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Maglev Trains: An Overview

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ABSTRACT

Maglev, short for magnetic levitation, is a method of transportation that uses magnetic levitation to carry vehicles with magnets rather than with wheels, axles and bearings. It propels and is more efficient than conventional trains, as there is no friction with the tracks. The Shanghai Maglev Train, the world's fastest passenger train, regularly exceeds 267 mph (430 km/h). The only other currently operational Maglev systems serving the public are the Linimo in Japan and Daejeon in South Korea. This paper takes a closer look at train transportation developments that rely on maglev technology.

KEYWORDS: *maglev trains, magnetic levitation, transportation, transportation industry*

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INTRODUCTION

Transportation is the movement of goods and persons from place to place and the various means by which such movement is accomplished. The growth of the ability to transport large quantities of goods or numbers of people over long distances at high speeds in comfort and safety has been an index of civilization.

Overcoming the grip of earth's gravity has been a major challenge for years. However, scientists and engineers have found many ways to achieve levitation. For example, a helicopter may be regarded as a levitation device, one that uses a stream of air to keep the aircraft floating. According to a theorem due to Earnshaw, it is impossible to achieve static levitation by means of any combination of fixed magnets and electric charges. Static levitation means stable suspension of an object against gravity. There are, however, ways to levitate by getting round the assumption of the theorem. Magnetic levitation employs diamagnetism, an intrinsic property of many materials referring to their ability to expel temporarily a portion of an external magnetic field. As a result, diamagnetic materials repel and are repelled by strong magnetic field [1].

Maglev train, also known as magnetic levitation train, uses magnetic repulsion both to levitate the train up from the ground, which reduces friction and to propel it forward. Maglev technology has nothing in common with a conventional railway: there are no longer the two rails that we have known for 200 years. A conventional train is shown in Figure 1 [2]. Maglev trains are high-speed trains that use magnets to levitate above the tracks instead of rolling on wheels. The name "maglev" is short for "magnetic levitation."

CONCEPT OF MAGLEV TRAINS

The term "levitation" indicates the rising or lifting of a person or thing by unnatural means. It is the process by which an object is held aloft, in a stable position, without mechanical support or physical contact. Magnetic levitation trains, or maglev trains, are high-speed AI-enhanced trains that move by gliding above dedicated magnetic guideways without making any contact with the tracks. Maglev technology represents the realization of the 21st-century engineering vision of high-speed, magnetically propelled vehicles that can move from one place to another, without the maintenance and safety concerns associated with traditional railroads.

Magnetic levitation (maglev) is a way of using electromagnetic fields to levitate things without any noise or the need for liquid fuel or air. Thus, maglev is the means of floating one magnet over another. A maglev train is a train-like vehicle that is suspended in the air above the track and propelled forward using the repulsive and attractive forces of magnetism.

There are two types of maglev [3]:

- *Electromagnetic Suspension* (EMS), which uses attractive force between electromagnets on the levitated object and the circuit on the ground. In this system, the bottom of the train wraps around a steel guideway. In the EMS system, the coils only conduct electricity when a power supply is present. The best example is the German Transrapid as a monorail, shown in Figure 2 [4].
- *Electrodynamic Suspension* (EDS), which makes use of the repulsive force between magnets (superconductive magnets) on the levitated object and induced current in the circuit on the ground. It uses superconducting electromagnets or strong permanent magnets that create a magnetic field, which induces currents in nearby metallic conductors when there is relative movement, which pushes and pulls the train towards the designed levitation position on the guide way. The most successful project is the Japanese Maglev.

The two types are illustrated in Figure 3 [4]. Any type of maglev system consists of three subsystems: suspension, a propulsion motor, and a power system. The magnetic suspension to ensure a stable suspension of a vehicle in its own magnetic field.

