

# Superconducting Maglev and Biophysics

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**ABSTRACT:** Maglev -- short for magnetic levitation -- trains can trace their roots to technology pioneered at Brookhaven National Laboratory. James Powell and Gordon Danby of Brookhaven received the first patent for a magnetically levitated train design in the late 1960s. The idea came to Powell as he sat in a traffic jam, thinking that there must be a better way to travel on land than cars or traditional trains. He dreamed up the idea of using superconducting magnets to levitate a train car. Superconducting magnets are electromagnets that are cooled to extreme temperatures during use, which dramatically increases the power of the magnetic field. The first commercially operated high-speed superconducting Maglev train opened in Shanghai in 2004, while others are in operation in Japan and South Korea. In the United States, a number of routes are being explored to connect cities such as Baltimore and Washington, D.C.

In Maglev, superconducting magnets suspend a train car above a U-shaped concrete guideway. Like ordinary magnets, these magnets repel one another when matching poles face each other.

"A Maglev train car is just a box with magnets on the four corners," says Jesse Powell, the son of the Maglev inventor, who now works with his father. It's a bit more complex than that, but the concept is simple. The magnets employed are superconducting, which means that when they are cooled to less than 450 degrees Fahrenheit below zero, they can generate magnetic fields up to 10 times stronger than ordinary electromagnets, enough to suspend and propel a train.

These magnetic fields interact with simple metallic loops set into the concrete walls of the Maglev guideway. The loops are made of conductive materials, like aluminum, and when a magnetic field moves past, it creates an electric current that generates another magnetic field.

Three types of loops are set into the guideway at specific intervals to do three important tasks: one creates a field that makes the train hover about 5 inches above the guideway; a second keeps the train stable horizontally. Both loops use magnetic repulsion to keep the train car in the optimal spot; the further it gets from the center of the guideway or the closer to the bottom, the more magnetic resistance pushes it back on track.

The third set of loops is a propulsion system run by alternating current power. Here, both magnetic attraction and repulsion are used to move the train car along the guideway. Imagine the box with four magnets -- one on each corner. The front corners have magnets with north poles facing out, and the back corners have magnets with south poles outward. Electrifying the propulsion loops generates magnetic fields that both pull the train forward from the front and push it forward from behind.

This floating magnet design creates a smooth trip. Even though the train can travel up to 375 miles per hour, a rider experiences less turbulence than on traditional steel wheel trains because the only source of friction is air.

Another big benefit is safety. Maglev trains are "driven" by the powered guideway. Any two trains traveling the same route cannot catch up and crash into one another because they're all being powered to move at the same speed. Similarly, traditional train derailments that occur because of cornering too quickly can't happen with Maglev. The further a Maglev train gets from its normal position between the guideway walls, the stronger the magnetic force pushing it back into place becomes.

This core feature is what's most exciting to Jesse Powell. "With Maglev, there is no driver. The vehicles have to move where the network sends them. That's basic physics. So now that we have computer algorithms for routing things very efficiently, we could change the scheduling of the entire network on the fly. It leads to a much more flexible transportation system in the future," he said.

**KEYWORDS:** Maglev, biophysics, superconducting, magnetic field, electrifying, magnetic levitation

## I. INTRODUCTION

In Gulliver's Travels (1726), Jonathan Swift described the maglev island of Laputa, which was capable of achieving levitation heights of several kilometers. In Dick Tracy and Spiderman comics, magnetic levitation also achieved considerable heights.

In 1842, Samuel Earnshaw, an English clergyman and scientist, proved another important limitation of magnetic levitation. He showed that stable contact-free levitation by forces between static magnets alone was impossible; the levitated part would be unstable to displacements in at least one direction.[1,2]

In March 1912, engineer and inventor Emile Bachelet had just learned that he had been granted a US patent for his “Levitated Transmitting Apparatus,” and he gave a public demonstration in New York of a model maglev train, with the hopes of exciting investors with the promise of high-speed ground transportation.

One of the first major applications of magnetic levitation was in supporting airplane models in wind tunnels. Researchers had found that mechanical support structures sometimes interfere with airflow enough to produce more drag than the drag force on the model. The solution developed by Gene Covert and his MIT colleagues in the 1950s was magnetic levitation (although they called it a “magnetic suspension and balance system”).

