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Design and Analysis of Maglev Trains

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Abstract: ***For decades, conventional trains, a major source of land transportation, have served people around the world. But the issue is that conventional trains create too much noise and pollution. Also the world is becoming a smaller place for business. As such, people travel longer distances, more often, and so there are longer travel times. This leads to too much fossil fuel consumption and that rate is increasing. That is why some people say, in the next 50 years, that the fossil fuel resource is going to run out. Faster fuel consumption also leads to increased pollution in the environment. So in short, we need travel times to be made shorter and we need a renewable energy source which is clean. A method of supporting and transporting objects or vehicles which is based on the physical property that the force between two magnetized bodies is inversely proportional to their distance. By using this magnetic force to counterbalance the gravitational pull, a stable and contactless suspension between a magnet (magnetic body) and a fixed guide way (magnetized body) may be obtained. In magnetic levitation (Maglev), also known as magnetic suspension, this basic principle is used to suspend (or levitate) vehicles weighing 40 tons or more by generating a controlled magnetic force. By removing friction, these vehicles can travel at speeds higher than wheeled trains, with considerably improved propulsion efficiency (thrust energy/input energy) and reduced noise. In Maglev vehicles, chassis-mounted magnets are either suspended underneath a ferromagnetic guideway (track) or levitated above an aluminum track.***

Keywords: Conventional, Magnetic Suspension, Maglev Train

1. Introduction

The concept of magnetically levitated or maglev trains is of very much interesting. The conventional trains with wheelsand guide rails turn to be uneconomical beyond 200 km/hr because at this high speed, air resistance and hence the dragforce increases. Therefore, they are very much expensive and require intensive maintenance. Maglev trains avoid thesedisadvantages and prove highly beneficial. It is based on the three principles viz. electro dynamic suspension, electromagnetic suspension and propulsion by LSMprinciple. Its various elements are carefully designed. The Maglev trains are proved very much useful by theenvironmental consideration. Because of its importance and benefits, it is important from the study point of view. Thus,thanks to scientists who have worked hard for its research and implementation? It is remarkably noted that progress hasbeen achieved in the field of science and technology. Hence by absorbing those techniques, it is believed that the day ofimplementation of maglev trains all over the world will not be far away. In most current designs, magnetic forces are used to perform all three functions, although a nonmagnetic source of propulsion could be used. No consensus exists on an optimum design to perform each of the primary functions. In the attraction-type system, a magnet-guideway geometry is used to attract a direct-current electromagnet toward the track. This system, also known as the electromagnetic suspension (EMS) system, is suitable for low- and high-speed passenger-carrying vehicles and a wide range of magnetic bearings. The electromagnetic suspension system is inherently nonlinear and unstable, requiring an active feedback to maintain an upward lift force equal to the weight of the suspended magnet and its payload (vehicle).

In the repulsion-type system, also known as the electrodynamic levitation system (EDS or EDL), a superconducting coil operating in persistent-current mode is moved longitudinally along a conducting surface (an aluminum plate fixed on the ground and acting as the guideway) to induce circulating eddy currents in the aluminum plate. These eddy currents create a magnetic field which, by Lenz’s law, opposes the magnetic field generated by the travelling coil. This interaction produces a repulsion force on the moving coil. At lower speeds, this vertical force is not sufficient to lift the coil (and its payload), so supporting auxiliary wheels are needed until the net repulsion force is positive. The speed at which the net upward lift force is positive (critical speed) is dependent on the magnetic field in the air gap and payload, and is typically around 80 km/h (50 mi/h). To produce high flux from the traveling coils, hard superconductors (type II) with relatively high values of the critical field (the magnetic field strength of the coil at 0 K) are used to yield air gap flux densities of over 4 tesla. With this choice, the strong eddy-current induced magnetic field is rejected by the superconducting field, giving a self-stabilizing levitation force at high speeds (though additional control circuitry is required for adequate damping and ride quality.

2. The Types of Maglev Methods

- Repulsion between like poles of permanent magnets or electromagnets.
- Repulsion between a magnet and a metallic conductor induced by relative motion.
- Repulsion between a metallic conductor and an AC electromagnet.
- Repulsion between a magnetic field and a diamagnetic substance.

- Repulsion between a magnet and a superconductor.
- Attraction between unlike poles of permanent magnets or electromagnets.
- Attraction between the open core of an electromagnetic solenoid and a piece of iron or a magnet.
- Attraction between a permanent magnet or electromagnet and a piece of iron.
- Attraction between an electromagnet and a piece of iron or a magnet, with sensors and active control of the current to the electromagnet used to maintain some distance between them.
- Repulsion between an electromagnet and a magnet, with sensors and active control of the current to the electromagnet used to maintain some distance between them.

