International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 09 | Sep 2021 www.irjet.net p-ISSN: 2395-0072

Design of DC Maglev Train

Abhijith Syam[1], Vaishnav S[1], Vishnu P S[1], Ms. Soumya A V[2]

[1,2]*Dept. of Electrical and Electronics, Mar Baselios College of Engineering and Technology,* Trivandrum, Kerala, India

---***---

Abstract - *This paper deals with the design of various systems of the DC-powered Maglev train. The design requirements and specifications of the Levitation, Propulsion, Guidance, and Transfer of energy to vehicle systems are discussed. A model has explained whose electromagnetic core material is mild steel. This paper also discusses the various experimentations conducted on the levitation of the train body such as the power supply testing for the train and track electromagnets. The future scope of the DC-powered maglev train, limitations of the model, and the various modifications that can be incorporated into the system for its better performance have been discussed in this paper. The paper also gives an overview of the conventional maglev train and its various shortcomings. Also, the starting and braking mechanisms of the DC maglev train, the various methods of magnetic shielding of the passengers as well as the minimization of leakage flux have been discussed.*

***Key Words*: Maglev, EMS, EDS, Horseshoe magnet, Propulsion segment, Propulsion electromagnet.**

1. INTRODUCTION

The word Maglev stands for 'Magnetic Levitation. Magnetic Levitation is a phenomenon that works on the interaction between magnetic fields produced by the track and train. The idea of a magnetic levitating train was first conceived by Hermann Kemper of Germany who patented it in 1934. Over the past few decades, there has been tremendous research work in the field which finally resulted in its first public service in 2003 in Shanghai, China. Techniques such as modeling and analysis of linear electric machinery and superconductivity were developed as a result of this research.

The Maglev offers numerous advantages over the conventional wheel-on-rail system such as the elimination of wheel and track wear providing a consequent reduction in maintenance costs, distributed weight-load reduces the construction costs of the guideway, owing to its guideway the train cannot be derailed easily, the absence of wheels removes much noise and vibration, the noncontact system prevents it from slipping and sliding in operation. Maglev trains can travel at higher speeds up to 600kmph as compared to wheel-on-rail trains that travel at a maximum of around 400 km/h.

The technology aspects of Maglev include Levitation, Propulsion, Guidance, and Transfer of Energy to the Vehicle. In conventional Maglev trains, Levitation can be done by three methods: 1) Electromagnetic suspension 2) Electrodynamic suspension [1]. The electromagnetic suspension uses attractive force whereas electrodynamic suspension uses repulsive force for levitation. The maglev train receives its propulsion from a linear motor, which is different from a conventional rotary motor. The linear motor is superior to the rotary motor in the case of rectilinear motion, because of the less significant amount of vibration and noise that are generated directly from the mechanical contact of components. Linear Induction Motor (LIM) and Linear Synchronous motor (LSM) are the two main types of Linear motors [2]. The Maglev train is a non-contact system that requires a guiding force for the prevention of lateral displacement. As is the case of levitation, the guidance is accomplished electromechanically by magnetic repulsive or attractive forces. Even though all Maglev trains have batteries electric power supply from the ground side is necessary for levitation, propulsion, onboard electrical equipment, battery recharging, etc. The transfer of energy all along the track involves the use of a linear generator or a mechanical contact based on the operation speed. At low speeds (up to 100 km/h) the Maglev train generally uses a mechanical contact such as a pantograph.

In the current scenario, the propulsion system of maglev trains powered by linear motors uses a three-phase AC power supply that produces iron losses in the magnetic core. The eddy currents produced in the laminated core account for heating losses. The DC maglev works entirely on direct current thereby reducing operational losses. The levitation system of the DC Maglev is a novel design that has an optimized magnetic circuit for maximum flux utilization. The novel design uses a combination of EMS and EDS. The propulsion system works on an arrangement that works entirely on DC. The propulsion system of the DC Maglev train works on an electromagnetic arrangement. Lateral displacement of the train concerning the track is prevented by the guidance system [1].

2. BLOCK DIAGRAMS

2.1 Main block diagram of DC Maglev train

The basic block diagram of the DC Maglev train consists of three main segments, namely: Supply system, Track system, and Train system. The supply system can be a power source supplying HVAC or HVDC. If AC is supplied, the power must be rectified to DC before being fed to the track and train systems. Thereby, HVDC is preferable for this project.

