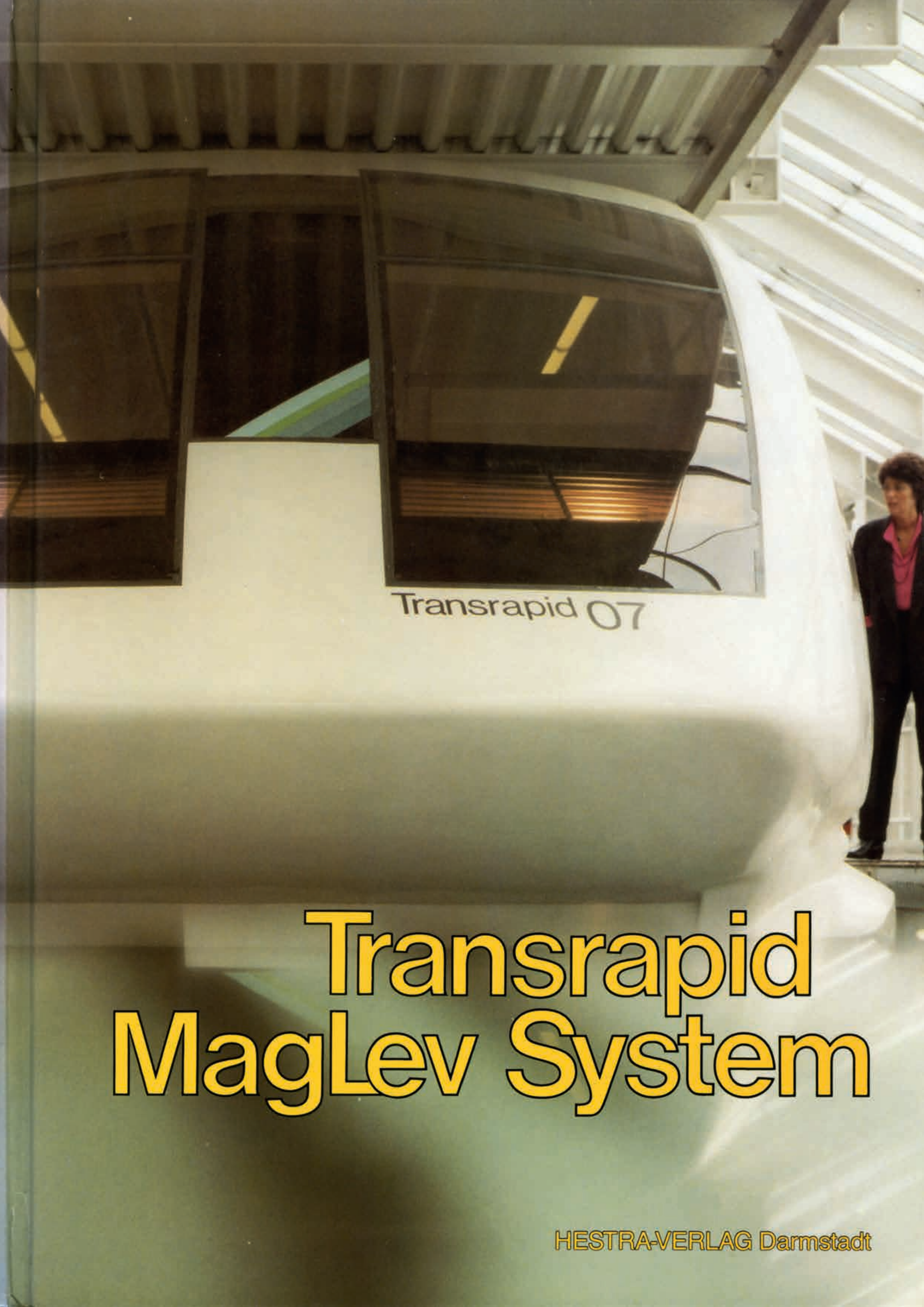


Transrapid MagLev System

HESTRA-VERLAG Darmstadt

Contents

The Transrapid Guideway

The first-generation guideway

The first functional demonstration of the electro-magnetic levitation system with linear-motor propulsion took place on short experimental guideways as early as 1971. This was followed during the next few years by component tests in larger test installations such as the Transrapid 04 experimental guideway in Munich, on the linear high-speed test rig KOMET at Manching, and on the functional installation for longstator MagLev technology in Kassel. Corresponding to the various concepts and aims of the tests these installations featured guideways vastly differing in the design of the supports and in the arrangement of the functional components.

