Characteristics and Verification of the New Concrete Gliding Strip for Transrapid Guideway

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Abstract

ThyssenKrupp Transrapid developed a coating system for the concrete guideway gliding strip for the use with the redundancy undercarriage of the Transrapid vehicle. In the unlikely case of the magnetic levitation being disabled at a levitation frame the gliding strip is used for mechanical support. The process of development – including qualification tests performed at the test facility TVE in Emsland, Germany – and the characteristics of the coating in tribological application with the employed gliding material CFC are presented.

The coating now provides the concrete guideway as a favorable and competitive alternative to other guideway types for any commercial short- and long-distance application. [1]

1 Introduction

As the basic concept of high-speed magnetic-levitation trains, the regular operation of the Transrapid vehicle is contact free. That is, the vehicle is levitated and guided by magnets arranged as illustrated in Fig. 1. In particular, each levitation frame is supported by two levitation magnets according to the redundant dimensioning of the undercarriage. If one of the levitation magnets is being temporarily or permanently disabled, the levitation frame will be supported by a single magnet. However, in the unlikely case of both levitation magnets being disabled at the same time, the magnetic levitation is replaced with mechanical support. This is realized by gliding of the assigned support skid on the gliding strip of the guideway. Therefore the support skids are called the redundancy undercarriage of the Transrapid vehicle. [2]

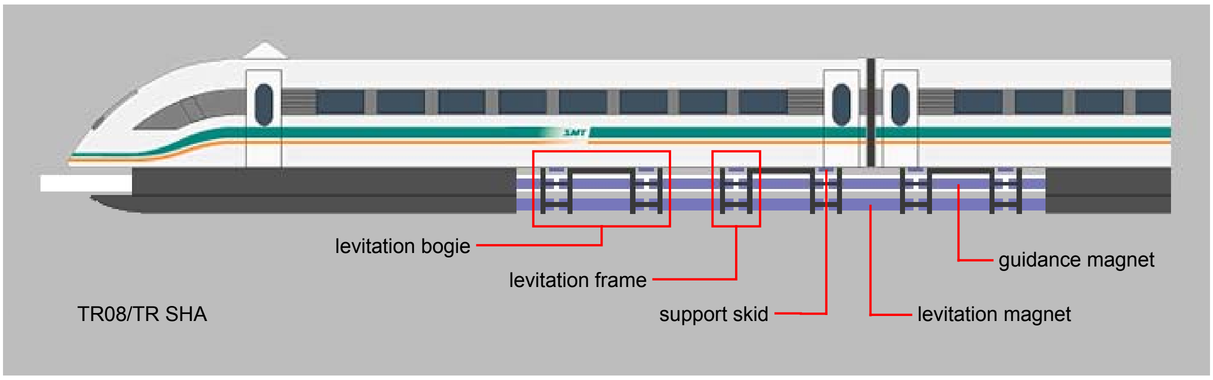

Fig. 1 Transrapid vehicle structure.

Fig. 2 Support skid with gliding elements.

Fig. 3 CFC gliding element.

The technical requirements for the support skid and the gliding strip are extremely high. For example, considering the 30 km long Transrapid link from Shanghai Pudong International Airport to the Metro station Long Yang Road in the financial district of Shanghai. Both, support skid and gliding strip (in this case consisting of steel with anticorrosive coating), have to withstand safely the mechanical and thermal loads, even if both magnets are disabled directly after leaving the Pudong station. Then a full round trip without changing the regular operational profile has to be completed with an unseated support skid before the vehicle can be reconditioned in the maintenance. That is, the gliding process has to be realized for more than 60 km with the maximum speed of 430 km/h.

The support skid of the TR08 vehicle operated at the test facility Transrapid Versuchsanlage Emsland (TVE) was further developed to meet the requirements for commercial applications as in Shanghai. Besides some design features, most importantly Carbon fiber reinforced carbon (CFC) is now used as the gliding material for the support skid, which shows excellent performance in the tribological pairing with steel. In particular, the very small wear as well as the high temperature stability and the high shock resistance of CFC shall be emphasized here. In Fig. 2 and Fig. 3 the support skid and the used CFC gliding element are shown.

But even if the developed CFC support skid had been successfully applied for the Shanghai application and is now state of the art for a guideway with steel gliding strip, yet it was not suitable to use this component for a concrete guideway with a concrete gliding strip due to the inappropriate characteristics of CFC and concrete as friction partners. Such a concrete guideway is predominantly in use at the TVE and represents a competitive alternative to the hybrid guideway as realized in Shanghai. For this reason, ThyssenKrupp Transrapid developed a coating system for the concrete gliding strip, which now affords the use of the CFC support skid with a concrete guideway. In the following, development and characteristics of the coated concrete gliding strip are illustrated.

2 Development of the Coating System

2.1 Task and Preliminary Tests

As described above, CFC and concrete can not be employed as friction partners in any tribological application due to inappropriate friction properties as galling for example. The task of the coating system of the concrete gliding strip is to prevent from extensive contact between CFC and concrete and to ensure permanently a well-defined tribological process while gliding of a support skid on the gliding strip. Of course, for the practical applicability inspection and maintenance of the coating may only be executed in large time intervals. The requested properties of the coating system can then be summarized as follows:

- a good applicability for the tribological use with the employed gliding material CFC, in particular regarding the specified friction coefficient and a limited temperature development,
- a high adhesive tensile strength of the coating at the concrete subsurface,
- a small wear of the coating while gliding of a support skid on the gliding strip, and
- a standardized and non-complex application method with regard to quality assurance.

Fig. 4 Roller drum test rig with support skid.

Fig. 5 Coated guideway for the qualification tests.

