Maglev Trains: An Application of Magnetic Levitation

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Abstract- 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 application of magnetic levitation technology which is the Maglev train.

I. INTRODUCTION

Magnetic levitation is the use of upward magnetic forces to balance the pervasive downward force of gravity. It has already found many important uses in science and technology.

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. Construction of 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 are being achieved.

The levitation effect is provided by linear induction motor, which is also explained in this paper.

II. LINEAR INDUCTION MOTOR

A Linear Induction Motor is a special type of induction motor used to achieve rectilinear motion rather than rotational motion as in the case of conventional motors.

The basic design and construction of a linear induction motor is similar to a three phase induction motor, although it does not look like a conventional induction motor. If we cut the stator of a poly phase induction motor and lay on a flat surface, it forms the primary of the linear induction motor system. Similarly, after cutting the rotor of the induction motor and making it flat, we get the secondary of the system.

- Construction and working of Linear Induction Motor (LIM):

For understanding the construction of Linear induction motor, we will first take a look at the construction of induction motor, shown in figure 1. If we cut the stator along the line ab and make it flat then the stator will appear as shown in figure 2. The stator is cut axially and spread out flat in Linear Induction Motor (LIM). In this type of motor, the stator and rotor are called primary and secondary respectively. The secondary of the linear induction motor consists of a flat aluminum conductor with a ferromagnetic core.

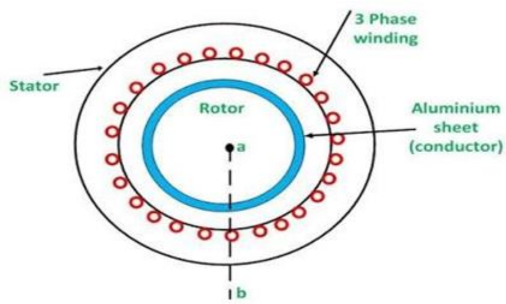

Figure 1: Induction motor

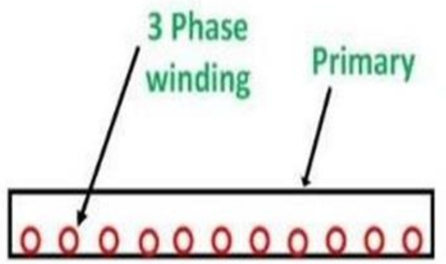

Figure 2: Primary of LIM

This makes the primary of an LIM. So primary of linear induction motor is flat and three phase winding is wound on it. Now if we make the rotor of induction motor flat then it will be nothing but a sheet of flat aluminum which is called the secondary of Linear induction motor (LIM) as shown in figure 3.

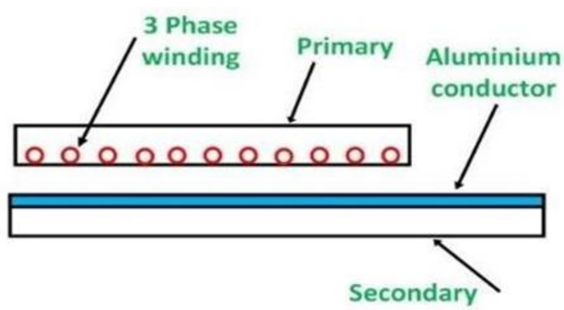

Figure 3: Secondary of LIM

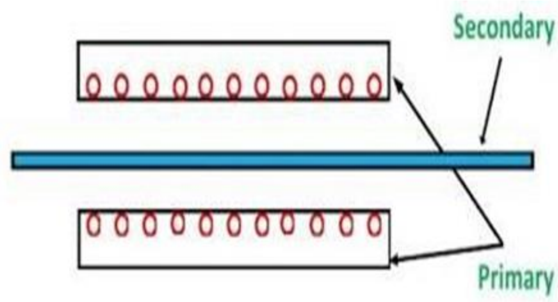

Figure 4: Secondary of LIM

If a three-phase supply is connected to the stator of an induction motor, a rotating flux is produced. This flux rotates at a synchronous speed in the air gap. Similarly, if the primary of the Linear induction motor is connected to the three-phase supply, a flux is produced which will travel across the length of the primary. Because of the travelling magnetic flux, a current will be generated in the conductor which is made of the aluminum material in the secondary of Linear induction motor.

