /MSB AG-FW GEO/.

The co-ordinate axes are designated Y, X and Z /MSB AG-FW GEO/ and are not described in these design principles.

Three-dimensional curve co-ordinate system (TCC)

The functional levels stator level, lateral guidance rail and gliding surface /MSB AG-FW GEO/, the clearance and the gauges /MSB AG-FW TRAS/ plus the installation space for the guideway equipment /MSB AG-FW ÜBG/ relate to the co-ordinate system following three-dimensional curve with local lateral tilt.

The co-ordinate axes are designated y, x and z /MSB AG-FW GEO/ and are not described in these design principles.

Requirements of the high-speed Maglev co-ordinate system (MCS)

The high-speed Maglev co-ordinate system (MCS) should be defined and geodetically realised as a technical special network.
The MCS should be designed in two network stages:

(1) Higher-level fixed point network (1st order) with point spacing of approx. 3 km as the basis for detailed routing.

(2) Routing fixed point network (2nd order) with point spacing of approx. 200 m, as the basis for surveying tasks during construction.

In the MCS the route obstacles of the routing are recorded as the basis for the detailed route. *This takes place by geodetic measurement or by transformation (see Chapter 0), if these route obstacles are not present in the MCS. It is also used for the performance of all subsequent surveying work during construction.*

Properties

The MCS projects the surface of the earth in a suitably conformal (i.e. differentially isogonal) manner in the planning and calculation planes.

Any (unavoidable) distance distortions that occur are limited to an order of magnitude that is non-critical for a project with high sensitivity to length preservation.

Requirements regarding

- the quality of the marking out (frost-free basis, uniform centering accuracy),
- homogeneity (same equal creation date, equivalent observation procedure),
- adjacency preserving (high quality requirement for geometric adjacency relationships),
- a reasonable point density (suitable for planning, marking out, approval and calculation) and
- a suitable configuration (suitable marking-out geometry)

are made of the MCS.

The realisation of the MCS takes place separately in the ground plan and vertical plan components.

This takes place on the basis of the different types of reference surfaces for the position (rotational ellipsoid) and the height (level surface) as well as the measuring methods for the determination of position and height that are sometimes still different today.

Determination of the positional components

A plane longitude / latitude system in the form of an inclined-axis, conformal projection of the ellipsoid is selected as the positional component of the MCS.

In this projection a geodetic line, defined by the point P_O and the azimuth α, is projected with length preservation.

To minimise the distance distortions, which increase with lateral distance a, the geodetic line is placed over the route as an averaging straight line.

Figure 251 shows as an example the fictitious position of a high-speed Maglev route and an advantageously positioned geodetic line, as well as the axis designations.

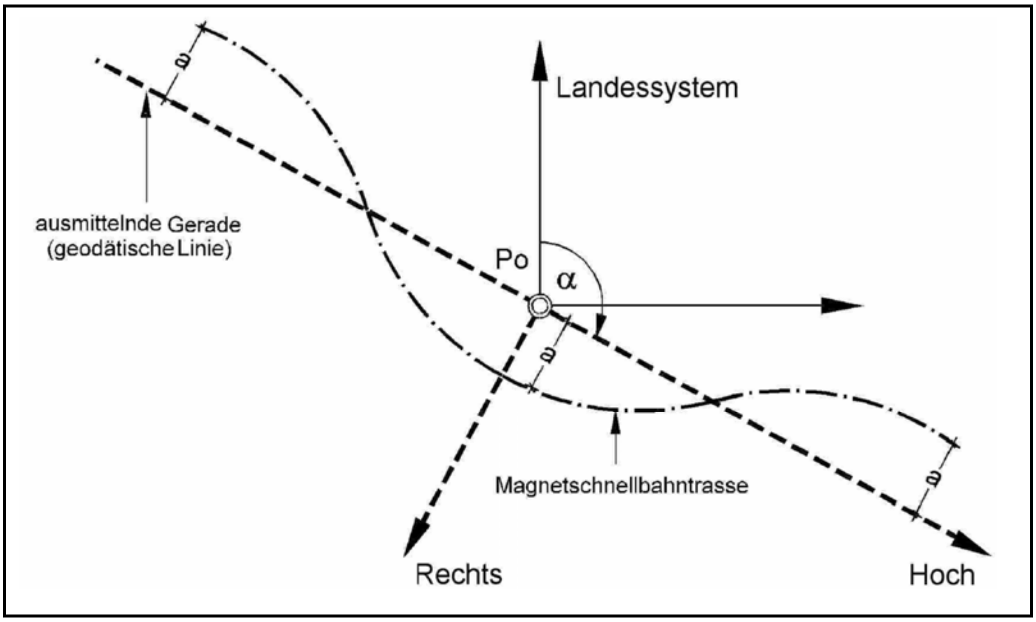


Figure 251: Parameter representation of the high-speed Maglev co-ordinate system (MCS)

Landessystem	National system
ausmittelnde Gerade (geodätische Linie)	Averaging line (geodetic line)
Magnetschnellbahntrasse	High-speed Maglev route
Rechts	Longitude
Hoch	Latitude

The remaining distance distortions (scale differences) can be estimated by:

$$Lv \approx \frac{a^2}{2 \cdot R_m^{\ 2}} \qquad (1)$$

where R_m = average radius of the Earth (6378 km)

The increase of these distance distortions with growing distance from the averaging straight line is shown in Table 156 based upon calculated examples.

Lateral distance a *[km]*	*Distance distortion Lv per 100 m* *[mm/100 m]*
10	*+0.1*
25	*+0.8*
50	*+3.1*
75	*+6.9*

Table 156: Projection distortions

The maximum lateral distance of the route to the selected geodetic line through P_O should be around 25 km.

This limitation means that the remaining deviations (projection distortions) lie in an order of magnitude of 1 mm per 100 m and are thus within tolerable magnitudes. They can thus be disregarded in all subsequent calculations / measurements.

The required calculations can then take place according to the simple formulae of plane trigonometry. In particular, the application of projection reductions can be dispensed with.

If the recommended maximum lateral distance a ≤ 25 km cannot be adhered to, several MCS sections with sufficiently large areas of overlap (at least 3 points of the higher-level fixed-point frame each, corresponding to approx. 6 km length) should be defined. Such an arrangement is shown in Figure 252.

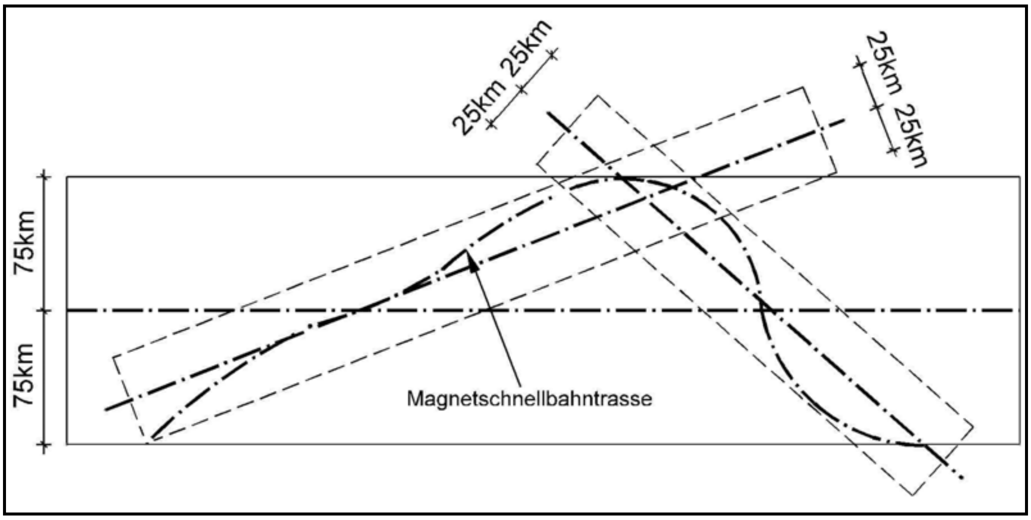


Figure 252: Lateral limitation of the MCS

Magnetschnellbahntrasse	High-speed Maglev route

Regardless of the properties of the above-mentioned projection, route measurements (in additional to the normal instrument and atmospheric corrections) must be geometrically reduced in the determination of the fixed-point network and during construction (reduction to the horizontal and construction horizon and taking into account the curvature of the earth).

