Chapter 6

MAGNETIC LEVITATION: STATUS AND OUTLOOK

Contents

Figure

Chapter 6
MAGNETIC LEVITATION: STATUS AND OUTLOOK

SUMMARY

Technology Status

Two different technologies using magnetic levitation (maglev) for high-speed intercity passenger service are being developed abroad. One, called attraction or electromagnetic suspension (EMS) maglev technology, employs conventional iron-core electromagnets, and is being developed by the Federal Republic of Germany. The other, called repulsion or electrodynamics suspension (EDS) maglev technology, employs superconducting magnets, and is being developed by Japan.

Both systems rely on electromagnetic forces to provide support (levitation), lateral guidance and propulsion (and braking) without direct physical contact between the vehicle and the guideway.

The attraction maglev system floats about ½ inch from the guideway surface and can levitate at any speed. The repulsion system floats about 4 inches away, but only works after sufficient forward velocity to achieve electrodynamics levitation is reached. Repulsion systems also require auxiliary wheels for support at low speeds.

The attraction system requires electronic sensing of the gap and continuous control of the magnetic current to achieve stable levitation. The repulsion system can levitate stably once sufficient forward velocity is attained.

Maglev systems are reported to have several advantageous features including:

- low track and vehicle repair and maintenance costs because of the low guideway loading and freedom from mechanical contact;
- higher speed capabilities with the resulting potential for improved productivity;
- enhanced safety, since derailment is theoretically impossible;
- less vibration and noise than conventional rail technologies; and
- low sensitivity to weather conditions due to elimination of mechanical contact between the guideway and the vehicle.

To date, neither technology has been tested and operated at sustained speeds or under the conditions required to demonstrate performance at levels and costs suitable for actual revenue service. However, the West German attraction maglev technology now has moved to the developmental testing stage. The West German tests are being conducted at the Emsland Test Facility in Lower Saxony. Complete test results are anticipated in late 1985 or early 1986. They will put one (two-car) system through approximately 160,000 miles of operation in the initial year of testing. * The Japanese repulsion maglev technology is still in the experimental stage, and, according to the Japanese National Railways (JNR), it will probably take 10 years before testing and demonstration are completed.[1]

Substantial technical development and testing still is required for both technologies, although there appear to be no insurmountable technical obstacles. A West German power distribution and conditioning system which controls the large amounts of power and the frequency required for propulsion is to be tested.[2] There are operational and cost uncertainties to be tested in this system. Additional development and funding may be required before it is ready for revenue service.

For the Japanese (repulsion) technology, development of a power conditioning system, and further research is required as well on the cryogenics

*According to Budd Co. officials, the initial year and 160,000 miles of tests will occur on the Emsland test track before the Southern loop of the facility is completed. Thereafter, they anticipate approximately 500,000 miles of tests annually as published in the Transrapid brochure.

[1]Responses to OTA questions by JNR official, Ichiroh Mitsui, February 1983.

[2]The Budd Co.

(the cryostat and refrigerator necessary for the superconducting magnets).

Concerns about maglev technologies that remain to be addressed in demonstration and testing include:

- suitable, reliable, and stable guideway structures since the gaps are small (½ inch for the attraction and 4 inches for the repulsion system) between the guideway and the vehicle, and the ability of the maglev suspension to follow gap variation is limited;
- emergency procedures and the suitability of current service restoration schemes in the event of breakdowns;
- possible electromagnetic interference in the electrical systems near maglev corridors;
- for the repulsion system, the effects of the superconducting magnets' electromagnetic fields on the passengers;
- the reliability and maintenance costs for both wheel and levitation components to be used in the repulsion system and, for the levitation components in the attraction system. Also whether wheels (currently not included in the attraction system design) will be needed as a backup in case of system failure;
- the performance level of switching devices; and
- positive detection and safety in the event of guideway defects and obstacles.

