MAGLEV SYSTEM MAINTENANCE STRATEGY

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Abstract

According to wear- and tearless operation of maglev, realised by mechatronic means, an appropriate maintenance strategy will be presented. A systematic methodology is described for identification of maintenance activities and prognosis of respective amount of labour, tools and spare parts. A description of maglev maintenance equipment and measures is given, which is based on experience with maintenance practice of the preseries vehicle TR08.

1 Introduction

Maglev represents a large mechatronic system where the main transportation functions, i.e. levitation, guidance, propulsion and braking are realised by electric and electronic means embedded in a mechanical structure operating without wear and tear, and having autonomous intelligence integrated in its components. The functions are realised by redundant line replaceable units, each having an autonomous supervision of its own function, switch-off in case of failure detection, and generation of respective on-line diagnosis information. Thus, maintenance of such a system is dominated by inspection of mechanical components and exchange of defective electronic modules indicated by on-line diagnosis.

2 Transrapid Vehicle Maintenance Features

2.1 Maintenance Strategy

The maintenance of the Transrapid subsystems is based on maintenance facilities with the following features

- coordination of measures with the operation control centre,
- reception and storage of the on-line diagnostic messages,
- prioritisation, planning, instructing and execution of maintenance measures,
- report of completion, feedback of results and release of the equipment serviced,
- management of personnel, material and resources.

Vehicle maintenance activities are primarily inspections and repair activities. Preventive measures are limited to some conventional components like vehicle doors, air conditioning and on-board batteries. Main activities of vehicle maintenance are inspection of structural components, function tests and replacement of electric and electronic components in case of diagnostic messages.

Normal scheduled and unscheduled measures can be carried out during operational train breaks. A standstill period of a vehicle is necessary for annual inspections, where disassembling of interior and outside cladding elements is required.

The technical features of the system result in high system availability with interruption of scheduled vehicle trips only occurring through failure of multiple component groups. It can be estimated, that a system break-down, which requires replacement of a defective component to resume scheduled operation, will occur only once within 1 to 2 years.

2.2 Maintenance Program

The maintenance program defines the scheduled and unscheduled maintenance measures required to ensure safety, availability and performance of the Transrapid system. The maintenance measures are based on fault tree/failure effect/maintenance analysis, inspection/test results, and manufacturers specifications for components.

Scheduled Maintenance:

Planned maintenance work is performed in maintenance centres.

All planned measures are listed in a table containing a consecutive number, maintenance code (IA-Code), the vehicle part, to which the measure shall be applied (called "zone"), short names of maintenance object and measure, categories for failure effect, for maintenance measure, planned periodic intervals or deadlines as e.g. operating hours, km or annually and vehicles operational status for execution of measure.

Scheduled maintenance measures include component function tests to detect specific failures, which can't be detected by the on-line diagnosis system in normal vehicle operation. An example are tests of control functions, which according to preconditions of fault tree analyses may start at annual intervals and, with increasing experience, can be modified in consideration of failure probability results.

Unscheduled Maintenance:

The unscheduled measures following messages of the on-line vehicle diagnosis, as used for the vehicle TR08, are listed in form of an EXCEL data sheet and will be converted to an ORACLE data base. The columns of the EXCEL table contain information like component type, message number and short name, name and code of maintenance action and a reaction time. This reaction time is derived from system redundancy and the implications on vehicle availability.

Considering the planned operation timetable, single failures are repaired by component replacement in the maintenance area or in decentralised service stations, depending on the travelling distances, without interruption of scheduled service. Typical reaction times for component replacement are

- end of single vehicle trip or vehicle round trip, especially in case of magnet control units,
- daily operating hours with elongated headway depending on traffic volume distribution,
- daily service interruption intervals,
- an about 10 days interval, when the on board power supply is periodically turned off and specific failures can be detected.

The principles and processes for creation of the maintenance program is one of the basic documents for type approval of the Transrapid system by the German Railway Authority (EBA). They are basis for the development of the maintenance programs of the Transrapid subsystems.