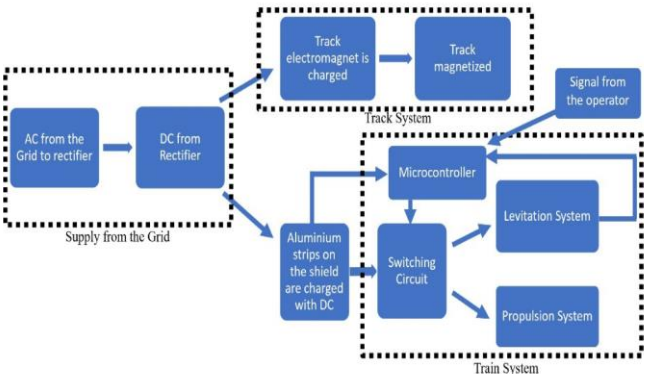

Fig -1: Main block diagram of DC Maglev train

The track system is an electromagnet that is always kept magnetically saturated when the train is in operation. A magnetic shield is present covering the track on all sides except the top. An aluminum strip arrangement is present along with the shield that is supplied with DC power. The power is then collected by the train using a rotating pantograph arrangement. The train system consists of the following main sub-systems: Levitation system, Propulsion system, Power electronic switching circuit, Control unit (microcontroller).
The train is activated by the control signal which is given by the train operator. The power collected by the rotating pantograph arrangement is sent to the Power electronic switching circuit that transfers the necessary power to various other systems of the train. The control unit is a microcontroller device that is used to control the functioning of the switching circuit by providing gate pulses. A detailed explanation for the Levitation and Propulsion systems is provided in the following sections.

2.2 Block diagram of Levitation system

The levitation of the DC Maglev is achieved by the magnetic attraction and repulsion between the electromagnets present in the train and track. The track resembles a long core type transformer whose upper and lower limb windings are supplied with DC. The windings are wound in such a way that the magnetic field is reinforced. The train electromagnet resembles a horse-shoe magnet which is a series magnetic circuit.

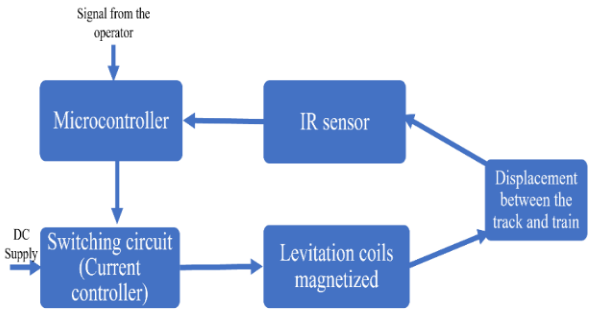

Fig -2: Block diagram for Levitation system

The Levitation system is activated by the control signal given by the train operator to the microcontroller. The microcontroller gives gate signals to the Power electronic switching circuit which is a current controller that passes the necessary amount of current to the Levitation horse-shoe electromagnets. The starting current supplied to the horse-shoe electromagnet is maximum to levitate the train and to have a minimum air gap of 1cm for the track electromagnet. An IR sensor is used to measure the displacement of the train from the track. Its output signal is sent to the microcontroller forming a closed-loop system. Accordingly, gate pulses are sent to the switching circuit to send the necessary supply to the horse-shoe electromagnet thereby, maintaining the air gap between the train and the track.

2.3 Block diagram of Propulsion system

Maglev trains can only propel in either direction. The Propulsion system consists of the propulsion electromagnets that are always kept magnetically saturated and the servomechanism to tilt the propulsion segment that houses the propulsion electromagnets. The propulsion or braking signals are given by the train operator to the microcontroller. Power is supplied by the microcontroller-powered switching circuit to the servomechanism which tilts the propulsion segment concerning the track. This creates a horizontal force component along the track that propels the train.

Fig -3: Block diagram for the Propulsion system

3. PROPOSED WORK

The electromagnets present in train and track levitate the DC Maglev by the magnetic attraction and repulsive forces produced between them. The track resembles a long core type transformer whose limb windings are supplied with DC. The train electromagnet resembles a horse-shoe magnet which is a series magnetic circuit. The track is wound in such a way that the upper limb becomes the North pole and the lower limb becomes the South pole based on magnetic orientation. An air gap is present between the poles of the track which are connected by connecting rods. The train horse-shoe electromagnet is wound in such a way that the top limb becomes the North pole and the bottom limb becomes the South pole. The south pole of the horse-shoe electromagnet is placed between the north pole and south pole of the track. Three consecutive forces are acting upwards against the weight of the train, which results in levitation.

