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Review Article

The Most Important Maglev Applications

Hamid Yaghoubi

Iran Maglev Technology (IMT), Tehran 1997857631, Iran

Correspondence should be addressed to Hamid Yaghoubi; info@maglev.ir

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The name maglev is derived from magnetic levitation. Magnetic levitation is a highly advanced technology. It has various uses. The common point in all applications is the lack of contact and thus no wear and friction. This increases efficiency, reduces maintenance costs, and increases the useful life of the system. The magnetic levitation technology can be used as an efficient technology in the various industries. There are already many countries that are attracted to maglev systems. Many systems have been proposed in different parts of the worlds. This paper tries to study the most important uses of magnetic levitation technology. The results clearly reflect that the maglev can be conveniently considered as a solution for the future engineering needs of the world.

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 that he had been granted a US patent for his "Levitated Transmitting Apparatus," and he gave a public demonstration in New York of a model maglev train, with the hopes of exciting investors with the promise of high-speed ground transportation.

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

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

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

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

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

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

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

Japan National Railway remains committed to construction of a roughly 300 km high-speed maglev line between Tokyo and Nagoya 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, and cost-effective (low maintenance and operating costs) ride. Therefore, Bachelet's 1912 dreams of "carloads of passengers whizzing on invisible waves of electromagnetism through space anywhere from 300 to 1,000 miles an hour" are being achieved.

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

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 [2]. Maglev usages from view point of engineering science can be categorized and summarized as follows:

(i) transportation engineering (magnetically levitated trains, flying cars, or personal rapid transit (PRT), etc.),

(ii) environmental engineering (small and huge wind turbines: at home, office, industry, etc.),

(iii) aerospace engineering (spacecraft, rocket, etc.),

(iv) military weapons engineering (rocket, gun, etc.),

(v) nuclear engineering (the centrifuge of nuclear reactor),

(vi) civil engineering including building facilities and air conditioning systems (magnetic bearing, elevator, lift, fan, compressor, chiller, pump, gas pump, geothermal heat pumps, etc.),

(vii) biomedical engineering (heart pump, etc.),

(viii) chemical engineering (analyzing foods and beverages, etc.),

(ix) electrical engineering (magnet, etc.),

(x) architectural engineering and interior design engineering including household and administrative appliances (lamp, chair, sofa, bed, washing machine, room, toys (train, levitating spacemen over the space ship, etc.), stationery (pen), etc.),

(xi) automotive engineering (car, etc.),

(xii) advertising engineering (levitating everything considered inside or above various frames can be selected).

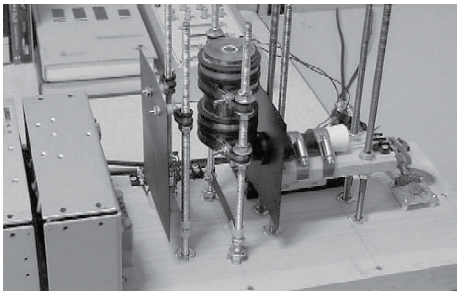


Figure 1: Magnetic levitation test-bed.

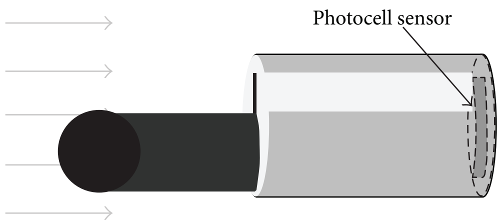


Figure 2: Positions sensor operation.

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 (Figure 1).

The system separates into two main subsystems. The force actuation subsystem 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 subsystem 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 (Figure 2). To enhance the behavior of the sensor, a light shield with a vertical slit opening is placed around the photocell.

These subsystems 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. Figure 3 shows the basic system setup with physical subsystem interfaces.

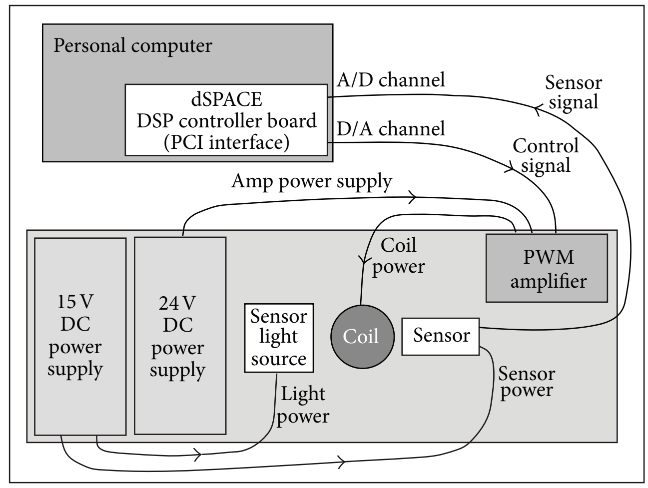


Figure 3: Magnetic levitation system interface diagram.

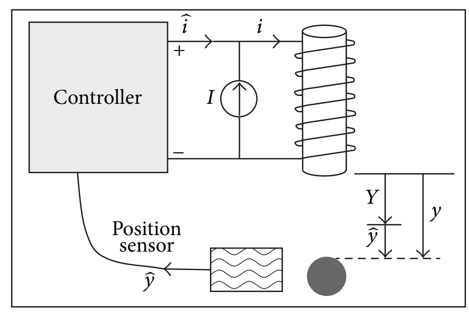


Figure 4: Magnetic levitation system schematic.