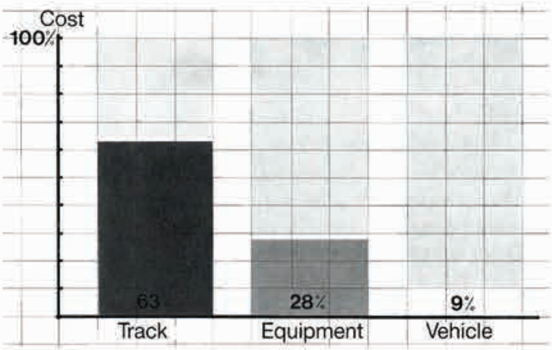
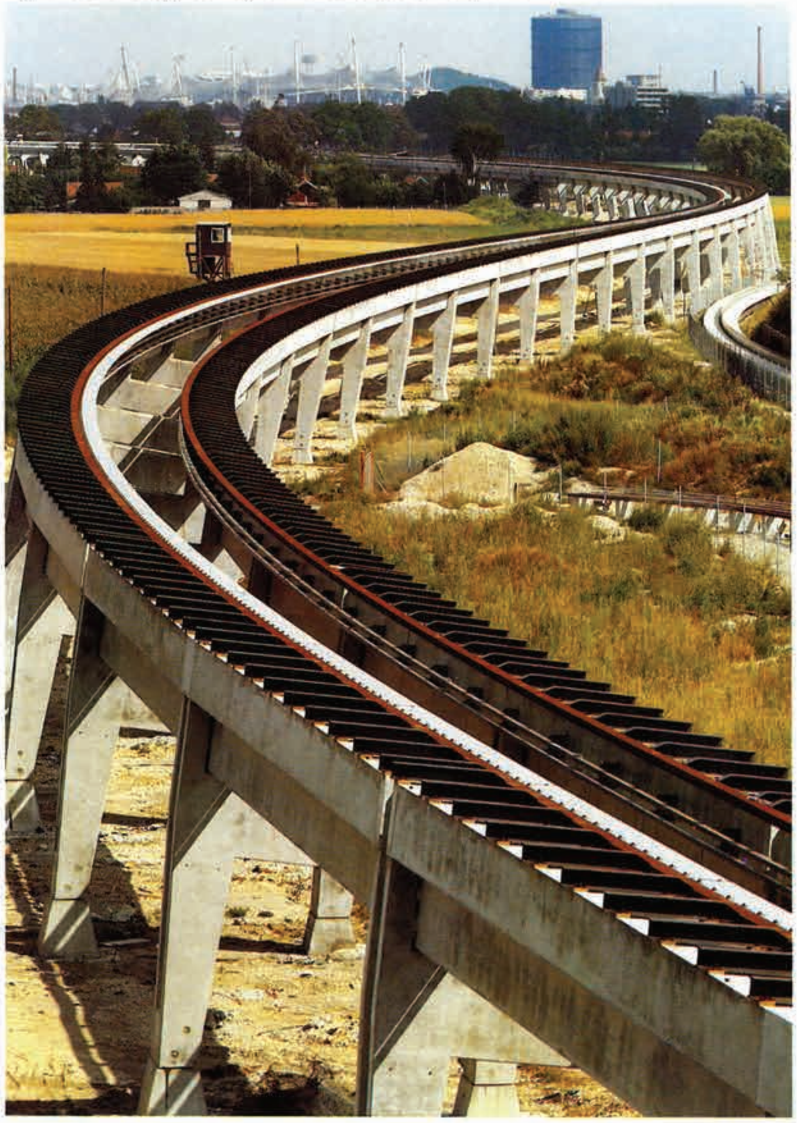


Fig. 2: Capital cost percentages of the MagLev System

Fig. 1: Concrete guideway of the Transrapid 04 experimental track



The Transrapid 04 experimental guideway was built as an elevated concrete guideway (Fig. 1), but also included a section of steel guideway. The guideways for the linear high-speed test rig and for the functional installation for long-stator magnetic train technology were executed in steel construction.

Further development of the guideway in the Seventies

Even the first trials of electro-magnetic levitating vehicles made the need for parallel work on and matching the guideway with the vehicle obvious. Considerations of economic viability of application systems demonstrated the decisive influence of the capital cost on the guideway and on its equipment in the feasibility and implementation of a magnetic train system (Fig. 2).

An expert group of steel construction and of concrete construction companies was therefore established; supported by the Federal Ministry of Research and Technology it carried out technical and economic investigations of the possible guideway systems in continuous close collaboration with the vehicle designers. The result of comprehensive investigations has produced a guideway for the Transrapid MagLev System with the following properties:

▷ single-beam guideway executed in steel or concrete,

Fig. 3: MagLev Demonstration System at the International Transport Exposition 1979

- ▷ single- and double-track line,
- ▷ elevated construction,
- ▷ span about 25 m.

The further development of the support- and guidance technology with the replacement of electromagnets rigidly fixed to the vehicle by support magnets individually arranged in levitating frames and the large-scale decentralization of control and power supply reduced the stringency of the demands made on the guideway and allowed an economical guideway design to be adopted.

On this basis alignment investigations were carried out to determine the capital cost of magnetic train in real terrain. The studies demonstrated the commercial viability and competitiveness of the magnetic train system, because compared with the conventional wheel-on-rail technology up to a 12° cant in curves and considerably steeper longitudinal gradients can be incorporated in the alignment of the guideway.

The MagLev demonstration System at the 1979 International Transport Exposition

The decision to build a demonstration System for the electro-magnetic levitation technique on the occasion of the International Transport Exposition in Hamburg (IVA 1979) resulted in the construction of the first elevated single-beam guideway, of about 1 km length. It consisted of steel beams with spans between 24 and 49 m. For visual reasons all beams were executed at a uniform structural height of 1.8 m (Fig. 3). Adaptation to the varying widths of span was achieved through the graduation of the cross sections of the upper and lower flange plates.