The maintenance program shall be checked periodically for efficiency and economic effectiveness against the experience gained from operation, inspection results, type and frequency of failures, and updated as necessary.

2.3 Vehicle Maintenance Manual

Requirements for the development of the maintenance manual were

- electronic database,

- structured search capabilities,
- easy, user-friendly access,
- adaptability in order to improve maintenance processes respecting the relevant configuration management procedures,
- easy distribution of up-to-date documents,
- use of future-oriented technique.

Based on the investigation of different alternatives the maintenance manual was realised in the html internet format. The use of hyperlinks allows for easy change between the different types of information which are classification according to hardware objects, maintenance measures, test device, protocols for reporting measures and results, configuration information consisting of lists of maintenance and operating instructions, drawings, documents and regulations, structural information subdivided in assembly and function structure and additional information. Figure 1 shows the homepage of the TR08 maintenance manual.

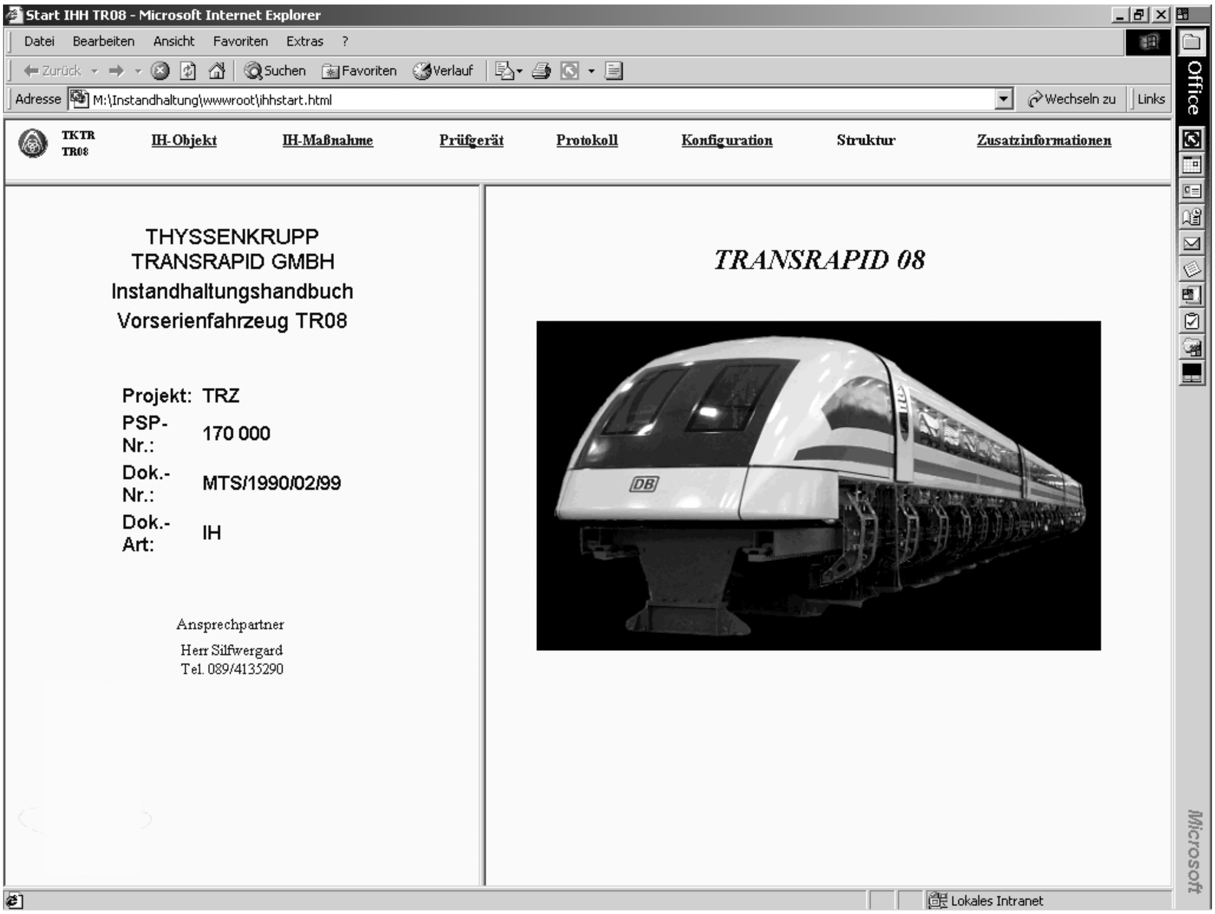

Figure 1: Homepage of TR08 Maintenance Manual

A numbering system was introduced for well-defined identification of all maintenance measures. A eleven-digit number consists of both hardware object and type of measure codes. The IH-Code serves for identification and classification of the hardware objects. The last three digits describe type and a consecutive number of the maintenance measures. Types of measures are

- preventive maintenance as e.g. preservation, cleaning, adjustments, exchange or replenishment of operating resources, and lubrication,

- inspection measures as e.g. general or thorough visual check, non-destructive or destructive material test, function test with or without testing instrumentation, measurements or inspection by on-line or off-line diagnosis and
- repair measures as e.g. modification, overhauling, component replacement or software program restart.

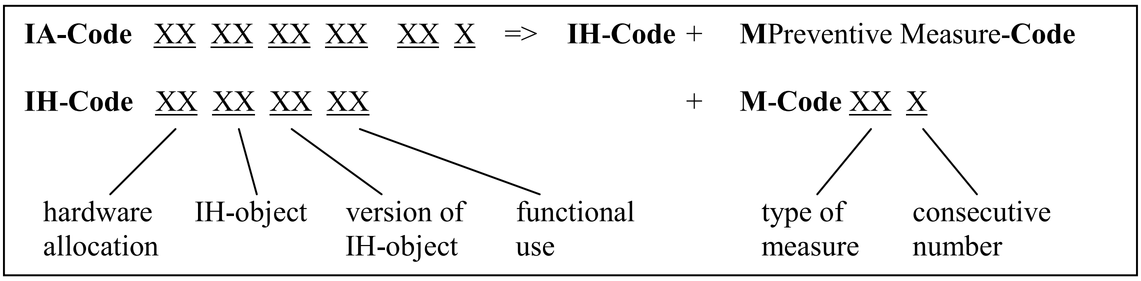

Figure 2 shows a detail of the hardware object description in the TR08 vehicle maintenance manual.

