Electromagnetic interference measurement for axle counters light rapid transit railway in Indonesia

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ABSTRACT

The measurement and analysis of electromagnetic interference (EMI) from light rapid transit (LRT) axle counters against magnetic field interference in Indonesia has been carried out. The low-cost magnetic sensors were developed according to the British Standard (BS) EN 50592:2016. The measurement setup and magnetic field limit were based on the British Standard EN 50592:2016 and ERA/ERTMS/033281 standard. Two frequency range of the measurements, lower and higher frequencies with two different train running mode, acceleration mode and deceleration mode were applied in this research. The results in lower frequency range (10 to 100 kHz) were very close to the limit value in both acceleration and deceleration mode, especially at the 30 to 50 kHz for the y and z directions. Although there may possibly magnetic interference at low frequencies, most of the magnetic field emissions were still in acceptable range.

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1. INTRODUCTION

The signaling system on the railway network demands security guarantees for monitoring the position of trains on the rails. The use of axle counters is essential in determining the state of occupation and clearance of the number of axles entering and leaving a track [1]–[6]. The advantages of using axle counters are cost-effective due to neglecting for insulated rail connections and requires only a few cables [7], [8].

The potential problem emerges with the use of axle counters is an error reading causing inaccuracy of the calculation of both occupation and clearance. This may occur when there is a power failure or electromagnetic wave interference. Several studies have shown the potential for magnetic field strength disturbed the performance of the axle counters detector [9]–[15]. This phenomenon is appeared when the electric current flowing through the train track and propagate on the rails which produce a magnetic field in the axle counters [16]–[18]. If the magnetic field value is too high, it can damage the axle counter detectors, therefore causing the counting errors [10], [11], [19]. Measurements and validation of electromagnetic compatibility (EMC) related to axle counters have also been carried out in the Italian and Swedish railway network to analyze the magnetic field strength and the major source of faults in the track section [7], [12], [13], [20].

Although the design of the measuring instrument (magnetic coil sensor as antenna) has been described in the standard, the detail specification remains open and has to be explored. Moreover, the price of the tool in the market is utterly high. Therefore, several developments and adjustments for antenna are required in order to obtain precise measurement results, low-cost, and fulfill the requirements of applicable standards. The design exploration and verification has been done in this paper [21]. Currently, Indonesia is promoting a light rapid transit (LRT) and the signaling system is a critical one as the LRT has to be properly operated [22]. Therefore, it is necessarily researching the electromagnetic disturbances in the LRT railway to ensure that the axle counter on the LRT showing the appropriate results.

The structure of this paper consists of a brief description of the standards in measuring the magnetic field strength from the axle counters in the LRT and the technique for evaluating the magnitude of the magnetic field. Then, the magnetic coil sensor was developed and verified. Measurement was done at the railway track and the data processing of the magnetic field result are shown in low and high frequencies range. Finally, the discussion and the conclusion are stated at the last section.

2. RESEARCH METHOD

2.1. Measurement of magnetic field strength

British standard (BS) EN 50592:2006 is the standard described the compatibility of axle counters against electromagnetic interference [23]. This standard is applied to ensure compatibility between LRT and axle counter systems. Moreover, it also contains measurement and evaluation techniques of the magnetic field emissions. The compliance is specified by the limit of magnetic field strength level which would potentially interfere the axle counter detectors system.

Based on study [23], a flowchart for measuring magnetic field strength in LRT railway is shown in Figure 1. The first step, the magnetic coil sensors (antenna) were created and verified both for lower frequencies (10 to 100 kHz) and higher frequencies (100 kHz to 1.3 MHz). The optimum characteristics of the coil has been validated by simulation and measurement [21]. The dimensions and the shape of the antennas refer to the standard BS EN 50592:2016 and is shown in Figure 2. The x-y-z direction represents the plane penetrated by the magnetic field due to the movement of the LRT on the train tracks. Meanwhile, the developed antennas are shown in Figures 3(a) and 3(b).

