Distributed Plastic Gapped Magnetic Shielding to Electromagnetic Interference for Electric Transportation

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***Abstract*—Magnetic shielding is an important design for all electrical system. This is especially important to today's electric mobility because nearly all traction drives are using electric motor and they are driven by high frequency carrier wave from 1kHz to 100kHz. The interference to the signal system of vehicle control unit should cost a damaging effect. Besides the use of filter of metal shielding, a new plastic based magnetic shielding technique is introduced that provides a flexible shielding for the EMI isolation. The new material is especially useful for transportation system because they are light weight, non-brittle, lower cost and prominent performance in high frequency.**

***Index Terms*—EMI Shielding, Plastic magnetic, high frequency, EMC, EMI, railway system, electric mobility**

I. Introduction

Electromagnetic interference is now the key safety issue in transportation. High frequency power operation in traction system is now very common. For high-speed rail, the power level is in 10 MW and voltage is in 27.5 kV. The motor is electric and the switching frequency or the carrier frequency is 5kHz. The switching action of the transistors in the motor inverter generates high frequency radiation. The radiation will have penetration to the control electronics, signal system, vehicle computer. Therefore a good shielding is needed for the enclosure and also for the cable that is used to conduct the signals. The power cable is also needed to have some shielding method to reduce the emission due to the high frequency and high power field [1], [2].

Conventional, electromagnetic interference (EMI) shielding is using braided/foil-type or solid metal but they are bulky and also they are conductor [3], [4]. It will impose electric safety issue because of the metal shielded may cause electrocution. The operational voltage for vehicle is high. For high speed rail, the overhead line is 25-27.5kVAC. It is conducted by a pantograph to the train car and then reduced to 1kV by the transformer rectifier unit. The DC is then inverted to drive the motor. Each step has high voltage from tens of kV to 1kV. It needs to provide control waveforms to the motor that is using high frequency as a carrier. This is called carrier wave. The frequency is from 1kHz to 100kHz. Therefore the high frequency and high voltage are imposed in the train system. For electric vehicle, the voltage is derived from the battery. The voltage is from 200V to 650V. It is then inverted to motor for traction drive. The frequency is usually high at 10kHz to 100kHz. Therefore the shielding is also critical. For high frequency of tens of kHz, the emission due to high frequency is extreme and the EMI emission is also high [5], [6]. The screening using conventional metal based is conventional. The screening using fabric magnetic has been reported in ref [5]-[7]. It is interesting to use lower relative permeability thin material, but how is the screening performance? For high voltage condition and the carrier wave is also at high frequency, the dv/dt is also high and therefore the emission due to the high frequency switching is therefore high.

This paper has presented a plastic bonded magnetic shielding, analyzing the basic features including the flux line carrying capability against relative permeability and calculating the surrounding magnetic field of the shielding. The values of flux densities around the shielding with varied conditions, involving high frequency (AC) and Direct Current (DC) excited fields. It suggests that the shielding is a promising candidate to isolate interfere magnetic fields. It can serve the high rail system for EMI in future. Two typical applications using this material are given in the end and, the simulation results also validate that this material is capable of preventing interfered magnetic fields.

II. The Plastic Bonded Magnetic Shielding

A. Classical EMI Shielding

Under the intensive EMI a common method for screening is to use metal and ferrites. The general comment is that the metal solid shield is extensive, heavy and not flexible. It makes the overall weight higher. Therefore it is not suitable to be used for transportation system. Also the solid metal does not have good frequency response. Under high frequency, the permeability of the materials drops significantly. Ferrite is a very good material. It has been used in EMI test chamber for EMI isolation. However, it is also expensive, brittle and heavy as well. The transportation, the cart or

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vehicle may be experienced with vibration, which will make the ferrite shielding easily to get broken. Therefore both of them may not be suitable for transportation systems.

Also when screening is needed to be done on cable, the above two materials are not suitable because flexible shape is needed for cable shield. In the past, the braided type of cable shielding is used, but it is still made from solid metal and the frequency range is not very wide.