Economic Feasibility

Capital and operating costs of maglev systems have been projected by technology developers. Those theoretical projections were not studied in this report. While some approximation of capital costs may be possible, the reliability of such projections must be examined in the context of the actual experience, testing and demonstration, particularly for guideways. Similarly, operating costs must be verified through tests and demonstrations under conditions that fully reflect revenue service. Given the fact that the systems have never been run at speeds and under conditions that reflect actual service, reliability of cost projections remains a concern.

Preliminary cost estimates have been included in several feasibility studies of maglev corridors in the United States by potential suppliers of the technologies. Experts and developers of the technologies claim operating cost as well as other advantages over conventional high-speed rail technologies.

Comparison With Other Modes

Maglev technologies are often termed "flying trains" because they are noncontacting and combine the high speeds of aircraft and the fixed guideway of trains. In a technical sense, maglev differs from conventional high-speed rail technology in many ways. In terms of the service it offers, however, the primary difference between maglev and conventional high-speed rail is speeds up to 50 to 150 mph higher than steel-wheel on rail technology.

Maglev proponents cite as an advantage the expected reduction in maintenance costs from having fewer moving parts with no friction from movement and pressure as in wheels on rails. Developers also claim reductions in land costs for the guideway if the structure is elevated, reductions in labor costs since the technology is highly automated, and reductions in noise and vibrational effect. Noise tests are scheduled at Emsland.

Economic comparisons between maglev and wheel-on-rail high-speed technologies are subject to question until more is known about the operating characteristics, and the operating and capital costs of maglev technologies. Aside from any cost differences, the "induced" demand that maglev might create because of its greater speed and novelty is a major factor making a maglev corridor appear more attractive to planners than other high-speed rail systems. Although there is no reliable way to predict how great "induced" demand might be, in one corridor proposal, estimates of "induced" demand represented approximately *50* percent of the total projected ridership.[3]

[3]Budd Co. Technical Center, "Executive Summary, Las Vegas to Los Angeles High Speed/Super Speed Ground Transportation System Feasibility Study," January 1983.

Two U.S. corridors have been considered for possible maglev introduction: Las Vegas-Los Angeles and Milwaukee-Chicago. Feasibility studies have been conducted on these corridors, by the developers or potential suppliers of the technologies. Las Vegas officials are actively seeking $10 million in venture capital for the project.

DISCUSSION

The search for an alternative to steel wheel on rail technology-with its high maintenance costs, noise, and energy consumption—is not new. Technologies explored include air and water cushion systems as well as magnetic levitation. However, attention increasingly has focused on maglev technologies as the most promising means to avoid many of the costs and problems associated with wheel-on-rail technology and, at the same time, to provide a smoother ride and much higher top speed than conventional rail could ever achieve. It became a serious contender as an alternative to the conventional airline in the 1960's, when it was believed that the capacity of airports in major cities soon would be exceeded and additional airports would be needed. New York considered a fourth airport, and London a third. Maglev seemed worth exploring as an alternative to the major expenditure, congestion, and environmental problems that additional airports would entail.[4]

Although the U.S. Government-sponsored maglev research programs from the National Science Foundation (NSF) and the Federal Rail Administration did not start until 1971, there were other U.S. programs supporting research and development of tracked air cushion vehicles and linear induction motors. U.S. maglev research and development was on a par with similar foreign research programs at the time the U.S. Government canceled it in the mid-1970's to shift to research in freight and conventional rail technology problems. The British, French, Canadian, and U.S. Governments, after study and some experimentation and have since abandoned work on high-speed maglev. The practical development of maglev technologies is now confined to West Germany and Japan.

Maglev Systems

There are two basic kinds of magnetic suspension—attraction and repulsion—and both have been combined with a variety of linear motor configurations in the pasts

Attraction/Repulsion Suspension Technologies

Magnetic levitation can be achieved by attraction or repulsion technology. In the attraction system, the track is suspended from the guideway and the vehicle drawn magnetically upwards toward it. The vehicle has conventional iron-core electromagnets which are controlled to maintain a gap between track and vehicle. Similar devices maintain a gap between the side of the guideway and the vehicle. In the repulsion system, the aluminum track is below the vehicle and suspension is achieved by magnetic forces which push the vehicle away from the guideway. These forces result from vehicle speed and do not exist when the vehicle is at rest.

