Interaction Vehicle / Guideway
Guideway Design Aspects for the Munich Airport Link
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Abstract

The Guideway System Engineering for the Transrapid Project "Munich Airport Link" has begun. Transrapid International (TRI), together with Siemens and ThyssenKrupp, received the order in September 2003 to perform the complete system engineering for this project by August 2004. The system engineering of the guideway and the creation and delivery of all the documents necessary for the guideway design and calculation in accordance with German laws and standards are included in this contract. This paper will explain the major results.

1 Introduction

The Superspeed Maglev System Transrapid has been developed for deployment in passenger and cargo transportation. Speeds of between 200kph and 500kph are feasible. The contact free levitation and propulsion enables attractive service and flexible application which are both economically and environmentally sound. Applications ranging from regional connectors and airport connectors to high speed long distance routes make the Transrapid the most attractive development in the transportation arena.

Based on the Feasibility Study for potential German projects, which was completed in January 2003 on the initiative of the German Federal Government, the overall planning as well as the system engineering of the German Transrapid project "Munich Airport Link" began in September 2003.

Transrapid International together with Siemens and ThyssenKrupp have received an order from the project authority "Bayerischer Magnetbahnvorbereitungsgesellschaft" (BMG) to perform the system engineering for the project.

Part of this is the definition of the guideway design for the Munich Airport Link.

Figure 1: TR07 exhibit on a Type II hybrid guideway in the Munich Airport

2 General Requirements of the Guideway of the Munich Airport Link

2.1 Arrangement of the Functional Components

In contrast to roads and railways, the guideway cross-section of the Transrapid technology includes both the ferromagnetic lateral guidance rails for the electromagnetic guidance and the functional components of the electrical propulsion as so-called stator packs. The stator packs, at the interface with the vehicle, simultaneously fulfill the following functions:

- Transfer of vehicle weight to the guideway and
- Conduction of the propulsion and braking forces.

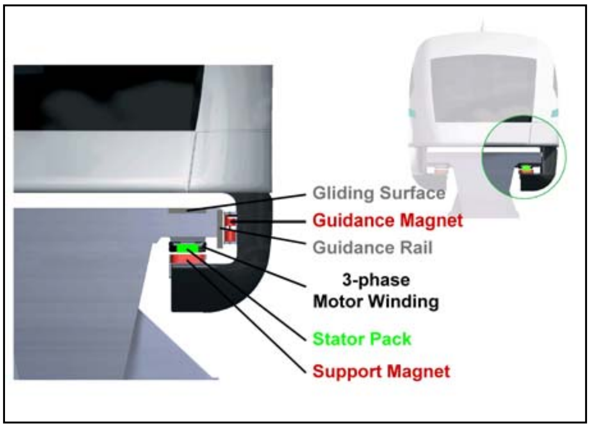

Figure 2: Guideway cross-section with long stator

The guidance forces are transferred via the lateral guidance rails. The slide plane enables the temporary setting down of a vehicle skid and the support magnet hinge point to which it is connected. Furthermore, the attachment locations for components of the vehicle's on-board power supply and location flags, which are used to locate the vehicles, also have to be taken into consideration when designing the guideway beam cross-section. Furthermore, the following requirements, among others, also pertain to the Transrapid guideway and its interaction with the vehicle, the propulsion and operation control system, as well as the environment:

- Operational life span 80 years,
- Economic efficiency,
- Minimization of the already low vehicle/guideway noise emissions,
- Minimization of ecological impact,
- Fulfillment of the interface between the vehicle, propulsion, and operation control systems
- Stability and
- Easy maintenance.

Compliance with the vehicle interface has been achieved under consideration of the operator's requirements for the Munich Airport Link. The vehicle design not only considers seating capacity, but also standing capacity. In this way, the maximum possible capacity utilization of the vehicle can be achieved. In comparison with previous planning, this requires an increase in the carrying capacity, which must be reflected in the capacity of the guideway. By contrast with previous planning, the live load of the guideway has been increased from ca. 25kN/m to ca. 30kN/m.