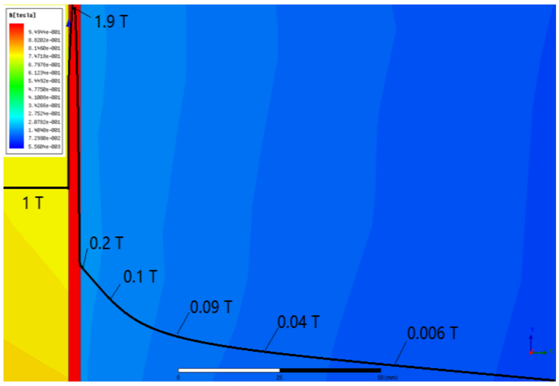
B. The New Shielding Materials

Low frequency screening is simple and is a well-known technology. Frequency response, especially at high frequency is poor. Usually or high frequency operation, the screening materials should be formed by small ferromagnetic materials in the size of micrometer. Ferrite is supposed to fulfil this requirement, but its adverse feature makes it difficult to be used in transportation system. Also the thickness is another concern. Usually a screening needs only thin wall for magnetic isolation, and a few mm is good enough. When ferrite is used, it is difficult to use ferrite thickness of a few mm because the material is brittle. Ferrite usually has relative permeability of over 2000. That is the magnetic flux conductivity in ferrite is 2000 times of air. In practice, a lower value may be good enough.

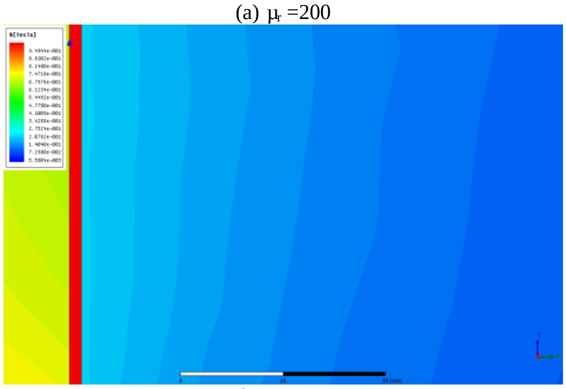
A new plastic based material has been developed that has both feature of plastic and ferromagnetic. A plastic based material is preferred to be the screening because it is more flexible and not easy to be brittle. It can also been made with thickness of a few mm sheet that is more practical for enclosure, screening and even cable shield. The new plastic based material has been developed that can be programmed to have μr =50, 100 and 200 [8]. It is a plastic mixed with magnetic materials. Fig. 1 shows the extrusive composites formed by the mix of the plastic and the magnetic powder.

The magnetic is using Ni, Co and Mn. Different combination of the mix with plastic can create different permeability materials. The size of the ferromagnetic particles is in powder form, in the size of tens to a few μm. Because the use of the metal powder is lower than solid metal, the cost is lower. The concept is similar to distributed airgap to control the effective permeability. It is anticipated that to use the materials to develop the shielding of the high power field. It is to be tested them under different conditions of thickness of the materials as an enclosure. One is a shield and the other is an enclosure and a cable.

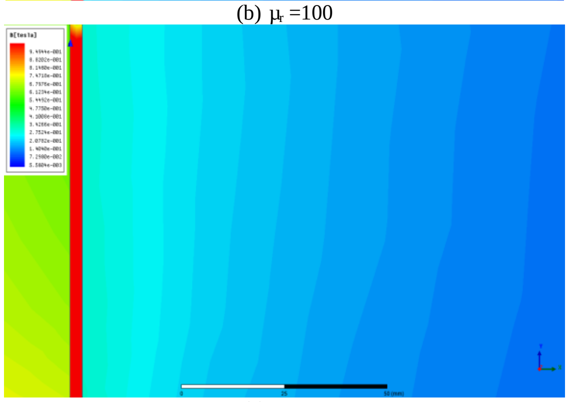
Figure 1. The extrusive composites of the proposed material



(a) μ_r =200



(b) μ_r =100



(c) μ_r =50

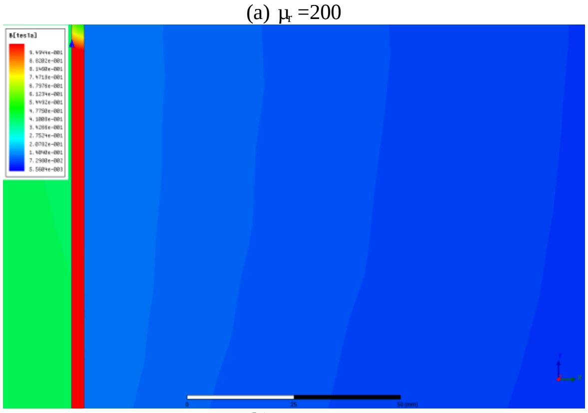
Figure 2. B value distribution with μ_r =200, 100 and 50 of the shield with shield thickness 3mm.

