INTRODUCTION

Immediately after the start of the Maglev project in Shanghai until its successful conclusion with its commissioning, the activities on the Transrapid Testfacility (TVE) were aimed at supporting the German industrial firms and the Chinese operator involved in this project (Metzner, 2004).

Thereafter, the focal point of the work moved, on the one hand, to the transfer of optimisations and modifications performed in Shanghai to the technical sub-systems installed at TVE. On the other hand, it became clear that TVE with all its available facilities was to be maintained as the test platform for future new technologies over a long period as an important basis for risk-minimised planning and commissioning for further commercial public service routes at a very high level of availability. After more than 20 years in operation, it was therefore necessary to refurbish out-of-date technical facilities or, in cases where a complete replacement was not feasible for financial reasons, for example, the guideway, incipient degradation was to be countered by commensurate maintenance procedures.

Moreover, adaptations to older systems' interfaces had to be performed in order to ensure the compatibility of the testfacility with the new technologies still to be tested.

To this end, numerous individual activities were defined as part of a modernisation programme and financed by the Federal German Transport Ministry and the systems industry companies involved in close cooperation with the operations and maintenance teams at TVE, who performed, tested and accepted the individual activities.

In this connection, the TVE operations team was particularly challenged to develop maintenance methods, optimisation possibilities and auxiliary diagnosis devices and apply these in practice for the now more than 20 years old guideway, on the basis of its comprehensive experience in dealing with the testfacility and Transrapid technology.

In addition to the activities in the modernisation programme were newly developed technologies and components, developed by the Transrapid systems industry, which to a very large extent were emerging from an own initiated further development programme, and which had to be integrated into the testfacility and embedded in the overall operating system.

As a result of the comprehensive changes in the technical facilities, the rules for operations and maintenance had to be adapted to the circumstances as the basis for the safety-directed activities of the operating and maintenance teams.

The planning for the tests to be conducted in active operations has to be so designed that the interested general public could continue to have the possibility of travelling on the TR08 Transrapid to the
greatest possible extent. The releases necessary for this by the responsible approval authorities were issued on the basis of the experience of the TVE Teams in the safe handling of the system (Metzner 2000), also under the more difficult conditions concerning commissioning and system tests still being conducted.

2 ACTIVITIES IN THE SUB-SYSTEMS

In the following, the measures performed as part of the modernisation, further development and maintenance of TVE are presented in an overview, assigned to the individual sub-subsystems.

2.1 Drive/Energysupply

The biggest challenge in the drive segment was the preservation of degraded motor windings on the 10km stretch of the route, i.e. on about one third of the length of the guideway. Caused by a not directly identifiable production fault in a batch of long stator windings in use now for over 20 years, the degradation was greater than specified in the insulated cable sheath as a result of weathering. That means, the usage duration for this part of a batch of long stator windings was clearly reduced. Water was able to penetrate as a result of embrittlement of the cable sheath and caused at numerous points the pinpointed destruction of the cable shield. There were basically two possibilities for the remediation of the damage. On the one hand, by replacing the old winding by a newer type of cable or the development and application of a repair method for sealing the winding and regenerating the necessary insulation resistance of the cable sheath. The second variant was selected, on the one hand, naturally due to the lower costs in comparison to the replacement of the long stator winding. On the other hand, the unique opportunity was here to hand to test and optimise under practical conditions a remediation method with which, in future public service projects, it would be possible to prolong the long stator winding located in the guideway cost effectively beyond the lifetime specified by the manufacturer.

The development and application of the remediation method were completely in the hands of the TVE team. In close cooperation, the specialist engineers responsible for power supply and for the guideway initially qualified in laboratory tests a suitable substance for the impregnation of the cable using a flushing and dipping process (Fig. 1).

Thereafter came the dimensioning of the special machines to be used on the guideway and the production of appropriate movable task scaffolds. The multi-stage procedure was initially optimised in preliminary tests and then successfully applied over the 10km length of guideway.

