Maglev (transport)

Maglev, or magnetic levitation, is a system of transportation that suspends, guides and propels vehicles, predominantly trains, using magnetic levitation from a very large number of magnets for lift and propulsion. This method has the potential to be faster, quieter and smoother than wheeled mass transit systems. The power needed for levitation is usually not a particularly large percentage of the overall consumption; most of the power used is needed to overcome air drag, as with any other high speed train.

The highest recorded speed of a Maglev train is 581 kilometres per hour (361 mph), achieved in Japan in 2003, 6 kilometres per hour (3.7 mph) faster than the conventional TGV speed record.

The first commercial Maglev "people-mover" was officially opened in 1984 in Birmingham, England. It operated on an elevated 600-metre (2000 ft) section of monorail track between Birmingham International Airport and Birmingham International railway station, running at speeds up to 42 km/h (26 mph); the system was eventually closed in 1995 due to reliability and design problems.

Perhaps the most well known implementation of high-speed maglev technology currently operating commercially is the IOS (initial operating segment) demonstration line of the German-built Transrapid train in Shanghai, China that transports people 30 km (18.6 miles) to the airport in just 7 minutes 20 seconds, achieving a top speed of 431 km/h (268 mph), averaging 250 km/h (160 mph).

History

First patents

High speed transportation patents were granted to various inventors throughout the world. Early United States patents for a linear motor propelled train were awarded to the inventor, Alfred Zehden (German). The inventor was awarded U.S. Patent 782312 (June 21, 1902) and U.S. Patent RE12700 (August 21, 1907). In 1907, another early electromagnetic transportation system was developed by F. S. Smith. A series of German patents for magnetic levitation trains propelled by linear motors were awarded to Hermann Kemper between 1937 and 1941. An early modern type of maglev train was described in U.S. Patent 3158765, Magnetic system of transportation, by G. R. Polgreen (August 25, 1959). The first use of "maglev" in a United States patent was in "Magnetic levitation guidance" by Canadian Patents and Development Limited.

New York, United States 1968

In 1961, when he was delayed during rush hour traffic on the Throgs Neck Bridge, James Powell, a researcher at Brookhaven National Laboratory (BNL), thought of using magnetically levitated transportation to solve the traffic problem. Powell and BNL colleague Gordon Danby jointly worked out a MagLev concept using static magnets mounted on a moving vehicle to induce electrodynamic lifting and stabilizing forces in specially shaped loops on a guideway.
**Hamburg, Germany 1979**

Transrapid 05 was the first maglev train with longstator propulsion licensed for passenger transportation. In 1979 a 908 m track was opened in Hamburg for the first International Transportation Exhibition (IVA 79). There was so much interest that operations had to be extended three months after the exhibition finished, having carried more than 50,000 passengers. It was reassembled in Kassel in 1980.

**Birmingham, United Kingdom 1984–1995**

In the late 1940s, Professor Eric Laithwaite of Imperial College in London developed the first full-size working model of the linear induction motor. He became professor of heavy electrical engineering at Imperial College in 1964, where he continued his successful development of the linear motor.[12] As the linear motor does not require physical contact between the vehicle and guideway, it became a common fixture on many advanced transportation systems being developed in the 1960s and 70s. Laithwaite himself joined development of one such project, the Tracked Hovercraft, although funding for this project was cancelled in 1973.[13]

The linear motor was naturally suited to use with maglev systems as well. In the early 1970s Laithwaite discovered a new arrangement of magnets that allowed a single linear motor to produce both lift as well as forward thrust, allowing a maglev system to be built with a single set of magnets. Working at the British Rail Research Division in Derby, along with teams at several civil engineering firms, the "traverse-flux" system was developed into a working system.

The world's first commercial automated maglev system was a low-speed maglev shuttle that ran from the airport terminal of Birmingham International Airport to the nearby Birmingham International railway station between 1984–1995.[14] The length of the track was 600 meters (1969 ft), and trains "flew" at an altitude of 15 millimeters (0.6 in). It was in operation for nearly eleven years, but obsolescence problems with the electronic systems made it unreliable in its later years and it has now been replaced with a Cable Liner.[15] One of the original cars is now on display at Railworld in Peterborough, while the RTV31 hover train vehicle is preserved on the Nene Valley Railway in Peterborough.

Several favourable conditions existed when the link was built:

1. The British Rail Research vehicle was 3 tonnes and extension to the 8 tonne vehicle was easy.
2. Electrical power was easily available.
3. The airport and rail buildings were suitable for terminal platforms.
4. Only one crossing over a public road was required and no steep gradients were involved
5. Land was owned by the railway or airport
6. Local industries and councils were supportive
7. Some government finance was provided and because of sharing work, the cost per organization was not high.

