

Will Pendleton

010531335

The Maglev Train

When the Transcontinental Railroad was constructed in 1866, it was hailed as the “remedy for every evil,” be it “social, political, financial, or industrial,” a chance for workers to be “remembered men” their generation. Yet, in the present day, railroads and the idea of travel by train has fallen by the wayside to the automobile and the airplane, now only holding a certain value of nostalgia in the hearts of Americans. However, with the idea of sustainable energy breathing down the collective neck of humanity more fiercely than ever, the idea of “the train” is making a comeback, in an all-knew, highly technological fashion. The Magnetic Levitation Train is not a train in the traditional sense, while it does carry passengers on pre-constructed track to designated locations, the Maglev Train does so using only the power of magnetism, all while hovering gently over the track. The Maglev technology offers the speed and efficiency of air travel, with the convenience of automobiles, all without depending upon traditional fuel and engine designs. Maglev Trains, which run solely on electricity, use the science of electromagnetism to operate, as well as some principles of permanent magnetism, and induction of current. Currently, there are two main designs of Magnetic Levitation trains: Electromagnetic Suspension, and Electrodynamic Suspension, each with slightly varying constructions on the Maglev train car, as well as the all-important track. Maglev trains offer an alternative to human transportation that may very well be a significant player in the future of infrastructure and transportation technology, all accomplished with simple principles of electromagnetism.

Before an in-depth discussion of Maglev systems can even be attempted, a cursory knowledge of the principles of electromagnetism, as well as train motion, is required.

The outright simplest way to explain the principle of Electromagnetism is this: “by running electric current through a wire, you can create a magnetic field” (howstuffworks.com). When a copper wire is connected to the both leads of a battery, current flows through it, this in turn produces a magnetic field that encircles the wire in a direction discernable by the “right hand rule”. To quickly explain the right hand rule, imagine a right hand grasping the copper wire in the example, with the thumb pointing in the direction of the flowing current. The resulting direction that the fingers curl around the wire is the direction that the magnetic field encircles the copper wire. A permanent magnet, which is most often identified in a bar shape, is one that constantly produces a magnetic field and has two poles: north and south. Magnets, and more specifically their poles, follow the principle that opposite poles attract each other and like poles repel each other. The basic principles that permanent magnets follow also apply to electromagnets, one important caveat being that in order to produce a magnetic field like a permanent magnet, an electromagnet must have current flowing through it.

The electromagnet design that is most commonly used in Maglev technology is the coil. When a current-carrying wire is wrapped in a loop, the resulting magnetic field it produces is in a certain direction, straight through the loop, dependent on the direction of current. This, once again is discernable using the “right-hand-rule”. Once again, imagine a right hand grasping the coil of wire with the fingers curling around the wire in the direction of the flowing current. The resulting magnetic field from this coil of wire is the

resulting direction of the thumb on the right hand. This current induced magnetic field produced by the coil of wire can be increased by adding to the number of turns in the wire, decreasing the overall length of the coil, and increasing the amplitude of the current running through the wire. If a length of copper wire were wrapped around a common wood nail a number of times, then connected to both ends of a battery, the result would be a rudimentary electro-bar-magnet. If current were run through the wire, a magnetic field would be produced within the coil which would transform the nail into a bar magnet with a north and south pole. However, as with all electromagnets, once the copper wire is disconnected and the current ceases to flow, the magnetic field will disappear.

Electromagnetic propulsion can be defined as “any method of propelling vehicles that uses the principle of electromagnetism” (articleworld.org). The main principle that this certain method of propulsion follows is that “when current is passed through a conducting coil” the result is a “magnetic force” that seeks to “oppose the flow of current” (articleworld.org). Electromagnetic propulsion is used mainly in two separate fields, spacecraft propulsion, and the subject of this report, magnetic levitation trains. The basic Maglev train makes use of electromagnetic force to account for three planes of motion: “guidance, propulsion, and levitation” (Singhal). Perhaps the most important plane of all three, the levitation of the train accounts for not only the “elimination of friction”, but also the “[reduction] of vehicle maintenance” (Freeman). In every Maglev system, the train is levitated due to either repulsion or attraction of magnet to magnet, resulting in a train that is hovering a short distance above the track. Of course, this levitation would be merely a parlor trick if there were nothing to propel the train down the track, or silently bring it to a halt. A general definition of propulsion, as it relates to