The big difference between a maglev train and a conventional train is that maglev trains do not have an engine, at least not the kind of engine used to pull typical train cars along steel tracks. The engine for maglev trains is rather inconspicuous. Instead of using fossil fuels, the magnetic field created by the electrified coils in the guideway walls and the track combine to propel the train. Maglev trains float on a cushion of air, eliminating friction. This lack of friction and the trains' aerodynamic designs allow these trains to reach unprecedented ground transportation speeds of more than 310 mph (500 kph). Some maglev trains are capable of even greater speeds.

HISTORY OF MAGLEV TRAINS

The evolution of mass transportation has fundamentally shifted human civilization. In the 1860s, a transcontinental railroad turned the months-long slog across America into a week-long journey. Maglevs were conceptualized during the early 1900s by American professor and inventor Robert Goddard and French-born American engineer Emile Bachelet. In the 21st century there are a few countries using powerful electromagnets to develop high-speed trains, called maglev trains. The fundamental theory of frictionless electromagnetic propulsion was created in theory by Nazi Germany during the Second World War. Between 1984 and 1995, the first commercial maglev system was developed in Great Britain as a shuttle between the Birmingham airport and a nearby rail station, some 600m. The idea of having trains that move by frictionless electromagnetic propulsion has been only put to practical usage with test tracks in Germany and Japan for the last twenty to thirty years. The first commercially operated high-speed superconducting maglev train opened in Shanghai in 2004, while others are in operation in Japan and South Korea.

HOW MAGLEV TRAIN WORKS

Magnetic levitation is achieved with the aid of three loops set in the guideway. The first loop provides an upward force that opposes gravitational pull and accounts for the hovering action of the train. The second loop stabilizes the object toward a home position while the third loop makes use of the attraction and repulsion forces of the magnet to keep the train moving along the guideway. When these loops are electrified through AC power, magnetic fields are generated. The field at the north poles pulls the train forward from the front while the field at the south poles pushes it forward from the rear enabling it to keep moving along its path. This is the basic idea and the driving principle behind maglev technology.

The maglev has these components:

- *Electromagnets:* Two sets of electromagnets are used: one repels the train away from the track, and the other propels the train forward.
- *Superconductors:* Some maglev trains use superconducting magnets, which are cooled to very low temperatures to increase the power of the magnetic field.
- *Rare-earth Elements:* Magnets made from rare-earth elements, such as scandium, yttrium, and neodymium-iron-boron, produce stronger magnetic fields.

As shown in Figure 4, a maglev must perform three functions: (1) levitation, (2) propulsion, (3) lateral guidance [5]. These functions are further explained in the cross section of the maglev train as shown in Figure 5 [5].

Maglev, or floating trains, make use of two sets of electromagnets: one set repels and pushes the train up off the track, and another set moves the elevated train ahead. They travel at unbelievably high speeds because of the superconducting electromagnets, cooled to extreme temperatures. These electromagnets increase the power of the field up to 10 times, generating powerful magnetic fields that are able to levitate and propel the train. Maglev trains do not make any physical contact with the rail. Maglev trains are now self-driving, and this entails making use of AI's neural networks to go wherever the programmed data network sends them [6]. Figure 6 shows how a maglev works [5].

APPLICATIONS OF MAGLEV LEVITATION

Maglev is a type of rail transportation system that uses two sets of large magnets to propel efficiently. Maglev trains use electromagnets to elevate and move along a track. These maglev investments are consistently focused on connecting huge, dense cities close enough to one another that traditional air travel offers limited time savings at enormous environmental costs. Research has proven the possibility of maglev transportation systems. Levitating trains and levitating displays are but two examples of electromagnetic levitation. Besides these, there are other vehicles that use magnetic levitation technology. These include the following:

- *Maglev Cars:* Maglev trains provide inspiration for the innovation of maglev cars, with China producing the first maglev car which levitated 35 millimeters (about 1.4 inches) above dedicated magnetic highways. This feat was achieved by modifying a car with a permanent magnet array to float through a magnetic conductor rail track on the road. Simply put, a maglev train car is just "a box with magnets on the four corners." There is, no doubt, a chance that the technology can be greatly improved. With a high operating range, these cars will save a lot of energy in the future.

