

# 40 Years MAGLEV Vehicles in Germany

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## Abstract

On May 6th 1971 the worldwide first MAGLEV vehicle was presented by Messerschmitt-Bölkow-Blohm (MBB) in Ottobrunn near Munich, Germany. Till the year 2000 different test and application MAGLEV vehicles followed, but no commercial use in Germany. Since December 31st 2002 the Shanghai MAGLEV Transportation System is successfully in operation, as the worldwide first and only one commercial used MAGLEV line.

The paper in honour of Prof. Dr.-Ing. Eveline Gottzein for her 80th birthday contains in the reference list her scientific publications about MAGLEV vehicle control systems.



## 1. Introduction

During the past five decades increasing interest has developed in new forms of high speed railway transportation systems including MAGLEV trains. In Japan since 1964 the Shinkansen is in operation and in French the TGV started in 1981. In Germany the attractive Electromagnetic System (EMS) was favoured while in Japan the repulsive Electrodynamic System (EDS), cooled with liquid helium, was developed. In contrary to the Electrodynamic System the Electromagnetic System has an inherent instability, so that every electro-magnet has to be actively controlled by an observer-controller system. In 1969 a company was commissioned by the German Federal Ministry of Transport to prepare a study on modern high-speed transport. This is the real beginning of research and development of MAGLEV vehicles in Germany, cf. [15,28]. In the paper the MAGLEV vehicles beginning with the MBB Demonstration Vehicle in 1971 till the Shanghai MAGLEV Transportation System of 2002 as the first commercial used MAGLEV line are presented.



Fig. 1: The 1971 MBB Demonstration Vehicle with short-stator linear motor, 5.8 t, 90 kmph. Test track 660 m.

## 2. The MAGLEV Test- and Application Vehicles

40 years ago, on May 6th 1971 the worldwide first magnetically levitated (MAGLEV) vehicle, the MBB Demonstration Vehicle with a separate support and guidance system, shown in Fig. 1, was presented to the public at Messerschmitt-Boelkow-Blohm (MBB) in Ottobrun near Munich, cf. [15,28]. It is the worldwide first large-scale passenger carrying proof of the feasibility of the magnetic levitation technology. In October 1971 it is followed by Krauss-Maffei Transrapid 02 with a combined support and guidance system and a speed of 164 kmph.

In 1974 Krauss-Maffei and Messerschmitt-Bölkow Blohm form the Transrapid E.M.S. joint venture company in Munich for further development of MAGLEV vehicles.

In 1975 tests started with the MBB Komet Component Testing Vehicle with a separate support and guidance system, cf. Fig. 2. Komet is an unmanned, magnetically supported and guided vehicle for testing components, such as electro-magnets, sensors, control systems, linear induction motors, and current collectors. Due to the short length of the test track of only 1.3 km, the MAGLEV vehicle Komet had to be accelerated by rockets, cf. [16,28].

In the same year the Krauss-Maffei Transrapid 04 with a combined support and guidance system was successfully tested with a speed of more than 250 kmph, cf. [16,28].

In 1976 the MBB Komet sets up a world speed record of 401.3 kmph for electro-magnetically levitated (MAGLEV) vehicles at the straight line test track in Manching, cf. [28].

In the same year Transrapid E.M.S. moves over from experimental MAGLEV vehicles to a transport concept and presents the Transrapid System with synchronous long-stator linear motor together with Thyssen Henschel (later ThyssenKrupp Transrapid).

Up to the end of 1978, the participating companies and the German Federal Ministry of Research and Technology have invested more than DM 300 million (EUR 150 million) in the development of the new MAGLEV high-speed ground transportation system.

In 1979 at the International Transport Exhibition held in Hamburg, the public have the first opportunity to ride in a MAGLEV vehicle (Transrapid 05, Fig. 3). The separate support and guidance control system was developed by Messerschmitt-Boelkow-Blohm, and the cabin by Krauss-Maffei. The elevated steel-guideway and the long-stator linear motor of this demonstration facility were built together with Thyssen Henschel, cf. [1,29].

In 1982 the 31.4 km Emsland test track is to become operational. The vehicle used is the Transrapid 06, cf. Fig. 4, with a speed of 355 kmph in December 1985 on the not finished guideway, cf. [2,25]. The Transrapid 06 with a separate support and guidance system was developed by the same companies as Transrapid 05.

In 1988 the speed attained by Transrapid 06 was 412 kmph on the finished closed loop guideway.

The Transrapid 07, shown in Fig. 5 and the Transrapid 08 (similar to the Shanghai MAGLEV Vehicle, shown in Fig. 6) designed by ThyssenKrupp Transrapid in 1992 and 1998, followed in the Emsland test facility, cf. [26].

Between 1982 and 2000 many application studies like Hamburg-Berlin, Ruhr District and Munich Airport Line were carried out in Germany, but no realization and therefore no commercial operation.

Since 2002 the Shanghai MAGLEV Transportation System, cf. Fig. 6, between Shanghai Pudong International Airport and Long Yang Road Metro Station is successfully in operation with a speed of 430 kmph and a maximum test speed of over 500 kmph on the 30 km double track guideway. It is the worldwide first and only one MAGLEV line with commercial operation, cf. [22,23,24,27]. Since 2002 it was used from 29.9 million passengers and the MAGLEV vehicles have driven already a distance of 8.97 million km, cf. [31].

Earlier ten years than the Chinese government decided to build the MAGLEV project in Shanghai, the first scientific paper about MAGLEV vehicle control was published 1991 in China at Tongji University, cf. [21].



Fig. 2: The 1975 MBB Komet with rocket engine, 8.8 t, 401.3 kmph. Double-span steel test track 1.3 km.