Another means of using a moving magnet to circumvent Earnshaw’s rule and achieve full levitation is to move the magnet in the presence of an electrical conductor, thereby inducing eddy currents in the conductor and associated repulsive forces on the magnet. This is the basis of the electrodynamic approach to maglev trains proposed by James Powell and Gordon Danby in the 1960s and developed most extensively by Japan National Railway. Strong superconducting electromagnets on the cars induce eddy currents in the conducting track that produce levitation once the cars reach sufficient speed. Levitation via induction and eddy-current repulsion can also be achieved with AC fields. This was the basis of the maglev train promoted in 1912 by Bachelet. One important industrial application of levitation via induction and AC fields is levitation melting, which allows the melting and mixing of very reactive metals without the need for a crucible.

In 1983, Roy Harrigan received a patent for a “levitation device” that consisted of a small spinning magnet floating above a large base magnet, and Bill Hones of Fascinations, Inc., later developed Harrigan’s idea into a successful commercial product called the Levitron. As with the rotor of the electric meter, the spinning magnet of the Levitron was pushed upward by the repulsion forces between like poles. But it floated fully contact-free, getting around Earnshaw’s rule because it was not a static magnet—it was spinning. At first glance, it seems that it is simple gyroscopic action that keeps the spinning magnet from tipping over, but detailed mathematical analysis by several prominent scientists soon showed that the stability of the Levitron is a bit more complicated than that.

In the 1930s, German scientists demonstrated levitation of highly diamagnetic graphite and bismuth, and after the development of high-field superconducting electromagnets, levitation of even much weaker diamagnets like water, wood, and plastic was accomplished. This was little noticed until 1997, when Andre Geim and colleagues used a 16-tesla superconducting magnet to magnetically levitate a small living frog, their “flying frog” finally drawing worldwide attention to the wonder of diamagnetic levitation. (Geim, winner of a 2010 Nobel Prize in Physics for research on graphene, was awarded an Ig Nobel Prize ten years earlier for frog levitation, an award he and corecipient Sir Michael Berry accepted with a call for “more science with a smile.”)

Superconductors are much more diamagnetic than frogs, and even much more diamagnetic than graphite and bismuth. They are superdiamagnets. Levitation of a permanent magnet above a superconductor was first demonstrated by V. Arkadiev in 1945, and the levitation of magnets above superconductors became much easier and more common after the 1987 discovery of high-temperature superconductors, materials superconducting at liquid-nitrogen temperature. Magnetic bearings based on repulsive forces between permanent magnets and high-temperature superconductors have been developed for a number of potential applications, including energy-storage flywheels and model maglev trains (carrying nitrogen-cooled superconductors on cars floating above permanent-magnet tracks).

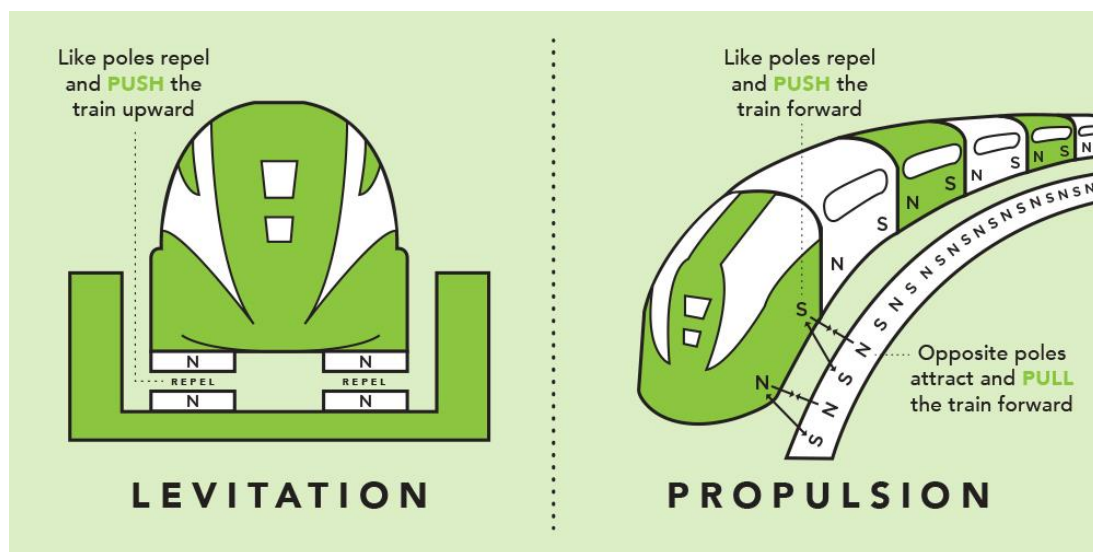
Jane Philbrick, a visiting artist at MIT, designed and built her “Floating Sculpture,” an arresting array of twelve large levitated balls that became a prominent part of her solo exhibition at a Swedish art museum in 2009 and was on view in New York City in spring 2011.