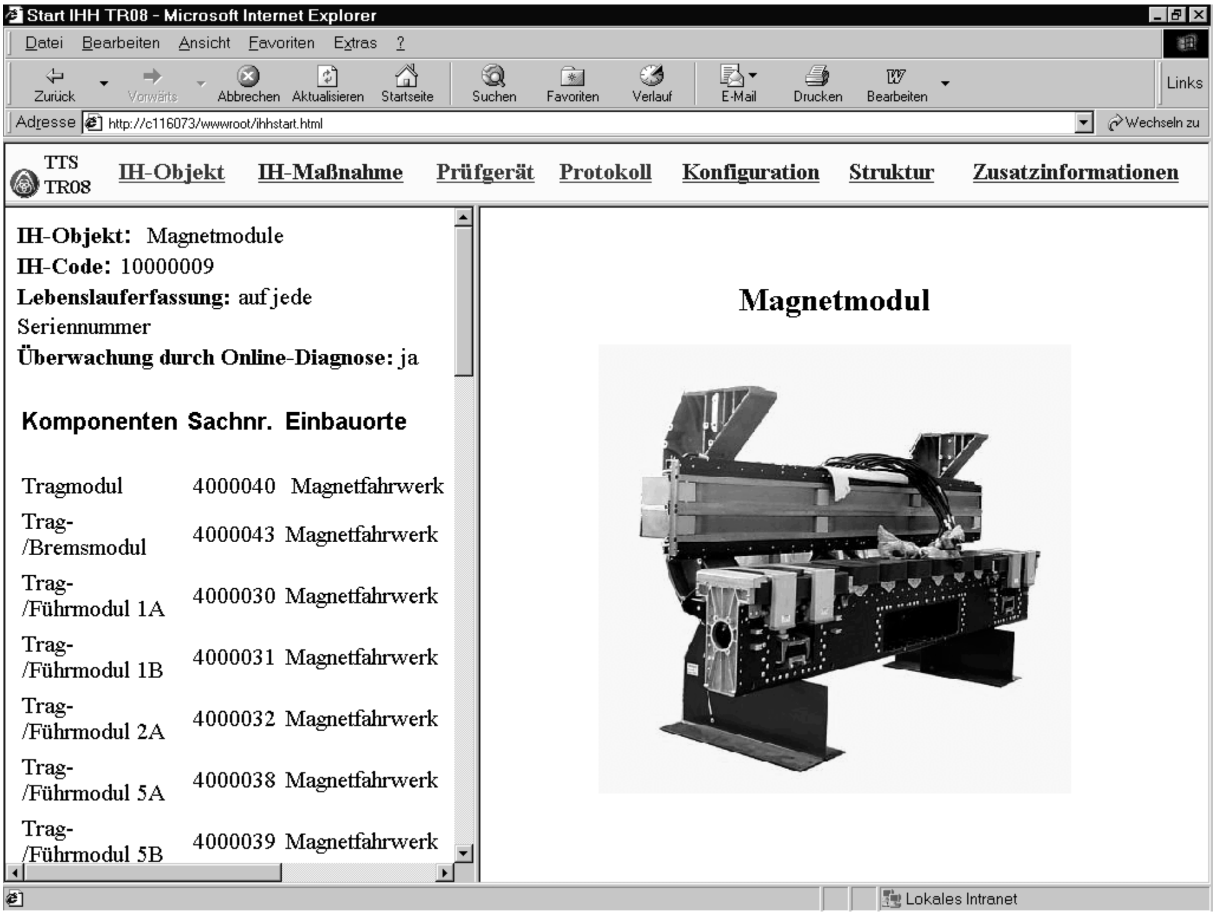

Figure 2: Detail from Hardware Object Description in Maintenance Manual

2.4 Maintenance Instructions

The IA-code given in the list of scheduled and unscheduled measures of the maintenance program is the easiest, non-ambiguous way of finding an instruction in the maintenance manual. Following the title with author of the instruction, technical release, quality control, issue date and modification index the manual contains the following chapters:

- documents to be applied including references to safety and accident-prevention regulations, drawings, and other maintenance or operating instructions,
- list of definitions and abbreviations used,
- application area,
- personnel with qualification and number and resources (spare parts, material, measuring and test devices, auxiliaries, etc.) required including average duration of measure,
- preparation with safety measures, boundary requirements,
- working plan with description of the sequence of operational steps and detailed instruction for reporting with hyperlink to the protocol form to be applied.

A single IA-Code is used in the same way for the identification of repair measures even in cases, where the diagnostic message doesn't allow for a precise identification of the faulty component. An example might be a missing magnet gap signal, which can be due to a failure of the gap measurement unit, of the signal cable or of the signal input circuits in the magnet control unit. For localisation of such a fault the sequence of operational steps is fixed according to experience so, that the origin of the diagnostic message is found in the most efficient way.

2.5 Training of Maintenance Personnel

The objective of predefined training procedures is to qualify engineers, technicians and skilled workers, before they start their daily work in operation or maintenance services to assure reliability and safety of the transport service.

A basic training assures an overall understanding of the system. It includes among others the following topics:

- theoretical lessons about procedural rules regarding safety and maintenance,
- lessons regarding the organisation of operation,
- basic technical functions of the Transrapid system,
- procedures and rules for information exchange using the technical communication infrastructure,
- practical participation in daily operation and maintenance in order to get basic knowledge and understanding about different types of services and responsibilities,
- practical safety training; trainees have e.g. to take part in simulated emergency evacuation procedures including the practical handling of the on-board safety equipment.