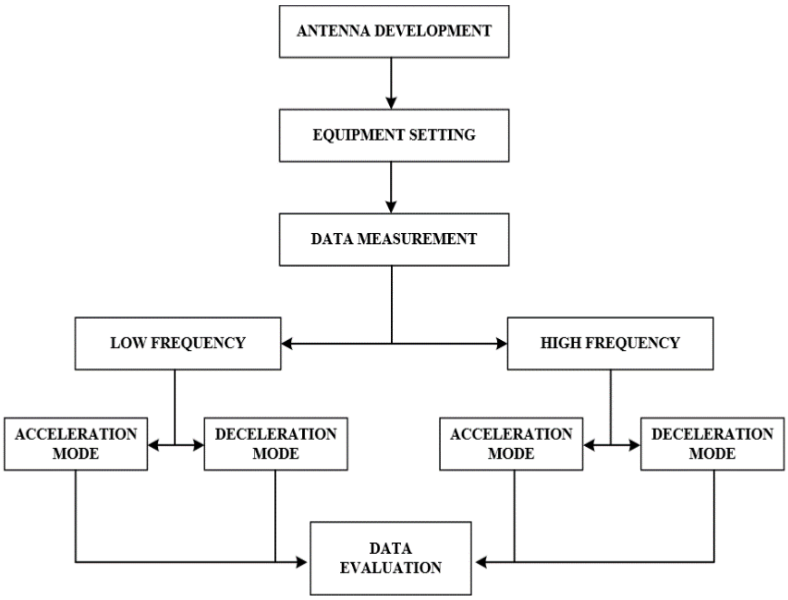


Figure 1. Flowchart to determine the magnetic field strength in LRT railway

Furthermore, the measurement setup and the mounting position of the antennas around the rails is shown in Figure 4. The measurement was taken in two different train running mode, acceleration mode and deceleration mode. As can be seen here, the sensors were placed at certain distance both from the track and the ground. There is also supporting plate made by acrylic to omit the unwanted interference effect which potentially disturbing the measurement system. During measurement, the accelerate and decelerate mode measurement were done sequentially based on the frequency band. The magnetic sensors are connected to 2-channels PicoScope with A/D converter then connected to the laptop. When the low frequency setting is ready, the train will pass through the track and the sensors will detect and capture the magnetic radiated emission from the track caused by the train in accelerate mode or decelerate mode. The emission was recorded in time domain and in 3-axis direction, x, y and z direction using sampling rate of 25 MS/s for higher and 12.5 MS/s for lower frequency range. Finally, the data processing was evaluated by utilizing both Excel and MATLAB by fast Fourier transformation (FFT) with Hanning window algorithm [7], [24], [25].

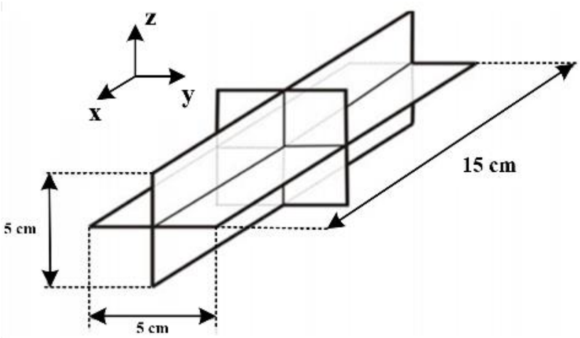
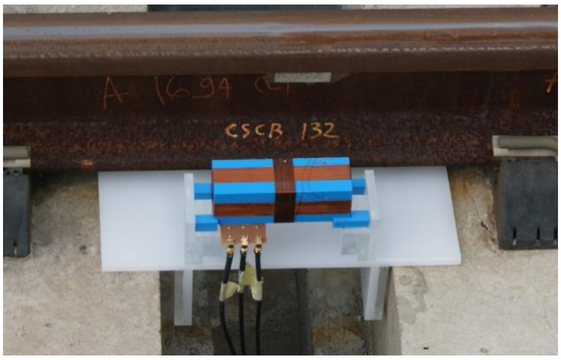
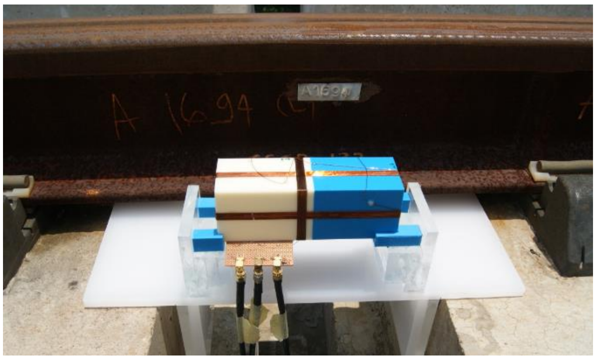