The guideway of the Emsland Transrapid Test Facility (TVE)

Last, but not least the positive experience and results of the elevated single-beam guideway of IVA 79 led to the adoption of the IVA 79 guideway for the construction of the Emsland Transrapid Test Facility (Fig. 4). For the first time switches were also required. TVE incorporates all the necessary track elements of the tracked transport medium.

The completion of the South Loop also demonstrates the simple adaptation of the elevated guideway to be surrounding landscape through the variation of the height of the columns.

Whereas the guideways for the experimental installations and for IVA 79 were still assembled mainly according to manual methods because of their short lengths, construction of the 31.5 km guideway for TVE called for the introduction of mass production

Günter Ciessow, Reinhard Friedrich, Hubert Hochbruck, and Gerhard Holzinger

The Long-Stator Propulsion System and its Power Supply

The near-service Transrapid 06 (TR 06) MagLev vehicle is powered by an iron-cored long-stator linear motor in combination with the magnetic levitation system. AEG, BBC, and Siemens were responsible for the development, manufacture, and commissioning of the entire propulsion system. Thyssen undertook the development and production of the motor components installed in the system.

On January 22nd 1988 the TR 06 attained a maximum speed of 412.6 kmph on the test track. This constitutes a decisive step towards revenue-earning service of the system; with the operation of the test facility, completed at the end of 1987, the necessary endurance tests have become possible.

The principle of long-stator propulsion

The contactless operating principle of the magnetic train calls for the linear motor as prime mover. This type of drive permits the transmission of thrust and brake forces without contact and thus independent of adhesion coefficients. With suitable planning, favourable alignment parameters resulting in reduced capital expenditure can be achieved, for instance in difficult mountainous terrain, through utilization of the good climbing ability of the MagLev vehicle. An iron-cored synchronous longstator motor in suspension stator design was chosen for the TR 06 propulsion system. The suspension magnets of the system also act as the excitation magnets of the motor. The stator with its three-phase travelling-field winding is arranged in the guideway (Fig. 1). This winding is divided into separate feeder sections to improve efficiency and utilization.

Through variation of the length of these motor sections the propulsion system can be adjusted to meet the demands of the alignment, of the gradients, of the acceleration and of the steady-state sections, as well as of the headway and of the length of the vehicle.

The tractive effort, and thus the propulsion power, is transmitted to the vehicle without contact via the magnetic motor field. Linear generators provide the power needed on board the vehicle for excitation of the magnets as well as for the air-conditioning plant and for the auxiliaries. These generators have three-phase windings in the pole shoes of the suspension magnets. Flux variations caused by the stator slots induce voltages in these windings as a function of the speed (Fig. 1).

One advantage of the long stator consists in that it obviates the need for any live on-board propulsion equipment such as pantographs, converters, etc. Particularly in view of the propulsion performance obtainable at high speeds this design ensures a high payload ratio of the vehicles.

The synchronous long-stator motor has the following characteristic features:

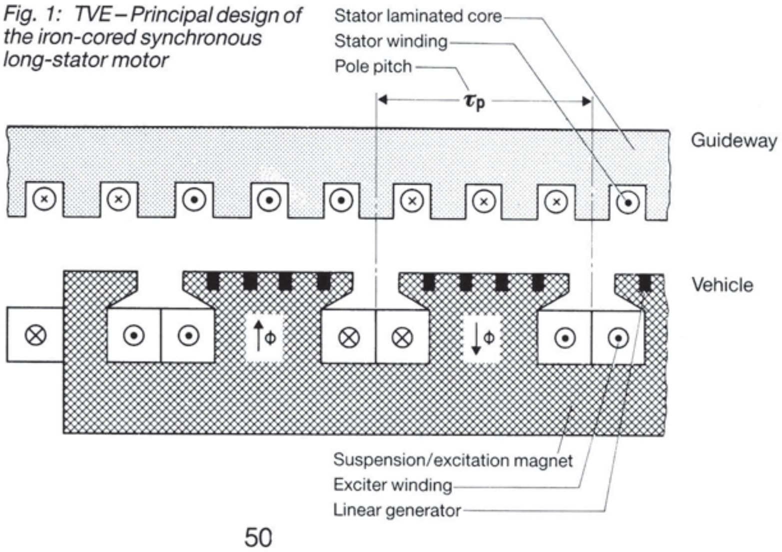
▷ As a result of the combination of the suspension and drive systems the weight of the vehicle determines the excitation of the motor

▷ control of the tractive effort keeps the flux of the motor air gap constant. The thrust can be varied only via the magnitude and the phase angle of the stator current

▷ the individual sections of the stator winding are longer than the vehicle. Consequently, leakage reactance of the stator winding and of the feeder cable primarily determines the motor characteristics

▷ the drive principle of the selected system calls for a three-phase current supply employing variable frequency and voltage. The motor is therefore supplied with power through static converters installed in substations along the line.

