

Christian Heymsfield

Lab Section 2

Magnetic Levitation Trains

Many of the far-reaching concepts of physics are thought provoking, but their application in modern – day life is limited. The universe may or may not be expanding, but there are plenty of pressing issues here on planet Earth. In this day and age, growing populations and environmental regulations have put an increased strain on the transportation industry. Engineers are looking for solutions that are efficient, clean, and economical. One idea utilizing the properties of electromagnetism that shows promise is the maglev train. A maglev (short for magnetic levitation) train has little in common with a traditional locomotive. It uses a system of magnets and magnetic coils to float suspended over the rails. The elimination of steel wheels and tracks greatly reduces friction. This allows maglev trains to reach unprecedented ground speeds while being quiet and comfortable. In addition, maglev trains do not require a constant supply of fuel, as they operate only on electricity. They produce no harmful emissions as a byproduct. Does all this sound too good to be true? Commercially operating maglev systems already exist. One is the low speed Linimo train in Japan. The other is the Shanghai Maglev Train in China, capable of reaching speeds of 431 km/h (268 mph) (Bonsor). In addition, testing facilities exist in Germany, Japan, and the United States. Looking to the future, there are several proposals to implement maglev systems in metropolitan areas in the United States and across the world.

The process of levitating a heavy object such as a train utilizes several fundamental concepts of physics. It is common knowledge that like poles on magnets repel each other. Conversely, a south pole-oriented magnet will draw a north pole-oriented magnet closer to

itself. This concept is fundamental in the operation of magnetic levitation. To levitate and propel a maglev train, the magnetic field attracting or repelling the train must be stronger than the force of gravity on the train. To accomplish this, powerful electromagnets are used (Bonsor). First, it is vital to know what an electromagnet is. An electromagnet is a conducting material that creates a magnetic field when a current is applied. It consists of a core of ferromagnetic material wrapped in a coil of wire (Daintith, Martin, 2010). When a current passes through the coil of wire, a magnetic field is produced inside the coil of wire. The stronger the current flowing through the wire is, the stronger the magnetic field. Increasing the number of turns in the wire will also increase the strength of the field (Stewart 2011). This magnetic field magnetizes the ferromagnetic material. The ferromagnetic material acts as a permanent magnet, as long as electric current is flowing through the wire. Just as a permanent magnet, the electromagnet will set up a north and south pole. However, unlike a permanent magnet, the magnetic field of the electromagnet can be controlled by a varying current (Bonsor). This property of the electromagnet is integral to the operation of one form of maglev technology, called electromagnetic suspension (EMS).

In an electromagnetic suspension system, the chassis of the train is “wrapped” around the tracks (Bonsor). Electromagnets are placed on the train’s undercarriage below the track. The electromagnets are attracted to the steel track above, and the train is levitated above the rails. Even at rest, the train maintains a separation of about one half-inch from the track (Freeman 1993). The setup of an EMS train is shown below in Figure 1.

The method of propulsion for an EMS also relies on electromagnets. A maglev train does not have a conventional “engine” or “motor”. Rather it moves forward due to the interactions between the onboard electromagnets and propulsion coils embedded in the

guideway rails (Bonsor). These propulsion coils exist throughout the distance of the track. When power is supplied to the coils, they create a magnetic field that attracts the electromagnets on the train. The current running through these coils is constantly varied and is generated in different sections of the track. The coils preceding the train are sequentially activated as the train moves down the tracks. By doing so, a traveling electromagnetic wave is created, and the train “chases” this wave down the track (Freeman 1993). Reversing the magnetic field has the opposite effect; it is used as a braking mechanism (Freeman 1993).

An EMS system also employs a guidance system to maintain the distance between the train and the track. This is required because of Earnshaw’s theorem. Earnshaw’s theorem states that stable levitation cannot be achieved using only an arrangement of static magnets (Gibbs and Geim 1997). Most often, a second set of electromagnets is used for guidance in both the lateral and vertical directions (Freeman 1993). An electronic monitoring system constantly measures the position of the train relative to the guideway. Current to the electromagnets is adjusted to maintain the proper separation between train and track. Stabilization of pitch, roll, and yaw is needed.

