



Practical Applications of Magnetic Levitation Technology

(Final Report, September 2012)



Prepared by:

Hamid Yaghoubi

Director of Iran Maglev Technology (IMT)

Practical Applications of Magnetic Levitation Technology

Hamid Yaghoubi

Director of Iran Maglev Technology (IMT)

Tehran, Iran

info@maglev.ir

Abstract

The name maglev is derived from MAGnetic LEVitation. Magnetic levitation is a highly advanced technology. It has various cases, including clean energy (small and huge wind turbines: at home, office, industry, etc.), building facilities (fan), transportation systems (magnetically levitated train, Personal Rapid Transit (PRT), etc.), weapon (gun, rocketry), nuclear engineering (the centrifuge of nuclear reactor), civil engineering (elevator), advertising (levitating everything considered inside or above various frames can be selected), toys (train, levitating spacemen over the space ship, etc.), stationery (pen) and so on. The common point in all these applications is the lack of contact and thus no wear and friction. This increases efficiency, reduce maintenance costs and increase the useful life of the system. The magnetic levitation technology can be used as a highly advanced and efficient technology in the various industrial. There are already many countries that are attracted to maglev systems. Many systems have been proposed in different parts of the worlds, and a number of corridors have been selected and researched. Maglev can be conveniently considered as a solution for the future needs of the world. This research chapter tries to study the most important uses of magnetic levitation technology.

Keywords: Maglev, Magnetic levitation, Technology, Levitation, Suspension, Practical Applications

1. 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.

In March 1912, engineer and inventor Emile Bachelet had just learned 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 co-recipient 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 super-diamagnets. 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 by about 2025. 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, cost-effective (low maintenance and operating costs) ride. Therefore, Bachelet's 1912 dreams of "carloads of passengers whizzing on invisible waves of electro-magnetism through space anywhere from 300 to 1,000 miles an hour" is being achieved.

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 multi-million-dollar photolithography systems, measures fine dimensions with sub-atomic 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 (Livingston, 2011).

2. Magnetic Levitation Technology

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 (Yaghoubi et al., 2012). Maglev usages from view point of engineering science can be categorized and summarized as follows:

- Transportation Engineering (Magnetically Levitated Trains, Personal Rapid Transit (PRT), etc.)
- Environmental Engineering (Wind Turbines)

- Aerospace Engineering (Spacecraft, Rocket, etc.)
- Military Weapons Engineering (Rocket, Gun, etc.)
- Nuclear Engineering (Centrifuge)
- Civil Engineering and Building Facilities (Bearing, Elevator, Lift, Fan, Compressor, Chiller, Pump, Gas Pump, etc.)
- Biomedical Engineering (Heart Pump, etc.)
- Chemical Engineering (Analyzing Foods and Beverages, etc.)
- Electrical Engineering (Magnet, etc.)
- Architectural Engineering and Household Appliances (Lamp, Chair, Sofa, Bed, Washing Machine, etc.)
- Automotive Engineering (Car, etc.)

2.1. ElectroMagnetic Suspension (EMS)

The test bed can be used as a platform for control theory and maglev work. The completion of the project demonstrates the feasibility of magnetic levitation for any number of diverse applications. The test bed is capable of levitating a small steel ball at some stable steady-state position. The levitation is accomplished by an electromagnet producing forces to support the ball's weight. A position sensor indicates the ball's vertical position and relays this to a PC based controller board. The control system uses this information to regulate the electromagnetic force on the ball. The system consists essentially of a platform test bed and a PC with a DSP controller board. The test bed contains the electromagnet actuator, optical position sensor, electromagnet PWM power amplifier, and 2 DC power supplies (Fig. 1).

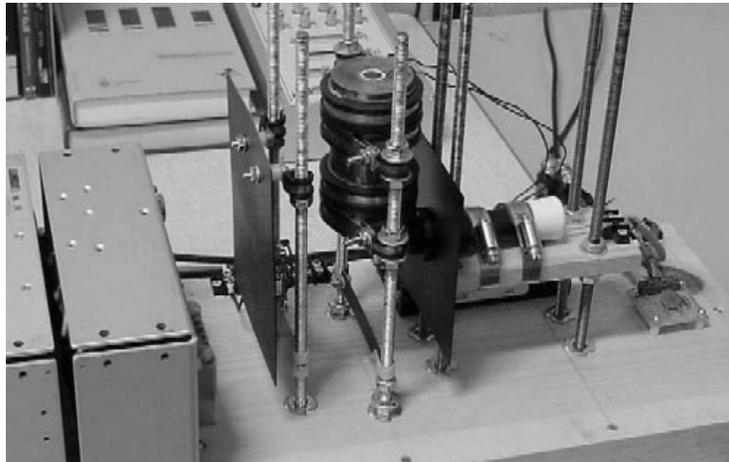


Fig. 1. Magnetic levitation test-bed

The system separates into two main sub-systems. The force actuation sub-system consists of an electromagnet coil with powder metal core, PWM power amplifier, and a 24 V DC power supply. The amplifier is powered by the DC power supply and based on its input control

signal sends a range of current through the coil. The position sensing sub-system consists of a photocell based sensor, incandescent light source, and 15 V DC power supply. This system operates by measuring light intensity as the levitated ball shields the light source opposite of the sensor (Fig. 2). To enhance the behavior of the sensor, a light shield with a vertical slit opening is placed around the photocell.

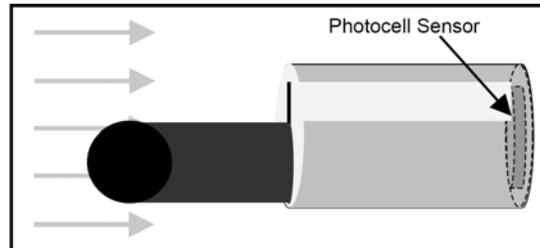


Fig. 2. Positions sensor operation

These sub-systems are mounted together on a base plate to form the test bed. This configuration allows for portability of the system and rigid but adjustable positioning of the components. The test bed interfaces input/output sensor signals with the dSPACE DS1104 controller board within a PC. Fig. 3 shows the basic system setup with physical sub-system interfaces.

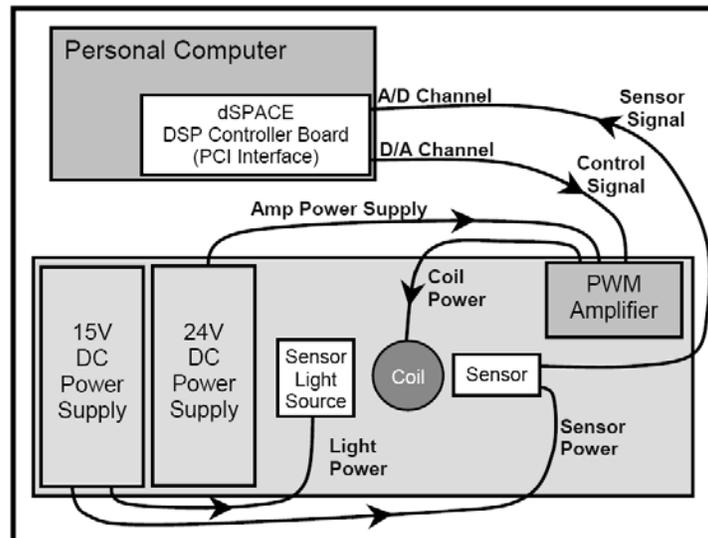


Fig. 3. Magnetic levitation system interface diagram

In order to design a suitable controller for the maglev system, the sub-system components must be modeled or characterized.

The sensor sub-system is modeled by measuring its voltage output as a light shield matching the ball's size moves vertically within the sensor range. Due of the small size of the photocell (~10 mm dia.) and nature of the sensor sub-system, the sensor's outputs remains linear for approximately 3 mm. Over a larger range, sensor readings become very nonlinear. The force actuation subsystem is modeled experimentally by measuring the forces applied to the ball as a function of the coil current and vertical ball position. This force is measured using an S-beam load cell. Within the small range of travel allowed by the sensor, magnetic force as a function of current is approximately linear. The plant model for the maglev system is just the ball mass under the influence of external forces.

Fig. 4 shows the basic control system setup of the magnetic levitation system. Its magnetic field creates an upward attractive force on any magnetic object placed below. A position sensor detects the vertical position of the object and passes this information to the controller. The controller then adjusts the current to the electromagnet actuator based on the object position to create a stable levitation.

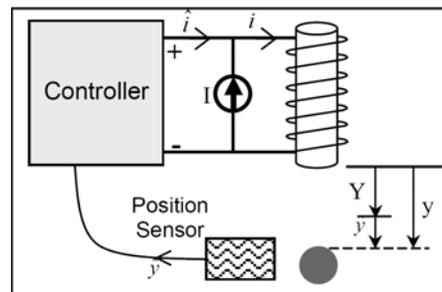


Fig. 4. Magnetic levitation system schematic

Using the force, plant, and sensor models discussed previously, a closed loop control system can be designed (Fig. 5). A lead-lag controller is chosen to stabilize the system. Using root-locus and frequency domain analysis, the controller is designed such that the settling time is ≤ 1.0 s and percent overshoot $\leq 50\%$. This linearized controller is able to hold the steel ball in stable levitation (Fig. 6) (Paschall II, 2002; Paschall II & Kim, 2002; Ambike et al., 2005; Kim et al., 2006).

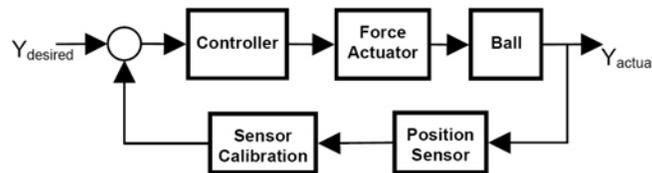


Fig. 5. Magnetic levitation system block diagram

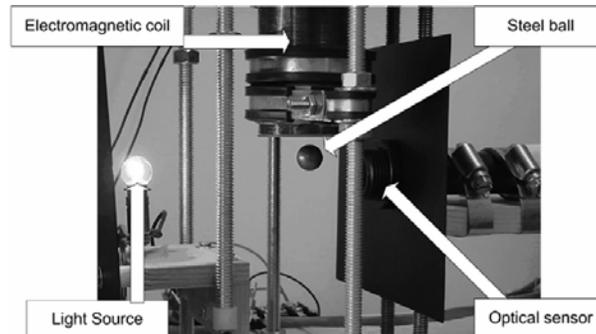


Fig. 6. Stable levitation of steel ball

2.2. ElectroDynamic Suspension (EDS)

Superconductors produce a supercurrent that creates a perfect mirror of a constant magnets poles. This mirror provides the magnet with a stable repulsion that causes the magnet to levitate called the Meissner effect. The superconductor, in order to have zero electrical resistance, must be cooled in liquid nitrogen. Without resistance the superconductor is able to mirror the constant magnet almost instantly. This allows the magnet to be able to spin, wobble, or bounce without the magnet shooting away or slamming to the ground (Fig. 7).



Fig 7. A sample of superconductor

Applying a voltage across a wire leads to an electric current in the wire. This electrical current has an analogy with a disk sliding down a board of organized pegs (Fig. 8) made famous in the popular game "Plinko" seen on the game show The Price-is-Right. The moving disk is analogous to an electron moving through a lattice of ions (the pegs). The gravitational pull on the disk when the board is tilted (which leads to the disk falling through the array of pegs) is analogous to applying a voltage difference to move electrons through a material. As the disk falls through the array, the disk scatters off the pegs and slows down, in analogy with the way that electrons scatter off the ions in a material. The electron scattering events lead to a resistivity - an intrinsic property of the material related

to the frequency of these scattering events which resist the flow of the electrons. Now, if we remove all the pegs, the disk will fall unimpeded. This unimpeded flow is exactly analogous to what happens when a material becomes superconducting - electrons no longer scatter. Some materials become superconducting below a critical temperature T_C , which is different for each material. A material which becomes superconducting below a certain temperature T_C has a resistivity which goes to zero below T_C and electrons flow unimpeded.

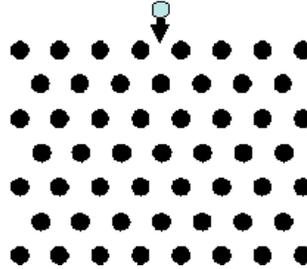


Fig. 8. A vertical peg board with stationary pegs (black circles). A blue disk falls and scatters through the lattice of pegs, analogous to electrons scattering off ions as they move through a wire, leading to resistivity.

Zero resistivity below T_C is the hallmark of superconductivity which was first discovered in 1911 by Kamerlingh Onnes for the element mercury below 4.2 K (Fig. 9). Not surprisingly, this discovery occurred three years after Onnes first liquefied helium in 1908. The majority of conventional superconductors have critical transition temperatures T_C below 10 K, and hence before the liquefaction of helium (boiling point of 4.2 K), there was no way to cool materials to cold enough temperatures to observe the superconducting phenomenon.

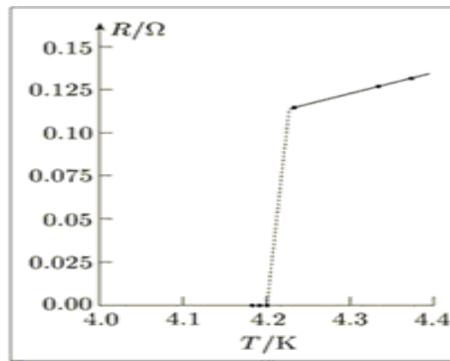


Fig. 9. Initial data from Onnes's resistance measurements on mercury showing a precipitous fall in resistance around $T_C = 4.2$ K

A second salient feature of superconductivity involves magnetic behavior known as the Meissner effect. When a magnetic field is applied over a superconductor at temperatures above T_C , magnetic field lines penetrate directly through the material just as magnetic fields penetrate through any standard material such as paper or copper. However, when the material is cooled through T_C and enters the superconducting state, magnetic field lines are expelled from the superconducting material (assuming a small enough magnetic field strength) (Fig. 10). This is what is known as the Meissner effect. Although the initial resistive properties of superconductors were discovered in 1911, the Meissner effect was not discovered until years later in 1933 by Meissner and Oschenfeld.

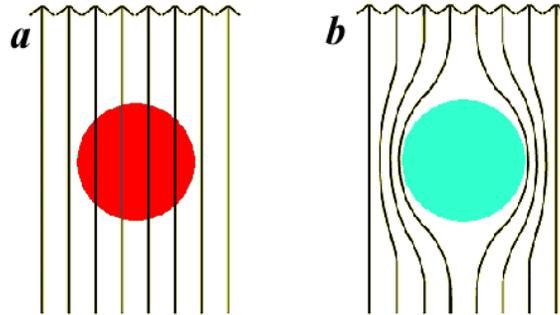


Fig. 10. a) Magnetic field lines penetrate through a superconductor at a temperature above its critical superconducting transition temperature ($T > T_C$). b) When the superconductor is cooled below its critical transition temperature ($T < T_C$), magnetic field lines are expelled from the interior of the superconductor due to the Meissner Effect.