- *Hyperloop:* This is the brainchild of Tesla Motors and SpaceX CEO Elon Musk, which promises to run trains at airplane speeds through vacuum-sealed tubes. First proposed and studied in the 1960s, the concept of hyperloop gained popularity after Elon Musk promoted it in 2012. Combining maglev with a vacuum tube would mean that the air resistance can be vastly reduced, further improving the train's efficiency and speed. The hyperloop will have high-speed capsules that glide through tubes with partial vacuum. They will reach top speeds of around 760 mph (1,200 km/h), allowing you to travel from Los Angeles to San Francisco in an incredible 35 minutes. Despite fawning press coverage, hyperloop would need to clear some major technological and practical barriers to become reality.

- *Elevators:* Maglev technology can be leveraged in other areas, such as for elevators, thereby promising many other possible opportunities in different industries.

MAGLEV TRAIN AROUND THE WORLD

Globally, the maglev still has too many enemies, too few friends. Since 1980s, various maglev projects have started, stalled, or been outright abandoned. However, there are currently six commercial maglev lines currently in operation around the world. One is located in Japan, two in South Korea, and three in China. Asia has become the first high-speed rail continent. Asia, initially led by Japan and now by China, is dominating the high-speed rail sector, outpacing Europe and leaving North America behind. We consider how the following nations are attempting to implement maglev [4,7].

- *China:* China, which had no high-speed rail at the start of the 21st century, aggressively built up these railways and now leads the world in this mode of transportation. China's ruling Communist Party has showcased the successful development of this modern transportation as evidence of the country's economic power, technology, and improved standard of living. The Chinese Transrapid is today the world's only high-speed maglev system in passenger service, in Shanghai, China. It runs at 430 km/h over a 30 km track. It was completed in 2004, but no other systems were built, and the German company that designed it, Transrapid, closed in 2008. The train runs well, but suffered from prohibitive construction costs. In China, the CRRC consortium recently presented a maglev capable of reaching speeds of 600 km/h. Such a high-speed maglev train is illustrated in Figure 7 [8]. Given the train's tremendous speed, a trip by train could be even faster than traveling by air under certain circumstances.

- *Japan:* In Japan, a maglev project seems the most successful. The first high-speed rail was Japan's 515-km (320-mile) Shinkansen line connecting Tokyo and Ōsaka, inaugurated in advance of the 1964 Summer Olympics. JR Central, which operates the existing Tokaido Shinkansen Line, plans to start the Tokyo-Nagoya section of the maglev line in 2027, and the Tokyo-Osaka service in 2045. Japan's shinkansen, traditional high speed train, is crucial to the national psyche as a symbol of high-tech might. However, many critics regard the maglev as a symbol of everything wrong with innovation in Japan: an unprofitable, capital-hungry white elephant with no export prospects and a threat to the existing shinkansen. Figure 8 shows the inside of a maglev in Japan [9].

