e ISSN 2277 - 3290
Print ISSN 2277 - 3282
Journal of Science
Engineering
www.journalofscience.net

AN INTRODUCTION & OVERVIEW TO MAGNETICALLY LEVITATED TRAIN

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ABSTRACT
In this paper an overview to magnetic levitated train is presented. In this context the history and development of maglev trains is discussed. The principle and working of maglev train with lateral guidance, levitation and propulsion system is discussed.

Keywords:Maglev train, Lateral guidance, Levitation, Propulsion, Linear induction.

INTRODUCTION

MEGLEV, or magnetic levitation is a system of transportation that suspends, guides and propels vehicles predominantly trains using levitation from a very large number of magnets for life and propulsion this method has the potential to exceed 4000 mph (6437 km/h) if deployed in an evacuated tunnel. If not deployed in an evacuated tube the power needed for levitation is usually not a particularly large percentage and most of the power needed is used to overcome air drag as with any other high speed train.

The term “maglev” refers not only the vehicles but to the railway system as well, specifically designed for magnetic levitation and propulsion. All operational implementations of maglev technology have had minimal overlap with wheeled train technology and have not been compatible with conventional rail tracks. Because they cannot share existing infrastructure, these maglev system is must be designed as complete transportation system. The Applied Levitation SPM Maglev system is inter-operable with steel rail track and would permit maglev vehicles and convention trains to operate at the same time on the same right of way.

There are three primary types of maglev technology:

- Electromagnetic suspension (EMS) uses the attractive magnetic force of a magnet beneath a rail to lift the train up.
- Electrodynamic suspension (EDS) uses a repulsive force between two magnetic fields to push the train away from the rail.
- Stabilized permanent magnet suspension (SPM) uses opposing arrays of permanent magnets to levitate the train above the rail.

Another experimental technology, which was designed, proven mathematically, Peer reviewed and patented but is yet to be built, is the magneto dynamic suspension (MDS), which uses the attractive magnetic force of a permanent magnet array near a steel track to life the train and hold it in place.

High speed Maglev vehicle has been the area of interest for researchers in the past [1, 2, 3 and 4]. The author [2] has carried out a broad survey of rail vehicle dynamics [5, 6] and performed ride analysis [7], dynamic analysis [8, 9], sensitivity analysis [10, 11], stability and eigenvalue analysis [12] considering 37 DoF coupled vertical-lateral model of Indian railway vehicles.

DEVELOPMENT OF MAGLEV TRAIN

Maglev has been a long standing dream of railway engineers for the past century. These engineers envisioned a train that could float above its tracks. They saw the enormous potential for a train like this. The vision of Maglev began in the beginning of the 20th century with two scientists.

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In 1904, Robert Goddard, who was a college freshman at the time, wrote a paper proposing a form of frictionless travel by raising train cars off the rail by using electromagnetic repulsion roadbeds. He said the train would travel at super-fast speeds. In 1910, Emile Bachelet applied for a patent on a rail car which for levitation would use alternating current electromagnets and for propulsion would use solenoids at intervals along a road-bed. Bachelet's dreams couldn't be realized because this concept uses too much power for conventional magnets.

In the early 1920s, a German scientist named Hermann Kemper pioneered in work in attractive-mode Maglev. He received a patent for magnetically levitating trains. Kemper continued to research and pursue his concept through the 1930s and 1940s and established the basic design for practical, attractive mode Maglev in a 1953 article.

In 1969 two Americans Gordon Danby and James Powell, were granted a patent on their design of a magnetically levitated train. This was the first patent for a design of this kind of train. This was around the same time that Germany and Japan were both getting very interested in Maglev technology. In 1970, both countries start investing money into researching maglev. In that same year the United State Federal Railroad Administration studied high-speed ground transportation.

