The Guideway

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ABSTRACT: During the last 25 years, different guideways for Transrapid maglev have been developed, constructed and tested. Approximately 20 different guideway types have been realized, both for the Transrapid test facility and for the Shanghai project. A comparison of the requirements and experience gained with these guideway types is possible on the basis of the guideway types currently in service. The basis for this comparison can be found in the following aspects:

- The interface between the guideway and the vehicle and propulsion system
- The interface to the environment

The requirements for the interface between the guideway and the vehicle and propulsion system comprise, among others, those requirements resulting from the geometry, the tolerances, the stiffness, the damping, the attachment of the longstator equipment and those requirements resulting from maintenance. The guideway girder also has to fulfill environmental criteria such as noise emission levels. In addition, the design of the guideway must be suitable for all weather conditions, in particular during winter. In addition to this it is necessary to create specifications required for bridges, tunnels and other alignment specific structures. This paper summarizes those aspects for the fulfillment of the guideway requirements.

1 SYSTEM INTEGRATION

During the last 25 years, different guideways for the Transrapid maglev have been developed, constructed and tested. Approximately 20 different guideway types have been realized, both for the Transrapid test facility and for the Shanghai project. A comparison of the requirements and experience gained with these guideway types is possible on the basis of the guideway types currently in service.

The basis for this comparison can be found in the following aspects:

- Compliance with the requirements at the interface between guideway, vehicle and propulsion system
- Comparison at the interface to the environment

The interfaces between the guideway, the vehicle and the propulsion system are considered in respect of questions relating to the requirements for the geometry, the tolerances, the stiffness, the damping behavior and the attachment of guideway equipment as well as the maintenance requirements.

The effects on the environment and the effects from the environment influence noise emissions and behavior under different weather conditions, including extreme differences between night and day temperatures and difficult winter conditions with snow and ice.

This not only applies to guideways as such but also to bridges, tunnels and other special structures along the route which are necessary in connection with the route alignment.

The comparison is based on experience gained from integration of the guideway in the system, consisting on

- definition of technical system requirements
Further Development
Operation / Maintenance
Monitoring of Planning/Realization
Definition of System Requirements
System Integration Guideway

- checking of design and construction of guideways
- checking of operations and maintenance up to
- further development as a continuous process.

The main goals of this process are:
- to evaluate the experience gained from the Transrapid test facility and the Shanghai project
- to integrate detectable requirements arising from planned projects
- to take into account new regulations and incorporate them in the requirements
- to evaluate aspects of environmental protection such as noise and vibrations from the system's technical point
- to specify technical requirements for vehicle movement in tunnels
- to summarize the requirements of the subsystems, i.e. vehicle, propulsion system and operations control system, for the guideway.

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In contrast to this, the systems engineer's job is to elaborate the requirements regarding availability, reliability and maintainability. The term RAMS which is used here and is commonly used in the technical literature stands for R = Reliability, A = Availability, M = Maintainability, S = Safety.

In addition, the engineer's task is to work with the partners responsible for the other subsystems to come to an agreement in respect of the interfaces to the vehicle, the propulsion system and the operations control system while taking into account the requirements for the system as a whole, the aim being to achieve a technically and economically optimum result for the whole system. Finally, the technical system requirements regarding noise emission and vibrations have to be taken into consideration, whereby, in this respect, the task focuses on the interaction of vehicle, propulsion system and guideway.

The final customer, namely the passenger who will eventually travel on the Transrapid, must also be remembered because he not only expects to be transported quickly by the high-speed Transrapid maglev but also wants a high level of traveling comfort in such a prestige vehicle as the Transrapid. During route alignment planning, production and assembly, this level of passenger comfort will be determined by the respective requirements regarding the geometry and spatial characteristics of the function planes. In the framework of the further development program required by the German Federal Ministry for Transport, Construction and Urban Development, these aspects will be taken into account by the specialist guideway committee when it draws up further guideway requirements. This specialist committee ensures that the aspects of further development are taken into account without the economic aspect being ignored. In addition, the aim of continuing to specify requirements regarding guideway design and construction is to do so neutrally as to the construction materials used and not to simply hand over a solution to the developer or technical designer but to formulate the requirements in such a way that they are clear but do not fail to do justice to the multi-faceted nature of the technical design.
Figure 4: Guideway Requirements

The principles of guideway design and construction which are thus added to continually are intended to be generally applicable as technical rules of practice and therefore be available for the realization of future projects independently of the type of construction.