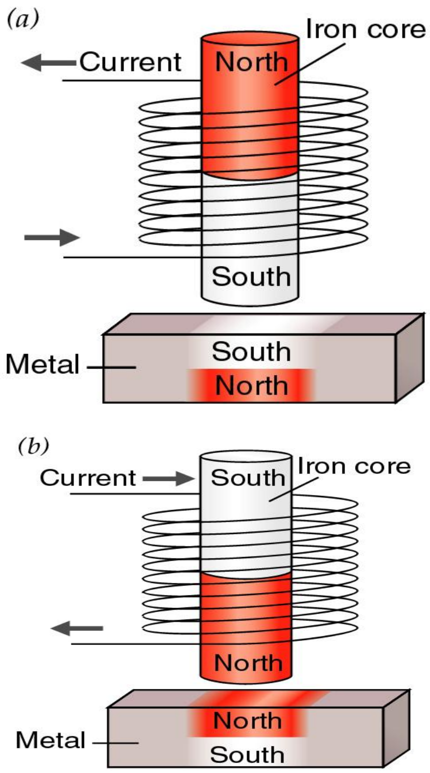

Figure 1: EMS suspension system

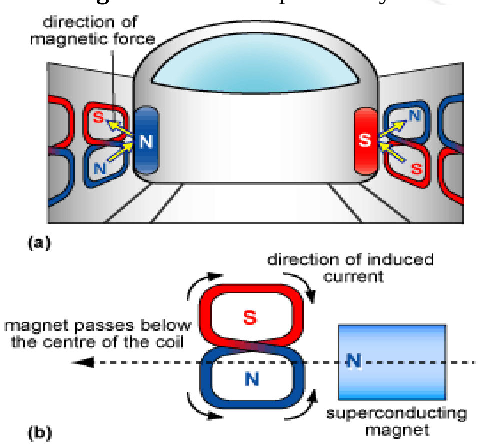

Figure 2: EDS suspension system

3. Evolution of Maglev

The goal of using magnets to achieve high speed travel with non-contact magnetically levitated vehicles is almost a century old. In the early 1900's, Bachelet in France and Goddard in the United States discuss the possibility of using magnetically levitated vehicles for high speed transport. However, they do not propose a practical way to achieve this goal.

On August 14, 1934, Hermann Kemper of Germany receives a patent for the magnetic levitation of trains. Research continues after World War II. In the 1970s and 1980s, development, commissioning, testing and implementation of various Maglev Train systems continues in Germany by Thyssen Henschel. The Germans name their Maglev system "Transrapid".

In 1966, in the USA, James Powell and Gordon Danby propose the first practical system for magnetically levitated transport, using superconducting magnets located on moving vehicles to induce currents in normal aluminum loops on a guideway. The moving vehicles are automatically levitated and stabilized, both vertically and laterally, as they move along the guideway. The vehicles are magnetically propelled along the guideway by a small AC current in the guideway.

In 1992, the Federal Government in Germany decides to include the 300 km long superspeed Maglev system route Berlin-Hamburg in the 1992 Federal Transportation Master Plan.

In January of 2001, in the US, Transportation Secretary Rodney Slater selects the Pittsburgh and the Washington - Baltimore routes for detailed environmental and project planning. Later that month in China, a contract is concluded between the city of Shanghai and the industrial consortium consisting of Siemens, ThyssenKrupp, and Transrapid International to realize the Shanghai airport link. In March, the construction of the Shanghai project begins.

In the future, Maglev promises to be the major new mode of transport for the 21st Century and beyond because of its energy efficiency, environmental benefits and time-saving high velocity transport. Because there is no mechanical contact between the vehicles and the guideway, speeds can be extremely high. Traveling in the atmosphere, air drag limits vehicles to speeds of about 300 - 350 mph. Traveling in low pressure tunnels, Maglev vehicles can operate at speeds of thousands of miles per hour.

The energy efficiency of Maglev transport, either in kilowatt-hours per passenger mile for personal transport, or kilowatt hours per ton-mile for freight, is much lower for Maglev than for autos, trucks, and airplanes. It is pollution free, can use renewable energy sources such as solar and wind power, and in contrast to oil and gas fueled transport, does not contribute to global warming. It is weather independent, and can carry enormous traffic loads - both people and goods - on environmentally friendly, narrow guideways. The cost of moving people and goods by Maglev will be considerably less than by the present modes of auto, truck, rail, and air.