GERMAN DEVELOPMENT

In 1969, the German government sponsored a research project which built first full scale model of a Maglev design. They called their version of the Maglev the TransRapid 01. A few years letter, the first passenger Maglev debuted and carried people for a few thousand feet at speeds of only 50 mph. The German company, Munich's KraussMaffei, which built the first TransRapid, continue to build improved versions of the TransRapid in a joint private-public funded research effort. In 1971, they completed the Transrapid 02. They completed the TR 03, TR 04 in 1972 and 1973, respectively. The TR 04 set set a new speed record for passenger Maglev by going 157 mph in December of 1973.

Germany's first large scale demonstration of the TR was in 1979 was at the International Transportation Fair in Hamburg where the TR 05 carried about fifty thousand visitors between a parking lot and the exhibition hall for six months.

At this time, a test track was erected to test the system in real word conditions. The test track was a nineteen mile track that was built between 1979 and 1987 in Northern Germany. The TR 06 was the first to be tested on this track and it reached speeds of 221 mph after the completion of the first 13 miles of the track. The TR 06 eventually reached a speed of 256 mhp and was finally retired after traveling 40,000 miles in 1990. The Trans Rapid 07 was build by Thyssen Co. in Kassel. The TR 07 reached a record speed of 280 mph. A Trans Rapid route was planned from Hamburg to Berlin in 1992. In 1998, a joint company was formed under the system houses Adtranz, Siemens, and Thyssen. This new joint company was called TransRapid International. In 2000, the government said that the Berlin Hamburg route will not be realized and TransRapid International proposed 5 alternative routes where the TransRapid can be built. None of the routes were accepted and TransRapid International started looking for outside interest in their project to save a billion dollars and 30 years of investment.

China expressed their interest in the German Maglev technology. After statistical gathering and analyzing, a contract was reached on January 23, 2001 between Shanghai and Trans Rapid International to build a line between Shanghai and its airport.

On December 31, 2002, the first commercially operated Maglev line look it maiden voyage carrying on boar Chinese Prime Minister Zhu Rongji, German Chancellor Gerhard Schroder and other high ranking politicians and business people from both countries. One year later, the world's first commercial Trans Rapid route start Schroder and other high ranking politicians and business people from both countries.one year the world's first commercial Trans Rapid route start scheduled operation in Shanghai.

JAPANESE DEVELOPMENT

The Tokaido Shinkansen was the early Japanese high speed train line. It Opened in 1964 and since then has expanded considerably. Its success also prompted the development of high speed train in the west. But the Japanese public demanded an even faster from high speed rail travel. The Shinkansen used a conventional train design, with motors and other equipment mounted on the rolling stock, electric power gathered gathered from overhead from overhead wires, and wheels running on rail. It was impossible to increase the speed much more. Some of the limitation included: Greater size and weight of on board equipment, difficulty in collecting electric power and reduced adhesion between wheels and rail at higher speeds that may cause wheel slipping. There had to be some new sort of Technology that could crate faster trains that wear just as safe as or even safe than the trains running on the Shinkansen line. The answer to this problem lied in electro magnetism.

The former Japanese National Railway (JNR) began conducting Maglev research and development in 1970. The Miyazaki Test Track was built in southern Japan was experiment and test runs were being conducted on the track. In 1979, the prototype ML-500 test train reached an unmanned speed of 517 km/h on the 7 km track, which proved that Maglev had a great potential for reaching higher speeds than any other train built before that. The Miyazaki track was later modified into a U shaped to simulate more real world track curves.

At this stage of development, the government started funding the project. The MLU001 was the first Maglev developed with government financial aid. Other models were built and continued to be tasted and experimented on the Miyazaki test track. But there was a problem with the track. It was too short and only had a single guideway with no tunnels and no inclines or declines. The experimental data gathered on the Miyazaki test track would be too limited to verify trains commercial potential and use.

After the JNR was split and privatized in 1987, the Tokaido Shinkansen experienced an increase in passenger which led to more calls to build a commercial Maglev line as soon as possible. As a result, the Yamanashi Test Line was constructed in Tamanashi Prefecture approximately 100 km west of Tokyo.