A special training for future work in operational or maintenance service contains:

- theoretical lessons about technical and functional details of the subsystems with respect to the specific service,
- handling procedures for necessary user interfaces, diagnostic systems, test devices, tools and spare parts,
- operation and handling of special maintenance vehicles,
- theoretical lessons and practice for the specific service reports and the use of specific electronic data processing tools,
- use of the maintenance management system.

A person responsible for levitation system maintenance e.g. will be provided with knowledge about the functions and reactions of the vehicle levitation system and the interfaces with other vehicle systems. In practise all necessary procedures for changing parts, using diagnosis and measurement tools and the documentation procedures for executing a maintenance measure will be trained.

3 Quantitative Maintenance Planning Methods

3.1 Vehicle On-line Diagnosis

In the vehicle, the diagnosis system reads out, in cycles, the process images of the modules on which a diagnosis procedure can be performed. The process image is the group of signals containing all the information transferred from a module to the vehicle diagnosis system. These can be in the form of raw data (simple signals) or diagnosis data (flags which have been set on the basis of evaluations carried out in the module and which display a diagnosis status in the module). The imported process images are checked by evaluation algorithms, which may also contain information transferred to components of the vehicle diagnosis system (e.g. speed signal, signal "vehicle raised"). If a fault is detected a diagnostic message is generated which will report the fault. If the fault disappears, a message will be generated that the fault does no longer exist. The diagnostic messages are sent to the central maintenance department and stored in a database, where they can be evaluated.

A distinction is made between the "vehicle diagnosis system" and "central diagnosis system" (Figure 3). The vehicle diagnosis system refers to all the diagnosis equipment in the vehicle, whilst the central diagnosis system refers to the diagnosis modules in the central maintenance facilities.

The radio transmission of the vehicle operation control system is used to transfer the diagnostic messages from the vehicle to the central diagnosis system. The data (diagnostic messages) are not modified on this route.