The technology most commonly associated with the term maglev in the mind of the general public is high-speed maglev trains, first proposed a century ago by Bachelet. About twenty years later, Werner Kemper of Germany proposed a train magnetically levitated by a feedback-controlled attractive force, and after many decades of development, his idea eventually evolved into the Transrapid system used in the Shanghai maglev train in 2003.

Japan National Railway remains committed to construction of a roughly 300 km high-speed maglev line between Tokyo and Nagoya . A basic design similar to the Kemper-Transrapid approach was used to construct a low-speed “urban maglev” at Nagoya that has been in successful operation since 2005, and China is currently building a similar urban line in Beijing. The advantage of low-speed urban maglev is a smooth, quiet, safe, reliable, and cost-effective

(low maintenance and operating costs) ride. Therefore, Bachelet's 1912 dreams of "carloads of passengers whizzing on invisible waves of electromagnetism through space anywhere from 300 to 1,000 miles an hour" are being achieved.[3,4]

Magnetic levitation, the use of upward magnetic forces to balance the pervasive downward force of gravity, has already found many other important uses in science and technology. Maglev today helps circulate blood in human chests, manufactures integrated circuits with multimillion-dollar photolithography systems, measures fine dimensions with subatomic resolution, enhances wind-tunnel and plasma research, melts and mixes reactive high-temperature metals, simulates the sense of touch in haptics systems, cools our laptop computers, enriches uranium and other isotopes in centrifuges, stores energy in spinning flywheels, and floats spinning rotors with low friction in countless rotating machines around the world. The future of maglev remains very bright. Fighting the forces of gravity and friction is one of the things that magnets do best [1].



