Latest Generation Maglev Vehicle TR09

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ABSTRACT: The latest generation Maglev vehicle TR09 and has been developed and built by ThyssenKrupp Transrapid GmbH and financed by the German Federal Ministry of Transportation (BMVBS). TR09 has started commissioning and test operation on the TVE in summer 2008 for verification of its features and for safety assessment.

TR09 represents an advanced design of TR08 which implies higher payload, improved ride comfort with particular regard to interior noise level and air conditioning. The vehicle meets the typical requirements of an airport shuttle service and offers wide entrance space and width of entrance doors. Finally a new design concept concerning the exterior and interior appearance was realized in close cooperation with Deutsche Bahn.

In addition several new technical features following up the tradition of a consequent advanced development have been implemented in the TR09 e.g. the contactless supply of external power in the low speed range by Inductive Power Supply IPS®. The paper includes a short description of such design innovations.

The safety assessment of TR09 is based on the CENELEC railway safety standards (EN 5012x) and on the Maglev design rules published by the German Federal Railroad Authority (Eisenbahn-Bundesamt).

The first results and experience of TR09 commissioning are presented in this paper.

1 DESIGN OBJECTIVES AND MEASURES

Figure 1 shows the TR09 in operation on the TVE. The vehicle was developed in accordance to the requirements of Deutsche Bahn with regard to an airport connector.

The transformation of these requirements had influence on the technical realization of several onboard systems, e.g. door system, air conditioning, carriage body design and auxiliaries, like onboard camera systems, fire detection and fighting system or the interface architecture concerning the passenger information systems. Also the levitation guidance system had to be adapted with regard to the requirements of higher payload. In addition several new technical features have been implemented in the TR09, e.g. the contactless supply of external power in the low speed range by Inductive Power Supply IPS®.

Figure 1. TR09 in operation on TVE

1.1 Economic aspects – payload and availability

With regard to the economic aspects the development of the TR09 has been followed up by two main characteristic features:

- Increase of the payload to meet peak hour demand by allowing standing passengers,
- Improve of the availability to decrease the need of stand-by reserve with the result of getting small vehicle fleet sizes and reduced maintenance expenses.

Table 1 shows the comparison of the relevant data concerning the transport capacity between TR09 and TR08.

Table 1. Comparison of transport capacity (3-section vehicle)

	TR08	TR09
Seats	310	156
Standing room	-	82.1 m^2
Max. Passenger capacity	310 persons	449 persons
Payload	27.9 t	40.4 t

In addition to the increased transport capacity the reliability of the TR09 has been improved. The initial calculation with the vehicle TR08 has based on MTBF-values of 20.000 h. The actual value of TR08 reached 40.000 h. The target value concerning the TR09 was 60.000 h and based on the current results the expectation is above 100.000 h. This means a significant reduction of maintenance expenses and the possibility to reduce the total number of vehicles due to higher availability. Furthermore the need for a backup vehicle in daily operation is not given.

Taking into account these results the economic effect for an exemplary airport connector project could be calculated as following:

Table 2. Economic effects on a typical airport converter project plan

	TR08	TR09
Number of vehicles in circular operation	3	3
Number of vehicles in reserve for long term maintenance	1	1
Number of backup vehicles for daily operation	1	0
Number of vehicle sections of each vehicle (comparable capacity)	4	3
Total number of vehicle sections	20	12
Effect of expences	100%	60%

1.2 Door system

The entrance doors differ from the ones used in the former vehicles, particularly with respect to:

- Increase of inner width,
- Arrangement of the doors in equal distance over the whole length of the vehicle,
- Communication interface to the gate door fulfilling the specifications for a automatic dispatching process.

The use of electrical driven main and rotary latch drives allowed further improvements with regard to the reliability.