After the original system closed in 1995, the original guideway lay dormant.[16] The guideway was reused in 2003 when the replacement cable-hauled AirRail Link people mover was opened.[17]
Japan

In Japan, there are two independently developed Maglev trains. One is HSST by Japan Airlines and the other, which is more well-known, is JR-Maglev by Japan Railways Group. The development of the latter started in 1969, and Miyazaki test track had regularly hit 517 km/h by 1979, but after an accident that destroyed the train, a new design was decided upon. Tests through the 1980s continued in Miyazaki before transferring a far larger and elaborate test track (20 km long) in Yamanashi in 1997. In that year, development of HSST started in 1974, based on technologies introduced from Germany. In Tsukuba, Japan (1985), the HSST-03 (Linimo) wins popularity in spite of being 30 km/h slower at the Tsukuba World Exposition. In Okazaki, Japan (1987), the JR-Maglev took a test ride at the Okazaki exhibition. In Saitama, Japan (1988), the HSST-04-1 was revealed at the Saitama exhibition performed in Kumagaya. Its fastest recorded speed was 30 km/h. In Yokohama, Japan (1989), the HSST-05 acquires a business driver's license at Yokohama exhibition and carries out general test ride driving. Maximum speed 42 km/h.

Vancouver, Canada & Hamburg, Germany 1986-1988

In Vancouver, Canada (1986), the JR-Maglev took a test ride at holding Vancouver traffic exhibition and runs. In Hamburg, Germany (1988), the TR-07 in international traffic exhibition (IVA88) performed Hamburg.

Berlin, Germany 1989–1991

In West Berlin, the M-Bahn was built in the late 1980s. It was a driverless maglev system with a 1.6 km track connecting three stations. Testing in passenger traffic started in August 1989, and regular operation started in July 1991. Although the line largely followed a new elevated alignment, it terminated at the U-Bahn station Gleisdreieck, where it took over a platform that was then no longer in use; it was from a line that formerly ran to East Berlin. After the fall of the Berlin Wall, plans were set in motion to reconnect this line (today's U2). Deconstruction of the M-Bahn line began only two months after regular service began that was called Pundai project and was completed in February 1992.

Other patents

High speed transportation patents were also granted to various other inventors throughout the world. Early United States patents for a linear motor propelled train were awarded to the inventor, Alfred Zehden (German). The inventor was awarded U.S. Patent 782312 (June 21, 1902) and U.S. Patent RE12700 (August 21, 1907). In 1907, another early electromagnetic transportation system was developed by F. S. Smith. A series of German patents for magnetic levitation trains propelled by linear motors were awarded to Hermann Kemper between 1937 and 1941. An early modern type of maglev train was described in U.S. Patent 3158765, Magnetic system of transportation, by G. R. Polgreen (August 25, 1959). The first use of "maglev" in a United States patent was in "Magnetic levitation guidance" by Canadian Patents and Development Limited.
Technology

Overview

The term "maglev" refers not only to the vehicles, but to the railway system as well, specifically designed for magnetic levitation and propulsion. All operational implementations of maglev technology have had minimal overlap with wheeled train technology and have not been compatible with conventional rail tracks. Because they cannot share existing infrastructure, these maglev systems must be designed as complete transportation systems. The Applied Levitation SPM Maglev system is inter-operable with steel rail tracks and would permit maglev vehicles and conventional trains to operate at the same time on the same right of way. MAN in Germany also designed a maglev system that worked with conventional rails, but it was never fully developed.[18]

See also JR-Maglev#Fundamental technology elements, Transrapid#Technology, Magnetic levitation

There are two particularly notable types of maglev technology:

- For electromagnetic suspension (EMS), electromagnets in the train attract it to a magnetically conductive (usually steel) track.
- Electrodynamical suspension (EDS) uses electromagnets on both track and train to push the train away from the rail.

Another experimental technology, which was designed, proven mathematically, peer reviewed, and patented, but is yet to be built, is the magnetodynamic suspension (MDS), which uses the attractive magnetic force of a permanent magnet array near a steel track to lift the train and hold it in place. Other technologies such as repulsive permanent magnets and superconducting magnets have seen some research.

Electromagnetic suspension

In current electromagnetic suspension (EMS) systems, the train levitates above a steel rail while electromagnets, attached to the train, are oriented toward the rail from below. The system is typically arranged on a series of C-shaped arms, with the upper portion of the arm attached to the vehicle, and the lower inside edge containing the magnets. The rail is situated between the upper and lower edges.

Magnetic attraction varies with the cube of distance, so minor changes in distance between the magnets and the rail produce greatly varying forces. These changes in force are dynamically unstable - if there is a slight divergence from the optimum position, the tendency will be to exacerbate this, and complex systems of feedback control are required to maintain a train at a constant distance from the track, (approximately 15 millimeters (0.6 in)).[19] [20]

The major advantage to suspended maglev systems is that they work at all speeds, unlike electrodynamic systems which only work at a minimum speed of about 30 km/h. This eliminates the need for a separate low-speed suspension system, and can simplify the track layout as a result. On the downside, the dynamic instability of the system demands high tolerances of the track, which can offset, or eliminate this advantage. Laithwaite, highly skeptical of the concept, was concerned that in order to make a track with the required tolerances, the gap between the magnets and rail would have to be increased to the point where the magnets would be unreasonably large.[18] In practice, this problem was addressed through increased performance of the feedback systems, which allow the system to run with close tolerances.
**Electrodynamic suspension**

In electrodynamic 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. A major advantage of the repulsive maglev systems is that they are naturally stable - minor narrowing in distance between the track and the magnets create strong forces to repel the magnets back to their original position, while a slight increase in distance greatly reduced the force and again returns the vehicle to the right separation.[18] No feedback control is needed.