Fig. 1: TVE – Principal design of the iron-cored synchronous long-stator motor



The TR 06 propulsion system

Design criteria

The TR 06 consists of two vehicle sections of 54 m combined length and 122 t weight and accommodating up to 200 passengers. The propulsion system is designed for a continuous speed of 300 kmph, and at a reduced vehicle weight of 108 t for a top speed of 400 kmph. The tractive resistance curve is decisive for the design of the vehicle (Fig. 2).

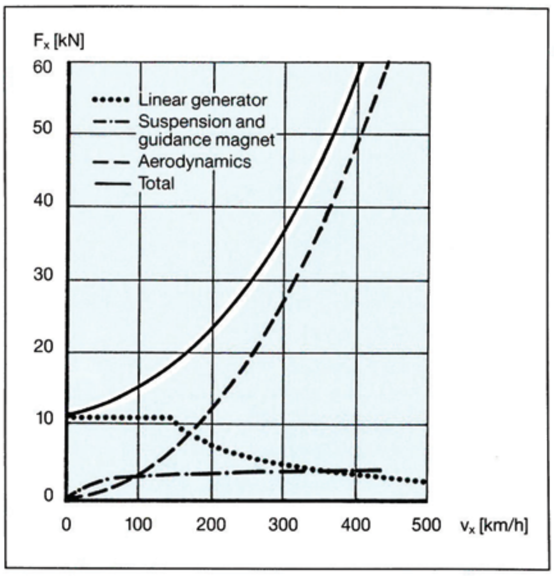


Fig. 2: TR 06 – Tractive resistance curve

The tractive resistance is made up of the following components:

▷ Resistance as a result of eddy currents in the rails of the lateral guidance system

▷ braking force of the linear generator, which serves for power supply on board the vehicle

▷ aerodynamic resistance, which at high speeds is by far the largest component and requires, for instance, a doubling of the power in order to raise the vehicle speed from 300 to 400 kmph.

The test track has a total length of 31.5 km and consists of a straight section about 12 km long for high-speed operation and of a northern and a southern reversing loop. A special feature of the track is its link with the test centre and gradients of 35‰ (1:28.6) in one reversing loop (Fig. 3). The long stator, which is 31.5 km long, is divided into 58 feeder sections to increase its efficiency and to improve its utilization. The length of these sections varies between 300 m in the high-speed section of the track and a maximum of 2000 m in the reversing loops, where the vehicles operate at reduced speed and power.

Design of the motor and power supply

The motor

Fig. 1 shows the basic design of the stator with its three-phase winding as installed on both sides of the guideway. Both halves of the stator are connected electrically in series. The stator consists of individual core assemblies made of cemented laminations and mounted on the underside of the guideway base.

The three-phase winding employing shielded single-core cable is preformed and installed in the trackside stator with the aid of a laying machine.

The selected pole pitch of 0.258 m and the maximum speed of 400 kmph yield a maximum motor frequency of 215 Hz. Given the wave form of the inverter output voltage and insulation level of 6/10 kv of the cable used in the motor winding, a phase voltage of 4250 v was chosen as the maximum effective motor voltage. It can be increased to about 4500 v for high-speed tests. The maximum motor current is 1200 amp. For test purposes the motor winding has the following conductor cross sections:

▷ 150 mm² Cu

in the first construction phase (northern loop)

▷ 300 mm² Al

in the second construction phase (southern loop)

▷ 285 mm² Cu

in the second construction phase (southern loop) on a gradient of 35‰ (1:28.6)

The maximum motor voltage, current, and frequency are decisive for the design of the power supply.

Feeder circuit concept

The individual motor sections are supplied with power according to the so-called leapfrog method, ie in alternating and overlapping fashion, from two inverter systems through separate feeder cable sys-

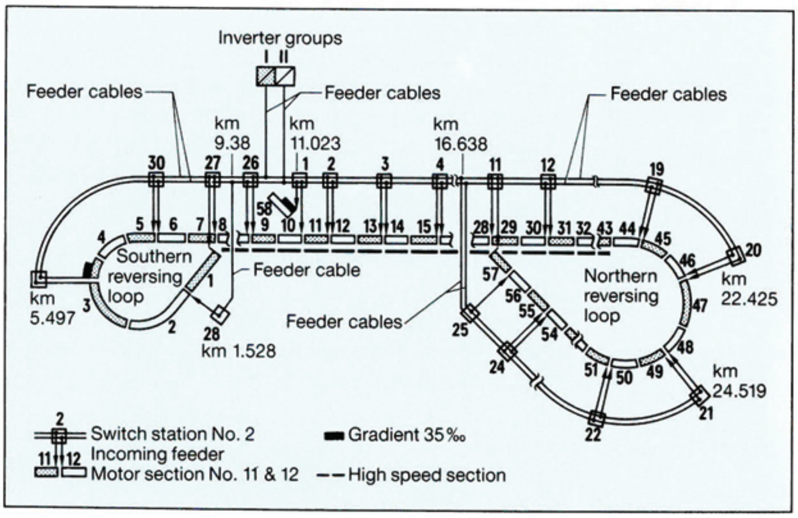


Fig. 3: TVE – Layout of motor sections

tems along the TVE test track (Fig. 4). Thus there is no break in the thrust during the change of motor sections. 30 switch stations are positioned along the track to activate and de-activate the allied motor winding sections by means of three-phase vacuum contactors of short operating times and long mechanical and electrical life.

