Thermal Effect on Electromagnetic Suspension for Air Gap Performance in Magnetic Levitation System

Deny Viviantoro1,a, Aliq Zuhdi1,b, Agus Purbhadi1,c, Mujamilah2,d

1Electromechanical Study Program, Polytechnic Institute of Nuclear Technology
Jl. Babarsari Yogyakarta 55281, Indonesia
2The Center for Science and Advanced Material Technology, National Nuclear Energy Agency of Indonesia, PUSPITEK Serpong, South Tangerang, Indonesia
E-mail : a dviviantoro@outlook.com, b aliq.zuhdi63@gmail.com, c aguspurbhadi@gmail.com, d ian@batan.go.id

Abstract. Maglev (magnetic levitation) technology becomes a basis for the development of new generation of rail-based transportation system. Maglev vehicle can be classified according to their suspension mechanism, there are Electromagnetic Suspension and Electrodynamics Suspension. Electromagnetic suspension as one of the three air gap forming methods in designing magnetic levitation system because of some advantages such as suitability for either low or high speed vehicle, cheap fabrication, commercially available component, and ease to control than other forming method. However, this method still has weakness characteristic wherein the magnetic flux generated by coil in the u-shaped iron core causes excessive heat generation due to the power loss and eddy current effect. The heat accumulated in iron core results in higher temperature that further increase the resistance of coil and reluctance of iron core, so the magnetic flux production decrease. This problem was investigated to determine the appropriate current flow in the coil, therefore the thermal effect can be reduced in order to maintain the air gap forming performance of the EMS-based magnetic levitation system.

Keywords: transportation system, electromagnetism, control, thermal effect

1. Introduction

Recently, magnetic levitation becomes a basis for the development of new generation of rail-based transportation system. Compared with the rail-based conventional transportation which is driven forward by using friction between wheels and rails, the maglev transportation offers some advantages due to the frictionless technique by levitated the coach on the guide way using electromagnet and also by applying the propulsion force electromechanically without any contact [1].

Even contactless, Maglev technology is not as simple as expected because it is still face the problem of the configuration, geometry and the range of the speed required. Principally, maglev vehicle is constructed using three basic system including levitation/suspension, propulsion and guidance systems. According to the levitation technique, maglev vehicle can be classified into Electromagnetic Suspension (EMS) and Electrodynamics Suspension (EDS) [1][2]. In case of EMS, the levitation technique is accomplished based on the magnetic attraction force between a guide way and the electromagnets shown in Figure 1. Therefore, precise air-gap control is indispensable in order to maintain a uniform and small air gap of around ± 10 mm. In other side, EMS is technically easier than EDS and is able to levitate by
itself in zero or low speed. However, application of EMS for high and low speed vehicle is still different depending on the stabilization of the operation. Furthermore, maglev vehicle needs high precision not only in terms of levitation but also the guidance system when operated with high speed, such as a high speed train, so that separation among them is required. Integrated levitation and guidance systems is recommended when EMS is operated on low speed vehicle application [1].

After the configuration and speed range is specified, there are still two possible geometries of electromagnet core for EMS such as E-core and U-core magnets. A U-core configuration needs a relatively wider guide way for sufficient window area to house the excitation coils. On the other hand, the eddy current induced in the guide way have been found to be substantially less than E-core magnets, so that U-core magnets are widely used for low- and high-speed vehicle. Furthermore, although EMS using U-core magnets look like better and easier than the other, this method still have limitation due to the large of $I^2R$ loss production [3].

The selection of the basic geometries of U-core magnets is an important aspect to achieve the required magnetic field production with minimum construction cost and $I^2R$ loss production. If thermal excess due to the loss production increase proportionally to the number of coil resistance, then the magnetic field production is reduced. This study is aimed to investigate thermal effect of electromagnet on EMS system to determine the appropriate current flow in the coil in order to maintain the air gap forming performance.

![Figure 1](image1.png)

**Figure 1** Electromagnetic suspension
(a) levitation and guidance integrated. (b) levitation and guidance separated [1]

2. Material and method
The Maglev vehicle was constructed using EMS system and U-shaped magnetic core. The magnetic field data was collected in High Current Electricity Laboratory in Polytechnic Institute of Nuclear Technology, Yogyakarta, Indonesia in August 2017 using Digital Tesla meter (Group 3 DTM-151). U-shaped magnets geometry is chosen on this research as shown in Figure 2 and the specification of U-shaped magnets and the coil is shown in Table 1 and 2, respectively. Generated force by U-shaped magnet in Figure 2 with two pole face areas will be expressed by the following equation [3]

$$F = \frac{B^2}{2\mu_0}(2pl)$$

for the construction of the real maglev train, ferrous metal as fixed body or guideway and the electromagnetic device as free body. Attractive force ($F$) produced by the magnetic field ($B$) will make free body move towards the fixed body. To relate Eq. (1) to coil housing (window area), dimension of U-shaped magnet needs to be identified by the following equation [3].
\[ F_a = \frac{F}{(2p + w)^2} \]

\[ \equiv \frac{B^2}{2\mu_0} \left( \frac{1}{1 + \frac{w}{2p}} \right) \]

Eq. (1) shows that for constant magnetic field \( (B) \), the increasing \( w/2p \) (of Fig. 2) reduces the attraction force. Thus if the pole width is given, the window area may be determined by using Eq. (2) [3]. Ferrous metal for U-shaped magnets and guideway on this experiment using ASTM A36 Low Carbon Steel and the coil is using enamel wire from Hellenic Wire with low internal resistance.