In order to design a suitable controller for the maglev system, the subsystem 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. Because of the small size of the photocell (~10 mm dia.) and nature of the sensor subsystem, the sensor's outputs remain 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.

Figure 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.

Using the force, plant, and sensor models discussed previously, a closed loop control system can be designed

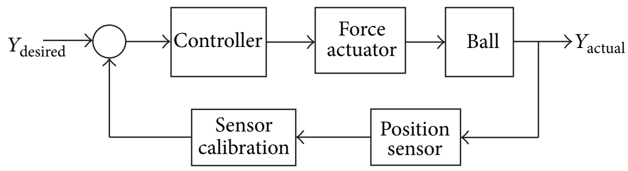


Figure 5: Magnetic levitation system block diagram.

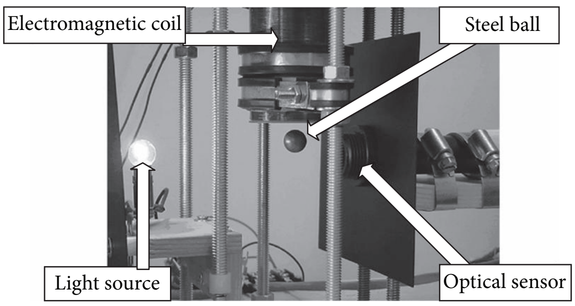


Figure 6: Stable levitation of steel ball.

(Figure 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 ≤50%. This linearized controller is able to hold the steel ball in stable levitation (Figure 6) [3–6].

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.

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 (Figure 7) 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.

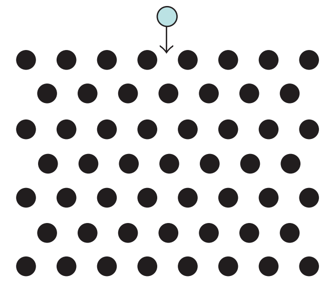


Figure 7: A vertical peg board with stationary pegs (black circles). A blue disk falls and scatters through the lattice of pegs, analagous to electrons scattering off ions as they move through a wire, leading to resistivity.

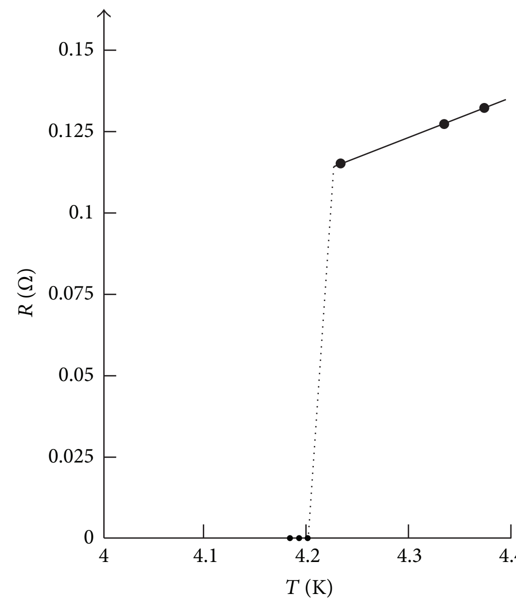


Figure 8: Initial data from Onnes's resistance measurements on mercury showing a precipitous fall in resistance around T_C = 4.2 K.

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.

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 (Figure 8). 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.

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,

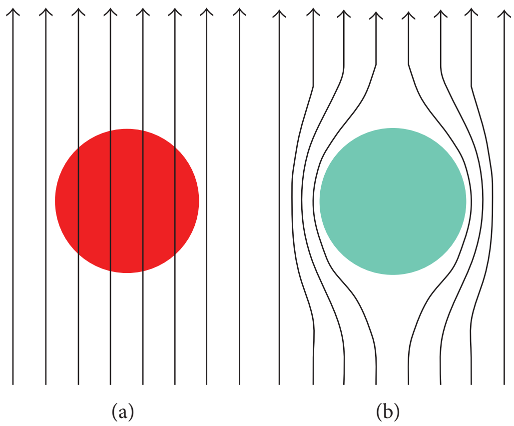


Figure 9: (a) Magnetic field lines penetrate through a superconductor at a temperature above its critical superconducting transition temperature ($T > T_C$). (b) When the superconductor is cooled below its critical transition temperature ($T < T_C$), magnetic field lines are expelled from the interior of the superconductor due to the Meissner effect.

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) (Figure 9). 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.

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.

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 its 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 magnetoencephalography (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 ~ 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

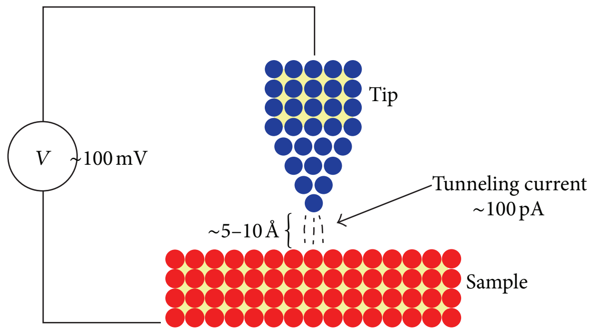


Figure 10: A schematic STM setup. When a tip is brought several angstroms away from a sample and a voltage are applied between them, a very small current flows—of order 10^{-10} amperes—between the last atom of the tip and the sample. For comparison, a typical light bulb usually has a flowing current 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.