Repulsive systems have a major downside as well. 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. Since a train may stop at any location, due to equipment problems for instance, the entire track must be able to support both low-speed and high-speed operation. Another downside is that the repulsive system naturally creates a field in the track in front and to the rear of the lift magnets, which act against the magnets and create a form of drag. This is generally only a concern at low speeds, at higher speeds the effect does not have time to build to its full potential and other forms of drag dominate.[18]

The drag force can be used to the electrodynamic system's advantage, however, as it creates a varying force in the rails that can be used as a reactionary system to drive the train, without the need for a separate reaction plate, as in most linear motor systems. Laithwaite led development of such "traverse-flux" systems at his Imperial College lab.[18] Alternately, propulsion coils on the guideway are used to exert a force on the magnets in the train and make the train move forward. 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 creates 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.
<table>
<thead>
<tr>
<th>Technology</th>
<th>Pros</th>
<th>Cons</th>
</tr>
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<tbody>
<tr>
<td>EMS (Electromagnetic suspension)</td>
<td>Magnetic fields inside and outside the vehicle are less than EDS; proven, commercially available technology that can attain very high speeds (500 km/h); no wheels or secondary propulsion system needed</td>
<td>The separation between the vehicle and the guideway must be constantly monitored and corrected by computer systems to avoid collision due to the unstable nature of electromagnetic attraction; due to the system's inherent instability and the required constant corrections by outside systems, vibration issues may occur.</td>
</tr>
<tr>
<td>EDS (Electrodynamic suspension)</td>
<td>Onboard magnets and large margin between rail and train enable highest recorded train speeds (581 km/h) and heavy load capacity; has recently demonstrated (December 2005) successful operations using high temperature superconductors in its onboard magnets, cooled with inexpensive liquid nitrogen</td>
<td>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; limitations on guideway inductivity limit the maximum speed of the vehicle; vehicle must be wheeled for travel at low speeds.</td>
</tr>
<tr>
<td>Inductrack System (Permanent Magnet EDS)</td>
<td>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 safely; Halbach arrays of permanent magnets may prove more cost-effective than electromagnets</td>
<td>Requires either wheels or track segments that move for when the vehicle is stopped. New technology that is still under development (as of 2008) and as yet has no commercial version or full scale system prototype.</td>
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Neither Inductrack nor the Superconducting EDS are able to levitate vehicles at a standstill, although Inductrack provides levitation down to a much lower speed; wheels are required for these systems. EMS systems are wheel-less. The German Transrapid, Japanese HSST (Linimo), and Korean Rotem EMS maglevs levitate at a standstill, with electricity extracted from guideway using power rails for the latter two, and wirelessly for Transrapid. If guideway power is lost on the move, the Transrapid is still able to generate levitation down to 10 km/h (6.2 mph) speed, using the power from onboard batteries. This is not the case with the HSST and Rotem systems.

**Propulsion**

An EDS system can provide both levitation and propulsion using an onboard linear motor. EMS 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**

Earnshaw's theorem shows that any combination of static magnets cannot be in a stable equilibrium. However, the various levitation systems achieve stable levitation by violating the assumptions of Earnshaw's theorem. Earnshaw's theorem assumes that the magnets are static and unchanging in field strength and that the relative permeability is constant and greater than 1 everywhere. EMS systems rely on active electronic stabilization. Such systems constantly measure the bearing distance and adjust the electromagnet current accordingly. All EDS systems are moving systems (no EDS system can levitate the train unless it is in motion).

Because Maglev vehicles essentially fly, stabilisation of pitch, roll and yaw is required by magnetic technology. In addition translations, surge (forward and backward motions), sway (sideways motion) or heave (up and down motions) can be problematic with some technologies.
Guidance
Some systems use Null Flux systems, also known as Null Current systems,[28] these use a coil which is wound so that it enters two opposing, alternating fields. When the vehicle is in the straight ahead position, no current flows, but if it moves off-line this creates a changing flux that generates a field that pushes it back into line.

Evacuated tubes
Some systems (notably the swissmetro system) propose the use of vactrains — evacuated (airless) tubes used in tandem with maglev technology to minimize air drag. This has the potential to increase speed and efficiency greatly, as most of the energy for conventional Maglev trains is lost in air drag.[29]
One potential risk for passengers of trains operating in evacuated tubes is that they could be exposed to the risk of cabin depressurization unless tunnel safety monitoring systems can repressurize the tube in the event of a train malfunction or accident. The Rand corporation has designed a vacuum tube train that could, in theory, cross the Atlantic or the USA in 20 minutes.

Power and energy usage
Energy for maglev trains is used to accelerate the train, and may be regained when the train slows down (“regenerative braking”). It is also used to make the train levitate and to stabilise the movement of the train. The main part of the energy is needed to force the train through the air (“air drag”). Also some energy is used for air conditioning, heating, lighting and other miscellaneous systems.
At very low speeds the percentage of power (energy per time) used for levitation can be significant. Also for very short distances the energy used for acceleration might be considered. But the power used to overcome air drag increases with the cube of the velocity, and hence dominates at high speed (note: the energy increases by the square of the velocity and the time decreases linearly.).