2.2 Environmental Aspects

The aim of the application between Munich Central Station and Munich Airport is to plan reliable, highly available operations on this route, which are impervious to weather conditions. In order to assure that adverse weather conditions cannot influence operations, the general weather conditions in this region of Bavaria have to be taken into account during the design of the guideway beams, the alignment and the cross section. In addition, a concept for operations in winter must be created. This Winter Concept is a prerequisite for operations, ensuring that the guideway can be kept clear under all conditions due to the combination of reliable weather prognoses for the Munich metropolitan area and practical measures for removal of snow and ice. Additionally, increasing the gradient of the at-grade guideway to ca. 30cm achieves a space below the clearance envelope for snow accumulation. A combination of these measures enables trouble-free operations despite wintery conditions.

Figure 3: TR 08 as 3-section vehicle on the TVE

2.3 Economic Aspects

During the development and construction phases, the mutual dependencies in the requirements of the following aspects must be optimized:

- Alignment
- Production options
- Transportation and montage expenditure.

The same level of consideration must be given to the often repeated question of the accuracy with which the guideway and its functional levels have to be produced. Furthermore, this means that the operating costs which result from the maintenance of the following components must also be kept under consideration:

- Guideway and its functional components
- Substructure
- Switches
- Other structural infrastructure

In economic terms, this means that the sum of investment costs and maintenance costs must be constantly optimized.

Currently this is achieved using guideway beams and switches, which were developed, produced and tested (either at the Transrapid Test Facility, Lathen (TVE) or in the first application project in Shanghai) between 1995 and 2000. As a result of this chronology, the following standard guideway beams are under consideration for the Munich Airport Link:

- Type I, elevated guideway beam with span width of 25 m (82 ft.)
- Type II, elevated guideway beam with a span width of 12.4 m (40.7 ft.) and
- Type III, at-grade guideway beam with a span width of 3.1 m (10 ft.).

These guideway beam types have been qualified as hybrid guideway beams, concrete guideway beams and steel guideway beams.