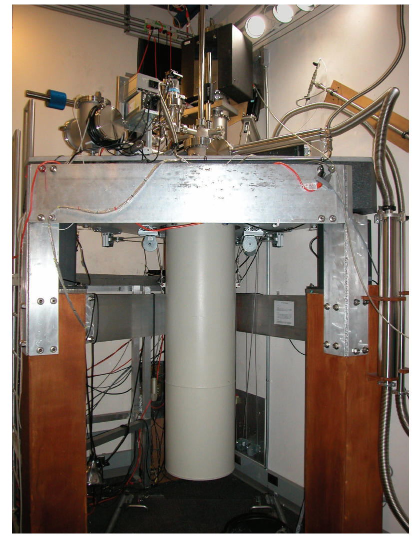


Figure 11: Scanning tunneling microscopy (STM), a custom designed UHV, variable temperature scanning tunneling microscope, Eric Hudson Group.

Figure 12: Scanning tunneling microscopy (STM), the same custom STM, but adapted for room temperature biological applications, Eric Hudson Group.

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_Cs which are above 77 K, the boiling point of liquid nitrogen which is both widely available (e.g., 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. 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 it brings. This section is intended to give the nonphysicist 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 (Å) 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 (Figure 10). 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 Å 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.

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 T_C and through T_C. With the information from these studies, they gain insight into the superconducting state of high-temperature superconductors (see Figures 11 and 12) [7].

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 noncontact 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 make it feasible to reach higher speeds of travel attributed to such trains. Manned maglev vehicles have recorded speed of travel equal to 581 km/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 [8].

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 high speed railways (HSRs) 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, and travel time. 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 [9, 10].

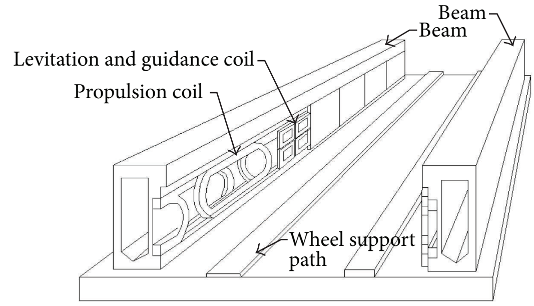


Figure 13: Schematic diagram of EDS maglev system.

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 paths 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 Figure 13. In EMS system, the vehicle is levitated about 1 to 2 cm above the guideway using attractive forces as presented in Figure 14. 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

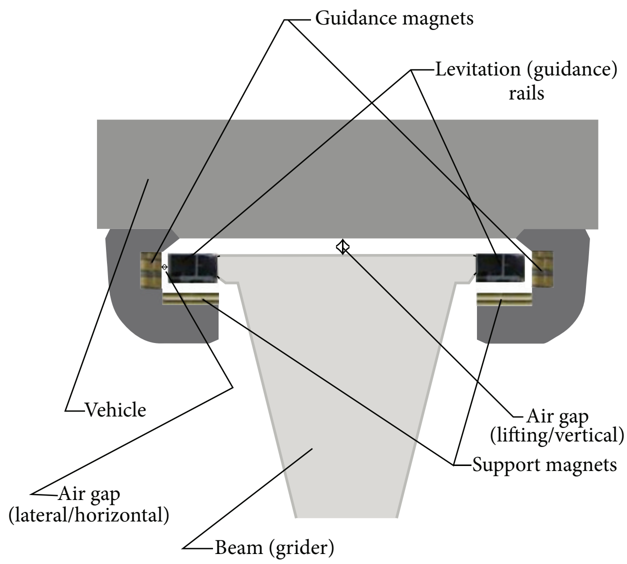


Figure 14: Schematic diagram of EMS maglev system.

air gaps between the guideway and vehicle is achieved by using highly advanced control systems. Figures 13 and 14 show the components of the guideway and track, including beam and levitation and guidance systems in aforementioned maglev systems [11].

Maglev is a system in which the vehicle runs levitated from the guideway (corresponding to the rail tracks of conventional railways) by using electromagnetic forces between superconducting magnets on board the vehicle and coils on the ground. The levitation coils are installed on the sidewalls of the guideway. When the on-board superconducting magnets pass at a high speed about several centimeters below the center of these coils, an electric current is induced within the coils, which then act as electromagnets temporarily. As a result, there are forces which push the superconducting magnet upwards and ones which pull them upwards simultaneously, thereby levitating the maglev vehicle. The levitation coils facing each other are connected under the guideway, constituting a loop. When a running maglev vehicle, that is a superconducting magnet, displaces laterally, an electric current is induced in the loop, resulting in a repulsive force acting on the levitation coils of the side near the car and an attractive force acting on the levitation coils of the side farther apart from the car. Thus, a running car is always located at the center of the guideway. A repulsive force and an attractive force induced between the magnets are used to propel the vehicle (superconducting magnet). The propulsion coils located on the sidewalls on both sides of the guideway are energized by a three-phase alternating current from a substation, creating a shifting magnetic field on the guideway. The on-board superconducting magnets are attracted and pushed by the shifting field, propelling the maglev vehicle.