This current, which is induced in the LIM secondary interacts with the travelling flux and produces a linear force. If secondary is fixed and the primary is free to move, the force will move the primary in the direction of the travelling wave. The working principle is depicted in figure4 using Double linear induction motor. This is another variant of Linear induction motor, used for increasing efficiency known as the Double-sided linear induction motor or DLIM. It has primary on either side of the secondary, for more effective utilization of the flux from both sides.

III. 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 acceleration. Maglev can create frictionless, efficient, far-out-sounding technologies. Though magnetically levitated trains have been the focus of much of the worldwide interest in maglev, the technology is not limited to train travel. The applications of maglev in various engineering sciences are Transportation engineering (magnetically levitated trains, flying cars), Environmental engineering (small and huge wind turbines), Aerospace engineering (spacecraft, rocket), Military weapons engineering (rocket), and Biomedical engineering (heart pump).

IV. MAGLEV TRAINS

The term maglev is derived from 'magnetic levitation'.

Basic principle of Maglev trains is about the performance of the following functions which help the train to run at high speeds.

1. Levitation
2. Propulsion
3. Lateral Guidance

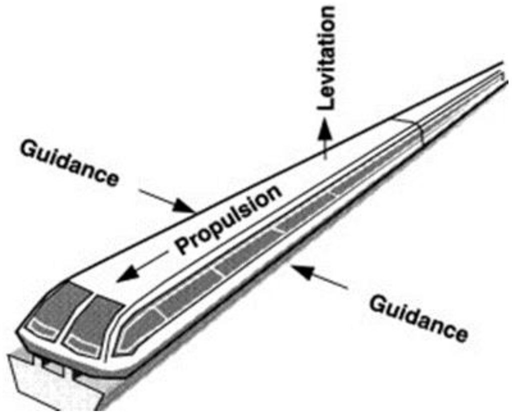

Figure 5: Functions of a Maglev train

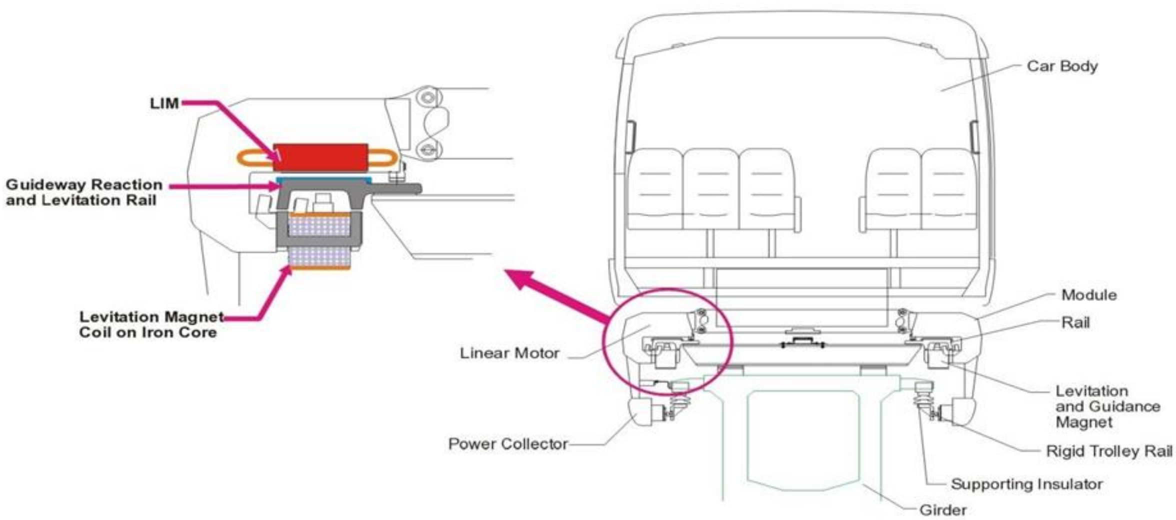

Figure 6: Closer view of propulsion/ levitation module for LIM

Maglev trains work on the principle of electromagnetic propulsion, wherein the cars are suspended, guided, and propelled using powerful magnets. The Maglev Train System has three important components – the power source, the track referred to as the 'guideway', and the gigantic magnets that are attached to the cars/track.