Table 3. Key features of TR09 entrance door system

Drive system	Electrical, 24 V DC
Door design	Single-leaf swinging-sliding door
Door width	1,580 mm
Inner width	1,300 mm
Door height	2,210 mm
Locking	3 chocks and 2 rotary latches
Weight of door wing	270 kg
Opening/ Closing Time	6 s
Door distance	12,384 mm
Air pressure	+/- 6,000 Pa

1.3 Ride comfort

In order to meet the requirements of a comparable comfort as for long distance trains with regard to interior noise level, air conditioning, riding comfort and pressure sealing, the construction of the carriage body and the related subsystems has to cover the following aspects.

1.3.1 Interior noise level

Several measures evaluated by a systematical theoretical interior noise study have been integrated into the TR09. For the detail measure and the prognosis results compared with the TR08 see table 4.

1.3.2 Air conditioning

To meet the demands a new technical design of the air treatment units and the compressor / condenser units was inevitable. A new air conditioning concept also had to be integrated into the TR09 which not only lives up the comfort standards according to prEN 14750-1, category A, climatic zone 2, but also realizes a maximum headroom and a convenient feeling regarding the air duct and air streaming concept. For these reasons the following measures have been realized:

- Construction and arrangement of new air handler at the end of the vehicle sections with higher performance,
- Increase of the electrical and thermal power,
- Position of the external air intakes taking into account the pressure conditions,
- Integration of the air ducts in the double floor construction and the elements of the roof interior claddings.

Table 4. Measures and prognosis results concerning the optimization of interior noise level

Measure	Area	Prognosis
Sound isolation of outer skin of carriage body	Double floor, Optimization of side wall and side windows	-5 dB(A)
Optimization of acoustics	Absorption equipment, materials of surfaces and construction of seats	-2 dB(A)
Reduction of sound sources	Decoupling of interior elements and the bearing of carriage body	-1.5 dB(A)

1.3.3 Others

Concerning the riding comfort and the pressure sealing characteristics the development of the TR09 took into account the following targets:

- The secondary suspension system of the carriage body has a natural frequency of about 1 Hz and a conventional air feeder supply system working with a maximum of 10 bar,
- The air sealing of the carriage body and the respective systems inlet valve of air conditioning and door systems fulfills the following requirements: high pressure stiffness of the carriage body structure, pressure sealing up to 5500 Pa with a constant $\tau > 20$ s.

2 VEHICLE SPECIFICATION

2.1 TR09 Layout and interior

The sections of the TR09 have a luxury standard one-design class fitting. The design and layout meets railway standards but also the specific requirements of an airport connector, e.g.:

- Integration of multi-purpose zones,
- Luggage deposit areas and racks,
- Meeting peak time demand by offering areas for standing passengers,
- Assuring short passenger changing times by wide entrance doors and areas,
- Seat arrangement with 2+2 vis-á-vis,
- Integration of interfaces for passenger information devices.

The figures 2-4 show the interior design and layout of TR09.

Figure 2. TR09 Interior Design

Figure 3. Area with 2+2 vis-á-vis seat arrangement

Figure 4. Entrance door and multi purpose area

2.2 TR09 Data sheet

Table 4. TR09 data sheet

# of sections	3
Length	75.8 m
Width	3.70 m
Height (over guideway gradient)	4.25 m (3.35 m)
Inner width carriage body	3.43 m
Inner height carriage body (Entrance door area)	2.10 m (2.05 m)
Dead weight	169.6 t
Max. total weight incl. payload	210 t
Design speed	505 km/h
Operation speed	350 km/h
Transport capacity	449 persons
Design Pressure Sealing time constant	+/- 5500 Pa $\tau > 20$ s

2.3 Long distance application

Even though the development of the TR09 was primarily focusing on regional transport, the TR09 is a platform which is also applicable to long distance projects.

For long distance only a modified carriage body has to be used which meets the requirements of these applications. These requirements are e.g. more seats, doors can be the same as for long distance rail vehicles or conventional toilet systems could be integrated. An example of a long distance version compared to the TR09 is shown in figure 5.