Figure 1: Qualification test for flushing process

Additionally, preliminary tests were conducted for the development of a technical diagnosis faculty, which is intended to enable automated observation of the long stator winding to be conducted, using special sensorics, from the Maglev vehicle during running operations. The aim is the recognition in good time of changes in the long stator winding before impacts on operations occur.

To increase the facility availability and simplify maintenance, the following changes were made to the drive system and energy supply:

- Adoption of the optimisations and modifications performed in Shanghai on the control and monitoring software during commissioning to the TVE drive system
- Decentralisation of the control technology for the cooling facilities for the drive system
- Creation of redundant functionalities in the control and monitoring of the drive
- Replacement of the input and output control gear in the older of the two drive substations by more recent technology
- Replacement of old track switches by more recent technology.

As part of the further development programme, there were the following activities:

- Inductive Power Supply (IPS)

In future public service projects, the power rails installed in the station and stops and the current collectors attached to the Maglev vehicle will be replaced by an inductive, contact-free energy supply system. The stationary energy supplies prototypes developed by the systems industry for this purpose and the vehicle-side facilities were integrated into
the test facility and subjected to first qualification tests. (Fig. 2). Included here was, among other things, the loading of the stationary facilities during permanent operation.

Figure 2: IPS-Testmodule installed at the guideway

- New Integrated Gate Commutated Thyristor (IGCT) Converter

The to date only equipped to 50% with gate turn-off (GTO) converters new drive substation on the TVE North Loop was supplemented with the most modern IGCT converter technology made by Siemens and is now available after successfully commissioning at full performance level. The new technology has been in use since the first quarter of 2006 in continuous test operations on the TVE.

2.2 Magnetic Levitation Vehicle

In connection with the TR08 Maglev vehicle, the following modifications and tests took place:

- The support magnets modified as part of the Maglev Shanghai project with the aim of greater availability were integrated into the current version of the TR08 test vehicle and subjected to further tests.

- To simplify the replacement of the support and guidance magnets as part of maintenance, the TVE team developed an, in part, movable, guideway beam segment (Fig. 3) and integrated it in the area of the maintenance hall into the guideway. The task time for the assembly/disassembly of support and guidance magnets was halved as a result of this measure.

- After the necessary adaptations to the slide rails of the concrete guideway, the conversion of TR08 for low-wear delevitation skids made from CFC, (Carbon Fibre Composite) took place. Comprehensive qualification tests ran positively, so that a certification for the permanent use of the new skids could be issued for the Maglev vehicle on TVE.

- After modifications to the guideway in the stator plane area, the reduction of the support gap at lower speeds was possible.

- Tests with modified current collectors for the investigation of the wear-and-tear behaviour at the step at the joint between rails were conducted.

Figure 3: Free access to magnets during maintenance after retraction of guideway module

- An automatic measurement facility for the identification of erroneous LRLs (location reference flags) along the guideway was developed and integrated for application in current operations into the Maglev vehicle.

- For the preparation of the "Transrapid Munich" project, travelling comfort investigations in connection with standing room were carried out in the Maglev vehicle. For this, a section of the TR08 was equipped with straps in the standing area. An assessment took place using test persons during operation in a wide range of differing scenarios.

- The optimisations of the parameters in the electronic regulation of support and guidance systems was continued constantly and led to a further increase in the availability of the Maglev
vehicle for running operations, in particular, under special conditions in the old TVE guideway beams area.

- In 2007, a further newly developed optimised Maglev vehicle, the TR09, is intended to be tested at TVE for use under the conditions to be met in the "Transrapid Project Munich". The preparations necessary for this for the adaptation of the TVE facilities have already begun to facilitate a smooth commencement on schedule of the testing.

2.3 Operation Control System

The hardware and software used to date at TVE for the operations control system was replaced by a newly developed system and thus matches the standards achieved in the public service project in Shanghai. The new system must be adapted to the special factors at TVE, in particular to its routing. After the conclusion of the theoretical safety verification, the practical safety testing and facility acceptance testing during operations took place at TVE. Included in this was also the practical loading of the new system in numerous different operations scenarios, which, in particular, served the verification of the safety system response under special operating conditions, such as component failures and redundancy loss. After the positive completion of all tests and acceptance tests, the release for the full technically secured automated operation using the new operations control system for TVE was issued by the certification authorities.