III. A LARGE SHIELD

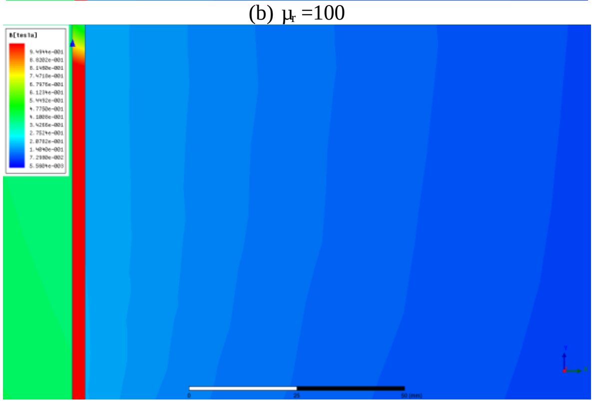
A. Direct Current (DC) Excited Field

Provided that a large shield that is nearly infinite is exposed to a magnetic field with a constant B value, the reduction of the magnetic field is obvious after allocated the shield. The investigation is firstly done with the thickness of the shield = 3 mm. Fig. 2 (a) shows the distribution of the B values of the magnetic field. Assuming that B values in one side of the shield nearly equal to 1 T, when the flux flows (the yellow area) into the shield, it is immersed into the magnetic field. The B value in the shield increases sharply because its relative permeability is 200 times higher than that of air, demonstrating by the red area. On the other side of the shield, the B value declines dramatically due to the shielding effect by the shield, isolating most of the flux penetrating it. When we alter the relative permeability of the shield from μ_r =200 to 100 and 50, as shown in Fig. 2 (b) and Fig. 1 (c), the reduction speed of the B value shielded for the opposite side decreases. It suggests that the higher the relative permeability the shield possesses, the faster of the reduction of the B value is. More importantly, the B value before passing through the shield decreases slightly with the decrease in relative permeability of the shield, which shows that the flux lines can pass through shields with lower relative permeability easier, similar to that water can overflow a low dam.

(a) μ_r =200



(b) μ_r =100



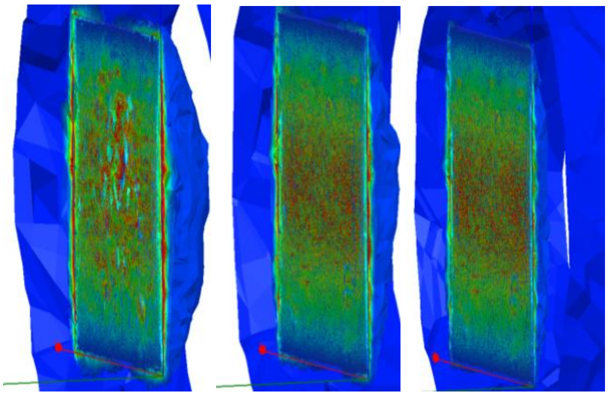
(c) μ_r=50

Figure 3. The magnetic flux density distribution in the constant B value 0.5 T by using different shields with relative permeability, (a) 200, (b) 100 and (c) 50, respectively.

Likewise, after the constant left B value is adjusted to 0.5 T, the distribution of flux density of the whole area is shown in Fig. 3 with the same conditions as Fig. 2. Compared with that of Fig. 2, the values of the overall flux density declines as the constant B value in the left side of the shield is halved. It can be seen that the magnetic flux density of Fig. 3 (a) drops significantly to around zero (blue zone in the right), totally shielded the magnetic field. From Fig. 3 below, it can be seen that the magnetic flux density distributions. The green area denotes the B value is 0.5 T and the red area is much larger than this value where the shield is allocated, followed by an air environment with much lower flux densities in the right part.

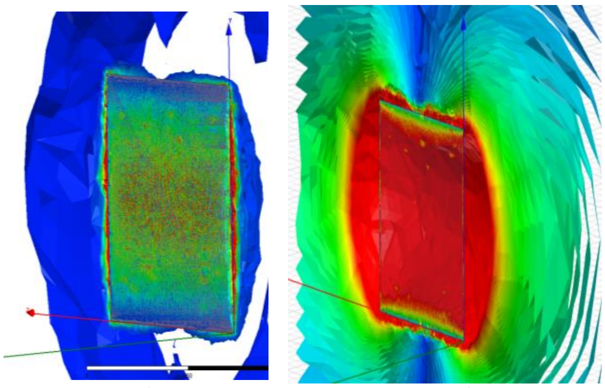
B. Alternative Current Excited Magnetic Field