Figure 5: Concrete Guideway, Generation C 1, TVE, 1981-83

Operations on the 31.5 km long test track enabled comprehensive testing of the guideway up to a maximum speed of 450 km/h. Extensive measurements were carried out on concrete and steel guideway girders with regard to the following criteria, among others:

- Temperature behavior of the guideway girder
- Vibrational behavior of the guideway/propulsion system
- Electromagnetic compatibility of the vehicle/guideway
- Transfer of force to the lateral guidance rail and then to the guideway girders
- Transfer of force to the stator packs and then to the guideway girders
- Noise emission of vehicle/guideway

Figure 6: Steel Guideway, Generation S 1, TVE, 1981-83

Although the outstanding feature of the Transrapid system is its non-contact, wear-free operation, the fact must not be ignored that vehicle and guideway interact in such a way that forces are transferred from the vehicle to the guideway. Different effects on the guideway therefore have to be taken into consideration, depending on the particular viewpoint.

Part 1: Overall Requirements
Part 2: Design Bases
Part 3: Geometry
Part 4: Alignment
Part 5: Surveying
Part 6: Maintenance
- deformation arising from vehicle load.

After extensive measurements carried out on guideways at the Transrapid test facility, it was possible to carry out design calculations for all the assemblies of a guideway on the basis of the finite element method (FEM). These calculations were not only used to improve individual components but also as a basis for further tests in the test bay carried out in order to verify the fatigue strength of the technical design.

The theoretical verifications and verifications by testing are a precondition for the assurance of future type certification by the Federal Railway Authority.

2.3 Geometry

A cross-sectional consideration of the guideway shows that the main supporting structure is located symmetrically under the vehicle which "wraps around" the guideway. Stator cores, lateral guidance rail and gliding surfaces are fastened to the cantilever arm. The resulting height stipulation for the guideway takes into account the stiffness requirement for the guideway whereas the stipulation for the guideway width and so-called guideway depth, i.e. the distance between the bottom of the stator pack and the top of the gliding surface, takes into account the defined interface to the vehicle.

In accordance with the technical stipulations for the system, the latter is designed for a maximum speed of 500 km/h. This means that the support magnets and guidance magnets of the vehicle levitate contact-free along the function planes at a speed of up to 138 m/s. Theoretical investigations and practical experience show what deviations (tolerances) have to be taken into account for these speeds in order to ensure that the support magnets and guidance magnets remain contact-free during vehicle movement along the function planes of the guideway.

Would be the best precondition for high passenger comfort and little dynamic vibration at the planned speed. In practice, however, compromises have to be made in connection with the properties of the materials used and the applied manufacturing and equipping processes. Great progress has been made here through the automation of manufacturing processes

- in the manufacture of the fastening points for the stator packs and the lateral guidance rail
- in the manufacture of the gliding surface.

2.4 Route alignment

The main task of route alignment is to stipulate the geometry of the guideway's function planes in such a way that the passenger enjoys maximum travel comfort when a vehicle travels on the guideway. This defines the limits for acceleration in the 3 spatial directions (x, y and z directions). Apart from acceleration, however, a consideration of changes in acceleration (jerk) is also an important aspect of comfort. Various mathematical formulas for the transition curves and lengths were therefore discussed with the following designs as a result:

- sinuousoidal transition curve in the horizontal plane and
- clothoidal transition curve in the vertical plane.

An exception to this is the track changing equipment, where, on the basis of beam theory, the transition curve of the turnout position is also in the form of a clothoid in the horizontal plane.

From the point of view of the traveler and also of the electromagnetic supporting and guidance systems, an ideal execution of the function planes belonging to the longstator and lateral guidance rail

Figure 7: Guideway Switch, Steel, elevated, TVE, 1981 - 83

When route alignment, including determination of the spatial curve, is carried out, these or other aspects are taken into account, as well as the system's characteristics

Figure 8: Concrete Guideway, Generation C 2, TVE, 1984 - 86
- gradient climbing capability up to 10 % and
- superelevation in curves up to 12°.

2.5 Maintenance

The guideway and its functional components are designed for a useful life of 80 years. In the course of this useful life, 130 passing vehicle movements per day are to be assumed, for example, or

- 47,450 passing vehicle movements per year, or
- approx. 3.8 million passing vehicle movements in 80 years.