The vacuum contactors in the switch stations are activated by the control system in the substation via telecontrol. The telecontrol equipment employs audiofrequency band multiplexing, which ensures high transmission reliability and obviates maloperation. In addition to the vacuum contactors and their controls the switch stations contain various monitoring and protective devices, which are also tele-moni-

Jürgen Meins and Werner Ruoss

The Support- and Guidance System

The development of the electro-magnetic support- and guidance system for the TR 07 is based on the task of ensuring the contactless support and guidance of the vehicle at minimum load on the guideway through consistent utilization of the existing development potential and the use of the most up-to-date technology and thus of making an important contribution towards minimizing the capital cost of the guideway. Of equal importance are the demands for high availability, reliability, safety, good riding comfort, and compatibility with the environment; on the component level operational and economic aspects such as simple handling and maintenance, as well as low-cost, streamlined production methods must also receive attention.

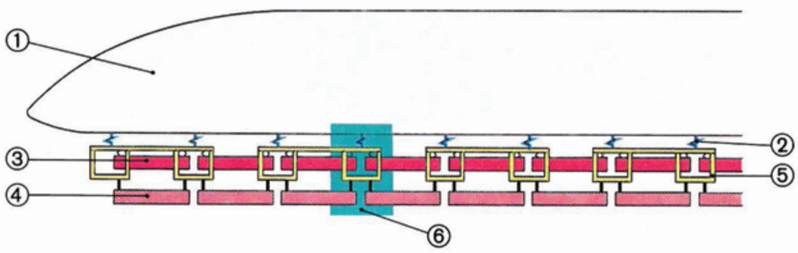
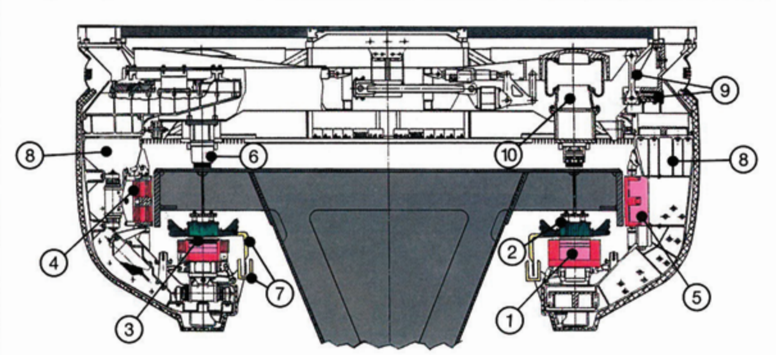


Fig. 1: Structure of the support- and guidance system

Fig. 2: Cross section of the support- and guidance system



Mechanical structure

The support- and guidance system of the TR 07 is characterized by a chain-like arrangement of magnets attached to hinge points and adjustable in two degrees of freedom with a secondary suspension system between the levitating frame and coach body (Fig. 1).

To minimize the unsprung masses the support magnets are suspended horizontally, the guiding magnets vertically through linear guides and rubber spring elements at about 1.5 Hz low frequency (Fig. 2). The vertical suspension of the coach body consists of a secondary suspension system with 16 level-controlled pneumatic springs installed between the coach body suspended pendulum fashion in vertical guides and the levitating frame. The guides also take over the horizontal springing of the coach body and permit the free lateral motion of the levitating frames relative to the coach body when curves are negotiated, without adverse effect on the pneumatic spring function.

The structure of the support- and guidance system described produces functional redundancy with appropriate layout and design of the components, ie individual breakdowns of the components of the magnet gap control loops are coped with without immediate effects on the running operation.

Other relevant conditions are suitably structured vehicle electrical systems for the power supply and control loop components with fail/safe function.

Vehicle power supply

Every 440 V vehicle electrical system has been designed as an earth-free, insulated network with selective consumer point fuse protection and permanent insulation monitoring to ensure high availability of the vehicle power supply. When the first insulation break occurs a fault message is generated and the run terminated without restriction. The probability of a fault occurring in the vehicle electrical system is extremely unlikely because of the construction and execution features listed below:

▷ short-circuit- and earth-leakage-proof wiring from the battery to a central switch unit in the centre of the section to the individual consumer point fuses,