The characteristic of the shield is also analyzed by means of three-dimensional (3D) finite element method (FEM). Under a frequency at 10 kHz, flux-carried shields with different relative permeability from 200, 100 to 50 are shown in Fig. 4. It is obvious from Fig. 4 (a) and Fig. 4 (b) that the shield with higher relative permeability can hold more flux lines, suggesting it can prevent more flux lines outside the shield. After the relative permeability is adjusted to 50, the flux line distribution from Fig. 4 (c) varies a little, compared with Fig. 4 (b). This phenomenon suggests that when the relative permeability of the shield is small, the AC magnetic field imposes a slight impact on the shield, with a small relative permeability varied. In all cases, the screened filed is very small. This can be seen from the colour blue of the environment.



(a) μ_r =200 (b) μ_r =100 (c) μ_r =50

Figure 4. The flux distribution with the shield in different relative permeability imersed in a high frequency magnetic field.



(a) f=10 kHz (b) f=100 kHz

Figure 5. The flux distribution of shield under high frequency environment.

However, the frequency of the magnetic field takes a significant influence to the shield as shown in Fig. 5. Fig. 5 (a) shows the flux distribution of around the shield under 10 kHz of the magnetic field and Fig. 5 (b) gives that under 100 kHz of the magnetic field. The difference between the two conditions is obvious. The flux density around the shield experiences a dramic increase in the rise of the frequency. It can also illustrate that the shield is capable of carrying the flux lines even in a high frequency environment.

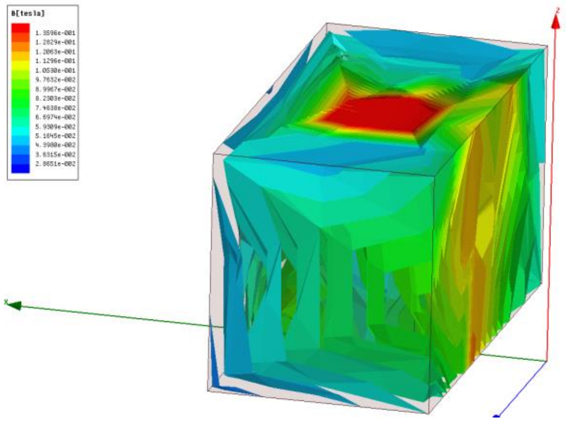
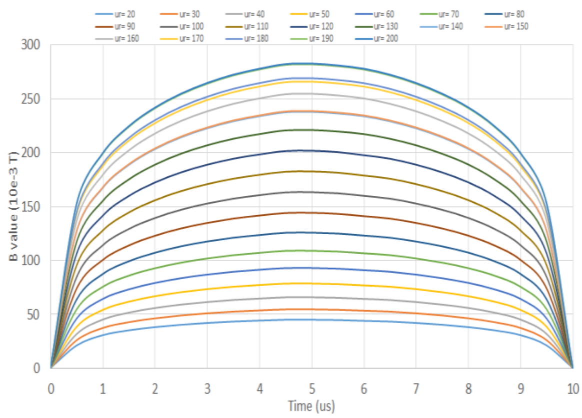
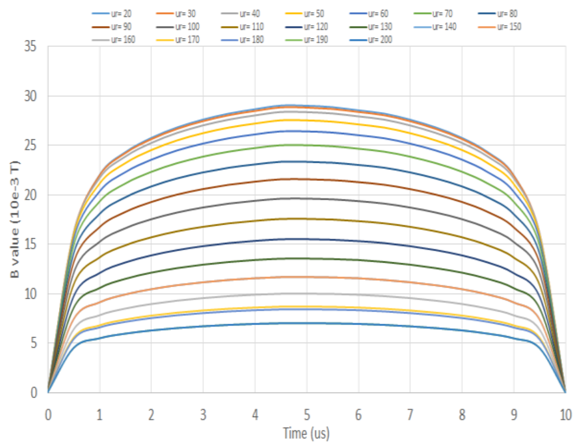


Figure 6. The flux distribution of the enclosure.