The guideway is made up of magnetized coils, which repel the magnets that are attached beneath the cars and make them levitate around 0.39 to 3.93 inches above the guideway. When the power is sent to these coils, it results in the formation of a unique magnetic field, which, in turn, moves the maglev.

Based on the technique used for Levitation there are two types of Maglev trains:

A. Electromagnetic suspension (EMS), wherein the attractive force of magnets is involved.
B. Electrodynamic suspension (EDS), where in the repulsive force of magnets comes into play.

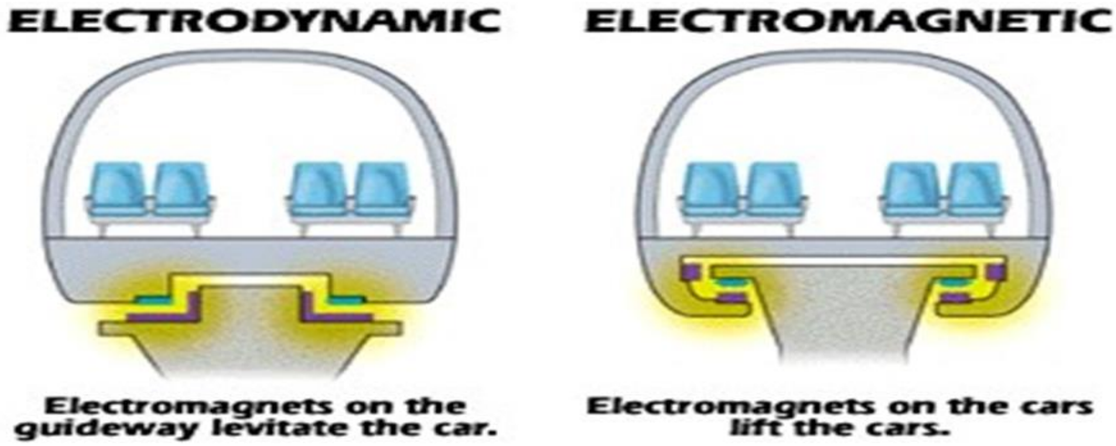

Figure 7: Levitation

A) Electromagnetic Suspension: (EMS)

Electromagnetic suspension (EMS) is the magnetic levitation of an object achieved by constantly altering the strength of a magnetic field produced by electromagnets using a feedback loop. In most cases the levitation effect is mostly due to permanent magnets as they don't have any power dissipation, with electromagnets only used to stabilize the effect.

Floating globe. Magnetic levitation with a feedback loop.

According to Earnshaw‘s theorem a paramagnetically magnetised body cannot rest in stable equilibrium when placed in any combination of gravitational and magnetostatic fields. In these kinds of fields an unstable equilibrium condition exists. Although static fields cannot give stability, EMS works by continually altering the current sent to electromagnets to change the strength of the magnetic field and allows a stable levitation to occur. In EMS a feedback loop which continuously adjusts one or more electromagnets to correct the object's motion is used to cancel the instability.

Many systems use magnetic attraction pulling upwards against gravity for these kinds of systems as this gives some inherent lateral stability, but some use a combination of magnetic attraction and magnetic repulsion to push upwards.

Magnetic levitation technology is important because it reduces energy consumption, largely obviating friction. It also avoids be wear and has very low maintenance requirements. The application of magnetic levitation is most commonly known for its role in Maglev trains

The test bed can be used as a platform for control theory and maglev work. 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).

Figure (8) 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.

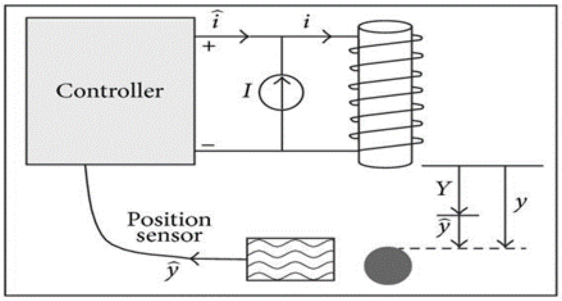

Figure 8: Magnetic Levitation System Schematic

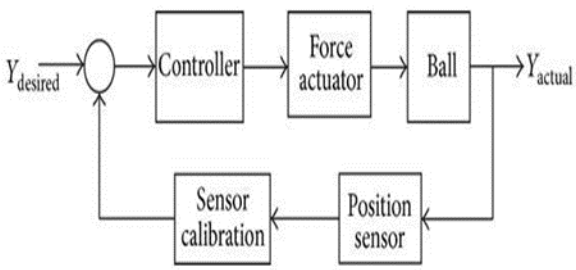

Figure 9: Magnetic System Block Diagram

Using the force, plant, and sensor models discussed previously, a closed loop control system can be designed (Figure 9). A lead-lag controller is chosen to stabilize the system.