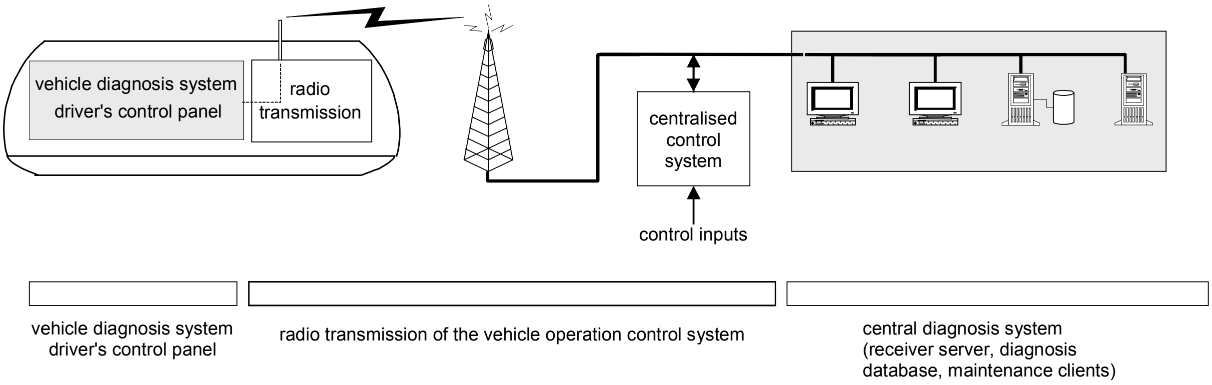

Figure 3: Vehicle and Central Diagnosis Systems

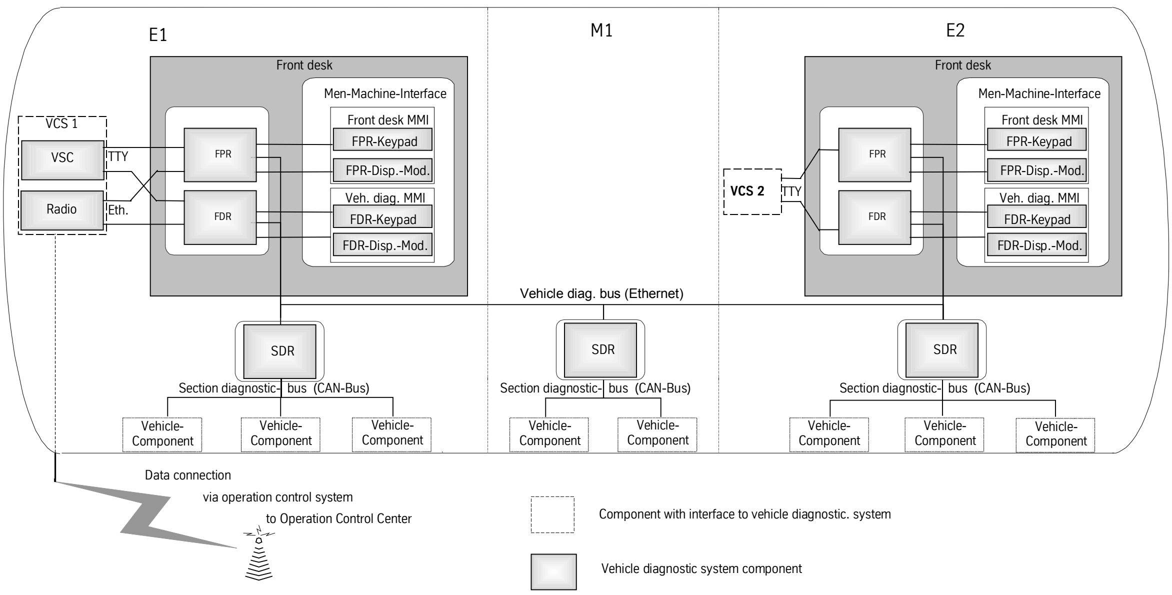

Figure 4: Components of the Vehicle Diagnosis System

A diagnostic message is generated in the diagnosis computer for vehicle section diagnosis, vehicle diagnosis computers or front desk controller and from there it is sent to the operation control centre database and the "vehicle diagnosis MMI". The diagnostic messages are supplemented by additional information such as the component mounting place and database-specific information. The receiver server of the operation control centre database converts the diagnostic messages into the database format and confirms to the vehicle that the diagnostic messages have been successfully transferred to the database or otherwise sends a correspondingly negative message if they haven't. Access to the diagnosis database is done via so-called "clients". From here, authorised maintenance personnel can retrieve diagnostic messages and perform reset operations.

Diagnostic messages of vehicle components are transferred within a vehicle section to the vehicle section diagnosis computer (SDR) via CAN-bus. Messages of the vehicle section diagnosis computers are sent via the vehicle diagnosis bus (Ethernet design) to the redundant existing vehicle diagnosis computers (FDR). The vehicle diagnosis computers are the central receiving points for all diagnostic messages generated in the vehicle. The FDR in end section 1 sends the diagnostic messages via the radio transmission of the vehicle operation control system to the operation control centre. If the FDR in E1 should fail, then the FDR in end section 2 will take over this task.

In order to display diagnostic messages on-site in the vehicle, the vehicle diagnosis computers also send the messages to the "vehicle diagnosis man-machine-interface" (vehicle diagnosis MMI), which comprises a FDR keyboard and the FDR display module. Figure 5 shows a view of the English version of the on-line vehicle diagnosis display with simulated example of a diagnostic message.

