Research on the Basic Electromagnetic Compatibility of Locomotive Based on Electromagnetic Simulation

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Abstract. By means of the electromagnetic simulation software, the cable model of the electric equipment inside the locomotive is established. The electromagnetic field of different types of cables, the situation of different positions and whether to add barriers are analyzed, so that the shielding effect can be reflected. Besides, the formula of shielding effectiveness is analyzed and the relevant conclusions are obtained. Through this paper, a conclusion can be drawn about the influence of different cable types, different cable placement methods, and whether or not to add barriers between cables on electromagnetic compatibility.

1. Introduction
With the continuous improvement of the level of locomotive manufacturing, the demand for power electronic equipment in the locomotive continues to increase, and the electromagnetic environment is becoming more and more complicated. The interior of the locomotive is a space where various signals of strong and weak electricity are interleaved. For example, high voltage, frequency conversion, network communication, microcomputer control and other electronic equipment and cable harness. Due to the bad electromagnetic environment of the locomotive, there are not only high-power radiation signal sources, but also high-sensitivity sensors and communication equipment. After being loaded, some of these equipment has unstable performance, such as crash and other faults in some working conditions of the locomotive; some of them cannot work normally, leading to dangerous situations such as running by, or even causing significant economic losses [1]. Therefore, the electromagnetic compatibility of the locomotive should be studied. A model of the internal cable of the locomotive can be established, which can play a certain role in the electromagnetic compatibility application.

2. Locomotive electromagnetic interference
Several common electromagnetic interference phenomena on locomotive are shown as follows.

The first is interference of high-voltage electrical equipment on locomotives. For example, the interference caused by the contact sliding of the locomotive pantograph on the power grid is extremely serious for the electrical equipment of the locomotive, especially when the locomotive passes through the phase area, it will produce a very high impulse voltage, which is easy to cause damage to the main converter, auxiliary converter voltage mutual inductor and other equipment of the locomotive.

The second is conduction interference caused by burning loss of electrical equipment. The sudden change of load caused by the fuse's fusing moment will produce a high-energy peak voltage, which will be transmitted to the circuit of control devices in turn through the wires connected with it, leading to the damage of devices. This kind of interference is the typical conducted interference.
The third is radiation interference caused by radio, antenna and electronic components. The most obvious ones, such as mobile phones and radio stations, will send out high-frequency radio signals, radiating outward through the equipment shell or gap, and spread to sensitive equipment to cause radiation interference [2].

3. Analysis
From the view of the limited academic ability and experimental environment of this study, this paper only focuses on the cable research. The following is the application of locomotive electromagnetic simulation.

3.1. Modeling of locomotive cables
According to Xie Junhua and Dong Liang's paper, the application of electromagnetic simulation in locomotive electromagnetic compatibility, [1] 240 cable (National standard aluminum core cable 5-core 240 square three-phase wire) is selected as the model, and its three-dimensional model is established. Electromagnetic simulation is carried out with the related material properties. The power cable parameters of diesel locomotive are as shown in table 1:

| Types          | Section mm² | Diameter mm | Insulation thickness mm | Shielding thickness mm | Length m |
|----------------|-------------|-------------|-------------------------|------------------------|----------|
| General cables | 240         | 22.8        | 2.8                     | 1                      |
| Shielded cables| 240         | 22.8        | 2                       | 0.5                    | 1        |

The cables 3D model established in the simulation software Maxwell is shown in figure 1.

Figure 1. General cable and shielded cable.

Shielded cable is a transmission line with metal mesh braid wrapping the signal wire. Because of the metal enclosure, the shielded cable is not as sensitive to the signal interference as the general cable. The braid is usually made of red copper or tinned copper. Thus, the right one shown in figure 1 is the shielded cable.

3.2. Simulation analysis of cable
The shielding effect of the shielding component comes from the absorption and reflection attenuation of electromagnetic wave. The shielding of low-frequency electromagnetic wave is mainly absorption attenuation, and the shielding of high-frequency electromagnetic wave is mainly reflection attenuation. The simulation project of the above cables with Maxwell are shown as follow: different cable types, the relative position of the cables, whether to place the cable trough.

3.2.1. Different cable types. The purpose of shielding is to guarantee the transmission performance of the system in the environment of electromagnetic interference. The anti-interference mentioned here should possess the following two properties: the ability to resist external electromagnetic interference
and the ability to radiate electromagnetic interference from the system itself. Theoretically speaking, the wire cable and connector are covered with a metal shielding layer, which can effectively filter out unnecessary electromagnetic waves (this is also the method adopted by most shielding systems)[3].

The application of the shielded cable can alleviate the electromagnetic interference of the electronic power equipment inside the locomotive from the source. Figure 2 and figure 3 illustrate the comparison of the magnetic field strength and electric field strength at 400mm between the general cable and shielded cable. In fig. 2, the blue line represents the general cable, and the red line represents the shielded cable. And in fig. 3, the purple black line represents the general cable, the red line represents the shielded cable.

As shown in fig. 2 and fig. 3, no matter in electric field or magnetic field, the strength around the shielded cable is obviously smaller than that of the general cable.