4. Technology and Working of Maglev Trains

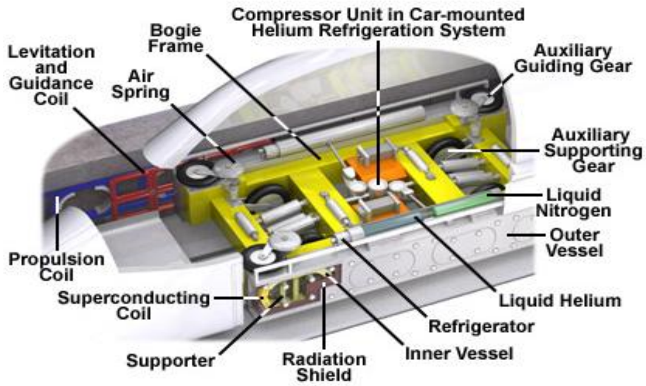

Figure 3: Internal working of the Maglev trains

Support electromagnets built into the undercarriage and along the entire length of the train pull it up to the guideway electromagnets, which are called ferromagnetic reaction rails. The guidance magnets placed on each side of the train keep it centered along the track and guide the train along. All the electromagnets are controlled electronically in a precise manner. It ensures the train is always levitated at a distance of 8 to 10 mm from the guideway even when it isn't moving. This levitation system is powered by onboard batteries, which are charged up by the linear generator when the train travels. The generator consists of additional cable windings integrated in the levitation electromagnets. The induced current of the generator during driving uses the propulsion magnetic field's harmonic waves, which are due to the side effects of the grooves of the long stator so the charging up process does not consume the useful propulsion magnetic field. The train can rely on this battery power for up to one hour without an external power source. The levitation system is independent from the propulsion system.

5. System

Electronically controlled support magnets located on both sides along the entire length of the vehicle pull the vehicle up to the ferromagnetic stator packs mounted to the underside of the guideway. Guidance magnets located on both sides along the entire length of the vehicle keep the vehicle laterally on the track. Electronic systems guarantee that the clearance remains constant (nominally 10 mm). To hover, the Maglev requires less power than its air conditioning equipment. The levitation system is supplied from on-board batteries and thus independent of the propulsion system. The vehicle is capable of hovering up to one hour without external energy. While travelling, the on-board batteries are recharged by linear generators integrated into the support magnets.