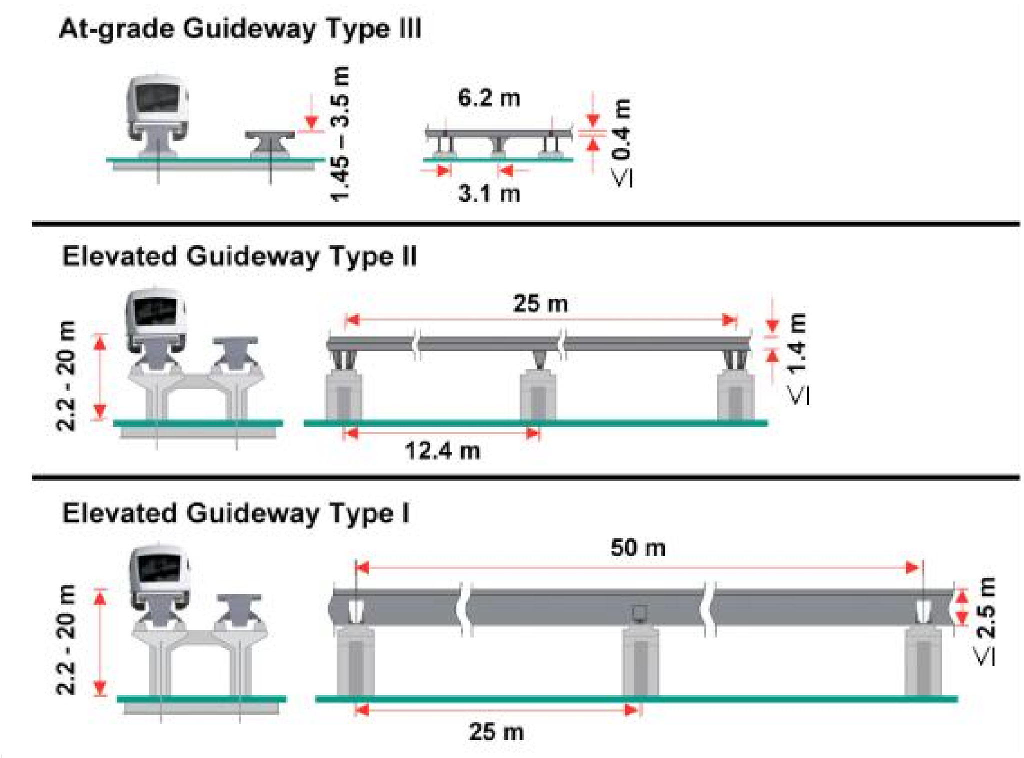

Figure 4: Guideway beams Type I, II, III

3 Requirements

3.1 Alignment

The most important task or essential aim when designing the alignment is to specify the geometry of the guideway's functional planes so that the passenger traveling in the vehicle on the guideway experiences optimum comfort during the journey. The geometry defines the limit values for accelerations in the three spatial directions (X, Y, and Z direction). However, apart from the acceleration, the consideration of the change in acceleration (jerk) is also an important aspect for comfort. Therefore, various mathematical formulae were discussed for the transition curves and lengths, with the result,

- the horizontal transition curves are designed as sinusoidal curves and
- the vertical transition curves are designed as clothoids.

An exception are the track switching devices which, on the basis of beam theory, are also designed using clothoids for the horizontal transition curves in the turn-out position. The alignment is designed and the space curve established (Table 1) taking into consideration the aspects given above as well as the system characteristics, e.g.

- climbing capability up to 10% and
- cant (superelevation) in curves up to 12%.

The space curve data are used in the next design phase as the design criteria for

- specifying the substructures,
- height of the columns,
- geometry of each individual beam,
- location of the track switching devices and for the
- precise location of the functional components on the beam.

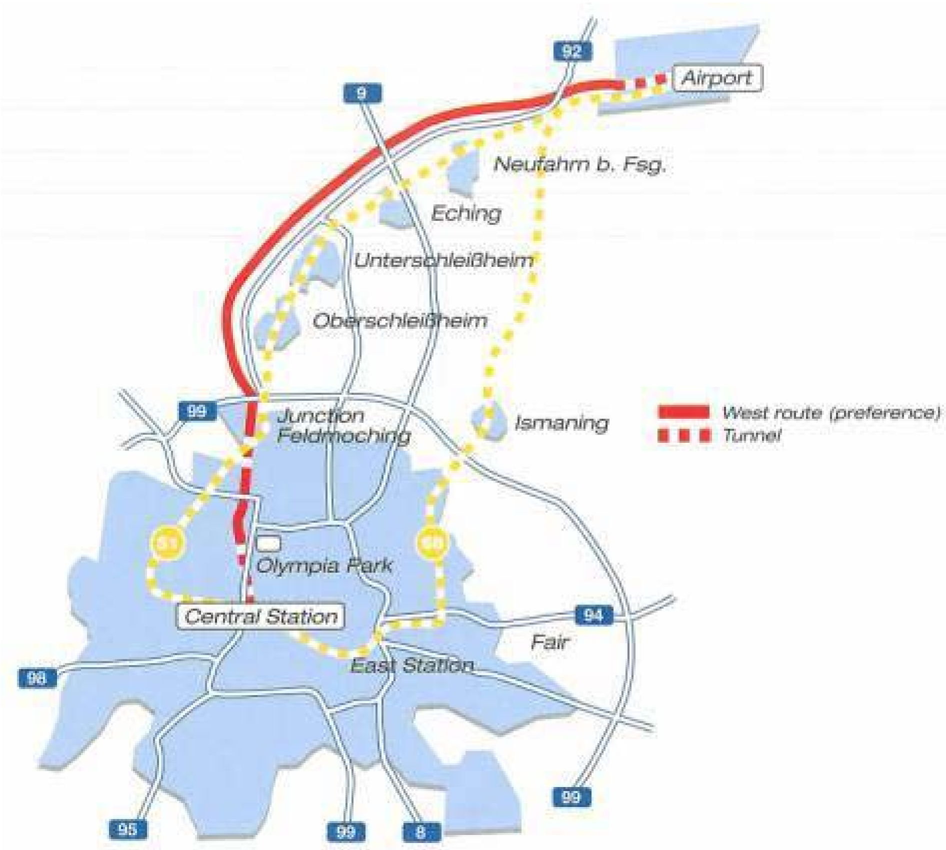

Figure 5: Link between Munich Central Railway Station and Munich airport

3.2 Design

The guideway design requirements take into account all the regulations to be applied as well as the knowledge and experience gained on the TVE. The most important criteria to be taken into consideration are:

- Stability,
- Fatigue resistance,
- Correctness for use,
- Economic efficiency,
- Transport and installation and
- Maintainability.