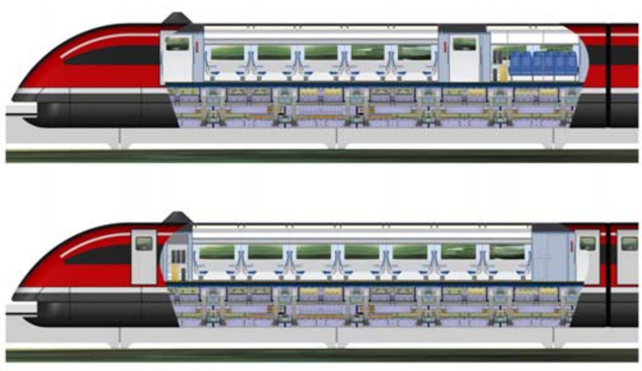

Figure 5. TR09 in regional and long distance version

3 TECHNICAL INNOVATIONS

Diverse innovations setting a new state-of-art for track bound vehicles are integrated in the TR09, e.g. the Inductive power supply system (IPS®), the modified bow construction, the automatic fire detection and fighting system or the front sight camera system.

3.1 Inductive power supply

At velocities below 100 km/h and during stops the Transrapid vehicle has to be supplied with energy by an external source for the on board power consumption. Instead of a conventional power rail system a contactless inductive power supply system, IPS®, was developed for the TR09. With IPS® the power supply will work without mechanical contact to the guideway as a consequent performance enhancement for the Transrapid with regard to the optimization of aeroacustical behavior and reduction of the scope of maintenance work.

The fundamental principle of the IPS® is the electromagnetic induction similar to a transformer. The primary coil becomes the induction loop at the guideway and the secondary coil is converted to the pickup coil fixed to the vehicle, see figure 6-8.

The main difference to the transformer is that the magnetic field can not be closed via an iron core. To achieve an efficient energy transfer nonetheless, the frequency is increased from 50 Hz to 20 kHz. This makes it possible to realize a non-contact system with an air gap.