The DC Maglev propels by magnetic repulsive forces established between the North-pole of the track and the propulsion arrangement in the train. The propulsion arrangement consists of the propulsion electromagnets that are connected to the train by an aluminum base. A servomotor arrangement is used to tilt the entire propulsion segment concerning the track. The change in the resultant force results in propulsion. Lateral displacement of the Maglev train concerning the track is prevented by the magnetic repulsive forces of the Guidance system. It consists of permanent magnets placed in the cavity of the horse-shoe magnet whose North-pole is placed facing the North-pole of the track.

The whole system can be powered by HVAC or HVDC. If AC is used, the power must be converted to DC before being supplied to the system. The track is always kept magnetically saturated by the power supply. The magnetic field is shielded from the surroundings by an aluminum shield which also prevents intrusion by living beings. Conducting strips are placed along with the shield for transferring DC power to the train by a rotating pantograph arrangement.

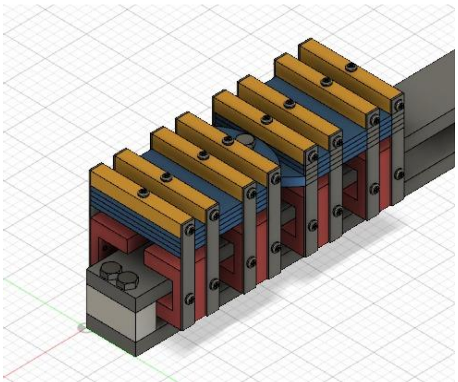

Fig -4: Proposed model of train

4. NOVEL DESIGN OF DC MAGLEV TRAIN

4.1 Levitation system

As mentioned earlier, the south pole of the horse-shoe electromagnet is placed between the north pole and south pole of the track. Magnetic repulsion is experienced between the south pole of the track and the south pole of the horse-shoe electromagnets. The magnetic attraction force is experienced between the south pole of the horse-shoe and the north pole of the track. The second force of repulsion is experienced between the north pole of the track and the north pole of the horseshoe magnet. These three consecutive forces are acting upwards against the weight of the train, which results in levitation.

$$B = \frac{\mu}{4\pi} . \frac{i}{r} . \sin(\phi_1 + \phi_2) \qquad (1)$$

The magnetic field density (B) at the center of the ferromagnetic core used in the Levitation electromagnets is calculated using equation (1). The cross-section of the electromagnets is rectangular. Thereby, the winding around the electromagnets has a rectangular shape. The magnetic field produced by the current in each limb of the winding is calculated using the above equation, where ϕ is the angle subtended by each end of the limb to the center of the cross-section. Here $\phi_1 = \phi_2 = \phi$.

Equation (1) is used to design the track and train electromagnet, it is done by calculating the magnetic field density at the center of the cross-section of the track, and also that of the train body which consists of horse-shoe electromagnets. (1) is used to calculate the magnetic field density at the center of the cross-section of the upper and lower limbs of the horseshoe electromagnet.

The maximum levitation force generated can be found out by first finding the value of the magnetic saturation point of mild steel and then calculating the levitation force produced by one horse-shoe magnet.

$$F = 0.1 \frac{B_1 . B_2 . A}{\mu_0} \qquad (2)$$

B_1 and B_2 represent the magnetic field densities of the track and horse-shoe magnets respectively. 'A' represents the area of cross-section of the effective air gap. μ_0 is the permeability of free space. (2) is used to calculate the levitation force produced by one horseshoe magnet and the track, the total force is calculated by multiplying it with the total number of horseshoe magnets.

4.2 Propulsion system

The magnetic field density produced by the propulsion electromagnets is calculated using Biot-Savart Law (1). (2) is used to calculate the maximum horizontal thrust force between the track and the propulsion segment as F_{Thrust}, and the maximum component which is used to move the train is taken as F_{Thrust}*$\sin(45^0)$ (as the propulsion segment is rotated through an angle of 45^0 by the servomotor for achieving maximum thrust force).

