Magnetically Levitated Trains (Maglev)

Abstract

Maglev systems represent a promising evolution in the high-speed ground transportation, offering speeds in excess of 500 mph along with the potential for low operating costs and minimal environmental impact. The goal of this effort is to investigate the feasibility and viability of maglev systems in the Japan. The emergence of a sophisticated technology such as maglev requires a need for a coordinated research test program and the determination of test requirements to identify and mitigate development risk and to maximize the use of domestic resources. The study is directed toward the identification and characterization of maglev systems development risks tied to preliminary system architecture. Research objectives are accomplished by surveying experiences from previous maglev development programs both foreign and domestic, and interviews with individuals involved with maglev research and testing. Findings include ninety-four distinct development risks and twenty risk types. Planning and implementation requirements are identified for a maglev test program, including the development of a facilities strategy to meet any operational concept that evolves out of early development effort. Also specified is the logical development flow and associated long-lead support needs for sub-scale and full-scale testing.

CONTENTS

Chapter 1

Introduction

Magnetic levitation transport, or **maglev**, is a form of transportation that suspends guides and propels vehicles via electromagnetic force. This method can be faster than wheeled mass transit systems, potentially reaching velocities comparable to turboprop and jet aircraft (500 to 581 km/h).

The only notable currently operating commercial application of a high-speed maglev line is the IOS (initial operating segment) demonstration line of Shanghai, China that transports people 30km (18.6 miles) to the airport in just 7 minutes 20 seconds (top speed of 431 km/h or 268 mph, average speed 250 km/h or 150 mph). Other maglev projects worldwide are being studied for feasibility. However, scientific, economic and political barriers and limitations have hindered the widespread adoption of the technology.

All operational implementations of maglev technology have had minimal overlap with wheeled train technology and have not been compatible with conventional railroad tracks. Because they cannot share existing infrastructure, maglev must be designed as complete transportation systems. The term "maglev" refers not only to the vehicles, but to the railway system as well, specifically designed for magnetic levitation and propulsion.

History of Maglev

Original patent (1941)

The first patent for a magnetic levitation train propelled by linear motors was German Patent 707032, issued in June 1941.

A U.S. patent, dated 1 October 1907, is for a linear motor propelled train in which the motor, below the steel track, carried some but not all of the weight of the train. The inventor was Alfred Zehden of Frankfurt-am-Main, Germany.

Tsukuba, Japan 1985

HSST-03 wins popularity in spite of being 30km/h and a run of low speed in Tsukuba World Exposition.

Okazaki, Japan 1987

JR-Maglev took a test ride at holding Okazaki exhibition and runs.

Saitama, Japan 1988

HSST-04-1 exhibited it at Saitama exhibition performed in Kumagaya, and runs. Best speed per hour 30km/h.

Yokohama, Japan 1989

HSST-05 acquires a business driver's license at Yokohama exhibition and carries out general test ride driving. Maximum speed 42km/h.

The history of maximum speed record by a trial run

- 1974 - West Germany - EET-01 - 230km/h
- 1975 - West Germany - Comet - 401.3km/h(by steam rocket propulsion)
- 1978 - Japan - HSST01 - 307.8km/h(by Supporting Rockets propulsion, made in Nissan)
- 1978 - Japan - HSST02 - 110km/h
- 1979 - Japan - ML500 - 517km/h (no with passenger)
- 1987 - Japan - MLU001 - 400.8km/h(with passenger)
- 1988 - West Germany - TR-06 - 412.6km/h
- 1989 - West Germany - TR-07 - 436km/h
- 1993 - Germany - TR-07 - 450km/h
- 1994 - Japan - MLU002N-431km/h(no with passenger)
- 1997 - Japan - MLX01 - 550km/h (no with passenger)
- 1999 - Japan - MLX01 - 552km/h (with passenger)

- 2003 - Germany - TR-08 - 501km/h (with passenger)

2003 - Japan - MLX01 - 581km/h (with passenger).

Chapter 2

Magnetically Levitated Trains

(*Maglev*)

Magnetically Levitated Trains

The principal of a Magnet train is that floats on a magnetic field and is propelled by a linear induction motor. They follow guidance tracks with magnets. These trains are often referred to as *Magnetically Levitated* a train which is abbreviated to *Maglev*. Although maglev don't use steel wheel on steel rail usually associated with trains, the dictionary definition of a train is a long line of vehicles traveling in the same direction - it is a train.

A super high-speed transport system with a non-adhesive drive system that is independent of wheel-and-rail frictional forces has been a long-standing dream of railway engineers. Maglev, a combination of superconducting magnets and linear motor technology, realizes super high-speed running, safety, reliability, low environmental impact and minimum maintenance.