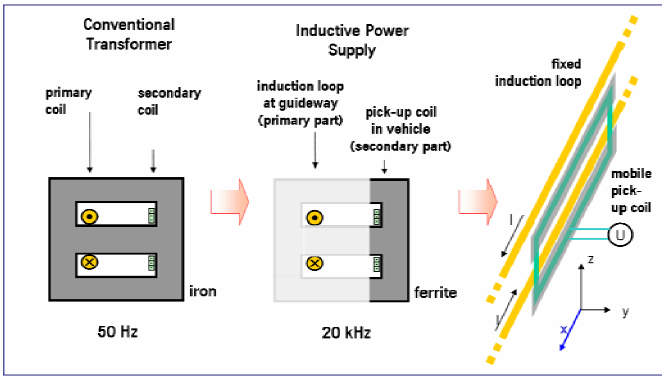

Figure 6. Principle of IPS®

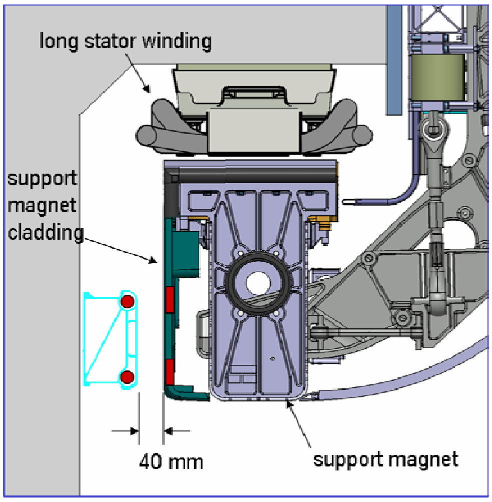

Figure 7. Arrangement of IPS®-Interface between guideway and vehicle

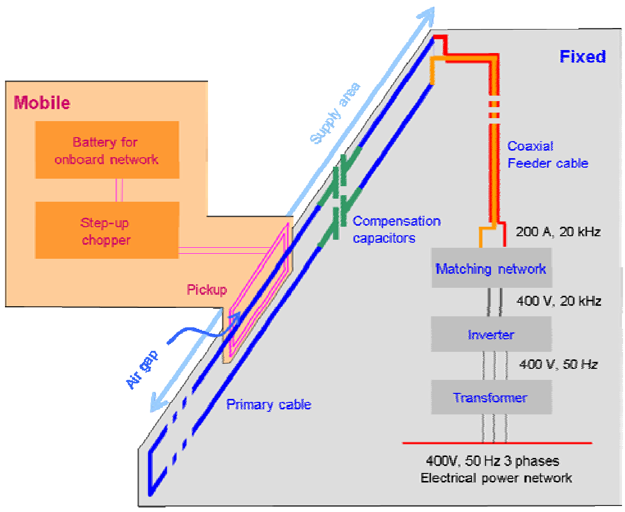

Figure 8. Functional frame of IPS®--system

3.2 *End section bow design*

The bow design of the TR09 was modified in order to fulfill the multifunctional requirements of the specific interactions between the guideway and a maglev vehicle.

The inlet conditions influence the aero dynamical and aero acoustical behavior, as well as the ability for wintertime operation and crash / impact resistance. Figure 9 shows the bow situation of the TR09. The surfaces in the area between guideway and vehicle have been designed in tunnel shape without any displacement or step to generate optimal aero dynamical behavior as well as to minimize the aero acoustical interaction and to avoid depositions of ice and snow during wintertime operation. The crash box arrangement is above the inlet tunnel and designed with respect to the crash cases defined in the design principles of high speed maglev systems.

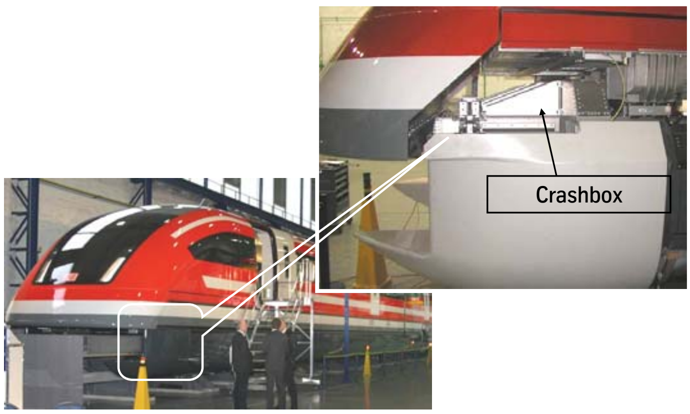

Figure 9. Bow situation of TR09

3.3 *Automatic fire fighting system*

The TR09 is equipped with an advanced fire detection and fighting system. Before this system was designed an extensive fire risk analysis ended up in an overall fire fighting protection concept of the TR09. The constructive fire protection of the TR09 fulfills the level S4 according DIN 5510.

Figure 10. TR09 fire fighting system, pressure bottles

As a part of the overall fire protection concept the fire detection and fighting system was realized. The detection system consists of several detection sensors in the carriage body linked by a digital bus system. In the case of fire a predefined logical sensor arrangement of two sensors must indicate the fire. The indication via the control computer includes the locating of the area with fire in the vehicle section.

A redundant fire fighting system will be activated in this case via the section control computer in the respective area. The sections are divided into 3 up to 4 fighting areas. A fine water mist will be sprayed out of several dies with 200 bar driven by nitrogen pressure. Figure 10 shows one of two water and nitrogen pressed bottles of each section.

3.4 *Front sight camera system*

The conventional front windows were substituted by a redundant front sight camera system in the TR09. In general the front windows of a high speed vehicle with aero dynamical bow shape are always the weak point of the vehicle structure. For this reason and in consequence to the advantages of a driverless high speed system the front view for commissioning and maintenance operation in the TR09 is realized by a camera system.

Figure 11. Camera system integrated in the front lights

The camera system consists of 2 different CCD-cams in each end section. One cam is equipped with a tele lens and one with a panoramic lens. The connection to the monitor is designed in real time transmission. The redundant recording is digital. Figure 12 shows the block diagram of the camera system.