Figure 2. Design and dimension of an antenna (magnetic coil sensor)



(a)



(b)

Figure 3. Magnetic coil sensors for measuring magnetic field strength in (a) the lower frequency and (b) the higher frequency

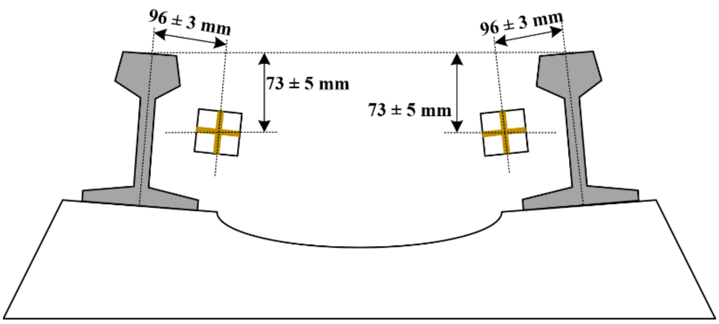


Figure 4. The mounting position of the antenna around the railway

2.2. Data evaluation technique

The ERA/ERTMS/033281 standard requires a limit of the magnetic field density of *dBμA/m* units in the frequency domain [26]. However, the PicoScope produced raw data of milli-volts in the time domain due to the presence of a magnetic field that penetrates the x-y-z plane. Therefore, conversion is necessary to obtain *dBμA/m* in frequency domain.

A sketch of the antenna plane detected a magnetic field (*H*) is given in Figure 5 [27]. In addition, the equivalent circuit between the antenna and the measuring instrument (PicoScope) is shown in Figure 6. The open voltage generated by the antenna (V_{oc}) arises due to the magnetic field that changes in time. Thus, assuming the measured magnetic field is only on perpendicular to the plane of the coil (θ = 90°), the V_{oc} equation can be written as in (1) [27].

$$V_{oc} = 2\pi f a b \mu_0 H N \quad (1)$$

f is the frequency (Hz), *a* and *b* are the length of the antenna's side in the x, y, or z direction in meters, μ_0 is the permeability of the magnetic field in free space (4π.10^{-7} H/m), *H* is the density the magnetic field that penetrates the coil (A/m) and *N* is the number of turns. Furthermore, the voltage equation in the PicoScope (V_P) shown in (2) is the comparison between the voltage against the impedance of antenna and PicoScope (Z_A and Z_P).

$$V_P = V_{oc} \frac{Z_P}{Z_P + Z_A} \quad (2)$$

The antenna factor values (*AF*) for each antenna, (A.V^{-1}.m^{-1}) is required to obtain the magnetic field density. The antenna factor equation is shown in (3) and the final equation to determine the value of the magnetic field density is shown in (4), and V_R is the voltage value reading by the PicoScope every time.

$$AF \rightarrow \frac{H}{V_P} = \frac{Z_P + Z_A}{2\pi f a b \mu_0 H N Z_P} \quad (3)$$

