The Simulation Analysis and Coupling Mechanism of harness and wire cable

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Abstract. Considering the complexity of the electromagnetic environment, a large number of electronic equipment and cable harnesses are concentrated. For different environments, this paper is prepared to consider the three problems of cable crosstalk, field-line coupling and cable radiation, which basically covers all cable electromagnetic interference problems. Considering the changes of cable length, cable height from the ground, cable distance, angle and grounding mode, this paper also takes these factors into account and explores the results by changing these parameters. According to this, the anti-interference measures between the cables of Electrical Multiple Unit can be obtained.

Keywords: Electrical Multiple Unit; Cable and harness; electromagnetic interference.

1. Introduction
The connection between different systems and the transmission and exchange of energy and information between different systems are realized through cables. The internal structure of the locomotive is very complex. A large number of electronic equipment and cable harnesses are concentrated in the interior of the carriage. Strong and weak current signals are interwoven in a limited space, resulting in different degrees of coupling, namely crosstalk. Crosstalk is a near-field coupling problem, signals in one line can be electromagnetically coupled to generate interference signals in the other line, resulting in equipment performance degradation or malfunction.

Practice has shown that improper handling of interconnection cables on equipment has caused most of the system electromagnetic compatibility problems. Due to the complexity of the system, many sudden non-linear phenomena will occur during the operation of locomotives, which cannot be studied by single line alone, so the field-line coupling study is introduced here. Therefore, the arrangement of interconnection cables on the train will be an important factor affecting the electromagnetic compatibility of the train system. Research on crosstalk and field-line coupling between cables will be helpful for cable routing design.

The study of transmission line theory began in the 1930s, while EF Vance began to use transmission line theory to study shielded cables in the 1960s, studying the calculation of transfer impedance and transfer admittance of shielded cables, and analyzing the transmission line model of shielded cables, but he did not consider the calculation of crosstalk between multi-conductor cables. C.R. PaulB established the crosstalk coupling model of transmission line by using the transmission line theory, which made a detailed analysis of the crosstalk problem between multi-conductor cables, and theoretically solved the
crosstalk through time domain and frequency domain. At the same time, he also analyzed the crosstalk coupling when the disturbed cable was shielded cable and twisted pair cable.

Literature [1] proposed crosstalk coupling model under low frequency, and predicted and analyzed the coupling between cables by equivalent circuit method. Literature [2] compares and analyzes different grounding conditions of parallel and double lines, and concludes that in order to reduce crosstalk, each signal line should preferably have an independent ground line. At the same time, when analyzing the coupling between cables, the influence of different parameters should be considered. Literature [3] analyzes the influence of signal frequency and cable length on crosstalk between cables. Literature [4] summarizes several factors that affect crosstalk coupling from several aspects such as coupling length, height from ground, line spacing, frequency and termination resistance. Literature [5] discusses the influence of grounding mode of cable shielding layer on coupling between cables, and puts forward some basic requirements for cable grounding, including grounding mode, selection of grounding point, etc.

However, it is necessary to directly study the electromagnetic coupling problem of cables through a field-line coupled transmission line model, and the establishment of the model is complicated. In order to facilitate the research on cable-coupled lightning electromagnetic fields, from 1994 to 2004, the university of Bologna in Italy, the Swiss federal institute of technology and the university of La Sapienza in Rome jointly developed the LIOV program based on Agrawal model, and continuously improved it, and later proposed a variety of link research methods.

Most of the previous literatures used the voltage on the disturbed cable load as the research object, but this method is not suitable for field testing. According to the transmission line theory, CST simulation software is used to establish a simulation model, and the influence of different parameters on crosstalk is expounded.

2. Inter-line crosstalk simulation

2.1. Single-line-coaxial line simulation model

A single-wire and coaxial line model is established in CST cable studio. The spatial positions of the two single wires are determined by setting the coordinates of four points. The circuits are connected and excitation sources are set for simulation. Both cables are set to 4m in length, 0.4mm in radius, 0.1m in height from the ground, 0.1mm in thickness of single wire insulation layer, 0.3mm in thickness of coaxial wire shielding layer, and 50 ohms in load impedance at both ends. The established model is shown in fig. 1. The circuit is connected by single-ended grounding and double-ended grounding. The circuit connection diagram is shown in fig. 1, and the crosstalk current image is shown in fig. 2.

