THE TRANSRAPID MAGLEV MAINTENANCE PROCESS

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Abstract

This paper describes the principles and procedures for creation of the maintenance programs and the execution of the respective maintenance measures. The realisation of the process is described with reference to the vehicle fleet of the Shanghai Maglev Transrapid Project. The evaluation of maintenance data and continuous optimisation of procedures is presented. The results confirm the excellent availability of the vehicles, and the effectiveness and efficiency of the maintenance process.

1 Introduction

The maintenance of the vehicles of the Shanghai Maglev Transrapid Project is carried out in compliance with the German Maglev Building and Operating Regulations (MbBO). The maintenance program has been created on the basis of principles and guidelines approved by the German Federal Railway Administration (EBA). According to these principles and guidelines, the maintenance measures are specified using systematic analyses of kind and effect of potential failures, and a continuous evaluation of maintenance and operations data for optimisation of measures and procedures. This process is described hereafter.

2 Principles and process for maintenance

2.1 Maintenance concept derived from safety and availability analysis

The Transrapid Maglev vehicles represent a mechatronic system where the functions levitation, guidance and safety braking are realised by electrical and electronic means with integrated intelligence, embedded in the mechanical structure.

Essential technical requirement of the safety concept is that Transrapid vehicles can always stop at one of the designated stopping areas where passengers are able to safely exit the vehicle, regardless of operational disturbances, failures, and/or emergency situations. This is achieved by the „safe hovering“ concept. Its essential features are

- safe-life function of levitation and guidance
- safe-life function of the vehicle-bound eddy-current braking system
- safe-life function of the on-board power supply.

These safe-life functions are realised in redundant structures using autonomous line-replaceable electric and electronic units with on-line diagnosis.

As a new transportation system, Transrapid has been subjected to a detailed and comprehensive safety analysis and evaluation. Systematic procedures were executed and approved prior to start of operation:

- failure mode and effect analysis, fault free analysis
- strength and fatigue analysis
- simulation and test bench trials
- trial runs

The aim of the study was the elaboration of a safety and maintenance concept, taking into account both the system's technical characteristics and operational parameters as well as its environment. System specific predefined measures combined with redundancy and on-line-diagnosis imply in addition to safety an outstanding availability, because external impacts are systematically minimised and component failures can be tolerated. The gross part of failures is detected by on-line diagnosis and repaired on daily intervals. Quantitative assumptions of fault tree analyses concerning periodic component test intervals and component down times in case of failures are included in the development of the maintenance plan. Scheduled maintenance includes component function tests necessary for monitoring control functions, starting mostly at annual intervals as defined in the maintenance program and being modified with increasing experience in failure probabilities.

The magnetic levitation as an essential function of the Transrapid system will be discussed as a representative example. Transrapid vehicles are equipped with a continuous series of levitation frames on both sides of the vehicle. Each vehicle section has four levitation chassis each containing four levitation frames. Functional redundancy at the levitation frame level, as shown in Figure 1, includes the following features:

- two half magnets, each with one magnetic control unit ,
- two air gap sensors per half magnet for measuring input signals to the magnet control circuit,
- air gap signal exchange with the neighbouring control circuit,
- pneumatic spring which can be depressurised in case of magnetic control circuit failure in order to reinstall nominal magnet load,
- mechanical support by gliding skids in case of seldom failure of both magnet control circuits.