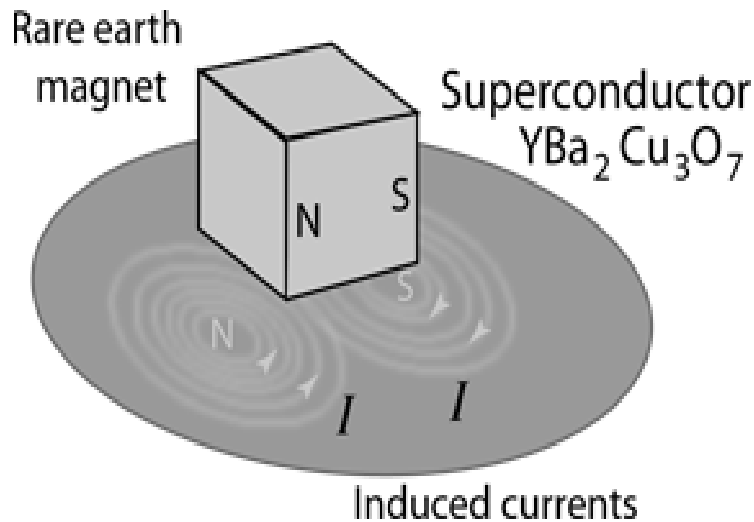
Working of Maglev

## II. DISCUSSION

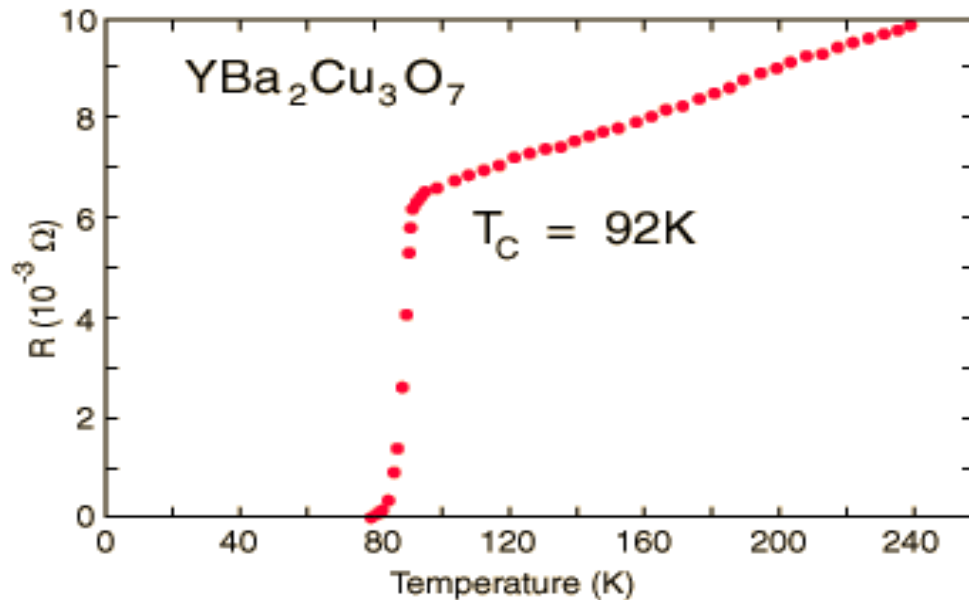
Magnetic levitation is a method by which an object is suspended in the air with no support other than magnetic fields. The fields are used to reverse or counteract the gravitational pull and any other counter accelerations. Maglev can create frictionless, efficient, far-out-sounding technologies. The principle of magnetic levitation has been known for over 100 years, when American scientists Robert Goddard and Emile Bachelet first conceived of frictionless trains. But though magnetically levitated trains have been the focus of much of the worldwide interest in maglev, the technology is not limited to train travel [2]. Maglev usages from view point of engineering science can be categorized and summarized as follows: (i) transportation engineering (magnetically levitated trains, flying cars, or personal rapid transit (PRT), etc.), (ii) environmental engineering (small and huge wind turbines: at home, office, industry, etc.), (iii) aerospace engineering (spacecraft, rocket, etc.), (iv) military weapons engineering (rocket, gun, etc.), (v) nuclear engineering (the centrifuge of nuclear reactor), (vi) civil engineering including building facilities and air conditioning systems (magnetic bearing, elevator, lift, fan, compressor, chiller, pump, gas pump, geothermal heat pumps, etc.), (vii) biomedical engineering (heart pump, etc.), (viii) chemical engineering (analyzing foods and beverages, etc.), (ix) electrical engineering (magnet, etc.), (x) architectural engineering and interior design engineering including household and administrative appliances (lamp, chair, sofa, bed, washing machine, room, toys (train, levitating spacemen over the space ship, etc.), stationery (pen), etc.), (xi) automotive engineering (car, etc.), (xii) advertising engineering (levitating everything considered inside or above various frames can be selected).

The Meissner effect in superconductors like this black ceramic yttrium based superconductor acts to exclude magnetic fields from the material. Since the electrical resistance is zero, supercurrents are generated in the material to exclude the magnetic fields from a magnet brought near it. The currents which cancel the external field produce magnetic poles which mirror the poles of the permanent magnet, repelling them to provide the lift to levitate the magnet.

The levitation process is quite remarkable. Since the levitating currents in the superconductor meet no resistance, they can adjust almost instantly to maintain the levitation. The suspended magnet can be moved, put into oscillation, or even spun rapidly and the levitation currents will adjust to keep it in suspension.[5,6]