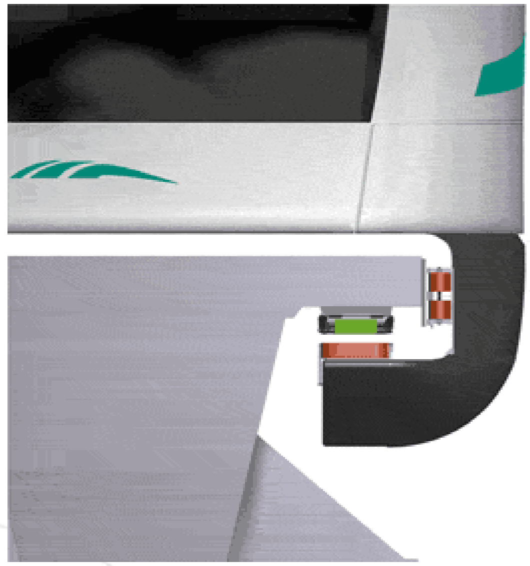

Figure 4: Maglev Guideway

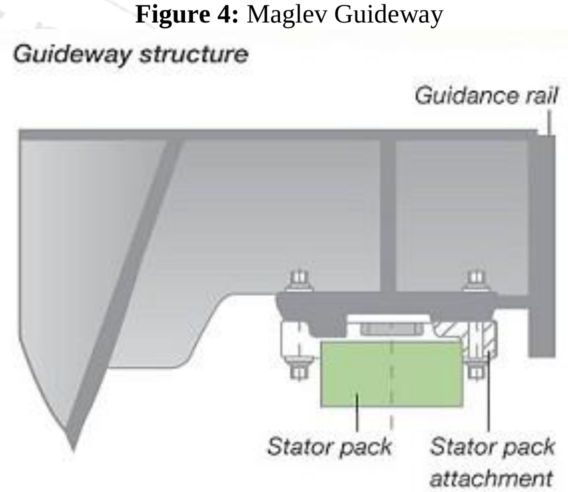

Figure 5: Guideway Structure

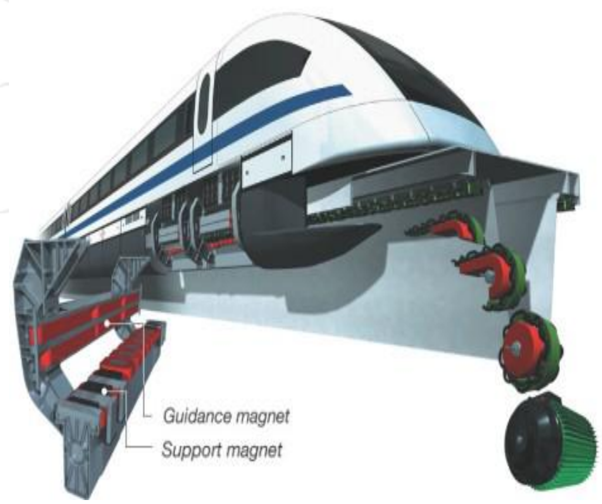

Figure 6: Guidance and Support Magnet

Maglev vehicles comprise a minimum of two sections, each with approx. 90 seats on average. According to application and traffic volume, trains may be composed of up to ten sections (two end and eight middle sections).

However, the Maglev is suitable for transporting goods as well. For high-speed cargo transport, special cargo sections can be combined with passenger sections or assembled to form dedicated cargo trains (payload up to 15 tons per section). As the propulsion system is in the guideway, neither the length of the vehicle nor the payload affect the acceleration power.The synchronous longstator linear motor of the Maglev system is used both for propulsion and braking. It is functioning like a rotating electric motor whose stator is cut open and stretched along under the guide way. Inside the motor windings, alternating current is generating a magnetic traveling field which moves the vehicle without contact. The support magnets in the vehicle function as the excitation portion (rotor). The propulsion system in the guideway is activated only in the section where the vehicle actually runs.

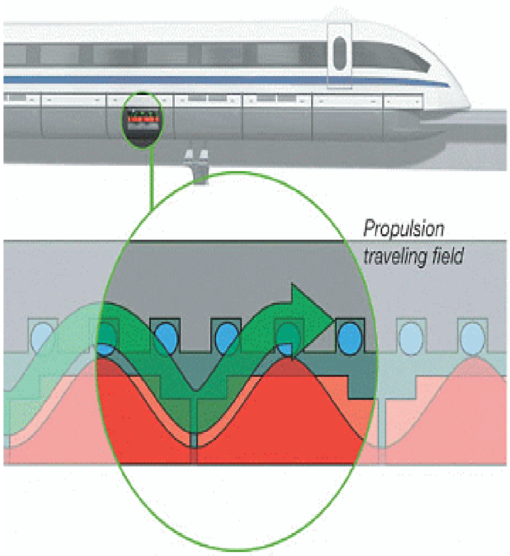

Figure 7: Process of Propulsion and the traveling field

The speed can be continuously regulated by varying the frequency of the alternating current. If the direction of the traveling field is reversed, the motor becomes a generator which brakes the vehicle without any contact. The braking energy can be re-used and fed back into the electrical network. The three-phase winded stator generates an electromagnetic travelling field and moves the train when it is supplied with an alternating current. The electronmagnetic field from the support electromagnets (rotor) pulls it along. The magnetic field direction and speed of the stator and the rotor are synchronized. The Maglev's speed can vary from standstill to full operating speed by simply adjusting the frequency of the alternating current. To bring the train to a full stop, the direction of the travelling field is reversed. Even during braking, there isn't any mechanical contact between the stator and the rotor. Instead of consuming energy, the Maglev system acts as a generator, converting the breaking energy into electricity, which can be used elsewhere.