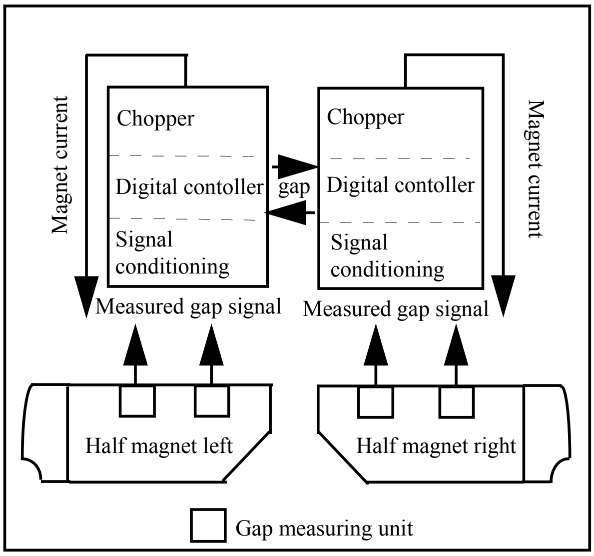

Figure 1: Levitation frame with two control circuits

If a failure occurs in an electronic device or a circuit board, the malfunctioning unit will be immediately disconnected from the system in order to minimise the disturbances to the entire levitation system. Due to full redundancy of all levitation functions, setting down of a levitation frame on gliding skids is a very rare event.

The steps of the analysis of both safety and availability comprise master diagram with systematic identification of all initial events causing risk of injury to any individual under the aspect of safety and the risk of service delay under the aspect of availability, FMEA for identification of safety relevant and availability relevant components considering mechanical structure and single parts as well as electric and electronic functions and components, FTA for quantification of probabilities of failure combinations, quantitative evaluation of consequences and service delays and finally analysis of various optimising measures. These steps represent a closed loop process resulting in a most efficient set of measures and an optimised safety concept and maintenance concept.

Additional optimisation of operation and maintenance is based on test results and experience with the new support skids. The results show, that the distances for airport connections allow to continue operation with a levitation frame set down on its skid so, that the vehicle can finish a scheduled trip. As a consequence high vehicle availability can be obtained without need of maintenance measures during the operations day. This means, that a vehicle exchange during the operations day for component replacement to restore system redundancy is not necessary. All component replacements can be performed after the end of the operations day.

2.2 Experience during vehicle commissioning

For the Shanghai Maglev Transrapid Project, three vehicles were delivered, each having five vehicle sections. Vehicle commissioning started with levitation tests of a three section vehicle in September 2002, first test runs at high speed > 400 km/h were carried out two weeks later. Operation of the second vehicle, which had its final configuration from the beginning, started in March 2003. Vehicle 3 carried out first test runs in initial configuration with three sections in July 2003. End of November 2003 all three vehicles were reconfigured to the final length of five sections.

Just before the final reconfiguration to five sections, with the first trip in the evening of Thursday November 13th, 2003, vehicle 1 was tested for 5 days in a configuration with eight sections. The next day this up to now longest Transrapid vehicle reached a speed of 423 km/h with simulated passenger load. In the same week, on November 12th, a speed record of 501,5 km/h for Transrapid maglev vehicles was reached with a five section vehicle. These tests were executed on demand of the customer, in order to demonstrate both, high transportation capacity with long vehicles, and 500 km/h speed with respect to future long distance operation.

