Guideway Maintenance

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ABSTRACT: Having gained experience from maintaining the testing facility TVE in Germany, building the Shanghai line and planning several lines in Germany, particularly the Munich Project the aspect of Guideway Maintenance gains ever more attention and importance for future Maglev Projects. In this term the guideway comprises not only the super- and substructures but also the special structures like tunnels, bridges, fencing, protective and other structures along the line. The activities to be considered include the planned inspections, corrective measures, improvements, measures required for vegetation control, winter service measures etc. Currently the standards for the maintenance of civil structures are rendered to meet the special requirements of Maglev-System more precisely. Furthermore the planning for the maintenance of the Munich Project is getting more detailed. Pointing to requirements regarding the maintainability of Maglev-structures, interfaces to system - operations and systemtechnical requirements the article it is supposed to present an overview of the current status on guideway maintenance in general.

1 STARTING SITUATION

Given that the planning for a Transrapid route in Germany is going ahead, increasing importance is being assigned to the aspect of maintenance.

Considering that the guideway usually represents the major share of investment costs and due to the potential effects of possible guideway malfunctions, maintenance of this subsystem is especially important.

This article is based on experience gained during operations at the Test Facility Emsland (TVE), implementation of the Shanghai project and the planning of many other projects. It is intended to provide an overview of the current state of knowledge regarding the planning and performance of maintenance work on the guideway and structures along the route.

As in other areas as well, the maintenance stipulations are based on the corresponding stipulations for construction in general and railway systems in particular. Nevertheless, special system-specific aspects of the high-speed maglev system have to be taken into account. These include the non-contact technology which prevents the wear and tear associated with railway systems. Another aspect which must be considered is that (contrary to the railways), there exist no alternative routes which could be used to maintain Transrapid services when extensive maintenance measures are necessary.

The existing set of rules does not adequately cover the specifics of the high-speed maglev. When the principles of guideway design and construction were being drawn up in the “Ausführungs-grundlage Fahrweg” (this document contains the building standards for guideway structures and is been compiled in the framework of the government's development program), special attention was therefore paid to the maintenance-related requirements for the guideway and structures. The corresponding requirements on maintainability, however, are not only defined in part VI "Maintenance" of the “Ausführungsgrundlage Fahrweg”. This part rather contains statements regarding maintenance and the resources needed for this purpose. Statements on the maintainability of the components and assemblies are contained in part I "General Requirements", whereas aspects of the technical design (in respect of the failure behavior of the respective construction) which require consideration are defined in part II "Technical Design". This illustrates how strongly and in how many ways the aspect of maintenance affects the later practical viability of a guideway development.

Moreover, it becomes clear that not only safety aspects have to be taken into account when a new girder is being examined. The topic of Safety is only one of four issues which are summarized under the

synonym "RAMS". From an overall technical point of view, the same attention is to be paid to the issues of "Reliability, Availability and Maintainability" during design, planning and realization of a guideway element. As the Technical department of Transrapid International, one of our main tasks is therefore to provide systemtechnical assistance and / or to carry out systemtechnical examinations in order to ensure the serviceability of the System..

In order to achieve the best results in the end we make sure that all relevant aspects are been considered at each stage, i.e. from the first feasibility studies to the acceptance tests of a completed project.

Since maintenance related issues form a vital part of this process the following takes a detailed look at it.

2 INSPECTIONS

Similar to the procedure involved in inspections of constructions for railway systems, a distinction is made between the following for maglev routes:

- Monitoring
- Examination
- Expert's assessment
- Special inspection

Monitoring
Monitoring of the guideway involves by far the largest amount of work and expenditure in guideway maintenance, especially in the first years of service life. Ways and Means of the Monitoring will always be specific to the type of construction and must be planned in accordance with the general project-specific parameters. However, the following fundamental criteria will have to be met:

- Permanent monitoring of structures
- Monitoring carried out during operations or during the nightly break in operations
- Mostly automated procedures
- (Later) evaluation of the results by specialist personnel after monitoring

The purpose of monitoring a route and its installations is to detect any deviations from the specifications. Depending on the design of the individual components, the monitoring measures are therefore to be defined in such a way that all relevant changes to the construction are detected directly or by way of their effects. It is acceptable that it may not be possible to immediately assign a clear cause to a result of automated monitoring as there will be various possible causes.

Example: Possible causes of a detected change in the offset on the stator plane at the guideway girder transition can be failure of a stator pack fastening or failure of a module fastening on the hybrid guideway.

