Transrapid Guideway - Some suggestions for improved inspection methods and design

Siegfried Droese & Dirk Sperling & Martin Empelmann
Institute for Building Materials, Concrete Construction and Fire Protection (iBMB) of the Technical University of Braunschweig, Germany.

ABSTRACT: In this contribution the authors show possibilities to improve the inspection of the Transrapid (Maglev) guideway. In particular, a new inspection method is described using the dynamic girder stiffness for the detection of structural damages. Furthermore, some ideas and proposals are given to optimize the design and the temperature deformations of the guideway girders.

1 INTRODUCTION

The elevated guideway is the most expensive subsystem of the Transrapid High Speed System (Maglev). Consequently, the essential aim of the research and development work on the Maglev guideway is the reduction of production and maintenance costs, which will also reduce the overall life cycle costs.

A development program named "Cost-Optimization of the Transrapid Guideway (WEP20)" was set up by the Federal Ministry of Transport (BMVBS). This program is running at present and is supposed to be completed at the end of 2007. However, it can be assumed that after finalisation of this programme some optimization potential with respect to the reduction of production costs for the Maglev guideway still exists.

On the other hand, considerable cost reductions can be achieved in the field of inspection and maintenance of the Maglev guideway. This cost factor is becoming much more important, with regard to the system operation and the overall life-cycle costs.

In chapter 2 the authors show how the inspection of the Maglev guideway can be carried out more efficiently and thus more economically. Further research and development tasks concerning the guideway design are identified in chapter 3 and are detailed by two examples.

2 SOME SUGGESTIONS FOR IMPROVED GUIDEWAY-INSPECTION AND MONITORING

2.1 Guideway inspection on the transrapid test facility (TVE)

In Germany the periodical inspection of bridges is specified in national standards (in particular DIN 1076). This applies as well to the guideway of the Transrapid Testing Facility Emsland (TVE). The inspections consist mainly of visual inspections, supplemented by geodetic measurements and further material testing, if necessary.

For some components of the guideway special tests and monitoring methods were developed, such as:

- checks of the friction-coefficient between sliding surface and gliding skid
- checks of the vertical fixings of the guideway girders by measuring the natural frequencies, in order to examine their prestressing force
- checks on the fastenings of the stator packs under dynamic loading (as shown in Fig.1)
- measurement of misalignment of the specific Maglev equipment elements, which is carried out by the Maglev train
- sensors for automatic detection of a motor vehicle impact at crossings between the elevated guideway and traffic routes /1/.

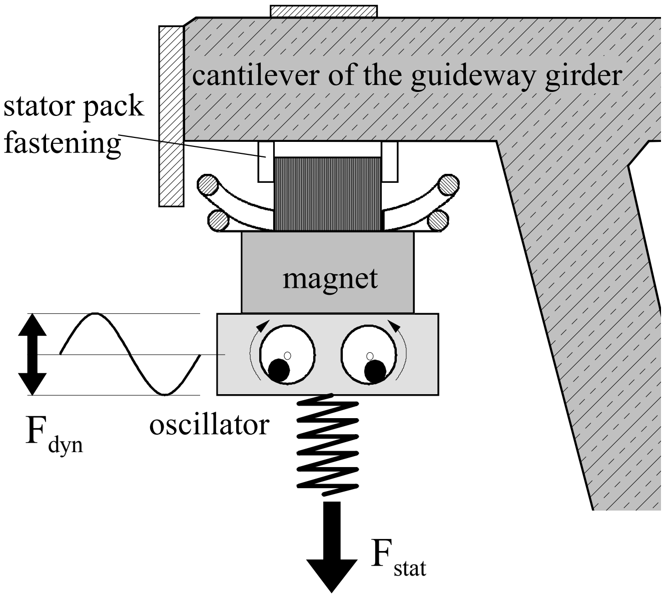

Fig 1: Principle of the test-setup for stator pack fastenings on the TVE /1/

The aforementioned checks and methods have been developed, carried out and proved at the TVE. However, they cannot be transferred one by one to a commercial operational line, such as the Munich Project. The reasons are:

- The standard inspection methods require relatively long breaks in the train operation, which are – in this extent – not possible on a commercial guideway.
- The Maglev technology requires an exceptionally high precision with regard to the position and shape of the guideway, which, in consequence, should be monitored constantly. Especially for the specific equipment elements of the Maglev system, such as stator packs, guidance rails and sliding surfaces, very low tolerances of misalignments are allowed. A small exceedance of these tolerances can cause a considerable reduction of the travelling comfort, which eventually could result in temporary guideway close-down.
- Due to the long inspection intervals, damages might be discovered too late and with the consequence of a considerable high repair effort.
- The results of a visual inspection naturally depend on the qualification of the inspection personal and are more or less a subjective impression of the respective inspector.