On this research in laboratory scope, electromagnetic device as free body is flipped as fixed body and replaced by ferrous metal because it accommodates more weight than the ferrous metal where it effects on high power consumption. Thermocouple’s sensor is placed on the middle of the surface of U-shaped magnet and Tesla meter sensor is placed on positive pole of the magnet. The observation is conducted by applying voltage form 20 VDC until 6 VDC in room temperature (uniformly at 31°C) and recorded every minute up to 40 minutes.

| Symbol | Dimension (mm) |
|--------|----------------|
| \( p \) | 20 |
| \( l \) | 298 |
| \( w \) | 4 |
| \( d \) | 20 |
| \( h \) | 30 |
| \( b \) | 88 |

**Table 1 U-Shaped Magnet Specification**

| Parameter                     | Value          |
|-------------------------------|----------------|
| Wire Diameter                 | 1.6 mm         |
| Turns                         | 319 turns      |
| Length of wire                | 218.375 m      |
| Electric resistivity at 31°C  | 2.2 Ω          |

**Table 2 Coil Specification**

3. Result and discussion

This study observes temperature, current flow and magnetic field production at several voltage of electromagnetic device as given in Figure 4, Figure 5 and Figure 6 respectively. Sharp rising curve at beginning of 20 V as shown in Figure 4 and sharp decrease as shown in Figure 5 and Figure 6 demonstrate that the amount of voltage has significant effect on this focus. The higher voltage operation the faster transformation on the curve and the lower voltage operation the more stable transformation on the curve.
Rate of temperature is shown in Figure 4. When 20 V operation is applied, the curve is rising sharp until 100°C in 40 minutes. However, when 18 V operation is applied, the rising curve is lower than 20 V operation and the curve will be stable along the voltage operation is decrease to 6 V operation. This curve will give impact to not only current flow amount, but also magnetic field production as shown in Figure 5 and Figure 6.

![Figure 4 Temperature Measurement](image)

Thermal accumulation in electromagnetic device makes the current flow decrease due to resistance increment of coil. According to Ohm’s Law, \( V = I \times R \), for constant voltage given, when the resistance increases then the current flow decreases proportionally. Figure 5 shows when 20 V operation is applied, the curve is decrease significantly. However, when 18 V operation is applied, decrement of current flow is lower than 20 V because the thermal rate is lower than it applied for 20 V operation and the curve will be stable along the voltage operation is decrease to 6 V. This curve will give the impact to electromagnetic device to generate magnetic field production.

![Figure 5 Current Measurement](image)

Decrement of current flow in coil makes the magnetic field production in pole is decrease. According to Biot-Savart’s Law, magnetic field production is proportional to current flow in coil. Results of measurement using Tesla meter shows that the magnetic field decrease significantly when 20 V operation is applied. However, the reduction rate of magnetic field is lower when the voltage applied decreased, and finally the curve shows the stability over time. Figure 6 shows when 20 V operation is applied, the curve is decrease significantly and will be stable along the voltage operation is decrease to 6 V.
The relationship between the three parameters can be drawn as follows. Magnetic field production decreases significantly when the electromagnet core has higher rate of temperature which further decrease the coil current flow. It is because of the conductor resistivity which decrease proportional to the temperature of the U-core. When temperature is rising, conductor’s ions vibrate with high amplitude, then the electron tend to collide each other [4].

4. Conclusion
We have developed maglev conveyor prototype with the aim of study to investigate the thermal effect to magnetic production. The higher voltage operation causes higher current flow on electromagnet coil and it further causes high increasing rate of temperature. The investigation of thermal and magnetic field production characteristic is to determine the appropriate cooling system for preventing of thermal excess. If the thermal rising is successfully controlled, the constant magnetic field production can be realized. However, the power consumption between with or without cooling system has to be considered to determine the most profitable method.

Acknowledgment
The authors would like to thank Unit Penelitian dan Pengabdian Masyarakat Polytechnic Institute of Nuclear Technology – National Nuclear Energy Agency, Yogyakarta for their cooperation and finance support during this work.

Reference
[1] Hyung-Woo Lee, Ki-Chan Kim, and Ju Lee, “Review of maglev train technologies,” *IEEE Trans. Magn.*, vol. 42, no. 7, pp. 1917–1925, Jul. 2006.
[2] Z. Liu, Z. Long, and X. Li, *Maglev Trains*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2015.
[3] H.-S. Han and D.-S. Kim, *Magnetic Levitation*, vol. 13. Dordrecht: Springer Netherlands, 2016.
[4] R. Riswanto, “ANALISIS RESISTANSI COIL KAWAT TEMBAGA TERHADAP PERUBAHAN SUHU SANGAT RENDAH SEBAGAI RANCANG DASAR PENGUKURAN SUHU RENDAH,” *J. Pendidik. Fis.*, vol. 3, no. 1, 2015.