In the West German attraction system, the clearance between vehicle and guideway is about ½ inch and suspension is independent of speed.

In the Japanese repulsion system, the vehicles have a clearance of about 4 inches increasing with speed. At speeds below about 50 mph, the vehicle runs on wheels. Magnetic suspension occurs, and the vehicle "lifts off, " as higher speeds are reached.

Propulsion

Maglev vehicles use linear motors for noncontacting propulsion. The principle of linear motors

'Comparative Assessment of New Forms of Intercity Transport, T. R. R. L., Report S. R.3., December 1971.

'Massachusetts Institute of Technology Library, "Long Term Assessment of Passenger Ground Transportation System Technology," 1982.

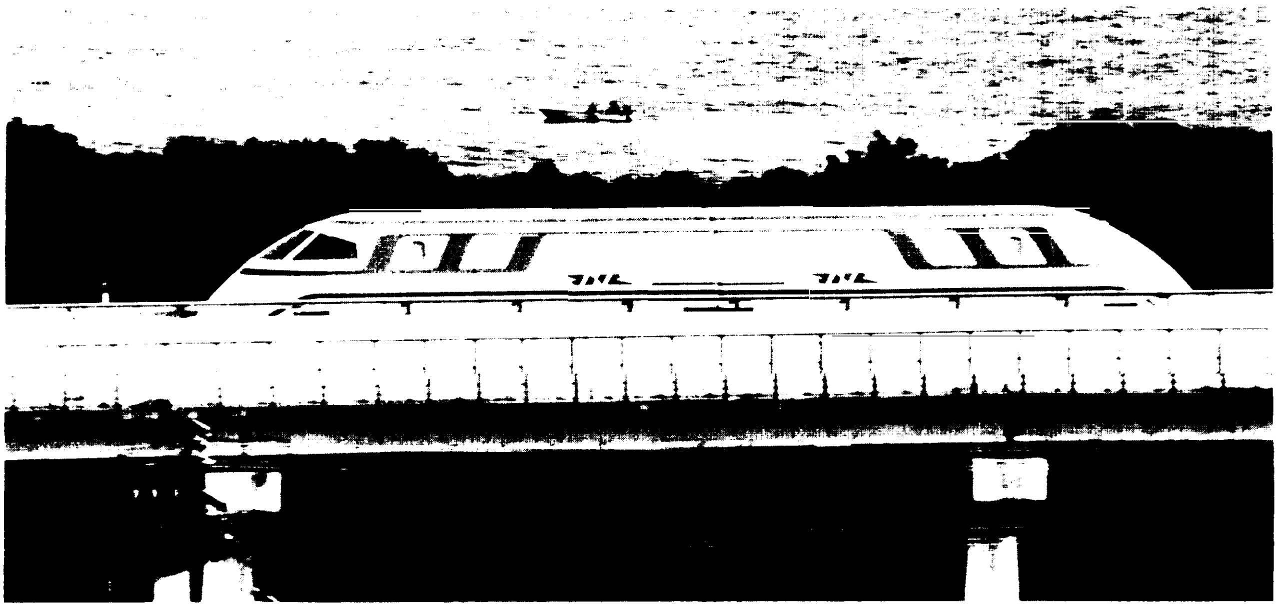


Photo credit: Japanese National ***Railways***

Repulsion maglev MLV-001 test vehicle in Japan

is simple; they are analogous to common electric rotory motors, but with their components "unwound" as shown in figure 10. The primary (rotor) is the onboard component, and the secondary (stator) is the guideway bound component of the motor. Such motors also require a power-conditioning unit (PCU) to regulate the current (amount) and frequency of electrical power to develop the propulsion forces.