A form of maglev called Diamagnetic levitation can be used to levitate light materials, water droplets and even live animals. It has been used to successfully levitate a frog in 2000. The magnetic fields required for this are very high, typically in the range of 16 tesla.

The Meissner effect corresponds to perfect diamagnetism for small enough magnetic fields. Diamagnetism is a property of many materials; when an external magnetic field is applied to a diamagnetic material, the diamagnetic material sets up its own internal magnetic field to partially cancel the externally applied field. The diamagnetic properties of water have been shown through impressive demonstrations where strawberries and frogs have been levitated in air above strong magnets (Fig. 11).

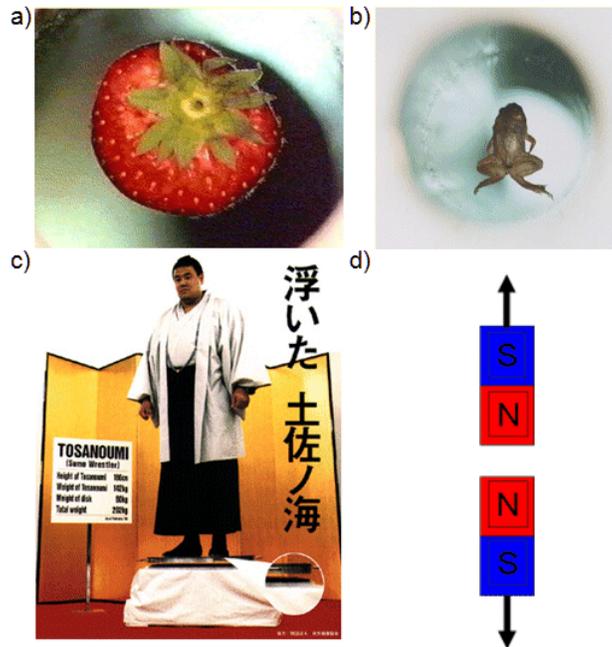


Fig. 11. a) A strawberry levitating in air in a strong magnetic field. The diamagnetic property of the water comprising the strawberry allows for this levitation. b) Similar to the strawberry, the frog contains enough water in its tissues to allow for its levitation in a strong magnetic field. c) Unlike the strawberry and the frog, the sumo wrestler is not levitated due to his composition of water. Instead, the sumo wrestler stands on a platform which is a strong permanent magnet disk. The cloth beneath the disk hides a superconductor cooled below its critical transition temperature. The sumo wrestler levitates due to the diamagnetic properties of the superconductor in the applied magnetic field of the disk platform. More information on these images available from HMFL. d) A conceptual way to visualize levitation and diamagnetism. If the one bar magnet represents the external field, the other magnet represents the diamagnetic response of a material where that material sets up a field in the opposite direction. We know there is a repulsive force between two bar magnets in this configuration. If the repulsive magnetic force is large enough to overcome the downwards gravitational pull on an object, then that object can levitate in air.

The macroscopic properties of superconductors have led to a number of applications - some in present use and some being developed for future use. Levitating strawberries and frogs are impressive but not particularly useful. However, superconductors are being used in the development of magnetic levitating trains, such as in the Yamanashi Maglev Test Line in Japan. The expectation is that trains will be able to reach higher speeds and utilize less energy if the trains move without friction - thus providing efficiency in travel time and energy usage. Utilizing superconducting wires with no resistance allows for the creation of "free" electromagnets. These magnets are free of the expense of supplying electrical power to

the magnet, which power is now required for all large magnets made of resistive wire. Indeed, if one were to take a loop of superconducting wire and were to set a current flowing in this wire, it would continue to flow virtually forever. A study conducted in 1962 found that the time for dissipation was well over 100,000 years. This means is that, unlike for a copper wire, one would not have to have a battery continuously connected to the wire to maintain the flow of current. Combining several of these superconducting wire loops on top of one another, one can create an electromagnet. Today superconducting wire is used in the electromagnets of medical MRI (Magnetic Resonance Imaging) machines. Utilizing a property of superconductors we have not yet mentioned and will not touch in the rest of this thesis, superconductors can also be used to create very sensitive magnetometers with the ability to measure very small magnetic fields (of order 10-15 Tesla). To illustrate the impressive nature of this measurement, these small fields are 20 billion times smaller than the earth's magnetic field. These magnetometers have been used in Magneto encephalography (MEG) which studies the magnetic fields generated by the human brain. Finally, superconductors can be used to store energy efficiently. The demand on power stations varies significantly during the course of a day with the smallest demand during the late evening and early morning hours. If during the times when demand is smallest, power stations could generate and then store energy without any dissipation, this would lead to increased efficiency and significant savings. General Electric and other companies are currently studying and developing small versions of this energy storage known as Distributed Superconducting Magnetic Energy Storage (D-SMES). A few of these systems are used at present as the technology continues to be developed. It seems that further progress will be needed because there is still a high cost associated with cooling the present superconducting systems. The hope is eventually to create better superconductors which do not need to be cooled to very low temperatures. Superconducting technology would then become widely applicable.

So far we have mentioned the salient macroscopic features of superconductivity (zero resistivity and the Meissner effect) as well as how those features can be used in technological applications. Both phenomenological and microscopic theories have provided insight into superconductivity. In 1957, Bardeen, Cooper, and Schrieffer formulated a microscopic theory of superconductivity (now known as BCS Theory) which could derive the macroscopic properties of superconductors starting from pairing of electrons below T_C . Due to the successes of this theory, the scientific community generally viewed superconductivity as a well-understood phenomenon. However, in 1986, this all changed due to a new discovery. BCS theory had predicted a general restriction on the maximum possible critical temperature, $T_{C, Max} \sim 28$ K. However, in 1986, Bednorz and Muller discovered a material (LaBaCuO) which enters the superconducting state below $T_C = 35$ K, a temperature above the BCS-restricted maximum. This was the first of a new class of superconductors known as "high-temperature" superconductors. A critical temperature T_C above the maximum T_C set by BCS theory indicates that something different occurs on the microscopic level. To this date, the microscopic mechanism for these superconductors is not known. The purpose of this thesis is to garner additional insight into these high-temperature superconductors on a microscopic level with the ultimate aim that this research will lead to a microscopic theory for high temperature superconductors. Understanding high-temperature superconductors has important technological implications, both because of the higher transition temperatures as well as the ability to carry larger currents than wires of

comparable size made out of copper. The higher transition temperatures mean that these superconductors can be cooled below their transition temperatures more easily than conventional superconductors. Liquid helium is the standard way to cool conventional superconductors below T_C . Liquid helium is both expensive and not widely available. More recent high-temperature superconductors have T_C s which are above 77 K, the boiling point of liquid nitrogen which is both widely available (for example in our breathable air) and inexpensive. The ability to push larger currents through high-temperature superconductors also has an advantage in terms of creating smaller wires as well as more powerful magnets.

Scanning tunneling microscopy (STM) is a powerful technique invented in 1981 by Binnig and Rohrer (Binnig et al., 1982). Because STM can probe materials on the atomic level, this technique naturally lends itself to the search for how high-temperature superconductors work on the microscopic level. The entirety of this thesis focuses on the application of STM to high-temperature superconductors and the insight this brings. This section is intended to give the non-physicist a glimpse of how STM works and the information it can provide.

In STM, we bring an atomically sharp tip a few angstroms from an atomically flat surface. An angstrom (\AA) is 10^{-10} meters, roughly the diameter of an atom. Applying a voltage between the tip and sample leads to a tunneling current flowing between the two (Fig. 12). This current is very sensitive to the tip-sample distance. A larger distance between the tip and sample leads to a smaller current. A tip - sample distance change of about 1 \AA leads to almost an order of magnitude change in the current, meaning that an STM is highly sensitive to very small changes in surface contours. Hence, as we scan the tip over a surface, the rises and falls in the surface topography (the rises and falls as we go over atoms) are easily captured.

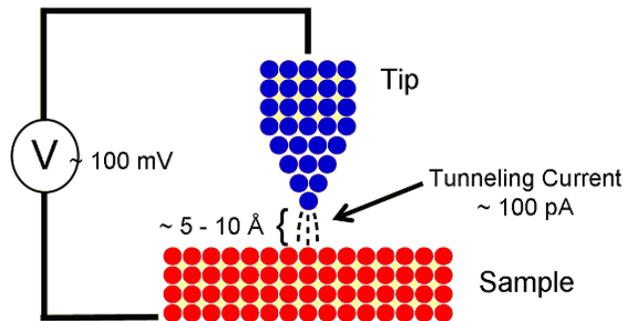


Fig. 12. A schematic STM setup. When a tip is brought several angstroms away from a sample and a voltage is applied between them, a very small current flows - of order 10^{-10} amperes - between the last atom of the tip and the sample. For comparison, a typical light bulb usually has a flowing current of order 1 ampere. Our tunneling current is roughly 10 billion times smaller. As we scan the tip over the surface, the rise and fall of the atomic landscape comprising the sample surface leads to changes in the current and hence to the STM's ability to image the surface (Fig. 13).

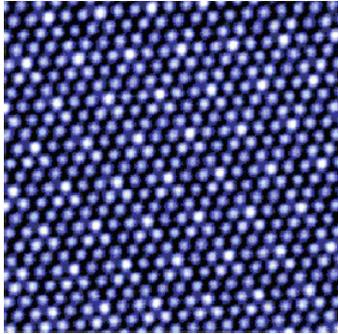


Fig. 13. A 70 Å-square scan taken by our custom-built STM over a material known as NbSe₂. Here we see the triangular lattice composed of selenium atoms. NbSe₂ is a superconductor below ~7.5 K and also exhibits another phenomenon known as charge density waves

Researchers are interested in studying this gap in the density of states of high-temperature superconductors, both as a function of position as well as of temperature. Because the STM has atomic resolution, they can study how this gap changes from one atom to the next. The STM has the ability to vary temperatures, and hence they can study how the density of states evolves with temperature both below TC and through TC. With the information from these studies, they gain insight into the superconducting state of high-temperature superconductors (Hoffman, 2003).



Fig. 14. Scanning tunneling microscopy (STM), a custom designed UHV, variable temperature scanning tunneling microscope, Eric Hudson Group



Fig. 15. Scanning tunneling microscopy (STM), a custom designed UHV, variable temperature scanning tunneling microscope, Eric Hudson Group



Fig. 16. Scanning tunneling microscopy (STM), the same custom STM, but adapted for room temperature biological applications, Eric Hudson Group

3. Magnetically Levitated Trains

Among useful usages of magnetic levitation technologies, the most important usage is in operation of magnetically levitated trains. Maglev trains are undoubtedly the most advanced vehicles currently available to railway industries. Maglev is the first fundamental innovation in the field of railroad technology since the invention of the railroad. Magnetically levitated train is a highly modern vehicle. Maglev vehicles use non-contact magnetic levitation, guidance and propulsion systems and have no wheels, axles and transmission. Contrary to traditional railroad vehicles, there is no direct physical contact between maglev vehicle and its guideway. These vehicles move along magnetic fields that are established between the vehicle and its guideway. Conditions of no mechanical contact and no friction provided by such technology makes it feasible to reach higher speeds of travel attributed to such trains. Manned maglev vehicles have recorded speed of travel equal to 581km/hr. The replacement of mechanical components by wear-free electronics overcomes the technical restrictions of wheel-on-rail technology. Application of magnetically levitated trains has attracted numerous transportation industries throughout the world. Magnetically levitated trains are the most recent advancement in railway engineering specifically in transportation industries. Maglev trains can be conveniently considered as a solution for transportation needs of the current time as well as future needs of the world. There is variety of designs for maglev systems and engineers keep revealing new ideas about such systems. Many systems have been proposed in different parts of the worlds, and a number of corridors have been selected and researched (Yaghoubi, 2008).



(a) Shanghai maglev train (SMT)



(b) Japanese MLX-01 maglev train

Fig. 17. Chinese and Japanese high-speed maglev trains

Maglev suspension systems are divided into two groups of ElectroMagnetic Suspension (EMS) and ElectroDynamic Suspension (EDS). There are varieties of vehicles that are manufactured based on these two types of systems. Vehicle path in EMS and EDS systems are called guideway and track, respectively. Basically, there are two main elements in a maglev system including its vehicle and the guideway. The three primary functions in maglev technology are levitation, propulsion, and guidance. Magnetic forces perform all of these. Magnets are used to generate such magnetic forces. For EMS systems, these magnets are located within the vehicle while for EDS systems magnets are located in the track. Performance of EMS system is based on attractive magnetic forces, while EDS system works with repulsive magnetic forces. In EDS system, the vehicle is levitated about 1 to 10 cm above the track using repulsive forces as presented in Fig. 18. In EMS system, the vehicle is levitated about 1 to 2 cm above the guideway using attractive forces as presented in Fig. 19. In EMS system, the electromagnets on the vehicle interact with and are attracted to levitation rails on the guideway. Electromagnets attached to the vehicle are directed up toward the guideway, which levitates the vehicle above the guideway and keeps the vehicle levitated. Control of allowed air gaps between the guideway and vehicle is achieved by using highly advanced control systems. Figs. 18, 19 show the components of the guideway and track, including beam and levitation and guidance systems in aforementioned maglev systems (Yaghoubi & Sadat Hoseini, 2010).

The guideway is the structure that maglev vehicles move over it and are supported and guided by it. Its main roles are: to direct the movement of the vehicle, to support the vehicle load, and to transfer the load to the ground. It is the function of the guideway structure to endure applied loads from the vehicle and transfer them to the foundations. It is the main element in maglev system and holds big share of costs for the system. It is vital for maglev trains (Behbahani et al., 2012). Maglev train levitates over single or double track guideway. Guideway can be mounted either at-grade or elevated on columns and consists of individual steel or concrete beams. Elevated guideways occupy the least amount of land on the ground. Moreover, with such systems there is guarantee of meeting no obstacle while along the route. To guarantee safety for maglev trains necessitates guarantee that there will be no intersection between guideway and other forms of traffic routes. To serve the purpose, general proposition is to have elevated guideways.

Guideway provides guidance for the movement of the vehicle, to support the vehicle load, and to transfer the load to the ground. In maglev guideways contrary to traditional railroad tracks, there is no need to ballast, sleeper, rail pad and rail fastenings to stabilize the rail gauge. Guideway consists of superstructures and substructures. A guideway consists of a beam (girder) and two levitation (guidance) rails. Guideways can be constructed at grade (ground-level) or elevated including columns with concrete, steel or hybrid beams. Maglev elevated guideways minimize land occupation and prevent collision with other forms of traffic at-grade intersections. Guideways are designed and constructed as single or double tracks (Fig. 20). Guideways can be U-shaped, I-shaped, T-shaped, Box, Truss and etc. Majority of cross-sections of guideway girders are also U-shaped. The rail gauges (track gauges) and spans are mostly 2.8 m and 24.8 m, respectively (Yaghoubi & Ziari, 2010).