Research and development of Maglev, which adopts superconducting technology, has been underway at RTRI of JNR since 1970. After fundamental tests in the laboratory to verify the feasibility of high-speed running at 500 km/h, the construction work of a 7-km test track began in Miyazaki Prefecture in 1975. The manned two-car vehicle MLU001 registered a speed of 400.8 km/h in 1987. And the latest vehicle MLU002N, which debuted in 1993, was running on the Miyazaki Maglev Test Track.

One main development aim of RTRI is the enhancement of reliability and durability of the superconducting magnet (SCM). The SCM suffers from external magnetic disturbances caused by ground coils and from mechanical vibrations generated by vehicle dynamics; these disturbances cause quenching troubles, or the sudden disappearance of magneto motive force of the SCM. We have studied these problems through many tests and studies, and have developed countermeasures.

Other development aims are as follows: aerodynamic brakes, which use the aerodynamic drag of panels on the car roof, and disc brakes for high-speed running; ground coils which consist of sidewall levitation coils; a high-power supply system for pulse width modulation (PWM) inverters using gate turn-off (GTO) thyristors; turnout for high- or low-speed passing.

A landmark for Maglev occurred in 1990 when it gained the status of a nationally-funded project. The Minister of Transport authorized construction of the Yamanashi Maglev Test Line, targeting the final confirmation of Maglev for practical use. The new test line called the Yamanashi Maglev Test Line opened on April 3, 1997 and is now being used to perform running tests in Yamanashi Prefecture. In the same year, the Maglev vehicle MLX01 in a three-car train set achieved world speed records, attaining a maximum speed of 531 km/h in a manned vehicle run on December 12, and a maximum speed of 550 km/h in an unmanned vehicle run on December 24. On March 18, 1999, MLX01 in a

five-car train set attained a maximum speed of 548 km/h. On April 14, 1999, this five-car train set surpassed the speed record of the three-car train set, attaining a maximum speed of 552 km/h in a manned vehicle run.

In March 2000, the Maglev Practical Technology Evaluation Committee of the Ministry of Transport of Japan concluded, "the JR-Maglev has the practicability for ultra high speed mass transportation system". The Committee also pointed out the necessity of further running tests for the following purposes: (1) Confirmation of long-term durability and reliability, (2) Cost reduction of its construction and operation, (3) Improvement of the aerodynamics of vehicles for environmental impacts. According to these recommendations, another five-year test was planed to improve these technical issues. The technical development of the Maglev has been in the second phase since fiscal 2000. On December 2, 2003, this three-car train set attained a maximum speed of 581 km/h in a manned vehicle run.

Chapter – 3

Technology & Working
Of Maglev

Technology of Maglev

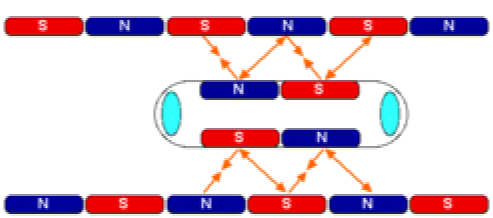
There are two primary types of maglev technology:

- Electromagnetic suspension (EMS) uses the attractive magnetic force of a magnet beneath a rail to lift the train up.
- Electrodynamics suspension (EDS) uses a repulsive force between two magnetic fields to push the train away from the rail.

Electromagnetic suspension

In current EMS systems, the train levitates above a steel rail while electromagnets, attached to the train, are oriented toward the rail from below. The electromagnets use feedback control to maintain a train at a constant distance from the track.

Electrodynamics suspension



EDS Maglev Propulsion via propulsion coils

In Electrodynamics' suspension (EDS), both the rail and the train exert a magnetic field, and the train is levitated by the repulsive force between these magnetic fields. The magnetic field in the train is produced by either electromagnets (as in JR-Maglev) or by an array of permanent magnets (as in Inductrack). The repulsive force in the track is created by an induced magnetic field in wires or other conducting strips in the track.

At slow speeds, the current induced in these coils and the resultant magnetic flux is not large enough to support the weight of the train. For this reason the train must have wheels or some other form of landing gear to support the train until it reaches a speed that can sustain levitation.

Propulsion coils on the guide way are used to exert a force on the magnets in the train and make the train move forwards. The propulsion coils that exert a force on the train are effectively a linear motor: An alternating current flowing through the coils generates a continuously varying magnetic field that moves forward along the track. The frequency of the alternating current is synchronized to match the speed of the train. The offset between the field exerted by magnets on the train and the applied field create a force moving the train forward.

Pros and cons of different technologies

Each implementation of the magnetic levitation principle for train-type travel involves advantages and disadvantages. Time will tell as to which principle, and whose implementation, wins out commercially.