A variety of linear motor types have been developed and tested with maglev vehicles, but only the linear synchronous motor (LSM) is being developed currently for the high-speed application for either attraction and repulsion systems. LSMs locate the PCUs wayside primarily because of the size and weight of the PCUs and the problems of power supply to fast-moving vehicles.

To avoid powering the entire route (which would have unacceptable power losses), only the short sections of guideway on which vehicles are traveling are powered at a given time. This system provides automatically for safety separation of following tracks. These sections, called blocks, are typically *0.5* to **5 km** long. The system for providing the sequential block activation is called the power distribution and conditioning system and includes the PCU.

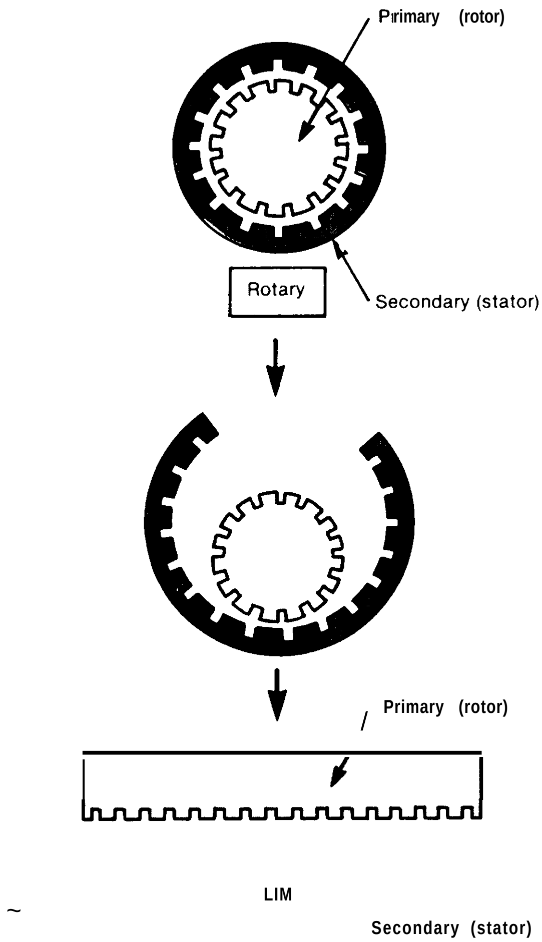
Power Distribution and Conditioning System

A major technical problem for both maglev systems is developing a power distribution and conditioning system suitable for revenue service. This system must control the large amounts of power required for propulsion of the vehicle. Two key aspects of this system are: 1) the power controlled by an individual PCU, and 2) the networking of PCUs required for the entire route.

A very sophisticated piece of electronics, the PCU provides closed loop, variable voltage, variable frequency (VVVF) electrical power for propulsion. The size of the individual PCU is determined by both the vehicle speed and train length of the individual system. But very few PCUs of the size required for high-speed, high-density systems exist today. Furthermore, they require more sophisticated control than typical industrial PCUs.

The number of PCUs employed in the network is of concern since the PCUs are expensive. The absolute minimum number of PCUs is determined

Figure 10.—The Principle of Linear Motors



SOURCE: "Long Term Assessment of Passenger Ground Transportation System Technology," Massachusetts Institute of Technology, 1982.

by either: 1) the number of vehicles simultaneously on a route (since each vehicle requires a dedicated PCU), or 2) the minimum practical spacing due to the problem of distributing VVVF power over large distances—whichever dominates. The basic design issue is that the network of PCUs must consider both the state-of-the-art individual PCUs and the optimum sequential switching schemes, which can be costly. * However, since the state of the art in individual PCUs is advancing rapidly, the overall network design most suitable for a maglev system could change in the near future.