The Shanghai Maglev Train is an example of a maglev train employing EMS technology. The train is a product of Transrapid International, a maglev company located in Germany (Bonsor). Construction on the line began in 2001, and it was opened for commercial use in 2004. It runs from Pudong International Airport to downtown Shanghai. The 19-mile journey takes just eight minutes, with the train reaching a maximum speed of 431 km/h (268 mph) ("Shanghai Maglev Train" 2012). In fact, the Shanghai Maglev Train is the fastest train in regular commercial service in the world. The train also achieves much higher rates of acceleration than wheeled trains. It is extremely reliable; however, service like this comes at a

price. Since the tracks are such an integral part of the maglev train, maglev trains require all new infrastructure. Total construction cost of the Shanghai Maglev Train was at least \$1.2 billion, or about \$63 million per mile ("Shanghai Maglev Train" 2012). Even so, a plan to extend the line to Hangzhou was proposed in 2006. The original total distance of the line was to be 169 km (105 mi). Public protest stopped construction of the project in 2008. Communities near the proposed line feared the possibility of electromagnetic radiation. Nevertheless, the extension was given the green light by the government in 2010. The completion of this project looks highly unlikely though. A non-maglev high speed connecting Shanghai and Hangzhou was opened in 2010, and construction of the maglev line was suspended once again ("Shanghai Maglev Train" 2012).

Electromagnetic suspension is not the only way to achieve magnetic levitation. A maglev train could operate on a different system, called electrodynamic suspension (EDS). Whereas EMS was considered an “attractive” system, EDS is a “repulsive” system (Freeman 1993). EDS works by taking advantage of some of the special properties of superconducting magnets. When these materials are cooled to extremely low temperatures, they experience zero electrical resistance (Powell and Danby 2003). Because of this, they consume virtually no power, except that which is needed to maintain their operating temperature. These are mounted to the bottom of the train, which levitates above the track. The track can be described as “U-shaped.” The train lies in between the parallel rails of the guideway. The appearance of the guideway can be seen in figure 4. Each side of the guideway consists of a series of conducting loops. According to Faraday’s law, a changing magnetic flux through a closed conducting loop will induce a current around that loop (Stewart 2011). In the case of the EDS maglev system, the passing magnetic fields of the superconducting magnets will induce a current in the

conducting loops of the guideway. This induced current repels the magnetic fields of the superconducting magnets aboard the vehicle. Consequently, the train levitates at up to four inches above the track (Bonsor). Unlike EMS, EDS does not achieve levitation at a standstill. Due to the nature of the system, the current induced in the guideway is not great enough at slow speeds to lift the train. Levitation is only possible above a certain point, about 20 to 50 mph (Powell and Danby 2003). A secondary set of wheels is employed to take the train up to speeds sufficient for liftoff.

The train in the EDS system is propelled by a linear synchronous motor. Similar to EMS, sections of the track preceding the train are activated, pulling the vehicle forward. Polarity of the coils behind the train is reversed, pushing the train. However, unlike EMS, EDS is inherently stable (Freeman 1993). In addition to having propulsion coils, EMS uses a second set of coils in the guideway for lateral stabilization. The distance between the train and guideway is controlled by a null-flux system. If an external force pushes the train away from the track, the magnetic field holding the train on the guideway is increased; if it moves closer to the track, the repulsive force between the train and the guideway is increased (Powell and Danby 2003). Thus EDS does not require an electronically controlled guidance system.

Some advantages of EDS are greater stability and reduced energy usage. A greater gap between train and track means that it is better able to withstand external forces, such as wind gusts (Freeman 1993). It can also be a safer option in the case of a power outage, because of its auxiliary wheels. In addition, the superconducting magnets aboard an EDS train do not require a continuous current to create a magnetic field. Therefore, operating costs are decreased, perhaps by as much as one-half.

Application of electrodynamic suspension in maglev trains was first proposed by American scientists James Powell and Gordon Danby in 1966. While research on this technology never took hold in the United States, it became very popular in Japan. As early as 1972, a superconducting maglev test vehicle achieved stable levitation ("Technical Page - Maglev Monorail Introduction"). By 1979, an unmanned test vehicle in Japan achieved a then record speed of 321 mph ("Technical Page - Maglev Monorail Introduction"). Today, JR (Japan Railways) Maglev is the foremost developer of EMS trains in the world. Their testing facility consists of 11.4 miles of track, and is located in Yamanashi Prefecture, north of Mt. Fuji (Railway Technical Research Institute). In 2003, the JR – Maglev MLX01 test vehicle attained a speed of 581 km/h (361 mph) in a manned vehicle run ("History of Maglev R&D" 2010). The mark is a world speed record for rail vehicles. A year later, two JR Maglev trains set the world record for fastest relative passing speed, when the vehicles passed each other with a combined speed of 1,026 km/h (638 mph) ("History of Maglev R&D" 2010). These records served as a great demonstration to showcase the capabilities of EMS maglev trains.