Moreover, for the further enhancement of the system availability in the South Loop area of the TVE guideway, additional radio masts with stationary facilities of the 38-GHz radio relay system were installed and commissioned. With this adaptation, a redundancy concept was realised on the testfacility, which is identical with commercial operations.

2.4 Guideway

One of the main activities in the guideway subsystem was the remediation of the degraded long stator windings, in close cooperation with the specialist drive and energy supply engineers, as described in detail in 2.1.

In order to ensure the compatibility of the TVE guideway with the newly developed skids for the Maglev vehicle made from CFC, (carbon fibre composites), it was necessary to modify the relatively rough slide rails, similarly made of concrete, in the concrete guideway area on the upper side of the guideway table. For this, a multi-layer bonding coating made from differing wear-out resistant composite materials had to be applied (Fig 4). In preparation for this, to reduce the roughness, the existing concrete slide rail was smoothed off using a grinding process.

For the qualification of the grinding and coating process and the fundamental verification of the suitability of the slide rail coating, initially a small part of the concrete guideway at TVE was treated. After the suitability of the both materials and process had been verified by means of targeted lowering tests under differing boundary conditions using the Maglev vehicle, the release for the treatment of the slide rails over the whole length of the concrete guideway was given for the testfacility. After the conclusion of the production phase, the wear-and tear resilience was verified by means of further comprehensive qualification tests of the CFC skids and the slide rail coating in operational use.

Figure 4: Coating of concrete slide rails

The biggest part of the TVE guideway continues to be equipped with beams of the first construction type selected over 20 years ago. The design weaknesses revealed in test operations of these old types of beams were corrected with the development of new types of beams. New guideway beams were integrated at selected sites for testing over a short stretch of the guideway. On costs grounds, it was, however, not possible to equip the whole 32km of guideway at TVE with a new type of beam. Hence it was decided to restrict to a justifiable degree the un-favourable thermal behaviour, that means the marked warping of the guide beams under solar radiation, by means of a light-coloured coating. The long-term measurements conducted at TVE over several years on individual guideway beams with different coatings were evaluated. The result showed that a white coating of the guideway table achieves the improvement targeted for the thermal behaviour.

After application of the white coating to the guideway table, the operating restrictions in the old guideway area, as had occurred under special cli-
matic conditions to date, in particular, in strong sunshine after low night-time temperatures, were no longer required.

The Maglev operations were restricted at some operations points due to the dynamic behaviour of the old steel guideway. In order to increase the operational availability, simple and cost-effective passive vibration damping systems were developed, which were intended to improve the dynamic behaviour of the steel beams in interaction with the Maglev vehicle (Fig. 5). In advance tests, initially, the inherent forms of the affected steel beams were determined. To this end, both permanent imbalance exciters were used as well as comprehensive measurements of the Maglev vehicle travelling at varying speeds were performed. Thus the basis for the dimensioning of the passive spring-mass damping to be applied was given. In the next step, prototypes of the damping system were fitted to individual guideway beams and the dynamic response again determined in testing terms. After the positively concluded optimisation of the dampers and qualification of the prototypes, the production of a preliminary series and its installation into the guideway beams took place. After a further test phase in support of the qualification of the method, the release decision for series production of the dampers could be taken. The whole steel guideway in the North Loop area was equipped with dampers. The result was positive, the previously still existing point operations restrictions were lifted and the use of the test facility was now also permitted unrestrictedly in the area of the steel guideway.

In 2005, the installation took place of further new prototype beams in the South Loop area of the TVE guideway. An at-grade guideway developed by the firm of Bögl in modular design (Fig. 6), consisting of 4, respectively, 9.3m long elements, was to be integrated into the guideway, with more than 80 measurement points and to be tested in running operations in a wide range of operation scenarios for the verification of the load absorbability to examine technical acoustic characteristics and for the verification of the vibrations induced into the ground. After the positive conclusion of the verification programme, the certification authorities and appraisers issued the release certificate for the permanent use of the new type of guideway for TVE.