Current Stage of Development of Maglev Systems

In Japan and West Germany, both the attraction and repulsion technologies of levitation have been tested and shown to be operational at an advanced experimental level. In each country, one system has now been discarded, and work has been concentrated on the other (each country rejected the opposite system).

In Japan, the Government is funding the development of a repulsion system by JNR. Although still in the experimental stage, very high-speeds (exceeding 300 mph) have been achieved with small vehicles (5 to 9 tons). The latest vehicle can carry eight passengers, but public demonstrations have not taken place nor are any planned at this time. JNR has now asked Government permission to build a larger scale test track.

The development program sponsored by the West German Government is in a more advanced stage. After success with experimental vehicles, a complete system using maglev vehicles on an elevated guideway was built and operated for several months. A track of about 0.6 miles was constructed in Hamburg in 1979 for the International Transportation Exhibition, on which a two-section vehicle, weighing 26 tons with seating for 72 passengers, was operated at speeds up to 50 mph. Although operated at low speed, the vehicles and guideway employed the same basic technology that is being developed for a 250-mph system. At present, an elevated guideway of 20 miles in length is under construction for the testing of two

*** The Budd Co., a subsidiary of Thyssen Henschel, developers of power-conditioning systems for several new locomotives and for the West German maglev system, indicates that the power distribution and conditioning system required for revenue service of the German maglev system will be demonstrated at the Emsland facility. According to Budd, the power distribution and conditioning system at the Emsland Maglev Test Facility includes a network transformer of 31.5 MVA, intermediate circuit transformers of 11.2 MVA each, two rectifiers of 17.2 MW each, two puls-inverter groups of 19.2 MVA each and two output transformer groups for higher frequency operation of 16.0 MVA each. The complex portion of the power distribution and conditioning system is the puls-inverters. At Emsland, each puls-inverter group will use two of these units in parallel. Revenue service application will require 30 to 35 MVA, thus necessitating the use of three or four of the puls-inverters in parallel. According to Budd, the use of these inverters in parallel and series has been demonstrated, as the Thyssen Henschel locomotive unit is composed of smaller capacity inverters configured in parallel and series to achieve 10-MW capacity.**

preproduction vehicles. The track will make possible sustained testing at 200 mph and limited travel at speeds up to 250 mph. Evaluations will be conducted by an independent group consisting of the West German Railways (DB), the West German national airline (Lufthansa) and the Federal Government. A likely candidate for initial commercial operation would be a high-speed connection between Hamburg and Hanover airport. Although timescales are vague, West German scientists and developers hope to consider possible future maglev corridors in their *1985* planning. If included in the 1985 Strategic Transportation Plan, construction of a corridor could begin in 1990,[6] otherwise consideration of maglev for application in West Germany would not occur again until the *1990* Strategic Transportation Plan.

Both West Germany and Japan have spent significant amounts of research money over the last decade to bring their respective systems to their current stages of development. The German system is further developed than the Japanese, not because the Japanese have placed less emphasis on research, but because more time is required to develop the technology of the superconducting magnets and cryogenics for the Japanese repulsion system.

Areas of Uncertainty

The Japanese System—Repulsion Maglev

This system is still in an advanced experimental stage. Significant changes in the overall system design are still occurring, from cryogenics to power conditioning to guideway shape.

The technology of superconducting magnets is new and untried in the field of public transportation. Although the cryogenics have not yet been shown to be sufficiently reliable for revenue service, JNR runs about a hundred levitation tests a year on this system. A recent advance in the refrigeration technology (for the magnet cooling) has been its location onboard the test vehicle.

The superconducting magnets, cryostat, and refrigeration are the areas in which continued development will occur.

The West German System—Attraction Maglev

This system is now at the preproduction stage. In the summer of 1983 the two vehicles were to be tested for system performance on 20 miles of guideway built to production system specifications. Speed will be increased progressively to 190 mph, and, for about a half mile on each circuit of the track, at speeds up to 250 mph.

