

# Design and Development of the Transrapid TR09

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**ABSTRACT:** Taking into account the requirements of the Deutsche Bahn AG and specifically the implementation of the Munich project it was necessary to review the body structure, entrance doors, air-conditioning concept and the overall Transrapid exterior and interior appearance. Because of the high demands which the entrance doors have to meet and which are imposed by the new dimensions of the TR 09, it was important to design a door meeting the requirements of a higher operational availability, pressure tightness and the passenger entry and exit time. Owing to the changes in design and the new entrance door location, the air-conditioning concept has to be adapted. The arrangement of the entrance doors does not allow the air ducts to be integrated in the side carpeting any longer. Therefore we have designed a double bottom which meets all sound level, stiffness and weight demands, which means that the body floor and the double bottom are now partially used as air duct. The change in the structure and subsystem designs of the vehicle required the appearance of the exterior and interior to be amended because of the higher body cell, the abolition of the windshield and the completely new TR 09 layout. Details of the design and function of the entrance door and the double bottom will be presented together with the results of the design study for the exterior and interior of the TR 09.

## 1 INTRODUCTION

In the course of the concept phase and as part of the development programme of the Federal Ministry of Transport, Building and Urban Development (BMVBS) a comparison of reference and actual values /3/ has been carried out on the basis of the product and quotation concept /1/ and the functional specification of the Munich high-speed maglev of the DB AG /2/ to allow the required modifications with respect to the TR08 vehicle designed for long-distance traffic to be systematically collected.

Owing to the requirements imposed in /2/ and/or the interactions between the two systems, the comparison of the reference and actual values revealed that the following subassemblies need to be adapted:

- Magnets
- Sensors
- Magnet control units
- On-board power supply
- On-board control/diagnosis system
- Cable systems
- Levitation frames
- Secondary suspension
- Carriage body

Because of the use of the TR 09 in „regional traffic“ and as „airport feeder“, e.g. the marked peaks in demand of the traffic surge curves required sitting

and standing rooms to be taken into account in the carriage body design. The dimensioning of the vehicle's structure therefore had to be based on a load collective that is adapted accordingly. Apart from structural modifications the changed and partially boosted demands also required the vehicle's interior to be redesigned.

This particularly referred to the size and arrangement of the entrance doors and the air-conditioning systems.

## 2 THE TR 09 VEHICLE

### 2.1 General

The sections of the TR 09 will have a luxury standard one-design class fitting. Footing on the basic concept for all regional traffic applications, the vehicle not only meets railway standards but also the specific demands of an airport feeder because of the flexibility with which its interior can be varied.

In this respect the targeted qualitative design features such as „innovation“, „integration“, „information“, „representation“, „aesthetics“ and „use“ have been taken into account in the best manner possible.

In order to be able to re-design the vehicle in a cost-effective manner within its economic service life, the interior outfit has been designed to provide

maximum flexibility. Owing to the standardised methods of attachment and modular construction of the interior outfit the vehicle can be easily adapted to changing customer demands. Apart from an interior design that is optimised to encounter vandalism, the TR 09 meets the demand for a maximum useful area referred to the vehicle's total area.

The pressure-sealed entrance doors especially devised for the TR 09 with their width of 1350 mm and their location in the quarter points of the sections warrant a smooth and quick change of passengers and a regular passenger flow within the stations.

Apart from the technical and optical design of the TR 09, development also focussed the attention on the passenger-relevant comfort criteria such as the headrooms inside the vehicle, the pressure tightness, the air-conditioning and the sound level inside the passenger compartment.

## 2.2 System requirements

The adaptations of the maglev vehicle which were systematically worked out in the course of the comparison of reference and actual values /3/ led to a supply specification for a triple-section vehicle /4/ and describe the system requirements to be met by the TR 09.

The main dimensions of the vehicle are summarised in the following.