The guideway and its functional components are designed for an 80-year service life.
The example of the steel guideway beam cross-section can be used to discuss the following characteristics:

- The closed web box enables construction without internal corrosion protection. The inside of the beam does not have to be accessible.
- The beam does not have any internal drainage.
- The surfaces of the beams with large, flat surfaces enable automatic structural inspection and simple, inexpensive maintenance of the corrosion protection.
- Equally, these flat surfaces provide the best prerequisites for smooth operational procedures in winter conditions. This is because snow is prevented from accumulating during regular operations and after night time operational breaks, the guideway deck can be easily, effectively and quickly cleared using special clearance vehicles.
- The cantilever section above the long stator components has durable corrosion protection.
- There are no offsets and no joints requiring scheduled maintenance.

These are the prerequisites in order to fulfill the requirements for a modern high-speed transportation system, whereby during the design, consideration is not only given to the maintenance aspect but equally to other aspects such as

- Winter operation,
- Noise emissions and
- Investment costs.

In general, these aspects are to be considered independent of the materials used.

A further example is the stator pack, which is part of the linear, synchronous long stator propulsion. Particular attention was paid to the design of the fastening used to attach the stator packs to the guideway beam. Due to the introduction of vertical, dynamic tensile forces, the solution designed for the attachment ensures that the forces acting on the stator pack are transferred. In addition, the solution enables redundant force transfer in the highly improbable case of failure of the fastening. In this special case, the stator pack drops by up to 2 mm (0.08 in.) and the measurement system installed in the vehicle enables automatic fault recognition with automatic fault identification.

Another design aspect is due to possible subsoil settlement, which would, through movements of the substructures, eventually result in deviations at the functional planes of the guideway. To compensate for such unwanted effects the bearings of the guideway beams are vertically and horizontally adjustable

Lateral acceleration a_y	**< 1.5 m/s²**	**< 4.7 ft/m²**
Vertical acceleration a_z		
– Crest	**≤ 0.6 m/s²**	**≤ 2 ft/m²**
– Sag	**≤ 1.2 m/s²**	**≤ 3.9 ft/m²**
Longitudinal acceleration a_x	**≤ 1.5 m/s²**	**≤ 4.7 ft/m²**
Jerk $\dot{a}_y$, $\dot{a}_z$, $\dot{a}_x$		
Lateral, vertical, longitudinal	**≤ 0.5 m/s²**	**≤ 1.6 ft/m²**
Omni-directional jerk		
– Standard guideway	**≤ 1.0 m/s²**	**≤ 3.3 ft/m²**
– Singular guideway sections (switches)	**≤ 2.0 m/s²**	**≤ 6.6 ft/m²**
Guideway cant α	**≤ 12 °**	
Guideway twist α'	**≤ 0.1 °/m**	
Guideway slope β	**≤ 10 %**	
Horizontal radii with av = 1.5 m/s², α= 12 °		
Minimum	350 m	1 148ft
200 km/h	855 m	2 805ft
300 km/h	1 920 m	6 299ft
400 km/h	3 415 m	11 204ft
550 km/h	6 455 m	21 178ft
Vertical radii with a_z = 0.6/1.2 m/s²	**Crest**	**Sag**
Minimum	530m/1739ft	350m/1 148ft
200 km/h	5 145m/17 766ft	855m/2 805ft
300 km/h	11 575m/37 976ft	1 920m/6 299ft
400 km/h	20 580m/67 520ft	3 415m/11204ft
550 km/h	38 905m/127 641ft	6 455m/21 178ft