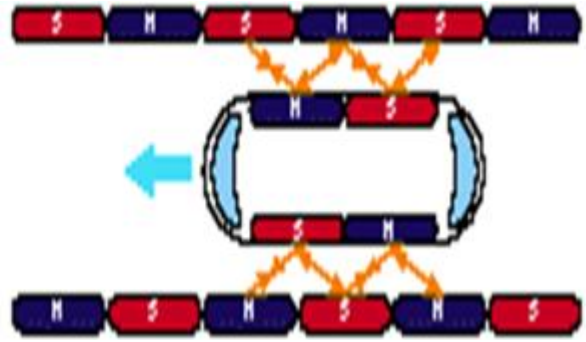

Figure 8: Repulsion of magnets

6. The Maglev Track

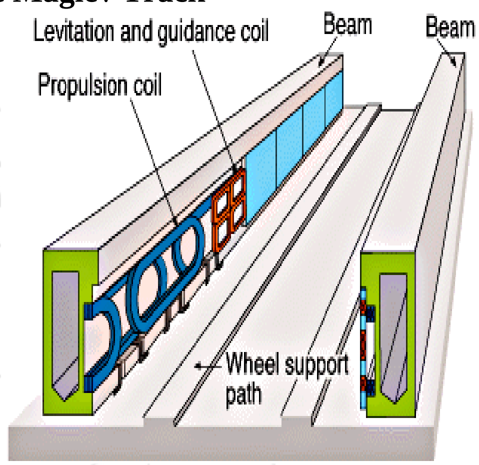

Figure 9: Maglev track

The magnetized coil running along the track, called a guideway, repels the large magnets on the train's undercarriage, allowing the train to levitate between 0.39 and 3.93 inches (1 to 10 cm) above the guideway. Once the train is levitated, power is supplied to the coils within the guideway walls to create a unique system of magnetic fields that pull and push the train along the guideway. The electric current supplied to the coils in the guideway walls is constantly alternating to change the polarity of the magnetized coils. This change in polarity causes the magnetic field in front of the train to pull the vehicle forward, while the magnetic field behind the train adds more forward thrust.

7. Electromagnetic Suspension (EMS)

This system is arranged on a series of C-shaped arms. Upper part of the arm is attached to the vehicle (the train) and lower inside edge of the arm contains the electromagnet coil. The guideways is placed inside the arm with another electromagnet coil is attached at the bottom of it. The two coils with opposite poles are facing each other and create an attractive force as shown in Figure 2. Then, the attractive force causes the train to be pushed upward and thus, levitate. However, the magnetic attraction varies inversely with cube of distance. It means a slight distance changes between the train and the guideway, will produce a significantly varying force. So, a feedback system is created to maintain the optimum distance (approximately 15mm or 0.59in) between the train and the guideway.

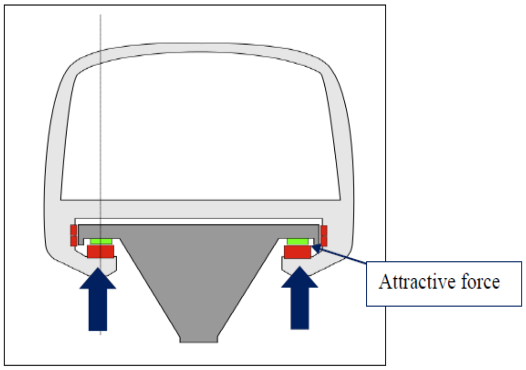

Figure 10: Electromagnetic Suspension. Source: "Magnetschwebebahn" by Moralapostel (vektorisiert von Stefan 024)

8. Electrodynamic Suspension (EDS)

In this system, both the train and the guideway exert magnetic fields. The train is levitated by repulsive and attractive forces between these magnetic fields. These magnetic fields are created by **superconducting** magnets that are attached to the train and the guideway. Looking at Figure 3, the repulsive and attractive force is created by the **induced magnetic field** in the conducting coils in the system. Nonetheless, at slower speed (below 30 km/h or 19 mph), current induced in this coils and resultant **magnetic flux** are not large enough to levitate the train. So, wheels or other form of landing gears are installed to support the train until it reaches the take-off speed.

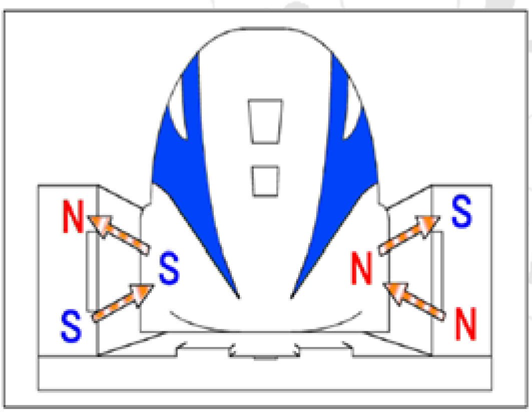

Figure 11: Electrodynamic Suspension. Source: "JR Maglev-Lev"

9. Propulsion

In order for the train to move, a force that drives it forward is needed. Generally, a Maglev train does not have an engine. It uses electric linear motor to achieved propulsion. A normal motor will have a **stator** and a **rotor**. A stator is used to generate rotating magnetic field that induced rotating force on a rotor. As a result, the rotor will rotate. Likewise, linear motor is like an unrolled version of the normal motor as shown in Figure 4. In this motor, instead of having a rotating magnetic field, the stator creates the magnetic field across its length. Therefore, the rotor will experience a linear force that is pulled across the stator making the rotor moves forward in straight line.