▷ installation of switch gears, fuses, protection-

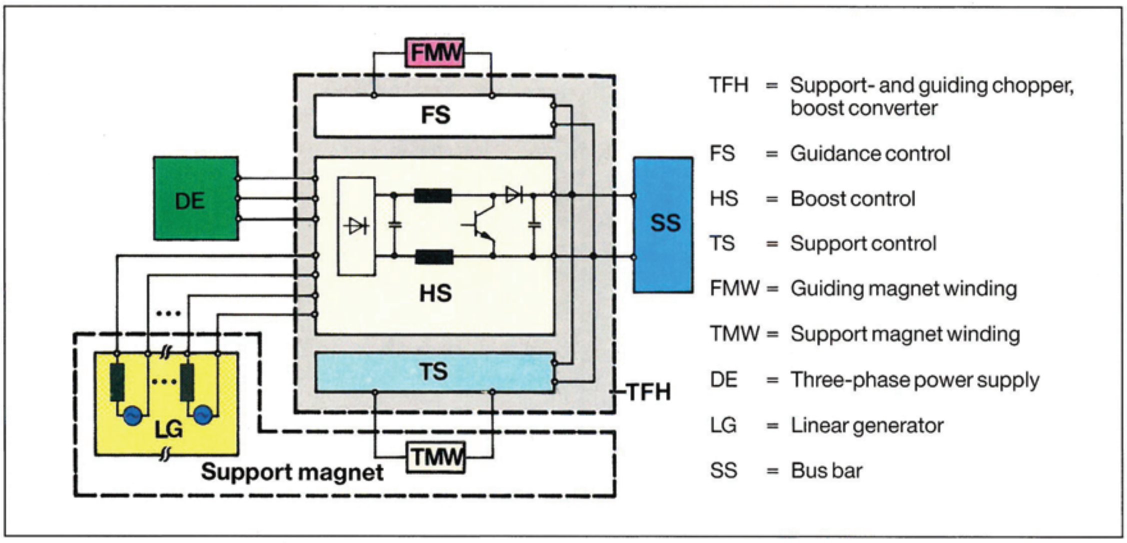


Fig. 3: Boost converter with energy supplies and loads

and monitoring units as well as of bus bars for all four vehicle networks in a Protection Class IP 65 central switch unit; the spatial separation of the four vehicle networks is maintained also in this field,

▷ use of high-quality halogen-free flame-resistant doubly insulated cables.

Boost converters/linear generators

During running the vehicle networks are supplied by the linear generators. For this purpose each support magnet is fitted with two five-phase symmetrical linear generators. The adaptation of the frequencies and voltages, which increase in proportion with the running speed, to the vehicle network is the task of the boost converters (Figs. 3, 4).

When the vehicle runs below the operational speed of about 100 kmph the boost converters are controlled so that they take the maximum possible power from the linear generators. Above the operational speed the on-board power requirement including the charge conservation operation for the batteries is covered by the linear generators. Through the functional principle of the boost converter – raising a low input voltage to a higher output voltage – in conjunction with the appropriate layout of the linear generators and of several mutually independent protective and monitoring devices and the high functional redundancy (30 units per section) overcharging the batteries or an increase of the vehicle network voltage to unduly high values is impossible and the power consumption of the vehicle is ensured independently of external factors.

During running operations above the operating speed the vehicle network is actively damped by the boost converter. Because of its high regulating dynamics it can cover the pulsating power requirement of the support- and guiding choppers immediately on site in the decentralized TFH unit (support- and guiding chopper, boost converter), which largely avoids loading the vehicle network with pulse currents. The oscillograms of Fig. 5 demonstrate this situation. Here, in the arrangement according to Fig. 4 the boost converter was experimentally separated from the bus bar.

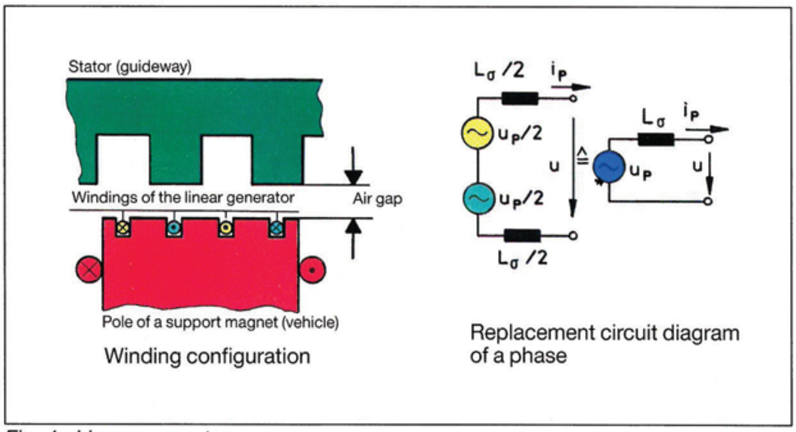
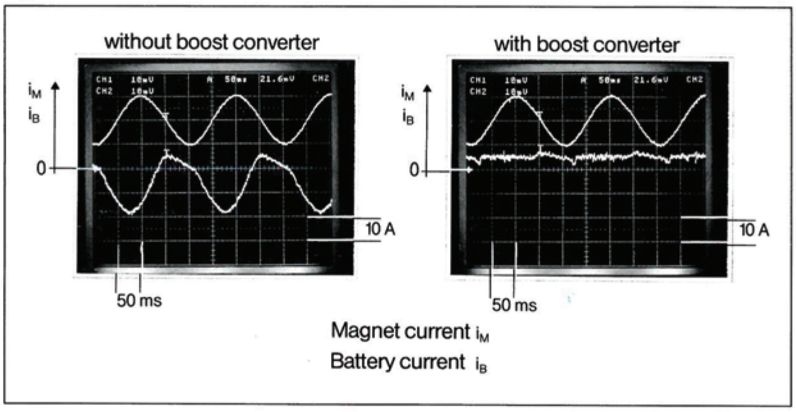


Fig. 4: Linear generator

Support- and guiding choppers

The field coils are supplied with a variable current commanded by the magnet gap control unit by separate choppers for the "support" and the "guidance" function respectively. The electrical circuitry of the magnets adjacent to a hinge point has been chosen so that two groups of coils bridging the hinge point are always supplied by one separate chopper. This arrangement guarantees that the support and guidance function on a hinge point is assured even if one of the parallel-acting control loops should fail (Fig. 6).