Therefore, it is necessary to develop automated inspection and monitoring methods. Furthermore, improvements in the construction can lead to a reduction of maintenance costs and, as a result, in a reduction of life-cycle-costs.

2.2 Suggestions for new testing methods for Maglev guideways

2.2.1 Crack detection with lock-in thermography

Detection of cracks and other structural defects in the guideway structure is an essential inspection task. The inspections are mostly carried out by human visual inspections. The problem of this method is the detection of cracks and other damages inside the concrete box girder or below the coating. For this task thermographic methods could be used.

In components, which are subjected to a constant heat flow, the thermal radiation is disturbed at structural defects and cracks. Therefore, these disturbances can be made visible with infrared-cameras. This method, for example, is used by German Railway for tunnel inspection.

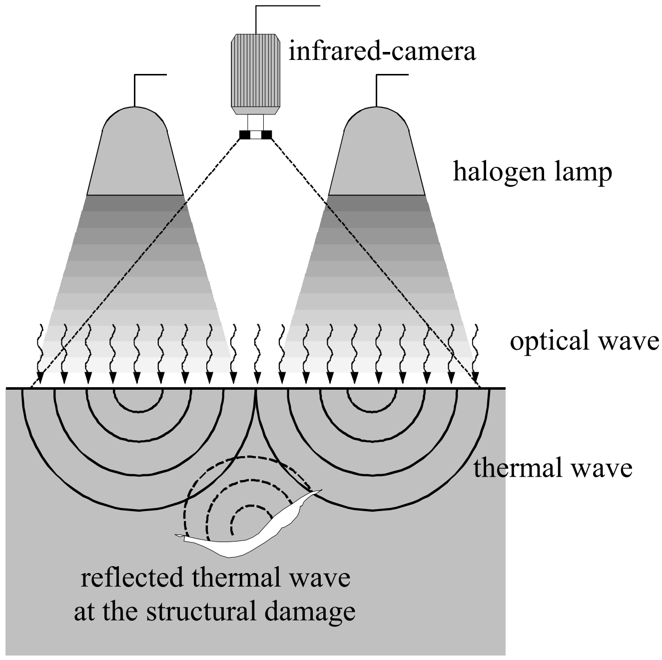

Fig 2: Detection of structural defects using the Lock-In-Thermography

Damages can also be detected with thermographic methods, when no constant heat flow is applied. Then, the surface has to be heated prior to thermography. The thermal wave is excited sinusoidally on the surface of the tested component with halogen lamps, laser or hot-air pistols. The wave propagates into the testing object and is reflected at imperfections inside the structure. In difference to common thermography, temperature changes are analysed only by the excitation frequency. The colour-coded phase image shows the time delay due to heat transportation. A practical advantage of phase images is the suppression of optical or infrared surface structures of the test object, which means that almost only the thermal structures become visible. The method is adjustable to different materials and testing circumstances /7/. Fig. 2 shows the principle of the Lock-In-Thermography. According to the authors' opinion, it is worthwhile to check if this method is suitable for the inspection of the Maglev guideway.

2.2.2 A new dynamic testing method for the detection of structural damages on prestressed concrete guideway girders

Fully prestressed concrete girders, as they are used for the Maglev guideway, normally have no cracks under the operational loading cases. Thus, significant crack formations in the concrete girders indicate that unplanned actions or structural damages have occurred, i.e. local failure of prestressing tendons. A consequence of concrete cracking is the local reduction in flexural stiffness. Thus, the reduction in flexural stiffness can be used as a suitable parameter for the degree of deterioration.

The measurement of flexural stiffness can be performed, for example, by a mobile test equipment, as shown in figure 3. On this vehicle variable weights are installed, which are supported by springs. The weight of the inspection vehicle is chosen in such a way that exactly the same bending moment is applied to the girder, as it would result from the actual Maglev train. In addition, a vibration exciter (vibrator) is installed in the inspection vehicle.

The inspection vehicle runs along the guideway at low speed. At the same time the vibrator permanently induces vibrations into the girder, and the harmonic response of the girders is recorded with on-board accelerometers. The deformation w(t) can be obtained from the acceleration signal a(t) = w''(t) by means of numeric integration. As the final result, the so-called dynamic stiffness is determined by the amplitudes of the dynamic forces and the associated deformation response.