In order to find a coating material meeting the postulated requirements, first preliminary tests have been carried out to obtain a pre-selection of coating systems to be considered. Among tribological tests at pin disc test facilities in cooperation with the Technical University of Dresden (TUD), gliding tests at a roller drum test rig have been performed. In Fig. 4 the roller drum with different types of coatings applied on the steel surface is shown. Moreover, the support skid in use mounted on a special test carrier and equipped with several thermocouples can be seen. The drum has a diameter of 4 m and a maximum peripheral velocity of 400 km/h. Due to the curved drum surface, the friction surface of the CFC gliding element was first adjusted accordingly.

The tests gave first results of the characteristics of several coating systems with regard to the friction coefficient and thermal development. In addition, the wear of the coatings could be estimated by eddy current and magnetic induction method as well as laser thickness measurements. As a conclusion, a coating system on the basis of polyurethane (PUR) was chosen for further enhancement regarding the application on a concrete subsurface.

2.2 Optimization of the Coating System

In order to optimize the characteristics of the PUR-based coating system with respect to the realization on a concrete subsurface, application and adhesive strength tests at the TVE concrete guideway have been conducted. Before, analyses of the concrete surface structure at the gliding strip performed by optical measurements were carried out to give substantial information about the surface roughness. Hence, with the tests

- cleaning and pre-treatment of the concrete subsurface,
- the choice of the priming coat, and
- the composition and layer thickness of the PUR top coat

were adjusted perfectly according to the requirements. In particular, as a target value at least the adhesive strength of concrete itself had to be achieved in order to avoid spalling. Finally, a multi-layer PUR coating system with optimized adhesion on concrete was derived.

2.3 Environmental Tests

In order to analyze also environmental influences on the coating system such as humidity, heat and frost, short- and long-term weathering tests have been started in cooperation with the TUD. In detail, the influence on the adhesive strength of the coating as well as the influence on the friction properties have been tested.

The simulated weathering at the TUD has been performed by a climatic exposure test cabinet according to DIN standard 50017. In particular, a temperature range from –10 °C up to more than 40 °C and a relative humidity up to 98 % have been realized. The results show that the tribological characteristics are not significant affected by the environment.

2.4 Qualification Tests at the Test Facility TVE

For the qualification of the developed coating system described above and the identification of the exact characteristics in the application, the gliding strip of a 350 m long section of the TVE concrete guideway shown in Fig. 5 was coated. In this area gliding tests with a CFC support skid mounted at the TR08 vehicle were performed, in particular regarding different vertical loads and velocities. Moreover, tests with a special test device called "Sulky" have been carried out to give circumstantial information about very slow vehicle crossing as well as deceleration and acceleration operation, since these tests could only be performed with advanced complexity using the TR08.

Additionally, tests with special maintenance vehicles have been performed, since they also use the gliding strip at the TVE guideway. In particular, the coating of the gliding strip have to withstand the according wheel-loads.

3 Characteristics of the Coating System

During the above mentioned qualification tests with the TR08 and the test device "Sulky" at the TVE more than 30 support skid crossings have been realized covering a velocity range from 10 km/h up to approx. 400 km/h. Moreover, vertical loads have been tested up to nearly 40 kN, whereas the regular vertical load during the unseating of a support skid is reduced to 8 kN by bleeding of the assigned air spring. The conducted gliding tests therefore can be treated as worst-case studies.

In accordance with the preliminary tests at the roller drum test rig, the mean wear of the coating system per support skid crossing was detected with less than 5 µm. In consequence a coated gliding strip section can be crossed at least 40 to 50 times before maintenance measures must be performed. It shall be pointed out here that statistically the unseating of a support skid appears only once in 37 years[1]. Fig. 6 shows the same section of the qualification coating of the gliding strip after the first and the 22nd gliding test with the TR08. The proceeding discoloration of the white coating caused by the carbon of the gliding material can clearly be seen.

Fig. 6 Gliding strip after the first (left) and the 22nd crossing of the support skid.

Tab. 1 Friction properties of gliding strip coating and CFC gliding element.

PUR-based coating system	
abrasion coating	≤ 5 μm per support skid crossing
friction coefficient 40 km/h 400 km/h	 ≈ 0.2 ≈ 0.1
temperature CFC gliding element	≤ 460 °C in 2 mm above friction surface
adhesive tensile strength	≥ 4 N/mm^2

The results of the performed tests concerning the gliding material CFC did not show any significant differences neither regarding the friction coefficient nor regarding the wear and temperature behavior in comparison to gliding on pure or coated steel. In particular, the measured temperature of the gliding elements did not exceed 460 °C. The maximum thermal load capacity of the CFC gliding elements is given by more than 1500 °C.

The evaluation of the adhesive strength tests performed at the qualification coating showed that the adhesion of the coating is even higher than the adhesion of the concrete itself. A summary of the derived friction properties of the coating system and the gliding material CFC is given in Tab. 1.

4 Outlook

After the qualification the gliding strip of all TVE concrete guideway with a length of approx. 20 km was coated with the developed PUR coating system. Accordingly, the 3-section-vehicle TR08 was equipped with the CFC support skids as used in Shanghai. Finally, at the beginning of 2004 the commissioning of the TVE after upgrading to the coated gliding strip was successfully completed with performed verification tests.

Since now CFC support skid and concrete guideway are qualified for the combined use, the concrete guideway is a favorable and competitive alternative to other guideway types for any short- and long-distance application. The TVE now provides an excellent opportunity to gather long-term experience under real conditions.

References

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[1] The statistical probability is calculated for a 3-section-vehicle with 8760 hours of operation per year.