$$dB\mu A/m = 20 log_{10}(V_R * AF) \quad (4)$$

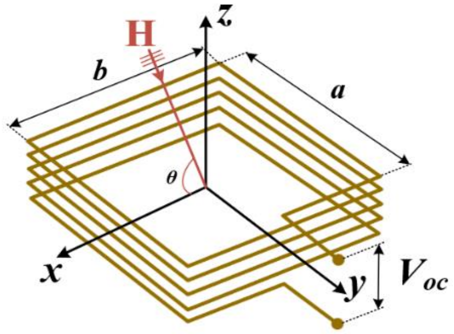


Figure 5. The cross-section of antenna in z-direction

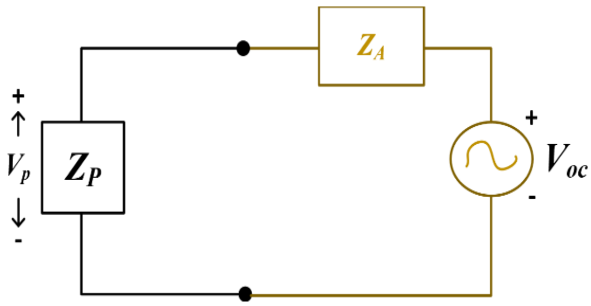


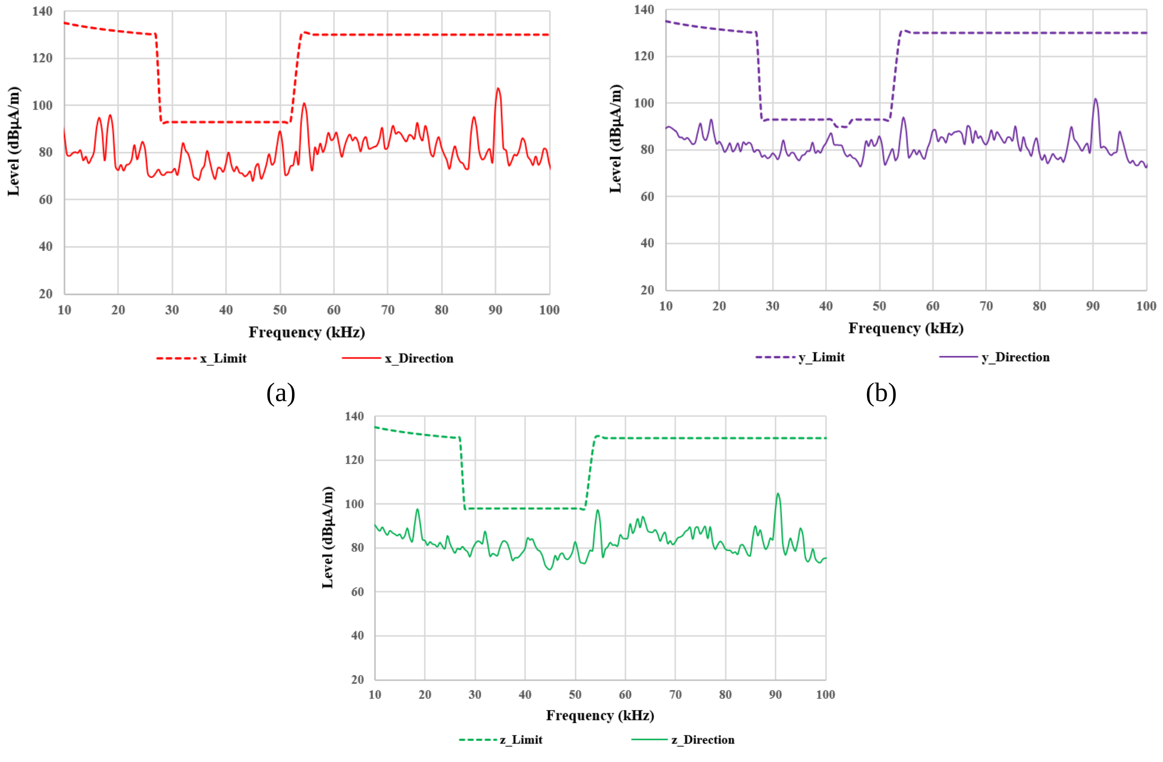
Figure 6. The equivalent circuit between antenna and PicoScope

3. RESULTS AND DISCUSSION

After going through the evaluation stage of data processing, including the time domain to the frequency domain conversion using FFT with Hanning algorithm, the displayed magnetic field value is divided into two range frequencies, namely lower frequencies and higher frequencies. In each range, there are two modes of LRT movement, the accelerate and the decelerate mode. The magnetic field limits for each direction refer to the ERA/ERTMS/033281 standard [26].

In Figures 7(a) to (c) and Figures 8(a) to (c), at the lower frequency range, 10 to 100 kHz and in the accelerate mode, the magnetic field levels are below the limit value for all direction, ranging from 70 to 100 dBμA/m. However, in the decelerate mode, the levels are very close to the limit value, especially at the 30 to 50 kHz for the y and z directions. This field strength may interfere the axle counters system and may potentially affect the counting results.