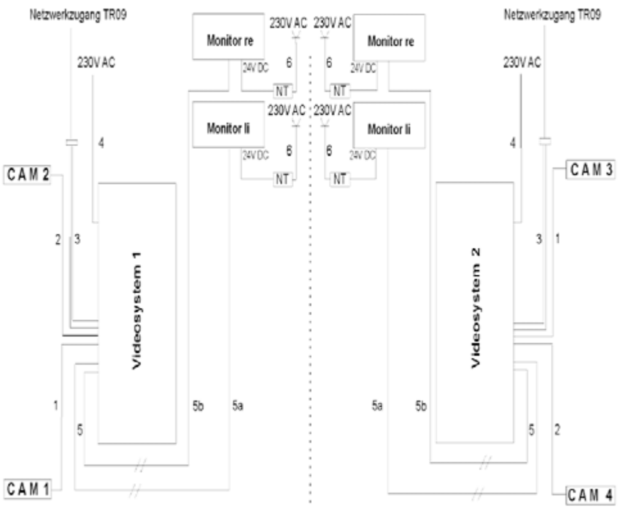

Figure 12. Block diagram of the front sight camera system

4 SAFETY ASSESSMENT

4.1 Rules and regulations for maglev vehicles

For the safety assessment of maglev vehicles three blocks of rules and regulations have to be applied:

4.1.1 Legal foundations

Basis for the mandatory approval in Germany is the MbBO (Magnetschwebebahn-Bau- und Betriebs-ordnung, Maglev Construction and Operation Regulations).

4.1.2 Design Principles of High-speed Maglev System

A comprehensive body of Rules and Regulations for Design and Operation of High Speed Maglev System exists, which strongly support the realization of Transrapid projects.

These Rules and Regulations were created under the leadership of the German Federal Railroad Authority Eisenbahn-Bundesamt (EBA) by an interdisciplinary team of experts from industry, safety assessment organizations, universities and German Railway (DB). The Rules and Regulations are based on verified facts and figures from long term experience with TVE and from the Shanghai Maglev Transrapid Project.

The Rules and Regulations were issued by EBA and notified by the European Union:

http://ec.europa.eu/enterprise/tris/pisa/app/search/index.cfm?fuseaction=getdraft&inum=1350561

They provide a detailed description of functions and subsystems, definition of interfaces between each other as well as criteria with verified quantifies, to design, build, operate and maintain the system. They also provide a clear guideline for overall safety assessment and acceptance.

The following design principles have been set up with regard to the Maglev vehicles:

- Vehicle Part I, General Requirements,
- Vehicle Part II, Design,
- Vehicle Part III, Kinematic Gauge,
- Vehicle Part IV, Levitation/Guidance System,
- Vehicle Part V, Brake System.

4.1.3 Applicable standards

The basic standards for the development process have been the CENELEC standards (DIN EN 50126, 50128 and 50129).

The development of the components has been done in accordance to the acknowledged rules of technology as described in the design principle for the complete system (GS) “GS – Annex 2 Statutes, Regulations, Standards and Directives”.

4.2 Procedure of safety approval

The type approval and safety case is based as described in chapter 4.1 on the CENELEC railway safety standards.

The development of the TR09 implies the implementation of a notable spectrum of modifications, from changed discrete components to new software and architecture in safety related vehicle electronics and to new designs in safety related vehicle mechanics.

According to DIN EN 50126 a system lifecycle including RAMS-Management was defined. As the TR09 is based on the TR08 a modification effect analysis of the whole vehicle was created to give an overview for the safety experts a) what has changed and b) what are the safety related effects of these modifications.

Secondly as the design principles and therefore the related inspection criteria have changed compared to the TR08 another change effect analysis of these changes has been carried out as well. These analyses have been the basics for the further assessment by passing through the CENELEC lifecycle of the vehicle.

The whole development was accompanied by safety experts e.g. by TÜV, EBA and other institutions.

5 COMMISSIONING AN TEST ON TVE

5.1 Test objectives and procedures

The tests are structured in accordance with their objectives in the following way:

- Tests of the specified functions of vehicle including interfaces and relations to other subsystems,
- Tests for evaluation of the environmental characteristics of the vehicle,
- Contractual acceptance tests,
- Tests to reach the approval for safety assessment with regard to international projects.