Using the maximum thrust force, the acceleration of the train is found out using Newton's Second Law (F=ma). The motor torque required for tilting the propulsion segment is calculated using the equation.

$$T = I\alpha \qquad (3)$$

where 'I' is the total moment of Inertia of the propulsion segment and α is the angular acceleration of the segment tilted. α is calculated from linear acceleration 'a' using (4).

$$g = r\alpha \qquad (4)$$

The moment of inertia of the distinct segments of the propulsion arrangement is calculated separately (For example, if segments of the propulsion arrangement are rectangular, (5) is used to calculate the moment of inertia about its base axis).

$$I = \frac{ml^2}{3} \quad (5)$$

For rotating the propulsion segment througn an angle of 450, a servomotor is preferred. Servomotors provide greater holding torque than other actuators thereby, facilitating a stronger hold position. Servomotors are easier to control using control signals and do not require a separate control circuit like stepper motors. They can be adjusted to specific positions very accurately and are not very expensive.

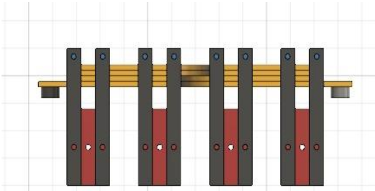

Fig -5: Model of Propulsion system

4.3 Guidance system

Strong permanent magnets with equal strengths are placed in the cavity of the horseshoe electromagnet. The north-pole of these magnets are placed facing the north-pole of the track. Due to equal magnetic repulsive forces on either horse-shoes, the train maintains an effective lateral displacement from the track.

Fig -6: Model of Guidance system

5. EXPERIMENTATION

5.1 Verification of Levitation and Propulsion principles

A small-scale model of the train and track was made as shown in Fig.7 and Fig.8. Disc-shaped permanent magnets were placed beneath the train body, over the track, and on the propulsion segment. In disc-shaped magnets the magnetic poles are on either side, thereby directional magnetic forces are achieved.

Fig -7: Experimental setup of train

Fig -8: Experimental setup of the track

After the arrangement was set up, the train body was placed on the track and it was observed that levitation occurred as shown in Fig.9, but it was observed that propulsion did not occur.

Fig -9: Experimental setup for Levitation

5.2 SMPS was used as the source

This experiment was conducted to check whether the 12V-10A SMPS and 12V-5A SMPS can be used as a source to magnetize the track and train respectively. The experimentation was performed in an electrical workshop. The 12V-10A SMPS was connected to the track windings. The 12V-5A SMPS was connected to the winded horse-shoe. The clamp-on ammeter gave a low reading of 0.1A. This current was not sufficient to magnetize the track. A magnetic compass was used to detect magnetic fields produced which showed very little deflection when placed near the track. The resistance of the track winding was measured to be 3Ω, hence a current of 4A was theorized to flow through the circuit according to Ohm's law.

Fig -10: Experimental setup for SMPS

5.3 Single-phase AC mains used as the source

This experiment was conducted to check whether single-phase AC mains can be used as a source for magnetizing track and train. A single-phase 230V-AC, 50Hz power supply was connected to the track winding. It was observed that not only was the track not magnetized, but the MCB also tripped when the power was supplied.

5.4 The battery used as a source for the track

This experiment was conducted to check whether a 12V-4A battery is sufficient to magnetize the track. A 12V-4A battery was connected to power the track coils. It was observed that the magnetic compass deflection was minimal.

5.5 The battery used as a source for the train

This experiment was conducted to check whether a 12V-4A battery is sufficient to magnetize four train horse-shoe coils connected in series. A 12V-4A battery was connected to power the train coils. It was observed that the magnetic compass deflection was comparatively more than when the same source was supplied to the track.

5.6 Series connection of two cells used as a source for the track

This experiment was conducted to check whether the series connection of 12V-4A and 12V-35A batteries is sufficient to magnetize the track. A series connection of 12V-4A and 12V-35A batteries were connected to power the track coils. It was observed that the magnetic compass deflection was comparatively larger when supplied from a single battery.
The same experiment was conducted with two 12V-35A cells connected in series and given as a source to the track. A 12V-4A source was used to magnetize the train horse-shoes. After connecting both the sources, it was observed that a slight levitation of the train body occurred. It was also observed that the magnetic compass deflection was high.

Fig -11: Experimental setup for Levitation

6. EXPERIMENT RESULTS AND DISCUSSIONS

From experiment 5.1, it was concluded that the permanent magnets placed on the propulsion segment are not sufficient for propelling the body of the train. So, it is replaced with electromagnets to increase the magnetic field strength thereby achieving better results for propulsion.