Maglev trains, is “a system, with no conventional engine, that uses the principle of attraction and repulsion to move” (Singhal). The final, but in no way least important plane of motion is that of guidance, or in other words, the force that keeps the train on the tracks. Guidance systems vary in all three systems, but the main principle of each is to keep the train within a very small parameter of lateral motion, using both repelling and attracting magnets. To give an example, if a Maglev train was too shifted far to the right, from the perspective of the engineer, the magnets on the right side of the train would increase the magnetic attraction on the train to draw it closer back to the track, while the magnets on the left would decrease their attractive force to allow more motion to the left, to correct the train. The final result of these three processes is a nearly autonomous train, capable of reaching airplane-speeds, while maintaining a safe, smooth, absolutely frictionless ride.

Electromagnetic suspension (EMS) is one of the two main systems employed today in Maglev train technology. This system uses “conventional electromagnets located on the underside of the train” (Singhal). These electromagnets are attached to “wrap around” fins that conceal the guideway, which is correspondingly “t-shaped” (Singhal). As seen in Figure.1, the electromagnets on the train’s bottom “fins” are directly underneath a “ferromagnetic guide rail” that is attached to the underside of the guideway’s “t-bars” (Singhal). Here lies the main driver behind the EMS’s levitation. When the electromagnets in the undercarriage of the train are powered on, they produce a magnetic field that, when paired with the ferromagnetic guide rail, resulting in a very strong attractive force, strong enough to lift the entire train and keep it levitated for the duration of the trip. The strength of the electromagnets responsible for levitation are

adjusted both manually by the conductor and electronically by the on-board computer in order to keep the train between 3mm and 12mm above the track.

The propulsion of the EMS train is based on the principle of “electromagnetic attraction”, or a “pull system” (Freeman). In the guideway, there are, in addition to the ferromagnetic guide rail used for levitation, ferromagnetic packets that “attract the electromagnet onboard the maglev...when activated” (Freeman). As the train moves down the track, the packets in the guideway are “sequentially activated” so that the activated packets are always “just in front of the Maglev vehicle”, which results in the electromagnets onboard “chasing the current forward along the track” providing “forward motion” (Freeman). The train “surfs” the travelling electromagnetic wave down the track until braking, which is done by simply “reversing the magnetic field”, although some models of trains are equipped with “air flaps” to increase drag and wheels that “extend downward” much like the landing gears of a plane (Freeman).

To account for the guidance of the EMS, “guidance coils and sensors” are placed both on the edges of the track as well as the fins of the train to keep the train “centered above the guideway (Singhal). The lateral gap of the EMS is nearly equivalent to the vertical, 3mm-12mm, which means that the on-board computer, as well as backup manual controls are used to “control the current running through the guidance magnets” to either attract or let the train move freely (Singhal). These guidance magnets also account for the EMS’s ability to “tilt, pitch, and roll” during turns much more freely than the EDS system (Singhal).

The benefits of the electromagnetic suspension system are many, and highly lucrative in regards to construction and maintenance. First of all, the EMS system, as

with all Maglev systems, does not produce any “concomitant heat” due to the friction of traditional “wheel in rail” train systems, and therefore cuts down on maintenance costs by “nearly half” (Freeman). Also, as with all Maglev systems, once the large “start-up capital construction cost” is covered, the operating cost of the system, since it primarily uses “electricity in electromagnets”, can be, at the most, “one-half that of conventional rail” (Freeman). However, these are shared benefits of all Maglev systems, the EMS-specific benefits have much more potential. The EMS, largely tested in Germany with the company Transrapid, has seen much more “in-field testing” with a large test track, and many years of successful work under its belt. It is because of this that it is largely agreed upon that if large-scale Maglev construction were to take place, EMS would be the system most commonly seen (Freeman). Also, unlike the EDS, the EMS requires no secondary propulsion system, as it is capable of maintaining levitation for days at a time. Also equally important, the EMS, with its wrap-around fins, is nearly impossible to derail, which means that even if power were to be severed from the train and the track, the train would fall a mere ~10mm and screech to a stop along the track. The experience would not be pleasant in the least, but the point is, it would be absolutely safe.