These inspections should be carried out in certain regular time intervals (i.e. annually) using the same boundary conditions and testing method. The detected difference or *change* in the dynamic stiffness is used as an indicator for structural changes of the girders and possible damages of the prestressing tendons, which have occured during the life-time of the Maglev guideway.

It should be noted that the frequency of the artificially excited vibrations is significantly lower than the first natural girder frequency. By this way unfavourable resonance effects are avoided, and, as a consequence, the results of the measurement are not influenced by mass effects.

The most important advantages of this inspection method are the relatively simple set up, the uncomplicated execution and the minor disturbance of the commercial operation.

As mentioned before the result of this testing method is the dynamic stiffness of the guideway girder, which is a "parameter of first order", and which can be used to describe the "state of health" of the guideway girder. The method was developed and investigated at the iBMB. First experience was obtained by theoretical and experimental examinations /2/ demonstrating its general functionality.

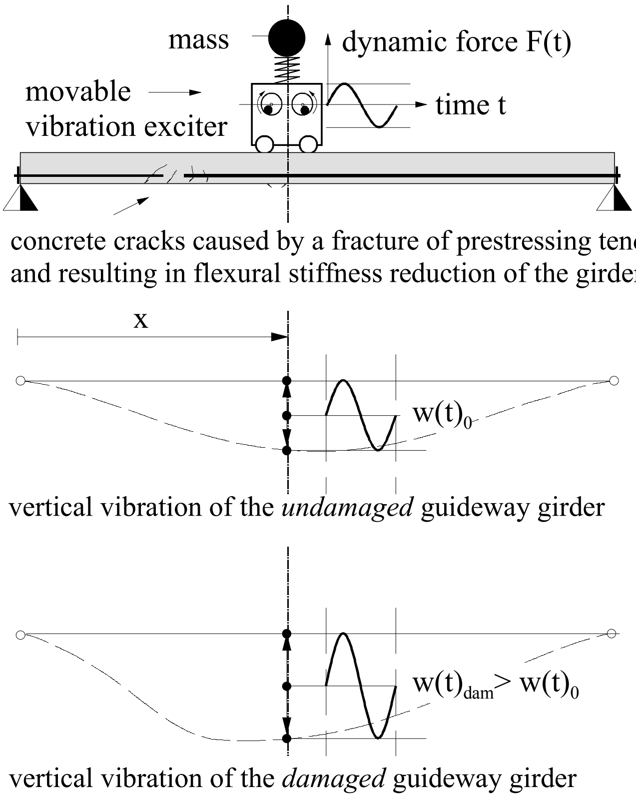

Fig 3: Principle of the dynamic stiffness detection method

2.2.3 Check of the specific equipment elements of the Maglev system

As mentioned before, the inspection and check of the specific equipment elements of the Maglev system (such as stator packs, guidance rails and sliding surfaces and their fastenings) are an important task during the operation phase.

The present construction of the stator pack fastening is designed as a redundant system. In case of a fastening-failure the stator pack drops down a few millimetres and is "caught" by additional fastenings, which means that a dangerous falling off can be avoided. The resulting geometric discontinuity can be detected by the measurement system, integrated into the Maglev train.

It would be better, from an economic point of view, to omit the relatively expensive redundancy-system. However, this would be only possible, if the failure of a fastening element could be detected earlier, before a geometric discontinuity and partial collapse occurs.

In /6/ Steinert suggests to further invest in the development of the present test method (as shown in Fig. 1) and to integrate it into the inspection vehicle . The basic concept of this proposal is comparable with the inspection method introduced in 2.2.2. An increased magnetic load is applied to the equipment elements of the Maglev system to be examined. In addition, a dynamic magnetic load will be generated and imposed to the elements. The dynamic answer is recorded and investigated with regard to discontinuities (i.e. changes of amplitudes, non-linear vibrations etc.). With this method changes could be detected and possible damaged components can be identified.

2.2.4 Bearing Checks

At present the inspection of bearings, and especially bearing displacements, are carried out conventionally by visual inspection of the scale attached to the bearing.

It is recommended, to carry out this tasks by monitoring system installed on the Maglev train. Figure 4 principally shows, how deformations of the bearings or of the foundation can be detected by measuring the gap between two girders.

3 SUGGESTIONS FOR THE IMPROVEMENT OF THE GUIDEWAY DESIGN

3.1 Ways to minimize the deformations caused by a vertical temperature gradient

For the determination of the guideway girder height, two design specifications must be taken into account.