- *South Korea*: Korean high-speed rail was first established in 2004 on a section of the Seoul-Pusan line; the entire line was completed in 2010. In 1993, South Korea completed the development of its own maglev train, shown off at the Daejeon Expo '93, which was developed further into a full-fledged maglev UTM-02 capable of travelling up to 110 kph (68 mph) in 2006. This final model was incorporated in the Incheon Airport Maglev which opened on 3 February 2016, making South Korea the world's fourth country to operate its own self-developed maglev after the United Kingdom's Birmingham International Airport, Germany's Berlin M-Bahn, and Japan's Linimo.
- *Europe:* The European continent, a leader in high-speed, is particularly keen to capitalize on the technical and especially financial mastery of the high-speed conventional train, symbolized by the TGV in France, the ICE in Germany, the AVE Talgo in Spain, and the Italian model, the only country where two high-speed rail companies operate on the same lines, by concurrence. Europe looks with big fears the coming of the Chinese CRRC, while the Japanese Hitachi is already present in Britain and Italy.
- *Israel:* Combining the advantages of maglev with the flexibility of personal transport is the SkyTran which is currently being built in Israel. It uses a “packet switching” model, meaning there is no speed lost on the main line and allowing for offline stops without slowing the main traffic. Passengers are being transported in small automated vehicles that fit up to 2. These cars can be called and the destination entered using smartphones. Travel speed is expected to be around 60 mph (100 km/h), but can go up to 100 mph (160 km/h). While the world looks at hyperloop projects with caution, it is useful to look at another railway technology: magnetic levitation, which Europe seems to have definitively cancelled.
- *India:* Indian Railways has decided to introduce maglev trains in India and plans to implement the first stretch of the project within a period of three years. A journey in the high-speed, state-of-the-art maglev trains that can run at a speed of 500 kmph, will not remain a distant dream for Indians anymore. The project will be implemented on a PPP (public-private partnership) basis.
- *United States:* The United States has focused more resources on highways than trains. Trains are not used extensively all over US, except in some big cities like New York and Philadelphia. Attempts to install a maglev in the United States have all failed. This is due to the fact that America is that land of cars, trucks, and planes; companies that make those vehicle have lobbied for decades to prevent maglev from evolving. The companies believe that building the maglev is about removing millions of people from their cars and fighting climate change, which will negatively impact their business.

FUTURE OF MAGLEV TRAINS

It is difficult to know exactly how maglevs will figure into the future of transportation. Advances in self-driving cars and air travel may complicate the deployment of maglev lines. If the hyperloop industry manages to generate momentum, it could disrupt all sorts of transportation systems. The future of maglev technology is maglev cars future because they do not need massive infrastructure projects to get off the ground. Maglev technology is going to lead to the production of cheap and affordable cars and also usher in a ground-breaking technological innovation of the 21st century. Most importantly, both hyperloop and maglev will need political support in order to get off the ground.

The future of maglev trains is bright. They significantly decrease travel times, thus presenting a solid challenge for air transport where distances are only slightly beyond the reachable ones by high-speed rail. The kind of reductions this technology offers in travel can continuously improve business interconnectivity and tourism and boost the growth of the connected regions.

BENEFITS

The benefits of maglev are hard to contest. By replacing wheels and supporting machinery with electromagnets or super-conducting magnets, levitating trains are able to reach incredible speeds. The track maintenance costs tend to be lower than for normal trains as there is not any wear or tear. Maglev trains do require more energy to run than conventional trains. Other benefits include the following [5]:

- *High Speed:* Speed is very important concerning energy consumption. The need for fast and reliable transportation is increasing throughout the world. High-speed rail has been the solution for many countries. Trains are fast, comfortable, and energy efficient. Conventional railroads operate at speeds below 300 km/hr, while maglev vehicles are designed for operating speeds of up to 500 km/hr. The high speed of maglev train is depicted in Figure 9 [9].

- *Improves Power Efficiency:* Maglev trains are more energy efficient than conventional trains. Maglev trains do not experience friction or rolling resistance due to the lack of physical contact with the track. There is, however, air resistance and electromagnetic drag, brought about by the use of superconducting electromagnets, which reduces energy consumption and improves power efficiency.
- *Minimizes Collision*: Floating trains guarantee comfortable, smooth, and turbulent-free travel because they are driven along a powered guideway. They also move at the same speed, eliminating the possibility of a crash or collision. With maglev trains, derailment is also avoided. The further a maglev train moves away from its guideway, the stronger the magnetic force pushes it back into its place.
- *Less Noise:* Because the major source of noise of a maglev train comes from displaced air rather than from wheels touching rails, maglev trains produce less noise than a conventional train at equivalent speeds.
- *Reliability:* Superconducting magnets are generally used to generate the powerful magnetic fields to levitate and propel the trains. These magnets must be kept below their critical temperatures (this ranges from 4.2 K to 77 K, depending on the material). New alloys and manufacturing techniques in superconductors and cooling systems have helped address this issue.
- *Control Systems:* No signaling systems are needed for high-speed maglev, because such systems are computer controlled. Human operators cannot react fast enough to manage high-speed trains. High-speed systems require dedicated rights of way and are usually elevated.
- *Weather*: A major advantage of maglev systems is their ability to operate in almost they are prepared for icy conditions because they do not require overhead power lines— parts that are subject to freezing on conventional railroads. In theory, maglev trains should be unaffected by snow, ice, severe cold, rain, or high winds. However, as of yet no maglev system has been installed in a location with such a harsh climate.