From experiment 5.2, it was inferred that the winding acted as a short circuit and the SMPS had a protection circuit designed in it which limited the output current to less than 1A. So, it was concluded that the SMPS cannot act as a suitable source for this arrangement.

By experiment 5.3, it can be concluded that when AC was supplied the coils acted as a short circuit and a high starting current flowed through it tripping the MCB. The conclusion drawn from experiment 5.4 is that the 12V-4A battery is not sufficient to magnetize the 1m long track with two limbs. From experiment 5.5, it can be concluded that the 12V-4A battery is still not sufficient to magnetize the horse-shoe magnet arrangement even though it produced more magnetic fields than the track.

According to experiment 5.6, it can be concluded that if the sources used for magnetizing the track and train were to be replaced with more powerful sources, the magnetic field strength would increase thereby better results for levitation could be achieved. Also, if the number of turns of the track and train is increased, stronger magnetic fields can be obtained.

7. ASSEMBLY OF THE WHOLE SYSTEM

In the DC maglev train, the magnetic core material used is mild steel, also aluminum has been used for joining various components of the model together. Consumables such as wires and Nomex paper have been used.

7.1 Mild-steel

The track and the horse-shoe are made up of mild steel. The reasons for selecting mild steel are its availability, affordability, and magnetic properties. Mild steel is a type of low-carbon steel. Carbon steels are metals that contain a small percentage of carbon (max 2.1%) which enhances the properties of pure iron. The carbon content varies depending on the requirements for the steel. Low carbon steels contain carbon in the range of 0.05 to 0.25 percent.

7.2 Aluminum

Aluminum is used for making strips that are used for connecting the horse-shoes to the base body of the train. Aluminum is chosen because it is non-ferromagnetic, thereby it is minimally affected by electromagnetic induction from the horse-shoe of the train and it is also lightweight.

7.3 Track

The track consists of two long beams which are connected by two connecting segments. The track is also coated with metal primer to prevent rusting.

Fig -12: Track of the DC Maglev

7.4 Horse-shoe

The horseshoe is made by connecting three mild-steel segments. It consists of two identical segments joined together by a third middle segment. The horseshoe is also coated with metal primer to prevent rusting.

Fig -13: Horse-shoes of the DC Maglev

7.5 Nomex paper

Nomex paper is an electrically insulating material that is used to prevent current leakages. Here it is wound on the track and the horse-shoe for the protection of the user. It is available in various thicknesses for various purposes. Nomex paper used in this case is of 0.5mm thickness. There are various grades of Nomex papers having a thickness from 0.1 – 1 mm.

7.6 Wire

1sq.mm, wires are used for winding the track and the horseshoe electromagnet. The upper segment is wound in such a way that it acts as the north pole and the lower segment acts as the south pole. In the horseshoe magnet, the upper limb acts as the north pole and the lower limb acts as the south pole.

8. CONSTRUCTION PROCEDURE

The main core parts such as track and horse-shoe were painted with metal primer for rust prevention. Then the parts were wound with Nomex paper for protection as Nomex paper is an electrical insulator. As aforementioned, the track consists of two long segments and two short segments, the long segments form the north and south poles of the track, and the short segments are used for completing the magnetic circuit and are connected by bolts. The longer segments are wound with wire to make them electromagnetic

The horse-shoe is also made up of three segments, two shorter similar segments, and one longer connecting segment. These three segments are joined together with bolts. Then they are coated with metal primer and wound with Nomex paper. The upper and lower limbs of the horse-shoe are wound with wire. The aluminum segment is used to connect the horseshoe and the train body using bolts. All the parts were assembled as per the design.