A process already used several times for corrosion protection of the stator packs was further optimised so that, by using a specially created, 75m long scaffold train (Fig. 7), the necessary maintenance tasks could also be carried out in autumnal weather conditions.

Moreover, by using simple measures, the to date possible water pools on the surface of the old types of guideway could be prevented to a very large extent. In winter conditions, thus the formation of icy patches, which could slip when the Maglev ran over them could be limited to a very large degree.

The metrology systems developed by the TVE team and in use now successfully for several years for the automated observation of the guideway geometry (Nieters, Snieders, Runde 2000) from the moving Maglev vehicle have been constantly optimised further and supply more precise measurement results now than with the first versions.
With respect to the commercial use of the Transrapid, the development of new types of guideway by the systems industry involved on the basis of the knowledge gained at TVE is being continued. The installation and testing of new guideway prototypes both for the high-speed range of the TVE guideway and also in the South Loop have been prepared and take place between April and July 2006 (Fig. 8, 9).

![Figure 8: Construction site south loop 2006](image)

![Figure 9: Construction site at high speed area 2006](image)

Based on existing experience in the measuring of new types of guideway in test operations, the TVE team again was given the task of preparing several hundred measurement points on the guideway beams, of compiling a concept for the required qualification tests and measurements and of performing these in close cooperation with the systems firms involved.

### 2.5 Operations

The success of the individual measures carried out as part of the modernisation programme was verified using the function acceptances. The specifications for this envisaged, on the one hand, the verification of increased system availability as part of an intensive timetable operation under as great a loading of the system as possible. Among other things, also daily timetable schedules in 2-shift operations were carried out. On the other hand, on the basis of targeted individual tests, the success of the measures performed was to be verified. In order to take differing climatic influences into consideration, the functional acceptance tests were repeated three times at different times of the year. Included here was, among other things, also automated 24-hour permanent operation, which were similarly repeated three times. In each of these 24h-operations cycles, a daily performance distance of more than 4 400 km was completed using the TR08 Maglev vehicle on the test facility. The individual non-stop runs performed as part of the 24-hour operations and repeated several times were respectively 930 km long with 4 hours travelling time and 460 km with a travelling time of 2 hours. The aims of the modernisation programme were hence achieved in full and the applicability of the system for long-distance travel also proven. Alone in the first quarter of 2006, parallel to the very stable test operations, 25 000 guests had the opportunity to participate in high-speed runs in the Maglev TR08.

As part of the practical verifications to be performed for the certification authorities proving the safe reaction to possible emergencies and the maintenance of the capability of the operating team, once a year evacuation exercises using test persons on board the Maglev vehicle are conducted. In order to collect experience in differing scenarios, one of the evacuation tests took place at night using only the emergency lighting available in TR08. In all cases, the safe evacuation sequence was proven within the specified time limit.

### 2.6 Organisation

At the end of 2005, the decision was taken in the Federal Ministry of Transport to simplify the organisation with respect to responsibilities for the test facility. To date, the owner's rights, the ownership of the operating approval and the responsibility for operations and maintenance were divided between several organisations. Linked to this was a relatively high coordination effort between the companies involved. In the sense of an increase in efficiency and for the generation of shorter lines of decision, the responsibility for ownership, operating approval, operations and maintenance should be transferred to a single organisation. Based on the many years' experience with respect to the TVE, the test team of IABG was selected. Corresponding contracts were to be drafted for this purpose. The process for the transfer of complete responsibility for the test facility
to the IABG operations team should be completed in the first half of 2006.

3 PERSPECTIVE

With now modernised sub-systems and a more efficient organisation, TVE and its experienced test team are ready to meet the requirements of the systems industry involved and the operators of future commercial public service systems in the coming years. This planning for the next few years envisages today the testing of new drive technology, new guideway elements and from 2007 the commissioning and intensive testing of a specially designed Maglev vehicle for the operation of the Transrapid project for Munich.

4 REFERENCES

Metzner, J. 2004. The Transrapid Testfacility- Experience for startup and commissioning of Shanghai Maglev, Maglev 2004