The test facility is located in Lower Saxony, near the Dutch border in low lying, marshy country. It will experience a wide range of weather conditions (–15° to +105° F), and the soil structure is poor from the point of view of track pylon stability.

The vehicles will be operated for 18 hours each day–in 30-minute operating cycles, constantly repeated. Two laps of track (about *48* miles when the track is completed) will be undertaken in 20 minutes, followed by a 10-minute stop.[7]

This program will test vehicle reliability in service by routines of starting, running at high-speed, and stopping repeatedly. A 90-percent availability rate is planned with the vehicles traveling about 160,000 miles in the initial year of testing. Thereafter, additional test miles are to be run assuming completion of the Southern loop of the Emsland facility. Tests are scheduled for completion by late 1985 or early 1986.’

If the test program goes as planned, it should be completed by 1986. It would be unusual if the system performs perfectly on initial testing, but Transrapid is confident that the system will perform to the standards and costs forecast.

Comparison of Attraction and Repulsion Systems

For both systems there are still substantial areas of uncertainty: the ability of each system to operate in multiple units, to reliably meet the performance standards required for revenue service, and construction of the new guideway systems to the close tolerances required are some.

---

[6]Discussions, January/February 1983. Dietmar Frenzel, West German Embassy; Udo Pollvogt MBB/ERNO; Horst Hesler, Managing Director, Transrapid International.

[7]Transrapid Consortium, "The Emsland Transrapid Test Facility," 1982.

‘Information provided by Transrapid Consortium in initial review of draft OTA document.