Irrespective of the type of construction of the respective guideway, monitoring must cover at least the following areas:

- (Visual) monitoring of the surfaces of parts (e.g. cracks, chipping, coatings, fastening elements)
- Geometric monitoring of the function planes (short-wave and long-wave)
- Monitoring of reference structures

(Visual) monitoring of the surfaces of parts (for example with a camera system) is mainly done from a special vehicle. It supplies visual information on the condition of the part and is usually carried out during the nightly break in services.

Currently a camera system mounted on a special vehicle is envisaged for this purpose. The system records the different surfaces of the guideway during nightly trips and evaluates the results automatically wherever possible. Final evaluation is then carried out by the day-shift personnel during one of the subsequent shifts.

A corresponding system is already being used for railway installations. At the Test Facility Emsland, some experience has already been gained with a system adapted to maglev needs.

Geometric monitoring of the function planes is based on the information provided by the passenger vehicle's support and guidance system. The contours of the stator plane and the lateral guidance rail plane are recorded during vehicle operations and are then compared with a stored set of reference data. If differences are found, a corresponding message is generated. Monitoring of these two function planes also enables indirect geometric monitoring of the gliding-strip plane in the case of the currently known guideway structures.

For this monitoring process, final evaluation is carried out by day-shift personnel during one of the shifts after the inspection.

A distinction is made here between short-wave monitoring of the function planes (offsets) and the long-wave examination generated from this (e.g. settlements).

Monitoring of reference structures, as the third component of monitoring, involves the monitoring of individual, specially selected structures at positions along the route which are exposed from a maintenance point of view.

Example: A guideway-girder at the lowest point of a tunnel, another guideway-girder fully exposed to sunshine in a north-south alignment.

The aspects to be monitored are to be defined in relation to the respective type of guideway construc-

tion and the route alignment. Examples would be as follows:

- Bearing wear
- Deformation behavior
- Monitoring of coating - thickness
- Carbonization of concrete parts
- General aging behavior

The purpose of monitoring these reference structures is to better evaluate the results of other knowledge gained from maintenance and is intended to enable or simplify the application of individual findings to the condition of the whole route. The resulting possibility of timely detection of systematic problems becomes very important, especially in respect of standardized guideway components.

It is important to match the technical design of the components to the nature and frequency of the monitoring procedures to be carried out.

Technical design of the guideway elements and assemblies must always take into account a sufficient number of load changes while, at the same time, considering the possible failure scenarios. Whereas the load/failure scenario to be taken into account depends on the technical design of the component, the inspection procedure, the reaction times to deviations and the operating program determine the number of load cases considered.

In addition, it is necessary to take into account whether such an additionally loaded component is subjected to this load once or several times in the course of its service life.

For these reasons, it is, in the end, the supplier of a guideway who is responsible for the monitoring method which is matched to its type of construction. During definition of the general parameters, however, as described in Chapter 1, the integration of the guideway in the overall system is of central importance.

Examination

Examinations are usually carried out manually. Either they become necessary due to the evaluation of the monitoring results (detailed examination) or they supplement permanent monitoring (scheduled hands-on inspections).

In order to be able to assign a cause to a deviation ("first detection") found during monitoring, manual examinations ("detailed examination") will become necessary. Usually, the first detailed examination consists of a focused hands-on examination of the problematic component by a maintenance employee.

If the hands-on visual inspection does not yield any clear ideas regarding the cause of the problem, a further examination is arranged. As shown in the example below, this could be a geodetic measurement.

If a concrete cause is suspected immediately after evaluation of the monitoring results on the basis of typical findings, it is possible to arrange for the probably necessary repair measure to be carried out at the same time as the hands-on inspection. In such a case, the repair measure could then be directly combined with the hands-on inspection.

Examples:

Monitoring findings	*Measure initiated*	*Result*
Problem detected during visual monitoring (camera)	*Detailed examination by employee on site (visual, hands-on)*	• *Crack* • *Chipping* • *Surface contamination* • *If necessary, initiation of a further examination (film-thickness examination of an anti-corrosion coating)*
Problem detected during short-wave monitoring of the stator plane	*Detailed examination by employee on site (hands-on)* *In the case of typical findings, simultaneous preparation of repairs*	*- Failed stator pack fastening*
Problem detected during long-wave monitoring	*Detailed examination by employee on site (hands-on)*	• *Damaged support bearing* • *Column movement* • *If necessary, initiation of a geodetic survey*

The results are evaluated manually with account being taken of the information gained during monitoring. In this regard, the respective component's history which is to be considered and the comparison with the results of reference-structure monitoring must be especially mentioned. Conclusions regarding problems to be expected in other parts of the route in future can, in relevant cases, become possible as a result of this. The results of the examinations must always be documented and made available for the expert's assessment of the route. The history of the construction must also be made available.