Table 1: Alignment parameters

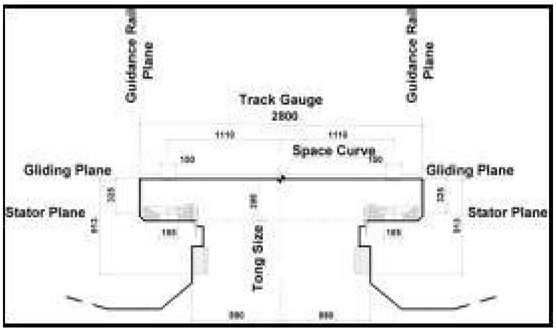

Figure 6: Technical cross-section, dimensioned and plate guideway Type III, TVE

Figure 7: Plate guideway Type III, TVE

3.3 Dimensioning

The Transrapid system's outstanding property is its non-contact, no wear operation. Nevertheless, the dynamic forces transferred from the vehicle into the guideway due to the interaction between the vehicle and guideway may not be ignored. Depending on the way the situation is viewed, various other effects on the guideway must be considered like

- global dynamics from the vehicle passing,
- local dynamics from the interaction between the support magnet and the stator or between the guidance magnet and lateral guidance rail,
- natural harmonics of components and
- deformations from traffic loads.

Dimensioning calculations were carried out for all guideway beams on the basis of the finite element method (FEM). These were not only used to optimize individual components but also as the data for further test bench trials, in order to verify the durability of the design. To date, this has been carried for all the guideway beams tested after 1995, especially for the cantilever area of the beam, on which the functional components stator pack, lateral guidance rails, and steel slide plane are fixed.
These theoretical and test verifications are the prerequisite for the granting of the assurance of Type Approval by the Federal Railway Administration (EBA).

3.4 Geometry

According to the technical system specifications, the Munich System is designed for a maximum commercial speed of 350 km/h (218 mph). This means that the support magnets and the guidance magnets of the vehicle levitate along the functional planes, without contact, with a speed of up to 100 m/s (328 ft/sec). Theoretical investigations and practical experience show which deviations (tolerances) have to be taken into consideration at these speeds in order to ensure the support and guidance magnets are without contact along the functional planes of the guideway. As a result, the following requirements are to be taken into account:

- Deflection under traffic load, approx. 6 mm per 25 m (0.24 in. per 82 ft.) (L/4000)
- Track gauge 2 800 mm ± 2 mm (9.2 ft ± 0.08 in.)
- Clamping dimension 398 + 3/-5 mm (15.7 +0.12 / -0.20 in.)
- Joint offset in Z-direction between individual stator packs ≤ 0.4 mm (0.02 in.).

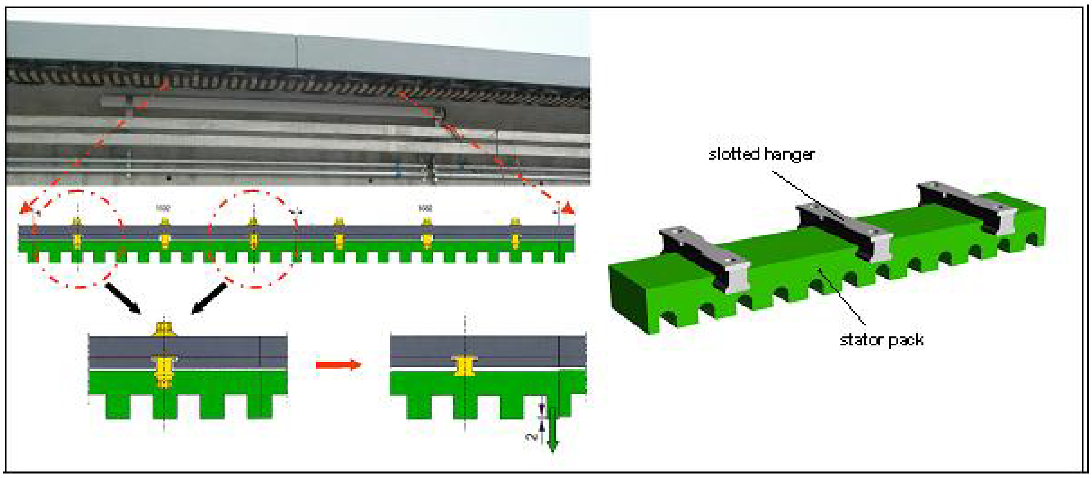

Figure 8: Redundant stator pack fastening and Stator pack

From the view of the passenger, as well the electromagnetic support and guidance technology, the straight and level course of the functional planes of the long stator and the lateral guidance rails represent the ideal preconditions for traveling with high ride comfort and low dynamic forces at he planned speeds. In practice, compromises have to be taken into consideration, which are associated with the properties of the materials used, e.g. the waviness of the steel plate for the 30 mm (1.2 in.) thick lateral guidance rail and the fabrication and machining process used.