Advantages and disadvantages

Compared to conventional trains
Major comparative differences between the two technologies lie in backward-compatibility, rolling resistance, weight, noise, design constraints, and control systems.

- **Backwards Compatibility**: Maglev trains currently in operation are not compatible with conventional track, and therefore require all new infrastructure for their entire route. By contrast conventional high speed trains such as the TGV are able to run at reduced speeds on existing rail infrastructure, thus reducing expenditure where new infrastructure would be particularly expensive (such as the final approaches to city terminals), or on extensions where traffic does not justify new infrastructure.

- **Efficiency**: Due to the lack of physical contact between the track and the vehicle, maglev trains experience no rolling resistance, leaving only air resistance and electromagnetic drag, potentially improving power efficiency.[30]

- **Weight**: The weight of the large electromagnets in many EMS and EDS designs is 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, and the energy cost of maintaining the field.

- **Noise**: Because the major source of noise of a maglev train comes from displaced air, maglev trains produce less noise than a conventional train at equivalent speeds. However, the psychoacoustic profile of the maglev may reduce this benefit: A study concluded that maglev noise should be rated like road traffic while conventional trains have a 5-10 dB "bonus" as they are found less annoying at the same loudness level.[31][32]
• **Design Comparisons**: Braking and overhead wire wear have caused problems for the Fastech 360 railed Shinkansen. Maglev would eliminate these issues. Magnet reliability at higher temperatures is a countervailing comparative disadvantage (see suspension types), but new alloys and manufacturing techniques have resulted in magnets that maintain their levitational force at higher temperatures.

As with many technologies, advances in linear motor design have addressed the limitations noted in early maglev systems. As linear motors must fit within or straddle their track over the full length of the train, track design for some EDS and EMS maglev systems is challenging for anything other than point-to-point services. Curves must be gentle, while switches are very long and need care to avoid breaks in current. An SPM maglev system, in which the vehicle permanently levitated over the tracks, can instantaneously switch tracks using electronic controls, with no moving parts in the track. A prototype SPM maglev train has also navigated curves with radius equal to the length of the train itself, which indicates that a full-scale train should be able to navigate curves with the same or narrower radius as a conventional train.

• **Control Systems**: EMS Maglev needs very fast-responding control systems to maintain a stable height above the track; this needs careful design in the event of a failure in order to avoid crashing into the track during a power fluctuation. Other maglev systems do not necessarily have this problem. For example, SPM maglev systems have a stable levitation gap of several centimeters.

### Compared to aircraft

For many systems, it is possible to define a lift-to-drag ratio. For maglev systems these ratios can exceed that of aircraft (for example Inductrack can approach 200:1 at high speed, far higher than any aircraft). This can make maglev more efficient per kilometre. However, at high cruising speeds, aerodynamic drag is much larger than lift-induced drag. Jet transport aircraft take advantage of low air density at high altitudes to significantly reduce drag during cruise, hence despite their lift-to-drag ratio disadvantage, they can travel more efficiently at high speeds than maglev trains that operate at sea level (this has been proposed to be fixed by the vactrain concept). Aircraft are also more flexible and can service more destinations with provision of suitable airport facilities.

Unlike airplanes, maglev trains are powered by electricity and thus need not carry fuel. Aircraft fuel is a significant danger during takeoff and landing accidents. Also, electric trains emit little carbon dioxide emissions, especially when powered by nuclear or renewable sources.

### Economics

The Shanghai maglev cost 9.93 billion yuan to build.[33] This total includes infrastructure capital costs such as manufacturing and construction facilities, and operational training. At 50 yuan per passenger[34] and the current 7,000 passengers per day, income from the system is incapable of recouping the capital costs (including interest on financing) over the expected lifetime of the system, even ignoring operating costs. This changes if capacity utilization increases from the current 20%.

China aims to limit the cost of future construction extending the maglev line to approximately 200 million yuan per kilometer.[33]

The United States Federal Railroad Administration 2003 Draft Environmental Impact Statement for a proposed Baltimore-Washington Maglev project gives an estimated 2008 capital costs of 4.361 billion US dollars for 39.1 miles, or 111.5 million US dollars per mile (69.3 million US dollars per kilometer). The Maryland Transit Administration (MTA) conducted their own Environmental Impact Statement, and put the pricetag at 4.9 billion dollars for construction, and 53 million a year for operations.[35]

The proposed Chūō Shinkansen maglev in Japan is estimated to cost approximately US$82 billion to build, with a route blasting long tunnels through mountains. A Tokaido maglev route replacing current Shinkansen would cost some 1/10th the cost, as no new tunnel blasting would be needed, but noise pollution issues would make it infeasible.
The only low-speed maglev (100 km/h) currently operational, the Japanese Linimo HSST, cost approximately US$100 million/km to build.\[36\] Besides offering improved operation and maintenance costs over other transit systems, these low-speed maglevs provide ultra-high levels of operational reliability and introduce little noise and zero air pollution into dense urban settings.