Electrodynamic Suspension (EDS) is the other main system of Maglev train construction. The main difference between the EMS and EDS systems is that the EDS is largely considered a “repulsive system” in which a majority of the three planes of motion are achieved due to principles of magnetic repulsion (Freeman). Also, the main construction of the EDS varies heavily from the construction of the EMS. As seen in Figure.2, the EDS train sits in a “trough-like” track, where the sides of the track, or guide walls, wrap around the lower half of the track, much like the EMS train wrapped around

the guideway. To account for levitation, the EDS contains “superconducting magnets” or “SCMs” in the bottom of the vehicle, located above a track that is either an “aluminum guide rail” or a “set of conducting coils” (Freeman). As the SCMs in the train pass over the track, an eddy current is induced in the guideway, that shares polarity with the SCMs onboard (Freeman). The result of this shared polarity is a repulsion effect on the magnets, and since the guideway is built into the ground and cannot move, the train is lifted up above the track and “levitated”. The gap between the track and train is much larger than the EMS system at around 5 inches, and is regulated by the induced eddy currents (Freeman). For example, if the train for some reason is carrying over its intended load, the distance between the track and train will decrease, however, with the decrease in distance, the resulting repulsion of the train by the conducting coils increases, resulting in a separation gap equivalent to the gap reached at capacity. The one drawback of the EDS’s levitation system is that no levitation is produced until the train reaches a minimum speed of 25 mph, since induced current produces the levitation.

The guidance system of the EDS functions very similarly to the levitation system of the same train. SCMs are placed in the sides of the train near the bottom and lined up with conductive coils in the guide walls. Like the induced “eddy currents” that produce levitation, the SCMs in the side of the trains induce currents that repel both sides of the train, maintaining a near perfect center of balance over the track. And like the levitation system, the guidance system has a built-in failsafe due to its particular method of induced currents. For example, if the train were to veer too far to the left side, in respect to the engineer, the coils on the left side of the train, now closer to the SCMs than before, would produce a magnetic force greater than the one before, pushing the train back the right.

From there the train would most likely oscillate left and right before aligning itself back in the center of the track again. However, this oscillation would occur over a very small distance, likely just a few inches, so a human rider, if seated, would hardly feel a thing.

The meat of the EDS system however is in its method of propulsion: “linear synchronous motors” (Freeman). The track of the EDS, in addition to containing coils dedicated to guidance and levitation, contains coils that are dedicated to “providing drive” (Freeman). The coils in the guideway are “excited” by an “alternating current” that in turn produces an “alternating magnetic field” or “standing magnetic wave” (Freeman). Like the EMS, these coils are activated sequentially as the train moves down the track immediately in front of it, “pulling the vehicle forward” (Freeman). However, unlike the EMS, once the train passes over the coil, the current is immediately reversed, which results in a reversed polarity of the coil. Once the switch has occurred, the coil exerts a “repulsive force” on the SCMs and continues to push the train along (Freeman). The effect of this is a train that can accelerate and decelerate much faster than the EMS as well as a system, which is more efficient with its use of electric power, by using the same coils for double the propulsion.

While sharing the same general benefits as the EMS, one of the main specific differences of the EDS is its capacity to cut down on power consumption, and its ability to achieve much greater speeds than the EMS system due to its larger air gap.

Maglev trains are a promising new field of study, offering a new, more sustainable system of transportation, that will potentially in the future, once we have perfected a way to incorporate these machines into our already present infrastructure, change the way humans will travel, forever.