Table 1: Vehicle configuration /4/

Dimensions of the vehicle sections	E1/E2 in mm	M in mm
Section lengths (referred to the centre of the section coupling)	25 500	24 768
Outer width of carriage body	3 700	3 700
Length of triple-section vehicle	75 768	

Table 2: Carriage body dimensions /4/

Height of carriage body above guideway gradient (without antenna)	3 350 mm
Height of carriage body above finished floor level on the outside	2 400 mm
Height of carriage body above finished floor level on the inside	2 330 mm

Standing area headroom above finished floor level (standing areas outside entrance zone)	min. 2 100 mm
Headroom of standing area / entrance zone above finished floor level	2 050 mm
Internal width of carriage body	3 430 mm
External width of carriage body	3 700 mm
Height of finished floor level above guideway gradient (vehicle levitated)	950 mm
Height of finished floor level above guideway gradient (vehicle set down)	930 ± 5 mm
Vehicle cross section	12.4 m <sup>2</sup>
Outside profile of vehicle	18.3 m

Table 3: Transport capacity /4/

Triple-section vehicle	Without luggage comp.	With luggage comp.
Seats	156	148
Standing room	82.1 m <sup>2</sup>	74.1 m <sup>2</sup>
Passenger capacity when all seats are occupied, 1 person/m <sup>2</sup> standing room (normal capacity)	239 persons	222 persons
Passenger capacity when all seats are occupied, 2 persons/m <sup>2</sup> standing room (full capacity)	321 persons	296 persons
Passenger capacity when all seats are occupied, 320 kg/m <sup>2</sup> standing room, approx. 4 persons/m <sup>2</sup> standing room (max. capacity)	449 persons	412 persons

Based on the vehicle layout shown in Figs. 1 to 3 and taking into account the door arrangement, the requirements to be met by the maglev vehicle TR 09 as defined in /2/ and /4/ could be realised in the following areas:

- Seat area
- Entrance zone
- Multi-purpose area
- Luggage area

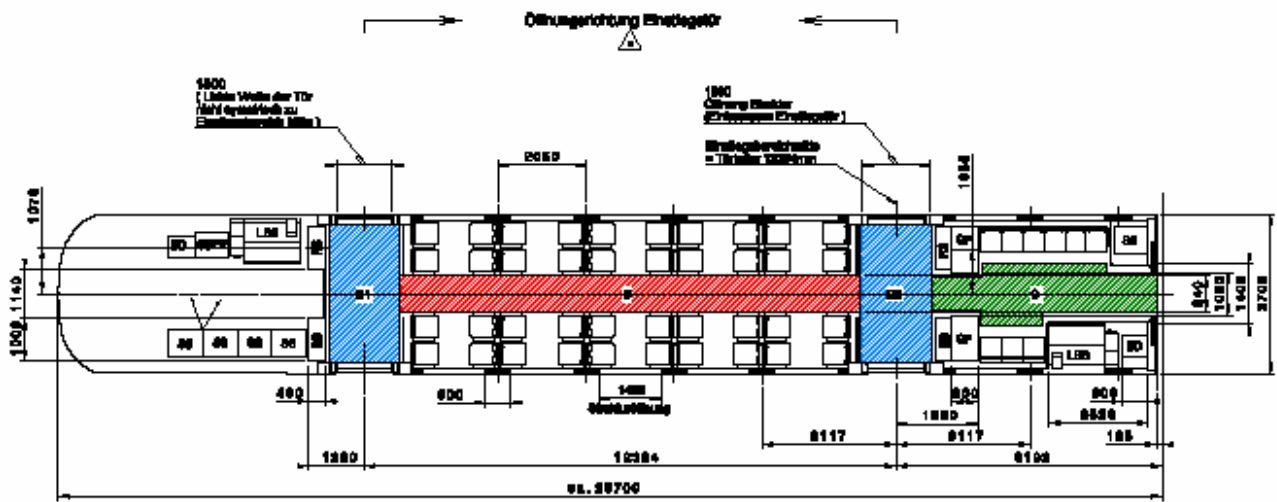


Fig. 1: Layout of end section E2 /4/

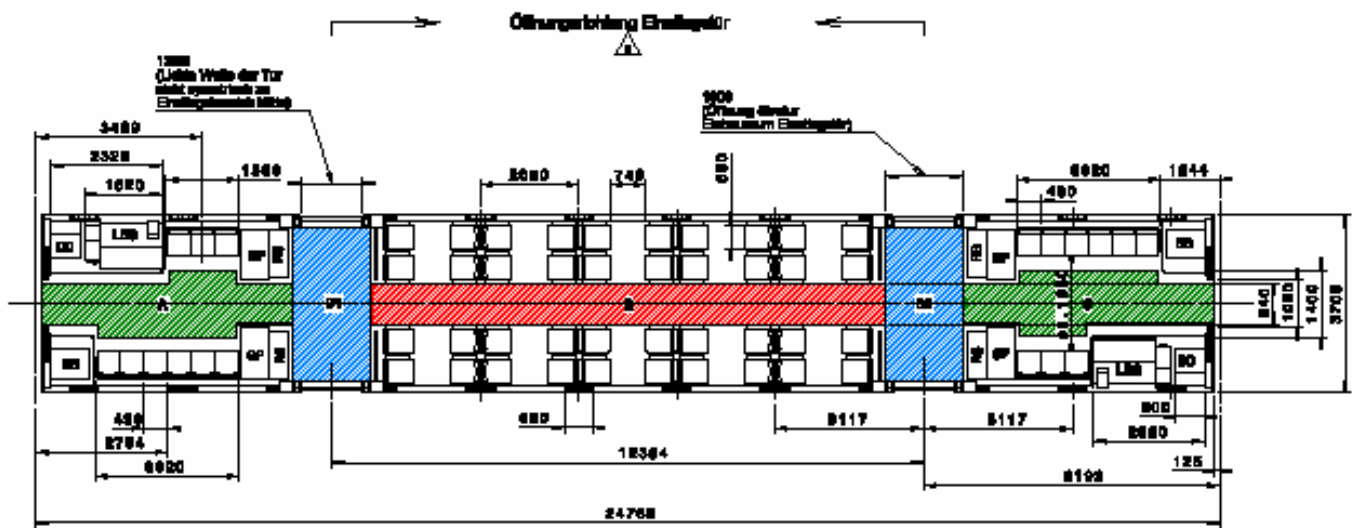


Fig. 2: Layout of central section /4/

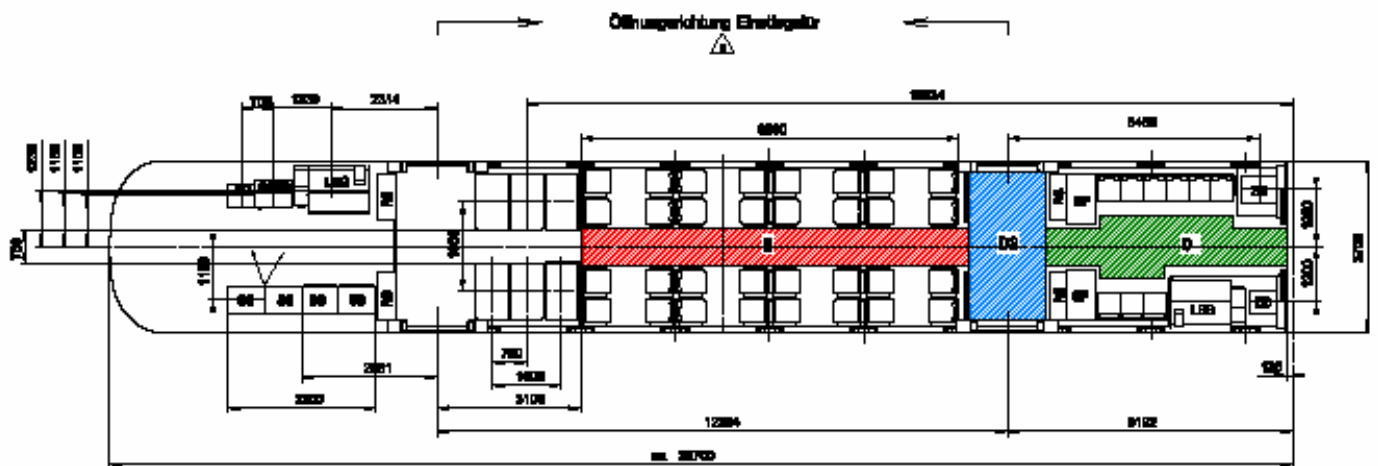


Fig. 3: Layout of end section with luggage section E1 /4/

### 3 CONSTRUCTION AND DESIGN

In close consultation with the project partners the construction and design of the maglev vehicle has been developed, co-ordinated and implemented step by step on the basis of a 3D CAD model and a 2D/3D design specification. In order to be able to check the design specifications some simple prototypes of critical components were created on a 1:1 scale.