All commissioning tests have been divided in three different phases:

- Phase 1: Tests in the laboratory and test benches with components and subsystems as well as tests with the vehicle in the factory in Kassel at the end of the assembly period of each vehicle section.
- Phase 2: Tests at site in the Maintenance Center at the end of the reassembly phase in standstill condition of the sections / vehicle.
- Phase 3: Running tests at site.

The scope of tests concerning the phases 1 and 2 has been successfully completed and the results took already part in the safety assessment procedure for TR09 operation on the TVE.

The scope concerning phase 3 encloses function and performance tests as well as measurements concerning the following subsystems and characteristics:

- On-board power supply,
- Diagnosis and on-board control,
- Levitation- / Guidance System,
- Fail safe brake system,
- Mechanical systems,
- Other vehicle systems, e.g. functions test of fire detection & fighting system function test or air conditioning system,
- Vehicle characteristics, e.g. measurements of interior noise or EMC.

5.2 First results

The commissioning of the TR09 in running operation as a part of the overall system integration with new Operations Control System, new components of the Propulsion System and new guideway girders has started on July 29, 2008.

Until the deadline of this paper the following milestones have been reached successfully:

- Tests of new guideway girders at limited speed,
- Tests of new functions of Operation Control System,
- High speed operation tests of the vehicle.

The TR09 and the IPS®-system shows excellent characteristics and features in operation. Concerning the riding comfort and the performance of the levitation / guidance as well as the functionality of the other vehicle systems have been fulfilled completely all expectations until now.

Subsequently two results should be explained in part:

The IPS®-system on TVE is the first application with this size and power range. The system is running in excellent performance and with high reliability. Fig. 12 shows exemplary the result of power transmission measurements. The objective of this test was to stimulate a maximum power demand of the vehicle. For this reason the TR09 has levitated with discharged batteries and full power consumption of the onboard assemblies e.g. air condition. Both IPS®-subsystems are able to supply the TR09 in this situation with a maximum of 250 kW each.

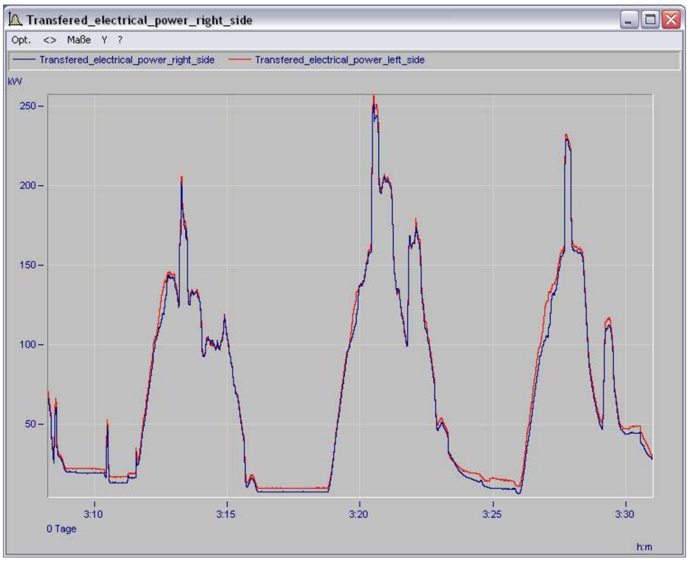

Figure 12. Exemplary results of IPS-power transmission measurements

The technology of the TR09 magnets was redesigned with regard to higher load-bearing capacity. The running behavior of the levitation / guidance system with regard to the vehicle-guideway interaction is in very good condition. Even the temperature level of the magnets in the operating point is as specified. In comparison to the TR08 the temperature level of the levitation magnets of the TR09 under similar operation and load conditions is about more than 25 °K lower than before.

6 CONCLUSION AND PROSPECTS

The latest generation Maglev vehicle TR09 has been started commissioning and test operation on the TVE successfully for verification of its features and for safety assessment. The vehicle test program will be completed at the end of 2008.

So far first results have proven that the design of TR09 implies excellent features for attractive operation world wide.

7 REFERENCES

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