The Yamanashi test line was 18.4 km long and supported a wide range of tests to determine the commercial feasibility of the Maglev train. The track was made up 16 km of tunnels and an open section that was 1.5 km long in the middle of the track. A substation for power conversion and other facilities were located in the 1.5 km stretch of open section. Part of the line was double tracked to simulate trains going in opposite direction at super high speeds.

Trial runs began on the Yamanashi Test line in April 1997. The cars weren't levitated but instead were driven at low speeds on rubber tires. Once tested confirmed that there were no defects in the vehicles or the guideway itself, levitation runs began at the end of May 1997. The speed was increased incrementally to monitor car movement and verify braking performance. On December 12, 1997, a new word record of 531 km/h was set for manned train travel. A maximum speed of 550 km/h was set for unmanned travel 12 days later.

There was only one more problem that remained: air vibration that rattles the windows of buildings near tunnel portals when a Maglev trains enters or leaves a tunnel at high speed. Everything else seemed to be in good shape. There were no environmental problems, ground vibration measurements were well within acceptable limits. Magnetic field measured at ground level directly under than the elevated guide ways were also within acceptable limits.

Test were conducted so that two cars other at high speeds. The Vibration of the trains passing each other was so small that it could only be felt by someone actually accepting it. Overall, there were no major problems that occurred during the last runs. More testing will be required before commercial use of Maglev train in japan will start. During the next few years, these test run will be focusing on 3 things:

- Verifying long-term durability
- Finding ways to reduce costs
- Achieving more aerodynamic car designs

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

The best-known high speed maglev currently operating commercially in the IOS (initial operating segment) demonstration line of the German-built Trans Rapid train in Shanghai, China that transports people 30 km (18.6 mile) to the airport in just 7 minutes 20 seconds, achieving a top speed of 431 km/h (268 mph), averaging 250 km/h (150 mph).

Other widely commercial operating lines exist in Japan, such as the Linimo line. Maglev projects worldwide are being studied for feasibility. In Japan at the Yamanashi test track, current maglev train technology is mature, but costs and problems remain a barrier to development. Alternative technologies are being developed to address those issues.

MAGLEV R&D

A super high speed transport system with a non-adhesive drive system that is independent of wheel and rail frictional forces has been a long standing dream of railway engineers. Maglev, a combination of superconducting magnets and linear motor technology, realizes super high-speed running, safety, reliability, low environmental impact and minimum maintenance.

Research and development of Maglev, which adopts superconducting technology, has been underway at RTRI of JNR since 1970. After fundamental tests in the laboratory to verify the feasibility of high speed running at 500 km/h, the construction work of a 7km test track began in Miyazaki prefecture in 1975. The manned two car vehicle MLU001 registered a speed of 400.8 km/h in 1987 and the latest vehicle MLU002N, which debuted in 1993, was running on the Miyazaki Maglev test track.

One main development aim of RTRI is the enhancement of reliability and durability of the superconducting magnet (SCM). The SCM suffers from external magnetic disturbances caused by ground coils and from mechanical vibrations generated by vehicle dynamics; these disturbances cause quenching troubles, or the sudden disappearance of magneto motive force of the SCM.

Other development aims are as follows: aerodynamic brakes which use the aerodynamic drag of panels on the car roof, and disc brakes for high speed running ground; coils which consist of sidewall levitation coils; a high-power supply system for pulse width modulation (PWM) inverters using gate turn- off (GTO) thrusters turnout for high-or low speed passing.

A landmark for Maglev occurred in 1990 when it gained the status of a nationally-funded project. The

Minister of Transport authorized construction of the Yamanashi Maglev Test Line targeting the final confirmation of Maglev for practical use. The new test line called the Yamanashi Maglev Test Line opened on April 3, 1997 and in now being used to perform running test in Yamanashi Prefecture. In the same year, the Maglev vehicle MLX01 in a three-car train set achieved world speed records, attaining a maximum speed of 550 km/h in an unmanned vehicle run on December 24. On March 18, 1999 MLX01 in a five-car train set attained a maximum speed of 548 km/h. On April 14,1999 this five-car train set surpassed the speed record of the three-car train set, attaining a maximum speed of 552 km/h in a manned vehicle run.