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 [12]. 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 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 (Figure 15). Guideways can be U-shaped, I-shaped, T-shaped, Box, Truss, and so forth. A 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 [13].

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. 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 an 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

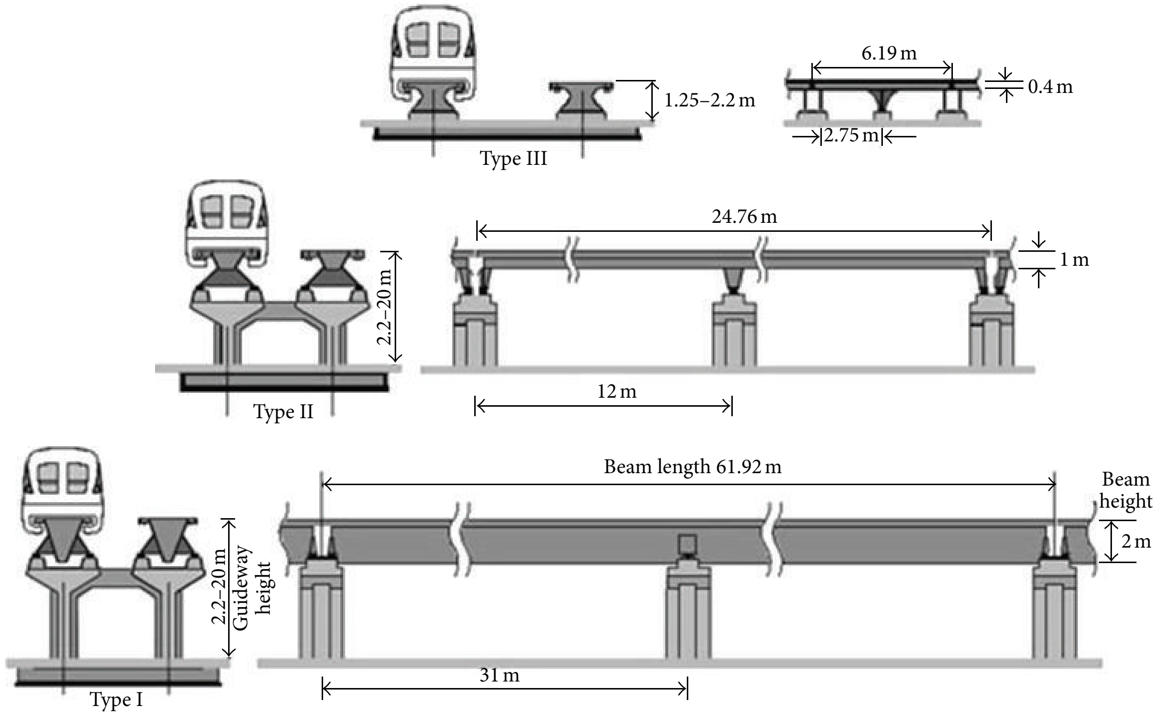


Figure 15: Standard guideway types.

that are combinations of the dead load, live load, and the prestressing forces of the tendon [14, 15].

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 [16].

4. Launching Rockets

A magnetic levitation track is up and running at NASA's Marshall Space Flight Center in Huntsville, Ala, USA. 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, USA. 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, Ala, USA (see Figure 16).

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 electromagnets to lift a vehicle a few inches above a track and then propel it forward with high acceleration. By using a

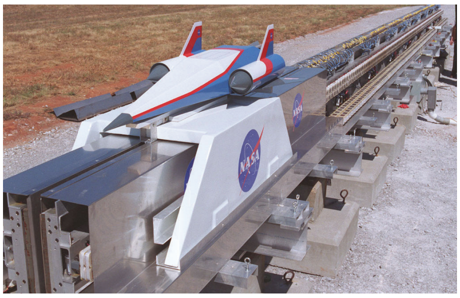


Figure 16: Different technologies to push a spacecraft down a long rail have been tested in several settings, including this Magnetic Levitation (Maglev) System evaluated at NASA's Marshall Space Flight Center. Engineers have a number of options to choose from as their designs progress. Photo credit: NASA.

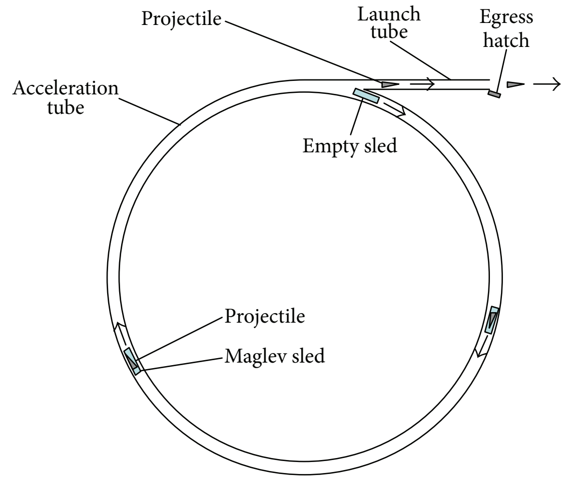


Figure 17: General launch-ring concept.