The determination of the MCS (position) should take place in the following sub-steps:

(1) Determination by maps of an averaging straight line such that the lateral distances between route and averaging straight lines are no more than 25 km (subdividing into several sections if necessary).

(2) Graphical determination of a reference point P_O (φ_o, λ_o) on the averaging straight line in the central area of the route (with rounded ellipsoidal co-ordinates if appropriate).

(3) Determination graphically or by calculation of the ellipsoidal azimuth α of the averaging straight line at this reference point P_O.

(4) Determination of the MCS such that

- the zero point is identical with the above-mentioned reference point P_O and
- the positive latitude axis corresponds to the geographical North in P_O.

(5) Projection of this North-oriented system in the map or calculation level in accordance with the rules for an inclined-axis conformal projection. Here the averaging straight line running through the reference point P_O (φ_o, λ_o) at the geographic direction angle α (corresponds to the ellipsoid of a geodetic line) is projected in the plane system with length preservation.

(6) Rotation in the (longitude / latitude) co-ordinate system (oriented in the main direction of the route) with subsequent additive zero-point displacement by the values latitude_O and longitude_O (to avoid negative co-ordinates).

- $\text{latitude} = \text{longitude}_{LK} \cdot \sin(\alpha) + \text{latitude}_{LK} \cdot \cos(\alpha) + \text{latitude}_o$
- $\text{longitude} = \text{longitude}_{LK} \cdot \cos(\alpha) - \text{latitude}_{LK} \cdot \sin(\alpha) + \text{longitude}_o$ (2)

Projection and transformation

The projection by calculation of the ellipsoidal co-ordinates for the points of the higher-level fixed point framework (cf. Chapter **Error! Reference source not found.**), generally derived from GPS measurements, takes place on the basis of the above-mentioned definitions (φ_o, λ_o and α).
For expedience, this projection is based upon the same ellipsoidal parameters (large semiaxis and oblateness) of the reference ellipsoid (currently WGS84), upon which the ellipsoidal co-ordinates are based.
We will dispense here with the representation of the comprehensive and confusing functions of the inclined-axis conformal projection. The mathematical principles can be found in geodetic technical literature.
The above-mentioned transformation equations are series, the development of which is limited to a corresponding calculation accuracy. In addition to the above-mentioned distance distortions to the

side of the line to be projected with length preservation (and the resulting maximum stripe width of 25 km to each side; see Chapter 0) this also limits the field of application (longitudinal extension).

This limitation is primarily dependent upon the following parameters:

(1) Geographic width φ_o of the reference point $P_{O,}$

(2) Orientation α of the primary axis (latitude),

(3) Longitudinal extension of the MCS,

(4) Stripe width of the MCS and

(5) Break off criterion in the calculation program used.

In order to keep calculation errors low enough to be negligible, the following are defined as reliable calculation accuracies:

(1) Maximum 1 mm between adjacent points at a distance of 1 km,

(2) Maximum 20 mm for the most distant point in relation to the co-ordinate origin.

In order to keep subsequent height reductions low the MCS is defined at an average construction horizon. From a calculation point of view the consideration of the construction horizon takes place for expedience by the adaptation of the parameters of the reference ellipsoid in the above-mentioned calculations. Depending upon the topography of the route it is sometimes possible to avoid height reductions in this manner, which is particularly advantageous during the detailed routing and the pegging out during construction.

Height component

As a height system, a fixed-point field is created that guarantees the adjacency preservation necessary for the routing of the high-speed Maglev system.

The height network is connected to the ordnance survey height reference area via connecting measurements. This simplifies co-ordination with other technical planning and the acceptance of data regarding the existing infrastructure.

The adjustment of the height network should be performed by a constraint-free positioning.

If there are different national height networks within the route, subsections can be created. If individual points or groups of points are connected to several height systems (e.g. system of Deutsche Bahn AG, the German waterways and shipping administration, etc.), independent point numbers should be issued for unique identification.

Realisation

The MCS is realised by the totality of all fixed points for position and height. The network structure is performed in two stages (for both position and height), these are broken down into:

(1) Creation of a higher-level fixed point network with point spacing of approx. 3000 m (cf. Chapter 0) for the performance of the work required for detailed routing and for subsequent integration in sections of the fixed point field for the route. The plane co-ordinates (longitude / latitude) or the height are determined according to the data in Chapter 0 and **Error! Reference source not found.**.

(2) The creation of a fixed point network for the route with point spacings of approx. 200 m (cf. Section 0) for surveying to assist construction.
The co-ordination of these points (position and height) takes place under forced connection to the higher-level fixed point framework.

The following reasons, amongst others, exist for the two-stage network structure:

(1) The necessary network homogeneity over the entire planning and construction phase;

(2) The technically well-balanced connection to the national system that can be made at a reasonable economic cost (see Chapter 0);

(3) Different measurement procedures used.

Higher-level fixed point network of the MCS

According to the fundamental geodetic principle "from big to small", a wide-meshed network with point spacings of approx. 3000 m should be set up along the route. This point field firstly serves the detailed planning or detailed routing.

Furthermore, it forms the framework into which the route-related fixed point network for the construction-related surveying work (see Section 0) is linked.

The points of the higher-level fixed-point network should be found such that

(1) Permanent point stability is guaranteed,

(2) GPS measurements can be performed (low shadowing),

(3) Route obstacles can be detected for the detailed routing,

(4) The subsequent connection of the route-related fixed point network (with higher point density) is facilitated (accessibility, visual connections, stability) and

(5) If possible, there are visual connections to the adjacent points of the higher-level fixed-point framework.

The investigation should be documented in the network design including an explanatory report taking into account the measuring procedure used.

The network design should be checked with regard to quality and economic viability by means of a simulated adjustment calculation and optimised if necessary.

The plane co-ordinates (longitude / latitude) and the height are determined according to the specifications in Chapter 0 and **Error! Reference source not found.**.

Position determination

The determination of the position of the points of the higher-level fixed point framework should take place using satellite-assisted measurement procedures.

For independent checking of scale, selected side lengths of the fixed-point network should be determined by means of conventional procedures (electro-optical distance measurement).

The free positioning in the national system takes place using identical points (e.g. EUREF, DREF points or higher-order TPs). A scale reduction should be applied if necessary.

The resulting positional co-ordinates are converted into the plane, right-angled MCS in accordance with Chapter 0.

All parameters should be three-dimensionally balanced out together with the GPS measurements.

The positional accuracies listed should be adhered to:

- Point-related accuracy in accordance with HELMERT < 5 mm
- Relative accuracy of the base lines < (5 mm + 1 ppm)

Height determination

The height determination of the fixed points of the higher-level fixed-point framework takes place by means of geometric detailed levelling.