In March the Maglev Practical Technology Evaluation Committee of the Ministry of Transport of Japan concluded, "The JR-Maglev has the practicability for ultra-high speed mass Transportation system," the committee also pointed out the necessity of further running tests for the following purpose: (1) confirmation of long-term durability, (2) cost reduction of its construction and operation, (3) improvement of the aerodynamics of for environmental impacts. According to this recommendation another five-year test was planned to improve these technical issues. The technical development of the Maglev has been in the second phase since fiscal 2000. On December 2, 2003, this three car train set attained a maximum speed of 581 km/h in a manned vehicle run.

PRINCIPLE OF MAGLEV TRAIN

The principal of a Magnet train is that floats on a magnetic field and is propelled by a linear indication motor. They follow guidance tracks with magnets. These trains are often referred to as Magnetically Levitated trains which are abbreviated to Maglev. Although Maglev don't use steel wheel on steel rail usually associated with trains, the dictionary definition of a train is a long line of vehicles travelling in the same direction – it is a train.

Magnetism in elementary science simply stales that like poles repel and opposites attract. When two magnets of which the same poles are towards each other are brought towards each other, a repulsion force can felt and likewise a pair of the opposite poles will attract. Maglev trains use these basic principles to force the train upwards above the track surface. The simple way of visualizing this is on imagine the train repelling away from the track surface.

So now that we have established the levitation part it, how does it move in the direction we want it to go? Maglev technology uses the principles of linear induction and magnetism to propel the train forward or backwards. Now imagine the train is levitated by magnetism upwards as well as forwards. The combination of repulsive and attractive magnetic force causes the train to move towards a region to track. In the same fashion, to slow down the train while it is moving we must apply the repulsive and attractive force in such a way opposite to which the motion started.

The easiest is to visualize this. In the diagram below, the lowercase letters represent the track's magnetic poles and the uppercase letters represent the train's magnetic poles.

Fig. 1 and Fig. 2 show the side view and top view of the track. The "==" represent the gap between the train and the track in which no contact is actually being made. Note that the side view magnets are not show in the top view so each diagram represents different set magnetic poles which controlled independently.

Notice how in the above diagram there is a force of attraction to the right. When the train reaches the position whereby the magnetic poles are directly in line with each other, the track switches the north poles (n) to south poles (s) and versa. If you continue this process the net force will result in acceleration

The braking system is the exact opposite of the above description where the net force is to the left causing the train to show down.

Since there is no physical contact between the maglev train and the track, the resultingFrictional forces due to contact are nonexistent. For this reason the only limiting factor for a maglev train's speed is air friction. If this technology was implemented in a vacuum there would be nothing holding the train back to stop if from accelerating.

There are many more complication and factors that must be considered order to fully understand the entire picture; however this is essentially the how it works

WORKING OF MAGLEV TRAIN

A maglev train floats 10 mm above the guidway on a magnetic field. It is propelled by the guidway itself rather than an onboard engine by changing magnetic fields (see right). Once the train is pulled into next section the magnetism switches so that the train is pulled on again. The electromagnets run the length of the guideway.

Understanding how Maglev trains work requires some knowledge in advance topics such as calculus, physics, and chemistry. It is important to know common variables assigned to physics terms and a brief overview of chemistry laws dealing with magnets. Most of the equations used to determine how the Maglev trains move is derived from formulas used to calculate electric current, induced voltages loops, and many other formulas dealing with electromagnetism.