(a) flux density on the surface

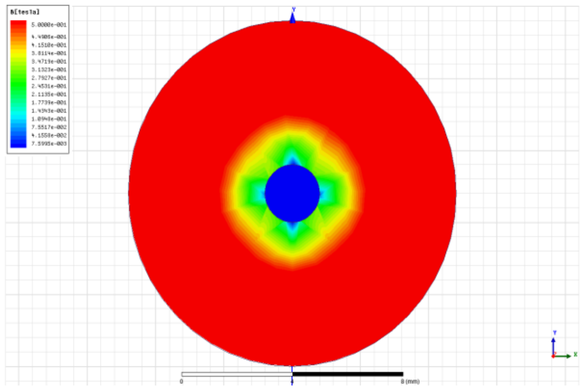


(b) flux density in the centre

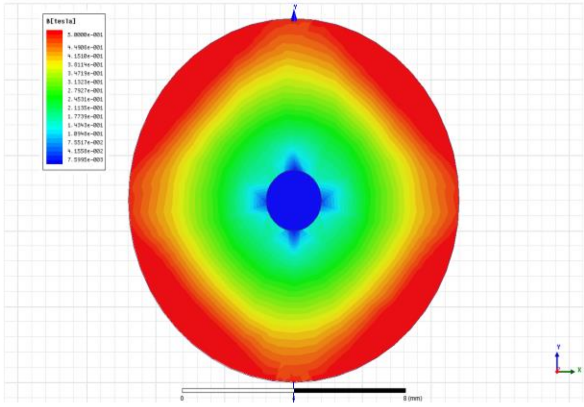
Figure 7. Flux density values of the enclosure.

IV. AN ENCLOSURE

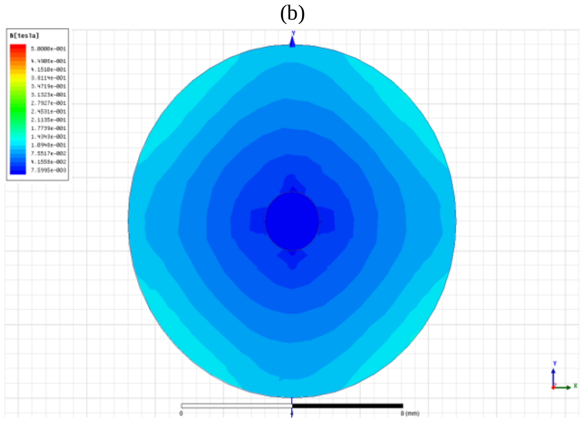
An enclosure produced by the propsoed plastic-magnetic material is also analyzed as shown in Fig. 6 that shows the flux density distribution inside and on the surface of the enclosure. The AC magnetic field is applied for the enclosure and, the flux density profiles on the surface and in the center of the enclosure are given in Fig. 7. Compared with the values from Fig. 7 (a) and Fig. (b), the maximum flux density on the surface is up to 0.27 T under the frequency of 100 kHz, roughly 10 times than that in the center.



(a)



(b)



(c)

Figure 8. Flux density countours of the cable with different surroundings under flux densitiy of (a) 1 T, (b) 0.5 T and (c) 0.1 T.

The B value profiles on the surface of the enclosure and in the centre of it are given in Fig. 7, with the relative permeabiliy changed from 20 to 200 in a period It can be seen that the flux density grows as the relative permabilty of the shield increases. However, the maximum value of the flux density is much low compared with that in DC environment. It suggests that the plastic magnetic material is often exposed in low magnetic field under high frequency magnetic fields.

V. A Cable Screening Analysis

The radius of the cable with relative permeability of 200 is 6 mm and the radius of the copper line in the centre is 1 mm. After the cable immersed into magnetic fields with varied values, 1T, 0.5 T and 0.1 T, the flux densities in said condition are shown by Fig. 8 (a), (b) and (c), respectively. It can be seen that in the central area, around 1mm radius, there is no flux (blue area), while the flux density is much larger than 0.5 T in the red area. The cable shield is capable of isolating the magnetic field no matter how high the magnetic field surrounded exists.

VI. Conclusion

This paper introduces a plastic based magnetic shielding. By simulations, characteristics of the shielding are calculated in both AC and DC environment. Simulation results suggest that this shielding is capable of isolating magnetic fields, especially in high frequency fields. Two examples for the application of the shielding are also given in this paper, to examine the flux density inside and outside the proposed plastic magnetic screening for the performance of the shielding material. It is suggested this material can be used to isolate interference due to magnetic fields, particular in high frequency environment. The material is non-brittle and low cost. Application for enclosure and cable has been successfully demonstrated. It is expected that it can be widely used for high rail traction system in the future.

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