Any operational restrictions for purposes of guideway maintenance are to be reduced to a minimum. This means that, even when the technical features of the guideway are being designed, not only stability, operational strength and suitability for practical use play an important role but also the requirements in respect of maintainability. The following are some aspects which have to be taken into account during technical design:

- Closed hollow boxes enable the manufacture, e.g. of steel guideway girders without corrosion protection on the inside.
The insides of the girder do not have to be accessible.
- The insides of the girder do not have to be drained.
- The surface of the girder with its large, even surfaces enables automatic inspection of structures and easy low-cost maintenance of anti-corrosion coatings on steel components.
- Even surfaces are the best precondition for smooth operations under winter weather conditions because snow drifts are avoided during regular operations and, after nightly breaks in service, the guideway surface can be easily and effectively cleared in a short time with special clearing vehicles.
- The avoidance of offsets and gaps at joints negates the necessity for scheduled repairs.
- Fault-tolerant and fault-revealing fastening of equipment parts enables defects to be detected during operations with a guideway measuring system fitted to the vehicle.
- Detected deviations do not lead to any operational restrictions but can be rectified according to schedule within a time window of 4 hours during nightly breaks in service.

These are the preconditions which have to be met in order to comply with the requirements for a modern high-speed transport system.

3 REQUIREMENTS ARISING FROM THE ENVIRONMENT AND TO THE BENEFIT OF THE ENVIRONMENT

The development of a completely new railway system only makes sense if it is advantageous for the environment. The non-contact magnetic levitation technology makes the Transrapid especially environment-friendly.

3.1 Space requirement

Compared to all other land-bound transport systems, the Transrapid requires the least amount of space and land. For an elevated double-track guideway, approx. 2 m² of land is needed for each meter of guideway and, for a ground-level double-track guideway, 12 m² is needed for each meter of guideway. A road alongside the guideway is not necessary after completion, either for safety reasons or for maintenance purposes.

Figure 10: Land Consumption (m²/m)

Compared to roads or conventional railway lines, especially the elevated guideway does not affect wildlife movement. Even the ground-level guideway allows small animals to pass underneath due to the
clearance planned under the guideway support surface.

3.2 Noise level

Thanks to the maglev system’s non-contact technology, there are neither rolling nor propulsion noises when it travels on the guideway in contrast to other land-bound means of transportation. At speeds up to 200 km/h, the noise level compared to other noises from the surroundings can hardly be heard. Up to this speed, therefore, there is no reason why it cannot run through cities and conurbations without further and additional noise insulation measures. At 250 km/h, the pass-by noise level is 71 dB(A) and, from 250 km/h upwards, the aerodynamic noises (wind noise) begin to dominate the noise level. The result is that, at a speed of 300 km/h, the system is no louder than a light rail vehicle and, at 400 km/h, the noise level can be compared to a conventional train traveling at around 300 km/h.

3.3 Vibrations

Whatever the kind of transport system, a passing vehicle always creates ground vibrations due to dynamic loading of the track. Depending on the speed, load transfer, load dispersion and the nature of the ground, these vibrations are transmitted through the ground to different degrees and may thus be felt as shocks in neighboring buildings.

For especially sensitive areas, technical solutions are currently being investigated which minimize the dynamic loads that are transferred from the vehicle to the guideway and then to the bearings in the supports and foundations. Spring elements between the guideway girder and bearings as well as mass-spring systems can be used.

Figure 12: Vibrations Measurements (Measuring Points)

3.4 Winter

Guided transportation systems are largely independent of weather conditions. This especially applies to the Transrapid maglev. The non-contact supporting, guidance and propulsion technology ensures full operational capability even in extreme weather.

Hardly any snow remains lying on the guideway even after a heavy snowfall because it is blown away by the continuous vehicle movements. Because the space between the underside of the vehicle and the upper surface of the guideway is sufficiently large, a snow height of up to 10 cm is permissible on the surface of the guideway. In the rare event that a higher snow cover forms there, clearing vehicles are deployed. This is also necessary if higher snow drifts have formed during the nightly break in services. The guideway is then cleared by clearing vehicles before the first trip with the maglev vehicle. The moving parts of the switch throwing mechanism which are exposed to the weather are heated.

Apart from snowfall, the formation of ice on the lateral guidance rail has to be taken into account. However, as in the case of other systems, preventive clearing is envisaged in the framework of operational planning so that conditions which favor ice formation are usually prevented from occurring in most cases. Under exceptionally rare extreme weather conditions, the use of thawing agents is envisaged.
3.5 Summer

The geometry of the guideway's function planes, i.e. mainly the underside of the stator cores and the outside of the lateral guidance rail, determines the quality of how the supporting and guidance system will behave later and is an indicator of the traveler's "hovering" comfort. During operational experience gained with different guideway types at the Transrapid test facility, the following influencing variables were identified:

- Deformation as a consequence of temperature differences between the top chord of the girder and the lower chord of the girder
- Deformation as a consequence of temperature differences between the right-hand and left-hand sides of the girder.