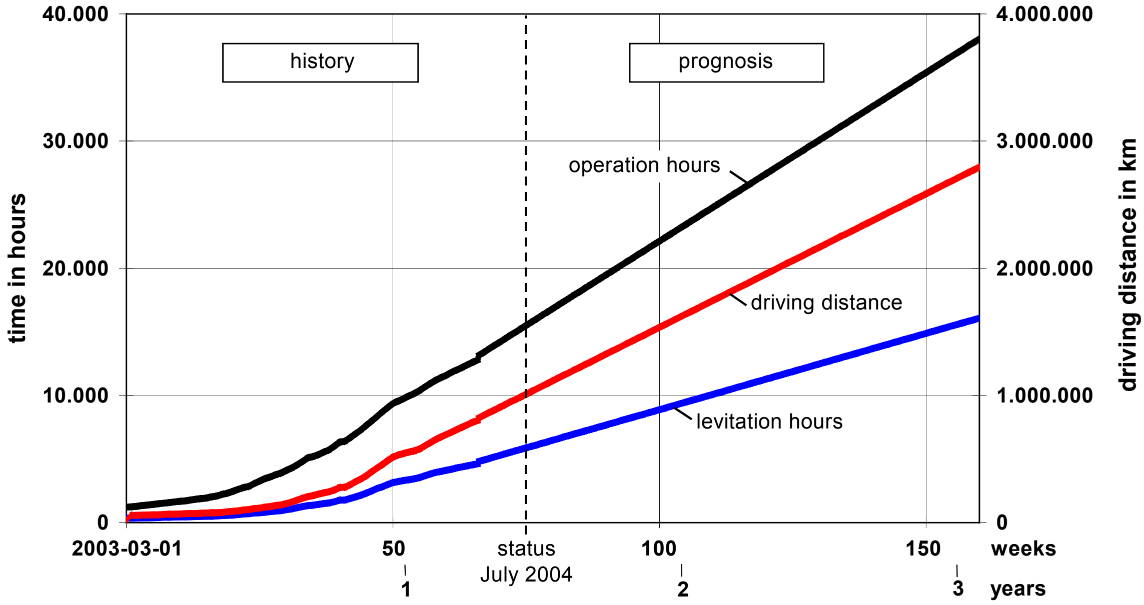

Figure 2: operation data of Shanghai Transrapid vehicles

For demonstration of the system performance, in calendar week 7, 2004, all three vehicles operated in circular mode with minimum headway of 10 minutes for a daily operation time of 16,5 hours. The average daily driving distance per vehicle covered in this week was about 1 500 km corresponding to a total of 31 200 km for this week. Current data in June 2004 are operation with 2 vehicles and 15 minutes headway and daily operation time of approximately 9 hours. Daily driving distance of the vehicles in operation is about 1050 km each. Current status and extrapolation based on the current data for operation and levitation hours, and of the overall driving distance of the vehicles are shown in Figure 2.

2.3 Continuous failure analysis and MTBF evaluation during operation

For the vehicles of the Shanghai Maglev Transrapid Project, a data base for recording of maintenance data was installed in parallel with the assembly of the first vehicle. The data-base includes life cycle data of the vehicle's components, records of detected failures/findings, and records of executed scheduled and unscheduled maintenance measures.

By doing so the process of analysis and evaluation of maintenance was initiated together with the start of commissioning of the first vehicle. In addition to detailed maintenance analysis, a weekly condensed report gives an overview about operations performance and findings/evaluation of maintenance.

MTBF data of electrical and electronic components of active vehicle systems are needed both as input data for safety and availability analysis calculation and for the prediction of average number of unscheduled maintenance measures.

Knowledge about failure mode and failure cause is derived in increasing detail in three steps from the following three information sources:

- diagnosis message, which is the first information leading to replacement of a vehicle component,
- test bench result and component repair by replacement of printed circuit boards (PCB). This results are basis for the evaluation of the MTBF values,

- most detailed understanding is derived from the determination of basic electronic element failures during test and analysis of the defective PCB's.

About 20 various types of special test benches are used for scheduled and unscheduled component tests, some of them are supplied in multiple number for redundancy. Among others are test benches for magnet control units and gap measurement units including a vibration test, for linear generator converters, on-board control units, on-line-diagnosis components and the other components involved in the active vehicle functions. Included are also a magnet test bench to test components of magnet control circuits under dynamic load conditions and maintenance equipment for scheduled servicing of battery containers to restore nominal battery conditions.

A maintenance history data base contains a classification of the reason for removal of a vehicle component. This classification, called "fault category", is based on messages of the on-line-diagnosis, visual findings at removal of the component, findings during function test on special test benches or other sources. Main fault categories or other reasons for component removal are

- non-systematic defects of electronic elements: this category of statistical faults is considered in MTBF evaluation,
- early failures from production, damage on transportation or mistakes in maintenance and operation,
- external impacts,
- scheduled function tests according to the maintenance program.

About 20 change proposals for vehicle hardware and software modifications have been placed and executed in the time between July 2003 and June 2004 as result of experience with operation and maintenance.

The collection of maintenance history data will be continued in the future with information from the operators maintenance personnel, which is responsible for vehicle maintenance since overall acceptance on April 13th, 2004.