Expert's assessment, special inspection

An expert's assessment of structures according to DIN 1076 is based on inspections every 3 or 6 years. Due to the special features of the Transrapid guideway, part VI of the “Ausführungsgrundlage Fahr-

weg" (document describing the principles of guideway design and construction) gives precise details of the requirements for expert assessment of the maglev guideway. An important fundamental aspect of an expert's assessment of maglev guideways will therefore consist of the results of permanent guideway monitoring and the results of the examinations. The knowledge thus gained will be supported by additionally initiated special inspections of the expert which will be carried out randomly.

The reference structures permanently observed in the context of monitoring constitute an important aid to decision-making for the expert as well.

For this procedure, however, it is necessary that all the documented principles of guideway design and construction and therefore the maintenance requirements are taken into account as early as the component design phase. Otherwise, guideway development can result in a guideway which has no defects from a structural or safety point of view but which does not satisfy the operational or technical system requirements of this modern transport system and therefore cannot be used.

In addition, the maintenance program which is to be prepared for the guideway specifically for each project should be agreed on with those parties involved in the project. These parties basically include the expert who has been appointed for the specific project and who is responsible for guideway maintenance, the party responsible for later operations, the party responsible for overall maintenance in the project and the party who carries out the guideway maintenance.

3 REPAIRS / SCHEDULED SERVICE / IMPROVEMENTS

Apart from the inspections, repairs, scheduled services and improvements are the second large group of maintenance measures.

These measures are not only dependent on the type of construction of components and structures but, in respect of how they are performed, are also heavily dependent on general project-specific parameters.

Basically, however, there are some general project-specific parameters which are applicable in most applications. They are briefly described below.

- A nightly break in services is exclusively available for the performance of such measures, whereby this break has to be defined for each specific project.
- Temporary relocation of operations to alternative parallel routes is not possible.
- A road running next to the entire route does not exist and therefore the measures in question always have to be carried out from a special vehicle.
- All improvements and all repair and maintenance measures must be possible during operations or the nightly break in services.
- Unusual measures (e.g. comprehensive renewal of the anti-corrosion coating) can be combined and carried out at large time intervals. Continuation of operations on one track must be ensured when these measures are performed.
- Measures for upholding operations such as winter services and vegetation care are to be integrated in the schedule of work
- Maintenance measures for other installations in the vicinity of the route (radio masts or switch stations if in the direct vicinity of the route as well as installations of third parties such as road bridges) are to be included in the schedule of work.
- Tunnels usually have only one track.

These typical project-specific general parameters inevitably lead to the maintenance requirements defined in the "Ausführungsgrundlage Fahrweg".

In order to verify the suitability of a guideway for use in practice, it is necessary to verify in a suitable form that all maintenance measures defined for the respective components can actually be implemented.

This has generally to be proven on a prototype component. The prove includes, for example, replacement of a component or repainting of the surface of the guideway under conditions which approximate those that will be encountered in practice.

The comprehensiveness of the prove must be defined on a project-specific basis and in relation to the type of construction.

4 AUXILIARY EQUIPMENT / SPECIAL VEHICLES / PERSONNEL

Self-evident as it sounds: the resources to be used for maintenance of the system are being selected, must be suitable for the intended purpose. However, one will soon find out that this requirement will almost certainly result in compromises if all technical, organizational and legal parameters are taken into account.

The necessary technical equipment must be defined in relation to the type of construction and on the basis of the previously defined maintenance measures (see maintenance programs and maintenance instructions). It has to be defined for each specific project on the basis of the concrete project stipulations (work and procedural instructions).

These considerations must also include a definition of the reference structures to be monitored, as well as a definition of the inspection systems, including the repair-, winter-service and other equipment.

When personnel is being selected, it must be ensured not only that the employees are suitably qualified and have appropriate personal experience but, furthermore, that the multi-faceted nature of the daily technical tasks involved is taken into account when the team is being formed. Questions relating to mechanical engineering, surveying, electrical topics and measuring must be dealt with as well as the technical structural aspects of steel and concrete structures.

The organizational unit entrusted with maintenance of the guideway must therefore possess a wide range of specialist knowledge which allows it also to manage external personnel that are brought in for a short term to perform special tasks.

When the technical resources are being planned, the main focus must be on the special vehicles to be used and the inspection systems.

The first step in this respect is to define the necessary inspection systems. These can be divided into stationary systems (e.g. at reference structures), passenger-vehicle supported systems (e.g. monitoring of the function plane geometry), systems restricted to special vehicles (camera systems) and other systems (e.g. geodetic measurements during examinations).