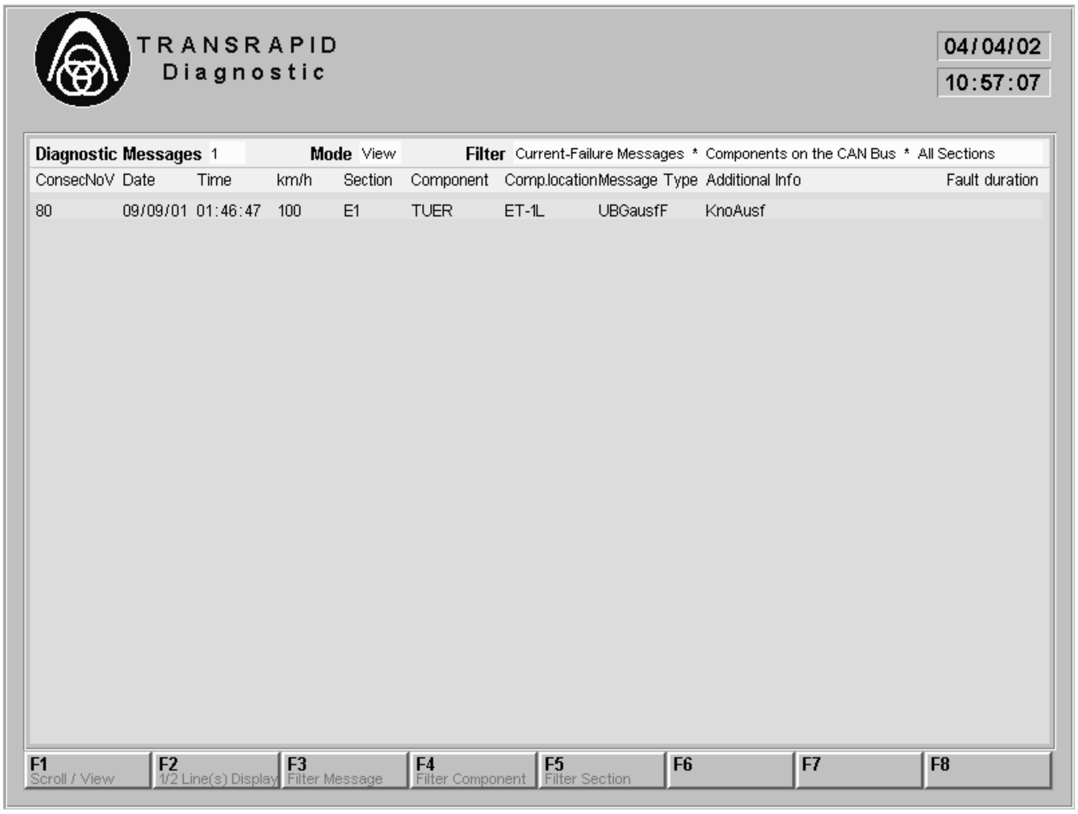

Figure 5: View of On-line Vehicle Diagnosis Display

Besides the vehicle components, the interfaces of the vehicle diagnosis system with other modules (e.g. with the vehicle operation control system or the radio system) and the diagnosis system components (e.g. SDR, FDR, vehicle diagnosis bus) are themselves monitored by the diagnosis system.

Another function of the vehicle diagnosis system, which is only mentioned in this context, is to transfer specific control signals from the keyboard of the front desk MMI to vehicle components (e.g. switching signals for lighting, headlamps on/off) and to transfer information on the switching status by means of "status signals" (e.g.: lighting, headlamps are on/off).

3.2 Repair Data Evaluation

Systematic reporting of vehicle component repair activities started in 1989 with a paper-based system for reporting component maintenance history. Now this reporting is part of a TVE-based computerised Transrapid maintenance management system (TIM: Transrapid Instandhaltungs-Management), whose data can be reported via internet by the companies involved in Transrapid development.

The experience with TR08 operation from September 1999 is to date (April 2002) based on approximately 5000 vehicle operation hours and a distance of close to 150.000 km covered.

The most important components for the active vehicle functions levitation and guidance, on-board power supply and emergency brake are magnet control units, gap measurement units and step-up chopper. A good statistical basis for reliability numbers of this components is the 3-section-vehicle TR08, where the large number of these components results in many accumulated operating hours and therefore highly accurate values (see table 1).