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.

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.

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.

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 (see Figures 17 and 18) [17, 18].

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

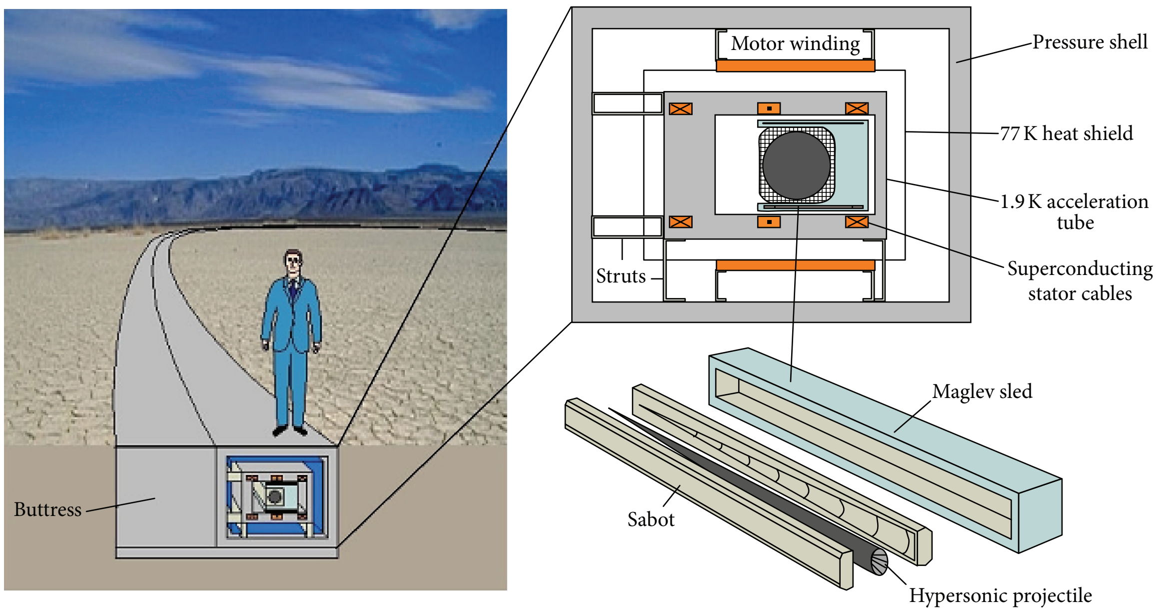


Figure 18: SCS launch ring.

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 [19, 20] 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 [21]. 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 [22]. Ground-based, high-powered lasers that augment the chemical energy of rocket propellant will also likely require large power supplies [21].

5. 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

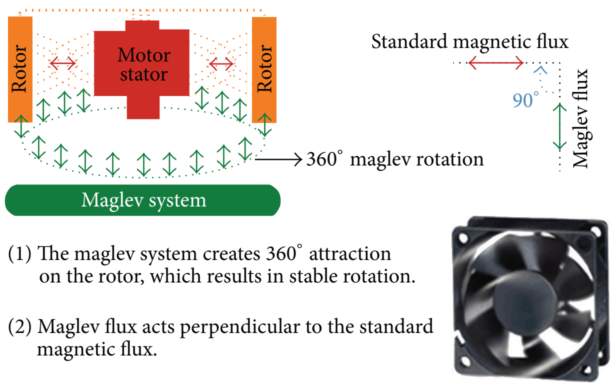


FIGURE 19: Maglev fan.

allow a service life of 50,000 hours or even longer at room temperature (see Figure 19).

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 of 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 (see Figure 20).

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,

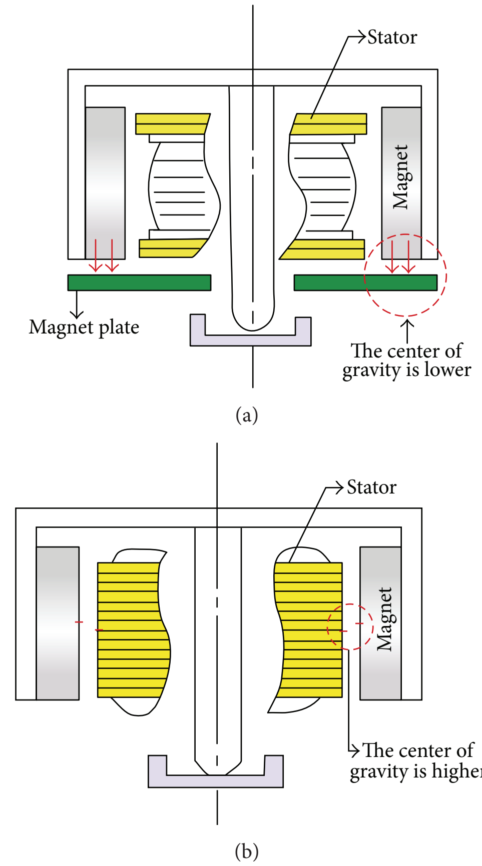


FIGURE 20: Comparison between maglev fan and traditional fan. (a) Maglev fan possesses 3 important factors: the magnet plate, the magnet, and the stator. The resulting interaction between the magnet plate and the magnet pulls the rotor downward in a full 360 degrees. Through the lower center of gravity, the rotor runs stably in a consistent orbit. (b) Traditional fan possesses 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.