The resulting requirements for the special vehicles can then be combined with the requirements arising from operation (time window, timetable, integration in operations control system etc.), the requirements arising from measures for upholding operations (winter service, vegetation control) and other requirements (track layout, clearances in cross-section, personnel planning etc.). On this basis, the number and technical characteristics of the special vehicles for a project can then be defined.

For cost reasons, it should be ensured that the special vehicles to be kept ready for later maintenance purposes are already available for commissioning purposes in the construction phase. This avoids duplication of investment costs.

From today's point of view, therefore, a modular special vehicle consisting of a basic vehicle with modules which can be added or removed as required is to be recommended for the diverse measures.

Another important aspect of technical resource planning are the requirements of the Overall System. The following questions are especially to be taken into consideration at the interfaces between operations, higher-level maintenance and guideway maintenance:

- Which guideway sections are available for maintenance of the guideway and when?
- What measures are necessary for upholding operations and when are they necessary (winter service, vegetation control)?
- Which inspections can be carried out on passenger vehicles during operations?
- What clearances are there in which section of track?
- Can the maintenance measures specific to the type of construction be implemented, given
    - the existing personnel planning
    - the planned equipment
    - the other measures necessary along the guideway
    - the possible deployment times
    - and the route planning?

As early as in the project planning phase, an iterative process of reaching agreement on these matters must be started.

5 REQUIREMENTS ON COMPONENTS

An essential part of the requirements regarding the serviceability of the guideway and its components for use in practice consists of the requirements arising from maintenance/maintainability.

Constructions therefore must always be designed to be robust and fault-tolerant. In addition, the constructions must be such that the principle of extensive automated initial detection with chronologically offset evaluations, detailed examinations and repair measures can be implemented.

As early as the technical design phase for the components and assemblies, an analysis of possible failure scenarios and the maintenance measures they necessitate (inspection systems, intervals, maintenance and repair measures) is necessary in order to be able to ensure sustained operations at a later time.

Moreover, prototypes are to be subjected to a test under general conditions which approximate those that will be encountered in actual practice. Experience shows that this test should preferably take place over a long period of time in order to gather as much experience and knowledge as possible.

As far as generally possible, (i.e. possible independently of a project and a type of construction) the maintenance-related requirements have been defined in the “Ausführungsgrundlage Fahrweg”. Compliance with these requirements, which are not always relevant to safety but are all the more important from the point of view of system-serviceability, will be checked by the systemtechnical examination.

6 DOCUMENTATION

Special attention must be paid to the documentation in order to safeguard sustained operations.

Only on the basis of a comprehensive documentation of the history of the components involved can long-term changes in the guideway be detected and the right maintenance measures defined. This is the more important since the individual persons involved in the project (and its individual phases) will change after the system is in operation for a long time.

In the “Ausführungsgrundlage Fahrweg”, therefore, the creation of a structure database is required. This must be updated continually and must contain the relevant information from the following phases:

- Planning and design approval
- Installation of components
- Commissioning
- Acceptance inspection of components
- Continuous maintenance and, if applicable, conversion

The structure database should be created on the basis of the guideway equipment list and should contain the information required in the “Ausführungsgrundlage Fahrweg”.

Furthermore a project-specific maintenance manual must be prepared by the operating company. This manual should be divided up as follows:

- Maintenance programs
- Maintenance instructions
- Procedural instructions and
- Work instructions

The maintenance programs and maintenance instructions are to be provided by the respective suppliers of the components and assemblies whereas the other parts are to be prepared by the operating company (or a third-party appointed by it).

The maintenance program must contain all the project-specific information which is required in the document to be provided by the operating company, the document being entitled "Principles and Procedures for the Preparation of Maintenance Programs" in accordance with the German MbBO (regulations governing the construction and operation of magnetic levitation systems). The maintenance program will basically contain a list of all the inspection and repair measures with statements on intervals, personnel needed, times required and similar.

The maintenance instructions must contain the location-independent technical instructions for performance of the individual maintenance measures on the structure supplied.

The procedural instructions must contain project-specific stipulations as to what procedures are to be followed when measures are performed whereas the work instructions depend on the previously provided information and contain location-related technical stipulations for the performance of individual measures.

A guideway designed, realized and maintained as described above and in line with the requirements of the new “Ausführungsgrundlage Fahrweg” ensures for its part that commercial operation of the Transrapid System will be a success. Possible faults will henceforth not interfere unduly with operation. However this requires a close cooperation among all project partners and an early consideration of not only safety but also serviceability and thus the aspects of maintenance.