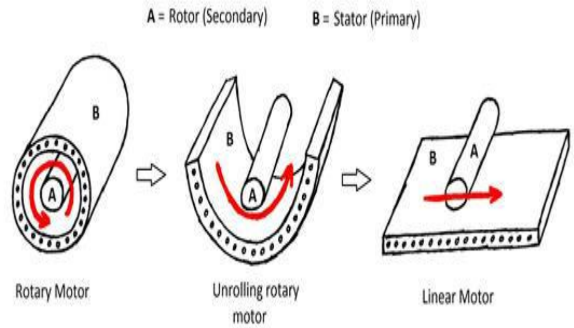

Figure 12: Normal motor and Linear motor. Source: Cornell Wilson

The concept is applied to the Maglev train. In this case, the train is the rotor and the guideway is the stator. As long as the guideway is induced with magnetic field, the train will move along its track. This system is called Linear Induction Motor (LIM). However, this system causes the train to be lag behind the guideway's**moving field** and results in speed and energy losses. So, a new system called Linear Synchronous Motor (LSM) is introduced. The lag is removed by attaching a permanent magnet to the train to create its own static magnetic field. With addition of the magnet, the train travel in synchronize with the moving field. For a long run in traction, LIM is preferred and for short run, LSM is preferred.

10. Guidance

Guidance is important to keep the train to be centered over the guideway and prevent lateral displacement. Guidance system generally uses repulsive magnetic force to achieve the position intended. However, different levitation system has a different guidance.

i) EMS

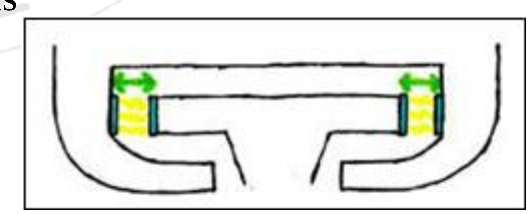

Figure 13: Guidance system in EMS. Source: Cornell Wilson

In this system, two electromagnetic coils are placed on the train, facing the sides of the guideways as shown in Figure 5. Repulsive magnetic force from both sides of the train keep the vehicle laterally on the guideway. Gap sensors are installed to detect changes in gap width so the current supplied to the guideway can be adjusted accordingly, allowing the train to shift back to the center.

ii) EDS

In this system, guidance is coupled in the levitation system. Looking at Figure 6, propulsion coils are set on the left and right side of the guideway. When the train runs in the center of the guideway, induced *electromotive force (EMF)* cancel each other out. Through this connection, if the train moves closer to either side of the guideway, circulating current between these two coils is induced; as result, it creates a force that will push the train back to the center.

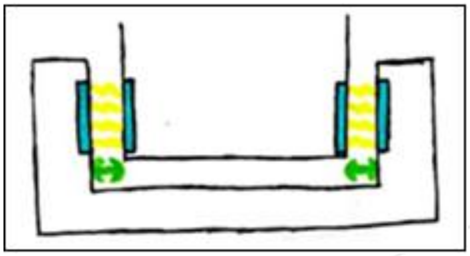

Figure 14: Guidance in EDS. Source: Cornell Wilson

11. Conclusion

The Maglev train is considered for both urban transportation and intercity transportation systems. In the low–medium speed Maglev train, the operating routine is shorter than the highspeed train. Therefore, EMS technology and LIM is preferred from the construction cost viewpoint. However, in high-speed operation, EDS technology and LSM is preferred for controllability and reliability. In addition, as along with the development of the high temperature superconductor and new type of permanent magnets, stronger magnetic energy that is more cost effective will be used for the Maglev train. Authors are sure that this technology can be utilized for not only train application but also aircraft launching systems and spacecraft launching systems.

It only remains to be said that besides core technologies, there is still the need to obtain a better understanding of how various factors may influence the system. For example, the dynamic behavior of the vehicle with the influence of the guideway may cause the mechanical dynamic resonance phenomena; air vibration rattles the windows of buildings near tunnel portals when a Maglev train enters or leaves a tunnel at high speed; the passenger safety issue is not considered fully; vehicle vibration generated from the rough guideway construction also remains. And furthermore, cost-effectiveness is still undecided.

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