As maglev systems are deployed around the world, experts expect construction costs to drop as new construction methods are innovated along with economies of scale.

**History of maximum speed record by a trial run**

- 1971 - West Germany - Prinzipfahrzeug - 90 km/h
- 1971 - West Germany - TR-02(TSST)- 164 km/h
- 1972 - Japan - ML100 – 60 km/h - (manned)
- 1973 - West Germany - TR04 - 250 km/h (manned)
- 1974 - West Germany - EET-01 - 230 km/h (unmanned)
- 1975 - West Germany - Komet - 401.3 km/h (by steam rocket propulsion, unmanned)
- 1978 - Japan - HSST-01 - 307.8 km/h (by supporting rockets propulsion, made in Nissan, unmanned)
- 1978 - Japan - HSST-02 - 110 km/h (manned)
- 1979-12-12 - Japan-ML-500R - 504 km/h (unmanned) It succeeds in operation over 500 km/h for the first time in the world.
- 1979-12-21 - Japan - ML-500R- 517 km/h (unmanned)
- 1987 - West Germany - TR-06 - 406 km/h (manned)
- 1987 - Japan - MLU001 - 400.8 km/h (manned)
- 1988 - West Germany - TR-06 - 412.6 km/h (manned)
- 1989 - West Germany - TR-07 - 436 km/h (manned)
- 1993 - Germany - TR-07 - 450 km/h (manned)
- 1994 - Japan - MLU002N - 431 km/h (unmanned)
- 1997 - Japan - MLX01 - 531 km/h (manned)
- 1997 - Japan - MLX01 - 550 km/h (unmanned)
- 1999 - Japan - MLX01 - 548 km/h (unmanned)
- 1999 - Japan - MLX01 - 552 km/h (manned/five formation). Guinness authorization.
- 2003 - China - Transrapid SMT (built in Germany) - 501.5 km/h (manned/three formation)
- 2003 - Japan - MLX01 - 581 km/h (manned/three formation). Guinness authorization.\[37\]
Existing maglev systems

Testing tracks

San Diego, USA
General Atomics has a 120 meter test facility in San Diego, which is being used as the basis of Union Pacific’s 8 km freight shuttle in Los Angeles. The technology is "passive" (or "permanent"), requiring no electromagnets for either levitation or propulsion. General Atomics has received $90 million in research funding from the federal government. They are also looking to apply their technology to high speed passenger services as well.[38]

Emsland, Germany
Transrapid, a German maglev company, has a test track in Emsland with a total length of 31.5 km (19.6 mi). The single track line runs between Dörpen and Lathen with turning loops at each end. The trains regularly run at up to 420 km/h (260 mph). The construction of the test facility began in 1980 and finished in 1984.

JR-Maglev, Japan
Japan has a demonstration line in Yamanashi prefecture where test trains JR-Maglev MLX01 have reached 581 kilometres per hour (361 mph), slightly faster than any wheeled trains (the current TGV speed record is 574.8 kilometres per hour (357.2 mph). A documentary video about the Japanese maglev can be viewed here[39].

These trains use superconducting magnets which allow for a larger gap, and repulsive-type electrodynamic suspension (EDS). In comparison Transrapid uses conventional electromagnets and attractive-type electromagnetic suspension (EMS). These "Superconducting Maglev Shinkansen", developed by the Central Japan Railway Company (JR Central) and Kawasaki Heavy Industries, are currently the fastest trains in the world, achieving a record speed of 581 kilometres per hour (361 mph) on December 2, 2003.[40] [41] Yamanashi Prefecture residents (and government officials) can sign up to ride this for free, and some 100,000 have done so already.

FTA’s UMTD program
In the US, the Federal Transit Administration (FTA) Urban Maglev Technology Demonstration program has funded the design of several low-speed urban maglev demonstration projects. It has assessed HSST for the Maryland Department of Transportation and maglev technology for the Colorado Department of Transportation. The FTA has also funded work by General Atomics at California University of Pennsylvania to demonstrate new maglev designs, the MagneMotion M3 and of the Maglev2000 of Florida superconducting EDS system. Other US urban maglev demonstration projects of note are the LEVX in Washington State and the Massachusetts-based Magplane.
Southwest Jiaotong University, China

On December 31, 2000, the first crewed high-temperature superconducting maglev was tested successfully at Southwest Jiaotong University, Chengdu, China. This system is based on the principle that bulk high-temperature superconductors can be levitated or suspended stably above or below a permanent magnet. The load was over 530 kg (1166 lb) and the levitation gap over 20 mm (0.79 in). The system uses liquid nitrogen, which is very cheap, to cool the superconductor.