- Criterion 1:
  Limitation of the vertical deflections caused by the design load of the Maglev train, which is taken as the mean train weight as specified in /3/.
- Criterion 2:
  Limitation of the vertical deflection caused by the vertical design temperature gradient, representing the extreme summer and winter conditions. It should be noted here that these temperature conditions only occur on a few days in the year.

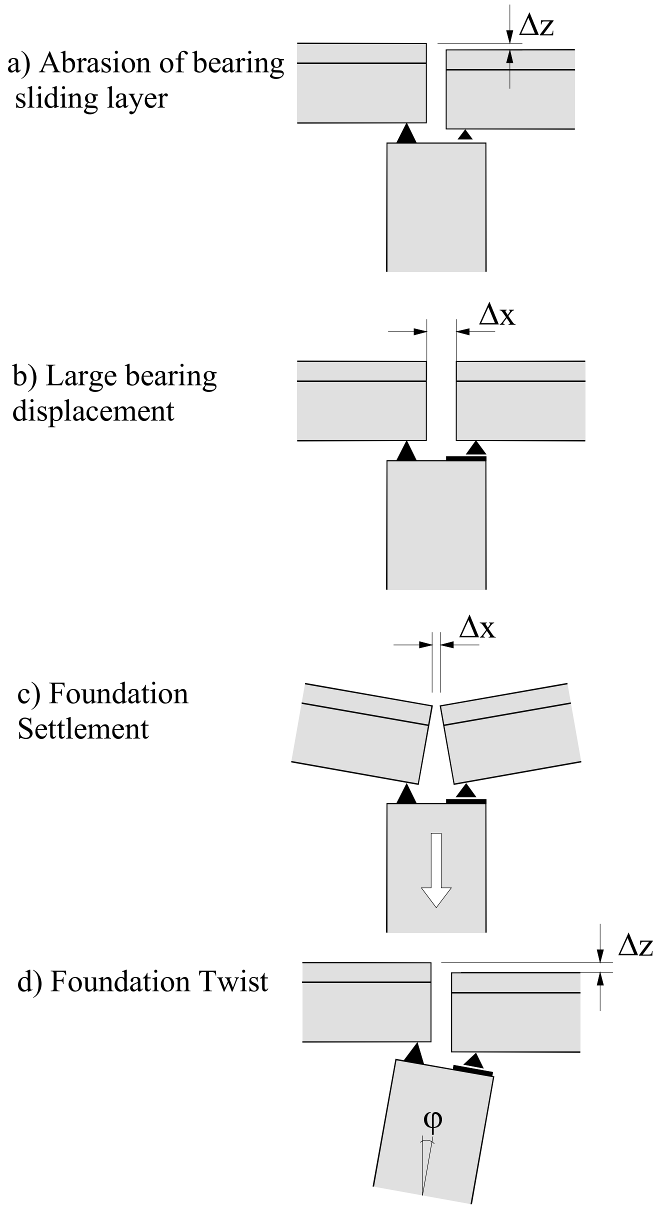

Fig. 4: Reasons for the change of gap between two girders

Usually criterion 2 is decisive for the design of single span girders, resulting in a considerable girder height. Consequently it would be more economic to determine the girder height by using criterion 1, which represents a quasi-permanent operational loading condition. However, the vertical girder deflections, caused by the extreme temperature gradients, have then to be reduced by other methods. In principle, the following methods could be used /4/, /5/:

- thermal insulation of the girder deck
- reflecting thermal radiation coating
- girder design, with regard to minimizing the formation of shades and thus an unequal girder heating
- active and adaptive correction of the girder deflection in case of extreme temperatures (i.e. by change of the prestress or by partial, artificial girder heating) and
- installation of heat exchanging pipes in the girder, in order to equalize the girder tempera-

tures and thus to reduce the girder deformations by a temperature gradient.