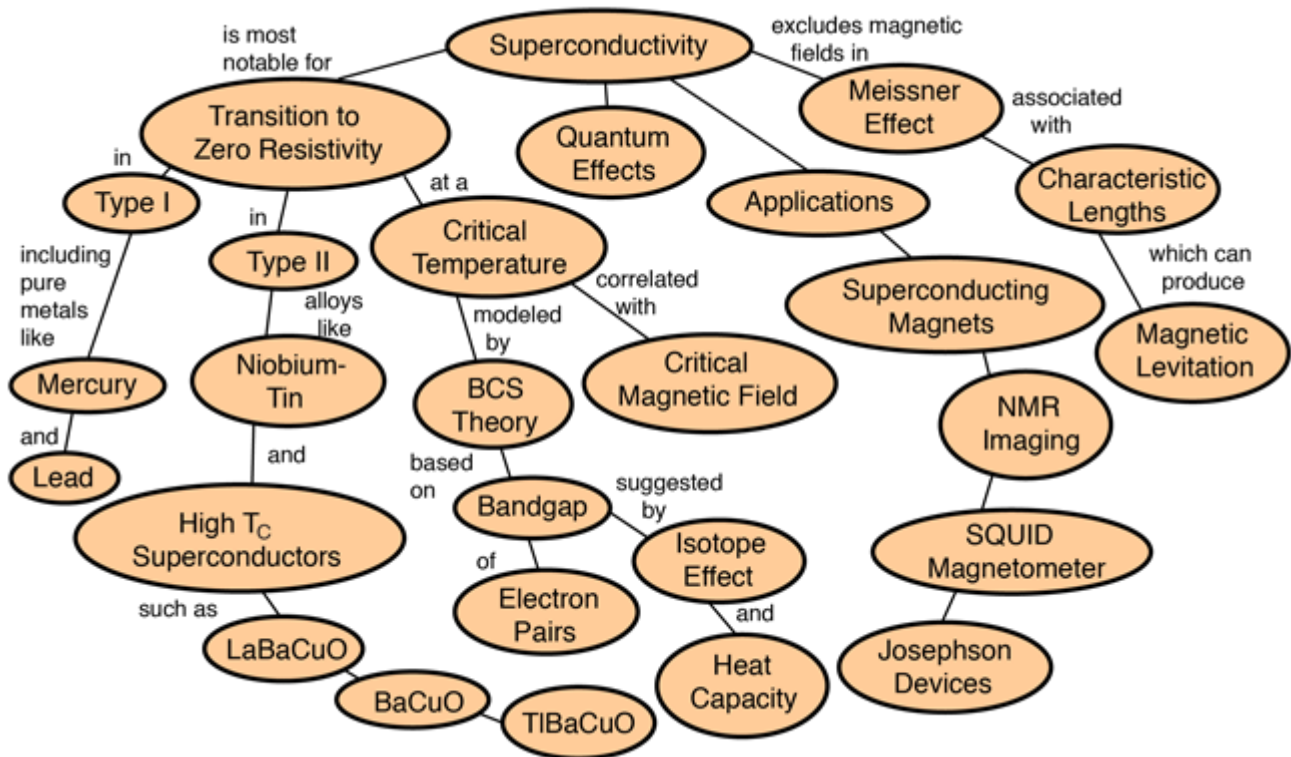
This ceramic material was the first of the high temperature superconductors to make the phase change at a temperature above the liquid nitrogen temperature (77 K).



This disc of YBaCuO certainly doesn't look or feel like an electrical conductor. It is a hard, brittle ceramic material. It looks like something you would make a grinding wheel out of - the fact that it can become a perfect conductor is hard to believe. But when a small rare-earth magnet is placed on it and liquid nitrogen is poured around it, the magnet levitates, showing the Meissner effect characteristic of the zero-resistance state. In the illustration, the black YBaCuO disc is held in a brass mount to facilitate cooling and holding it at liquid nitrogen temperature.



## III. IMPLICATIONS



As if ceramic superconductors were not strange enough, even more mysterious superconducting systems have been discovered. One is based on compounds centered around the "Fullerene". The fullerene name comes from the late designer-author Buckminster Fuller. Fuller was the inventor of the geodesic dome, a structure with a soccer ball shape. The fullerene - also called a buckminsterfullerene or "buckyball" - exists on a molecular level when 60 carbon atoms join in a closed sphere. When doped with one or more alkali metals the fullerene becomes a "fulleride" and has produced Tc's ranging from 8 K for Na<sub>2</sub>Rb<sub>0.5</sub>Cs<sub>0.5</sub>C<sub>60</sub> up to 40 K for Cs<sub>3</sub>C<sub>60</sub>. In 1993 researchers at the State University of New York at Buffalo reported Tc's between 60 K and 70 K for C-60 doped with the interhalogen compound ICl.

