Measurement of magnetic fields on electric train

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Abstract. Electric train is one of the most widely used transportation modes in Indonesia especially Jakarta. In general, all electrical and electronic based equipment when operated will produce electromagnetic fields. At present, the railway system uses electric power, both as to its driving force, as well as a supporting part (light system, air conditioner, etc.), and instead uses very large electric power. So surely the train system produces an electromagnetic field. Electromagnetic fields are a combination of invisible electric and magnetic fields of force. They are generated by natural phenomena, but also by human activities, mainly through the use of electricity. The magnetic field on the train generally occurs in areas close to the source. In this paper, already measured the magnetic field (near field) in the electric train in the frequency range 0.015 kHz up to 1 kHz. The measurement results show that the highest magnetic field is obtained when the train starts up at 333.76 nT. The magnetic field level is small when away from the electrical inverters. The average level of the magnetic field when the train is at its highest is 223.26 nT and during braking there is an increase of 323.93 nT.

1. Introduction

Today, travelling by train is the easiest, fastest way to explore another city. People using electric train is increasing year by year and become one of alternative public transportation that likely choose by peoples and society around Jakarta. Based on data from PT. Kereta Api Indonesia (KAI), the number of electric train passengers throughout 2018 reached 336.71 million passengers, up approximately 6% from previous year [1]. The amount is around 1.2 million/day [2].

In general, all electrical and electronic based equipment when operated will produce electromagnetic fields [3]. Electromagnetic fields are present everywhere in our environment but are invisible to the human eye [4]. Electromagnetic fields are a combination of invisible electric and magnetic fields of force. More than 3 billion people across the world are exposed to electromagnetic fields every day [5]. At present, the railway system uses electric power, both as to its driving force, as well as a supporting part (light system, air conditioner, etc.), and instead uses very large electric power. In general, train infrastructure operates in a complex and non-homogeneous environment, where low-power electronic equipment must function in an environment with large voltages and currents such as on electric rail trains [6]. The environment of railway tracks is exposed to magnetic and electric fields from trains, the railway power supply systems, nearby electric power transmission lines [7]. In addition, according to research conducted by the International Commision on Non-Ionizing Radiation Protection (ICNIRP), the electromagnetic field can also affect human health, which means here are train passengers themselves [8]. In 1998, ICNIRP issued a guideline to limit radiation emitted by trains [9]. The magnetic field on the train generally occurs in areas close to the sources. In
2011, Wuwus et al conducted a research of the measurement of the electromagnetic field from the electric train [10]. Therefore, the current study aims to measure the intensity of magnetic field in the electric trains of Jabodetabek in different conditions.

2. Basic Theory

2.1. Magnetic Field
Magnetic fields and electric fields are interrelated, and are both components of the electromagnetic force, one of the four fundamental forces of nature [11]. Magnetic fields are widely used throughout modern technology, particularly in electrical engineering and electromechanics. A magnetic field is an area which is under the influence of a magnetic charge. A magnetic field, like an electric field, is due to the polar nature of electric or magnetic charges. Poles are oriented in north and south directions, and a magnetic field's strength depends on the strength of magnet that is creating it. Magnetic fields are a basic principle behind countless appliances and modern-day gadgets.

A magnetic field can be generated in two ways: either around a magnet or in the victim of moving electric field (when electric charge carries such as electrons move through space or within an electrical conductor). Magnetic and electric fields interact differently depending on the environment into which they are placed. An object placed in a magnetic field experiences a force which depends on its orientation within the field. Properties of a magnetic field are rendered in electromagnetism, which is basis of technological advancements such as bullet trains, elevators, escalators, and cathode-ray tube televisions [12].

2.2. Electric Train
In an electric railway system, the train is provided by sliding contact from a supply line that is placed over the railway tracks. The electric train uses two types of electricity sources, namely a DC source of 600 V, 750 V, 1500 V, and 3000 V, while for an AC source of 15 kV (16.7 Hz) and 25 kV (50 Hz). A pantograph use to deliver electricity from the source above to the converter then forward to the motor (Figure 1) so that the train runs. The pantograph must always contact continuously with the source conductor, besides that the pantograph must be aerodynamic because it is used at relatively high speed continuously [13].

The current generally return to the substation via the rails, a separate return conductor, or via the earth. The large electrical plants in the network are constituted of sub-plants, which are essentially independent. Every single sub-plant consists essentially of overhead lines, buried cables, and rails. Two different substations that are equipped with static AC–DC conversion groups supply the sub-network. The return path of the current is constituted by the rails that are connected by means of cables to the negative pole of the supply. DC electrical motors controlled by choppers are employed for traction. In order to compensate for the voltage drop along the lines, several substations are used as line subway feeders. The power delivered by the substation is transmitted to the traction vehicle via a system of flexible suspension contact lines (overhead or centenary) with which a locomotive mounted articulated
device (pantograph) is brought into contact. On the traction vehicle, the power is regulated using choppers and then supplied to electric motors to control the movement. Auxiliary power that is lower than that which is supplied to the electric traction motors is also conditioned and regulated using static converters, inverters, and rectifiers. The rails ensure that the current return and the sources of magnetic fields on the train are often under the floors. [14].