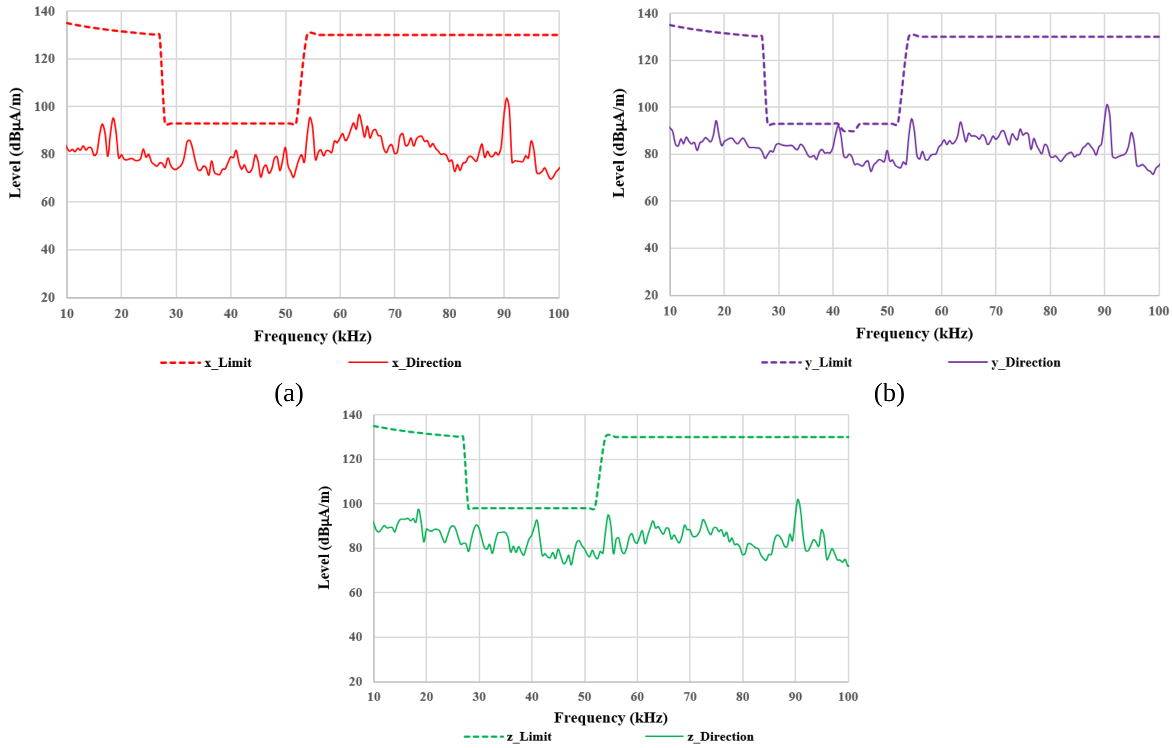
Similar results are also shown in Figures 9(a) to (c) and Figures 10(a) to (c). In the higher frequency range, the field strengths are below the required limit for the x, y, and z directions respectively ranging from 30 to 90 dBμA/m. However, the value of the magnetic field in the x direction is lower than in the other directions when compared to the results at lower frequencies. Thus, the value of the magnetic field generated on the LRT railway is in acceptable range, although there may potentially interference at low frequencies. However, further studies still need to be carried out particularly on the impact of high magnetic field emissions which would causing error readings on axle counters to ensure the accuracy of readings.



(a) (b)

(c)

Figure 7. Magnetic field level at lower frequencies for (a) x-direction, (b) y-direction, and (c) z-direction in acceleration mode



(a) (b)

(c)

Figure 8. Magnetic field level at lower frequencies for (a) x-direction, (b) y-direction, and (c) z-direction in deceleration mode