Technology		*Pros*		*Cons*

EMS (Electromagnetic)		Magnetic fields inside and outside the vehicle are insignificant; proven, commercially available technology that can attain very high speeds (500 km/h); no wheels or secondary propulsion system needed		The separation between the vehicle and the guide way must be constantly monitored and corrected by computer systems to avoid collision due to the unstable nature of electromagnetic attraction.

EDS (Electrodynamics')	Onboard magnets and large margin between rail and train enable highest recorded train speeds (581 km/h) and heavy load capacity; has recently demonstrated (Dec 2005) successful operations using high temperature superconductors in its onboard magnets, cooled with inexpensive liquid nitrogen	Strong magnetic fields onboard the train would make the train inaccessible to passengers with pacemakers or magnetic data storage media such as hard drives and credit cards, necessitating the use of magnetic shielding; vehicle must be wheeled for travel at low speeds; system per mile cost still considered prohibitive; the system is not yet out of prototype phase.

Inductrack System (Permanent Magnet EDS)	Failsafe Suspension - no power required to activate magnets; Magnetic field is localized below the car; can generate enough force at low speeds (around 5 km/h) to levitate maglev train; in case of power failure cars slow down on their own in a safe, steady and predictable manner before coming to a stop; Halbach arrays of permanent magnets may prove more cost-effective than electromagnets	Requires either wheels or track segments that move for when the vehicle is stopped. New technology that is still under development (as of 2007) and has as yet no commercial version or full scale system prototype.

Propulsion

An EMS system can provide both levitation and propulsion using an onboard linear motor. EDS systems can only levitate the train using the magnets onboard, not propel it forward. As such, vehicles need some other technology for propulsion. A linear motor (propulsion coils) mounted in the track is one solution. Over long distances where the cost of propulsion coils could be prohibitive, a propeller or jet engine could be used.

Stability

Static magnetic bearings using only electromagnets and per magnets are unstable, as explained by Earnshaw's theorem. EMS systems rely on active electronic stabilization. Such systems constantly measure the bearing distance and adjust the electromagnet current accordingly. As all EDS systems are moving systems (i.e. no EDS system can levitate the train unless it is in motion), Earnshaw's theorem does not apply to them.

Pros and cons of maglev vs. conventional trains

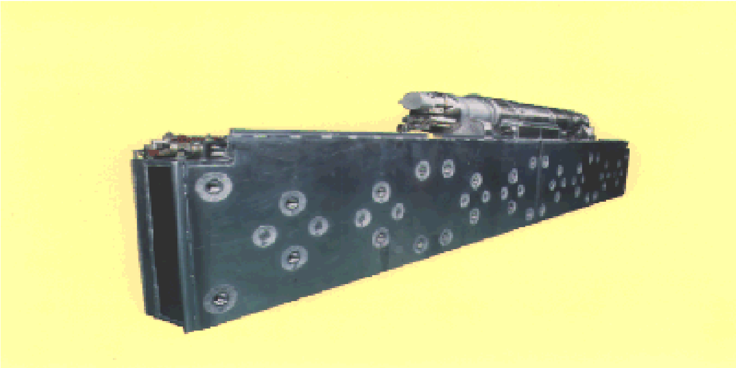
Due to the lack of physical contact between the track and the vehicle, there is no rolling friction, leaving only air resistance (although maglev trains also experience electromagnetic drag, this is relatively small at high speeds).

Maglev can handle high volumes of passengers per hour (comparable to airports or eight-lane highways) and do it without introducing air pollution along the right of way. Of course, the electricity has to be generated somewhere, so the overall environmental impact of a maglev system is dependent on the nature of the grid power source.

The weight of the large electromagnets in EMS and EDS designs are a major design issue. A very strong magnetic field is required to levitate a massive train. For this reason one research path is using superconductors to improve the efficiency of the electromagnets.

Due to its high speed and shape, the noise generated by a maglev train is similar to a jet aircraft, and is considerably more disturbing than standard steel on steel intercity train noise. A study found the difference between disturbance levels of maglev and traditional trains to be 5dB (about 78% noisier).

SCM of the Yamanashi Maglev Test Line

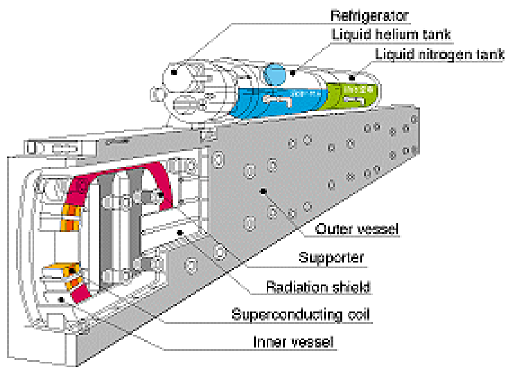


SCM of the Yamanashi Maglev Test Line

The SCM (**S**uper**c**onducting **M**agnet) is the core element of superconducting Maglev. Two SCMs are mounted on each bogie.