The stated discrepancy (D) of the forward and backward levelling between two adjacent fixed points should be adhered to:

$$D[mm] = \pm 3 \cdot \sqrt{S[km]} \qquad (3)$$

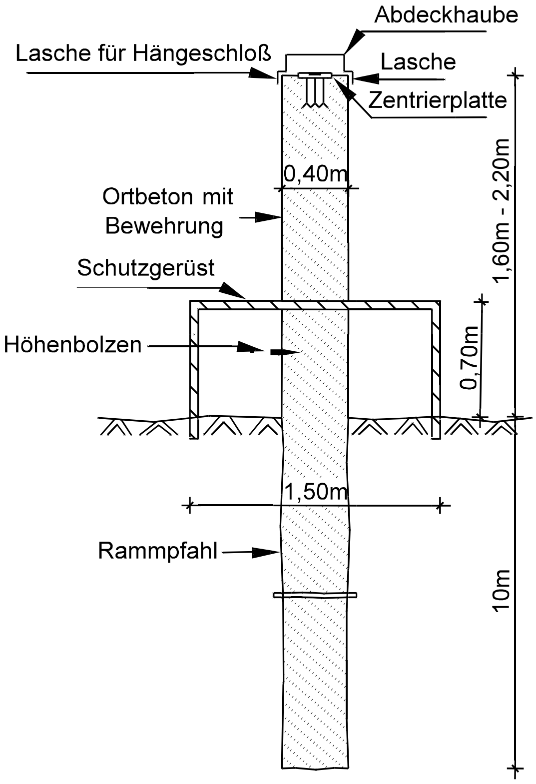
See Chapter **Error! Reference source not found.** for the definition of the height system of the MCS and for the adjustment sequence according to the procedure.

Marking out

The individual fixed points (position and height) should be marked out in a stable and permanent manner.

The marking out (see Figure 253 for example) should be performed in good time due to possible initial settling.

Local concrete pillars with positive centering and concreted-in height pegs	Base point with centering hole and height pegs



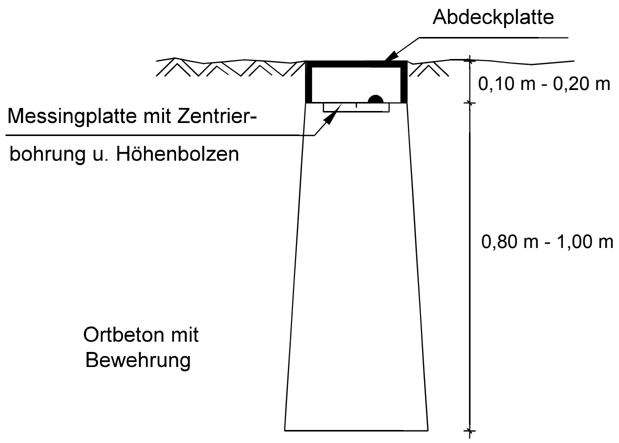


Figure 253: Examples of the design of fixed-point markers

Lasche für Hängeschloß	Shackle for padlock
Abdeckhaube	Covering cap
Lasche	Shackle
Zentrierplatte	Centering plate
Ortbeton mit Bewehrung	Site-mixed reinforced concrete
Schutzgerüst	Guard scaffolding

Höhenbolzen	Height peg
Rammpfahl	Driven foundation pile
Abdeckplatte	Covering plate
Messingplatte mit Zentrierbohrung u. Höhenbolzen	Brass plate with centering hole and height peg

Transformation of the planning system in MCS

The planning documents from the national system should each be transferred into the MCS in sections by means of a 4-parameter transformation.

In addition, from each two adjacent fixed points of the higher-level fixed-point network the parameters

(1) 2 x translation

(2) 1 x rotation

(3) 1 x scale factor

should be determined for the 4-parameter positional transformations.

Graphical planning contents should be transformed in sections using the determined transformation parameters.

Route-related fixed-point network in the MCS

As the basis for all construction-related surveying work (marking out, detailed positioning, acceptance, etc.) the higher-level fixed-point network described in Chapter 0 should be compressed.
The point spacing of the route-related fixed-point network is approx. 200 m.
The lateral distance of the fixed points to the planned guideway is generally 30 m to 60 m (see Figure 254).
In special cases (e.g. vicinity of stations, grade separation structures) a smaller compression interval or a smaller lateral distance from the high-speed Maglev layout is possible.

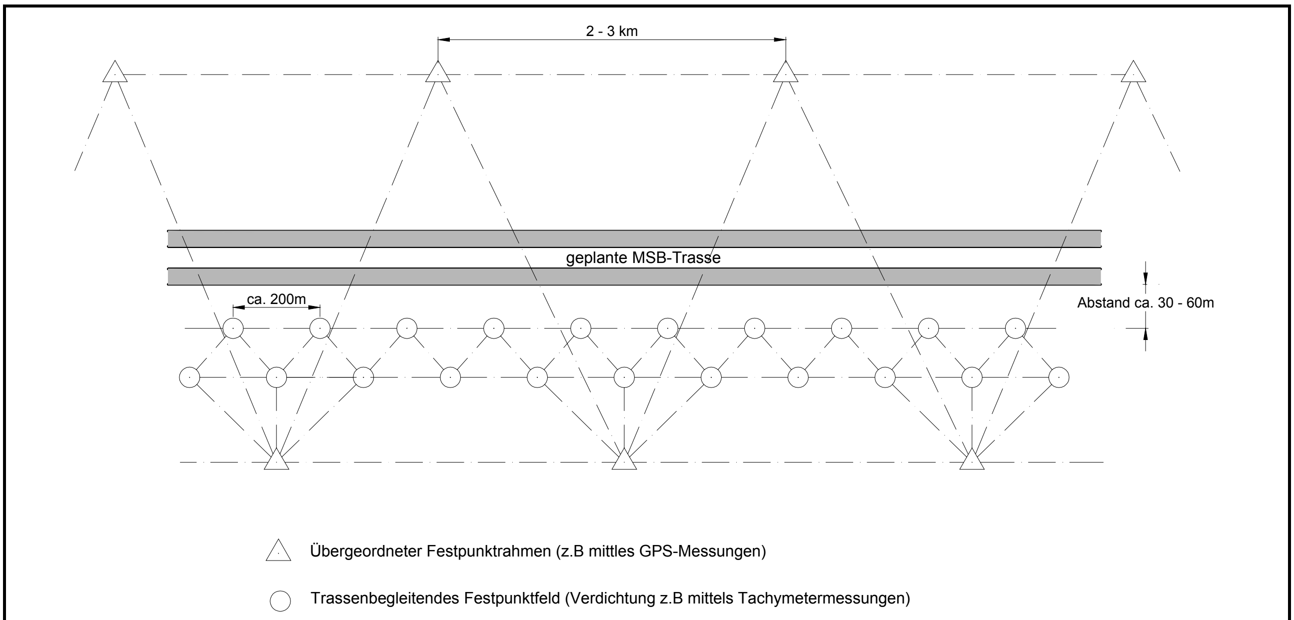


Figure 254: Recommended route-related fixed-point field

geplante MSB-Trasse	Planned high-speed Maglev route
Distance	Spacing
ca.	approx.
Übergeordneter Festpunktrahmen (e.g. mittles GPS-Messungen)	Higher-level fixed-point framework (e.g. central GPS measurements)
Trassenbegleitendes Festpunktfeld (Verdichtung z.B. mittels Tachymetermessungen)	Route-related fixed-point field (compression e.g. by means of tachymeter measurements)

The co-ordination of these points (position and height) takes place under forced connection to the higher-level fixed-point network.

Position determination

The position determination of the route-related fixed-point field should be performed at a high level of accuracy in accordance with the latest measuring technology developments.

The listed positional accuracies should be adhered to:

- Point-related accuracy according to HELMERT < 2 mm

The measuring accuracies for the route-related positional fixed-point network are defined as follows:

Standard deviation of the arithmetic mean

- of a measured direction $s_{a(Hz)}$ = 0.2 mgon
- of a measured distance to adjacent point $s_{a(Sh)}$ = 1.0 mm

The calculation of co-ordinates (position) of all newly defined fixed points between two points of the higher-level fixed-point framework takes place by common network adjustment in the plane (longitude / latitude) system of the MCS.
The individual measuring elements should be assigned a weighting based on their standard deviations.
The adjustment accuracy below should be adhered to:

$s_{a((\Delta long, \Delta lat)}$ = 1.0 mm adjusted co-ordinate difference

Standard deviations of the adjusted co-ordinate difference Δlongitude or Δlatitude of two adjacent route-related fixed-points

Height determination

The height determination of the route-related fixed-point network takes place by means of geometric detailed levelling.