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 connection 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 Figure 21.

Advantages of sleeve bearing are the following.

(i) More impact-resistant, less damage resulted during delivery.

(ii) Sleeve bearings cost much lower in comparison with ball bearings.

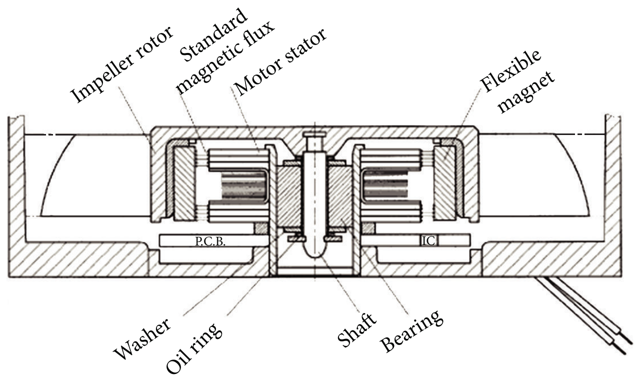


Figure 21: Sleeve bearing.

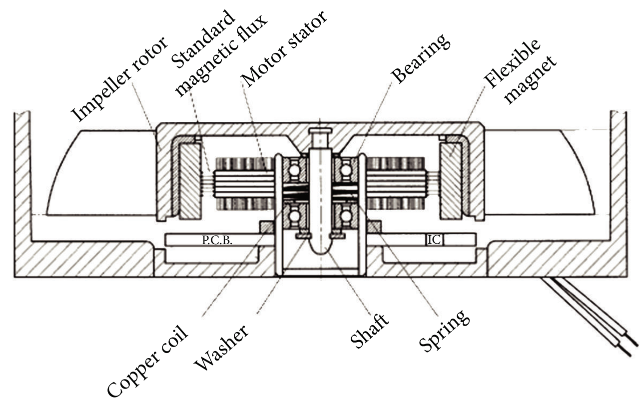


Figure 22: Ball bearing.

Imperfections of sleeve bearing are the following.

(i) Dust from outside may penetrate 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.

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 (see Figure 22).

Advantages of ball bearing are the following.

(i) Steel ball bearings have an operating life much longer than that of sleeve bearings.

(ii) However, the product must avoid rough handling or being dropped on the ground.

Imperfections of ball bearing are the following.

(i) Ball bearings are quite weak. It cannot bear any external impact.

(ii) When the fan motor is operating, the steel balls inside will generate a higher rotational noise than that of a sleeve bearing.

(iii) High price makes it uneasy to compete with sleeve bearings.

(iv) Limitation on both supply sources and supply quantities makes it unacceptable for mass production needs.

(v) The use of tiny assemblies, such as springs, results in inefficiencies for mass production.

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, for example, the swaying and tilting have faded and have become fixed perpendicular to the ground. This is the simple concept that maglev fan system roots form (see Figure 23).

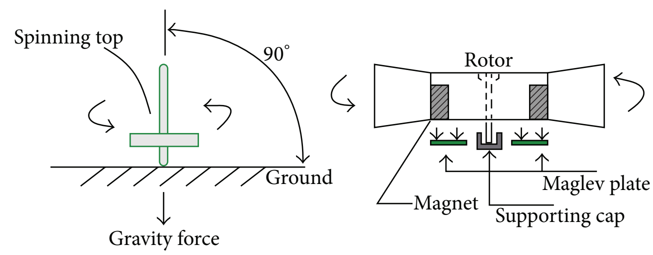


Figure 23: Performance of maglev fan system roots.

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 (see Figure 24).

(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, and 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. There are 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

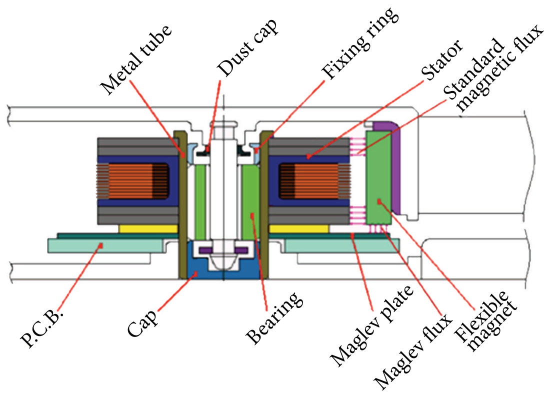


Figure 24: Vapo bearing.

how the fan is placed, no slanting and wobbling occurred, which means it is 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 can be explained as follows.

(i) 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.

(ii) 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.

(iii) This new system eliminates the use of oil rings and washers, thus leaving space for the release of gas occurring during normal operation. There are no more clogging problems. Vapo bearing is named after this character.

Maglev fans prevent the defects of conventional fans (see Table 1).

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.

