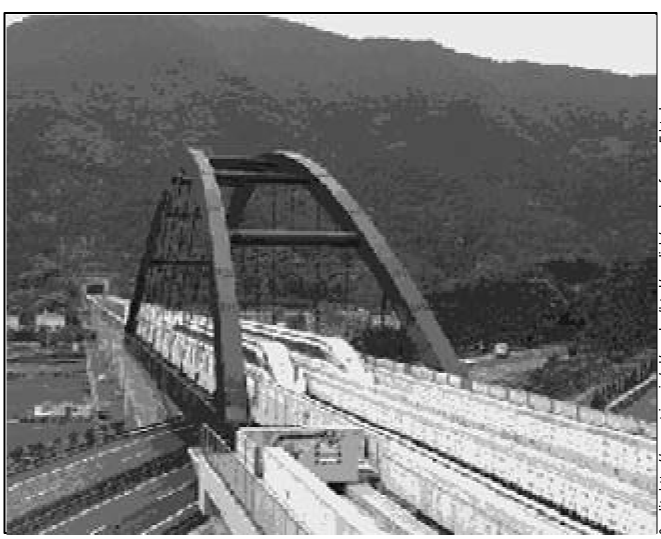
Magnetic Levitation: *Transportation for the 21st Century?*

By Jonathan Jacobs

At the dawn of the 21st century, transportation is more vital than ever. Thus far, the huge demand has been met by relying heavily upon automobiles and airplanes, but this has placed great strains on our transportation system that will only continue to grow. The effects of this pressure include highway congestion, airport overcrowding, heavy usage of limited oil supplies, and pollution. Solving our nation's transportation dilemma will likely require more than simply sinking more resources into expanding highways and airports. One possibility is to revitalize the venerable concept of the train. Proponents of magnetically levitated trains (maglevs) envision a future in which taking the train means comfortably and safely bulleting on a cushion of air at over 500 km/hr. If they are right, maglev could become a major part of travel in the 21st century.

Why Maglev?

The idea behind maglev has been around for decades, attracting attention with its anticipated speed, efficiency, and convenience (1). These systems would harness the power of electromagnetism to levitate and accelerate a massive train. Such a train would essentially ride on air, thereby experiencing very little of the friction experienced by current trains. The elimination of rail friction brings about three major benefits over conventional trains. First, a maglev system could in theory attain speeds far surpassing that of wheeled trains. Speeds of more than 550 km/hr have been obtained by Japanese maglev prototypes, setting the world record for rail speed (7). This is worlds apart from the relatively sluggish maximum running speed of most Amtrak trains in the United States (around 130 km/hr) and could attract many passengers away from air and automotive transportation (1,10). Second, the reduced friction allows maglevs to attain this speed far more efficiently than possible with wheeled designs. Without the huge power drain of friction, far less energy is required to accelerate and maintain the speed of a maglev compared to a wheeled train. Third, the lack of contact with rails allows maglevs to operate with far less noise than conventional trains, minimizing the disruption caused by a maglev to neighborhoods it passes through (2).



Credit: http://www.rtri.or.jp/rd/maglev/html/english/maglev_frame_E.html

Prototype Japanese maglev vehicles running on the Yamanishi test track.