Fig. 5: On-board network stabilization with boost converter



William Dickart and Manfred Wackers

A Study of MagLev Projects in the U.S. (Las Vegas–Los Angeles Corridor)

The early introduction of the maglev propulsion technology into international planning activities is designed to demonstrate the system advantage of this new technology in tracked transport and to prepare the ground for the international application of MagLev technology. The results of the feasibility study of the Las Vegas–Los Angeles corridor are of special significance in this context.

These studies must also be regarded as particularly important because, on the basis of a concrete case of application, system comparisons are made between the Transrapid magnetic train and advanced wheel-on-rail systems. The results favour the introduction of a magnetic train system. The link between Las Vegas and Los Angeles must be considered a corridor representative of the USA, which generally offers an important market for tracked transport systems of the future.

Study Phase I: 1982–1983

In 1982 the City Administration of Las Vegas initiated Phase I of the feasibility studies for various high and super speed systems for tracked transport. The Budd Company were commissioned by the City of Las Vegas with the investigation of the feasibility of the construction and operation of a tracked high-speed transport system between Las Vegas and Los Angeles. Under the management of Budd Company, the US firms Bechtel and Transtech International, and Transrapid International of the Federal Republic of Germany took part in the study.

The following problems were dealt with:

▷ feasibility of a high-speed rail link between Las Vegas and Los Angeles

▷ technological and economic choice of a suitable high-speed rail system

▷ determination of the system costs and productiveness

▷ cost/benefit analysis

▷ recommendation of a system

▷ preparation of an implementation plan

▷ financing plan

▷ operating services.

A number of high-speed wheel-on-rail systems, (Shinkansen high-speed railway, TGV, ET403/DB, APT, LRC etc.) as well as the Japanese (electrodynamic levitation system/JNR) and the German Transrapid MagLev railway were included in the systems comparison.

For the practical case of Las Vegas–Los Angeles clear preference was given to the German MagLev railway system. This decision, so favourable to Transrapid, was justified as follows:

The figures of transport volume determined in comparison with the wheel-on-rail systems promised a future profitable operation of the system (up to 20% return on investment). The German magnetic train was preferred to the Japanese one based on electrodynamic levitation technology because a significantly more advanced level of development was found to have been attained by the Transrapid system. It has been shown that a wheel-on-rail system at a maximum speed of 260 kmph requires 2 hrs 10 min to cover the distance between Las Vegas and Los Angeles, but a 400 kmph maglev railway will do it in only 1 hr 10 min. The determination of the transport volume revealed that halving the journey time – roughly corresponding to the difference between that of the maglev railway and of the French TGV on the Las Vegas–Los Angeles line – will almost double the transport volume.

In 1983 the capital cost of the 370 km magnetic train guideway was estimated at $ 1,900 m. The cost of the wheel-on-rail line was of a comparable order. The potential transport volume was assessed at 3.8 m passengers annually at a return fare, at 1982 prices, of $ 65.–.

Phase I of the project was completed in January 1983 with the presentation of the results and the recommendation to use the German Transrapid MagLev railway system as the basis for further investigations. Because of the highly promising results the City Administration of Las Vegas appointed a project coordinator for Phase II of the investigations, which started in the autumn of 1984.

Study Phase II: 1984–1987

Phase II comprised the execution of studies commissioned on the basis of competitive tenders submitted by about 50 companies specializing in this field at the end of 1984/beginning of 1985. The execution of the studies was based on the following specifications:

- ▷ Basis system to be used: Transrapid 06
- ▷ other systems: JNR-MAGLEV, TGV.

The following subjects were investigated: transport volume, socio-economic effects, effects on the environment, organization financing planning, technological status of the systems.

The final report with recommendations for the further proceedings was submitted to the U.S. Federal Railroad Administration by the City of Las Vegas in June 1987.