Depending on the progress achieved in the course of the project this has been sustained by intensive workshops held with the respective system suppliers. This mainly related to the subsystems listed in the following, which have a substantial impact on the construction and design of the TR 09:

- Passenger information and communication system
- Entrance doors
- Seats
- Floor covering
- Air-conditioning
- Fire alarm and fire fighting system

With the aid of computational models the current working statuses were continuously visualised. Based on the 3D CAD models a CFD simulation of the flow and temperature distribution inside the carriage body was carried out at the same time to optimise the design of the air-conditioning system. In addition to this the optimisation measures taken to reduce the internal sound level were verified and assessed through laboratory tests. This allowed the work results to be confirmed without delay.

Because of the new door arrangement as well as the large door width and the corresponding stiffening of the carriage body structure it quickly became apparent that apart from the interior outfit the entrance door and air-conditioning system are the sub-assemblies which substantially influence the targeted comfort criteria of the carriage body of the new maglev vehicle.

#### 3.1 The entrance door

##### 3.1.1 Requirements to be met by the entrance door

Because of the demands defined in /2/ and /4/ the entrance doors differ from the ones used in the former maglev vehicles, particularly with respect to

- greater inner width
- greater headroom
- shorter door opening times
- boosted safety requirements to realise an automatic operation

Apart from the demand to live up to the general technical rules applying to a door system used in a high-speed application and the legal stipulations applying to maglev systems, the planned driverless automatic operation of the TR 09 required the following additional safety requirements to be met:

- Communication interface to the gate door
- Speed-dependent locking of the emergency unlocking system
- Fulfilling the specifications originating from a partly automatical dispatching process

The use of electrically driven main and rotary latch drives allowed further improvements with respect to the reliability and quality as well as the process safety and maintainability of the entrance door to be achieved.

#### 3.1.2 Comparison of TR08 and TR09 door systems

Table 4: Comparison of door systems

TR08	TR 09
Main drive mode	
Pneumatic drive cylinder	Electrical drive unit with displacement/time sensor
Control mode	
Solenoid valves	Direct control of the drive unit and locking via door control
Protection against squeezing	
Pneumatic pressure waves in the rubber finger guard	Electrical switching straps (with direct diagnosis via door control)
Drive mode of the rotary latches	
Pneumatic rotary latches	Electrical rotary latches (with direct control, diagnosis via door control)
Displacement	
900 mm	1300 mm
Total weight	
230 kg	270 kg
Weight of door wings	
125 kg	175 kg
Displacement time	
4 sec.	6 sec.

Despite the fact that the door wings are heavier and the displacement is longer, an acceptable displacement time of only 6 seconds could be achieved for the dispatching process.

### 3.1.3 The implementation of the design

Drive system:	electrical drive
Door design:	single-leaf swinging-sliding door, air tight
Door width:	1580 mm
Door height:	2210 mm
Door thickness:	53 mm
Lower door guide:	pivot lever roller guide
Door stroke:	top area 105mm bottom area 89 mm
Inner width:	1300 mm
Operating voltage:	24 Volt
Air tightening:	$\pm 6000$ Pa
Locking:	3 chocks on MCE 2 rotary latches on SCE
Guard:	electrical switching strap
Weight:	270 kg

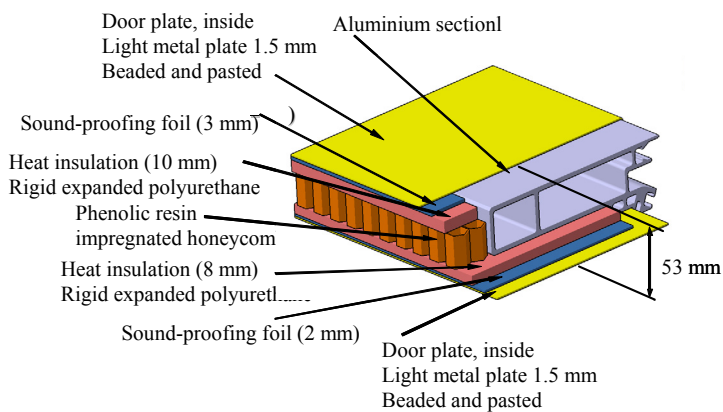


Fig. 4: Door leaf composition (Bode)