The stated discrepancy (D) between the forwards and backwards levelling between two adjacent route-related fixed points should be adhered to:

$$D[mm] = \pm 3 \cdot \sqrt{S[km]} \tag{4}$$

The measured values should arranged in sections to form height networks and adjusted under forced connection to the higher-level height fixed-point framework. If height points of the national height fixed-point field are drawn into the MCS then these are treated as new points, i.e. the existing national heights remain unconsidered.

The adjustment accuracy stated below should be adhered to:

$\mathbf{s_{a((\Delta height)}} = 1.0$ mm adjusted height difference

Standard deviation of an adjusted height deviation between two adjacent route-related fixed points

Detailed positioning of the guideway beams

The detailed positioning of the guideway beams takes place some time after the rough assembly (the laying) of the guideway beams.

The procedure for the detailed positioning should be drawn up on a project-specific basis.

The geometric requirements of the functional levels within the guideway beams are described in /MSB AG-FW GEO/.

The longwave deviations should be calculated for the two functional levels stator level (in z-direction) and lateral guidance level (in y-direction), taking into account the calculated target pre-bending.

The requirements for the relative spatial position are derived from the permissible longwave deviation within the guideway beam.

Adherence to the permissible tolerances for these longwave deviations in the y- and z-direction of the BPC (beam production co-ordinate system), (/MSB AG-FW GEO/) prevents unplanned accelerations and jerks.

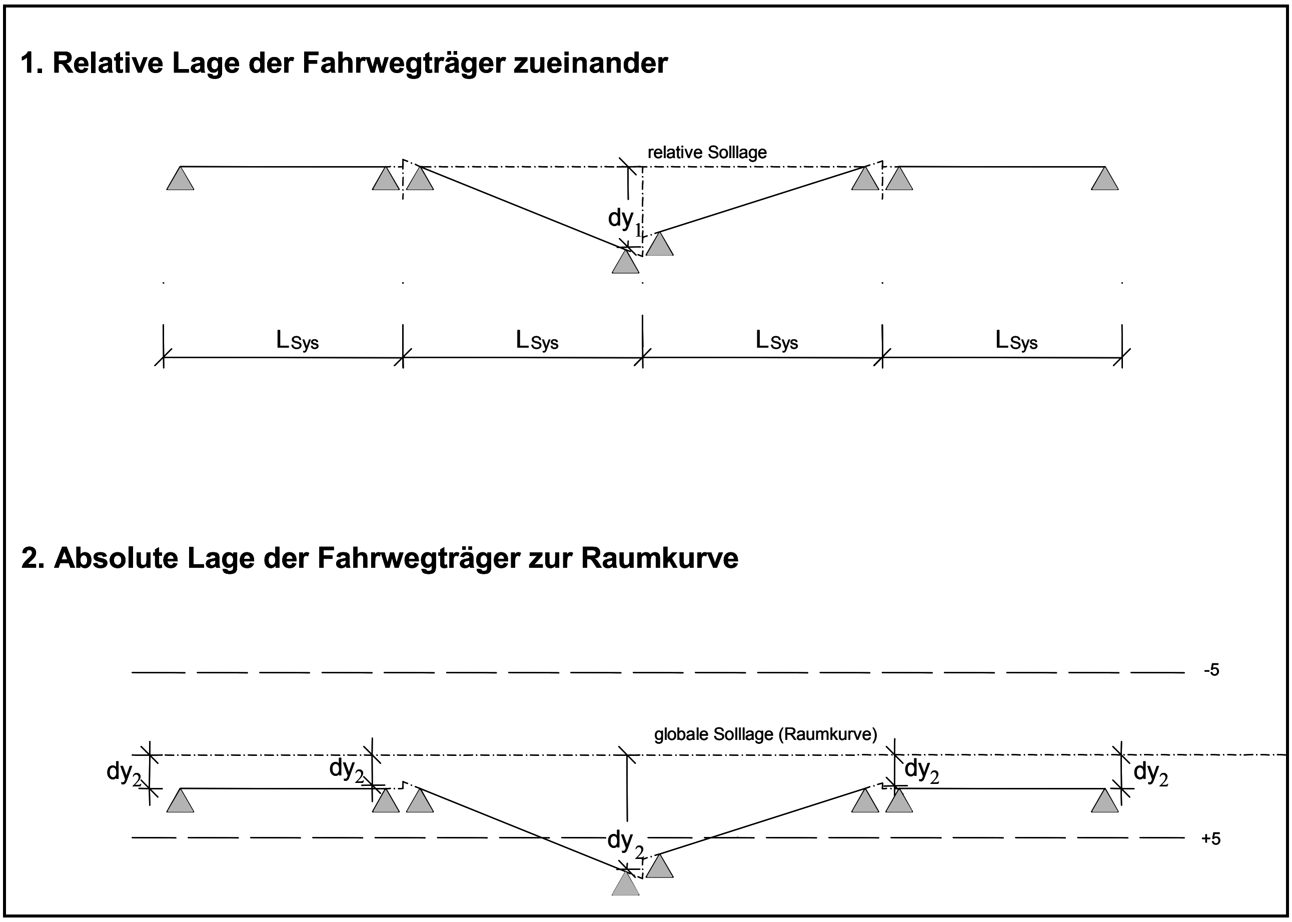


Figure 255: Requirements of the detailed positioning of the guideway beams

Relative Lage der Fahrwegträger zueinander	Position of guideway beams in relation to one another
relative Solllage	Relative target position
Absolute Lage der Fahrwegträger zur Raumkurve	Absolute position of guideway beams on three-dimensional curve
globale Sollage (Raumkurve)	Global target position (three-dimensional curve)

For the detailed positioning of a guideway beam the requirements are divided into the

- relative spatial position (in each case considering the previous and next guideway beam) and
- absolute spatial position (position of the guideway in relation to the three-dimensional curve).

The measuring points on the functional levels stator level, lateral guidance rails and sliding surfaces are defined in /MSB AG-FW GEO/ within the beam.

The requirements relate to the average beam position in the beam joint (system axis). The permissible tolerance of the relative spatial position of the guideway beam (spanning beams) in the beam joint is:

For beam lengths > 12.384 m:

$$dy_1 = \pm \frac{2.0}{24768} \cdot L_{sys} \quad [mm] \tag{5}$$

$$dz_1 = \pm \frac{2.0}{24768} \cdot L_{sys} \quad [mm] \tag{6}$$

where L_{sys} = field width *(e.g. 24768 mm)*

For beam lengths < 12.384 m:

$$dy_1 = \pm 1.0 \quad [mm]$$

$$dz_1 = \pm 1.0 \quad [mm]$$

The geometric requirements of the offset and the NGK in the beam joint are defined in /MSB AG-FW GEO/.

The permissible tolerance of the absolute spatial position of the guideway beam in relation to the planned three-dimensional curve is as follows in the beam joint:

$dy_2 = \pm 5.0$ [mm]

$dz_2 = \pm 5.0$ [mm]

Documentation

The requirements of the quality assurance and documentation are set down in /MSB-AG FW ÜBG/.

Appendix V-A Gauß-Krüger co-ordinate system

Official topographical maps, in particular those with large and medium scale, build upon the Gauß-Krüger co-ordinate system.
Gauß-Krüger co-ordinates are a conformal projection of the ellipsoid of the earth as a plane. The earth is divided into meridian stripes 3° wide. Its limiting meridians lie precisely 3° apart. In the centre of the meridian stripe runs the so-called central meridian. Each meridian stripe has a reference figure. In the classic determination this is derived from the integer multiplication of 3° for the central meridian (0°, 3°, 6°, etc.).