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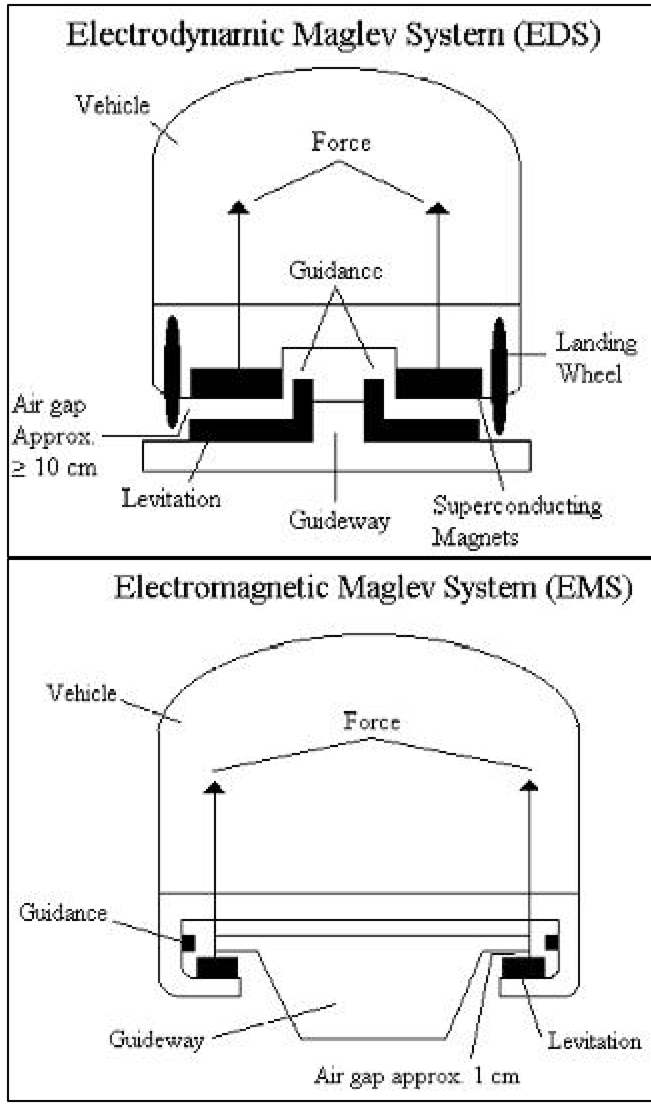
Maglevs would have many other benefits as well. For instance, not only would maglevs use less energy than airplanes and cars, but they would also use electricity taken from the power grid rather than using oil. As a result, maglevs would conserve oil and would release far less pollution than cars and planes (1,2). Maglevs would have the added benefit of being very safe. Like high-speed trains in Europe and Japan, maglevs would have sophisticated automatic control systems, frequent automated inspections, highly capable personnel, and lack on-board fuel that could ignite in an accident (2). Such measures have made high-speed rail among the safest modes of transportation available (2). Maglev would have an additional safety edge over high speed rail because accidents related to wear and tear and the weather would be reduced by the lack of physical contact between the maglev train and the guideway (2). Moreover, like current high speed trains, maglevs would be more reliable than transportation by road or air, as they would run on a regular, largely invariant schedule whereas other forms of transportation are subject to frequent delays and congestion (1). Finally, just like conventional trains, maglev systems would have huge capacity for transporting people and freight (1). This would allow maglevs to accommodate the rapidly expanding number of travelers in the near future and to carry freight to help cover operating costs.

Two Types of Maglev: EDS and EMS

The many advantages of maglev have resulted in numerous past attempts to develop and implement maglev technology. This past work has led the scientific community to recognize two fundamental designs for using magnetism to levitate and guide a train: those based on electromagnetic suspension (EMS) and those based on electrodynamic suspension (EDS).

The more intuitive of the two designs is EDS, which relies upon repulsive forces. In most EDS concepts, the maglev vehicles have superconducting magnets (SCMs) underneath them that interact with a conducting guideway. SCMs are far more powerful than normal electromagnets because the lack of electrical resistance in superconductors allows currents (and hence the magnetic fields they produce) to far exceed those in conventional electromagnets. As the vehicle moves over the guideway, induction creates a magnetic field in the guideway that repulses the magnetic field of the SCMs, levitating the train (2). In EDS designs, the vehicle needs to be accelerated on wheels briefly to attain enough speed to levitate. An EDS system is inherently stable since the repulsive force increases as the gap between vehicle and guideway decreases (2). Such stability allows the EDS vehicle to take upon more weight without losing much levitation and prevents any dangerous sudden losses of levitation (8).

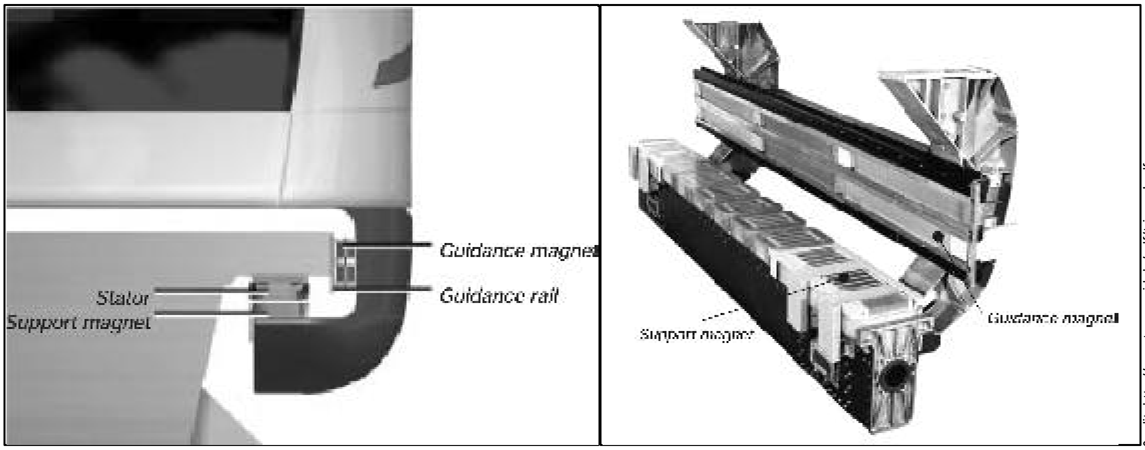
Maglev concepts using electromagnetic suspension (EMS), on the other hand, employ attractive forces. In EMS designs, the bulk of the maglev vehicle rides above the tracks but a portion of the vehicle on each side wraps around the guideway (2). These J-shaped extensions each contain electromagnets that are attracted to magnets underneath the guideway; this attraction causes the entire vehicle to elevate off the tracks (2). A system of sensors and feedback circuits controls the current in these electromagnets, carefully maintaining a constant gap between the rails and the vehicle (2). In contrast to an EDS system, EMS is fundamentally unstable, as the attractive forces involved increase exponentially as the gap between track and vehicle decreases.