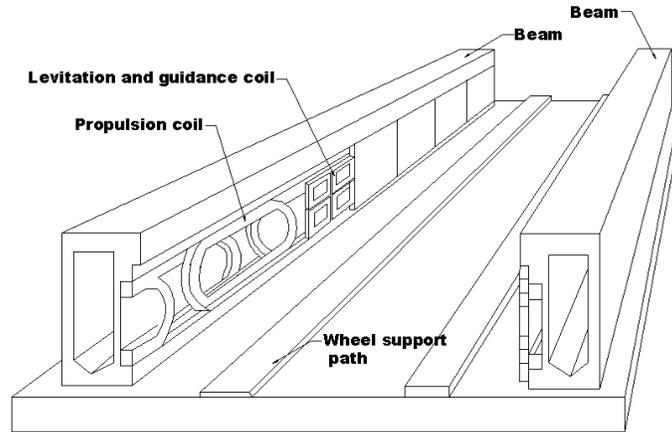


Fig. 18. Schematic diagram of EDS maglev system

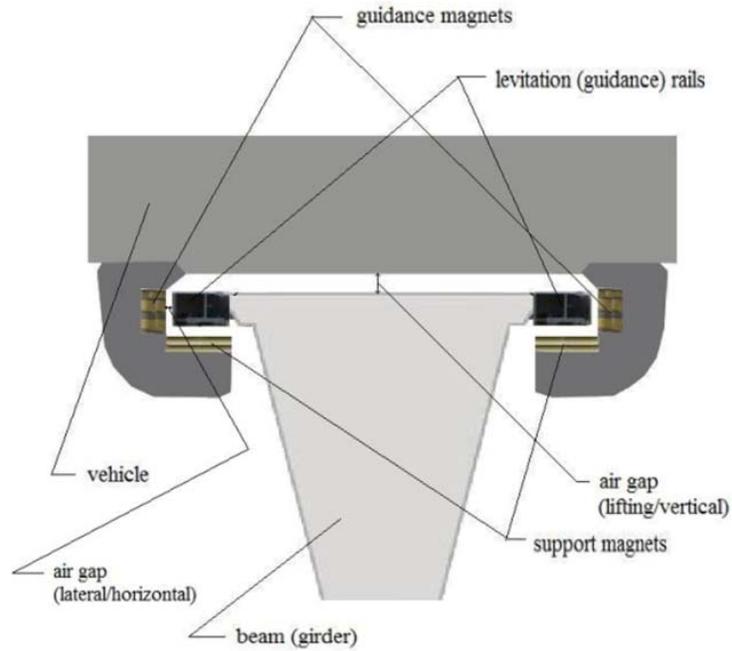


Fig. 19. Schematic diagram of EMS maglev system

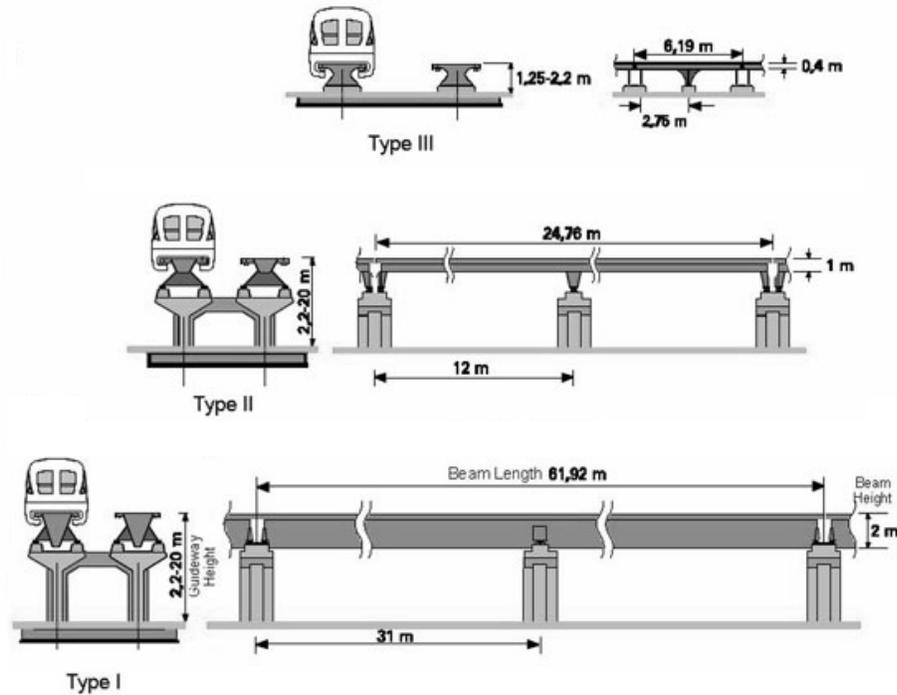


Fig. 20. Standard guideway types

The most important part in the analysis and design of guideway is structural loading. The loading of the maglev vehicle is an important parameter in the practical application. It is related to the magnetic forces (He et al., 2009). The guideway must carry a dead load due to its own weight, and live loads including the vehicle loads. To incorporate the dynamic interaction between the guideway and the vehicle, the live load is multiplied by a dynamic amplification factor. Lateral and longitudinal loads including wind and earthquake loads may also need to be considered. The guideway loadings are modeled as dynamic and uniformly distributed magnetic forces to account for the dynamic coupling between the vehicle and the guideway. As maglev vehicle speeds increase to 300-500 km/h, the dynamic interactions between vehicle and guideway become an important problem and will play a dominant role in establishing vehicle suspension requirements. Magnetic forces are generated by the maglev vehicle and cause structural loading that transmits to the guideway. This can happen whilst such a vehicle is stationary or in motion.

Guideways are designed and constructed with concrete or steel girders. Concrete guideway girders can be as reinforced or prestressed. Guideway girder is evaluated for different load cases. As example, the Shanghai guideway girder was evaluated with respect to as many as 14,000 load cases by consideration of the deflection, dynamic strength and thermal expansion. The guideway girder for Urban Maglev Program in Korea was also evaluated for five load cases that are combinations of the dead load, live load and the prestressing forces of the tendon (Yaghoubi & Ziari, 2011; Yaghoubi & Rezvani, 2011).

Maglev stations are centers for planning, traffic attraction, and preparing the fleet. They definitely play a key role in any maglev system. The annual increase in passenger numbers and increasing willingness to use maglev systems indicate the necessity of design for stations.

Maglev stations are centers for planning, traffic attraction, and preparing the fleet. They definitely play a very important and influential key role in any maglev system. The efficiency of maglev systems over the national and regional development depends on stations. The development hub of maglev systems mainly formed around the stations. Stations have emerged as a new central place in metropolitan cities. They have become hub of networks due to their high accessibility by different modes of transport in high scale level. They produce movements that offer sufficient opportunity for the development of commercial land use. Maglev stations provide regional and local intermodal connections, as well as national and international connections to passenger facilities.

Maglev stations are key regional transportation facilities designed to provide access for high volumes of passengers. The annual increase in passenger numbers and increasing willingness to use maglev systems indicate the necessity of design for stations. Maglev is a sophisticated surface transportation technology. Stations are designed to express the technological sophistication of the system. All station designs are planned to be consistent with buildings character in the area of operation or predicated on community standards of the local area where each station is located. The design should express fundamental aesthetic values of the maglev system. Aesthetic features of stations are intended to reflect intrinsic values of the maglev system, including advanced technology, movement, and speed (Yaghoubi & Keymanesh, 2012).



Fig. 21. Shanghai maglev station

Despite high speeds, passengers are safer in maglev vehicles than in other transportation systems. The electromagnetically suspended vehicle is wrapped around the guideway and therefore virtually impossible to derail. Elevated guideways ensure that no obstacles can be in the way. In order to prevent contact between the vehicle and the guideway and maintain the required gap between them, the system is continuously under Operation Control System (OCS) command. The Operation Control System (OCS) comprises all technical facilities for planning, monitoring and safeguarding of vehicle operation (Behbahani & Yaghoubi, 2010).

Rapid increase in traffic volume in transport systems plus the need for improving passenger comfort have highlighted the subject of developing new transport systems. The recent required increases in the traffic volume in transport systems, as well as a need for the improvement of passengers' comfort, and required reductions in track life cycle costs, have caused the subject of the development of a new transportation system. One of the important systems which have attracted industries is maglev transport system. In this regard, maglev transport system turns out to be a proper choice for transportation industries around the world. Maglev systems have been recently developed in response to the need for rapid transit systems. The maglev system comes off clearly better and surpasses the HSR systems in almost most fields. These include the pollution, noise emission, vibration level, environmental issues, land occupations, loading, speed, acceleration and deceleration, braking, maintenance costs, passenger comfort, safety, travel time, etc. With the maglev guideway it is also possible to reach to the minimal radiuses for the horizontal and vertical curves. A maglev vehicle can as well travel at the steeper gradients compared with the HSR systems. This considerably reduces the total length of track for the maglev routes compared to the HSR systems. The possibility of traveling with the higher grade angles also reduces the number of tunnels that are required to travel through the mountainous areas. This can also shorten the total length for the maglev route. Therefore, construction of the maglev routes in the hilly areas, in addition to many other advantageous of these systems, can be considered as an attractive choice for the transportation industries. The lower energy consumption of the maglev vehicles in comparison with the HSR systems is also among major characteristics of the magnetically levitated trains. This can be easily associated with the absence of the wheels and the resulting situation of no physical contact between the maglev vehicle and its guideway. Therefore, the energy loss due to the unwanted friction is out of the equations. Furthermore, the vehicle weight is lower due to the absence of wheels, axles and engine. On the other hand, reduction in the travel time considerably reduces the energy consumption. The limited energy resources that are currently available to the nation have highlighted the fact that every individual has to be the energy conscious. The government had to take steps, and it started by setting the preventative rules and the tightening access to the cheap energy resources. Clearly, the widespread application of the magnetically levitated trains for the public transport, in short and long distances, can provide the nation with huge saving in the energy consumption. This is not a fact that can be easily ignored nor can it be bypassed (Yaghoubi, 2011; Yaghoubi et al., 2011).

Germany and Japan are clearly the front runners of the maglev technology. German's Transrapid International (TRI), a joint venture by Siemens AG and ThyssenKrupp, with EMS system has presented ninth generation of its maglev vehicles namely TR01 to TR09. TRI has been investigating electromagnetic levitation since 1969 and commissioned TR02 in 1971. The eighth generation vehicle, TR08 operates on 31.5 km of the guideway at Emsland test track in northwest Germany. The contract for implementing the world's first Transrapid commercial line was signed in Shanghai in January 2001. Construction work of the Shanghai Transrapid line began in March 2001. After only 22 months of construction time, the world's first commercially operated Transrapid train made its successful maiden trip on December, 31 2002. On December, 2003, the world's first commercial Transrapid line with a five section train started scheduled operation in Shanghai. TR08 and TR09 vehicles are used for the Shanghai Maglev Train (SMT) and TR09 Munich project, respectively. TR08 consists of 2 to 10 car bodies. SMT consists of 5 car bodies and travels on a 30km double-track elevated

guideway, connecting the LongYang Road station (LYR), served by Metro Line 2 situated in the Pudong trade centre in Shanghai, to the Pudong International Airport (PIA). High-speed signifies operation of at least at $250_{\text{km/hr}}$. SMT has reached to the record speed of $501_{\text{km/hr}}$, a average speed (peak operating speed) of $431_{\text{km/hr}}$ and average speed of $268_{\text{km/hr}}$.

4. Flying Cars or Personal Rapid Transit (PRT)

SkyTran pods promise to bring maglev transportation to the skies. Each private pod, suspended from an elevated guideway, could carry three passengers and would use maglev technology to reach speeds of up to 150 mph. Theoretically, SkyTran could bring passengers anywhere they wanted to go along the route of the guideway, without making unnecessary stops for other passengers. The system could work using technology that is already available, and claims to be able to eliminate congestion while reducing carbon-dioxide emissions and dependence on foreign oil. NASA has shown an interest in this technology, and in 2009 it partnered with Unimodal (the creators of SkyTran) to evaluate advanced transportation software.



Fig. 22. Flying cars

5. Launching Rockets

A magnetic levitation track is up and running at NASA's Marshall Space Flight Center in Huntsville, Ala. The experimental track is installed inside a high-bay facility at the Marshall Center. Marshall's Advanced Space Transportation Program is developing magnetic levitation or Maglev technologies that could give a space launch vehicle a "running start" to break free from Earth's gravity. A Maglev launch system would use magnetic fields to levitate and accelerate a vehicle along a track at speeds up to 600 mph. The vehicle would shift to rocket engines for launch to orbit. Maglev systems could dramatically reduce the cost of getting to space because they are powered by electricity, an inexpensive energy source that stays on the ground - unlike rocket fuel that adds weight and cost to a launch vehicle.

The Foster-Miller experimental track accelerates a carrier to 57 mph at its peak traveling 22 feet in 1/4 second, the equivalent of 10 times the acceleration of gravity. The tabletop track is 44 feet long, with 22 feet of powered acceleration and 22 feet of passive braking. A 10-pound carrier with permanent magnets on its sides swiftly glides by copper coils, producing a levitation force. The track uses a linear synchronous motor, which means the track is synchronized to turn the coils on just before the carrier comes in contact with them, and off once the carrier passes. Sensors are positioned on the side of the track to determine the carrier's position so the appropriate drive coils can be energized. Engineers are conducting tests on the indoor track and a 50-foot outdoor Maglev track installed at Marshall last September by NASA and industry partner PRT Advanced Maglev Systems Inc. of Park Forest, Ill. The testing is expected to help engineers better understand Maglev vehicle dynamics, the interface between a carrier and its launch vehicle and how to separate the vehicle from the carrier for launch. Future work on large systems will be led by NASA's Kennedy Space Center, Fla. Rockets of the future might be launched using a Magnetic Levitation (Maglev) launch track similar to the test track recently built at NASA's Marshall Space Flight Center in Huntsville, Alabama.

A Maglev system uses magnetic fields to levitate and accelerate a vehicle along a track. Similar systems are in use today as high-speed trains and some of the newer, radical-ride roller coasters. Maglev systems use high-strength electro-magnets to lift a vehicle a few inches above a track and then propel it forward with high acceleration. By using a Maglev for launching, the spacecraft would be accelerated up to speeds of 600 mph (965 kph) without using any on-board fuel. When the spacecraft nears the end of the track, it could take off like an airplane and then switch to more conventional rocket engines to continue to orbit. The weight of propellant is a major culprit in the high cost of conventional rocket launches. But because Maglev uses off-board electricity for launch assist, the weight of the vehicle at liftoff is about 20% less than a typical rocket. This makes getting to space less expensive.