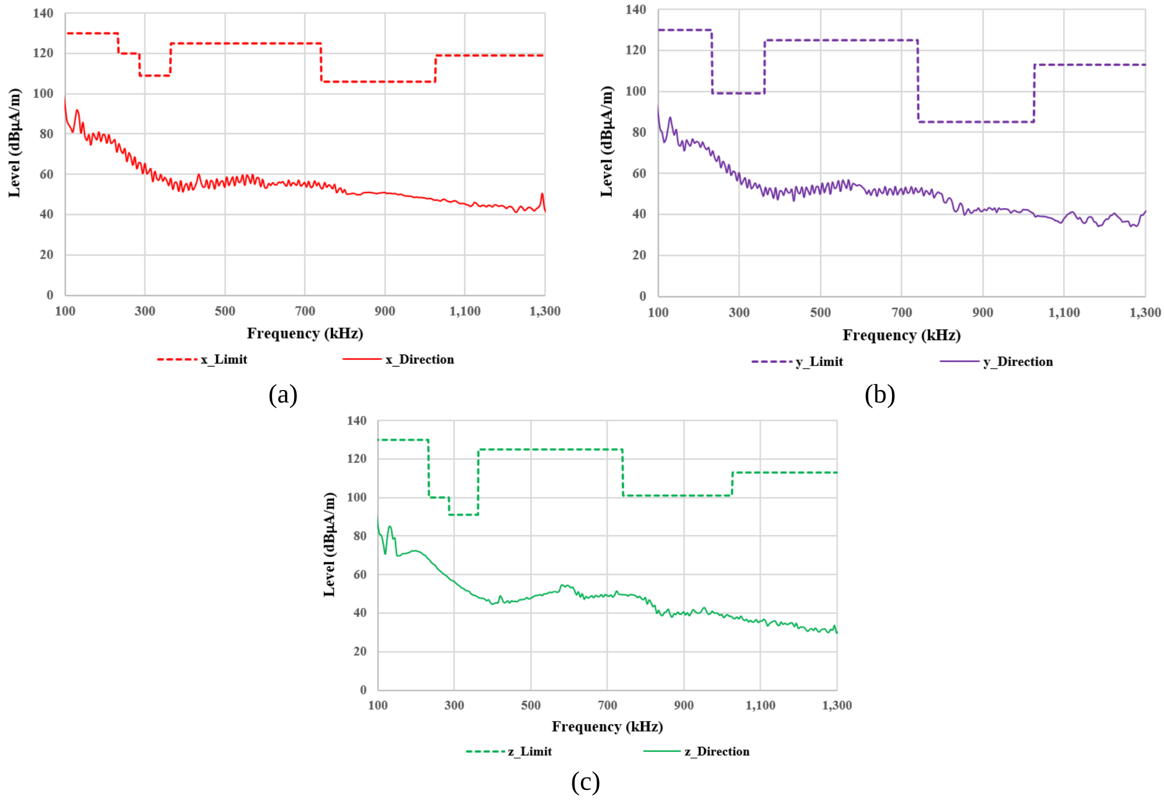


Figure 9. Magnetic field level at higher frequencies for (a) x-direction, (b) y-direction, and (c) z-direction in acceleration mode