Fullerenes, like ceramic superconductors, are a fairly recent discovery. In 1985, professors Robert F. Curl, Jr. and Richard E. Smalley of Rice University in Houston and Professor Sir Harold W. Kroto of the University of Sussex in Brighton, England, accidentally stumbled upon them. The discovery of superconducting alkali metal fullerenes came in 1991 when Robert Haddon and Bell Labs announced that K<sub>3</sub>C<sub>60</sub> had been found to superconduct at 18 K.

Larger, non-spherical pure carbon fullerenes that will superconduct have only recently been discovered. In April of 2001, Chinese researchers at Hong Kong University found 1-dimensional superconductivity in single-walled carbon nanotubes at around 15 Kelvin. And in February 2006, Physicists in Japan showed non-aligned, multi-walled carbon nanotubes were superconductive at temperatures as high as 12 K. Silicon-based fullerenes like Na<sub>2</sub>Ba<sub>6</sub>Si<sub>46</sub> will also superconduct. However, they are structured as infinite networks, rather than discrete molecules. Fullerenes are technically part of a larger family of organic conductors which are described below.[7,8]

"Organic" superconductors are part of the organic conductor family which includes: molecular salts, polymers and pure carbon systems (including carbon nanotubes and C<sub>60</sub> compounds). The molecular salts within this family are large organic molecules that exhibit superconductive properties at very low temperatures. For this reason they are often referred to as "molecular" superconductors. Their existence was theorized in 1964 by Bill Little of Stanford University. But the first organic superconductor (TMTSF)<sub>2</sub>PF<sub>6</sub> was not actually synthesized until 1980 by Danish researcher Klaus Bechgaard of the University of Copenhagen and French team members D. Jerome, A. Mazaud, and M. Ribault. About 50 organic superconductors have since been found with Tc's extending from 0.4 K to near 12 K (at ambient pressure). Since these Tc's are in the range of Type 1 superconductors, engineers have yet to find a practical application for them.

However, their rather unusual properties have made them the focus of intense research. These properties include giant magnetoresistance, rapid oscillations, quantum hall effect, and more (similar to the behavior of InAs and InSb). In early 1997, it was, in fact (TMTSF)<sub>2</sub>PF<sub>6</sub> that a research team at SUNY discovered could resist "quenching" up to a magnetic field strength of 6 tesla. Ordinarily, magnetic fields a fraction as strong will completely kill superconductivity in a material.

Organic superconductors are composed of an electron donor (the planar organic molecule) and an electron acceptor (a non-organic anion). Below are a few more examples of organic superconductors.

(TMTSF)<sub>2</sub>ClO<sub>4</sub>  
[tetramethyltetraselenafulvalene + acceptor]

(BETS)<sub>2</sub>GaCl<sub>4</sub>  
[bis(ethylenedithio)tetraselenafulvalene + acceptor]

(BEDO-TTF)<sub>2</sub>ReO<sub>4</sub>H<sub>2</sub>O  
[bis(ethylenedioxy)tetrathiafulvalene + acceptor]

A maglev train, or magnet-enhanced train, is a transport system that uses the magnetic force of magnets on a large scale for levitation and propulsion, and is controlled 'without touching the ground'. This mode of transport is faster, quieter and jerkless than wheeled mass transit systems.

The highest speed ever recorded for a maglev train is 581 kilometers per hour (361 mph). This record was set in Japan in 2003, which was 6 kilometers per hour (3.7 mph) faster than the recorded speed of the conventional TGV. [9,10]

The first commercial maglev "people-transporter" was officially commissioned in 1984 in Birmingham, England. It was operated on an elevated 600-metre (2,000 ft) section of monorail track, between Birmingham International Airport and Birmingham International Railway Station, at a speed of 42 km/h (26 mi/h). The system was finally discontinued in the year 1995 due to reliability and design problems.