Operational systems servicing the public

Linimo (Tobu Kyuryo Line, Japan)

The commercial automated "Urban Maglev" system commenced operation in March 2005 in Aichi, Japan. This is the nine-station 8.9 km long Tobu-kyuryo Line, otherwise known as the Linimo. The line has a minimum operating radius of 75 m and a maximum gradient of 6%. The linear-motor magnetic-levitated train has a top speed of 100 kilometres per hour (62 mph). The line serves the local community as well as the Expo 2005 fair site. The trains were designed by the Chubu HSST Development Corporation, which also operates a test track in Nagoya. [42]

Shanghai Maglev Train

Transrapid, in Germany, constructed the first operational high-speed conventional maglev railway in the world, the Shanghai Maglev Train from downtown Shanghai (Shanghai Metro) to the Pudong International Airport. [43] It was inaugurated in 2002. The highest speed achieved on the Shanghai track has been 501 km/h (311 mph), over a track length of 30 km. Despite the speeds, the maglev has been criticised as having few stops and a questionable commercial success. [44] Construction of an extension to Hangzhou was planned to be finished in 2010, but has been postponed in favour of a conventional high speed railway running at 350 km/h. The Shanghai municipal government was considering building the maglev line extension underground to allay the public's fears of electromagnetic pollution; [45] this same report states that the final decision has to be approved by the National Development and Reform Commission.

Daejeon, Korea

The first maglev utilizing electromagnetic suspension opened to public was HML-03, which was made by Hyundai Heavy Industries, for Daejeon Expo in 1993 after five years of research and manufacturing two prototypes; HML-01 and HML-02. [46] [47] [48] Research for urban maglev using electromagnetic suspension began in 1994 by the government. [48] The first urban maglev opened to public was UTM-02 in Daejeon on 21 April 2008 after 14 years of development and building one prototype; UTM-01. The urban maglev runs on 1 km track between Expo Park and National Science Museum. [49] [50] Meanwhile UTM-02 remarked an innovation by conducting the world's first ever maglev simulation. [51] [52] However UTM-02 is still the second prototype of a final model. The final UTM model of Rotem's urban maglev, UTM-03, is scheduled to debut at the end of 2012 in Incheon's Yeongjong island where Incheon International Airport is located. [53]
Under construction

Old Dominion University

Track of less than a mile in length has been constructed at Old Dominion University in Norfolk, Virginia, USA. Although the system was initially built by AMT, problems caused the company to abandon the project and turn it over to the University. This system uses a "smart train, dumb track" that involves most of the sensors, magnets, and computation occurring on the train rather than the track. This system will cost less to build per mile than existing systems. The $14 million originally planned did not allow for completion. The system is currently not operational, but research has proved useful. In October 2006, the research team performed an unscheduled test of the car that went smoothly. The whole system, unfortunately, was removed from the power grid for nearby construction. In February 2009, the team was able to retest the sled, or bogie, and was again successful despite power outages on campus. Tests will continue, increasing both speed and distance. Meanwhile, ODU has partnered with a Massachusetts-based company to test another maglev train on its campus. MagneMotion Inc. is expected to bring its prototype maglev vehicle, which is about the size of a van, to the campus to test in early 2010.

AMT Test Track - Powder Springs, Georgia

The same principle is involved in the construction of a second prototype system in Powder Springs, Georgia, USA, by American Maglev Technology, Inc.

Applied Levitation/Fastransit Test Track - Santa Barbara, California

Applied Levitation, Inc. has built a levitating prototype on a short indoor track, and is now planning a quarter-mile outdoor track, with switches, in or near Santa Barbara.

Proposed systems

Many maglev systems have been proposed in various nations of North America, Asia, and Europe. Many are still in the early planning stages, or even mere speculation, as with the transatlantic tunnel. But a few of the following examples have progressed beyond that point.

Australia

Sydney-Illawarra Maglev Proposal

There is a current proposal for a Maglev route between Sydney and Wollongong. The proposal came to prominence in the mid-1990s. The Sydney - Wollongong commuter corridor is the largest in Australia, with upwards of 20,000 people commuting from the Illawarra to Sydney for work each day. Current trains crawl along the dated Illawarra line, between the cliff face of the Illawarra escarpment and the Pacific Ocean, with travel times between two and three hours between Wollongong Station and Central. The proposed Maglev would cut travel times to 20 minutes.
Melbourne Maglev Proposal

In late 2008, a proposal was put forward to the Government of Victoria to build a privately funded and operated Maglev line to service the Greater Melbourne metropolitan area in response to the Eddington Transport Report which neglected to investigate above ground transport options.\[^{63}\][\[^{64}\]] The Maglev would service a population of over 4 million and the proposal was costed at AUD $8 billion.

However despite relentless road congestion and the highest roadspace per capita Australia, the government quickly dismissed the proposal in favour of road expansion including an AUD $8.5 billion road tunnel, $6 billion extension of the Eastlink to the Western Ring Road and a $700 million Frankston Bypass.