Fig. 23. Different technologies to push a spacecraft down a long rail have been tested in several settings, including this Magnetic Levitation (Maglev) System evaluated at NASA's Marshall Space Flight Center. Engineers have a number of options to choose from as their designs progress. Photo credit: NASA

The test track at Marshall, which is 50 feet (15 meters) long, about 2 feet (0.6 meters) wide and about 1.5 feet (0.5 meter) high, is mounted on concrete pedestals. It consists of 10 identical, 5-foot-long (1.5 meter) segments that weigh about 500 pounds each. Most of the weight is iron used in the motor. The track is shrouded with nonmagnetic stainless steel. Some time in future, a larger 400-foot (122 meter) track will be installed at Marshall.

The space tourism company Galactic Suite already has 38 reservations made by tourists who, the company says, in 2012 will travel on board a magnetically levitated spacecraft to an orbiting luxury hotel, complete with a floating spa. The trip, which costs 3 million Euros, will provide four days in orbit 450 kilometers above the earth and includes 18 weeks of training on a Caribbean island for the tourists to prepare for their spaceflight. The Galactic Suite Spaceport is being built on the island and features the first maglev rocket where the spacecraft will accelerate to speeds up to 1,000 km/h (620 mph) in 10 seconds and lift off from a vertical runway.

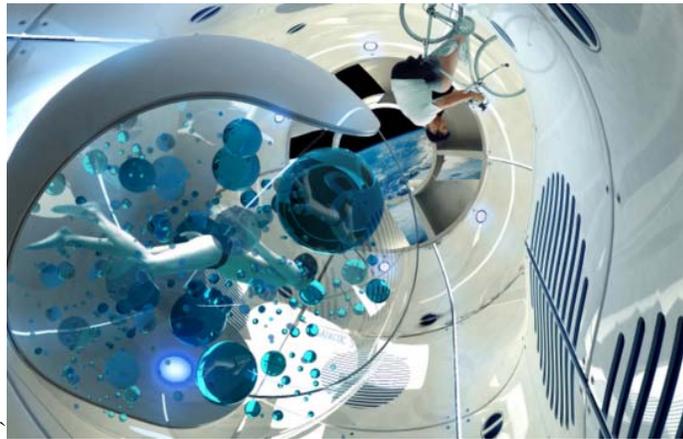


Fig. 24. Space Spa on Galactic Suite Hotel. Credit: Galactic Suite

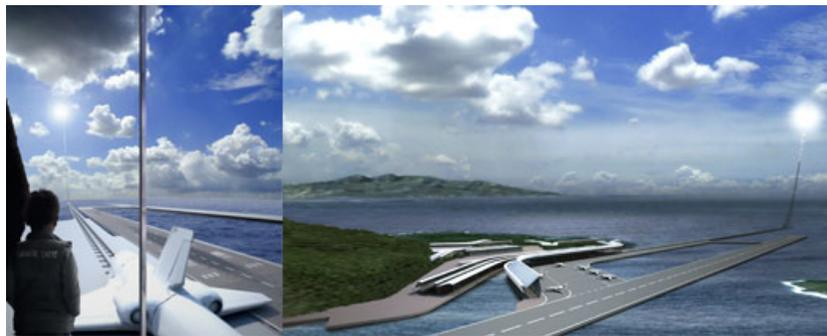


Fig. 25. Galactic Suite Spaceport. Credit: Galactic Suite

After reaching approximately the speed of sound, the spaceship will detach from its maglev carrier and accelerator, and will ascend to orbit using rocket or air-breathing engines. The maglev accelerator will then brake to a stop and return to its starting point for the next launch. The launch track will be about 3 kilometers long. Maglev launch assist technology will enable space tourists to travel to our space resorts in orbit on a commercial basis. The most expensive part of any space travel to low-Earth orbit is the first few seconds – getting off the ground. This technology is cost competitive with other forms of space transportation, environmentally friendly and inherently safety. The stay at the hotel will offer a mixed programme of reflection and exercise to seize the unique physical conditions encountered in space. One of the most innovative experiences that tourists can experience is the bathroom in zero gravity. Galactic Suite has developed the space spa. Inside the spa, tourists can float with 20 liters of water bubbles. According to Galactic Suite materials, the tourist, already trained to avoid the effects of water in a state of weightlessness, can play with the bubble dividing it into thousands of bubbles in a never-ending game. In addition, the transparent sphere may be shared with other guests. Galactic Suite is a private space tourism company, founded in Barcelona in 2006. The company hopes to make space tourism available to the general public and will combine an intensive program of training astronauts to relax with a programme of activities on a tropical island as a process preparation to space travel.

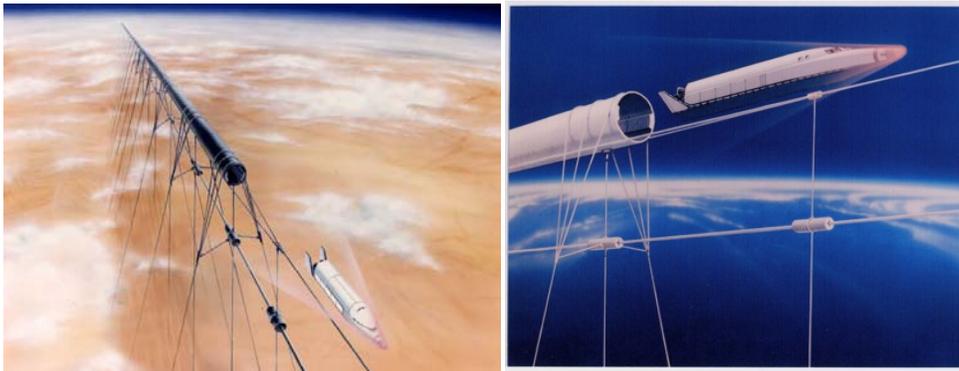


Fig. 26. Travel into space with maglev

The launch ring consists of a maglev system in which a levitated vehicle is accelerated in an evacuated circular tunnel until it reaches a desired velocity and then releases a projectile into a path leading to the atmosphere. So far, the chemical rocket has been the only technology that mankind has successfully used to move people and material from the Earth's surface into low-earth orbit and beyond. The cost of this technology, even with partially reusable rockets, has remained sufficiently high that its use has remained limited. There is general acceptance that a lower cost alternative to rockets would greatly increase the volume of traffic to space (Hull et al., 2006; Fiske et al. 2006).

The space elevator is probably the best-known proposed alternative technology to rockets. The usual contemporary design concept for a space elevator is based around a mechanical

cable extending radially inward and outward from a geosynchronous orbit, usually with a counterweight at the outer radius and with the innermost part of the cable attached to the ground at the equator. An elevator car can then attach to the cable and ferry people or material up or down. Unfortunately, currently available materials are not strong enough to support their own weight in a constant-cross-sectional-area cable from an earth geosynchronous location to the earth's surface. In principle, such a cable can be constructed by tapering the cross section from a small diameter at the ends to a very thick diameter at the geosynchronous point. In practice, the strength of presently available engineering materials makes the mass of such a cable uncomfortably large. Other types of proposed space-elevator concepts that could provide access to low Earth orbit include a high-Jc superconducting cable that can self-levitate in the Earth's magnetic field (Hull & Mulcahy, 2001; Hull et al., 2002) and a massive ring rotating in a vertical plane such that the centrifugal force of the ring counters the gravitational force in the upper part of the orbit.

Another generic type of alternative consists of accelerating a projectile to high velocity at the Earth's surface. These "gun" concepts include railgun, coilgun, electrothermal-chemical gun, light-gas gun, RAM accelerator, and blast-wave accelerator (McNab, 2003). Most gun concepts involve short acceleration times, and the subsequent large power supplies to boost even modest masses to the required velocity are likely to be expensive. Electromagnetic launch has been proposed to give rockets an initial velocity component, with most of the required velocity provided by combustion of the propellant (Schultz, 2001). Ground-based, high-powered lasers that augment the chemical energy of rocket propellant will also likely require large power supplies (McNab, 2003).

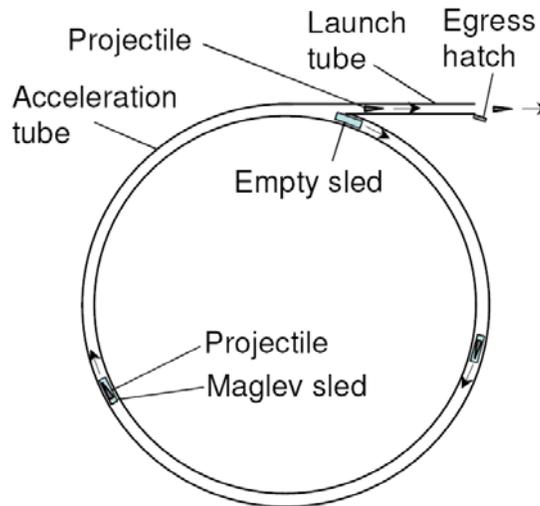


Fig. 27. General launch-ring concept

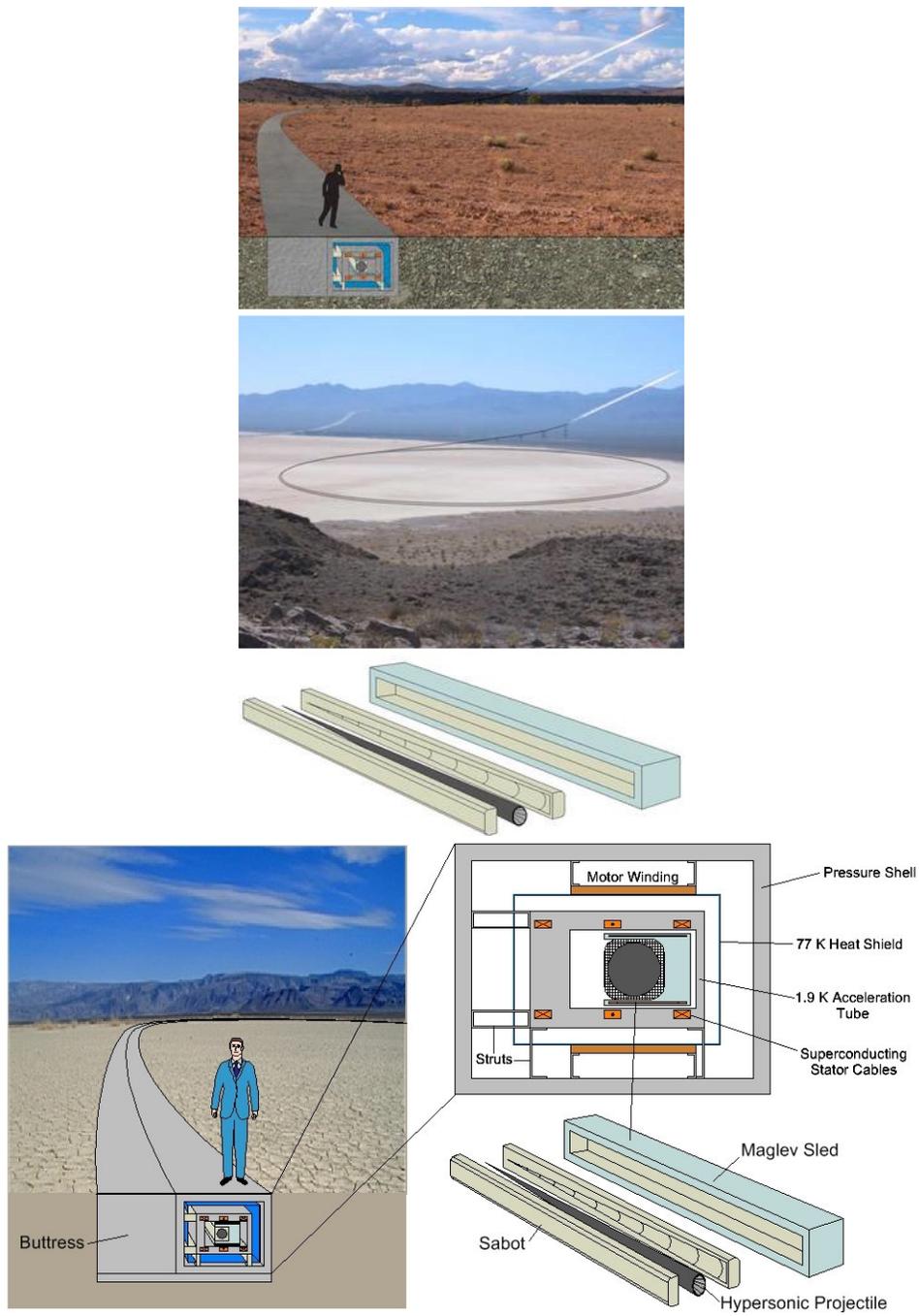


Fig. 28. SCS Launch ring

6. Magnetic Bearings

Magnetic levitation is not just for far-out technologies; it is already being used in down-to-earth applications. Industrial equipment such as pumps, generators, motors, and compressors use levitation to support moving machinery without physical contact. The same bearings used to support maglev trains are used in electric power generation, petroleum refining, machine-tool operation, and natural gas pipelines. These bearings also eliminate the need for lubrication, which is important in machines where lubricants can be a source of contamination, or in evacuated tubes where lubrication would fail. Magnetic bearings tend to be complex and custom-tailored to the machine. These low-friction parts could play increasingly important roles in industrial applications.



Fig. 29. Magnetic bearings

Magnetic bearings use magnetic fields to levitate spinning rotors and other components. Consequently there is no contact, essentially zero friction or drag, and no wear. Magnetic bearings are used in energy storage flywheels to enable ultra high-speed operation in a vacuum, in blood pumps to enhance reliability and biocompatibility, and in machine tool spindles for research and in micro-positioning. Magnetic bearings are designed using electromagnets and permanent magnets. Electromagnet-based bearings are referred to as Active Magnetic Bearings. Coil currents are feedback controlled in order to accomplish stable levitation. This feedback control enables active damping of rotor vibration and very stiff support at the cost of sensors and the electronic control system. The maximum load of active magnetic bearings is limited by the saturation flux density of the iron used. A common rule of thumb for load is 100 psi times the cross sectional journal area in square inches. Thus for a 2 inch diameter bearing occupying 2 inches axially on a rotor, the peak load is approximately 400 lbs. The load can be increased significantly through design optimization and the use of cobalt-based ferrous materials. Permanent magnet bearings are comprised of cylindrical arrays of permanent magnets. Permanent magnet bearings are compact and inexpensive, but they have roughly half the load capability (50 psi times the cross sectional journal area in square inches). At additional cost, Halbach arrays can be used in permanent magnet bearings to increase the load capability to about 90 psi. Permanent magnet bearings have little inherent damping, are lower in stiffness than active bearings, and are unstable in the axial direction. The axial instability is usually controlled with an active magnetic bearing as in design for blood pumps.