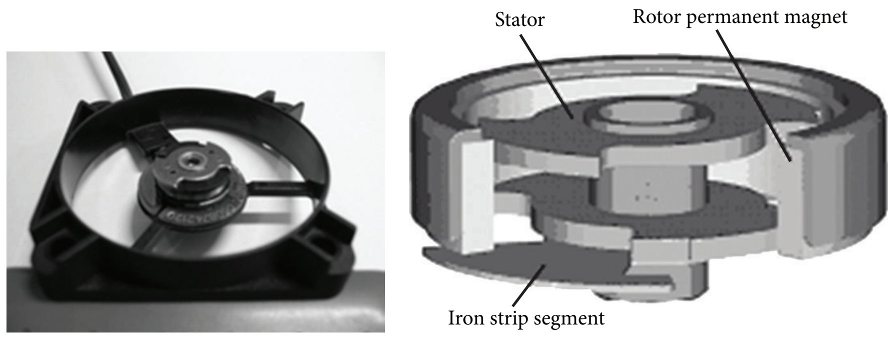
The axial-flow radial-flux permanent magnet motor along with an iron strip segment, as shown in Figure 25, has been used for small-power cooling fan applications [23]. This motor is equipped with only one set of axial stator winding that can supply the desired radial flux through adequate stator pole 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 Figure 25(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 [24, 25].

The major concerns on cooling fan motor manufactures are low construction/maintenance cost and high operational reliability [26]. 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 [25].

6. Maglev Heart Pump

Heat failure is one of the main causes 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, there is a serious shortage of donated hearts and will result in transplant rejection reaction. The support of traditional artificial heart pumps often uses rolling or sliding bearings. Because of the contact between bearing and blood, the blood will be polluted and will 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 reduced the damage of blood cells and improved the heart pump life and safety.

Artificial heart pump requires small structure, low energy consumption, 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



(a) Photograph of the stator base (b) Conceptual structure of the motor

Figure 25: An axial-flow radial-flux permanent magnet motor with a stator iron strip segment.

Table 1: The defects of conventional fans.

	Deficiencies of traditional motors	Maglev fan solution
Sleeve bearing	(i) 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. (ii) The oil ring and mylar washer not only result in added friction area but also block 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.	(i) The 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. (ii) Oil ring, washer, and lubricant are no longer used in maglev structure. Hence there is no more oil leakage or stuck rotor problems. (iii) Maglev design allows an operating temperature higher than 70°C.
Ball bearing	(i) When the fan motor is operating, the steel balls inside will generate a higher rotational noise than that of a sleeve bearing. (ii) The construction of ball bearings is quite weak and unable to absorb external impact. It is easily damaged and results in louder rotational noise.	

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 are 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 has 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 to increase speed for obtaining much greater pressure. Axial flow pump has a tight structure, smaller drive components, low power consumption, light weight, high efficiency, and so forth, 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, and 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 [27, 28].

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 gyroeffect, namely, a rotating body with high enough speed could maintain its rotation stably [29, 30].

To simplify the electrically maglev rotary pumps, a shaftless full-permanent maglev impeller pump without actively controlled coil for rotor suspension has been developed (Figure 26). The left side of the impeller is a magnet's disc

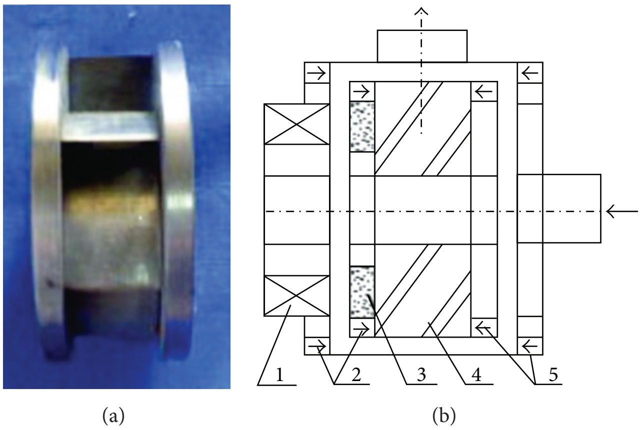


Figure 26: Permanent maglev centrifugal pump (b) and its impeller (a), (1) motor coil; (2) passive magnetic bearing; (3) rotor magnets; (4) impeller; (5) passive magnetic bearing.

for rotation and the right side of the impeller is a magnet's disc for suspension. The pump weighing 150 g has a maximal diameter of 42 mm, and its length in largest point is 35 mm.

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 winded 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 100 mmHg 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) [31].

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 microelectromechanical system technology is still uncertain. Several groups have proposed estimating flow rate using the motor power of the centrifugal blood pump (CBP). Figure 27(a) shows a schematic of an implantable ventricular assist system using a rotary pump [32].

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

Key attributes of the PediaFlow Pediatric VAD include the following:

(i) unparalleled biocompatibility due to the maglev technology, streamlined single-flow-path design, and computer-optimized design process;

(ii) exceptionally small due to the supercritical (above resonance frequency) rotordynamic technology;

(iii) valveless turbodynamic design with one moving part to minimize size;

(iv) 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 [33–36].

7. 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, and 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) (see Figure 28) [37].