D) Electrodynamic Suspension: (EDS)

Electrodynamic suspension (EDS) is a form of magnetic levitation in which there are conductors which are exposed to time-varying magnetic fields. This induces eddy in the conductors that creates a repulsive magnetic field which holds the two objects apart.

These time varying magnetic fields can be caused by relative motion between two objects. In many cases, one magnetic field is a permanent field, such as a permanent magnet or a superconducting magnet, and the other magnetic field is induced from the changes of the field that occur as the magnet moves relative to a conductor in the other object.

Electrodynamic suspension can also occur when an electromagnet driven by an AC electrical source produces the changing magnetic field, in some cases, a linear induction motor generates the field.

EDS is used for maglev trains, such as the Japanese SC Maglev. It is also used for some classes of magnetically levitated bearings.

Superconductors produce a supercurrent that creates a perfect mirror of 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 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.

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.

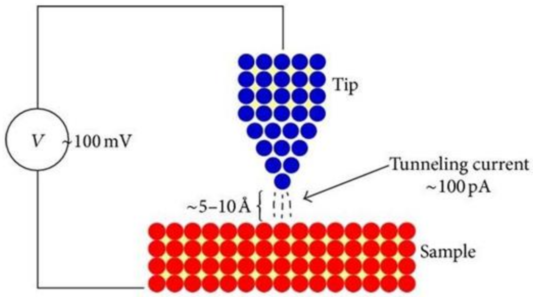

Figure (10): A schematic STM setup

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. 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.

V. ADVANTAGES OF MAGLEV TRAINS

1. The foremost advantage of maglev trains is the fact that it doesn't have moving parts as conventional trains do, and therefore, the wear and tear of parts is minimal, and that reduces the maintenance cost by a significant extent.
2. More importantly, there is no physical contact between the train and track, so there is no rolling resistance. While electromagnetic drag and air friction do exist, that doesn't hinder their ability to clock a speed in excess of 200 mph.
3. Absence of wheels also comes as a boon, as you don't have to deal with deafening noise that is likely to come with them.
4. Maglevs also boast of being environment friendly, as they don't resort to internal combustion engines.
5. These trains are weather proof, which means rain, snow, or severe cold don't really hamper their performance.
6. Experts are of the opinion that these trains are a lot safe than their conventional counterparts as they are equipped with state-of-the-art safety systems, which can keep things in control even when the train is cruising at a high speed.

VI. DISADVANTAGES OF MAGLEV TRAINS

While the advantages of Maglev Train System may seem quite promising in themselves, they are not enough to overshadow the biggest problem with the maglev trains: the high cost incurred on the initial setup. While the fast conventional trains that have been introduced of late, work fine on tracks which were meant for slow trains, maglev trains require an all-new set up right from the scratch. As the present railway infrastructure is of no use for maglevs, it will either have to be replaced with the Maglev System or an entirely new set up will have to be created—both of which will cost a decent amount in terms of initial investment. Even though inexpensive as compared to EDS, it is still expensive compared to other modes.

VII. ADVANCEMENTS OF MAGLEV TRAINS

Magnetic Levitation (maglev) can create frictionless, efficient, far-out-sounding technologies. Maglev trains reach speeds faster than 300 miles per hour while hovering a few inches above the rail. By eliminating friction, maglev trains use less energy and can significantly reduce costs.

CONCLUSION

Magnetic Levitation is an advanced technology with promising future scopes to be used in every field. It has various cases including clean energy, building facilities, transportation systems, weapons, toys and so on. There are so many countries which are attracted to maglev systems. Many systems have been proposed all over the countries and number of corridors have been selected and researched. The main point of all these applications is the lack of contact and thus no wear and friction. The increase efficiency, reduce the maintenance cost and increase the useful life of the system.

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