Tests done at the Yamanashi Testing Facility are part of a bigger plan, called the Chuo Shinkansen. In 2011, the Japanese government approved construction of a maglev line connecting Tokyo, Nagoya, and Osaka ("Chuo maglev project endorsed" 2011). The total proposed distance of the route is 550 km (342 mi). Interestingly enough, more than 60% of the track will be in tunnels. Maglev trains are expected to make the journey from Tokyo to Nagoya in 40 minutes and from Tokyo to Osaka in an hour. In doing so, they will achieve a maximum speed of 505 km/h (314 mph) ("JR Central unveils L0 maglev" 2010). The project will not receive any government financing; it will be up to Japan Railways Central to raise the

necessary funds, and it will not be an easy task. Total cost of the line was estimated in 2011 to be 9 trillion yen, equivalent to about \$117 billion ("Chuo maglev project endorsed" 2011).

Construction on the Chuo Shinkansen is expected to begin in 2014. However, preparations are already under way. The test track located at Yamanashi is currently being extended to 42.8 km (26.6 mi). The construction of the extension is due to be finished in 2012 ("Chuo maglev project endorsed" 2011). Once completed, it will be incorporated into the total length of the Chuo Shinkansen.

So is maglev a viable option in the United States? While Germany and Asia have shown their support for this new method of transportation, America has somewhat lagged behind. Politicians have been slow to award funds to maglev projects, because of their high start up costs. In the current state of our economy, the government is reluctant to invest in projects that will not pay for themselves in the short term. Engineers at the Florida based Maglev 2000 are optimistic that they can change perceptions of maglev in the US. The company has developed their own maglev system, which is a second generation EDS system based heavily on the work of Danby and Powell. The Maglev 2000 system will be cheaper than German and Japanese systems, while also having the ability to transport freight and to switch guideways at high speeds (Powell and Danby 2003). The company has an ultimate goal of a National Maglev Network, a 16,000 - mile network serving 90 percent of the population (Powell and Danby 2003).

In reality, the future of maglev in the U.S. is not too promising, at least in the near future. A federal act in 1997 created the National Magnetic Levitation Transportation Deployment Program. The goal of this act is to “demonstrate high speed maglev technology in commercial service through a project of about 40 miles in length” (Federal Railroad

Administration). Seven projects were selected to compete for funding from the Department of Transportation. Of these seven, a plan to link the Baltimore and Washington D.C. areas and a project in Pittsburgh, Pennsylvania were chosen for further consideration ("Maglev Projects"). The Baltimore-Washington Maglev Project was formed in 2001. Total cost of the 39.1-mile maglev route was predicted to be \$3.74 billion in 2002 ("Project Overview"). All that can be said about the progress of this line is that it had completed its Draft Environmental Impact Statement, as of 2003 ("Maglev Projects"). There have been no further developments. The Pennsylvania High Speed Maglev Project is also still in the planning stages. The 54-mile route was estimated in 2003 to cost \$3.7 billion to construct ("PA Project Facts"). Ultimately, the high start up expense of these railways has detracted government funding.

Despite its failure to completely enamor the American policymakers, the potential of maglev cannot be denied. This technology is faster, safer, and less costly to operate, all while requiring less maintenance because there are fewer moving parts. As the world's supply of oil becomes a bigger and bigger issue, the idea of clean transportation will get more attention. To understand maglev, one must consider the two main forms of operation: electromagnetic suspension (EMS) and electrodynamic suspension (EDS). EMS uses the attractive force between electromagnets on the undercarriage of the train and magnetic coils in the guideway to levitate and propel the train. EMS is the more established technology; a commercial maglev train using EMS is currently operating in Shanghai, China. EDS differs from EMS by using superconductors as magnets to levitate the train above the track. This allows EDS to eschew the complex stability systems needed for EMS. Both forms of magnetic levitation meet our need for a simple, high-performance, and environmentally friendly mode of transport. In

conclusion, maglev represents the next logical step in the progression of transportation technology.