3. Methodology

Ideally, the measurement is at the distance as close as possible to the source so that get the maximum measurement results. However, because the condition of the train is moving and the position of the motor is under the carriage, it is not possible to take the ideal near field measurement. The possible approach is to take measurements on the train floor area exactly where the motor is installed. Magnetic field measurements are carried out in the frequency range of 0.015 kHz - 1 kHz. The antenna is placed 10 cm above the surface of the train floor. Setup measurements can be seen in Figure 2.

![Figure 2. Measurement setup](image)

The measurement conditions are as follows (Figure 3):

- a. When the electric inverter starts at point 1
- b. When after the electric inverter starts up at point 2
- c. When after the electric inverter starts up at point 4
- d. When after the electric inverter starts up at point 5
- e. When the first acceleration starts at point 5
- f. When the train is running at point 5
- g. When braking starts at point 5

![Figure 3. Measurement point](image)

4. Results and Discussion

The results of near field magnetic field measurements are shown in the following graphs:
From the picture above it can be seen at the measurement point 1 when the electric inverter starts to turn on the highest value of the magnetic field reaching 333.76 nT which is at the frequency of 50 Hz. A few moments after the inverter startup is seen in point 2 there is a decrease in the magnetic field value to 249.11 nT at the same frequency. At this point, it should be the maximum magnetic field due to the electricity inverter. But because of the limited measurement time so that the initial data when the inverter starts to be completely turned on cannot be done at this point.

**Figure 4.** Measurements graph when the electric inverter starts at point 1 (0,015 kHz-1 kHz)

**Figure 5.** Measurements graph after the electric inverter starts at point 2 (0,015 kHz-1 kHz)

**Figure 6.** Measurements graph after the electric inverter starts up at point 4 (0,015 kHz-1 kHz)
Figure 7. Measurements graph after the electric inverter starts up at point 5 (0.015 kHz - 1 kHz)

Figure 6 and Figure 7 are the results of measurements on the third train where it is located far from the electricity inverter and from the measurement results, it is seen that the magnetic field level is almost the same at both points which are around 130 nT. This value is relatively much lower than at the start of the starts up.

Figure 8. Measurements graph when the first acceleration starts at point 5 (0.015 kHz - 1 kHz)

Figure 9. Measurements graph at point 5 when the train is running (0.045 kHz-0.065 kHz)
Figure 10. Measurements graph at point 5 when braking begins (0.015 kHz - 1 kHz)

Measurement results (Figure 8-10) show that the highest field is generated during regenerative braking and maximum acceleration. According to measurements done in Switzerland by the Biel Technical University [15] the strength of the magnetic fields changes constantly as the car travels along, and is greatly dependent on the way the car is advancing or braking, the magnetic fields were between 0.1 and 3 µT. Figure 8 shows an increase in the magnetic field level at point 5 (above the inverter motor) when the first acceleration occurs or the train starts moving from a stationary position. Figure 9 is a graph of the average magnetic field measurement results measured at a point just above the motor inverter when the train runs. The graph shows that the largest magnetic field level at a frequency of 50 Hz with a magnetic field strength of 223.26 nT. From Figure 10, it can be seen when the train is braking, there is an increase in magnetic field level with a field strength of 323.93 nT.

If all measurement results are compared with the limit recommended by the ICNIRP which is only 100µT for passengers (general public) then the magnetic field level of the train is relatively low. For further application, the units in µT can be converted into units of dBµA/m using the following equation:

\[
dB\mu A/m = 20 \log (\mu T/1.25) + 120
\]

So that the results are as follows:

| Condition          | Measurement point | Frequency (Hz) | Magnetic field (nT) | Magnetic field (dBµA/m) |
|--------------------|------------------|----------------|---------------------|-------------------------|
| Electric inverter starts | 1                | 50             | 333.76              | 108.53                  |
| After electric inverter starts up | 2                | 50             | 249.11              | 105.98                  |
| After electric inverter starts up | 4&5              | 25             | 130                | 100.34                  |
| First acceleration  | 5                | 25             | 292.17              | 107.37                  |
| When driving       | 5                | 50             | 223.26              | 105.03                  |
| When breaking      | 5                | 45             | 323.93              | 108.27                  |

5. Conclusion

In this study, magnetic field measurements have been carried out on the electric trains. The measurement results show the magnetic field level when measured near the electricity inverter is higher than when measured far from the electricity inverter. The highest level of the magnetic field is obtained when the train starts, which is equal to 333.76 nT. The average level of the magnetic field when the train driving is 223.26 nT and during braking an increase of 323.93 nT. The value of the
magnetic field strength at the two farthest points from the electricity inverter looks almost the same, which is around 130 nT. This value is relatively much lower than at the start of the start up.

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