CHALLENGES

The maglev was quickly dismissed by Britain due to great uncertainties to its technical and financial master, in favor of a classic high-speed line. After the failure and the stopping of the tests in Germany, there is no more project of this type in Europe. Maglev, a magnetic levitation train, is now active in six locations in Asia, the only continent that still believes it. Maglev trains move at very high speeds, and this raises grave concerns about the safety of passengers. Complications resulting in accidents will usually lead to high human fatalities. Maglev trains are much more expensive to construct than conventional trains because of the high number of superconducting electromagnets and permanent magnets required, which are usually very costly. Other challenges include the following [6]:

- *High Cost:* Maglev systems are incredibly expensive to build and this has eventually killed off most of the proposed projects. Maglev trains are much more expensive to construct than conventional trains because of the high number of superconducting electromagnets and permanent magnets required, which are usually very costly. Maglev trains do not make use of the conventional steel rail tracks and their existing infrastructure, but instead standalone track network systems designed for magnetic levitation and propulsion. The cost of this is also very high and capable of discouraging further research into the technology.
- *Safety:* Safety is a greater concern with high-speed public transport due to the potential for high impact force and large number of casualties. In the case of maglev trains as well as conventional high-speed rails, an incident could result from human error, including loss of power, or factors outside human control, such as ground movement caused by an earthquake. Maglev trains move at very high speeds, and this raises grave concerns about the safety of passengers. Complications resulting in accidents will usually lead to high human fatalities. Also, constant exposure to strong and large amounts of the electromagnetic field poses huge health risks not just to the nearby community but also to human operators and passengers alike.
- *Expensive Maintenance:* Repairs and new parts are more expensive than off-the-shelf alternatives. In case of repair or replacement, the challenge is the adaptation to the volatile market of electronic components. In addition, the low market of maglev train and the important specificity of the components make the spare parts very expensive.

- *Incompatible Track:* The greatest obstacle to the development of maglev systems is that they require entirely new infrastructure that cannot be integrated with existing railroads and that would also compete with existing highways, railroads, and air routes. Alongside the financial challenges is a lack of market opportunities to build a mainline maglev. Despite maglev systems have demonstrated drastically reduced operating costs and carbon emissions, incompatibilities with existing rail infrastructure and $50-200 million per mile construction costs have become insurmountable impediments to mainstream adoption.
- *Accidents:* Currently, the last decade there have only been two recorded accidents with Maglev train travel. First, case was in Germany 2006 when at a test site a Maglev train ran into a maintenance car left on the guideway. Second, in Shanghai, China in 2006 when one of the car units caught on fire during usage, but no passengers were within the car at the time of the accident.

CONCLUSION

Maglev has no wheels, no engines, less problem. It shows us tomorrow's world and is going to make domestic air travel defunct. Amid the traffic jams and pollution, a greener mass transit solution makes sense more than ever. While there have only been a handful of commercially viable systems built, all in Asia, more are now being tested around the world.

Similar to any developmental process of any new technology, the maglev in the various countries has come with some challenges. In spite of this, the trains of the future are among us and they are only going to get better. The future maglev must overcome the two key challenges holding back maglev railways up until now: it costs less than previous efforts and it can run on existing infrastructure without the need for costly, complicated, and time-consuming modifications. More information about maglev can be found in the books in [10-16].

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Figure 1 A conventional train [2].

Figure 2 An example of electromagnetic suspension maglev [4].