Each SCM of the Yamanashi Maglev Test Line consists of 4 SC coils. The SCM features high reliability and high durability, embodying the achievements of the Miyazaki Maglev Test Track and RTRI (Kunitachi, Tokyo).

The cylindrical unit at the top is a tank holding liquefied helium and nitrogen. The bottom unit is an SC coil alternately generating N poles and S poles. At one end of the tank is the integrally-attached on-board refrigerator, which serves to re-liquefy the helium gas once vaporized by regular heat absorption and external disturbances during running.



SCM of the Yamanashi Maglev Test Line (cut model)

Pole pitch	**Layout**	**Fitted height**
1.35 m	4-pole, 2-row (symmetrical on both sides)	0.57 m (height above SC coil center in wheel run)
Magneto motive force	**Left-right spacing**	**SC coil dimensions Length x width**
700 kA	2.98 m	1.07 m x 0.5 m (race track)
Car-mounted refrigeration system		
Circular re-liquefaction by direct cooling		

Electrical Facilities of the Yamanashi Maglev Test Line

External view of the inverter unit

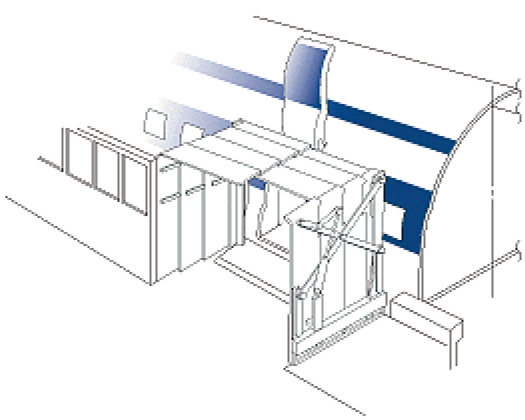
The inverter installed at the substation for power conversion is a facility to transform the power supplied from the utility company at commercial frequency into one of a frequency required for train operation.

For the Yamanashi Maglev Test Line there are inverters provided in three sets respectively for three phases, of 38 MVA for the north line and 20 MVA for the south line.
Depending on the train speed, the north line inverters give a frequency output of 0-56 Hz (550 km/h) and the south line inverters give a frequency output of 0-46 Hz (450 km/h). The operation control system at the test center formulates run curves, which in turn instruct the drive control system at the substation for power conversion.

Boarding Facilities of the Yamanashi Maglev Test Line

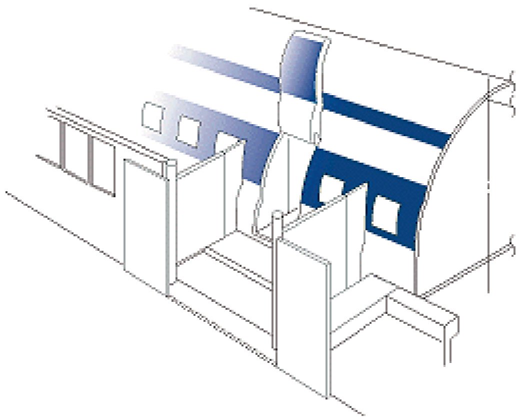
In the Maglev operation, for the purpose of shielding the passengers from the magnetic fields of the SCMs, boarding facilities resembling boarding bridges at airports are installed on the platform so that the passengers can safely get on or off the train.

Test platform (extending type)



This is a four-layered box-like structure making a passage that extends and contracts like bellows.

Test platform (rotating type)



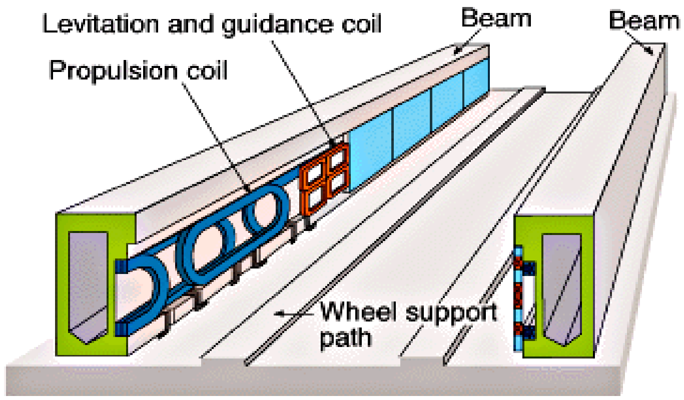
This is a three-sided structure consisting of a floor and two sidewalls. For boarding, pair of doors on the platform side rotates 90 degrees and sliding boards emerge, making a passage.