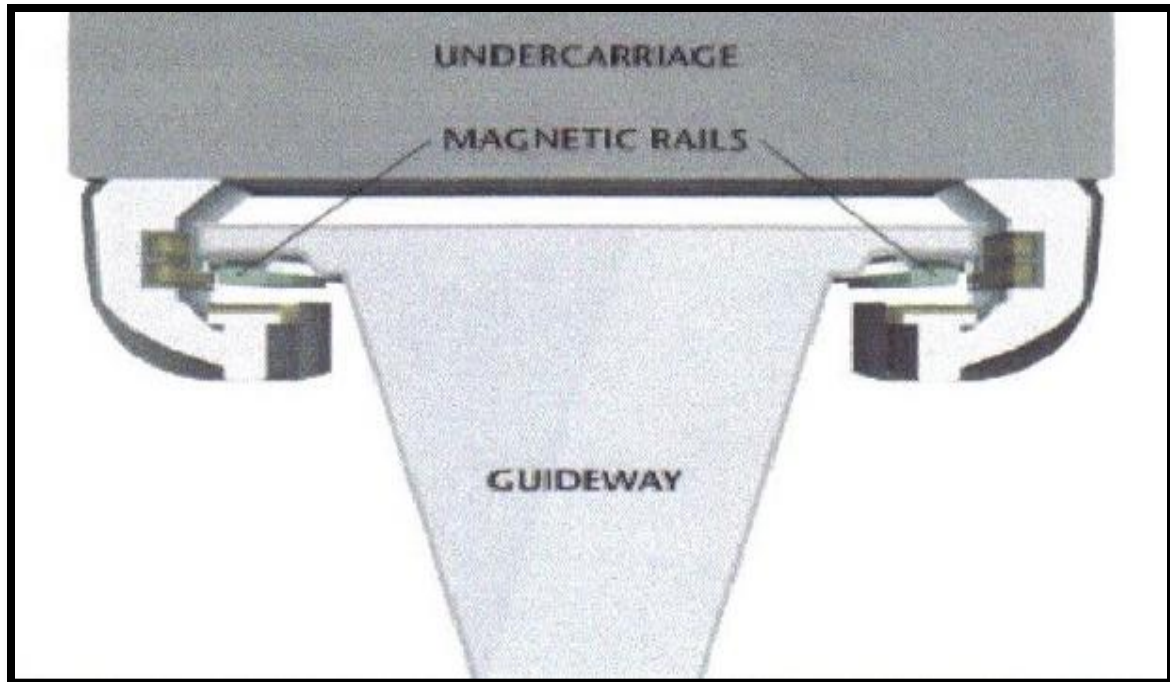


Figure 1 - EMS
(Singhal)

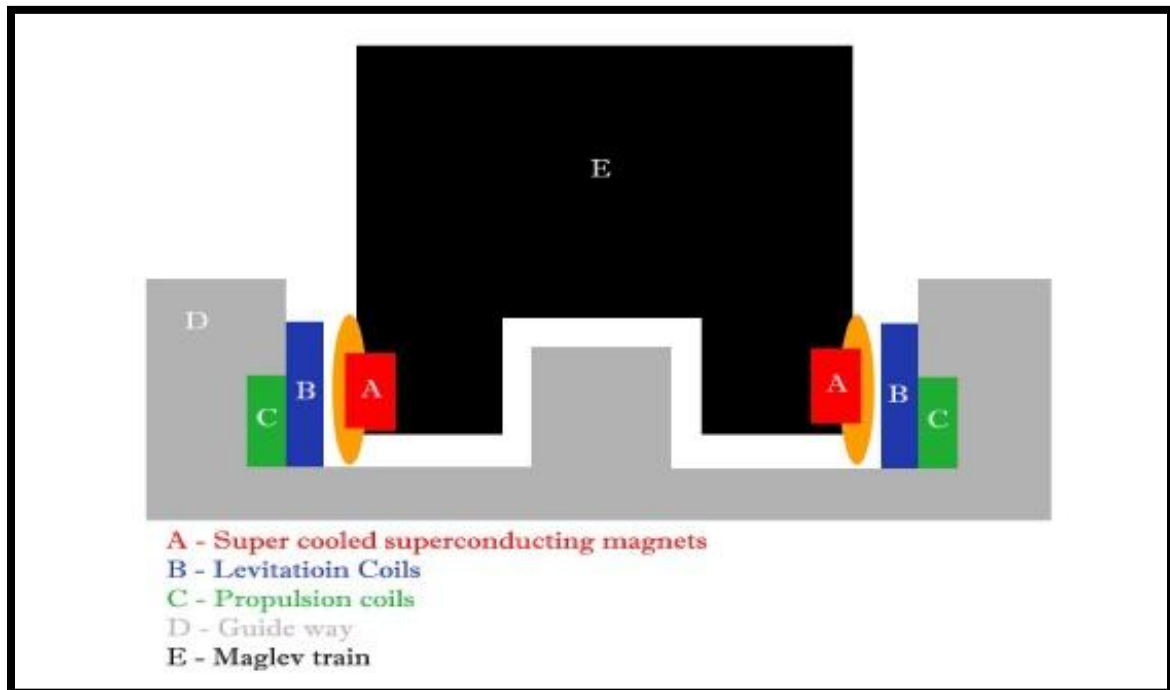


Figure 2 - EDS
(Singhal)