8. Conclusion

The name maglev is derived from MAGnetic LEVitation. Magnetic levitation is a highly advanced technology. It has various uses, including clean energy (small and huge wind turbines: at home, office, industry, etc.), building facilities

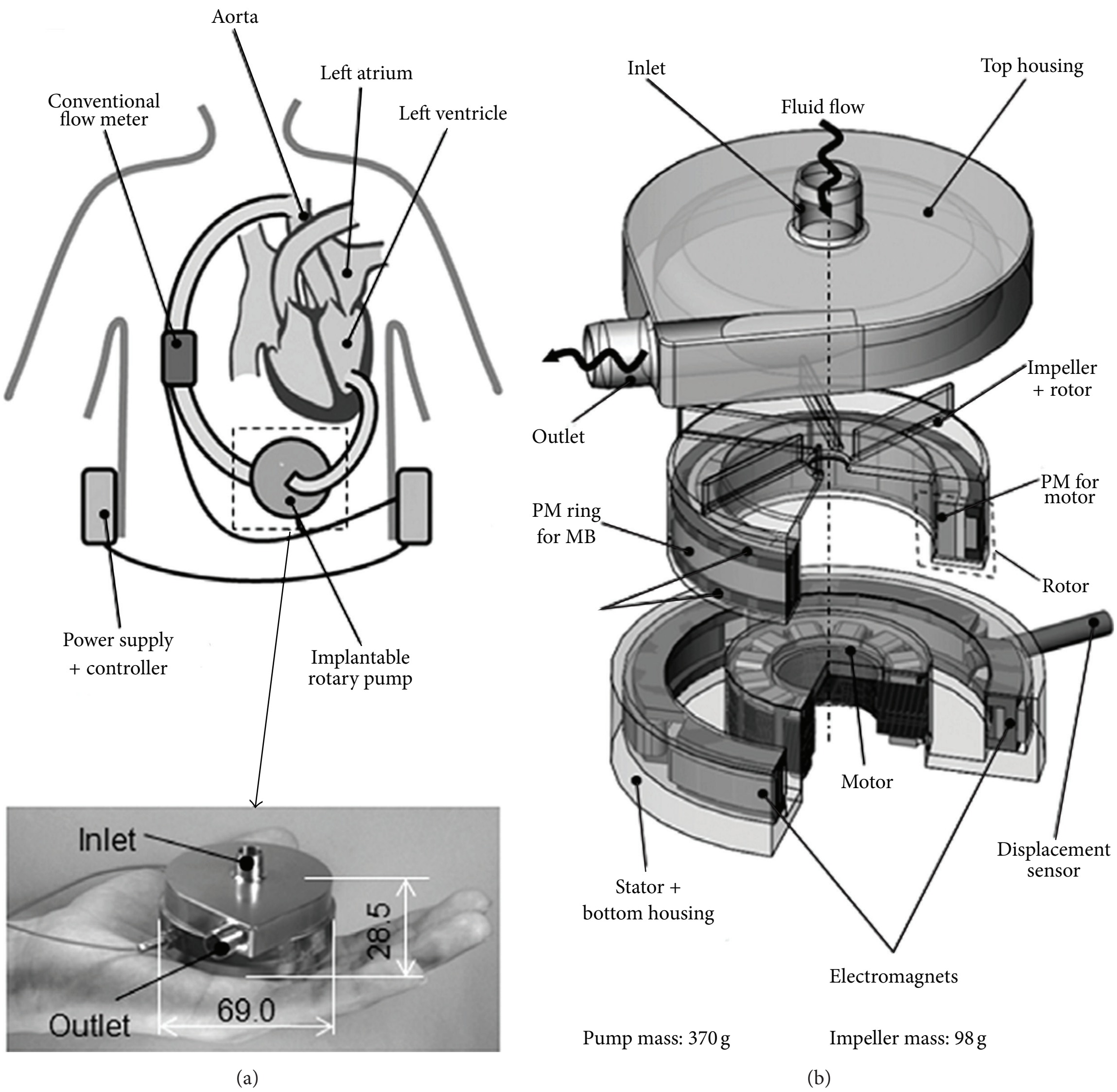


FIGURE 27: (a) Ventricular assist system and photograph of an implantable maglev CBP, and (b) configuration of the implantable maglev CBP.

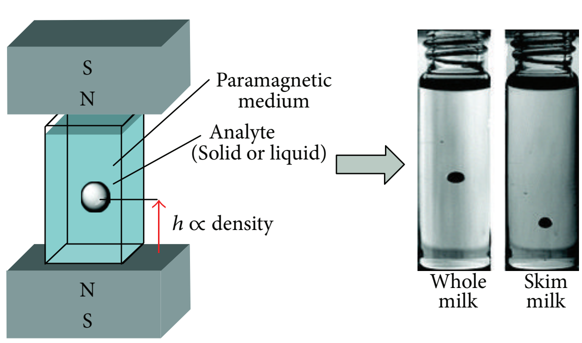


FIGURE 28: Maglev sensor.

(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.), and stationery (pen). The common point in all these applications is the lack of contact and thus no wear and friction. This increases efficiency, reduces maintenance costs, and increases the useful life of the system. The magnetic levitation technology can be used as an efficient technology in the various industries. There are already many countries that are attracted to maglev systems. Many systems have been proposed in different parts of the worlds. This paper tried to study the most important uses of magnetic levitation technology. The results clearly showed that the maglev can be conveniently considered as a solution for the future engineering needs of the world.

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