Table 1: Number of TR08 Electronic Components

component	number of units in TR08
magnet control units (levitation, guidance, brake)	216
gap measurement units (levitation, guidance)	384
step-up chopper	92
other electronic components	290

All replaceable units are sent to the manufacturer for repair. Repair data collected in form of quality notifications and excel data sheets are besides transport and repair times the mounting position of the defective component in the vehicle, associated diagnostic message, type and serial numbers of component and sub-assembly, description and material number of defective device, potential origin of failure, description of repair measures and fault classification.

The fault classification is result of the analysis of the findings in the repair process. Measures to improve reliability are hardware or software design modifications or modification of manufacturing, transport or handling processes. The very low number of outside impacts is analysed with respect to the specified application conditions as e.g. environmental or other boundary conditions. The number of unconfirmed failure reports is low as well, which is due to the accuracy of the diagnosis system. All statistical failures are reviewed regularly in order to detect potential systematic failures which may result in design changes.

At the end of this process MTBF-values are derived which are used for the prediction of reliability and unscheduled repair probability values.

3.3 Spare Part Provisioning

Specification of spare parts required for an application system is important for planning of initial investment and storage capacity.

The determination in the maintenance concept, which units have to be replaced or repaired at the site of an application system are basis for a list of type of spare parts. The spare parts provisioning is based on TR08 experience and considers

- the number of units in the vehicle,
- the implication of a failure to system availability,
- a basic spare part number of every type,
- a statistically derived spare part depending on the component MTBF-values for unscheduled exchange measures,
- scheduled exchange of components with defined lifetimes, where the necessary units are provided in due time for the scheduled measure,
- spare parts delivery time,
- and the spare part price.

A statistical spare part prediction, which is described in the following in more detail, is possible by using MTBF-values derived from TR08 experience as basis for the spare part number determination for application systems. The probability *P(r)* that *r* or less failures will occur for a total number of n_o components of one type in the vehicle within a time interval *T* can be calculated for components with constant failure rate using the statistical formula of the cumulative Poisson distribution

$$P(r) = \sum_{x=0}^{r} \frac{p^x}{x!} \cdot \exp(-p)$$

with

$$p = n_o \ \lambda \ T.$$

The time interval *T* considered in spare part provisioning depends on logistic times (e.g. transport times), times for repair and tests for repairable components or on procurement lead times for new components. The proposed probability of having sufficient spare parts is usually $P(r) \geq 99$ %.

3.4 Maintenance Equipment

In addition to the usual equipment of maintenance facilities, special equipment is required at the site of an application system to perform measures according to the maintenance program, in particular dealing with test of electronic units. This are special test devices e.g. for magnet control units, gap measurement units and others and maintenance equipment for vehicle batteries.

These test devices are used for scheduled maintenance like annual component function tests and for unscheduled function tests to confirm failures of components replaced in case of a diagnostic message.

The number of test devices required is determined with respect to the number and duration of the scheduled tests and the expected number of additional unscheduled tests, considering the number of components to be tested in the application system, test duration as well as the daily and annual schedule of required tests and personnel.

Special maintenance equipment are as well special vehicles used for guideway inspection and maintenance.

4 Summary and Conclusions

Using the favourable properties of the Transrapid maglev system and experience with modern maintenance methods in other high-tech areas, an effective and modern maintenance strategy has been developed. Based on experience with maintenance practice of the preseries vehicle TR08 and analytical procedures, an adequate maintenance program has been defined. Maintenance manual and instructions have been worked out with the user-friendly access possibility and future-oriented technique of the html internet format and hyperlink use for easy change between different types of information.

Systematic quantitative methods based on TR08 experience are used for prognosis of spare parts, equipment and manpower required for maintenance. The properties of the on-line diagnosis system and predefined training of maintenance personnel assure reliability and safety of the Transrapid system.

The detailed planning of maintenance is the final step to have the Transrapid system ready for application.