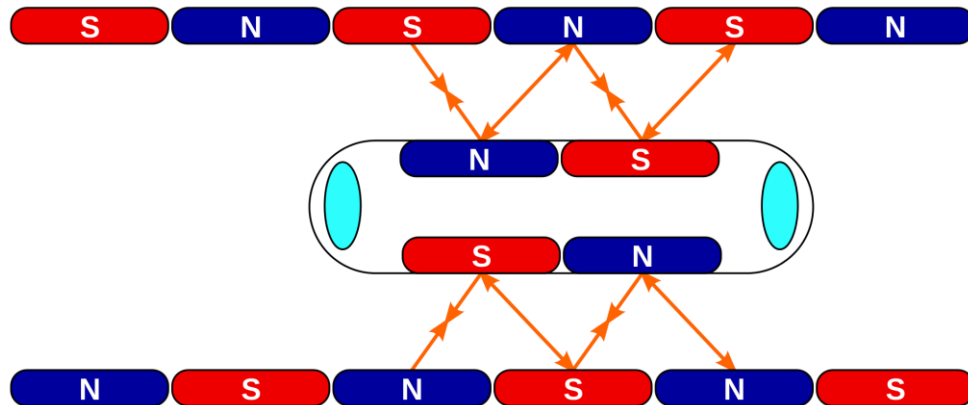
Perhaps the best-known implementation of fast-speed maglev technology currently operating commercially is the IOS (IOS meaning initial operating segment or initial operating segment) demonstration line of the German-built TransRapid train operating in Shanghai, China, with a maximum speed of 431 km/h (268 mph) and an average speed of 250 km/h (160 mph) takes people 30 km (18.6 mi) to the airport in just 7 minutes 20 seconds.

In electrodynamic suspension (EDS), both the track and the train exert a force on a magnetic field, and the repulsive force between these magnetic fields causes the train to levitate. The magnetic field in the train is generated by either electromagnets (as in the JR-Maglev) or an array of permanent magnets (as in the Inductrack). An induced magnetic field in the wires or other conductors in the track creates a repulsive force in the track. A major advantage of repulsive maglev systems is that they are inherently stable - a slight contraction in the distance between the track and the magnets. A large amount of force is generated that pushes the magnets back to their original positions, while a slight increase in distance reduces the force and once again the vehicle returns to the correct separation. [15] No feedback controls are necessary.

There is also a major downside of countermeasures systems. At slow speeds, the induced current in these coils and the resultant magnetic flux is not high enough to support the weight of the train. For this reason it is very important for the train to have wheels or some other type of landing gear to support the train until it reaches a speed capable of maintaining leverage. Since a train can stop at any point, for example due to equipment failure, the entire track must be capable of supporting both low-speed and high-speed operation of the train. Another downside of this is that repulsive systems naturally create a field in the track in front and behind the lift magnets that acts against the magnets and creates a kind of stretch. This is generally a concern for low-speed systems, [15]

Traction force can be used to the advantage of an electrodynamic system, however, because it generates a variable force in the tracks that can be used as a reactionary system to propel the train, with a separate The feedback plate is not needed, as is the case with most linear motor systems. Lathwaite led the development of "transit-flow"-like systems in his laboratory at Imperial College. [15] Alternatively, the propulsion coils of the guideway are used to exert force on the train magnets and propel the train forward. The propulsion coil that exerts a force on the train is effectively a linear motor. Contains: A variable current flowing through the coils produces a continuously variable magnetic field that

continues to move along the track. The frequency of the variable current is synchronized to match the speed of the train. The difference between the field created by the force of the magnets in the train and the applied field produces a force that moves the train forward.[11,12]



EDS maglev propulsion via propulsion coil

#### IV. RESULTS

For many systems, it is possible to define a leverage-to-traction ratio. For maglev systems, these ratios can be higher than aircraft (for example, Inductrack can reach a high speed of 200:1, which is far higher than any aircraft). This could increase the maglev's per kilometer capacity. However, at high cruising speeds, the aerodynamic traction is much greater than the levitation induced traction. Jet transport aircraft take advantage of low air density to reduce traction during cruising at high altitudes, so despite the loss of their leverage-to-traction ratio, they can travel more efficiently than maglev trains at higher speeds. which operate on the surface of the sea (also known as vactrainis proposed to be determined by the concept). Aircraft are also more flexible and can serve more destinations with the provision of suitable airport facilities.