Taking into consideration the alignment data, it is possible and economical to attach the equipment so that, compared with the space curve, the long wave tolerance is less than 1 mm (0.04 in.) and the short wave deviation ≤ 0.4 mm (0.02 in.). At this point, reference is made to a system advantage, in that the support and guidance system is capable of levitating across expansion gaps of up to 180 mm (7.1 in.) in the area of the functional planes e.g. at guideway switches or bridges, without irregularities.

3.5 Production

Compared to conventional bridge construction, the production of guideway beams for new Transrapid routes requires a change in thinking. Similar to railway track construction and primarily for economic reasons the production process has to be mechanized and automated to a large extent. From a system engineering point of view, the prerequisites for this were created by reducing the number of guideway beam types to three, independent of the construction materials used. This modular system (Figure 9) includes

- Type I, elevated guideway beam with span width of 25 m (82 ft.)
- Type II, elevated guideway beam with a span width of 12.4 m (39 ft.) and
- Type III, at-grade guideway beam with a span width of 3.1 m (10 ft.).

Figure 9: Girder production Shanghai

This modular system is taken into consideration in the planning and design, independent of the construction material used.
In route realization, the advantage of this is being able to fall back on previously tested beam types, produced on the basis of data gained from the alignment, on numerically controlled machines in mechanized and automated production sequences, and with consistently high quality.
In contrast to the fabrication and machining of the standardized guideway beams and the attachment of the equipment, the substructures are designed and built according to the local conditions. The local situation is taken into consideration in the alignment design and leads to individual substructure solutions

- based on the level of the gradient,
- due to special local circumstances along the route,
- taking into consideration overpasses and underpasses over/under other transportation routes, as well as
- due to changing ground conditions.

4 Experiences

The requirements which now form the basis for the Munich Airport Link have been based on many years of development, construction, production, commissioning and verification. A significant volume of dimensioning results could be generated at the TVE. The most interesting of these results came from tests with the Transrapid 08 on guideway structures of the latest design. The most recent dimensioning results come from the Shanghai Project. Following the commissioning of the double-track guideway it was possible to carry out the first ever dimensioning of vehicle pass-by at speeds of up to 500kph (311mph).

4.1 Noise Emissions

A key, characteristic feature of the development of noise could be identified using targeted Ray-dimensioning. The source of noise, in so far as it is not aerodynamic noise, is located in the support and guidance system i.e. from the perspective of the guideway, in the area of the Stator pack. This explains the further noise dispersion as well as the noise level registered at the measurement point. The key feature of noise dispersion results from the cross section design of the guideway beam, which yields the direction of the maximum noise level. The trapeze shaped cross-section of the guideway beam proved the most suitable in this case. Depending on the beam type, dimensioning at the TVE of a vehicle pass-by at 350kph (218mph) resulted in values of 89 dB(A).

The directional characteristic of noise at at-grade guideways is similar to that of elevated guideways. The favorable behavior of an at-grade concrete guideway is used here as an example. In this case, the surface of the surroundings was covered with grass. The result for the vehicle pass-by at 350kph on an at-grade guideway type was even approx. 2 dB lower than at the elevated concrete guideway.