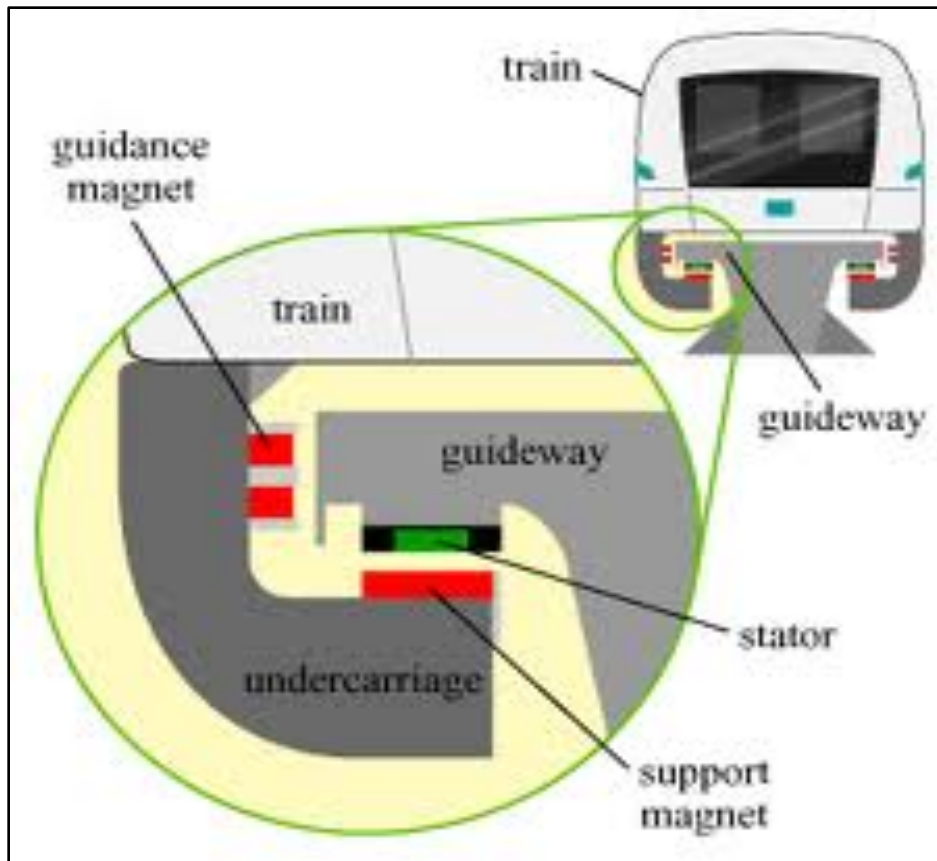


Figure 1 - EMS (www.hk-phy.org)

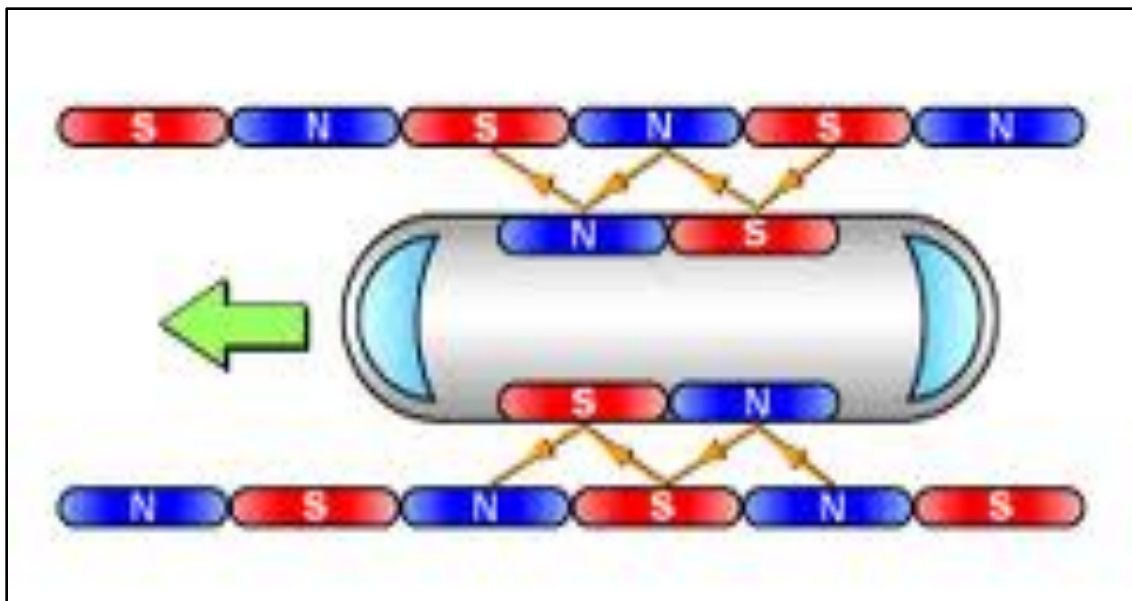


Figure 2 - EMS Propulsion (en.wikipedia.org)