Unlike airplanes, maglev trains are powered by electricity and thus do not need to carry fuel. Aircraft fuel becomes a major hazard during take-off and take-off accidents. In addition, electric trains emit less carbon dioxide, especially when powered by nuclear or renewable sources.

The cost of building the Shanghai Maglev was 9.93 billion yuan. This total includes the capital cost of infrastructure, such as manufacturing and manufacturing facilities and operational training. Currently income from this system at 7,000 passengers per day and 50 yuan per passenger is unable to cover capital costs (including interest on financing) excluding operating costs for the anticipated life of the system. . This may change if the capacity utilization is increased by 20 percent from the present.

China has set a target of limiting the cost of future construction of an extension of the maglev line to about 200 million yuan per kilometer.

According to the United States Federal Railroad Administration's 2003 draft Environmental Impact Statement for a proposed Baltimore–Washington maglev project, the 2008 estimated capital cost for 39.1 miles is US\$4.361 billion, or US\$111.5 million per mile (69.3 million dollars). US dollars per kilometer). The Maryland Transportation Administration (MTA) conducted its own environmental impact statement and set a target of \$4.9 billion per year for construction and 53 million per year for operation.

The estimated cost of construction of Japan's proposed Chuo Shinkansen maglev is US\$82 billion, including the construction of a long tunnel route through the mountains. The cost of the K Tkaid maglev route to replace the current Shinkansen would be approximately 1/10th of the total cost as it would not require any tunneling, but noise pollution issues would make it unviable.[13,14]

The cost to build the only low-speed maglev (100 km/h) currently in operation, the Japanese linimo HSST, is approximately US\$100 million per km. In addition to providing improved operation and maintenance costs over other transportation systems, these low-speed maglevs provide ultra-high levels of operational reliability and generate very little noise and zero air pollution in dense urban settings.

As maglev systems are employed around the world, experts expect construction costs to come down as new construction methods appear to be more economical as well as innovative.

Mumbai – Delhi : An American company submitted a proposal for a maglev line project to Lalu Prasad Yadav , the Railway Minister of India. If approved, this line will provide service between the cities of Mumbai and Delhi, Prime Minister Manmohan Singh said that if this line project is successful, then the Government of India will build these lines between other cities and also between Mumbai Center and Chhatrapati Shivaji International Airport. Will do

The state of Maharashtra has also approved a feasibility study to be carried out for a maglev train between Mumbai (the commercial capital of India as well as the state government capital) and Nagpur (the state's second capital), about 1000 km away. There are plans to connect the developed areas of Pune and Mumbai with Nagpur via the hinterland under development via Ahmednagar, Beed, Latur, Nanded and Yavatmal. [14]

## V. CONCLUSION

Maglevs have several other advantages compared with conventional trains. They are less expensive to operate and maintain, because the absence of rolling friction means that parts do not wear out quickly (as do, for instance, the wheels on a conventional railcar). This means that fewer materials are consumed by the train's operation, because parts do not constantly have to be replaced. The design of the maglev cars and railway makes derailment highly unlikely, and maglev railcars can be built wider than conventional railcars, offering more options for using the interior space and making them more comfortable to ride in. Maglevs produce little to no air pollution during operation, because no fuel is being burned, and the absence of friction makes the trains very quiet (both within and outside the cars) and provides a very smooth ride for passengers. Finally, maglev systems can operate on higher ascending grades (up to 10 percent) than traditional railroads (limited to about 4 percent or less), reducing the need to excavate tunnels or level the landscape to accommodate the tracks. The greatest obstacle to the development of maglev systems is that they require entirely new infrastructure that cannot be integrated with existing railroads and that would also compete with existing highways, railroads, and air routes. Besides the costs of construction, one factor to be considered in developing maglev rail systems is that they require the use of rare-earth elements (scandium, yttrium, and 15 lanthanides), which may be quite expensive to recover and refine. Magnets made from rare-earth elements, however, produce a stronger magnetic field than ferrite (iron compounds) or alnico (alloys of iron, aluminum, nickel, cobalt, and copper) magnets to lift and guide the train cars over a guideway.[15]

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