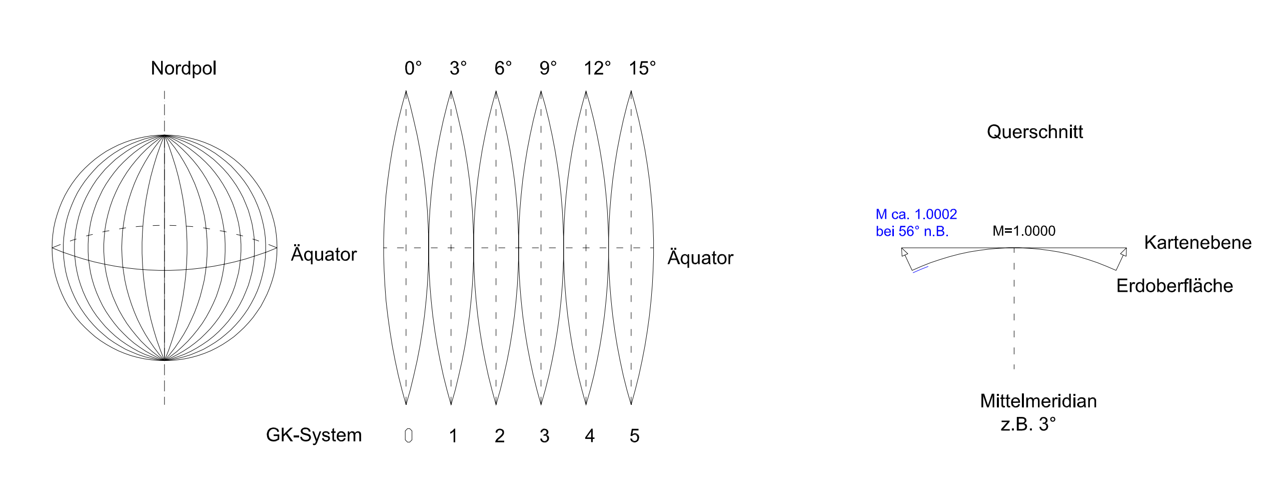


Figure 256: Scale distortion in the Gauß-Krüger system

Nordpol	North pole
Querschnitt	Cross-section
Kartenebene	Map plane
Erdoberfläche	Surface of the earth
Äquator	Equator
GK-System	GK system
Mittelmeridian	Central meridian

For mapping the curved surface of the earth is projected onto the map plane. The projection distortions that arise increase with increasing distance from the central meridian (see Figure 256).

These locally-differing length distortions must be taken into account by calculation in the detailed planning (detailed routing) and the local conversion of all relevant subsystems of the high-speed Maglev system. A continuous routing calculation with "true" distances is not possible.

All relevant components (e.g. guideway beams, longitudinal stators) and e.g. the directory of equipment would have to be taken into account in the planning co-ordinate system with corresponding scale factors.

Annex V-B Universal, transversal mecator projection

For the ordnance surveying of all German Länder the ETRS89 (European Terrestrial Reference System 1989) with UTM projection will be compulsory as of 2009.

The ETRS89 is a three-dimensional Cartesian co-ordinate system. It relates to geocentric co-ordinates the origin of which lies in the geocentre (centre of gravity of the earth). In UTM projection, the ellipsoid of the earth is divided into 6° wide stripes, which all run through the poles and are at the greatest distances from each other at the equator.

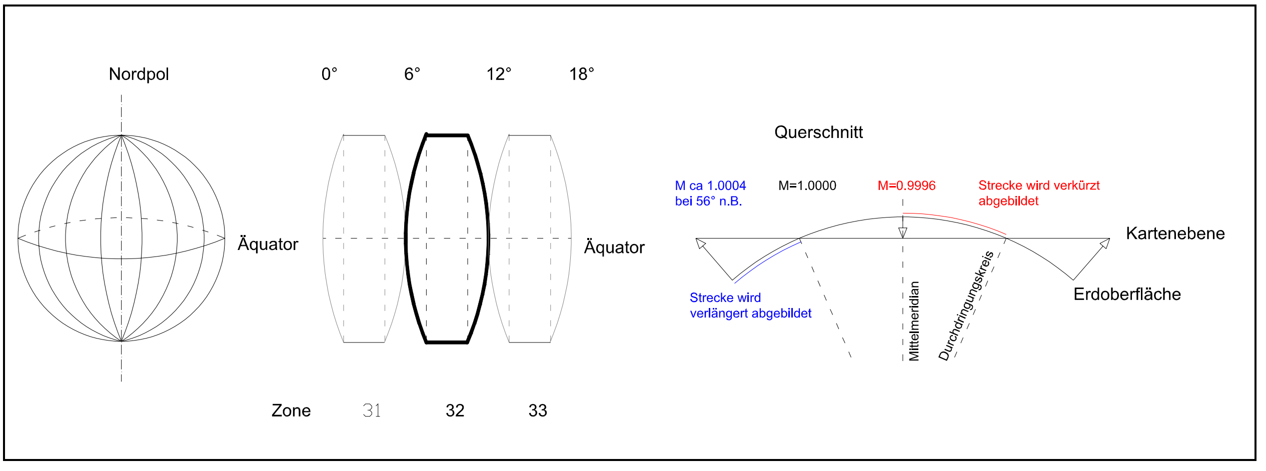


Figure 256: Scale distortion in the UTM system

Nordpol	North pole
Querschnitt	Cross-section
Äquator	Equator
Strecke wird verkürzt abgebildet	Section is shortened in projection
Kartenebene	Map plane
Erdoberfläche	Surface of the earth
Mittelmeridian	Central meridian
Durchdringungskreis	Penetration circle
Strecke wird verlängert abgebildet	Section is extended in projection

For UTM projection the curved surface of the earth is projected onto the map plan using 2 penetration circles. Only on the penetration circles is the depiction length-preserving. Between the penetration circles, distances are compressed, outside the penetration circles, distances are extended (see Figure 256).

These locally differing length distortions must be taken into account in the detailed planning (detailed routing) and the local conversion of all relevant subsystems of the high-speed Maglev system by calculation. A continuous routing calculation with "true" lengths is not possible.

All relevant components (e.g. guideway beams, long stators) and e.g. the list of equipment would have to be taken into account in the planning co-ordinate system with suitable scale factors.

High-speed Maglev system
Design principles

Guideway
Part VI
Maintenance

Distributor

This document was released for publication by the ‘Guideway’ committee of experts.

Overview of revisions

Date of release: 15.02.2007, currently valid version, 'Guideway' committee of experts.

Table of contents

General

Purpose and field of application

This document specifies in binding terms the general specifications for the maintenance of high-speed Maglev guideways, insofar as safety and order are involved. Furthermore, these design principles contain recommendations.
This document is one of the foundations that should be taken into account in the design, planning, realisation and operation of application projects of the high-speed Maglev.
The statements in the document are subordinate to those of the MbBO and are based upon the existing state of the art for the maintenance of structures.
Part VI of the guideway design principles should be used in association with Parts I to V of the guideway design principles, the complete system design principles and the design principles relating to the other subsystems.
This document includes:

- General requirements for guideway maintenance;
- Fundamental requirements for the processes of guideway maintenance;
- Fundamental requirements for the technical performance of monitoring;
- Fundamental requirements for documentation;

The requirements of this document should be more precisely specified and supplemented on a project-specific basis and according to the current status of the project.
Requirements regarding the maintainability of the individual assemblies can be found in the /MSB AG-FW ÜBG/.
These design principles apply for a high-speed Maglev system in accordance with the Allgemeinem Magnetschwebebahngesetzt /AMbG/ (General Law on Magnetic Levitation Systems).