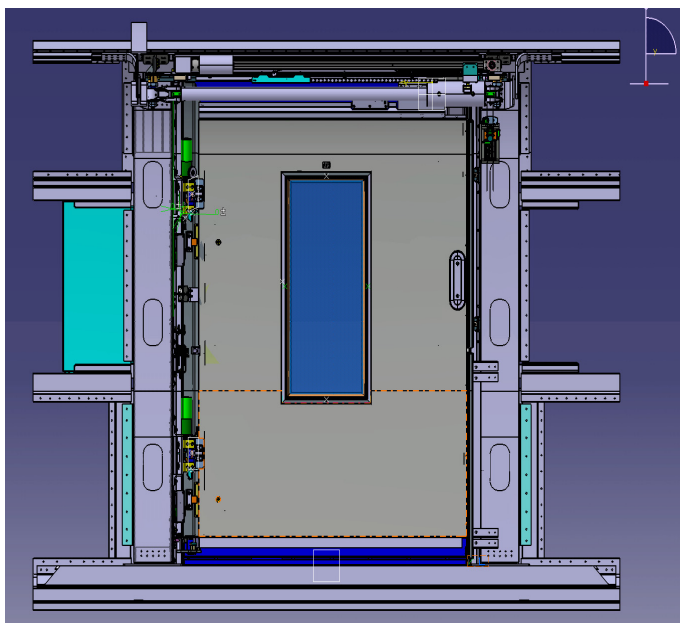


Fig. 5: Interior view of the entrance door from the 3D model of the carriage body (TKT-TR)

### 3.1.4 Testing

As the entrance doors are quite large for a high-speed vehicle and the demands with respect to the pressure tightness of the carriage body are high, the entrance door prototype for the TR 09 is presently undergoing a long-term test run in which the door system is put into a pressure chamber especially designed for the test and being run through 1 million cycles (opening and closing) in a period of approx. 9 months.

Additional static pressure tests will complete the long-term test run and will ensure the system's pressure tightness for future applications.

## 3.2 Air-conditioning

### 3.2.1 Air-conditioning requirements

In order to be able to meet the demands defined in /2/ and /4/, not only a new technical design of the air treatment units and the compressor/condenser units was needed. A new air-conditioning concept also had to be worked out which not only lives up to the comfort standards of prEN 14750-1, Category A, Climatic zone 2, but also allows the maximum head-room inside the passenger compartment to be realised.

The concept and the implementation of the design features are mainly influenced by the:

- arrangement of air handler units at the ends of the car bodies,
- increase of the electrical and thermal performance,
- position of the external air intakes taking into account the external pressure conditions,
- structural changes influencing the arrangement of the air-conditioning ducts.

### 3.2.2 Implementation of the design

The air-conditioning system of the TR 09 is designed as a split system. Each section has two air handler units inside the passenger compartment and two compressor/condenser units in the subfloor structure (Fig. 6).

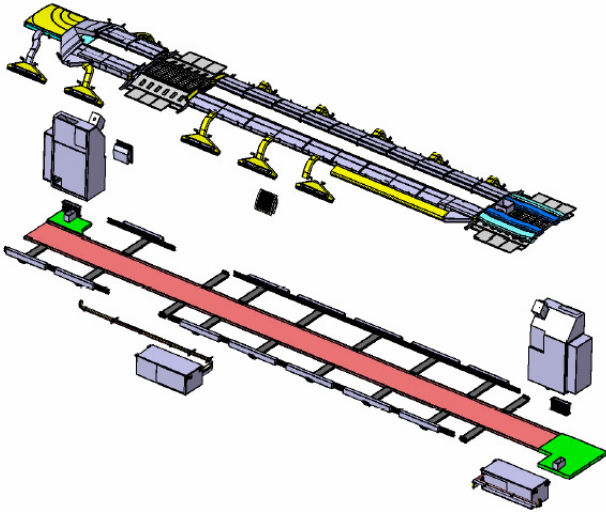


Fig. 6: Air-conditioning ducts of the TR 09 (TKT-TR)

Control and diagnosis of the air-conditioning system are effected separately. In a way the operation of the air-conditioning system is redundant, i.e. should one of the systems fail, a reduced supply of fresh air is safeguarded at all times by a common system of air supply ducts.

The ducts for the heating air are integrated in the double floor, the air duct (Fig. 7/8) being formed by the structural floor together with the double floor in the area of the central corridor.