Credit: Glanz, James. Maglev: Will It Ever Really Fly? *R&D Magazine* v. 35, n. 9 (August 1993): 40-42.

Diagram of the basic features of the EDS and EMS maglev systems (dark bars represent magnets).

While each system is capable of levitation, they each have different drawbacks that set them apart. The main downside of EMS, aside from its inherent instability, is that it requires normal electromagnets, which can only levitate a maglev vehicle about 1 centimeter before costs and weight become prohibitive (2). EMS vehicles must use normal electromagnets because levitation in an EMS system requires rapid changes in magnetic field that are not possible with far more powerful superconducting electromagnets (SCM) (2). EDS systems, on the other hand, do not require changes in the vehicle's magnetic field and so can effectively use the constant magnetic force supplied by a SCM to create a gap of between 5 to 15 centimeters (2). While these issues make the EMS less favorable than EDS, EMS remains a viable choice because existing EDS designs use more power, require stronger magnetic fields, and are more



Credit: http://www.transrapid.de/pdf/tri_engl.pdf

A diagram showing one of the J-shaped extensions of a Transrapid train wrapping around its guideway. The support magnet levitates the train and the guidance magnet keeps the train centered on its track. On the guideway, the stator produces alternating electromagnetic waves that propel the train forward.

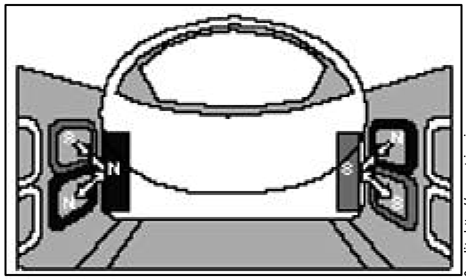
expensive than EMS designs (2).

While maglev trains are distinguished primarily by their mechanisms of levitation, they all require some means of acceleration. The propulsion system that has been most widely used in maglev designs is known as a linear synchronous motor (LSM). A LSM generates a magnetic field that travels along the guideway (2). This field interacts with the vertical component of the magnetic field produced by the vehicle's onboard magnets (11). By keeping the traveling field in synchrony with the vehicle, a LSM causes magnetic interactions that push and pull the vehicle forward (2). LSM has not only been found to be an effective propulsion system, but also has the added benefit of ensuring that two trains can never be traveling in opposite directions on the same guideway and can never overtake one another since all vehicles would be riding the same magnetic waves (2). This makes it nearly impossible for maglev trains to collide.

Maglev in Practice: Transrapid and the Japanese Maglev

There are two currently operational high speed experimental maglev systems, one German and one Japanese, that demonstrate EDS and EMS put to practice. Of these two prototypes, Germany's Transrapid EMS maglev system is the closest to commercial service. Transrapid has been operating a prototype on an Emsland test facility since 1984 and now routinely provides demonstration rides to tourists (4). The first commercial Transrapid line is scheduled to become operational early 2003 in Shanghai, servicing the 30 km distance between Shanghai's airport and its downtown (4). Two additional lines are being planned in Germany and one in the United States, although the site of this line has not been decided yet (4).

The Transrapid system uses a T-shaped steel guideway upon which ride vehicles with J-shaped extensions that wrap around the guideway (4). The J-shaped portion of the vehicle contains electromagnets positioned underneath and to the sides of the guideway (4). The electromagnets underneath the guideway, powered by onboard batteries and recharged by the guideway's magnetic fields, levitate the train by pushing upward towards ferromagnets along the bottom of the arms of the T-shaped guideway (4). The side magnets are used to generate lateral forces that keep the train centered on the tracks (4). Propulsion is provided by a LSM consisting of stators in the guideway that generate a traveling magnetic field pulling the vehicles forward (4).