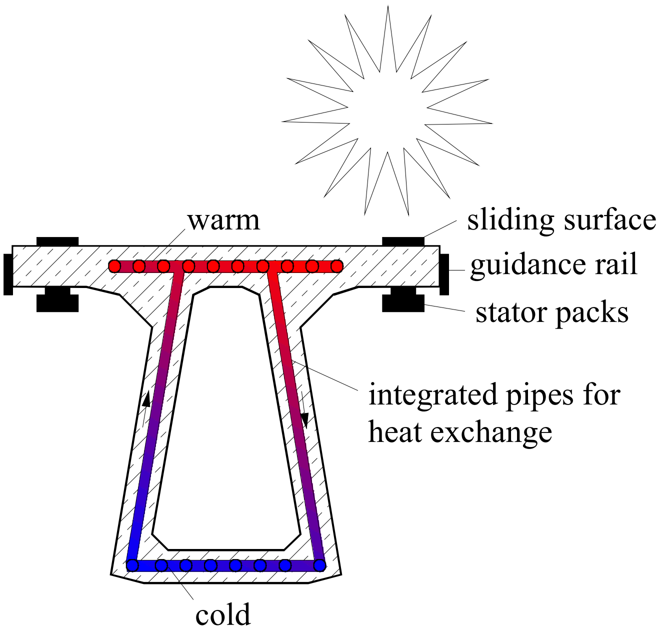

Fig. 5: Cross section of a Maglev box girder with a built-in heat exchanger to minimize the vertical temperature gradient

Figure 5 shows the cross section of a concrete box girder with a built-in heat exchanger. The heat exchanger consists of meandered pipes, filled with a liquid with a high thermal transmittance coefficient. With these pipes a cooling circle is constructed, which reduces the temperature gradient of the girder and thus the vertical deflections. This method is a simple way to reduce the temperature deformations, however it is recommended to investigate the practicability and the performance of such a "heat exchanging system" in guideway girders installed on the TVE.

3.2 Bearings

The current Maglev girder design implies the application of standard bearings. However, such bearings cause, on one hand, specific work during the guideway construction, and on the other hand, high investments and maintenance costs. Therefore, it is worthwhile to discuss the need of such bearings. It is the authors' opinion that it would be also possible to design and construct Maglev guideways without such bearings. Figure 6 shows a frame construction without bearings, which, due to its stiffness, produces only small restraint forces. However, the disadvantage of such a frame construction is the missing possibility to adjust the girder alignment.

Therefore, the use of such frame constructions is limited to guideways founded on stiff soils or strong foundations with a small deformation capacity.

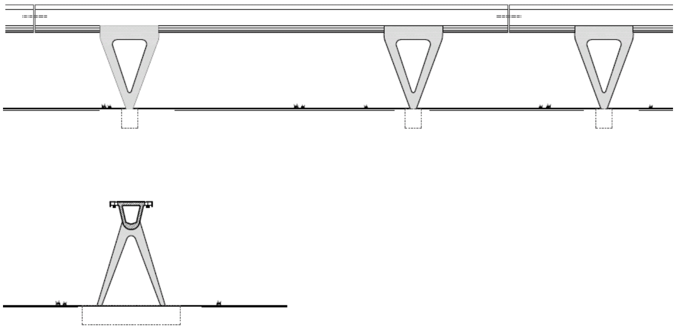

Fig. 6: Example of a Maglev guideway without bearings

REFERENCES

/1/ WEP 21-Abschlussbericht:
Konzeption von Fahrweg-Inspektionsverfahren für den Betrieb der Magnetschwebebahn im Regionalverkehr unter besonderer Berücksichtigung der betrieblichen, der trassierungsbedingten und der allgemeinen verkehrlichen und logistischen Verhältnisse für mögliche Anwendungsstrecken in Bayern und Nordrhein-Westfalen. Im Auftrag des Bundesministeriums für Verkehr, Bau und Wohnungswesen. Bearbeitet von der IABG Lathen, dem iBMB der TU Braunschweig und dem Ingenieur- und Vermessungsbüro H.-J. Marx. Nov. 2002.

/2/ Sperling, D. Eine baudynamische Prüfmethode für Fahrwegträger der Magnetschwebebahn Transrapid, Vortrag auf der 5. Dresdner Fachtagung Transrapid, 2005.

/3/ Ausführungsgrundlage Fahrweg – Teil II: Bemessung, herausgegeben vom Fachausschuss Fahrweg.

/4/ WEP 28-Abschlussbericht: Studie zum temperaturoptimierten Einfeld-Fahrwegträger. Im Auftrag des Bundesministeriums für Verkehr, Bau und Wohnungswesen. Mangerig und Zapfe Beratende Ingenieure. München. Sep. 2002.

/5/ Droese, S.: Der ideale Fahrwegträger für die Magnetbahn Transrapid, Vortrag auf der 5. Dresdner Fachtagung Transrapid, 2005.

/6/ Steinert, W., Bohlscheid, A.: „Transrapid Guideway: Safety Assessment for A New Design of long Stator Packs Fastening. 19th International Conference on Magnetically Levitated Systems and Linear Drives, 13. - 15. September 2006 Dresden – Germany.

/7/ www.edevis.de