Guideway of the Yamanashi Maglev Test Line

Guideway of the Yamanashi Maglev Test Line

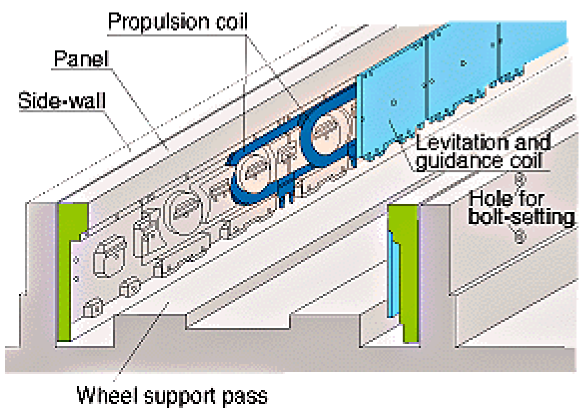
The guide way consists of a structure corresponding to the conventional track and ground coils corresponding to the conventional motor. It is a vital element of Maglev. For the Yamanashi Maglev Test Line, the following methods of installing the ground coils for propulsion, levitation, and guiding to the guideway are adopted, out of which the best one for commercial operation will be selected.

Beam Method



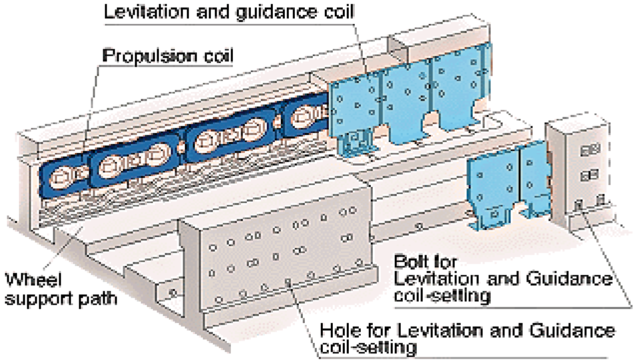
In the beam method, the sidewall portion will be constituted solely of concrete beams. The entire process from beam manufacturing to installation of the ground coils take place at the on-site factory (provisional yard). A finished beam is transported to the work site within the guideway, to be placed on two concrete beds set up in advance there.

Panel Method



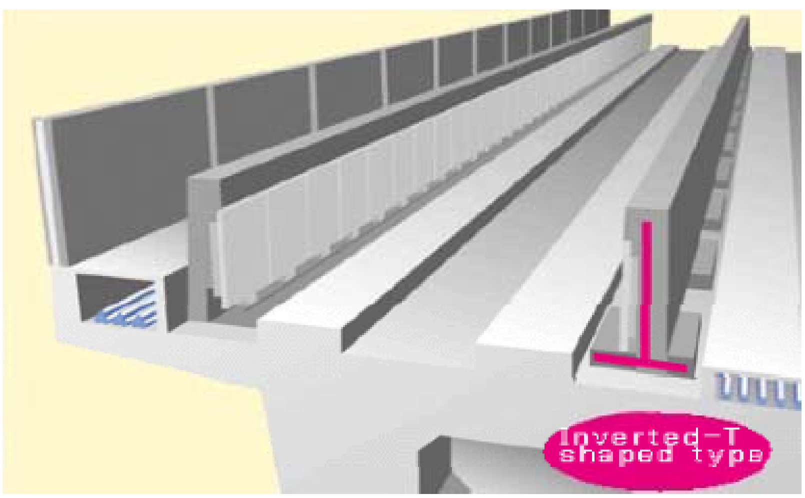
In a factory set up on-site (provisional yard) the concrete panel is produced and attached with ground coils. The finished assembly is carried to the work site, where it is fixed, with 10 bolts, to the concrete sidewall erected in advance there.

Direct-Attachment Method



At the work site in the tunnels or on the bridges a concrete sidewall portion is produced. At the same site the finished sidewall is directly fitted with the ground coils. With no need for the factory or transport vehicle, this method is economically superior to the other two, but its drawback lies in that it allows only slight adjustments of individual ground coils to correct the irregularities.