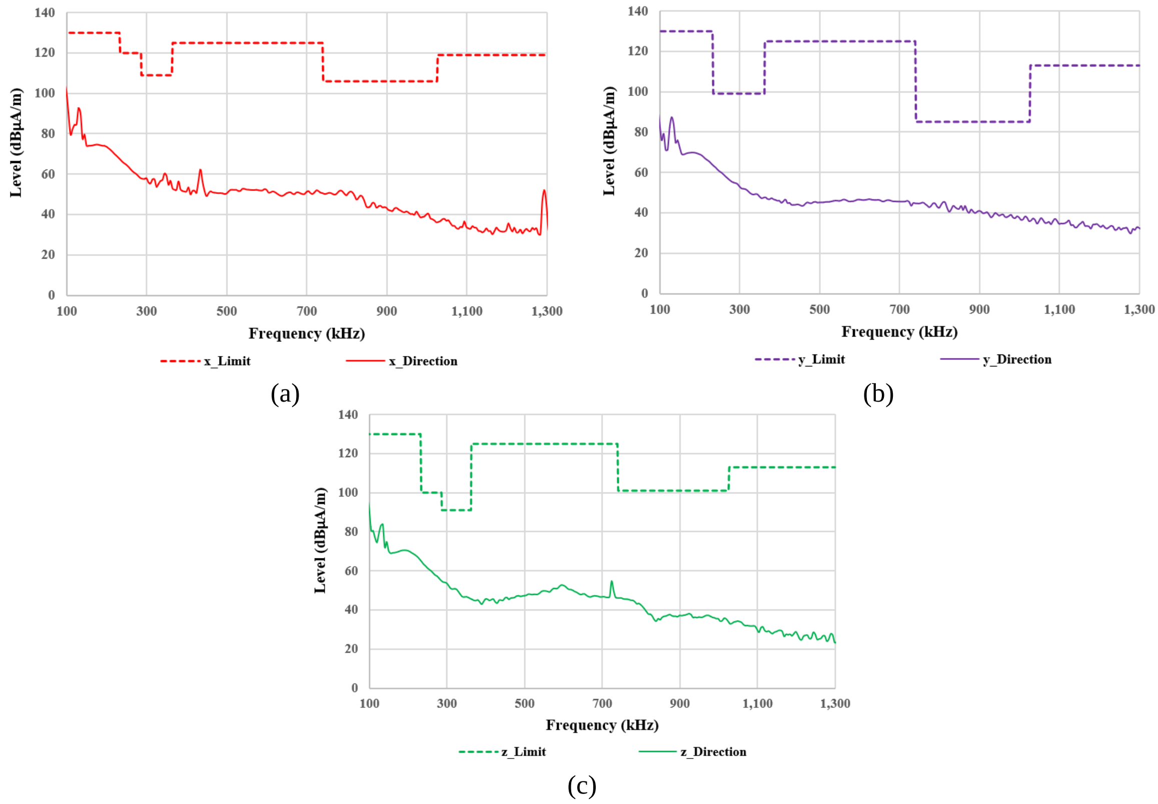


Figure 10. Magnetic field level at higher frequencies for (a) x-direction, (b) y-direction, and (c) z-direction in deceleration mode

4. CONCLUSION

It has been done the measurement and analysis of the EMI for the axle counter of the LRT's track. The results show all the magnetic field level are below the limit value and meet the standard requirement. However, at lower frequency, the levels are very close to the standard limit which most probably could interfere the axle counters system. Further research on the effect of high magnetic field strength into the axle counter are needed.

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REFERENCES

[1] M. V. Nikolic, B. D. Kosic, M. D. Milanovic, N. M. Antonic, Z. M. Stojkovic, and I. Z. Kokic, "Railway axle counter prototype," in *2014 22nd Telecommunications Forum Telfor (TELFOR)*, Nov. 2014, pp. 694–697, doi: 10.1109/TELFOR.2014.7034503.

[2] J. Hofbauer, "Challenges with applying axle counter technology in the USA," in *2017 Joint Rail Conference, JRC 2017*, 2017, pp. 1–5, doi: 10.1115/JRC2017-2293.

[3] P. R. Goundan and A. Jhunjhunwala, "Axle counter based block signalling for safe and efficient train operations," in *Gateway to 21st Century Communications Village. VTC 1999-Fall. IEEE VTS 50th Vehicular Technology Conference (Cat. No.99CH36324)*, 1999, vol. 2, pp. 824–828, doi: 10.1109/VETECF.1999.798444.

[4] T. Mcpeake and O. Rail, "Integrated axle counter block solution," in *AusRAIL PLUS 2013*, 2013, pp. 1–10.

[5] Chu-liang Wei *et al.*, "A fiber bragg grating sensor system for train axle counting," *IEEE Sensors Journal*, vol. 10, no. 12, pp. 1905–1912, Dec. 2010, doi: 10.1109/JSEN.2010.2049199.

[6] A. Zamani and A. Mirabadi, "Analysis of sensor orientation in Railway axle counters using response surface methodology," in *5th SASTech, Khavaran Higher-Education Institute*, 2011, pp. 1–7.

[7] R. D. Persichini, D. Di Febo, V. Calà, C. Malta, and A. Orlandi, "EMC analysis of axle counters in the italian railway network," *IEEE Transactions on Electromagnetic Compatibility*, vol. 57, no. 1, pp. 44–51, 2015, doi: 10.1109/TEMC.2014.2360065.

[8] G. Grundnig and C. Pucher, "Benefits of using modern axle counters in CBTC and light rail projects," in *2014 Joint Rail Conference*, Apr. 2014, pp. 1–6, doi: 10.1115/JRC2014-3809.

[9] M. Minea, "EMC and related problems in detection of road and rail vehicles," in *8th Int. Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services*, 2007, pp. 581–584, doi: 10.1109/TELSKS.2007.4376079.

[10] A. Cozza and B. Démoulin, "On the modeling of electric railway lines for the assessment of infrastructure impact in radiated emission tests of rolling stock," *IEEE Transactions on Electromagnetic Compatibility*, vol. 50, no. 3 PART 2, pp. 566–576, 2008, doi: 10.1109/TEMC.2008.924387.