Credit: http://www.rtri.or.jp

Representation of how the superconducting magnets onboard the Japanese maglev vehicle interact with the guideway to provide levitation.

The Transrapid has been shown in testing to have many advantages over the Germans' current high speed rail system, termed the inter city express (ICE). For instance, it accelerates far more rapidly, taking half as much time as the ICE to accelerate to 250 km/hr, and can attain a far greater speed (up to about 500 km/hr compared to 300 km/hr for the ICE) (5). Despite this, passengers aboard the demonstration vehicle have described the Transrapid as having a smoother and more comfortable ride than an ICE train (5). The Transrapid has also been shown to be more versatile than existing trains, capable of moving up inclines of as much as 10 degrees compared to 4 degrees for wheeled trains (5). In addition, the Transrapid has been shown to make considerably less noise than any other train at a comparable speed and to have a safe external magnetic field that is considerably less than that of a television set (5).

While the Transrapid system is already on its way to commercial use, the Japanese are still testing their prototypes to find ways to make them more cost effective (6). They are currently developing an EDS system powered by superconducting magnets (SCMs) (7).

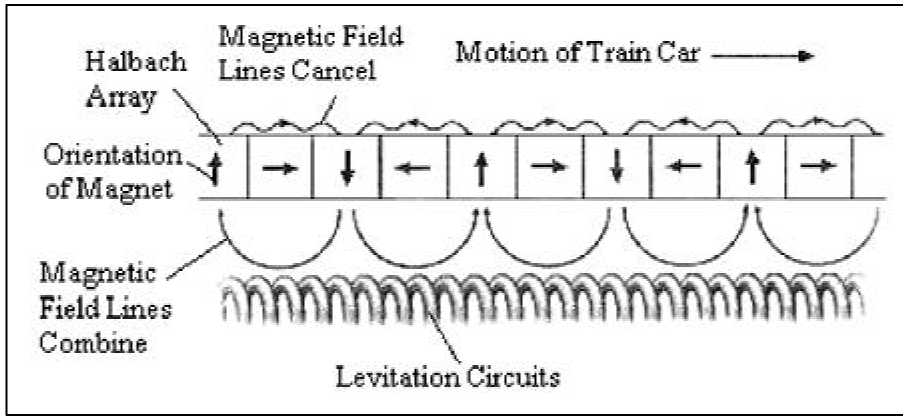
Research work on the Japanese maglev has been carried out since the late 70's at the Miyizaki test track (7). The recently constructed Yamanishi test track set the world speed record for trains last year by attaining a speed of 552 km/hr in a manned test (7).

The Japanese design uses U-shaped elevated guideways with sidewalls containing levitation coils, some below and some above the level of the SCMs on the maglev vehicles (7). As the train and its SCMs passes by, an electric current is induced in the coils (7). This temporary current creates a temporary magnetic field that either has repulsive interactions with the SCMs (coils below the SCMs) or attractive interactions (coils above the SCMs), resulting in a net upward force that levitates the train (7). The coils are also arranged such that any lateral movement by the train creates repulsive forces on one side of the train, keeping the train centered on the track (7). Like the Transrapid, the Japanese maglev vehicle is propelled by a LSM (7).

The main obstacle to implementing the Japanese system is the need for onboard SCMs, which must be kept at a temperature below 5 K (7,8). This temperature, necessary for superconduction to occur, is attained using an on-board refrigeration system based upon liquid nitrogen and helium (7,8). The great expense required to maintain this optimal temperature has prevented the concept from being applied commercially, and ongoing research is focusing upon methods of reducing the system's cost.

The Latest Maglev Concept: the Inductrack

While Germany and Japan have each had working prototypes of maglev trains for more than a decade, maglev concepts in the U.S. have never gone beyond the design and proof-of-concept stage even though American efforts began in the 60's (9). However, a recent American concept that has attracted considerable attention has the potential to revitalize American maglev efforts. In research publicized several years ago, Dr. Richard Post of the Lawrence Livermore National Laboratory developed a new maglev design that avoids the major failings of the Japanese and German maglevs (11). This concept, christened "Inductrack," is essentially an EDS system using permanent magnets rather than superconducting magnets.



A diagram showing the magnetic fields created by Halbach arrays on an Inductrack vehicle.