The detailed procedure of the MTBF evaluation is described in a work instruction. The evalution of the overall MTBF value of the electrical/electronic vehicle components with operation time, as shown in Figure 3 for week 28, 2004, is included in weekly reports on vehicle operation and maintenance. It must be pointed out, that the detailed results from the determination of basic electronic element failures during test and/or repair of the defective PCB's are not considered in this evaluation results. These detailed findings are used for further product improvement.

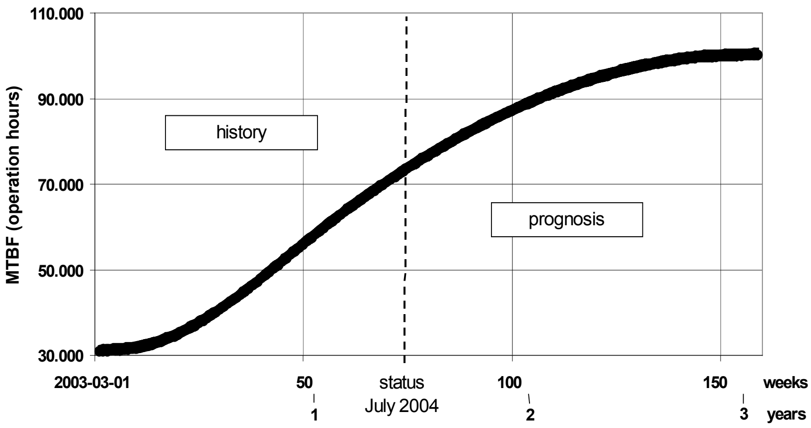

Figure 3: MTBF of electrical components of the vehicles

The specific MTBF evaluation for components which have most influence on vehicle function is used to confirm fault tree analysis input data. All MTBF values show an increase during system operation, as can be seen from Figure 3. The prognosis indicates a MTBF of about 100.000 h.

2.4 Maintenance activities during night operation break

All scheduled maintenance measures and replacement of defective components are carried out in the night shift during the operation break. After arrival of a vehicle in the maintenance centre the following steps are carried out:

- complete deactivation of vehicle and shut-down of power rails,
- general visual check, taking about 30 min,
- replacement of defective components,
- regular inspection with measures and intervals according to maintenance program: these inspections are carried out zone by zone in consecutive night breaks,
- in addition, all scheduled component function tests on test benches are performed during the operation break, with the components being reassembled to the vehicle before end of the night break.

The preparation of the vehicle starts 45 min before leaving the maintenance area with the following steps:

- general visual check,
- activation of the vehicle,
- system check consisting of
  - check of basic settings for location system check,
  - eddy current break system test and
  - general function test including activation of levitation system,
- replacement of defective components is carried out on demand before start of operation, if a failure is indicated during the self-checks being performed during vehicle activation.

Defective components, which have been replaced during the night break, are tested and repaired using the specific test bench during daytime.

2.5 Optimisation of maintenance

The essential part of the maintenance process is a continuous analysis and evaluation of the parameters related to these functions during operation, in particular kind and number of failures and findings. The result of systematic maintenance analyses may be:

- to enlarge the intervals of maintenance measures or even cancel certain measures, if failure/findings occur less frequent than expected or never, or
- to shorten intervals or define additional measures, if failures occur more frequent than expected, or new findings occur.

With this method, a continuous adaptation of the maintenance to actual demand takes place, optimising effectiveness and expense.

Main focus of the improvements of the maintenance manual was insertion of supplementary information to the client including instructions and drawings, and consideration of increasing experience. Such improvements are e. g. changes in the sequence in order to reduce the number of working steps for failure localisation, optimisation, addition or removal of individual working steps or optimisation of report forms.

Figure 4 gives an overview of the change of instruction and drawing number in the course of at present four releases of the maintenance manual.

The maintenance program consists of a total number of about 400 different scheduled and 60 unscheduled measures. About 150 measures are visual checks, with, except from 5 daily measures, longer intervals up to 10 years. Approximately 80 of the measures are function tests, 33 of them annually, 10 at three month interval and 25 as unscheduled measure in case of diagnostic message after replacement of the component at the end of operation day. About 180 measures are exchange measures. Included are the unscheduled measures in case of failure, replacement of operating resources like air filters for the air-conditioning system and about 30 exchanges of minor wearing parts like rubber bearings.