One of the first concept that from the basis of how Maglev trains work is understanding magnetism and the use of magnetic propulsion. If you were to have a bar magnet you should know that one end is designated a north pole while the other end is called the South Pole. Now suppose you are given a second bar magnet experimenting with if you will find that opposite poles attract while attractive poles repel. This simple form of attraction and repulsion is the same idea used to move those gigantic Maglev trains. Since the magnets needed required enough strength to move a train engineers have devised, the Maglev train using electromagnets and superconducting magnets. Electromagnets are metals with electric current running through them giving the metals a magnetic field similar to that of the bar magnets and superconducting magnets are able to induce charge, or give charge, to a material causing repulsive forces.

Maglev railway development has since integrated these two types of magnetic systems for propulsion to control how the trains move. These magnetic suspension systems are designed so that the Maglev train can glide through air by levitating it above the actual rail line reducing friction that would normally be crated from the metal wheel and rail line used in conventional railway train. The TransRapid systems developed by in Germany utilize regular electromagnets on the undercarriage of the train to levitate the vehicle while an additional set of magnets are used to guide the train. The electrodynamic suspension or EDS system developed in Japan use superconducting electromagnets for their Maglev trains allowing the train to remain aloft for a while even after the electric current is turned off using the property of the metals to easily allow electrons to flow easier. What both systems do though is control the Maglev train's lateral guidance, levitation system, and its propulsion.

In electrodynamic system (Fig. 3), a current carrying coil is built into the vehicle. As the vehicle moves, the flux produced by the current flowing in the on-board coil induces currents either in passive coils located in the guidway or in conducting nonmagnetic sheets (typically aluminum) which form the guideway's surface. The induced currents produce a magnetic flux, which opposes that of the coils located on the vehicle and produces lift, which is a function of vehicle velocity. By using superconducting cryogenic coils in the vehicle, very high currents and, therefore, fields can be produced with negligible resistance losses.

LATERAL GUIDANCE SYSTEM

The Lateral guidance system controls the train's ability to actually stay on the track. It stabilized the movement of the train from moving left and right of the train track by using the system of electromagnets found in the undercarriage of the Maglev train. The placement of the electromagnets in conjunction with a computer control system ensures that the train dose not deviate more than 10mm from the actual train tracks.

The lateral guidance system used in the Japanese Electrodynamic suspension system is able to use on "set of four superconducting magnets" to control lateral guidance from the magnetic propulsion of the null flux coils located on the guideway of the track. Coils are used frequently in the design of Maglev trains because the magnetic fields created are perpendicular to the electric current, thus making the magnetic field stronger. The Japanese Lateral Guidance system also uses a semi-active suspension system. This system dampens the effect of the side to side vibration of the train car and allows for more comfortable train rides. This stable lateral motion caused from the magnetic propulsion is the joint operation from the acceleration sensor, control device, to the actual air spring that dampens the lateral motion of the train car.

The lateral guidance system found in the German transrapid system is similar to the Japanese model. In a combination of attraction and repulsion, The Maglev train is able to remain centered on the railway. Once again levitation coils are used to control lateral movement in the German Maglev suspension system. The Levitation coils are connected on both sides of the guideway and have opposite poles. The opposite poles of the guideway cause a repulsive force on one side of the train while creating an attractive force on the other side of the train. The location of the electromagnets on the TransRapid system is located in a different side of the guideways. To obtain electromagnetic suspension, the TransRapid system uses the attractive forces between iron-core electromagnets and ferromagnetic rails .

LEVITATION SYSTEM

The Levitation systems used in the design of the Maglev railway allow it to glide above the actual track. In electrodynamic suspension system the actual train can be as high as 80 mm above the track while the TransRapid suspension system allows it to go less than 12 mm from above the track. In the case of air drift or a turn in the railway course causes the train to lift above the distance needed to stay on track, there is enhanced current input into the levitation magnets to increase the magnetic force. Doing this ensures that the train stay on the track with gap sensors on the rail line to detect any change in the lateral shift.