Credit: Post, Richard. Maglev: A New Approach. *Scientific American* v

Before Dr. Post unveiled his idea, it was believed that permanent magnets would provide too little levitating force to be useful in any maglev design (8). The Livermore team worked around this by employing a special arrangement of powerful permanent magnets, known as a Halbach array, to create a levitating force theoretically powerful enough to operate a maglev (8). In a Halbach array, high field alloy magnetic bars are arranged such that each bar's magnetic field is orientated at a right angle to the adjacent bar (8). The combination of magnetic field lines from this array results in a powerful field below the array and almost no magnetic field lines above the array (8).

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Just as in an EDS system, levitation is generated by the repulsive interactions of the Halbach array's magnetic field with the magnetic field induced in the conducting guideway by the moving Halbach array (8). The Inductrack guideway would contain two rows of tightly packed levitation coils, which would act as the rails (8). Each of these "rails" would be lined by two Halbach arrays carried underneath the maglev vehicle: one positioned directly above the "rail" and one along the inner side of the "rail" (8). The Halbach arrays above the coils would provide levitation while the Halbach arrays on the sides would provide lateral guidance that keeps the train in a fixed position on the track (8). Like EDS systems, this levitation would be inherently stable since the repulsive levitating force increases exponentially as the gap between vehicle and guideway decreases (8). But unlike EDS systems, Inductrack trains can continue levitating in the event of a power failure because of their reliance upon permanent magnets and non-electrified coils (8). As a result, they would glide to a stop rather than suddenly slamming onto the tracks at high speed (8). As with other maglev designs, propulsion would be provided by a LSM (8).

The Inductrack holds a considerable theoretical efficiency advantage over existing maglevs as a result of its use of permanent magnets. The Inductrack levitation occurs independently of any power source, in stark contrast to the energy needs of the complex electromagnets of the Transrapid system or the expensive cryogenic equipment on the Japanese maglevs (8). As a result, Inductrack only requires power for propulsion and only loses power to aerodynamic drag and electrical resistance in the levitation circuits (8).

The Inductrack system is quite new relative to the two existing maglev prototypes. So far, there has only been one demonstration of the Inductrack: a 20 meter track upon which a 22 kg vehicle with Halbach arrays levitated after reaching a speed of only 4 m/s (8). Currently, the Inductrack team is working on building another scale model of the Inductrack system that will be 100 meters long and capable of accelerating a vehicle to about 600 km/hr (8). This model is being built under a contract with NASA to study the feasibility of using Inductrack for launching payloads into space; nevertheless, such studies will develop the Inductrack system and may lead to a workable maglev system for the future (8).

The Future of Maglev

The technology exists for maglev systems to be put into practice, but a number of practical issues have prevented maglevs from being widely implemented. The most important of these is cost. A maglev system would require massive investment to build the long stretches of guideways on which the maglev trains would operate. In addition, maglev trackway is more expensive than trackways for existing high-speed rail systems. However, the higher investment costs are offset by lower operating costs since maglevs use less energy and require far less maintanence than current high-speed trains (8,13). Electromagnetic fields (EMFs) represent another concern. However, EMS maglevs such as Transrapid produce relatively weak EMFs that can be easily shielded and EDS systems, while producing much more powerful EMFs, should also not pose a health risk with proper shielding (12,13).

It remains to be seen whether any country will make the huge investments in new infrastructure required for a functional maglev system. This is not likely in Europe and Japan because these countries already have extensive high-speed rail networks (12). The U.S. is in a better position than either Europe or Japan to invest in new transportation technologies by virtue of its relative lack of effective high-speed rail and mass transit systems, but support for maglev technology has historically been weak. The federal government had held the position that development of maglev systems should be left to the private sector (both the German and Japanese efforts are publicly funded) until the Transportation Equity Act of 1998 appropriated $950 million for a small maglev project (6). Currently, two proposals (one for a line connecting Pittsburgh's airport to its downtown, the other connecting Washington and Baltimore) that would use Transrapid technology are competing for this federal grant (4).

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The potential benefits of maglev are considerable and the technology is within our reach. Maglev may never become practical due to its costs, improvements in current high-speed rail, or novel transportation technologies that prove superior. Yet, maglev also has the potential to become a major component of future mass transportation. It is possible to imagine maglevs someday traveling through vacuum tubes across the country at speeds faster than those attained by current airplanes while retaining all the convenience and capacity of rail (2). But only with further investment in exploring the technology will we ever truly know whether a revival of the train as a sleek, levitating marvel of engineering can become reality.

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