New Method



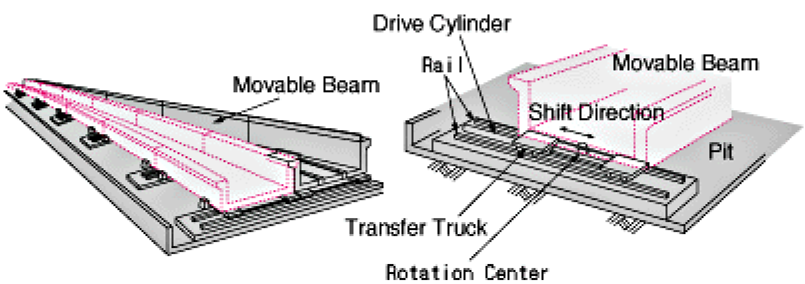
Former three types of sidewalls were adopted as the guideway structure to evaluate their functions and clarify merits and defects. We developed the new type guideway structure taking advantage of the merits based on the evaluation results. We placed emphasis on the improvement of the efficiency of installing sidewalls to concrete roadbed, as a means to reduce costs for the construction or maintenance. We discussed a shape of the sidewall in all aspects of the efficient installation, and eventually adopted an invert-T-shaped sidewall.

Turnout Facilities of the Yamanashi Maglev Test Line

Turnout Facilities of the Yamanashi Maglev Test Line

The turnout facilities (switches) are an indispensable element for distributing the train routes. Depending on the train speed dictated by the purpose, there are three types, for high speed, for low speed, and for the train depot. On the Yamanashi Maglev Test Line, they are selectively employed for testing purposes.

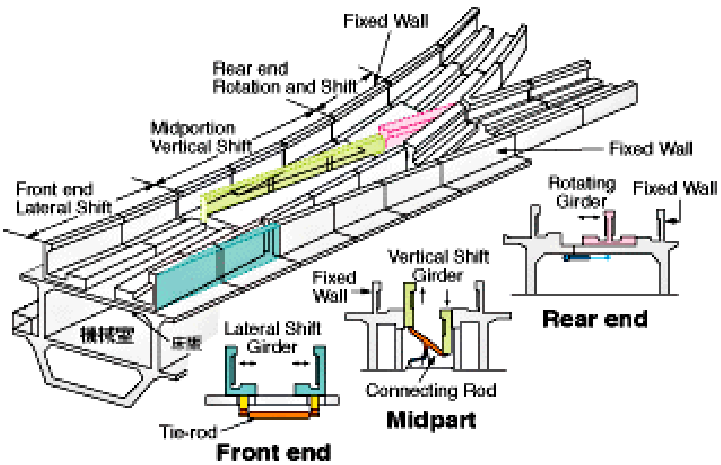
High-speed (traverse) type



A traverse is installed to switch routes between the straight main line where the vehicle runs levitated at high speed and the curved branch line where the vehicle runs on wheels at low speed.

In the high-speed (traverse) type, the guideway is divided into several laterally movable beams, which shift to switch routes. On the Yamanashi Maglev Test Line, two shift-drive systems, electrical and hydraulic, are tested.

Low-speed (sidewall-shifting) type

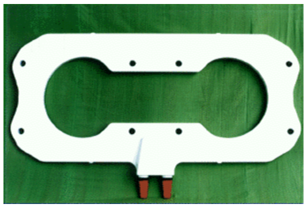


The sidewall-shifting type is employed at terminals where the line starts and ends; and where low-speed wheel runs takes place on the straight main line and curved branch line. In this type the route is formed by merely shifting the sidewalls, instead of the girder, vertically or laterally. The front and rear ends permit the sidewalls to be moved laterally, while the mid-part permits the sidewalls to be moved vertically.

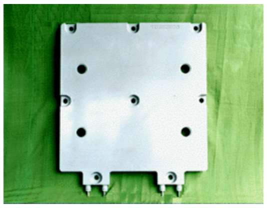
Train-depot type

For the Yamanashi Maglev Test Line, the train-depot type is adopted on the section where the vehicle is place on a tractor-pulled run. In this type, the vehicle is guided along the guide rail on the ground.