7. Maglev Wind Turbine

Standard wind turbines convert only 1 percent of wind energy into usable power, and part of that glaring inefficiency stems from the loss of energy due to friction as the turbine spins. Researchers at the Guangzhou Energy Research Institute have estimated that magnetically levitated turbines could boost wind energy generation by as much as 20 percent over traditional turbines. The researchers proposed using a colossal turbine with vertical blades that are suspended above the base of the turbine using neodymium magnets. Because the moving parts would not touch, the turbines would be virtually frictionless and could capture energy from winds as slow as 1.5 meters (5 feet) per second. Maglev turbines could lower the price of wind energy to less than 5 cents per kilowatt-hour, which is on par with coal-generated electricity and only about half the typical cost of wind power. The researchers say that a 1-gigawatt maglev turbine may require 100 acres of land, but it could supply electricity to 750,000 homes. In comparison, it would cost much more to build a wind farm of similar capacity using traditional turbines, and it would require 64,000 acres of land to house the 1000 turbines.



Fig. 30. Maglev wind turbine

8. Maglev Fan

The maglev fan provides superior performance, low noise and long life. By using magnetic levitation forces, these fans feature zero friction with no contact between shaft and bearing. With excellent rotational stability, the maglev fan eliminates vibration and typical wobble and shaking typically experienced in fan motors. The maglev fan also provides excellent high temperature endurance that results in long life. And, the maglev fan models also feature all-plastic manufacture of major items for optimal insulation resistance and electrostatic discharge (ESD) performance. The maglev fan offers a true solution to equipment and systems cooling, with the promise of lower cost of ownership and long service life. The maglev fan overcomes the problems of noise, abrasion, and short service life

that beset traditional fan motors. The maglev motor fan features zero friction and no contact between the shaft and bearing during operation. The maglev fan design is based on magnetic principles and forces that not only propel the fan but also ensure stable rotation over its entire 360 degrees of movement. Utilizing the attraction of the magnetic levitation force, maglev eliminates the wobbling and shaking problems of traditional motor fans. With this new technology, the maglev fan propeller is suspended in air during rotation so that the shaft and bearing do not come into direct contact with each other to create friction. The result is a new and improved fan with a low noise level, high temperature endurance, and long life. Maglev fans can be used in various industries and products that require high-level heat transfer, such as notebook computers, servers, projectors, and stereo systems. Traditional fans apply the principle of like-pole repulsion to rotate. But with no control exerted over blade trajectory, the fan blades tend to produce irregular shuddering and vibrations. After long-term use, the shaft will cause severe abrasion on the bearings, distorting them into a horn shape. The worn-out fan then starts to produce mechanical noises and its life-time is shortened. The unique feature of the maglev fan is that the path of the fan blades during operation is magnetically controlled. The result is that the shaft and bearing have no direct contact during operation and so experience no friction no matter how the fan is oriented. This means that the characteristic abrasion noises of worn-out components are not produced and also allows a service life of 50,000 hours or even longer at room temperature.

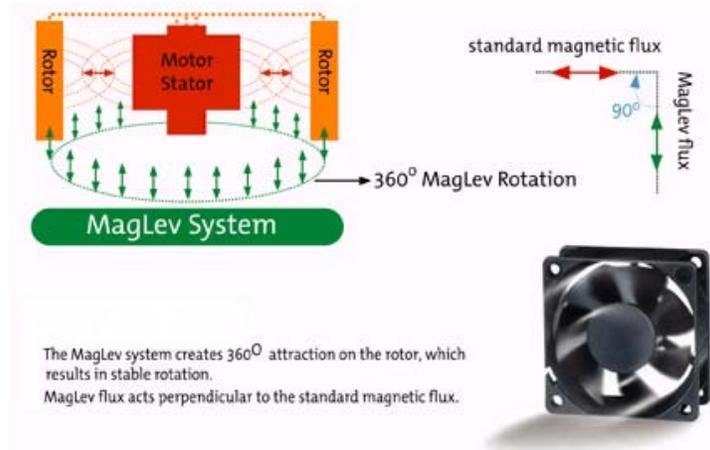
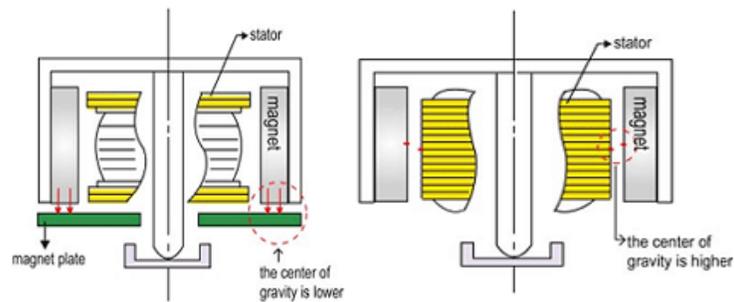


Fig. 31. Maglev fan

In a traditional fan, the embedded magnets of the rotor and the stator exert repulsive forces, and it is this continuous force of repulsion that makes the fan spin. This is the basic principle behind all cooling fans. If we visualize the magnetic forces between the stator and the rotor, we see only dense lines of standard magnetic flux running without any control mechanism to stabilize vibration of the blade rotor during the repulsion-driven operation. The maglev fan includes just such a control mechanism in its design. This requires that each fan, in addition to standard magnetic flux, contains maglev flux required to sustain for the unique maglev orbit in its design. A maglev cross-section view reveals a uniquely designed set of conductive elements on the main board-the maglev plate. This maglev plate and the

embedded magnets in the fan blades together generate comprehensive vertical magnetic forces, which is the maglev flux. From the cross-section, the standard magnetic flux and maglev flux form a 90-degree vertical angle, in others words, the maglev flux acts perpendicular to the standard magnetic flux. This is the first key trait to use to identify a maglev fan. The design of vertically intersected standard magnetic flux and maglev flux ensures that the rotator is affixed to the maglev orbit. Therefore, regardless of the mounting angle the fan, the shaft will always rotate around a fixed point and at a constant distance from the bearing without coming in contact with it to produce friction or mechanical noise. The problem of bearings being worn down into an oval shape or horn aperture after long use is effectively resolved. The greatest benefit with maglev flux is in fact the 360-degree complete force of attraction between the conductive element (maglev plate) and the rotor above it. This ensures an evenly-distributed force of attraction to help keep the optimal balance of the rotor during operation and to avoid shuddering or instability. Fans with well-balanced blades not only last longer but produce a steady air flow. In short, the second easy trait for identification of the maglev fan is that the maglev system creates 360° attraction on the rotor, which results in stable rotation.



(A) Maglev Fan	(B) Traditional Fan
<p>Possesses 3 important factors: the magnet plate, the magnet and the stator. The resulting interaction between the magnet plate and the magnet pulls the rotor downward in a full 360-degrees. Through the lower center of gravity, the rotor runs stably in a consistent orbit.</p>	<p>2 factors: the magnet and the stator. The conventional fan utilizes a deviating magnetic center to attract the rotor downwards. This kind of technology causes the rotor to vibrate violently due to both the lack of a consistent orbit and a deviation of the magnetic center.</p>

Fig. 32. Comparison between maglev fan and traditional fan

In the traditional DC brush-less fan motor design, the impeller rotor (simply called Rotor) by means of a shaft which extended through the bore of oil-impregnated bearing, or Sleeve bearing, pivotally held in the center position of motor stator. A suitable air gap was maintained between the rotor and the stator. Of course, there must be gap between shaft and bearing bore, otherwise, the shaft would be tight-locked and unable to rotate. The stator assembly (simply called stator) after connected to power supply will generate induced magnet flux between rotor and stator. With the control of driving circuitry the fan motor

will start to rotate. In a traditional fan motor structure, there is an impeller rotor, a motor stator and a driving circuitry. The rotor is pivotally joined to the stator by the rotor shaft and bearing system. The rotor is driven to rotate by the induced magnetic field between stator and rotor as shown in Fig. 33.

Advantages of Sleeve Bearing

- More impact-resistant, less damage resulted during delivery.
- Sleeve bearings cost much lower in comparison with ball bearings.

Imperfections of Sleeve Bearing

- Dust from outside may penetrated into bearing and mix with nitride particles to clog the motor, which may result in noise and much slower operation of the motor. The inner surface of bearing bore easily gets worn and influences the performance. The space between the shaft and sleeve-bearing bore is small this results in rough uneven start-ups.

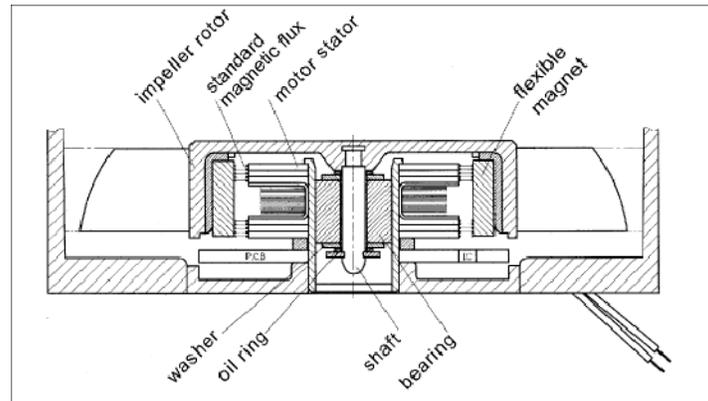


Fig. 33. Sleeve bearing

Ball bearing workings utilize small metal balls for rotation. Since they have only point-contacts rotation can be started easily. With the use of springs to hold the outer metal ring of the ball bearing above, the weight of the entire rotor can sit on the ball bearing, indirectly supported by the springs. Therefore, ball bearings are ideal for use in portable devices with various mounting angles. However, caution should be used to prevent the product from falling and impact damaging the ball bearing, which could lead to noise and shortened product life-time.

Advantages of Ball Bearing

- Steel ball bearings have an operating life much longer than that of sleeve bearings.
- However, the product must avoid rough handling or being dropped on the ground.

Imperfections of Ball Bearing

- Ball bearings are quite weak. It cannot bear any external impact.
- When the fan motor is operating, the steel balls inside will generate a higher rotational noise than that of a sleeve bearing.
- High price makes it uneasy to compete with sleeve bearings.
- Limitation on both supply sources and supply quantities make it unacceptable for mass production needs.
- The use of tiny assemblies such as springs, result in inefficiencies for mass production.

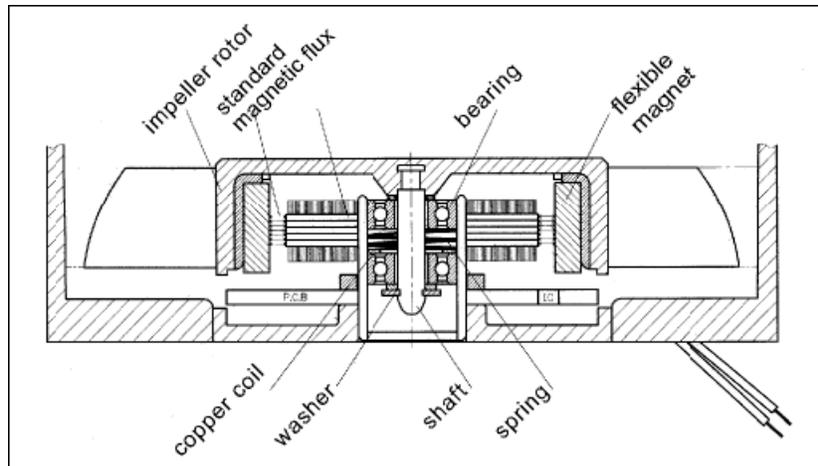


Fig. 34. Ball bearing

When a spinning top (a kind of toy) is thrown, the top continues to accelerate even as it hits the ground. During this acceleration the top tilts and sways until a consistent speed is obtained. At this point, the top will balance itself - e.g. the swaying and tilting have faded - and has become fixed perpendicular to the ground. This is the simple concept that maglev fan system roots form.

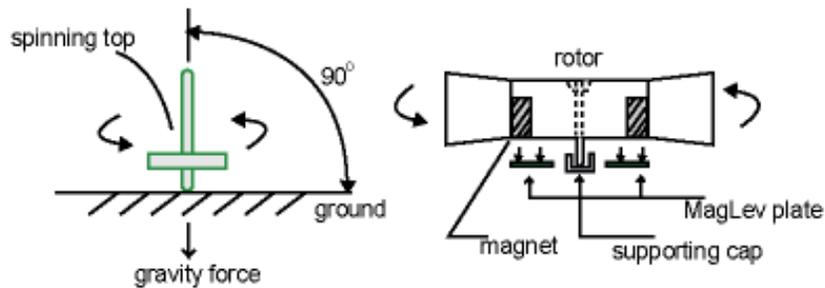


Fig. 35. Performance of maglev fan system roots

From the illustration above, we know that no matter how the motor fan is mounted, the force induced by the existing magnet inside the hub and the magnetic plate that is added to the PCB of the fan attracts the rotor continually. This results in the rotor rotating perpendicular to the ground with a constant distance between bearing and shaft without any contact. Therefore, no rubs or noise can occur. The operating life of the motor fan is extremely long.

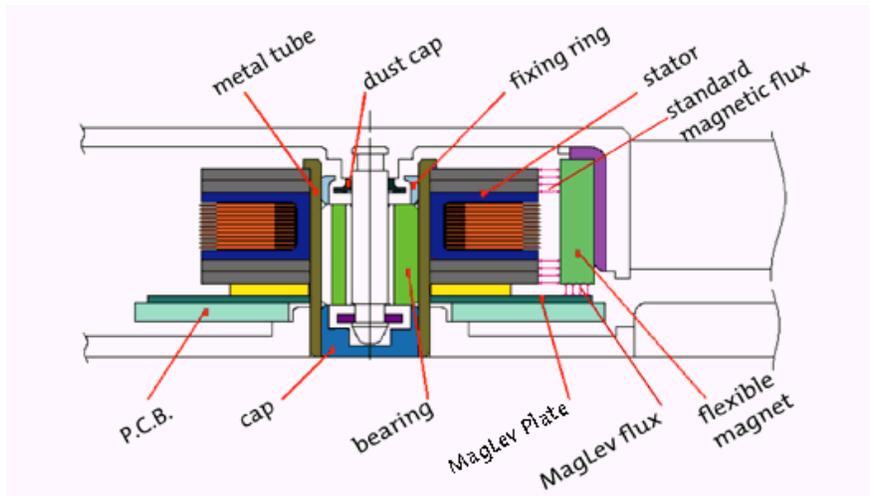


Fig. 36. Vapo bearing

1- Maglev system helps the impeller to rotate evenly in a fixed orbit within the orbit center. Consequently, the shaft inside the Vapo bearing bore turns without creating friction. The bearing bore is hardly ever abraded into irregular or oval shapes such as seen in conventional fans. Hence the operating life of the bearing becomes very long.

2- The shaft inside the bearing bore is in friction with nothing except air, the fan motor starts up easily.