United Kingdom

**London – Glasgow:** A maglev line was recently proposed in the United Kingdom from London to Glasgow with several route options through the Midlands, Northwest and Northeast of England and was reported to be under favourable consideration by the government.\[^{65}\]

But the technology was rejected for future planning in the Government White Paper *Delivering a Sustainable Railway* published on July 24, 2007.\[^{66}\] Another high speed link is being planned between Glasgow and Edinburgh but there is no settled technology for it.\[^{67}\][\[^{68}\][\[^{69}\]

Iran

Iran and a German company have reached an agreement on using maglev trains to link the cities of Tehran and Mashhad. The agreement was signed at the Mashhad International Fair site between Iranian Ministry of Roads and Transportation and the German company. Maglev trains can reduce the 900 km travel time between Iranian Ministry of Roads and Transportation and the German company. Munich-based Schlegel Consulting Engineers said they had signed the contract with the Iranian ministry of transport and the governor of Mashad. "We have been mandated to lead a German consortium in this project," a spokesman said. "We are in a preparatory phase." The next step will be assemble a consortium, a process that is expected to take place "in the coming months," the spokesman said. The project could be worth between 10 billion and 12 billion euros, the Schlegel spokesman said. Siemens and ThyssenKrupp, the developers of a high-speed maglev train, called the Transrapid, both said they were
unaware of the proposal. The Schlegel spokesman said Siemens and ThyssenKrupp were currently "not involved." in the consortium.

Japan
Tokyo — Nagoya — Osaka

The plan for the Chuo Shinkansen bullet train system was finalized based on the Law for Construction of Countrywide Shinkansen. The Linear Chuo Shinkansen Project aims to realize this plan using the Superconductive Magnetically Levitated Train, which connects Tokyo and Osaka by way of Nagoya, the capital city of Aichi, in approximately one hour at a speed of 500 km/h. In April 2007, JR Central President Masayuki Matsumoto said that JR Central aims to begin commercial maglev service between Tokyo and Nagoya in the year 2025.

Venezuela
Caracas — La Guaira: A maglev train (TELMAGV) has been proposed to connect the capital city Caracas to the main port town of La Guaira and Simón Bolívar International Airport. No budget has been allocated, pending definition of the route, although a route of between six and nine kilometres has been suggested. The proposal envisages that, initially, a full-sized prototype train would be built with about one kilometre of test track.

In proposing a maglev system, its improved life and performance over mechanical engines were cited as important factors, as well as improving comfort, safety, economics and environmental impact over conventional rail.

China
Shanghai — Hangzhou: China is planning to extend the existing Shanghai Maglev Train, initially by some 35 kilometers to Shanghai Hongqiao Airport and then 200 kilometers to the city of Hangzhou (Shanghai-Hangzhou Maglev Train). If built, this would be the first inter-city maglev rail line in commercial service.

The project has been controversial and repeatedly delayed. In May 2007 the project was suspended by officials due to concerns about radiation from the maglev system. In January and February 2008 hundreds of residents demonstrated in downtown Shanghai against the line being built too close to their homes, citing concerns about sickness due to exposure to the strong magnetic field, noise, pollution and devaluation of property near the lines. Final approval to build the line was granted on August 18, 2008. Originally scheduled to be ready by Expo 2010, current plans call for construction to start in 2010 for completion by 2014. The Shanghai municipal government is considered multiple options, including building the line underground to allay the public's fear of electromagnetic pollution. This same report states that the final decision has to be approved by the National Development and Reform Commission.

China also intends to build a factory in Nanhui district to produce low-speed maglev trains for urban use.
India

Mumbai – Delhi: A maglev line project was presented to India's railway minister Lalu Prasad Yadav by an American company. If approved, this line would serve between the cities of Mumbai and Delhi, the Prime Minister Manmohan Singh said that if the line project is successful the Indian government would build lines between other cities and also between Mumbai centre and Chhatrapati Shivaji International Airport.[82]

The State of Maharashtra has also approved a feasibility study for a Maglev train between Mumbai (the commercial capital of India as well as the State government capital) and Nagpur (the second State capital) about 1000 km away. It plans to connect the developed area of Mumbai and Pune with Nagpur via underdeveloped hinterland via Ahmednagar, Beed, Latur, Nanded and Yavatmal.[83]

United States

Union Pacific Freight Conveyor: Plans are under way by American railroad operator Union Pacific to build a 4.9 mi (8 km) container shuttle between the ports of Los Angeles and Long Beach, with UP's Intermodal Container Transfer Facility. The system would be based on "passive" technology, especially well suited to freight transfer as no power is needed on-board, simply a chassis which glides to its destination. The system is being designed by General Atomics.[38]

Seattle-Vancouver International Maglev: The Seattle-Vancouver International Maglev corridor is proposed to extend part of an I-5 expansion plan, but the U.S. government has ruled it must be separated from public works projects, while Canadian federal and provincial politicians have not been receptive to these proposals. Further studies have been requested although no funding has yet been agreed. It is in demand for the area due to the high level of current traffic.

California-Nevada Interstate Maglev: High-speed maglev lines between major cities of southern California and Las Vegas are also being studied via the California-Nevada Interstate Maglev Project.[84] This plan was originally supposed to be part of an I-5 or I-15 expansion plan, but the federal government has ruled it must be separated from interstate public works projects.

Since the federal government decision, private groups from Nevada have proposed a line running from Las Vegas to Los Angeles with stops in Primm, Nevada; Baker, California; and points throughout San Bernardino County into Los Angeles. Southern California politicians have not been receptive to these proposals; many are concerned that a high speed rail line out of state would drive out dollars that would be spent in state "on a rail" to Nevada.