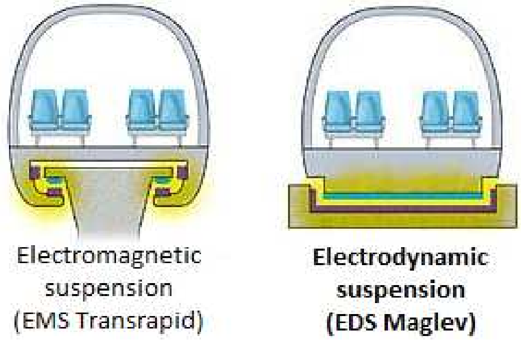

Figure 3 Two types of maglev [4].

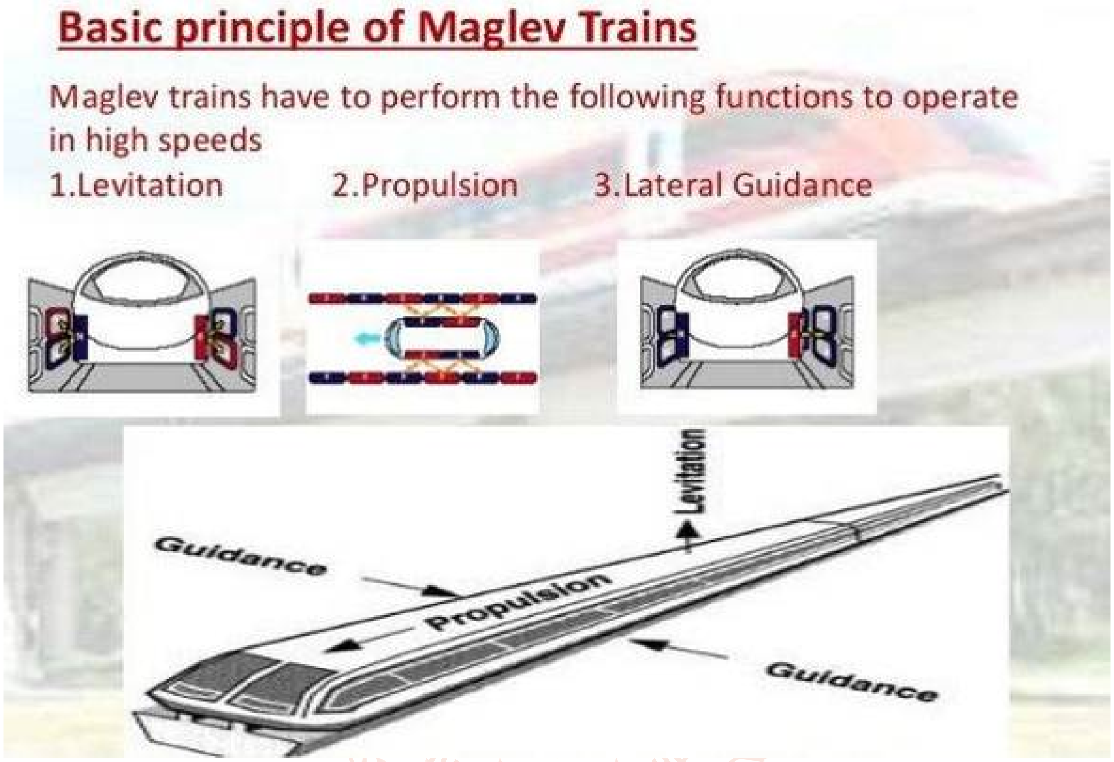

Figure 4 A maglev must perform three functions: (1) levitation, (2) propulsion, (3) lateral guidance [5].