Design principles for high-speed Maglev systems

This document is part of the documentation for high-speed Maglev systems comprising several sets of design principles. The document tree is shown in Figure 1 /MSB AG-GESAMTSYS/.

The higher-level document 'Design principles, complete system' and its appendices apply consistently for the entire documentation:

- High-speed Maglev system design principles, complete system, doc. no.: 50630, /MSB AG-GESAMTSYS/ with the appendices:
  - Annex 1: Abbreviations and definitions, doc. no.: 67536, /MSB AG-ABK&DEF/
  - Annex 2: Laws, regulations, standards and directives, doc. no.: 67539, /MSB AG-NORM&RILI/
  - Annex 3: Environmental conditions, doc. no.: 67285, /MSB AG-UMWELT/

- Annex 4: Rules for operation (train service and maintenance), doc. no.: 69061, /MSB AG-BTR&IH/
- Annex 5: Noise, doc. no.: 72963, /MSB AG-SCHALL/

Abbreviations and definitions

The abbreviations and definitions given in /MSB AG-ABK&DEF/ apply.

The assemblies of the guideway are defined in 'Design Principles, Guideway, Part I'. In deviation from the terminology in the other design principles, the terms shortcoming, error and damage are used in accordance with the terminology of construction in guideway design principles.
A shortcoming in the sense of the document is an impermissible deviation of an assembly from the target state that existed at the moment of acceptance. It is insignificant here whether the shortcoming was recognised at the moment of acceptance or not until later. A shortcoming can cause one or more cases of damage.
An error is an inappropriate action or an omission which can lead to one or more shortcomings and / or cases of damage.
Damage is an impermissible deviation of an assembly from the target state which occurs during use.

Laws, regulations, standards and directives

The normative documents listed in /MSB AG-NORM&RILI/ contain statements that become part of the high-speed Maglev design principles when referred to in the high-speed Maglev design principles. In the case of dated normative documents in /MSB AG-NORM&RILI/ subsequent changes or revisions to these publications do not apply. In the case of undated references the latest edition of the normative document referred to applies.

The status of the standards and directives to be taken into consideration in a Maglev project must be specified on a project-specific and binding basis.

Identification and binding nature of requirements

In the creation of this document the rules in accordance with /DIN 820/ were mainly applied.

In the sections that follow and in the appendices to this document

- requirements are printed in standard type and
- explanations, guide values and examples are printed in *italics*

(see /MSB AG-FW ÜBG/).

Requirements regarding guideway maintenance

Basic principles

In accordance with DIN 31051 the maintenance of the guideway comprises

(1) Inspection,

(2) Servicing,

(3) Maintenance and improvements

of the named components of the guideway (the improvements are dealt with in this document together with other, e.g. operationally determined measures).
The overriding goal of maintenance is to put in place the technical prerequisites for the continuation of the operation of the high-speed Maglev system in accordance with regulations. Preventative and condition-oriented maintenance should ensure that repairs leading to disruption to the guideway are not necessary.
The monitoring and testing of the guideway should accompany operation and should be automated as far as possible. The safety level achieved may not be lower than in a conventional structure test on the basis of /DIN 1076/ or the valid regulations regarding wheel/rail technology. The time intervals specified in these regulations can however be adapted to the peculiarities of a high-speed Maglev route where appropriate.
The purpose of the regular monitoring is to recognise shortcomings and any damage that have occurred early enough that the necessary measures can be taken at an early stage or to rectify shortcomings and any defects that have arisen before safety and availability are impaired.
Furthermore, the necessary data material for a forward-looking maintenance planning should be provided.
The independence of the personnel entrusted with the maintenance for the guideway regarding technical decisions in relation to

(1) the necessity of the performance of inspection measures;

(2) the technical release;

shall be ensured by appropriate organisational rules.
A project-specific maintenance concept shall be drawn up for the engineering structures of the guideway in accordance with /MSB AG-FW ÜBG/, containing statements regarding the monitoring and testing of the structures of the guideway for the high-speed Maglev system in relation to stability, traffic safety and durability.
Note: According to MbBO there is a duty of disclosure towards the supervising and testing agency with regard to data and findings that are relevant to the monitoring and testing of the structure and that are detected and assessed within the framework of operation.
It should be ensured that in addition to the person responsible for the system, the works manager and the responsible supervisory body, third parties who can demonstrate a legitimate interest in the results of investigation (e.g. project manager for crossing traffic routes), are informed of maintenance events that are relevant to them.

Specifications and recommendations for the maintenance strategy

Specifications

The maintenance of the guideway rests upon a known condition. This condition is recorded and documented in the framework of the manufacture and maintenance of the guideway as the “zero condition” on the finished guideway (section) before its first negotiation by a Maglev vehicle.
During subsequent operation all significant changes from the original “zero condition” are continuously documented and assessed and if necessary set down as a new reference condition.
Any substitution of components in the existing equipment (e.g. exchange of a stator assembly) can necessitate the definition of a new reference condition, which then forms the basis for future monitoring.
Maintenance programs should be drawn up in accordance with “Principles and procedures for the drawing up of the maintenance program”, Section 5.3.3 in /MSB AG-GESAMTSYS/ and the /MSB AG-BTR&IH/.
Maintenance programs should be drawn up for all assemblies by the manufacturer / supplier in question.
The individual maintenance programs should be summarised in a maintenance program.
The guideway maintenance program developed from this must be compatible with the requirements of the complete system.
The guideway maintenance program should be drawn up on the basis of the database of structures.
For each individual measure included in the maintenance program the manufacturer / supplier should drawn up an instruction card for the maintenance in accordance with Section 5.3.3 in /MSB AG-GESAMTSYS/ and /MSB AG-BTR&IH/.
The construction of the components and assemblies of the guideway should be designed in accordance with the ‘Design Principles, Guideway, Part I’ such that it is fault-tolerant, so that maintenance need not take place immediately after the detection of damage.
Maintenance-related feedback on other subsystems (e.g. levitation/guidance signals from the vehicle) should be taken into consideration in the maintenance of the guideway).
The maintenance must be performed exclusively by suitably qualified personnel (see also /MSB AG-BTR&IH/).
Possible influence by third parties should be taken into consideration in the maintenance strategy on a project-specific basis.
Findings and documentation from the manufacture and commissioning should be documented and drawn upon for the maintenance.

Recommendations

The monitoring of the guideway (where appropriate with the exception of special structures and the route periphery) should be performed continuously (or at short intervals of time), as far as possible on an automated basis, and in a manner that supports operations.
Maintenance measures should be performed from the guideway (special vehicle) as far as possible. The maintenance measures should be planned such that they can be performed within the space defined for them on a project-specific basis.
The time period available for maintenance measures should be defined on a project-specific basis (it should take place in the pause in operations to be defined on a project-specific basis).
The evaluation and assessment of the inspection results should take place within a short period of time. Specially monitored reference objects should be defined at points in the route to be defined on a project-specific basis.
Drawing upon the other findings from operation and maintenance, the monitoring of the reference objects should facilitate a condition analysis for the guideway.
Measures relating to structures (e.g. the renewal of the corrosion protection on steel components after long periods) should be considered separately in the maintenance planning. Assemblies for which a planned replacement is necessary during the required period of use of the route or for which the probability of failure leads to the expectation that replacement will be necessary should be kept in stock in a sufficient number on a project-specific basis.

Requirements relating to personnel

The overriding requirements of the personnel are defined in the design principles for the complete system.
The leader of the agency responsible for monitoring and testing the guideway must be entitled to manage the title “engineer”. The position must be occupied by a person with the necessary technical knowledge and relevant vocational experience of at least five-years.