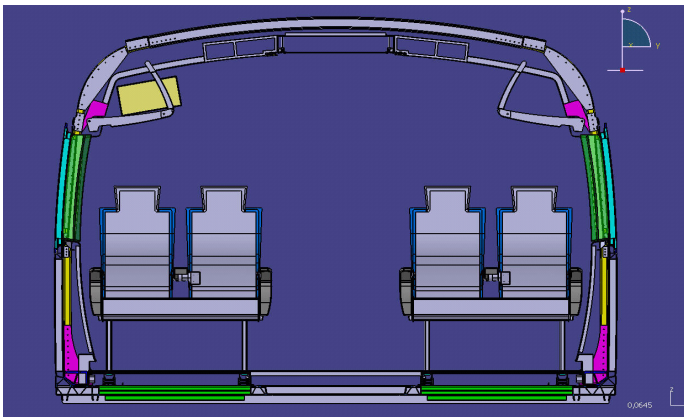


Fig. 7: Double floor with integrated heating air duct (D&T)

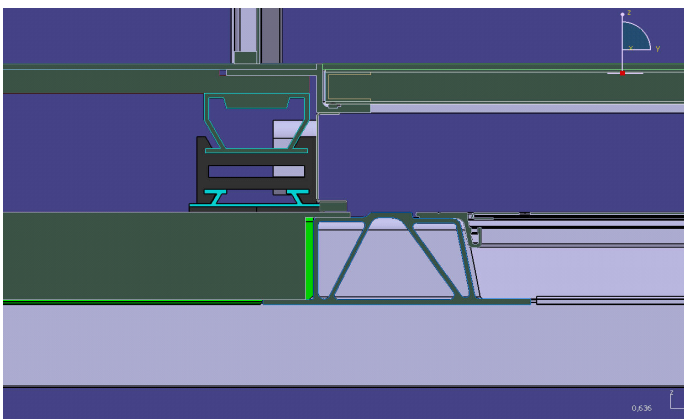


Fig. 8: Enlarged view of the integr. heating air duct in the double floor (D&T)

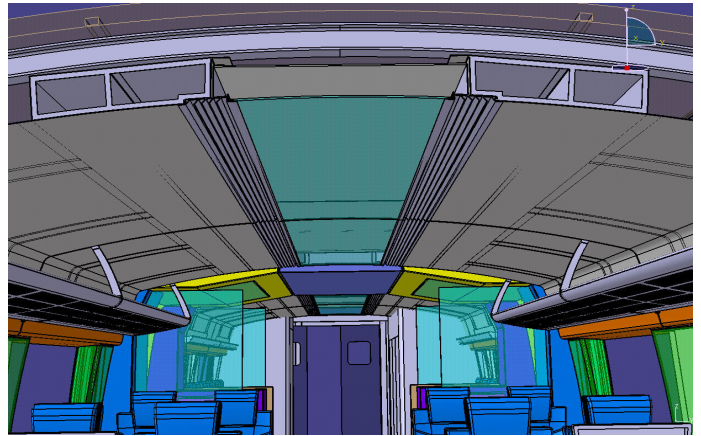


Fig. 9: Cold air ducts as part of the ceiling panelling (D&T)

In the cooling mode the air is distributed inside the vehicle through the air ducts integrated in the ceiling panelling which are also used as structural stiffeners for the internal panelling (Fig. 9).

The external air is usually taken in through air grids in the band of windows equipped with protective pressure valves. Only for the air handler units in the bow, the air is taken in through the roof area between the two entrance doors because of the prevailing external pressure conditions and the requirements to be met with respect to the design of the passenger compartment. The air inside the passenger compartment is taken in directly at the air treatment units. The exhaust air of the air treatment units is blown out through the subfloor structure where the differences in temperature allow it to be used for cooling purposes.

### 3.2.3 Testing

Within the framework of prototype testing the individual components of the air-conditioning system, particularly the air treatment unit and the compressor/condenser unit, were subjected to the following tests:

- Resistance to shock and vibrations as per DIN EN 61373
- Air conveyance and performance as per prEN 14750-1

In addition to this, the design and dimensioning of the air-conditioning system - referred to the limits authorized by prEN 14750-1 - were checked in a flow and temperature simulation and it was confirmed that the limits were met.

## 3.3 Exterior and interior designs

### 3.3.1 Exterior design

Since the DB AG assigned the Munich project maglev to the business segment DB Regio, the appearance of the vehicles can no longer be compared



to that of the TR 08 (long-distance traffic). This applies to the interior as well as to the exterior.

The principal colour and material concept of the DB Regio business segment and the appropriate colours were adopted for the interior and exterior, respectively (Fig. 10).