[11] D. Adamski, K. Ortel, and J. Furman, "Research on measurement of electromagnetic fields generated by electric and combustion powered rolling stock.," in *MATEC Web of Conferences*, 2019, vol. 294, doi: 10.1051/matecconf/201929403016.

[12] S. Niska, "Measurements and analysis of electromagnetic interferences in the Swedish Railway systems," Luleå University of Technology, 2009.

[13] S. Niska, "Electromagnetic interference: A major source of faults in Swedish Railway," *International Journal of Performability Engineering*, vol. 5, no. 2, pp. 187–196, 2009, doi: 10.23940/ijpe.09.2.p187.mag.

[14] S. Yasukawa *et al.*, "Design optimization of magnetic sensor for train detection," *IEEE Transactions on Magnetics*, vol. 51, no. 3, pp. 1–4, Mar. 2015, doi: 10.1109/TMAG.2014.2358379.

[15] S. Zhang, W. K. Lee, and P. W. T. Pong, "Train detection by magnetic field measurement with giant magnetoresistive sensors for high-speed railway," *Applied Mechanics and Materials*, vol. 284, pp. 2102–2114, 2013, doi: 10.4028/www.scientific.net/AMM.284-287.2102.

[16] A. Mariscotti, "Distribution of the traction return current in AC and DC electric railway systems," *IEEE Transactions on Power Delivery*, vol. 18, no. 4, pp. 1422–1432, 2003, doi: 10.1109/TPWRD.2003.817786.

[17] S. M. Apollonskii and A. N. Gorsky, "Calculation of electric and magnetic field strengths produced by a direct current traction network," in *Ieee Eurocon 2009, Eurocon 2009*, 2009, pp. 873–880, doi: 10.1109/EURCON.2009.5167737.

[18] Y. Liu, W. Tong, X. Jin, and Z. Li, "Magnetic circuit modeling and analysis of unilateral axle-counting sensor," *IEEE Access*, vol. 6, pp. 51834–51842, 2018, doi: 10.1109/ACCESS.2018.2868293.

[19] L. Xiaotian, Z. Haijing, Q. Bo, and H. Bochong, "EMC in rail transportation," *Energy Procedia*, vol. 104, pp. 526–531, 2016, doi: 10.1016/j.egypro.2016.12.089.

[20] Å. Wisten, S. Niska, J. Ekman, D. Björklöf, and J. Delsing, "Experimental investigation of EM noise environment surrounding detector systems in Swedish railways," *IEE Proceedings - Electric Power Applications*, vol. 153, no. 2, 2006, doi: 10.1049/ip-epa:20050040.

[21] Y. Yoppy *et al.*, "Design exploration of passive magnetic coil for use in EMC measurements of axle counters," *Transactions on Electromagnetic Compatibility*, no. TEMC-280-2021, pp. 1–10, 2021.

[22] D. W. Karmiadji, M. Gozali, A. Anwar, H. Purnomo, M. Setiyo, and R. Junid, "Evaluation of operational loading of the light-rail transit (LRT) in capital region, Indonesia," *Automotive Experiences*, vol. 3, no. 3, pp. 104–114, 2020, doi: 10.31603/ae.v3i3.3882.

[23] European Standard, *BS EN 50592:2016 Railway applications - Testing of rolling stock for electromagnetic compatibility with axle counters*, 1.0. BSI Standards Institution 2016, 2016.

[24] J. Barros and R. I. Diego, "On the use of the hanning window for harmonic analysis in the standard framework," *IEEE Transactions on Power Delivery*, vol. 21, no. 1, pp. 538–539, Jan. 2006, doi: 10.1109/TPWRD.2005.852339.

[25] K. F. Chen and S. L. Mei, "Composite interpolated fast fourier transform with the hanning window," *IEEE Transactions on Instrumentation and Measurement*, vol. 59, no. 6, pp. 1571–1579, 2010, doi: 10.1109/TIM.2009.2027772.

[26] European Railway Agency, *ERA/ERTMS/033281 interfaces between control-command and signalling trackside control-command and signalling trackside and other subsystems*. 2018.

[27] S. Youn, T. H. Lim, E. Kang, D. H. Lee, K. B. Kim, and H. Choo, "Design of a miniaturized rectangular multiturn loop antenna for shielding effectiveness measurement," *Sensors (Switzerland)*, vol. 20, no. 11, pp. 1–10, 2020, doi: 10.3390/s20113178.

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