Ground Coils of the Yamanashi Maglev Test Line



Propulsion Coil

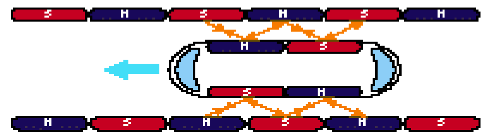


Levitation Coil

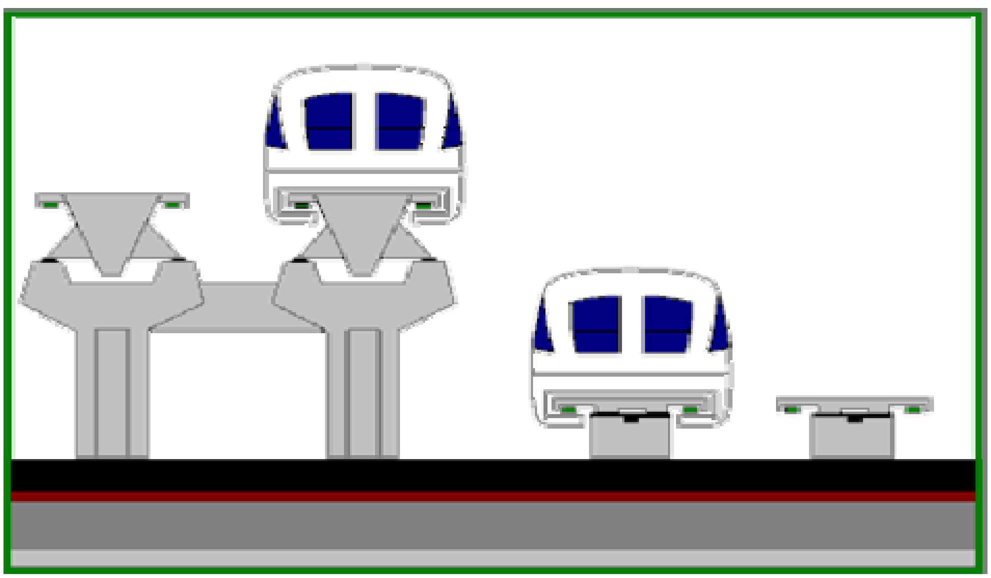
For the superconducting LSM (LSM; Linear Synchronous Motor), the ground coil is an essential element corresponding to the armature in the conventional motor and to the conventional rails. The ground coils come in two types: propulsion coils to propel the vehicle and levitation coils serving both to levitate the vehicle and to guide it laterally. When electric current flows in these coils fitted to the guide way, the Maglev vehicle can run.

On the Yamanashi Maglev Test Line, the propulsion coils are arranged in two overlapping layers to reduce the external electromagnetic disturbances influencing the Superconducting Magnet; and the levitation coils are placed on these propulsion coils. Both the propulsion coils and the levitation coils are wound aluminum conductors and molded with resin. The propulsion coils are required to be electrically insulated and mechanically strong, while the levitation coils are required mainly to be mechanically strong. Therefore the propulsion coils are moldings of epoxy resin, while the levitation coils are moldings of unsaturated polyester resin respectively reinforced with glass fiber.

<u>Working of Maglev</u>:



A maglev train floats about 10mm above the guidway on a magnetic field. It is propelled by the guidway itself rather than an onboard engine by changing magnetic fields (see right). Once the train is pulled into the next section the magnetism switches so that the train is pulled on again. The Electro-magnets run the length of the guideway.



Mechanism of Maglev Train

CHAPTER – 4

Advantages & Disadvantages
of
Maglev

Advantages of Maglev:

Well it sounds high-tech, a floating train; they do offer certain benefits over conventional steel rail on steel wheel railways.

The primary advantage is maintenance. Because the train floats along there is no contact with the ground and therefore no need for any moving parts. As a result there are no components that would wear out. This means *in theory* trains and track would need no maintenance at all.

The second advantage is that because maglev trains float, there is no friction. Note that there will still be air resistance.

A third advantage is less noise, because there are no wheels running along there is no wheel noise. However noise due to air disturbance still occurs.

The final advantage is speed, as a result of the three previous listed it is more viable for maglev trains to travel extremely fast, i.e. 500km/h or 300mph. Although this is possible with conventional rail it is not economically viable.

Another advantage is that the guidway can be made a lot thicker in places, e.g. after stations and going uphill, which would mean a maglev could get up to 300km/h (186mph) in only 5km where currently takes 18km. Also greater gradients would be applicable.