Servicing

Planning, performance and revision of servicing must take place on the basis of the specifications defined in Section 5.3.3 in /MSB AG-GESAMTSYS/ and in /MSB AG-BTR&IH/.
Specifications regarding the servicing of the assemblies in the maintenance program and in the maintenance instructions should take place on a make- and model-specific basis.
The following principles apply for servicing:

(1) The servicing of the individual assemblies should not obstruct the operation of the system;

(2) It should be possible to perform the servicing within the times defined on a project-specific basis;

(3) It should be possible to perform the servicing within the space to be defined for the maintenance on a project-specific basis;

(4) It should be possible to perform the servicing using the resources (personnel, equipment) and processes defined on a project-specific basis;

(5) The realisability of the servicing tasks should be demonstrated (on a prototype if appropriate) under preconditions similar to those of application.

Inspections

General requirements relating to inspections

Planning, performance and revision of the inspections must take place on the basis of the specifications defined in Section 5.3.3 in /MSB AG-GESAMTSYS/ and in /MSB AG-BTR&IH/.
Inspections can be subdivided into:

(1) Monitoring

(2) Investigations

(3) Expert opinions

(4) Special inspections

Information on the inspection of the assemblies in the maintenance programs and in the maintenance instructions should take place on a make- and model-specific basis. The following principles apply for inspections:

(5) The inspections of the individual assemblies should not obstruct the operation of the system;

(6) It should be possible to perform the inspections within the times defined on a project-specific basis;

(7) It should be possible to perform the inspections within the space to be defined for the maintenance on a project-specific basis;

(8) It should be possible to perform the inspections using the resources (personnel, equipment) and processes defined on a project-specific basis;

(9) The realisability of the inspections should be demonstrated.

This should take place, using a prototype where appropriate, under preconditions similar to those of application.

The inspection intervals should be defined on a model-dependent and project-specific basis in accordance with “Principles and Procedures for the Drawing up of the Maintenance Program”.
If the inspection of the assemblies of the guideway does not take place on the basis of /DIN 1076/ or the current state of the art for wheel/rail technology, demonstration of an equal safety level is necessary.

Monitoring

Monitoring takes place by the annual viewing of the guideway and/or by taking photographs. Furthermore, at short intervals (continuously where appropriate) supplementary procedures (e.g. monitoring of functional level geometry) should be applied.
Monitoring is a part of planned inspections to be performed.
It can be vehicle assisted or special vehicle assisted. Project-specific procedures are also possible.
The monitoring of the guideway should take place on a project-specific basis and in a manner dependent upon the make and model.

Regardless of model-specific peculiarities, particular attention should be paid to the following during monitoring:

(1) Monitoring of the shortwave geometry of the functional levels;

(2) Monitoring of the longwave guideway geometry;

(3) Monitoring the condition of the supports;

(4) Surface changes (e.g. cracks in the concrete, flaking off of corrosion protection);

(5) Monitoring of the guideway equipment;

(6) Monitoring of the defined spaces;

(7) Monitoring of the special structures and the route periphery;

(8) Determination of the effects of external influences (collision at road crossings, winter service, vegetation, earthquakes, vandalism, etc.);

(9) Where appropriate, monitoring of selected reference objects.

The results should be evaluated continuously and within a short period of time in accordance with project-specific specifications, so that any shortcomings/damage jeopardising safety and order can be found without delay.

The necessity of reference objects, and their number and position should be determined on a project-specific basis.

Note: These reference objects are, for example, a few guideway beams in exposed positions, to be specified in co-ordination with the responsible supervisory authorities and their recognised representatives. These should be particularly monitored using measuring technology (e.g. temperature path, carbonisation, coating thickness of the corrosion protection, etc.).

The results of the monitoring of the reference beams are used to evaluate the overall condition of the route and to evaluate the individual findings.

Investigations

The periods for the investigations should be adjusted in line with the peculiarities of the structural shape, the loads and the sensitivity of the assemblies. The periods should be stated on a model-specific basis for all assemblies of the guideway in the project-specific maintenance plan *(inspection plans)*.

The assemblies of the guideway should be regularly closely inspected for obvious shortcomings or damage in the framework of the investigation. This close inspection should initially be performed every year.

This interval can be altered depending upon the project-specific preconditions.

The maximum interval between two investigations is six years.

In the close investigation, particular attention should be paid to shortcomings / damage that are externally visible but cannot be detected by the guideway monitoring systems. The investigation also includes a viewing and evaluation of the monitoring results for the route section that is to be subject to close investigation.

Appraisals

In an appraisal it should be determined whether:

(1) The soundness of the assemblies still complies with the specifications from the planning phase and the status of the preceding appraisal;

(2) There is a danger of the progression of shortcomings and damage within the next six years to an extent that could significantly impair the fitness for use or soundness;

(3) Shortcomings, damage or dimensional deviations from the planned condition exist that necessitate a more detailed investigation.

The appraisal extends to all assemblies of the guideway. Operational influences, which exhibit a not inconsiderable importance for the guideway (e.g. vegetation in the surrounding area, change to the peripheral development in the area near the route) should be taken into account. Appraisals should be performed every six years.

The time between an investigation and an appraisal should be no greater than 3 years.

In the appraisal, all significant shortcomings and damage in the guideway should be assessed and documented. Any impairment to soundness should be established, evaluated and also documented, as should the remaining safety and durability. If necessary, special investigations (e.g. additional geodetic measurements on the guideway) should also be commissioned.

To provide evidence of the appraisal, a detailed report should be drawn up on the scope of the inspection, the depth of the inspection and the inspection results. This report should include a prediction on the further course of the shortcomings and damage found. Furthermore, recommendations should be formulated within it on changes to the maintenance periods and on the maintenance work necessary within the next appraisal interval.

If procedures for the automated monitoring of the guideway are installed and used and / or reference objects are monitored, inspection results can be used as part of the appraisal.

If the appraisal of the assemblies of the guideway does not take place on the basis of /DIN 1076/ or according to the current state of the art in wheel/rail technology, the appraisal should take place by the evaluation of the results of the previous inspections.

The following points should be taken into account in this connection:

(4) Continuous monitoring of the guideway or the assemblies covered by this regulation;

(5) Documentation and evaluation of all inspection results;

(6) Evaluation of the findings of the monitoring of reference beams;

(7) Regular close viewing in the framework of the investigations with the focus upon those assemblies that are not automatically monitored;

(8) Accessibility of guideway documentation.

Special inspections

Special inspections must be performed after special events influencing the condition of the guideway, or if stipulated by the results of structure inspections.

Events that necessitate a special inspection can be:

(1) Findings from monitoring, investigation and appraisal;

(2) Collision of (road) vehicles on the guideway;

(3) Unforeseen mode of operation of a vehicle with significant effect upon the guideway;

(4) Conclusion of measures covering structures or maintenance measures on the guideway, if there is any possibility that the guideway may be damaged due to this work;

(5) Extraordinary environmental influences.

This list is not comprehensive.

In the framework of a special inspection the stability of the assemblies can also be demonstrated by experiment (e.g. by loading experiments). In this connection, the performance of tests should be supported by calculations so that damage to the guideway due to overloading is ruled out. These experiments may only be planned and performed by specially qualified personnel, and require the approval of the responsible supervisory bodies.

Maintenance

Planning, performance and revision of maintenance must take place on the basis of the specifications defined in Section 5.3.3 in /MSB AG-GESAMTSYS/ and in /MSB AG-BTR&IH/.
The following principles apply for maintenance:

(1) The maintenance of the individual assemblies should not obstruct the operation of the system;

(2) It should be possible to perform the maintenance within the times defined on a project-specific basis;

(3) It should be possible to perform the inspections within the space to be defined for the maintenance on a project-specific basis;

(4) It should be possible to perform the inspections using the resources (personnel, equipment) and processes defined on a project-specific basis;

(5) The realisability of the inspections should be demonstrated (where appropriate on a prototype) under boundary conditions approximating those of practical application.