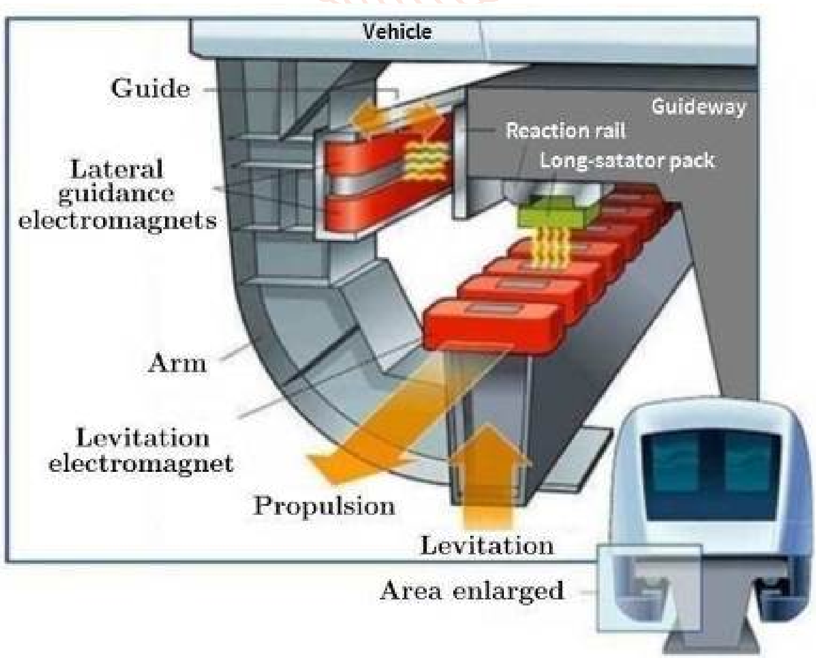

Figure 5 The cross section of the maglev train [5].

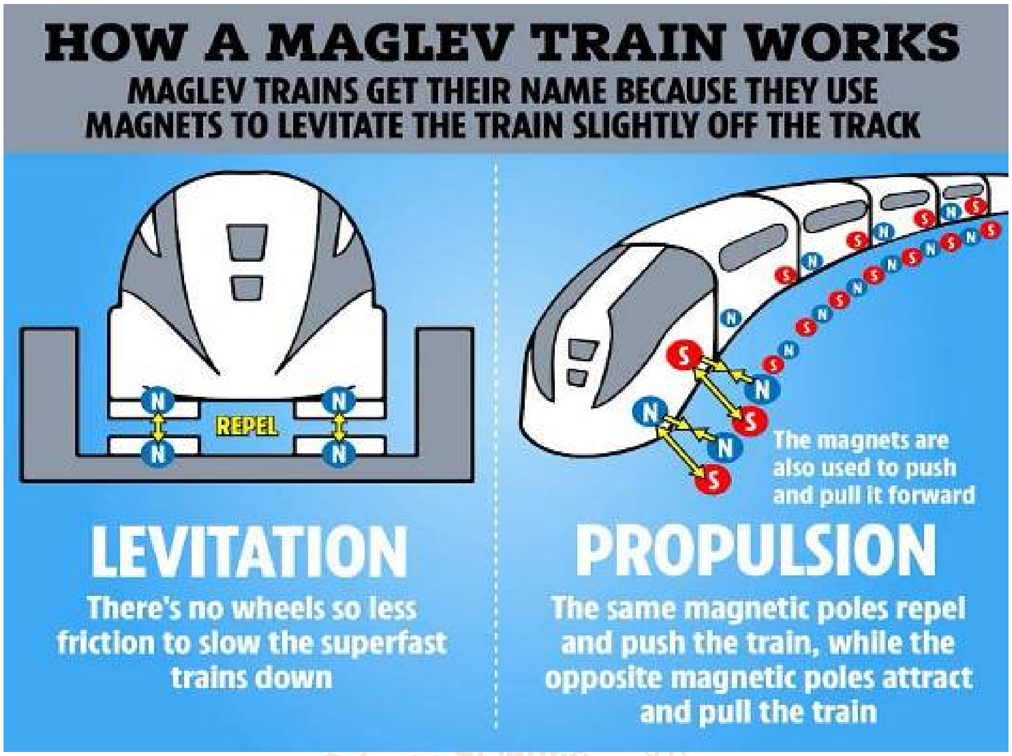

Figure 6 How a maglev works [5].

Figure 7 A high-speed maglev train in China [8].

Figure 8 Inside a maglev in Japan [9].

Figure 9 The high speed of maglev train [9].