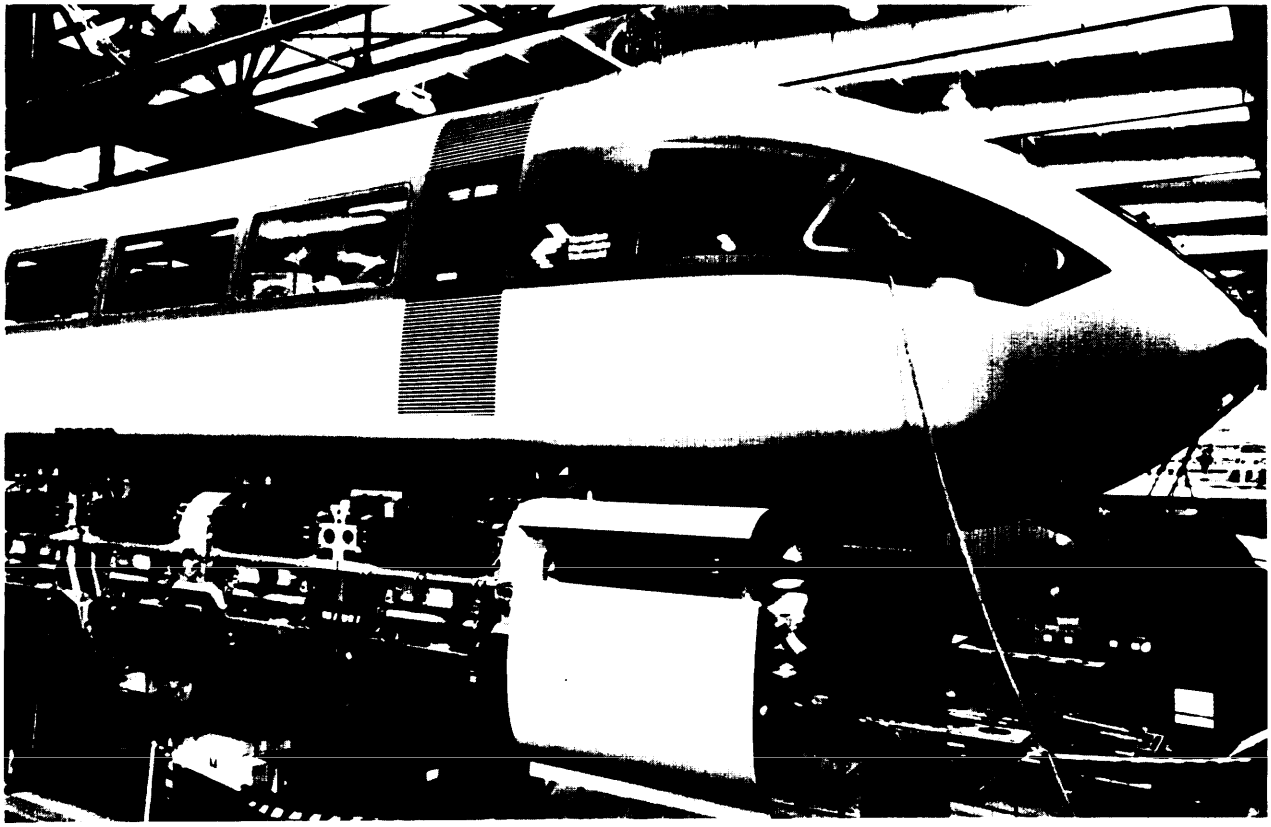


Photo credit: The Budd Co.

Attraction maglev vehicles to be tested at Emsland Test Facility in West Germany

One major difference between the systems concerns the air gap between guideway and vehicle. In the Japanese system, the air gap increases with speed and levels off at about 4 inches, and in the West German system it is about % inch and remains constant. There is disagreement in the scientific community over the significance of gap sizes in terms of vehicle operation.

A second major difference between the systems concerns the magnets on the vehicles. The repulsion system depends on superconducting magnets necessarily cooled to within a few degrees of absolute zero. The attraction system uses electromagnets of developed technology making them closer to deployment for commercial application. So far the superconducting magnets have been tested only under strict supervision and control, and only recently with refrigeration on the vehicle itself. Questions regarding operational and system concerns still remain regarding the superconducting magnets.

In both systems, hotel power* is required on the vehicles. In addition, both systems require power for the magnets. In the attraction system, the power required for the magnets increases with speed, while in the repulsion system, this power is constant. However, the repulsion system requires refrigeration power for maintaining the cryogenic refrigeration for the superconducting magnets. Onboard power plus hotel power for either system are sufficiently low so that it can be inductively coupled from the guideway as the Japanese and West German developers are doing.[9]

*Hotel power includes power necessary to light, cool, and heat the vehicles.

[9]Dr. Robert Borcherts, Research Scientist, Ford Motor Co.