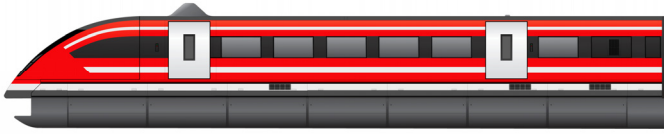


Fig. 10: Exterior design of an end section of the TR 09 (Nose)

As the exterior design was being worked out, it proved to be very important to compensate the elimination of the windscreen which because of its weight was substituted by a camera system. In other words the front design required the vehicle to be given a new appearance that lived up to the targeted design standards.

This could be achieved by integrating a new modular LED headlight system never used before on a maglev vehicle. Its shape and design together with the paintwork of the front section are very convincing (Fig. 11).

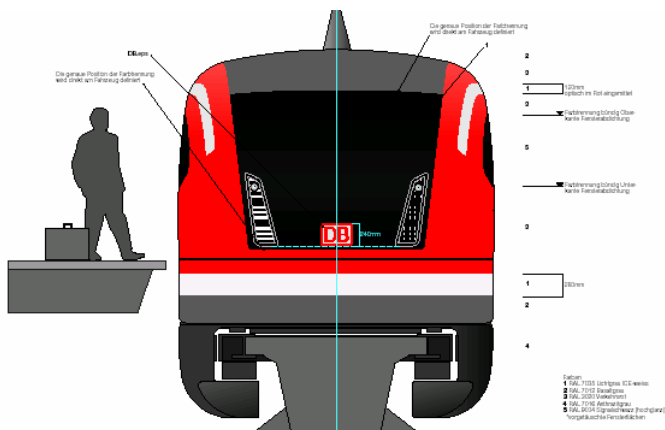


Fig. 11: Design of the front section of the TR 09 (Nose)

### 3.3.1.1 Interior design

Based on a design study which NOSE prepared in 2001 on behalf of the DB AG on the subject of a maglev regional vehicle to be used as airport feeder and on the specification included in /2/ an interior design was created that takes into account all main standards which an airport feeder must live up to.

- A generous design of the interior (Fig. 12)
- Taking into account the provision of certain information (Fig. 13)
- Meeting peak demands by offering standing room

- Luggage deposit areas and racks
- A room atmosphere marked by comfort
- Assuring passenger changing times
- Seats arranged 2+2 vis-à-vis (Fig. 14)
- Integration of multi-purpose zones (Fig. 15)
- Meeting the air-conditioning comfort values
- Improvement of the sound level by using a double floor, optimised windows and a structural connection to the panelling elements



Fig. 12: Interior view TR09 (Nose)



Fig. 13: Passenger information system (Nose)



Fig. 14: Seat arrangement 2+2 vis-à-vis (Nose)



Fig. 15: Multi-purpose zone (Nose)

Apart from any specified functional requirements which the interior has to fulfil, the design process was focussed on the harmonisation of the lighting and the decorative patterns.

### 3.3.1.2 Lighting concept

In order to optically increase the room height of the TR 09, the side lights integrated into the luggage racks will be supplemented by a light duct in the middle of the ceiling. The duct will be laterally illuminated by a row of lamps, the light being uniformly radiated downwards by a fine-structured aluminium plate. The duct is covered by a partly frosted glass completing the ceiling contour to form a uniform arc. The depth of the duct remains sensible and makes the room look higher.

The windows are combined into a continuous luminous band by illuminated window columns. The white window column is covered by a frosted colourless panelling fitted at close distance. The light

radiated from above into the clearance makes the window column shine in a soft light (Fig. 16).

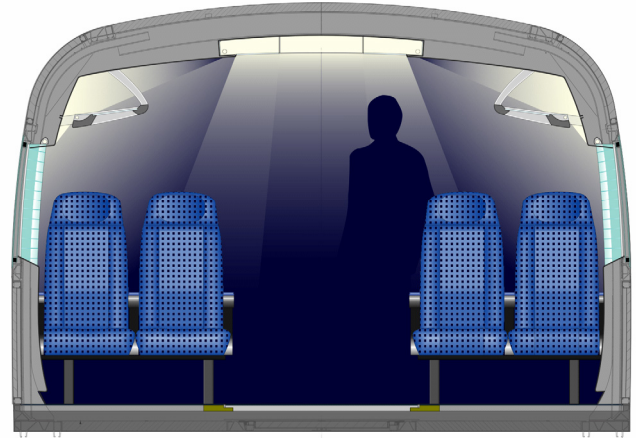


Fig. 16: Lighting concept TR 09 (Nose)

### 3.3.1.3 Decorative patterns

In the course of the efforts to continue the development of the vehicle's predecessor model various patterns are used to structure uniform surfaces. Based on the 2050 mm window arrangement the etch pattern of the lighting duct, the hole pattern of the luggage rack and the magnet pattern of the side wall panelling were harmonised.