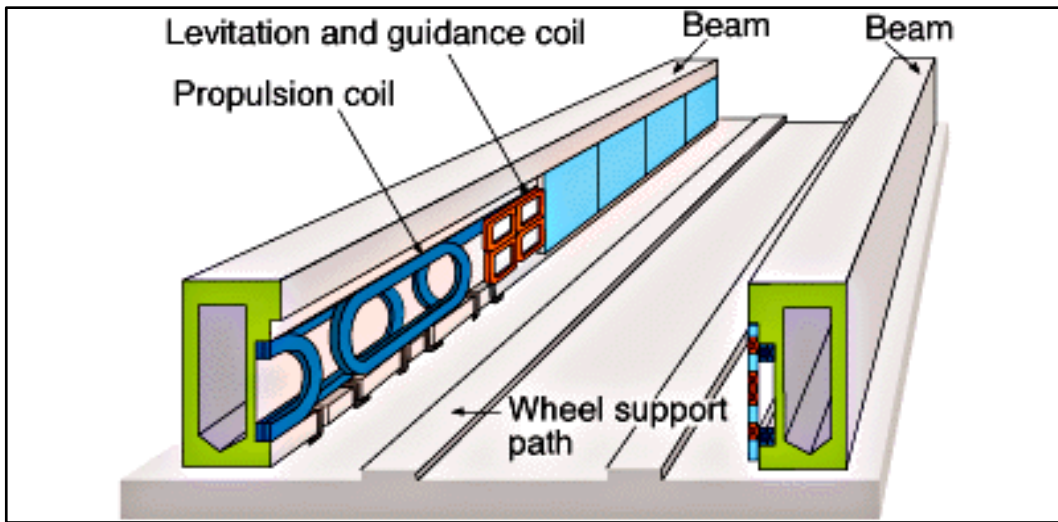


Figure 3 - The Maglev Track (Bonsor)



Figure 4 - Guideway at the Yamanashi Test Track (Railway Technical Research Institute)

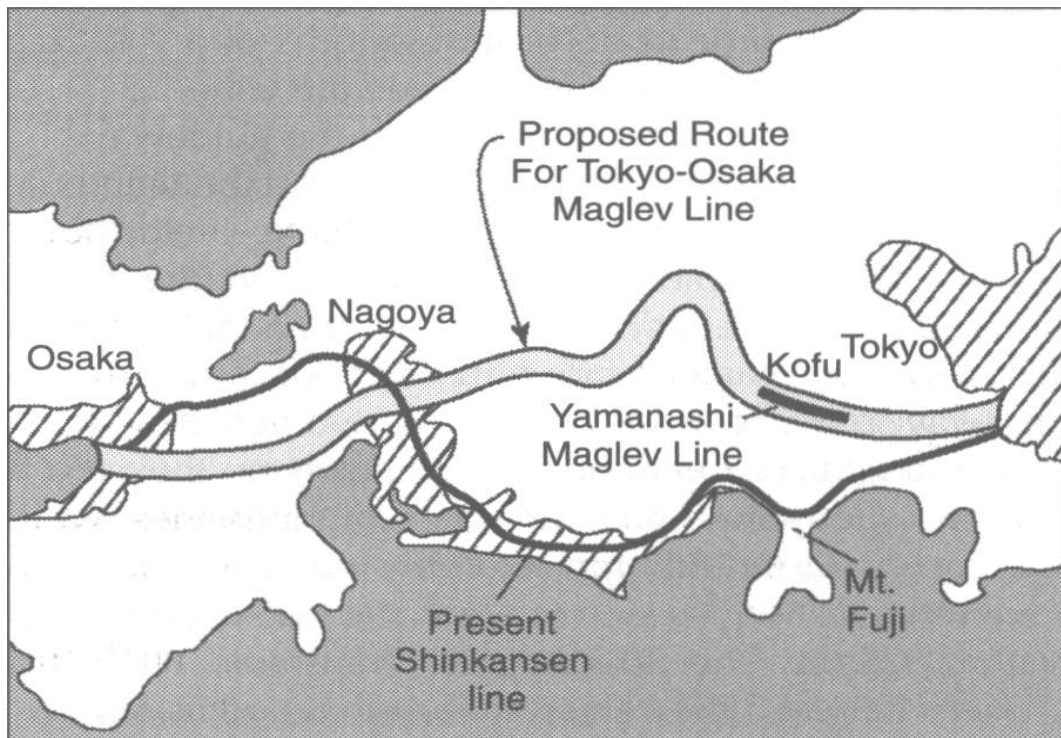


Figure 5 - Proposed Route of the Chuo Shinkansen (Powell and Danby)

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