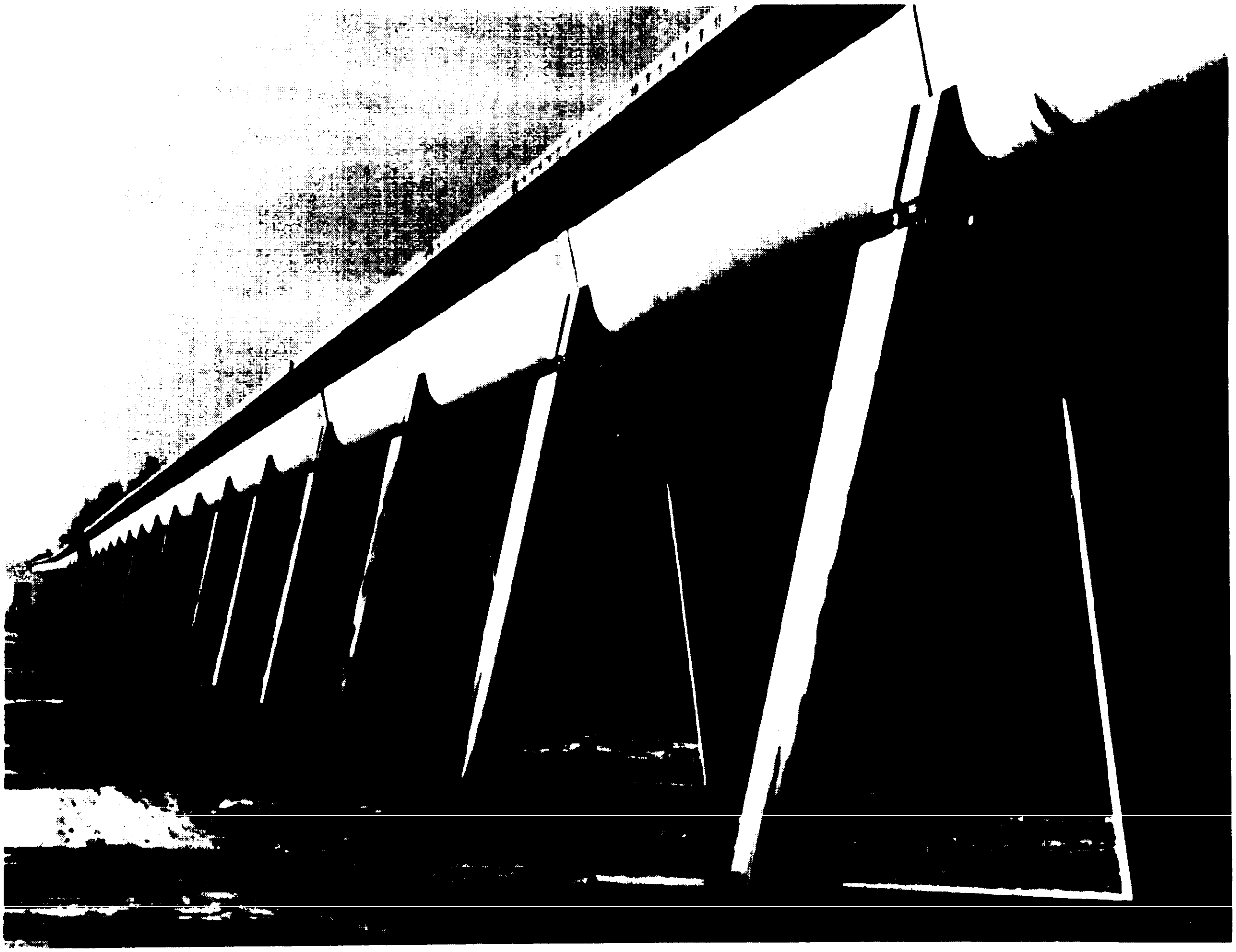


Photo credit: The Budd Co.

Maglev test guideway at Emsland Test Facility in West Germany

Magnetic drag is substantial in the repulsion system, requiring greater propulsion power than the attraction system. Since propulsion power to overcome this drag is relatively independent of speed, and is a significant fraction of total drag (magnetic and aerodynamic) at lower speeds, the repulsion system is much less favorable at speeds under *250* mph.

The next stage in West Germany might have been the construction of a full-scale vehicle for use on a limited length track for test purposes. However, the West Germans have telescoped this stage with the final stage of demonstration of the system under operational conditions. The new track at Emsland is a replica of a section of the proposed guideway and is suited to testing the vehicles at 190 to 200 mph for long periods and for speeds up to 250 mph for short stretches. The vehicles have been constructed of the materials, according to the final design, and by the methods that will be used for production. Nevertheless, questions have to be answered before the system can be said to be fully operational:

- The two vehicles must be shown to meet the performance levels forecast under controlled conditions.
- The system (i.e., vehicles, guideway, power distribution and conditioning system) must

then be shown to continue to perform under operational conditions for a substantial test period, with an acceptable level of maintenance.

The main test schedule provides for 160,000 miles of operation in the initial year of testing with additional mileage anticipated thereafter until test results become available by 1985.[10] Success at this level would undoubtedly lead to full certification in Germany.

Failure in the initial first 160,000 miles of tests could lead to modifications of certain systems or components involving a new cycle of experimental work. This need not take as long as the past development work, since only some of the components would have to be reviewed, however, it would probably delay the project.

[10] Communique from Transrapid International, Apr. 6, 1983.