In order to enable non-contact support and guidance of the vehicle at speeds up to approximately 140 m/s, the subsequent behavior of the support magnets and guidance magnets must be such that a quasi "hard" connection is established. The subsequent behavior of the magnets can thus be compared with the subsequent behavior of a wheel on a rail. Irregularities in the underside of the stator and the outer surfaces of the lateral guidance rail can be transferred as disturbances into the interior of the vehicle via primary springs and secondary springs.

The guideway girders tested in practical operations which, as a result of their technical design, displayed different levels of stiffness in the z and y direction at the Transrapid test facility show that a stiffness of L/4000 in the z direction is the optimum in design terms and in terms of economic efficiency. Given the standard guideway length of 24,768 m, the sagging under traffic load is therefore approximately 6 mm.

Apart from stiffness, however, deformation when there are temperature differences between the upper chord of the girder and the lower chord of the girder is an important criterion. The small cross-section of the guideway girder reacts less favorably to corresponding weather conditions in contrast to the experience gained in the area of road or railway bridge construction. In series of measurements carried out over several years, it was possible to verify that temperature differences of up to 25 °C between the upper chord of the girder and the lower chord of the girder have to be taken into consideration. The different weather conditions can cause the girder to become deformed upwards, downwards or towards the side. In order to limit this temperature-related deformation, different measures can be taken such as

- a two-span type of girder
- Insulation of the surfaces
- Bright reflecting paint coatings
- Increase in the girder's height
- Coupling of the girders

The best method is to be decided on specifically for each project according to which is most economically efficient.

4 STATE OF DEVELOPMENT

When the Transrapid test facility was built in Em- sland from 1982 to 1987, a total of 4 different guideway types were realized which have very different design characteristics in respect of both the guideway girder itself and the guideway equipment. The operational experience gained with these guideways led to further development in the context of system integration. This, in turn, led to additions being made to the requirements from 1993 onwards. Since 1995, there has been a series of newly developed guideways. Their development, manufacture
and installation at the Transrapid test facility laid the foundations for future considerations.

**Figure 15:** Steel Guideway, Generation S 4, elevated two-span 2 x 24.8 m, TVE, 1995

In accordance with the range of types finally decided on, the following guideways have been realized:

- 1995: prototype guideway as an elevated steel guideway, type 1, two-span type of girder
- 1997: prototype guideway as an elevated steel guideway, type 2, two-span type of girder, and a ground-level steel guideway (plate), two-span girder.

At the same time as this, an elevated concrete guideway, heat-insulated, type 1, and a ground-level concrete guideway (plate), two-span girder, was installed at the Transrapid test facility.

**Figure 16:** Steel Guideway, Generation S 4, Type II two-span 2 x 12.4 m, TVE, 1997

In 1999, there followed an elevated hybrid guideway, type 1, two-span girder.

For these guideways, with the exception of the elevated heat-insulated concrete guideway, an application was made to the Federal Railway Authority for type certification. An assurance of future type certification was issued by the Federal Railway Authority for these guideways after they were installed at the Transrapid test facility, commissioned, examined by measurement and subjected to practical operational testing.

**Figure 17:** Steel Guideway, Generation S 4, Type III two-span 2 x 3.1 m, TVE, 1995

**Figure 18:** Concrete Guideway, Generation C 4, Type I single-span 24.8 m, TVE, 1995

**Figure 19:** Concrete Guideway, Generation C 4, Type III, at grade 2 x 3.1 m, TVE, 1998

On the basis of this development, the guideway for the Transrapid in the Shanghai project was realized as a double-track guideway with a length of 30 km in 2001 and 2002. The route was then opened and approved by the Chinese authorities. A special feature of the guideway in Shanghai is its wider base which was implemented on the basis of experience gained with the prototype guideway installed and tested in Emsland.

**Figure 20:** Hybrid Guideway, Generation H 1, Type I as two-span girder 2 x 31 m, TVE, 1999

The outstanding operational characteristics of this guideway, however, are accompanied by a disadvantage. Due to the wider base, the noise emission compared to the noise emissions measured at the guideway beams in the Transrapid test facility is approximately 5 db (A) higher.
At the moment, operational testing of further guideway types is pending:

The guideway made by the company Bögl, put into operation in the southern loop of the test facility in summer 2005

Qualified guideway types which meet the requirements specified in the principles of guideway design and construction are thus available for further applications in diverse concrete designs and steel designs. Perfected, qualified and tested products are thus waiting to be used in Transrapid applications.

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