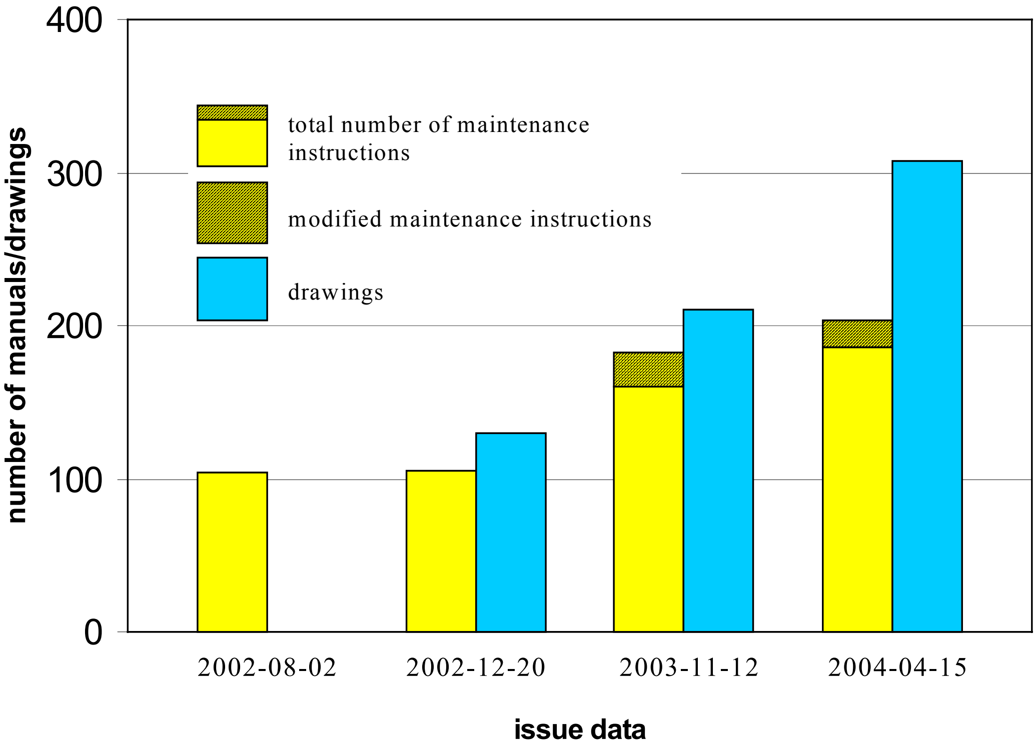

Figure 4: Maintenance manual optimisation

23 new measures have been added in the latest issue of the maintenance programme. 43 measures have a change index in the new issue, most of the changes concerning changes in the reference documentation. Intervals were changed for six maintenance measures. In for cases longer intervals are determined according to increased experience. In two cases an interval for door pneumatic cleaning required after longer parking time of a vehicle has been adjusted from a six weeks period to execution on demand.

3 Results - performance of vehicles

By July 11th, 2004 the accumulated operating time of the three vehicles from start of commissioning was 13.500 h, here of 4.850 h levitating time. The total mileage of all three vehicles until July was about 1.000.000 km, representing more than 30.000 trips. The number of Transrapid passengers reached 1 million on July 3rd, 2004.

Since end of commissioning, the actual availability of the vehicles for execution of scheduled passenger trips reached 99,9 %. This considers all cases, where scheduled trips were cancelled or delayed for more than five minutes.

All items, which caused cancel or delay, could be solved by further optimisation of handling procedures and elimination of a weak point in the doors. In no case from the beginning of commissioning, an unscheduled stop was forced between the two stations due to a malfunction in any of the three vehicles.

The excellent performance of the Transrapid vehicles and its maintenance process has been demonstrated impressively.

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