To remind passengers of the special drive technology the magnet pattern is continued throughout the interior on a constant horizontal level. By blanketing an optically indistinct sine wave by a precisely printed wave pattern passengers are given the feeling of spatial depth even though both patterns are applied to the same subbase of the HPL material (Fig. 17).

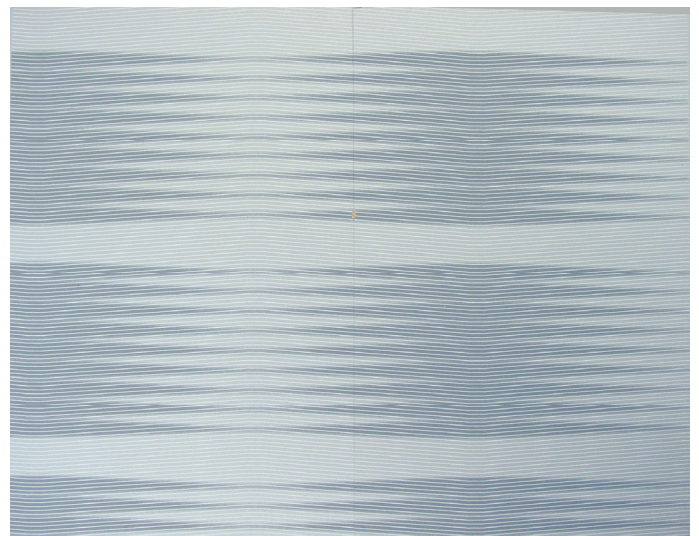


Fig. 17: Magnet pattern on the side wall panelling (Nose)

## 4 PROSPECTS

The integration of all partners involved in the project and in particular the close and constructive co-



operation between the user and manufacturer as well as between the design and construction departments have allowed in a very short time to design and implement a vehicle that not only meets the demand of the future operator for a maglev airport feeder but also lives up to the standards expected by future passengers.

Future potentials are offered by the active fire fighting system used for the first time in a maglev vehicle combined with a fire alarm system that meets a higher vehicle fire protection standard than the one specified in normal technical standards and allows a large variety of synergy effects to be achieved.

## 5 LITERATURE

- /1/ Produkt and Angebotskonzept der Magnetschnellbahn München Hauptbahnhof - München Flughafen (04.02.2004)
- /2/ Lastenheft Magnetschnellbahn (Betreiberanforderungen) der DB AG vom 27.08.03
- /3/ Technischer Bericht Soll/Ist-Vergleich Fahrzeug gem. Betreiberanforderungen WEP, Dok. Nr.: TS/9123/10/03 F vom 24.03.04
- /4/ Lieferspezifikation WEP -3-Sektionen-Fahrzeug, Dok. Nr.: TS/8915/09/03 F vom 24.03.04
- /5/ ZEVrail Glasers Annalen – Sonderheft Transrapid 2003 Anforderungen an das Magnetschnellbahnsystem Transrapid and Einsatzfelder aus Betreibersicht am Beispiel der Weiterentwicklung des Fahrzeugs Transrapid 08
- /6/ Technischer Bericht Gestaltungskonzept TR09, Dok. Nr.: PFM/12296/03/06 vom 10.03.06

## 6 LIST OF ABBREVIATIONS

TR 09	Transrapid 09
BMVBS	Bundesministerium für Verkehr, Bau und Stadtentwicklung
CAD	Computer Aided Design
2D/3D	two-/three-dimensional
CFD	Computational Fluid Dynamics
DB AG	Deutsche Bahn AG
TR 08	Transrapid 08
MCE	Main closing edge
SCE	Secondary closing edge
DB Regio	Regional traffic of the Deutsche Bahn
LED	Light-emitting diode
Nose	Messrs. NOSE Applied Intelligence
D&t	Messrs. Design and Technik
Bode	Messrs. Gebrüder Bode
TKT-TR	ThyssenKrupp Transrapid