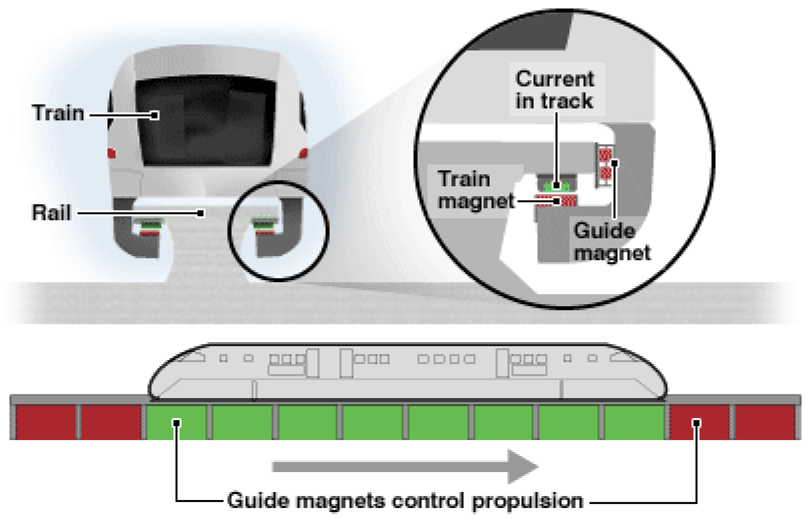


Fig. showing Guide mechanism

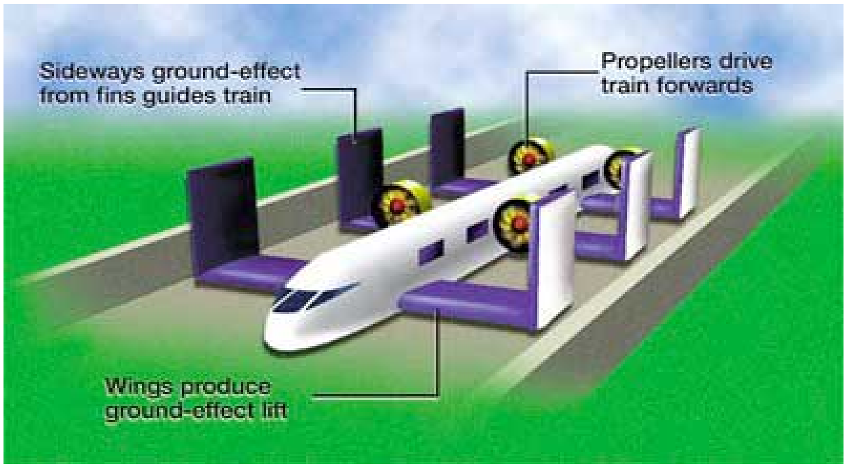
Disadvantages with Maglev:

There are several disadvantages with maglev trains. Maglev guide paths are bound to be more costly than conventional steel railways.

The other main disadvantage is lack with existing infrastructure.

A possible solution

Although I haven't seen anywhere a solution could be to put normal steel wheels onto the bottom of a maglev train, which would allow it to run on normal railway once it was off the floating guideway.



Advancement in Maglev Train

CHAPTER – 5

Accidents & Precautionary measures

<u>Accidents with Maglev Trains:</u>

Most significant accidents and incidents

1. August 11, 2006 fire

On August 11, 2006 a fire broke out on the Shanghai commercial Transrapid, shortly after leaving the terminal in Longyang.

2. September 22, 2006 crash

On September 22, 2006 an elevated Transrapid train collided with a maintenance vehicle on a test run in Lathen (Lower Saxony / north-western Germany). Twenty-three people were killed and ten were injured. These were the first fatalities resulting from a Maglev train accident.

Maglev is Safe:

Maglev trains have a remarkable safety record. By the end of 1989, the HSST series of German-type experimental maglev trains in Japan and Vancouver Canada had carried 2.67 million paying passengers at speeds up to 191 miles per hour, with a reliability factor of 99.96%, and no accidents. No other form of transportation has ever come close to that record. Several other types of maglev trains have traveled over 300 mph, also with no accidents.

A Seattle Times headline read: “Forty-two-Vehicle Pileup on I-5. Chain-reaction crash injures 24, closes rain-slick freeway for hours. Two in critical condition.” That type of thing happens frequently on our highways; but it could never happen on dual mode guideways. A major factor in the above chain accident and others like it is following too closely for the conditions and the speed being traveled. The recommended two-second spacing (headway) between cars (three or four seconds is recommended at the higher speeds) is seldom being observed. The more it is violated the higher the accident rates, but the more it is followed the lower the capacity of our highways.

On the driverless 200-mph guide ways the synchronized cars will have a minimum time-spacing of roughly five-hundredths of a second at one-foot clearance between cars. This very close spacing will make the system even safer: It is impossible for things practically touching each other to collide very hard. A knockout punch starts way back, not at the opponents jaw.

CHAPTER – 6

Scope of Maglev

Scope of Maglev

Provided maglev can be proved to be commercially viable (which has not yet been done) it should be a success. Most people have their eyes on Germany, where the first maglev will run in commercial service. This may decide whether or not maglev will be used across the world. Maglev may become the preferred path for new high speed railway lines although it would depend whether or not services were needed to stretch beyond a high speed line. For example, if you have 300km of conventional track between two cities cleared for over 200km/h but there was a 60km long section only cleared for 80km/h then it would make sense to build a new high speed (300km/h) line for the 60km distance. If a maglev train were to be used a track 300km long would have to be built. However if there is no existing rail network (only the case in the USA) then it makes sense to build a maglev line. Whether or not new railway lines stopped being built in favor of maglev, one thing is certain, there is 31932km of track in the UK, 34449km in France and 40726km Germany, no one is going to convert all of this into maglev track, conventional trains are here to stay for a long time.

Therefore, the future of Maglev holds an undisputed demand level at the global level

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