Baltimore-Washington D.C. Maglev: A 39.75 mi (64 km) project has been proposed linking Camden Yards in Baltimore and Baltimore-Washington International (BWI) Airport to Union Station in Washington, D.C.[85] It is said to be in demand for the area due to its current traffic/congestion problems.

The Pennsylvania Project: The Pennsylvania High-Speed Maglev Project corridor extends from the Pittsburgh International Airport to Greensburg, with intermediate stops in Downtown Pittsburgh and Monroeville. This initial project will serve a population of approximately 2.4 million people in the Pittsburgh metropolitan area. The Baltimore proposal is competing with the Pittsburgh proposal for a $90 million federal grant. The purpose of the project is to see if the maglev system can function properly in a U.S. city environment.[86]

San Diego-Imperial County airport: In 2006 San Diego commissioned a study for a maglev line to a proposed airport located in Imperial County. SANDAG says that the concept would be an "airports without terminals", allowing passengers to check in at a terminal in San Diego ("satellite terminals") and take the maglev to Imperial airport and board the airplane there as if they went directly through the terminal in the Imperial location. In addition, the maglev would have the potential to carry high priority freight. Further studies have been requested although no funding has yet been agreed.[87]

Atlanta – Chattanooga: The proposed maglev route would run from Hartsfield-Jackson Atlanta International Airport, run through Atlanta, continue to the northern suburbs of Atlanta, and possibly even extend to Chattanooga,
Tennessee. If built, the maglev line would rival Atlanta's current subway system, the Metropolitan Atlanta Rapid Transit Authority (MARTA), the rail system of which includes a major branch running from downtown Atlanta to Hartsfield-Jackson airport.\[88\]

**Germany**

On September 25, 2007, Bavaria announced it would build the high-speed maglev - rail service from Munich city to its airport. The Bavarian government signed contracts with Deutsche Bahn and Transrapid with Siemens and ThyssenKrupp for the 1.85 billion euro project.\[89\]

On March 27, 2008, the German Transport minister announced the project had been cancelled due to rising costs associated with constructing the track. A new estimate put the project between 3.2 and 3.4 billion euros.\[90\]

**Indonesia**

There are plans to build a 683 km long Maglev rail service between Jakarta and Surabaya. This Maglev will have 7 stations including Semarang. PT Maglev Indonesia working together with SNCF, Transrapid Deutschland, and other corporations will begin this construction around 2010.

**Significant incidents**

There have been two incidents involving fires. The Japanese test train in Miyazaki, MLU002, was completely consumed in a fire in 1991.\[91\] As a result of the fire, political opposition in Japan claimed maglev was a waste of public money. On August 11, 2006 a fire broke out on the Shanghai commercial Transrapid, shortly after leaving the terminal in Longyang;\[92\] nobody was injured. The cause is believed to be a fault with the Maglev's electrical system,\[93\] it has been suggested to have been an onboard battery unit.\[94\]

On September 22, 2006 a Transrapid train collided with a maintenance vehicle on a test/publicity run in Lathen (Lower Saxony / north-western Germany).\[95\] \[96\] Twenty-three people were killed and ten were injured; these were the first fatalities resulting from an accident on a Maglev system. The accident was caused by human error, charges were brought against three Transrapid employees after a year long investigation.\[97\]

**See also**

- Ground effect train
- Land speed record for railed vehicles
- Launch loop would be a maglev system for launching to orbit or escape velocity
- Mass driver
- Nagahori Tsurumi-ryokuchi Line
- Oleg Tozoni is working on a published non linearly stabilised maglev design
- Railway
- SkyTrain (Vancouver)
- StarTram - a maglev launch system
- Tracked Hovercraft
Further reading


External links

- Urban Maglev [99]
- Windana Research [100]
- United States Federal Railroad Administration [101]
- Applied Levitation [60]
- Fastransit [102]
- Maglev Net - Maglev News & Information [103]
- The International Maglev Board [104]
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- Magnetic Levitation [108] at the Open Directory Project
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- Magnetic Levitation for Transportation [110]
- News of Brazil's Maglev project (in Portuguese) [111]
- Maglev Trains [112]

Audio slideshow from the National High Magnetic Field Laboratory discusses magnetic levitation, the Meissner Effect, magnetic flux trapping and superconductivity

References

[6] These German patents would be GR643316(1937), GR44302(1938), GR707032(1941).


"Transrapid claims to use a quarter less power at 200 km/h than the InterCityExpress" (http://www.transrapid.de/cgi-tdb/en/basics. prg?session=968fa4345146d8b9a_re=47). Transrapid. Retrieved 2009-09-07.


"Nagoya builds Maglev Metro" (http://www.findarticles.com/p/articles/mi_m0BQQ/is_5_44/ai_n6054072). International Railway Journal, May 2004.


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[95] "Several Dead in Transrapid Accident" (http://www.spiegel.de/international/0,1518,438657,00.html). Spiegel Online. 2006-09-22.


[99] http://www.urbanmaglev.us
[100] http://www.windana.com
[105] http://www.transrapid.de/