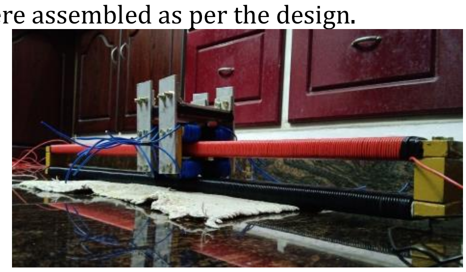

Fig -14: Train and track

9. COMPARATIVE STUDY BETWEEN CONVENTIONAL MAGLEV AND DC MAGLEV TRAIN

System	Conventional Maglev Train	DC Maglev train
Levitation	It works either on magnetic attraction (EMS) or magnetic repulsion (EDS).	It works on both magnetic attraction (EMS) and magnetic repulsion (EDS).
Propulsion	• It works on linear motors. • A separate arrangement for propulsion is needed in track. • A three-phase AC supply is used for propulsion. • Propulsion is controlled by the track. Change in polarity determines the speed of the train.	• It works on an electromagnetic arrangement • No arrangement is needed in track. • DC supply is used for propulsion. • Propulsion is controlled by the propulsion segment on the train body. Change in the angle of the propulsion segment determines the speed of the train.
Guidance	In AC Maglev trains, Guidance is achieved using permanent magnets, electromagnets, or super-conductors according to their speed	In DC Maglev trains, since the speed is comparatively less than AC Maglev trains either permanent magnets or electromagnets are needed and superconductors need not be used.

10. FUTURE SCOPE

Shortly, most of the countries in the world would be switching to HVDC systems. So, a DC Maglev train would prove to be more efficient in such a scenario because DC Maglev trains could be directly supplied from the HVDC system without power rectification. Also, there is a possibility of powering the entire track and train of the DC Maglev train using solar panels, which is a green energy source. Even though the installation cost of solar panels for powering the DC Maglev train would be slightly high, the maintenance and running cost would be comparatively much less than AC Maglev trains.

A disadvantage of DC Maglev is that it requires a larger quantity of ferromagnetic material when compared to conventional Maglev trains. This may in turn increase the initial cost of installation, but considering the lesser maintenance cost, it would be more economical in the long run. When compared to the high-temperature superconducting Maglev trains which consume a large amount of electrical power to keep the superconducting material at cryogenic temperatures, the running cost of the slower DC Maglev is very less.

11. CONCLUSIONS

Most of the countries in the world would shortly be switching to HVDC systems. So, a DC Maglev train would prove to be more efficient in such a scenario because DC Maglev trains could be directly supplied from the HVDC system without a rectification module. Also, there is a possibility of powering the entire track and train of the DC Maglev train using solar panels, which would ensure a green energy source.

The DC Maglev is a variant of the conventional maglev train in a way that it works entirely on DC. Thereby, it does not have any iron losses and hence lesser operational loss resulting in greater efficiency and lesser running costs. The main disadvantage of the DC Maglev is that it requires a greater quantity of ferromagnetic core material when compared to the conventional maglev thereby having a greater capital cost. This can be reduced if a cheaper and lighter ferromagnetic material is developed. Since the DC Maglev works entirely on DC the cost of power electronic control is minimized, thereby having lesser maintenance cost than the conventional maglev train.

REFERENCES

[1] Hyung-Woo Lee, Ki-Chan Kim, and Ju Lee, Review of Maglev Train Technologies, IEEE Transactions on Magnetics, VOL. 42, NO. 7, pp. 1917-1925, JULY 2006.
[2] Hongliang Wang, Jian Li, Ronghai Qu, Junquan Lai, Hailin Huang, and Hengkun Liu, Study on High-Efficiency Permanent Magnet Linear Synchronous Motor for Maglev, IEEE Transactions on Applied Superconductivity, VOL. 28, NO. 3, APRIL 2018.
[3] F. N. Werfel, U. Floegel- Delor, R. Rothfeld, T. Riedel, P. Schirrmeister, R. Koenig, Experiments of Superconducting Maglev Ground Transportation, IEEE Transactions on Applied Superconductivity, VOL. 26, NO. 3, April 2016.
[4] Luguang Yan, Development and Application of the Maglev Transportation System, IEEE Transactions on Applied Superconductivity, VOL. 18, NO. 2, JUNE 2008.
[5] Yan Luguang, Progress of High-Speed Maglev in China, IEEE Transactions on Applied Superconductivity, VOL. 12, NO. 1, MARCH 2002.
[6] Jaewon Lim, Chang-Hyun Kim, Jong-Min Lee, Hyung-suk Han, Doh-Young Park, Design of Magnetic Levitation Electromagnet for High-Speed Maglev Train. In: 2013 International Conference on Electrical Machines and Systems, Oct. 26-29, 2013, Busan, Korea, pp 1975-1977.
[7] Gabriella Crotti, Antonio Delle Femine, Domenico Giordano, Carmine Landi, Mario Luiso, Andrea Mariscotti, and Paolo Emilio Roccato, Pantograph-to-OHL Arc: Conducted Effects in DC Railway Supply System, IEEE Transactions on Instrumentation and Measurement, VOL. 68, NO. 10, OCTOBER 2019.