3.2.2. Electric field strength of parallel and triangular shielded cables. This part simulates the relative position of cable placement. There are two main types of relative positions of three-phase cable cores: parallel straight-line layout and equilateral triangle layout. As shown in figure 4, the abscissa represents time and the ordinate represents electric field strength. The purple and black line is placed in parallel, and the red line is placed in triangle. It can be seen that when the cable is placed in triangle, the electric
field strength is significantly lower than that in parallel, so the cable triangle has better electric field shielding effect.

3.2.3. Simulation of adding partition between cables. The cable trough can effectively protect the electromagnetic radiation of the cable. In turn the cables in the same cable trough will also have the influence of mutual electric field. In order to reduce this influence, the partition board can be inserted between the cables in the cable trough.

Figure 5 shows that there is no partition between cables, and the electric field between cables is interwoven. Figure 6 shows that the partition between cables is inserted. It can be seen that compared with figure 5, the partition in figure 6 helps weaken the electric field interaction between cables.
Shielding effectiveness refers to the shielding ability and effect of shield on electromagnetic interference. It is related to the connection effect of shields, shield materials, the distance between shields and interference sources, the frequency of the interference source and the discontinuity or process defect of shield surface structures [4]. The formulas of shielding principle can be written as follows:

\[
 SE_{E} = 20 \log \frac{E_0}{E_1} \text{ (dB)} \\
 SE_{H} = 20 \log \frac{H_0}{H_1} \text{ (dB)}
\]

(1)  
(2)

In the above formula, \(E_0, \ H_0\) are the field strength before shielding, \(E_1, \ H_1\) are the field strength after shielding. The comprehensive shielding effectiveness can be expressed as:

\[
 SE = A + R + B(\text{dB})
\]

(3)

In this formula, \(A\) means absorption loss. \(R\) means reflection loss. And \(B\) means multiple reflection correction factor.

\[
 A = 0.131t \sqrt{\mu_r \sigma_r} \text{ (dB)}
\]

(4)

In this formula, \(A\) means absorption loss. \(t\) means sheet metal thickness(mm). And \(f\) means radiation frequency. \(\mu_r\) means relative permeability of metal plate. And \(\sigma_r\) means relative conductivity of metal plate.

\[
 \begin{cases}
    \text{Electric field shielding} R_E = 141.7 - 10 \log \left( \frac{\mu_r f^2}{\sigma_r} \right) \\
    \text{Magnetic field shielding} R_H = 74.6 - 10 \log \left( \frac{\mu_r}{\sigma_r f} \right) 
\end{cases}
\]

(5)

In this formula, \(R\) means reflection loss.

\[
 \begin{cases}
    \text{near field} \\
    \text{far field}
\end{cases}
\]

\[
 R = 108.1 - 10 \log \frac{f \mu_r}{\sigma_r} \text{ (dB)}
\]

(6)

\[
 B = 20 \log \left[ 1 - \left( \frac{1}{2} \right)^2 \cdot 10^{-0.14} \left( \cos 0.23A - j \sin 0.23A \right) \right] \text{ (dB)}
\]

(7)

In this formula, \(B\) means multiple reflection correction factor, \(Z\) is the air wave impedance, and \(Z_S\) is the metal wave impedance.

| metal shielding materials | \(\sigma_r\) | \(\mu_r\) | \(\sqrt{\sigma_r \mu_r}\) |
|---------------------------|------------|----------|-------------------|
| Silver                    | 1.064      | 1        | 1.03              |
| Aluminum                  | 0.61       | 1        | 0.70              |
| Brass                     | 0.35       | 1        | 0.59              |

The better the conductivity and magnetic conductivity of the material are, the higher the shielding efficiency will be. Whereas, it is impossible to take both aspects into account. For example, copper has good conductivity, while the magnetic conductivity is poor. In contrast, iron possesses good magnetic conductivity but poor electrical conductivity. According to the specific shielding which material should be used, mainly depends on the reflection loss or the absorption loss to decide whether to focus on conductivity or magnetic conductivity. However, some conclusion can be drawn:

The first is, the thicker the shielding material is, the greater the absorption loss will be. What is more, the higher the permeability is, the greater the absorption loss will be. In addition, the higher the conductivity is, the greater the absorption loss will be. At last, the higher the frequency is, the greater the absorption loss will be.

4. Conclusion

EMC prediction is a method to analyze and evaluate the EMC degree of electronic equipment or system by theoretical calculation [5]. Through the prediction and analysis of electromagnetic interference, the potential interference can be quantitatively calculated and estimated, thus proving provides theoretical guidance for EMC measures and design methods [6].
Through the above basic electromagnetic simulation combined with the formula of shielding effectiveness, it can be concluded that the electromagnetic compatibility inside the locomotive will be affected by the type of cable, the location of the cable, as well as whether the partition is inserted between the cables. Of course, the influential factors are far more than these, and the research on these aspects also has a deeper level. In order to go deeper into the complex electromagnetic problems, more about Maxwell need to be learned.

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