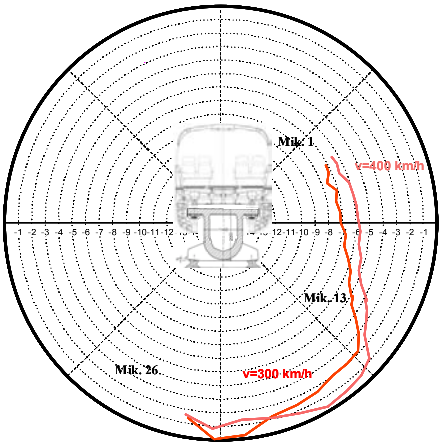

Figure 10: Radiation characteristic of the multi-microphone arrangement

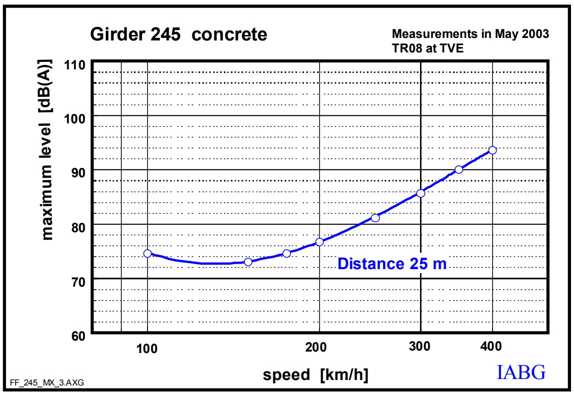

Figure 11: Maximum level for a distance 25 m

These favorable values result in a reduction of the passive noise emission protection measures for the Munich Airport Link to just 3 % of the route.

4.2 Interaction Vehicle/Guideway

Dimensioning has been carried out both at the TVE and on the Line in Shanghai in order to determine the dynamic behavior of the guideway beam and the vehicle levitating above it. During this dimensioning the dynamic coefficients were established both for the entire guideway beam and for local components. The dynamic behavior of the guideway beam, for example with a span width of ca. 24m (79 ft.), can be calculated with a coefficient of $\varphi_z \leq 1.2$ for the entire speed range. The local vibration coefficient, which for example must be considered at the attachment of the stator pack to the guideway, is $\varphi_{z\ local} \leq 1.5$.

4.3 Vehicle Pass-By

The first ever opportunity to dimension the pass-by of two vehicles came with the Shanghai Project. It was proved using dimensioning that the pressure changes defined on the basis of water canal studies and theoretical models resulted in the correct design of the section superstructure.

Figure 12: Shanghai Maglev Transrapid Vehicle Pass-by

4.4 Ride Comfort

Extensive dimensioning was carried out in the context of the commissioning of the Shanghai route in order to establish ride comfort values. The accelerations measured in the vehicle resulted in a value of less then 0.15 m/s^2 (0.5 ft/s^2) at a velocity of 350kph.

Additionally a series of tests was carried out at the TVE in order to establish the influence of switch passing (both bent and in straight ahead position) on passengers standing in the vehicle. As a result of the questioning of the test persons it has been established that the ride comfort of the Transrapid while passing switches is very good. The result of the measurements was the redefinition of maximum lateral jerks on bending switches. The permissible lateral jerk for passing single low speed switches in the bent position was restricted to 1.0 m/s^3. In case of a crossover connection the two individual jerks were limited to 0.5 m/sec^3 each.

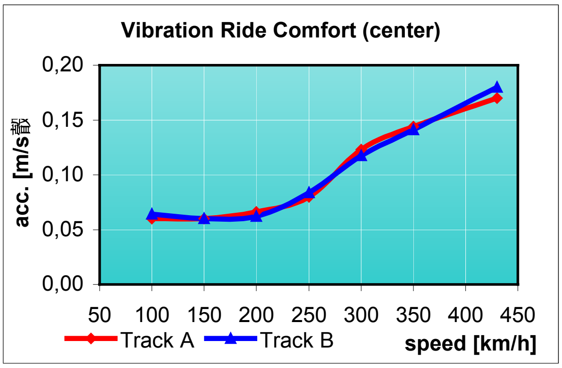

Figure 13: Ride comfort on Track A and B

5 Outlook

The design of the guideway for the Munich Airport Link is based on extensive, long-term experience in the development, construction, production and operation of guideways of varying types. The fulfillment of particular requirements for the Munich Airport Link is assured. All aspects, which could effect economic efficiency or cost effective maintenance, have been verified in the past years. A suitable concept for the handling of the guideway in winter has been created. All of these elements speak for the fact that the Munich Airport Link will be completely available for 365 days in the year, and that the climate of Upper Bavaria will not impact negatively on the availability of the System.

Figure 14: Transrapid and motorized urban rail in front of the entrance to the Munich airport tunnel