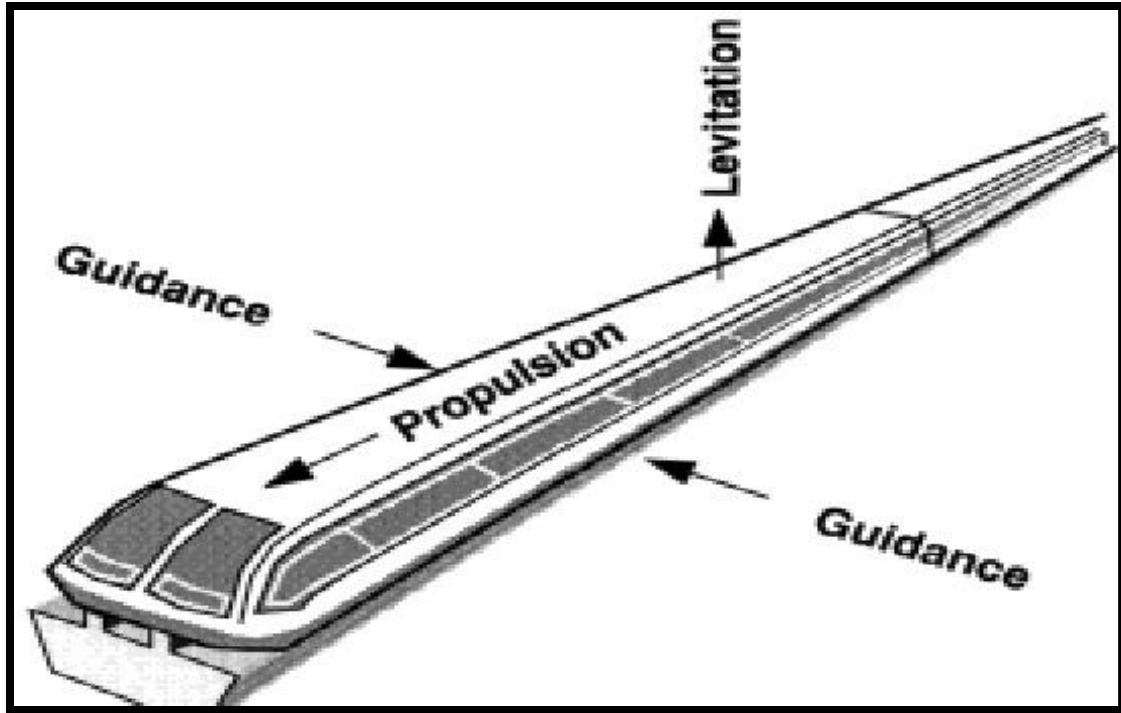


Figure 3 - Three Planes
(NASA)

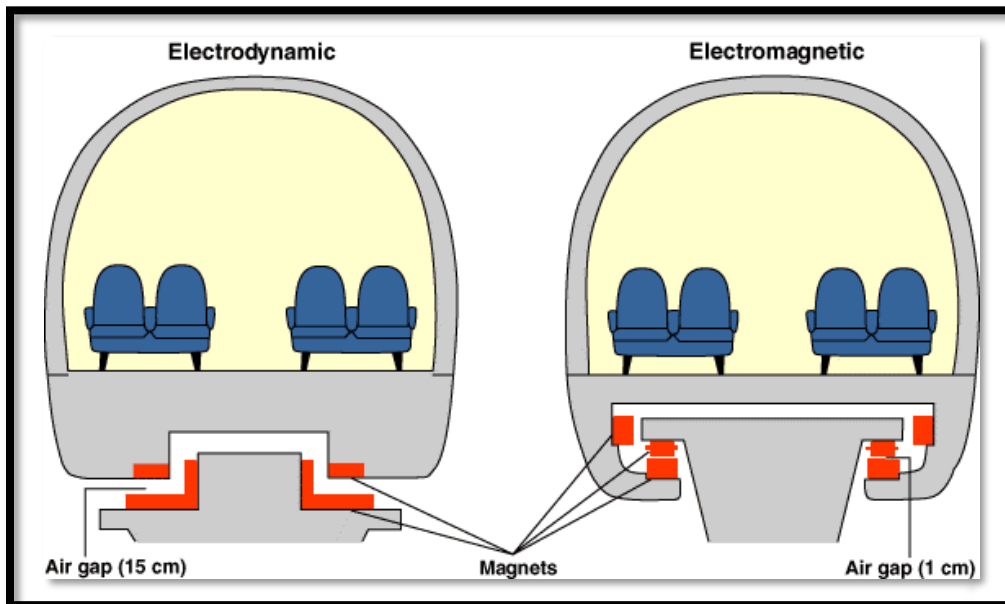


Figure 4 - Comparison
(Matsumoto)

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