3- This new system removes the use of oil rings and washers, thus leaving space for the release of gas occurred during normal operation. No more clogging problems. Hence, the fan motor may operate smoothly for quite a long time.

4- The use of magnet flux and supporting cap creates the same function as ball bearing, therefore, no matter how the fan is placed, no slanting and wobbling occurred, which means it's suitable for design in portable applications.

5- Vapo bearings are made of a material specially treated for wear-resistance and impact-resistance. When used in conjunction with the maglev, it creates a spring function, which helps the fan motor to bear impact.

6- Vapo bearing with maglev is capable of an operating temperature of more than 70°C. It also performs very well in a low temperature environment.

7- The elimination of washer and oil ring may also allow the automatic production thus brings manufacturing efficiency.

8- The dust cap prevents dust penetrating into bearing and mixing with nitride particles to clog the motor, which may result in noise and slower motor operation.

With the combination of maglev design and Vapo bearing, all the advantages of ball and sleeve bearings are maintained, while eradicating all the imperfections.

Vapo Bearing:

- Vapo bearings are made of a material specially treated for wear-resistance and impact-resistance. When used in conjunction with the maglev, it creates a spring function, which helps the fan motor to bear impact.

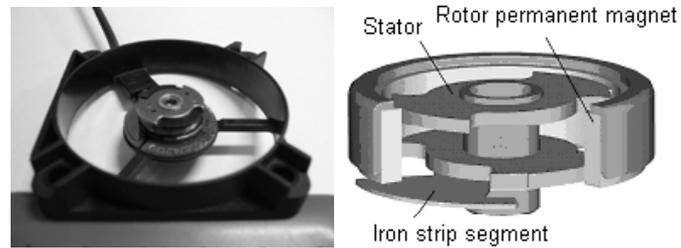
- Maglev design helps the rotor to rotate evenly in a fixed orbit within the orbit center without any friction with the bearing bore. No vibration occurred.
- This new system eliminates the use of oil rings and washers, thus leaving space for the release of gas occurring during normal operation. No more clogging problems. Vapo bearing is named after this character.

	Deficiencies of traditional motors	Maglev fan solution
SleeveBearing	<ul style="list-style-type: none"> - Weight of rotor is entirely loaded on to the shaft. Abrasive rotation between shaft and bearing will result in an irregular and rough surface on the inner surface of bearing bore. The fan motor rotation becomes uneven and in turn, causes operational noise and shortens fan life. - The oil ring and mylar washer not only results in added friction area but also blocks the high temperature gases, which if not released before solidification, would become nitride particles that, in turn, clog in the gap between shaft and bearing bore then causing a much slower rotation of rotor and noise. 	<ul style="list-style-type: none"> - Entire weight of rotor is completely attracted by magnetic force in any mounted position, keeping the motor rotating evenly at a fixed point and keeping a consistent distance from inner surface of the bearing. No more traditional rubs and noise occur. - Oil ring, washer, and lubricant no longer used in maglev structure. Hence no more oil leakage or stuck rotor problems.
BallBearing	<ul style="list-style-type: none"> - When the fan motor is operating, the steel balls inside will generate a higher rotational noise than that of a sleeve bearing. - The construction of Ball bearings is quite weak and unable to absorb external impact. It is easily damaged and results in louder rotational noise. 	<ul style="list-style-type: none"> - Maglev design allows an operating temperature higher than 70°C.

Table. 1. The defects of conventional fans

There is no friction and contact between the shaft and the bearing during operation. They have become favorite due to its superior features such as low noise, high temperature endurance and super long life.

The axial-flow radial-flux permanent magnet motor along with an iron strip segment, as shown in Fig. 37, has been used for small-power cooling fan applications (Hornig, 2003). This motor is equipped with only one set of axial stator winding that can supply the desired radial flux through adequate stator pole design, and such structure design is quite promising for applications with limited spaces. With the undesired vibration forces mainly generated in the motor radial direction, the concept is to provide adequate flux path such that a passive magnetic suspension can be established. As can be observed from Fig. 37(b), the magnetic fluxes generated from the motor stator winding will first flowing through its stator center shaft, getting out of the stator pole pairs at its top/bottom part, and then coming back to the bottom/top part stator pole pairs after passing through the corresponding rotor magnets. With the pole pairs on the stator top and bottom parts being perpendicular to one another, undesired vibration forces mainly generated in the motor radial direction will be exhibited. The resultant frictions applied onto motor bearing system will certainly generate extra heat and energy losses, and thus reduce the reliability and lifetime of this motor (Liu et al., 2004a, b).



(a) Photograph of the stator base.

(b) Conceptual structure of the motor.

Fig. 37. An axial-flow radial-flux permanent magnet motor with a stator iron strip segment

The major concerns on cooling fan motor manufactures are low construction/maintenance cost and high operational Reliability (Gieras & Wing, 2002). In addition to satisfy these construction prerequisites, it is also desired that the overall performance of such motors can preserve their market competitions without implementing complicate sensor and driver control devices. A magnetic suspension will be established through the extra flux path being provided. Though it is anticipated that the attraction force between the rotor permanent magnet and the passive magnetic suspension segment will be induced to stabilize the rotor vibrations, intuitively it is also suspected that this segment with high permeability might yield the motor rotational performance (Liu et al., 2004 b).

9. Maglev Heart Pump

Heart failure is one of the mainly cause of death. Treatments of heart failure generally have heart transplantation, ventricular mechanical assistance, artificial organs substitution and so on. Although heart transplantation is a relatively nature technology, but there is a serious shortage of donated hearts, and will result in transplant rejection reaction. The support of traditional artificial heart pumps often use rolling or sliding bearings. Because of the contact between bearing and blood, the blood will be polluted and easily produce thrombosis. With the development of maglev, motor and control technology, artificial heart pump overcome the problems such as friction, sealing and lubrication, which reduce the damage of blood cells, and improved the heart pump life and safety.

Artificial heart pump requires small structure, low energy consumption and certain stiffness and damping for transplanting and long time using. A hybrid-type axial maglev blood pump not only has small size, almost no energy, and poor dynamic characteristics of permanent magnet bearing but also has low power consumption, long life and good dynamic characteristics of magnetic bearing.

Artificial heart pump (also known as blood pump) can be divided into displacement, pulsating, and continuous-flow heart pump. The bionic performance of pulsating pump is good but its disadvantages is relatively large volume, and will be prone to hemolysis because it has big blood contact area. These shortcomings seriously restricted its application. Continuous-flow artificial heart pump can be divided into axial flow pump, centrifugal pump and mixed flow pump. Maglev centrifugal heart pump have a greater pressure in a small flow rate, and has fewer destruction to blood in low speed, while its disadvantage is

not suitable for implantation; the axial maglev heart pump has a big flow rate, low pressure, which need increase speed for obtaining much greater pressure. But axial flow pump has a tight structure, smaller drive components, low power consumption, light weight, high efficiency, etc. so it is easier to implant, and can save the cost of the surgery and the possibility of infection. But its impeller has a high speed and its hemolytic is also high. Either axial or centrifugal, the traditional supports are contacted bearings such as ceramic bearing, there are some problems about friction, lubrication and sealing which is easy to damage the blood, leading to hemolysis and blood clots. The magnetic bearing avoid contact of rotor and stator by the magnetic force which does not need lubrication, and overcome the traditional shortcomings such as direct friction, big loss and short life, and it is one of the ideal support for a new generation of artificial heart pump (Wu et al., 2011, 2012).

It has been widely acknowledged that permanent maglev is unstable according to Earnshaw's theory (1839). This theorem is applicable only to a levitator in static state. A passive magnetic (PM) bearings could achieve stable maglev in all centrifugal pumps, if the rotor had high enough speed and thus obtained a so-called gyro-effect, namely, a rotating body with high enough speed could maintain its rotation stably (Qian et al., 2006, 2008).

To simplify the electrically maglev rotary pumps, a shaft-less full-permanent maglev impeller pump without actively controlled coil for rotor suspension has been developed (Fig. 38). The left side of the impeller is a magnets disc for rotation and the right side of the impeller is a magnets disc for suspension. The pump weighing 150g has a maximal diameter of 42mm, and its length in largest point is 35mm.

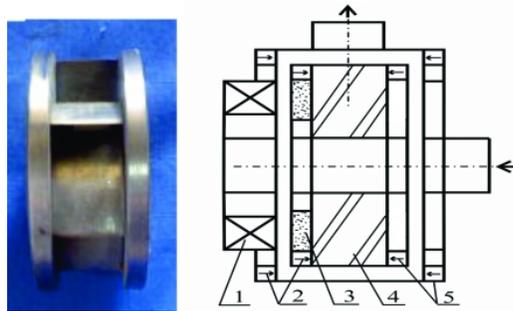


Fig. 38. Permanent maglev centrifugal pump (right) and its impeller (left)

1. motor coil; 2. passive magnetic bearing; 3. rotor magnets; 4. impeller; 5. passive magnetic bearing.

The device consists of a stator and a rotor. The stator has a hard polyurethane housing with cylindrical inner surface; on its left side an axially driven DC motor coil wound on an iron core is connected and on its right side a balancing iron ring is screwed. The rotor is compacted by a magnet disc for rotation (in the left), an impeller (in the middle) and a magnet disc for suspension (in the right). The attractive force between the motor coil iron core and the rotor magnet disc for rotation is balanced by the attractive force between the magnet disk for suspension and the balancing iron ring. Furthermore, two novel patented permanent magnetic bearings are devised on both sides of the rotor, eliminating the remaining attractive forces and preventing the rotor being affiliated axially to the stator

either in the left or in the right. Each bearing is composed of a small and a big permanent magnetic ring, the small ring is inlaid into the rotor and the big ring is buried in the stator. Two rings magnetized in the same axial direction reject each other, providing an axial bearing force. The attractive force between the rotor and the stator resists the radial eccentric movement of the rotor and thus serves as a radial bearing. The inlet and outlet of the pump are located respectively in the center of the balancing iron ring and onto the periphery of the PU housing. By the bench testing with water the pump produces a flow as large as 10 l/min with 100mmHg pressure head. The pump weighing 150 g has a maximal diameter of 42 mm and a length of 35 mm (excluding inlet and outlet tubes) (Qian et al., 2007).

Implantable rotary pumps have been developed and used to assist the impaired heart ventricle because of lack of heart donors for transplant. Pulsatile flow rate measurement is important for controlling the flow rate of these rotary pumps. Conventional flow meters are not particularly compact; while the reliability and durability of small flow meters made using micro-electro-mechanical system technology is still uncertain. Several groups have proposed estimating flow rate using the motor power of the centrifugal blood pump (CBP). Fig. 39(a) shows a schematic of an implantable ventricular assist system using a rotary pump (Pai et al., 2009).

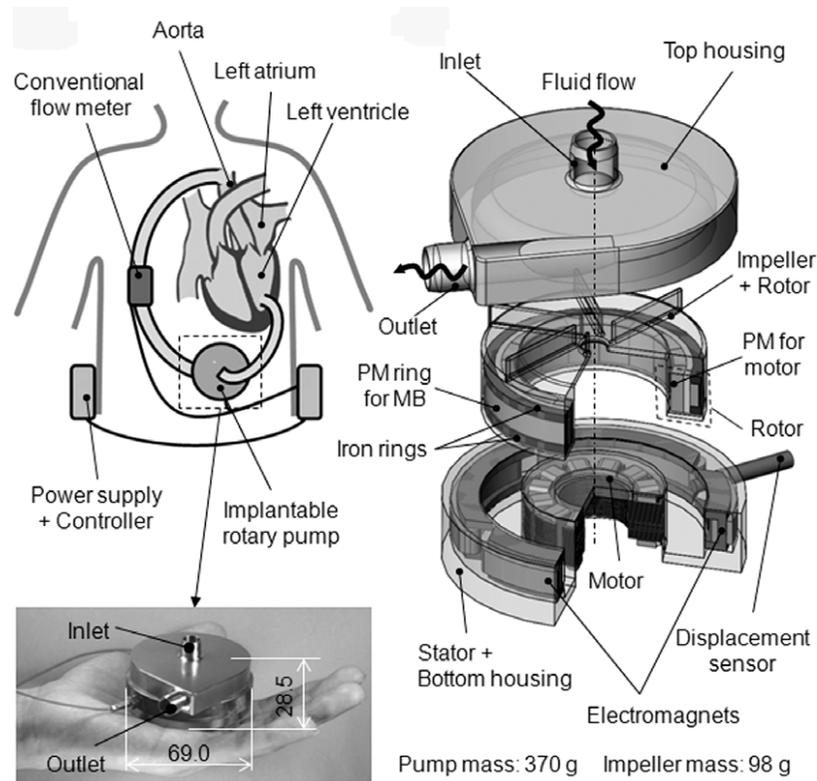


Fig. 39. (a) Ventricular assist system and photograph of an implantable maglev CBP, and (b) configuration of the implantable maglev CBP.

The fourth design iteration (PF4) of the PediaFlow™ Pediatric Ventricular Assist Device (VAD) was developed for infants and toddlers with congenital and acquired heart disease.

Key attributes of the PediaFlow™ Pediatric VAD include:

- Unparalleled biocompatibility due to the maglev technology, streamlined single-flow-path design, and computer-optimized design process;
- Exceptionally small due to the supercritical (above resonance frequency) rotordynamic technology;
- Valveless turbodynamic design with one moving part to minimize size;
- Computationally optimized using first principles of bioengineering and physics.

The current VAD design arose from the comprehensive evaluation of three pump topologies incorporating a variety of magnetic suspension, motor, and fluid path arrangements. Each of the selected topologies utilized permanent magnet radial and moment bearings, an active axial thrust bearing, and a brushless DC motor (Noh et al., 2008; Gardiner et al., 2007; Borovetz et al., 2006; Noh et al., 2005).