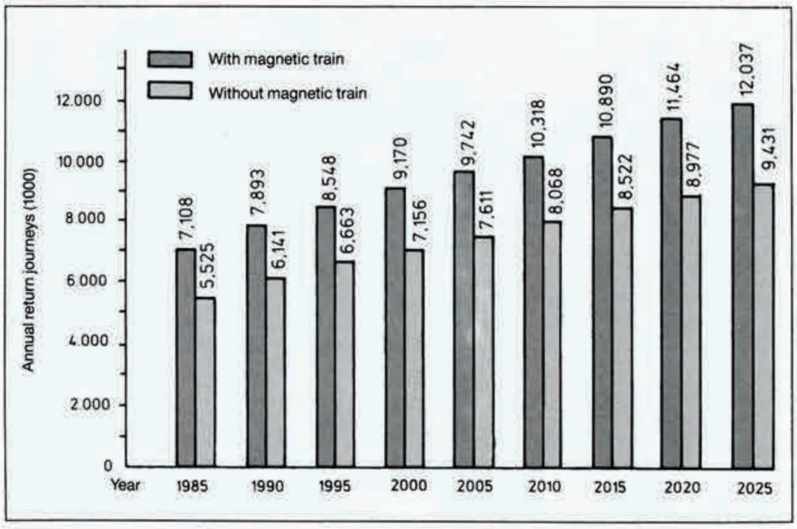


Fig. 2: Annual transport volume between Las Vegas and Los Angeles

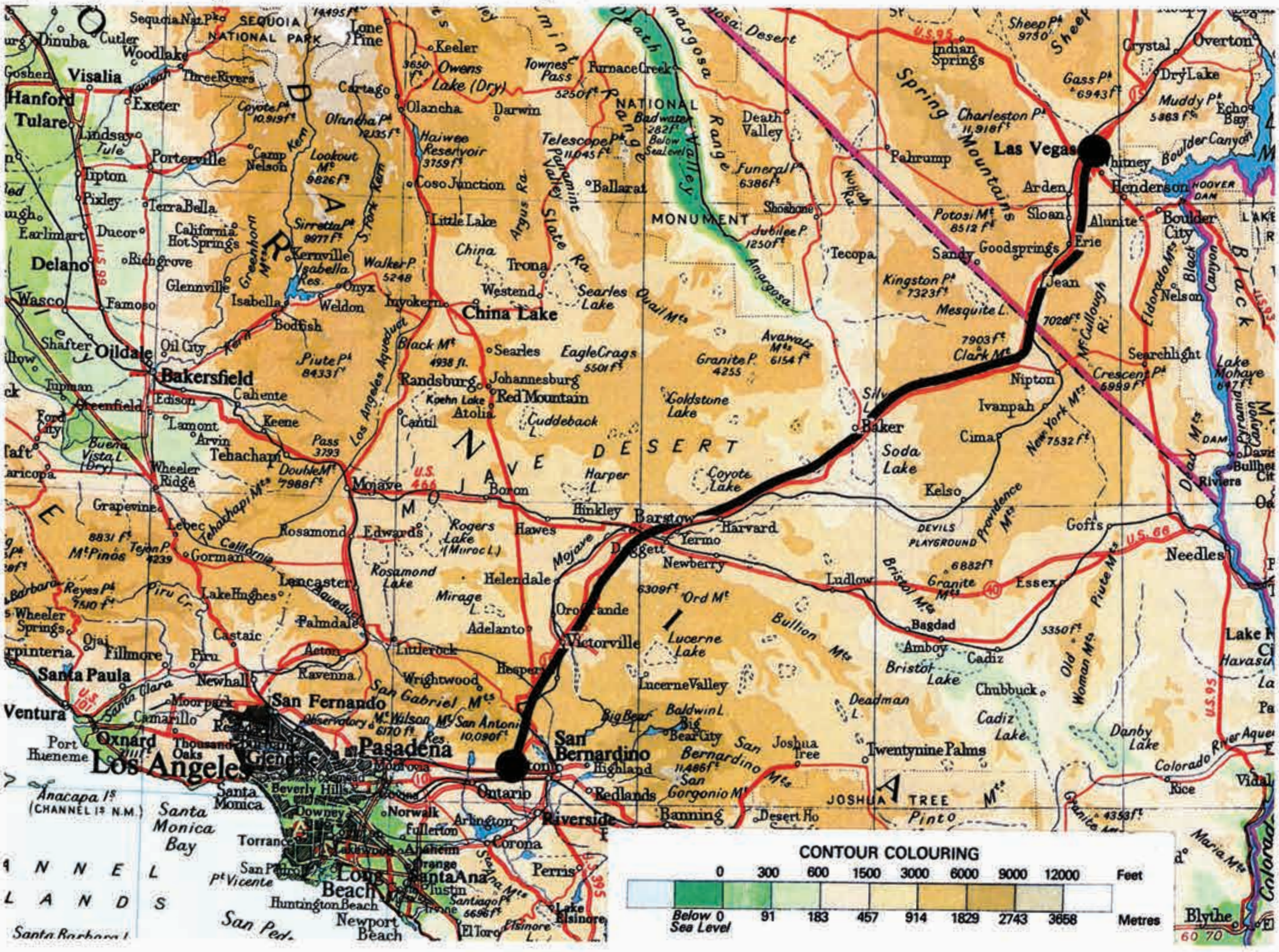
Transport Volume

Las Vegas has 15 m visitors per year, with the trend still rising; 40% come from Southern California by car, coach or plane. The passenger volume of air transport to Las Vegas today is the fifth highest out of Los Angeles; the motorway has reached the limit of its capacity.

Thus 5.5 m persons travelled between Southern California and Las Vegas in 1984. 84% used a road vehicle, almost 90% of all the journeys were of a private nature. In 2025 this transport volume will exceed 12 m travellers, of whom about 40% will use the super speed MagLev train. The use of an attractive super speed system will produce an increase of the transport volume by newly generated traffic of up to 28%.

The shift of traffic will be mainly away from private transport, of which one third would switch to the MagLev railway in the event of its introduction. This

Fig. 1: Super speed magnetic train corridor Las Vegas–Los Angeles



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