In order to use magnetic levitation by induction, the team behind EDS had created a system that allowed five degress of motion. The physics of the actual lift can be described in mathematical terms. The calculated voltage of the magnetically induced coils can be tabulated according to where N is the number of turns.

V=-N coil (1)

Once the voltage is found in the coils used in the indication, a formula can be derived for the coil's current, i, as show in (2) with respect to time. Knowing the i, engineers apply Lorrentz force equation (3) calculate the lift force caused by the magnets.

Using these equations and additional equations magnetic flux you can describe the five degrees of motions in the electrodynamic suspension levitation system. These degrees are levitation height, sideways displacement, yaw, pitch and roll. Each dimension contributes to the torque of the EDS Maglev train.

The electromagnetic suspension system used in the German Transrapid system levitates the train a few millimetres from the actual track. Using a system of electromagnets, the Transrapid system attracts the coils found in the guideway of the Maglev train. The attraction of the magnetic forces occur because the currents found in both the train and the guideway flow in the same direction. Since this system uses electricity to power the magnetic fields the train is always above the track unless cut from the electric current. To prevent this from happening German engineers have put in a backup battery in the actual Maglev train in case of power failure. In electromagnetic suspension system (Figure 4 and Figure 5), a current-carrying coil excites a magnetic circuit consisting of an iron core in the vehicle and a ferromagnetic rail fixed to the track and the on-board core is attracted to the rail. Lift is provided essentially independently of vehicle velocity. When excited by a current or voltage source, the suspension is statically unstable, and appropriate displacement sensors (gap sensor) and control circuits are required to achieve statically stable and dynamically acceptable suspension characteristics. The brackets, which support the rail, are designed so that the magnet is at a specified distance from the ground. The distance is selected to restrain the vehicle from falling to gaps, which are so large that the vehicle leaves the track. The general configuration will have four magnets, one at each corner of the vehicle. Additional magnets are used for lateral control or it may be possible to obtain lateral guidance with only the lifting magnets.

PROPLUSION SYSTEM

There are two types of propulsion system used in current Maglev train. The Linear Induction Motor (LIM) is used to propel the Japanese EDS system while the Linear synchronous Motor (LSM) propels the German Transrapid system both of the system are move by the guideways themselves instead for the actual train car propulsion occurring in the Liner Induction motor is caused from the sum of four individual linear motors. The motor induce voltages to the four motors. When these voltages are combined they produce a repulsive force that pushes the train car forward. The speeds for Linear induction Motors is determined by the ratio of length of the vehicle magnet system of the length of the energized block, the sum of the coupling coefficients between vehicle magnets and the guideway coils, applied voltage and the current following in the superconducting coils.

The speed of Maglev trains in Linear Synchronous motor is determined by the frequency of the alternating current and the magnetic field direction. Propulsion is created when the current is in 'synch' with the frequency allowing for forward propulsion. In order for the train car to brake and slow down, the field simply has to be reversed allowing the train car to back without the use of friction.

Figure 1. Magnetic Levitation (Track Side View)

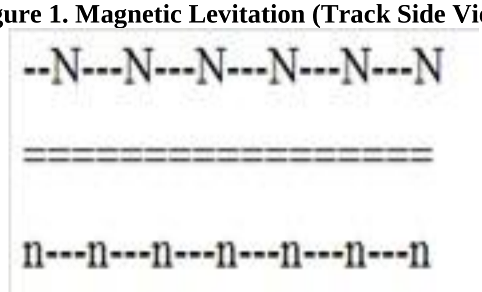


Figure 2.Magnetic Propulsion (Track top View)