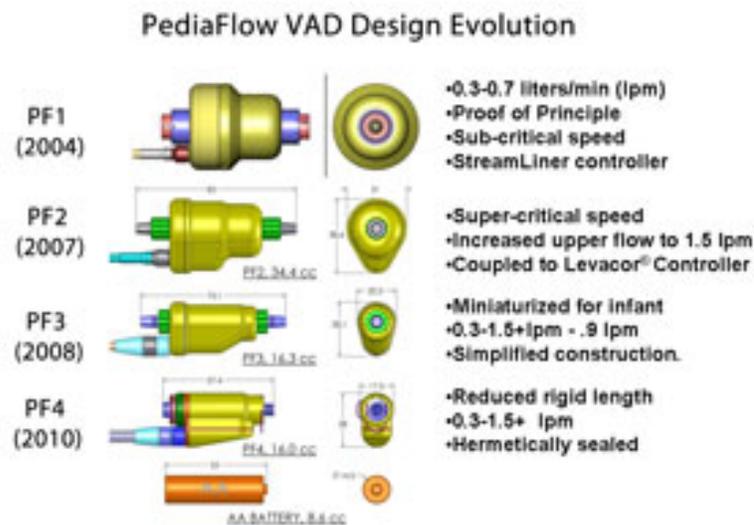
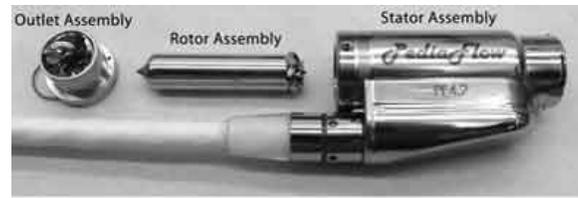
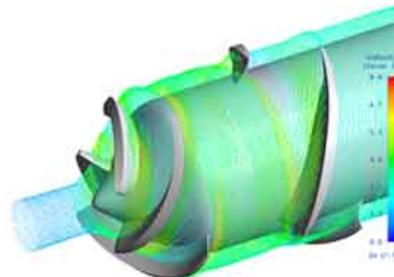
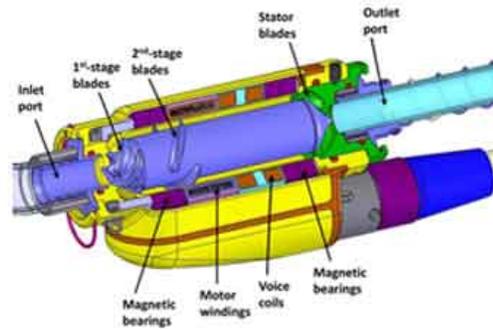
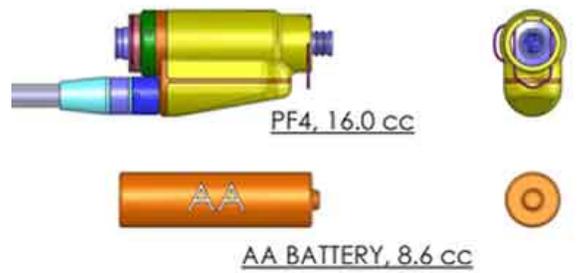


Fig. 40. PediaFlow™ Pediatric Ventricular Assist Device (VAD)



Current PediaFlow PF4 Design



CFD-predicted flow field at speed = 16,000 rpm. Velocity vectors on mid-span blade-to-blade surface for first- and second-stage impeller (Q=1.5 LPM). (Jinchun Wu, LaunchPoint Technologies Inc., 2012)

Fig. 41. The fourth design iteration (PF4) of the PediaFlow™ Pediatric Ventricular Assist Device (VAD)

10. Compressor, Chiller, Pump, Gas Pump

Maglev chillers, geothermal heat pumps, etc. cost effectively maximize energy savings while reducing the environmental impact of air conditioning systems in existing facilities.



Fig. 42. Maglev Turbo Pump with enhanced performance for Light Gas

The adixen ATP 2300 M is a 5 active axis maglev turbomolecular pump

Its pumping capacity, above 1750 l/s in H₂, make it suitable for the HDPCVD Dielectric and Ion Implant applications. Features include low level of vibration, high compacity (less than 300 mm high), and a low power consumption.

11. Maglev Elevator

Instead of wheels and rails, the maglev elevator will use magnetic forces for movement. This translates into quieter, smoother, and a more comfortable ride no matter the direction. It can travel up to 984 feet/minute, a number that is relatively slower when compared to standard lifts.

The basic difference between a mechanical or a hydraulic elevator and a Maglev elevator is that it is based on electromagnetic suspension. Two electromagnetic systems will be used in the maglev elevator. One system of axial wires and circular coils attached to the elevator will counteract the effect of gravity, suspending the elevator. The coils would be repelled by the wires thus ensuring higher stability (making sure that the coils don't hit against the wire). The coils would have a surface current going radially outwards on which the force would act in the vertical direction. These coils would be strongly connected to the capsule, thus levitating the capsule. Another system of ElectroDynamic Suspension (EDS) (only the motion part) would be used to move the elevator up or down. The principle of the motion is that there will be electromagnet coils on the undercarriage of the elevator and also on the outer frame. These coils will attract or repel (as per the relative position of the elevator) the capsule, thus culminating in motion. The relative position of the electromagnets and the capsule would be calculated using IR proximity detectors, whose output would be fed to the control system, which will regulate the direction of current in the outer electromagnets, thus achieving attraction or repulsion. The lift would also have buffer zones at the bottom and the top which will have a very high perpetual repelling magnetic field thus ensuring the safety of the elevator.

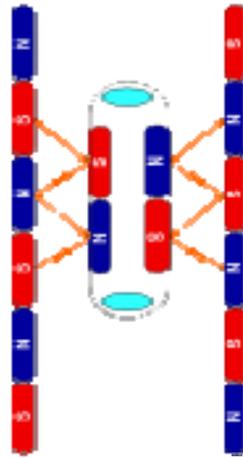


Fig. 43. Motion system of the elevator

There is less friction due to no contact between the pulley and the suspension rope. Therefore higher speeds can be attained, which is useful in tall skyscrapers. Also the power required for the elevator would be reduced. Due to the use of electromagnetism, the elevator can have a higher weight to power ratio than a normal elevator. The safety system

using electric buffers would be a failsafe. Such a design would be better suited to electrical 21st century than a mechanical elevator.

In a normal elevator, the power provided from the source would be required to do two kinds of work. The first would be the work required to raise the elevator (or retard it) and the second would be the work done against friction. In maglev elevator, the power from the source is not wasted upon friction, which minimizes losses. As the working of the elevator is based on the principle laws of electromagnetism (creation of magnetic field due to current, force on a conductor due to magnetic field), the elevator design can be practically attained and is feasible. Moreover, the construction of the elevator (exterior frames and the capsule) would be difficult but quite possible within the timeframe.

12. Analyzing Food and Beverages

Measurements of a substance's density are important in the food industry, health care, and other settings because they provide key information about a substance's chemical composition. Density measurements, for instance, can determine the sugar content of soft drinks, the amount of alcohol in wine, or whether irrigation water contains too much salt to use on a farmer's field. Existing devices for making those measurements are far from ideal, and a need exists for simpler, less expensive, easy-to-use technology.

Scientists describe development of a special sensor that uses maglev to meet those needs, suspending solid or liquid samples with the aid of magnets to measure their density. About the size of an ice cube, the sensor consists of a fluid-filled container with magnets at each end. Samples of different materials can be placed inside, and the distance they migrate through the fluid provides a measure of their density. Scientists showed that the device could quickly estimate the salt content of different water samples and the relative fat content in different kinds of milk, cheese, and peanut butter. Potential applications of maglev may include evaluating the suitability of water for drinking or irrigation, assessing the content of fat in foods and beverages, or monitoring processing of grains (e.g., removing husk or drying) (Mirica et al., 2010).

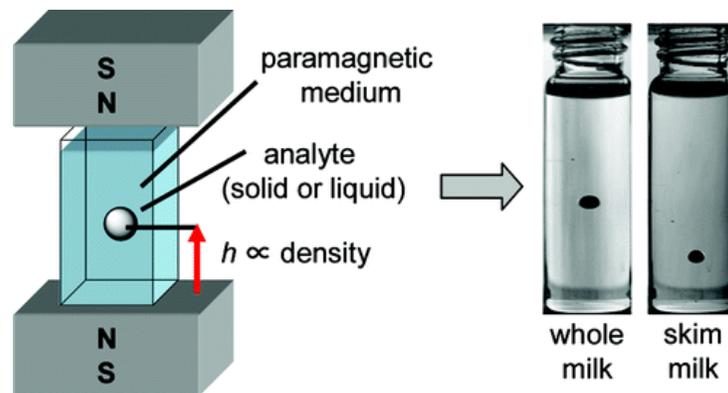


Fig. 44. Maglev sensor

13. Maglev Washing Machine

The concept maglev washing machine is sure to bowl you over with its looks and features. The traditional spinning drum is replaced by a spherical drum held in place by a series of electromagnets in the maglev. One set of electromagnets keeps the drum levitating within the body of the machine, while a second set induces movement, allowing the drum to spin in all directions. A lot of noise is reduced as the drum never actually contacts the body. The design also cuts water and detergent usage.

The maglev washing machine is designed with the intention of creating a washing machine that improve the effectiveness of the washing process while reducing the consumption of water and washing powder. The industrial design creation replaces the cylindrical drum, revolving about single axis rather than rotating around different axis. The magnetic levitation allows the washing process in a great way, like maglev train, using rails with electromagnets. There are many electromagnets which are put on a surface of the drum. These electromagnets are divided into two groups. One group of electromagnets caters to levitation in the magnetic field which is created by electromagnets located in the body of washing machine. The second group of electromagnets makes a movement of drum in the magnetic field and its rotation around all directions. There is no contact between the drum and body of machine, which means there is tremendous reduction in sound. To emphasize on the drum's function and its rotation motion, the transparency sphere is used as major object that's standing on three legs. There is a source of magnetic field and also a water pump in the bowl under a drum. In front part under the display is inbuilt a cartridge chamber of washing powder. Users only sometimes fill it up by a slot under a display. Opening of washing machine is possible by pressing the top transparent cover.





Fig. 45. Maglev washing machine designed by Jakub Lokes

14. Maglev Bed

Dutchman architect Janjaap Ruijsenaars has created a magnetic floating bed - a sleek black platform, which hovers above the ground through magnetic force. He spent the last six years working on the development of this bed. A scale model of it was presented at the Millionaire Faire recently. This bed can also double as a dining table or a plinth. Magnets built into the floor and into the bed itself repel each other, pushing the bed up into the air. The bed simply floats in the air, above magnets, can carry up to 900 kilos (1,984 pounds). To make sure that the bed doesn't float away should it become windy, it's tethered and held to the walls in place through four very thin steel cables.



Fig. 46. Maglev bed

15. Maglev Car

This futuristic Citroen Maglev race car concept is part of the industrial designer's research to develop a race car that you can drive outside the race track. Considering by the time we reach 2030 most cars would be electric, this race car is also designed to be totally electric with ultra light body material. The driver seat is located at the center of this three-wheeled futuristic vehicle, the lower center gravity will avoid accidental roll over at high speed.





Fig. 47. Futuristic Citroën maglev race car concept by Turkish designer Ozgun Culam

Nissan iV is perhaps the most serious bid for victory in LA Design Challenge. The project implemented by a team of 13 people headed by Alfonso Albeysoy (head of Nissan Design America), and about all his fancy, well-designed. Body Nissan iV will be grown on beds – an idea similar to the offer designers Mercedes-Benz, but more elaborate. Body panels will create the fastest growing of GMO ivy, “spud” nanorobots. Twisted and hardened saliva spider plant is a natural composite material, ultra-light and very durable. Cap Cab nissanovtsy want to make out again super lightweight material (99% lighter than glass), while possessing the properties of solar batteries. Flat bio-batteries will provide Nissan iV reserve of 1200 miles (1930 km), and the technology of supercapacitors will recover 60% of the consumed energy. Nissan’s patented concentric wheel without the hub, not only do their direct role – roll, but also include elements of the steering and suspension. In the node based on the principle of magnetic levitation. Security System Safety Shield, which came up for Nissan iV, uses the principles of fish behavior in a flock, so that developers are hoping to completely avoid accidents and reduce the weight of the machine, since the passive elements were not needed.



Fig. 48. LA Auto Design Challenge – Nissan iV

16. 3D cell cultures

A team of scientists has taken aim at a biological icon - the two-dimensional petri dish - and unveiled a new technique for growing 3D cell cultures. The new process uses magnetic forces to levitate cells while they divide and grow to form tissues that more closely resemble those inside the human body. This represents a technological leap from the flat petri dish and could save millions of dollars in drug-testing costs. According its developers, the 3D technique is easy enough for most labs to set up immediately. To make cells levitate, the

research team modified a combination of gold nanoparticles and engineered viral particles called "phage". This targeted "nanoshuttle" can deliver payloads to specific organs or tissues. There is a big push right now to find ways to grow cells in 3D because the body is 3D, and cultures that more closely resemble native tissue are expected to provide better results for preclinical drug tests. For cancer research, the "invisible scaffold" created by the magnetic field goes beyond its potential for producing cell cultures that are more reminiscent of real tumors, which itself would be an important advance. The new technique is an example of the innovation that can result when experts come together from disparate fields. The researchers study ultracold atoms and use finely tuned magnetic fields to manipulate them. They had been working for several years on methods to use magnetic fields to manipulate cells. They were developing a gel that could load cancer cells with magnetic nanoparticles, which it led to a new idea. They might be able to use magnetic fields to manipulate the cells after the gels put magnetic nanoparticles into them. The nanoparticles in this case are tiny bits of iron oxide. These are added to a gel that contains phage. When cells are added to the gel, the phage causes the particles to be absorbed into cells over a few hours. The gel is then washed away, and the nanoparticle-loaded cells are placed in a petri dish filled with a liquid that promotes cell growth and division. In the new study, the researchers showed that by placing a coin-sized magnet atop the dish's lid, they could lift the cells off the bottom of the dish, concentrate them and allow them to grow and divide while they were suspended in the liquid.

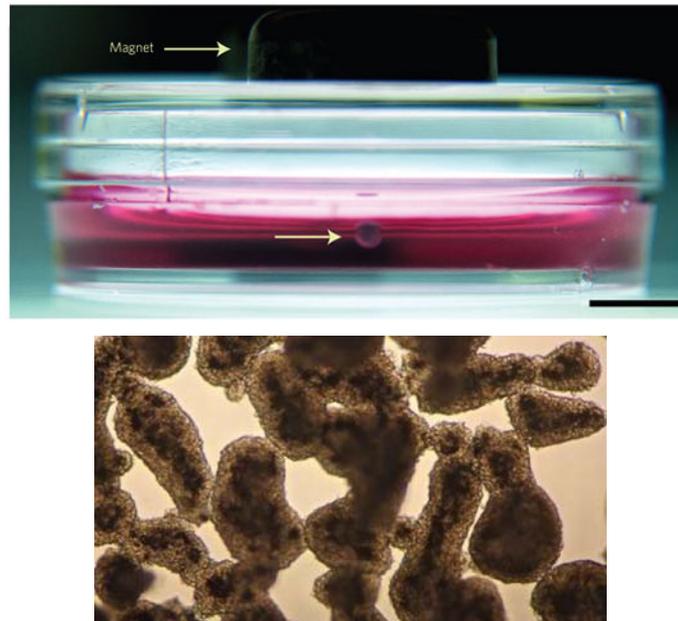


Fig. 49. A 3D cell culture grown with magnetic levitation

A key experiment was performed in which the technique was used on brain tumor cells called glioblastomas. The results showed that cells grown in the 3D medium produced

proteins that were similar to those produced by glioblastoma tumors in mice, while cells grown in 2D did not show this similarity. The researchers are now conducting additional tests to compare how the new method stacks up against existing methods of growing 3D cell cultures. They are hopeful that it will provide results that are just as good, if not better, than longstanding techniques that use 3D scaffolds. The beauty of this method is that it allows natural cell-cell interactions to drive assembly of 3D microtissue structures. The method is fairly simple and should be a good point of entry in 3D cell culturing for any lab that is interested in drug discovery, stem cell biology, regenerative medicine or biotechnology.