Fig. 3: The 1979 Transrapid 05 with long-stator linear motor, 36 t, 75 kmph, 68 passengers. Steel track 908 m.



Fig. 4: The 1982 Transrapid 06 with long-stator linear motor, 120 t, 412 kmph, 200 passengers. Track 31.4 km.



Fig. 5: The 1992 Transrapid 07 with long-stator linear motor, 90 t, 450 kmph. Test track 31.4 km.



Fig. 6: The 2002 Shanghai MAGLEV Transportation with long-stator linear motor, 505 kmph. Track 30 km.

### 3. The Electromagnetic Support and Guidance Control System

The support and guidance control system consists of electro-magnets on the vehicle and reaction rails on the elevated guideway. Because the electro-magnets attract the vehicle to the rails the system is inherent unstable and a control system maintains a constant gap of about 10 mm between the guideway and the magnets. Sensors continuously measure the narrow air gap, the magnet acceleration and the magnetic flux and transmit the measurements thus obtained to the support and guidance observer-controller system, which keeps magnetic attraction at the necessary level and thus allows the vehicle to levitate reliably, cf. [3,5,12,21]. When the magnets are switched off the MAGLEV vehicle rests on a spring glide system.

In the MBB Demonstration Vehicle and the MBB Komet all support and guidance electro-magnets were fixed rigidly on the car body. Therefore the degrees of freedom heave, slip, pitch, roll, and yaw of the whole vehicle are controlled by five observer-controllers (centralized control system), cf. [5,19]. In the Transrapid 05 and the Transrapid 06 the electro-magnets were connected with springs on the levitation frame. The translational degree of freedom of every magnet is controlled by independent observer-controllers (decentralized, modular control system), while the rotational degree of freedom is blocked by mechanical equipment. This control strategy was already tested successfully with the MBB Komet M (Modular) in 1976, cf. [3,4,12,13,14]. The worldwide first MAGLEV digital control system was designed and tested successfully with a sampling frequency of 100 cps for the MBB Demonstration Vehicle in 1973, cf. [20]. All the support and guidance control systems in the MAGLEV vehicles above mentioned were developed by Messerschmitt-Bölkow-Blohm in the Control Dynamics and Simulation Department under the leadership of Prof. Dr.-Ing. Eveline Gottzein, cf. [2-15,17-20].

In the Transrapid 07 and the Transrapid 08 (similar with the Shanghai MAGLEV Vehicle) designed by ThyssenKrupp Transrapid, the translation and rotation of every support and guidance electro-magnet pair is controlled by a modified observer-controller system.

### 4. The Linear-Motor Propulsion System

There are various ways of providing contact-free propulsion. A system analysis must therefore be conducted first to find out which method is most cost-effective. While even propeller or jet engines are conceivable for propulsion purposes, developments in Europe have been concentrated on linear induction motors.

Contrary to the rotating electric motor with its rotary motion, the linear induction motor produces what experts call a translatory motion. Imagine its mode of operation by considering a rotating motor cut open. The rotary magnetic field generated in the stator of the motor and causing the rotor to turn, now becomes a travelling magnetic field which induces a forward motion, cf.[28].

In the asynchronous short-stator linear motor, used in the MBB Demonstration Vehicle, the Transrapid 02 and the Transrapid 04 the active part of the motor developing the travelling field is housed in the vehicle, while the reaction rail is in the track. Propulsion energy must therefore be transmitted to the vehicle, where it is conditioned for the motor by frequency converters. Because the increasing power for propulsion at high speed, the electric equipment inside the vehicle gets very heavy and the loading capacity will be reduced.

This problem does not arise with the synchronous long-stator linear motor (track motor) used in Transrapid 05 to Transrapid 08 (similar to Shanghai MAGLEV Vehicle), where the travelling field is generated in the guideway by stationary frequency converters next to the track. Here it is the track – and not the vehicle – which involves greater complexity. The long-stator linear motor was already tested successfully in the Thyssen Henschel HMB2 Vehicle in 1976, cf. [29,30].

### 5. The Elevated Guideway

Because of strong restrictions on the use of existing land and a high degree of availability the guideway of a MAGLEV line is an elevated, periodically supported track, cf. [32]. Early computer simulations of the vehicle-guideway dynamics with single- and double-span guideways demonstrates the advantage of the single-span guideway for speeds over 400 kmph, cf. [17,18]. Test runs with the MBB Komet and with the Transrapid 06 in the Emsland test facility confirm this result, cf. [19]. To reduce the guideway construction costs a flexible light weight guideway together with a more sophisticated MAGLEV control system was proposed from Messerschmitt-Bölkow-Blohm in 1975, cf. [17,18]. But in the Shanghai MAGLEV Transportation System a very stiff and heavy concrete guideway was realized by the Fifth Shanghai Construction Limited Company to minimize the requirements of the MAGLEV control system.

## 6. Conclusions

Four decades ago the worldwide first MAGLEV vehicle was presented to the public at Messerschmitt-Bölkow-Blohm in Munich, Germany. Till the year 2000 several test and application MAGLEV vehicles followed. However after Germany MAGLEV Emsland test line and China Shanghai MAGLEV Transportation commercial operation line, the MAGLEV technology was almost lost in the tide of high-speed railway train development in Europe and Asia. MAGLEV trains have almost no development hope today, when high-speed railways in China with speeds over 350 kmph are still in the mainstream.

Sometimes the development of the times has its own law: perhaps MAGLEV trains are the future technology, because people prefers high-speed transportation. With 350 kmph the operational speed of the railway is close to the limit. The operational speed of MAGLEV trains may develop from 500 kmph now to 600 kmph in the future or even higher. In the oil depleted future MAGLEV trains are superior to airplane and also suitable for long-distance transport. Maybe that the future Europe-China connection will be realized with a super-speed MAGLEV line.

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