The instructions to be drawn up for the maintenance of the guideway must cover at least the following points:

(1) Required personnel (number and qualifications);

(2) Required equipment and materials;

(3) Required working time;

(4) Technological specifications (e.g. hardening times, etc.);

(5) Predictions regarding environmental influences.

Comprehensive maintenance measures that influence operation should be considered separately and on a project-specific basis as special measures (examples of this are the full replacement of the corrosion protection on steel components or a fundamental concrete refurbishment).

Other measures

Other measures can be operationally determined or become necessary due to maintenance and should be defined on a project-specific basis.
They typically include:

(1) Improvements of/to assemblies;

(2) Comprehensive maintenance measures that influence operation;

(3) Measures for the care and control of vegetation;

(4) Winter service measures.

Similarly, the technical requirements of maintenance as described in this document also apply to the performance of the other measures. Project-specific concepts and programs should be developed in good time before the performance of the measures.

Requirements regarding the sequences of maintenance processes

The following requirements are made of the sequences of maintenance processes:

(1) The specifications in /MSB AG-GESAMTSYS/ and /MSB AG-BTR&IH/ take precedence;

(2) Maintenance processes that are proven, are not time-critical, can be performed in any weather and that require little special knowledge on the part of staff should be given preference;

(3) The condition before first use (time of creation) or after maintenance has taken place (actual condition) must fulfil the specifications according to the plan; this condition should be documented, it then serves as a reference condition for the evaluation of changes that have occurred;

(4) Determination of the actual condition;
The actual condition, which changes over time and should ideally be known at all times, is compared with the reference condition and evaluated with regard to the changes that have taken place; the limits at which measures must be implemented should be defined and set down for the guideway;

(5) For all assemblies a preventative, condition-oriented maintenance should be the goal;

(6) It is possible to deviate from the preventative maintenance for technical, economic or operational reasons;

(7) By additional inspections or inspections carried out at closer intervals an extension of the period of use of assemblies can be achieved;

(8) Severe damage to the guideway, which cannot be rectified by a simple repair should be taken into account in the planning of maintenance;

(9) The required measures (emergency support, replacement of entire beams, etc.) should be conceptually planned in advance to the extent that the maintenance work can be begun within a short period of time after the occurrence of the damage;

(10) Measures on third-party systems should be performed in accordance with the general statutory provisions;

(11) Express reference is made to the Magnetschwebebahnplanungsgesetz (MBPlG) (Magnetic Levitation System Planning Act) and the project-specific crossing agreements to be concluded;

(12) Measures in the immediate vicinity of the route require project-specific handover and release procedures.

Note: the following steps should typically be observed in such cases:

(13) Drawing up of a work order e.g. by the organisational unit charged with the maintenance of the guideway and co-ordination with the train service;

(14) Recorded handover of the work area (e.g. guideway section) from train service to maintenance;

(15) Performance of the measures and recording of the information required for documentation;

(16) Technical release of the work area by the maintenance;

(17) Recorded acceptance of the work area from the maintenance by the train service;

(18) Documentation of the measures performed.

Note: to make work easier the operational departments can be jointly represented in relation to the agency charged with the maintenance of the guideway by a "Co-ordinator for train services / structure testing". The co-ordinator has a duty of reporting / disclosure in relation to the agency charged with the maintenance of the guideway and to the supervisory bodies.

Technical notes on the performance of inspections

Possibilities for monitoring

Normally the monitoring procedures to be used can be broken down as follows:

(1) *Measurements from the vehicle (during train service);*

(2) *Monitoring by measurement from special vehicle (generally during breaks in train service);*

(3) *Stationary monitoring by measuring (generally ongoing);*

(4) *Other procedures.*

In the selection of the monitoring systems those systems that recognise damage or changes that indicate damage as early as possible should be given preference. The data transfer of the results of individual monitoring processes generally does not take place online. The evaluation of the data therefore generally takes place after a time delay; model- and project-specific preconditions should be taken into account in the setting of evaluation periods.
A decision should be made regarding the necessity of online transfer of monitoring information to the district control office on a project-specific basis.

Degree of automation of the inspections

The aim should be the maximum possible automation of the monitoring of the guideway. The degree of automation and the tasks to be performed by the automated inspections should be defined on a project-specific basis.
If the intention is to draw conclusions about the condition of a large number of assemblies from the automated inspection of individual assemblies, the number and exposure of the monitoring sensors should be defined to facilitate a safe prediction.
The functionality of the automated inspection systems should be monitored. The method of recognising the failure of the automated system should be defined.
The measures that will be taken to ensure that the inspection tasks are still performed even after the failure of an individual automated system should be defined on a project-specific basis.
For the assemblies with particular relevance to safety, it may be necessary to provide the possibility of independent checking in an automated inspection for the verification of the measurement or test results.

Inspection of the geometry

The inspection of the guideway geometry covers the inspection of the shortwave and the longwave geometry.
In both cases the monitoring should take place on the basis of the documented reference condition.
The inspection of the shortwave geometry (offset, NGK, track gauge, guideway depth, gap) shall take place according to the state of the art.

Adherence to the specifications defined in /MSB AG-FW GEO/ should be monitored.
Model-specific preconditions (failure recognition, redundancy, error loops) should be taken into account when specifying the inspection technique.

The inspection of the longwave geometry takes place on the basis of a reference measurement and according to the state of the art. Geodetic measurements should be performed and documented during commissioning (see Section 0).
Subsequent geodetic measurements can be used to quantify any changes found or to evaluate the changes.

Visual inspections

Visual inspections can be both close and automated. The specifications for these should be made on a project-specific basis and according to the state of the art.

Inspection by means of stationary measuring devices

Stationary measuring devices are installed at reference objects.
They should correspond with the current state of the art and should be selected by model and in agreement with the responsible supervisory authorities and where appropriate their recognised representatives.
The method of recognising the failure of stationary measuring devices should be determined. If weather data is recorded along the route, the measuring points should be in the immediate proximity of individual reference objects in order to be able to produce direct relationships between weather data and measuring data.

Other inspections

Further inspections that are required from the point of view of maintenance or that cover operational aspects such as clearance monitoring, the accumulation of snow and ice, vegetation control, etc. should be defined on a project-specific basis.
These inspections should correspond with the current state of the art and be selected on a model-specific basis and in co-ordination with the responsible supervisory authorities and where appropriate their recognised representatives.

Fundamental requirements regarding documentation

The specifications in /MSB AG-GESAMTSYS/ and /MSB AG-BTR&IH/ take precedence.
A database of structures should be created on a project-specific basis.
It should either be generated from the system-based directory of equipment or a clear relationship to this document should be created.
The database of structures contains all important data on the guideway (or refers to it) that is necessary for the fulfilment of the monitoring and testing tasks on an object-related basis.
All relevant results of the maintenance must be entered into the database of structures. The database of structures must contain at least the following information:

(1) Representation and brief description of the assemblies or equipment components;

(2) Type and location of the storage of documents or storage of data, from which detailed information about planning, approval, manufacture, previous investigations and measurement results can be drawn;

(3) Conservation and maintenance measures performed;

(4) Significant changes to the guideway equipment or supporting structure. The database should be updated and maintained on a continuous basis. Data from the phases

(5) Planning of structures and approval;

(6) Construction of structures;

(7) Commissioning;

(8) Acceptance of structures;

(9) Ongoing maintenance, repairs and renovation

should be acquired.
The method of preparation and representation of data should be defined on a project-specific basis.
The documentation should make a trend in the changes of conditions recognisable. This requires for example that bearing distances are always related to the same reference temperature.