17. Studying Weightlessness

Being weightless can have serious health consequences for astronauts. For every month that an astronaut spends in zero gravity, he loses one to two percent of his bone density (compared to the same amount per year for people on Earth). Muscles deteriorate, fluids redistribute throughout the body, and the immune system becomes weakened. Using magnetic levitation to simulate weightlessness here on Earth, scientists can better understand these changes and their consequences. For many years, NASA scientists have used superconducting magnets to levitate insects, frogs, and mice. Cells are largely made of water, which is weakly diamagnetic. So in the presence of a strong magnet, water's electrons rearrange to oppose the magnet. When researchers expose living organisms to superconducting magnets, this molecular effect causes the organisms to levitate. Just some months ago, floating fruit flies helped scientists to discover that weightlessness can change expression in over 200 fly genes. The genes most affected were responsible for metabolism, immune functioning, and cell signaling. It is possible that humans show similar expression changes during weightlessness. By understanding how the body reacts to weightlessness, this research could eventually make prolonged spaceflight—such as a journey to Mars—safer for humans.



Fig. 50. NASA maglev simulator

18. Maglev Room

The maglev room is an interactive art experiment proposed and created by Sean Bennett. The room is painted white and is completely empty except for the levitating object/s. Inside the walls of the room are a series of ceramic yttrium based superconductors set up in a grid pattern. These superconductors can be moved left, right, up, and down in order to move the object/s.



Fig. 51. Maglev room

The room is filled with over 100 three inch neodymium magnetic balls that are levitated and moved around the room by the superconductors. Neodymium magnets are a type of rare-earth magnet known to be the most powerful type of permanent magnets.

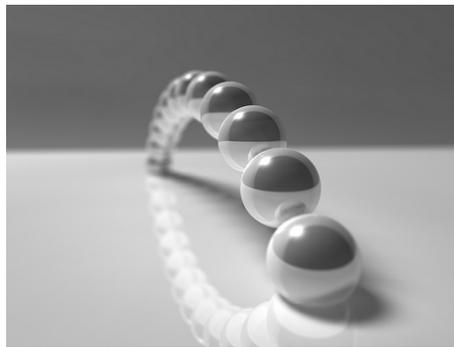


Fig. 52. Neodymium magnetic balls

The controls for the magnets must be housed outside the room due to the strong magnetic forces at work within the room. The person interacting with the room uses a touch screen display that has buttons programmed to create specific geometric shapes within the room.

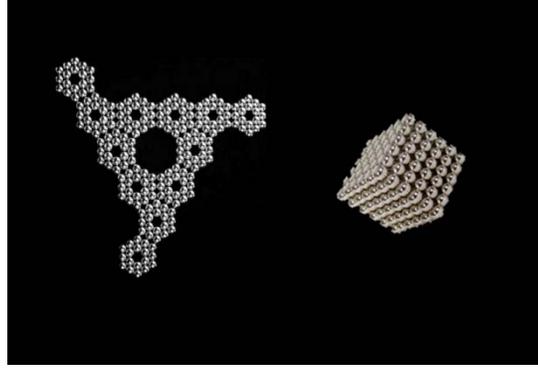


Fig. 53. Controls

This technology carries with it many future possibilities. Using different sized magnets to hold object in the air, the MagLev Room can be used to display high quality goods in mid air. Other possible commercial applications could be floating novelty items, floating stairs, floating tables, etc.

19. Maglev Lamp

Maglev lamps are extremely low in power consumption. To levitate and illuminate, the lamps are packed with futuristic electromagnetic components and LEDs. This lamp can be dimmed but never ignored.



Fig. 54. Maglev lamp

20. Maglev City

Our planet can be a crowded, polluted, crazy place. But a new design concept proposes that we rise above it all, literally, by moving to a magnetically levitated island in the sky, complete with green forests, mountains, and urban centers. The concept, called Heaven and Earth, was created by Chinese architect Wei Zhao and won an honorable mention in eVolo's 2012 Skyscraper Competition. Zhao has proposed that the massive donut-shaped platform could hold magnets on its underside that would repulse the earth's magnetic field to hold the island aloft. The floating platform would rotate, generating energy as it spins and theoretically fueling a completely sustainable society.



Fig. 55. Maglev city

21. Conclusion

The name maglev is derived from MAGnetic LEVitation. Magnetic levitation is a highly advanced technology. It has various cases, including clean energy (small and huge wind turbines: at home, office, industry, etc.), building facilities (fan), transportation systems (magnetically levitated train, Personal Rapid Transit (PRT), etc.), weapon (gun, rocketry), nuclear engineering (the centrifuge of nuclear reactor), civil engineering (elevator), advertising (levitating everything considered inside or above various frames can be selected), toys (train, levitating spacemen over the space ship, etc.), stationery (pen) and so on. The common point in all these applications is the lack of contact and thus no wear and friction. This increases efficiency, reduce maintenance costs and increase the useful life of the system. The magnetic levitation technology can be used as a highly advanced and efficient technology in the various industrial. There are already many countries that are attracted to maglev systems. Many systems have been proposed in different parts of the worlds, and a number of corridors have been selected and researched. Maglev can be conveniently considered as a solution for the future needs of the world. This research chapter tried to study the most important uses of magnetic levitation technology.

22. Acknowledgment

This report was performed by Iran Maglev Technology (IMT).

23. References

- Ambike, A., Kim, W. J., & Ji, k. (2005). Real-time operating environment for networked control systems. *American Control Conference*, Portland, OR, USA.
- Behbahani, H. & Yaghoubi, H. (2010). Procedures for safety and risk assessment of maglev systems: a case-study for long-distance and high-speed maglev project in Mashhad-Tehran route. *The 1st International Conference on Railway Engineering, High-speed Railway, Heavy Haul Railway and Urban Rail Transit*, Beijing Jiaotong University, Beijing, China, China Railway Publishing House, pp. 73-83, ISBN 978-7-113-11751-1.
- Behbahani, H., Yaghoubi, H., & Rezvani, M. A. (2012). Development of technical and economical models for widespread application of magnetic levitation system in public transport. *International Journal of Civil Engineering (IJCE)*, Vol. 10, No. 1, pp. 13-24.
- Borovetz, H. S., et al. (2006). Towards the development of a pediatric ventricular assist device. *Cell Transplantation*, Vol. 15, Supplement 1, pp. 69-74(6).
- Fiske, O. J., Ricci, M. R., Ricci, K. & Hull, J. R. (2006). The launch ring - circular EM accelerators for low cost orbital launch. *American Institute of Aeronautics and Astronautics*.
- Gardiner, J. M., Wu, J., Noh, M. D., Antaki, J. F., Snyder, T. A., Paden, D. B. & Paden, B. E. (2007). Thermal analysis of the PediaFlow pediatric ventricular assist device. *ASAIO Journal*, Vol. 53, pp. 65-73.
- Gieras, J.F., & Wing, M. (2002). *Permanent magnet motor technology*, New York, Marcel Dekker.
- Hoffman, J. E. (2003). A search for alternative electronic order in the high temperature superconductor $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ by scanning tunneling microscopy. *Ph. D. dissertation, University of California, Berkeley, U.S.A.*
- Hornig, A. (2003). Direct current brushless motor of radial air-gap, *US Patent No. 6,538,357*.
- Hull, J. R., Fiske, J., Ricci, K. & Ricci, M. (2006). Analysis of levitational systems for a superconducting launch ring. *Applied Superconductivity Conference*, Seattle, WA.
- Hull, J. R. & Mulcahy, T. M. (2001). Magnetically levitated space elevator to low earth orbit. *3rd International Symposium on Linear Drives for Industrial Applications*, pp. 42-47, Nagano, Japan.
- Hull, J. R., Mulcahy, T. M. & Niemann, R. C. (2002). Magnetically levitated space elevator to low earth orbit. *Adv. Cryog. Engng.* Vol. 47, pp. 1711-1718.
- Kim, W. J., Ji, k., & Ambike, A. (2006). Real-time operating environment for networked control systems. *IEEE Transactions on Automation Science and Engineering*, Vol. 3, No. 3, pp. 287-296.
- Liu, C. T., Chiang, T. S., & Hornig, A. (2004a). Three-dimensional flux analysis and guidance path design of an axial-flow radial-flux permanent magnet motor. *The Eleventh Biennial IEEE Conference on Electromagnetic Field Computation*, Sheraton Grande Walkerhill Hotel, Seoul, Korea.

- Liu, C. T., Chiang, T. S., & Horng, A. (2004b). Three-dimensional force analyses of an axial-flow radial-flux permanent magnet motor with magnetic suspension. *IEEE/IAS 39th Annual Meeting*, Weatin Hotel, Seattle, Washington, USA.
- Livingston, J. D. (2011). *Rising Force: The Magic of Magnetic Levitation*, Harvard University Press, ISBN-10: 0674055357 / 0-674-05535-7, ISBN-13: 978-0674055353.
- McNab, I. R. (2003). Launch to Space with an Electromagnetic Railgun. *IEEE Trans. Magn.* 39, pp. 295-304.
- Mirica, K. A., Phillips, S. T., Mace, C. R. & Whitesides, G. M. (2010). Magnetic levitation in the analysis of foods and water. *Journal of Agricultural and Food Chemistry*, Vol. 58. No. 11, pp. 6565–6569.
- Noh, M. D., Antaki, J. F., Ricci, M., Gardiner, J., Paden, D., Wu, J., Prem, E., Borovetz, H. S. and Paden, B. E. (2008). Magnetic Design for the PediaFlow™ Ventricular Assist Device. *ARTIFICIAL ORGANS*, Vol.32, No. 2, pp. 127-135.
- Noh, M. D., Antaki, J. F., Ricci, M., Prem, E., Borovetz, H. S., and Paden, B. E. (2005). Magnetic levitation design for the PediaFlow™ ventricular assist device. *Proceedings of 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, pp. 1077–1082.
- Paschall II, S. C. (2002). Design, fabrication, and control of a single actuator magnetic levitation system. *Senior Honors Thesis, Dept. Mech. Eng., Texas A&M Univ.*
- Paschall II, S. C. & Kim, W. J. (2002). Design, fabrication, and control of a single actuator maglev test bed. *Dept. Mech. Eng., Texas A&M Univ.*
- Pai, C. N., Shinshi, T. & Shimokohbe, A. (2009). Sensorless measurement of pulsatile flow rate using a disturbance force observer in a magnetically levitated centrifugal blood pump during ventricular assistance. *Flow Measurement and Instrumentation*, doi:10.1016/j.flowmeasinst.2009.11.003.
- Qian, K. X., & Jing, T. (2008). Use of PM bearings in permanent maglev centrifugal pumps for stability investigation. *International IEEE Conference on BioMedical Engineering and Informatics (BMEI)*, Sanya, China, Vol. 2, pp. 535-538.
- Qian, K. X., Ru, W. M., Wang, h. & Jing t. (2007). A Mini axial and a permanent maglev radial heart pump. *The 3rd Conference of World Association of Chinese for Biomedical Engineering*, Bangkok.
- Qian, K. X., Zeng, P., Ru, W. M. & Yuan, H. Y. (2006). New concepts and new design of permanent maglev rotary artificial heart blood pumps. *Medical Engineering & Physics*, Vol. 28, pp. 383–388.
- Schultz, J. H., Radovinsky, A., Thome, R. J., Smith, B., Minervini, J. V., Myatt, R. L., Meinke, R. & Senti, M. (2001). Superconducting magnets for maglifter launch assist sleds. *IEEE Trans. Appl. Supercond.*, Vol. 11, pp. 1749-1752.
- Wu, H., Wang, Z. & Hu, Y. (2012). Study on support properties of axial maglev blood pump. *Applied Mechanics and Materials*, Vol. 150 (Research Progress of Magnetic Levitating Bearings and Some Advanced Technology), pp. 187-193.
- Wu, H., Wang, Z. & Lv, X. (2011). Design and simulation of axial flow maglev blood pump. *International Journal of Information Engineering and Electronic Business*, Vol. 3, Issue 2, pp. 42-48.
- Yaghoubi, H. (2008). *Magnetically Levitated Trains, Maglev*. Vol. 1, Pooyan Farnegar Publisher, ISBN 978-600-5085-05-1, Tehran, Iran.
- Yaghoubi, H. (2011). The most important advantages of magnetically levitated trains, *Towards Sustainable Transportation Systems Proceedings of the 11th International*

- Conference of Chinese Transportation Professionals (ICCTP2011)*, Nanjing, China, American Society of Civil Engineers (ASCE) Publisher, pp. 3974-3986, ISBN 978-0-7844-1186-5.
- Yaghoubi, H., Barazi, N. & Aoliaei, M. R. (2012). Maglev, Chapter 6, Infrastructure Design, Signalling and Security in Railway. pp. 123-176, ISBN 978-953-51-0448-3, *InTech*, University Campus STeP Ri, Rijeka, Croatia.
- Yaghoubi, H., Barazi, N., Kahkeshan, K., Zare, A. & Ghazanfari, H. (2011). Technical comparison of maglev and rail rapid transit systems, *The 21st International Conference on Magnetically Levitated Systems and Linear Drives (MAGLEV 2011)*, Daejeon Convention Center, Daejeon, Korea.
- Yaghoubi, H., Keymanesh, M. R. (2012). Design and evaluation criteria for stations of magnetically levitated trains. *Journal of Civil Engineering and Science (JCES)*, World Academic Publishing (WAP), Vol. 1, No. 3.
- Yaghoubi, H. & Rezvani, M. A. (2011). Development of maglev guideway loading model. *ASCE, Journal of Transportation Engineering*, Vol. 137, No. 3, pp. 201-213.
- Yaghoubi, H. & Sadat Hoseini, M. (2010). Mechanical assessment of maglev vehicle - a proposal for implementing maglev trains in Iran. *The ASME 10th Biennial Conference on Engineering Systems Design and Analysis (ESDA)*, Yeditepe University, Istanbul, Turkey, Vol. 2, pp. 299-306, ISBN: 978-0-7918-4916-3.
- Yaghoubi, H. & Ziari, H. (2010). Assessment of structural analysis and design principles for maglev guideway: a case-study for implementing low-speed maglev systems in Iran. *The 1st International Conference on Railway Engineering, High-speed Railway, Heavy Haul Railway and Urban Rail Transit*, Beijing Jiaotong University, Beijing, China, China Railway Publishing House, pp. 15-23, ISBN 978-7-113-11751-1.
- Yaghoubi, H. & Ziari, H. (2011). Development of a maglev vehicle/guideway system interaction model and comparison of the guideway structural analysis with railway bridge structures. *ASCE, Journal of Transportation Engineering*, Vol. 137, No. 2, pp. 140-154.