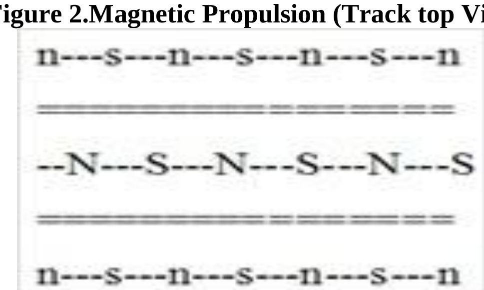


Figure 3.Electrdynamic Suspension

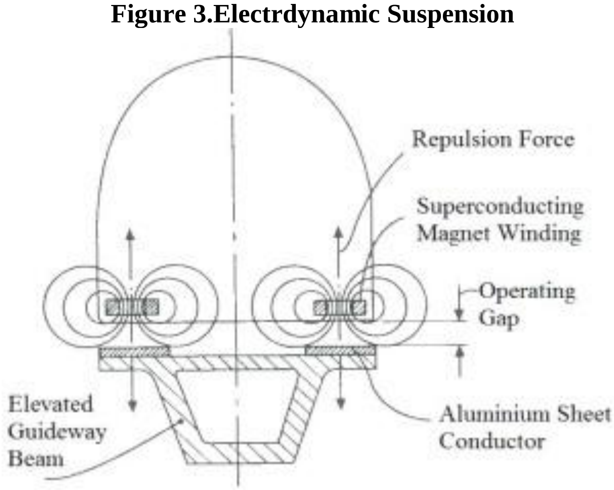


Figure 4.Electromagnetic Suspension

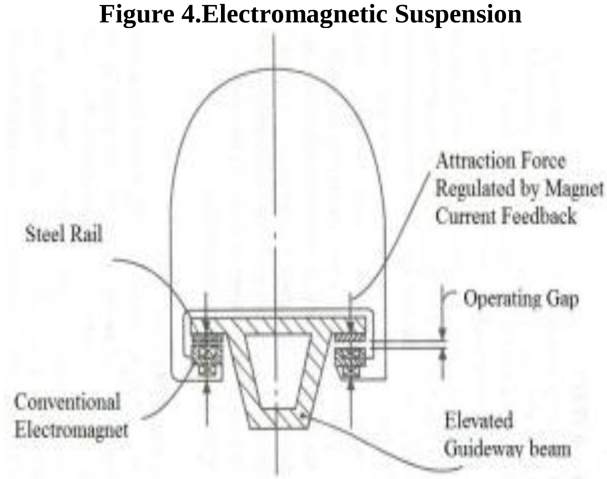
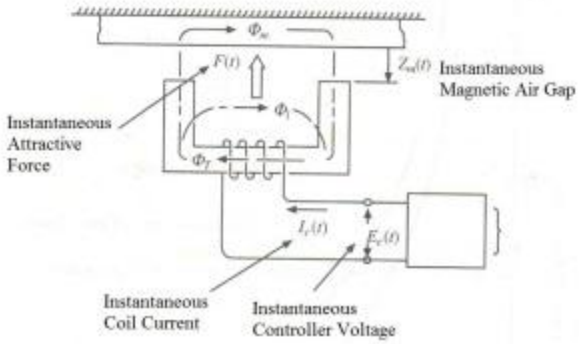


Figure 5.Schematic of Electromagnetic Suspension



CONCLUSION

Non-contacting characteristic is the main feature of Maglev, Which is concentrated on high-speed operation and environmental acceptability. There are certain areas, which require further attention such as braking at high-speeds in case of power failure. The main features of Maglev train which makes it a better choice over conventional railways are as follows:

- Greater safety; the guideway system reduces the possibility of derailment.
- Faster travel; higher maximum speeds allow fast service from city centre to city centre, permitting reduction in total travel time
- Less noise and vibrations due to absence of physical contact.
- Less maintenance as non-contact system eliminates rail replacement, wheel renewal and catenary rewiring.
- Good ride comfort at all ranges of speeds due to absence of track irregularities or track inputs.
- Spin-off benefits: development of latest technologies, such as cryogenics and superconductivity, can be expected to produce spin-off benefits for other industries.

ACKNOWLEDGEMENT: NIL

CONFLICT OF INTEREST:

The authors declare that they have no conflict of interest.

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