![Figure 1. circuit connection diagram(double-ended grounding)](image1)

![Figure 2. simulation image of crosstalk current of single line and coaxial line](image2)

It can be seen from the image that in the range of 100Hz-1MHz, the crosstalk coefficient gradually increases with the increase of frequency by 20dB/10X. Although it continues to increase in the range of 1MHz-10MHz, the trend gradually flattens. In the range of 10MHz-100MHz, the coupling coefficient pattern shows a wavy change, which is caused by resonance due to the influence of distribution parameters and delay caused by crosstalk voltage signals when the frequency is too high.
2.2. Influence of Simulation Parameters on Crosstalk

a. Grounding mode

Keep other parameters unchanged, and set the grounding modes as single-ended grounding and double-ended grounding respectively. The obtained schematic diagram of crosstalk current at P1 is shown in fig. 3.

When two terminals are grounded, the coupling coefficient gradually increases between 100 and 5000 Hz. In the range of 5-10kHz, the coupling coefficient is approximately a constant, then the coupling coefficient gradually decreases, and resonance phenomenon begins to appear after 10MHz. The reason for this is that double-ended grounding suppresses the coupling phenomenon, and the more obvious the suppression effect is with the increase of frequency, so the coupling coefficient increases first, then stabilizes, and then decreases with the increase of frequency. At high frequencies, resonance occurs due to inevitable coupling interference.

In addition, in order to ensure the preciseness of the simulation results and eliminate the influence of cable types on the simulation results, the simulation is carried out by means of single-wire crosstalk and single-end grounding of shielding layer to investigate the influence of single-end grounding and cable shielding layer on the results. The result image is shown in fig. 4.

As can be seen from the figure, when the shielding layer of the shielded cable is grounded at one end, the shielding layer does not play a shielding role because the loop area of the current does not change. By comparison, it can be found that the coupling amount is basically the same as that without the shielding layer. Therefore, it can be seen that double-ended grounding can inhibit cable coupling.

b. Ground clearance

Under the condition that the frequency range and other conditions are unchanged, the height from the ground is changed, and the obtained crosstalk current at P1 is schematically shown in fig. 5.

According to the simulation results, it can be seen that at the same frequency, the coupling coefficient increases with the increase of the height from the ground, while the influence of the increase of the
height from the ground on the crosstalk between lines decreases gradually, and the overall graphic trend is consistent.

c. Cable length

The crosstalk current at P1 obtained by changing the cable length without changing the frequency range and other conditions is shown in fig. 6.

According to the simulation results, we find that in a certain frequency range, the length of the interfered cable increases, the trend of crosstalk waveform is similar, the crosstalk current increases continuously, and the waveform in 10MHz-100MHz will also change. As the ratio of changes in cable parameters decreases, the increase of crosstalk becomes slow.

d. Cable spacing

The crosstalk current at P1 obtained by changing the cable spacing without changing the frequency range and other conditions is shown in fig. 7.

Through the simulation results, we find that in a certain frequency range, with the increase of cable spacing, the crosstalk current decreases and the speed trend of attenuation becomes slower and slower. The reason for this is that the mutual inductance becomes smaller due to the increased spacing. Since the self-capacitance per unit length increases and the mutual capacitance decreases, the spacing increases, the interference current value decreases and the attenuation slows down. At low frequencies, crosstalk increases monotonically with increasing frequency. At high frequencies, coupling interference produces resonance.

3. Field line coupling

3.1. Model

It is difficult to use the field method to calculate the field line coupling problem and the lumped parameter model based on the circuit theory generally does not meet the practical conditions. Therefore, the transmission line model based on the transmission line theory is used to study the field line coupling problem under the condition of neglecting the mode induced current. Figure 8 shows the transmission line model in general. The height of the conductor above the ground is $h$, the radius of the conductor is $a$, the incident electric field is $E_0 \hat{k}$, and $k$ is the direction of plane wave propagation.

The schematic diagram of the simulation model established according to the general model is shown in FIG. 9, and FIG. 10 is the circuit connection diagram. In the simulation, the earth is taken as the ideal lossless medium.
3.2. Simulation analysis of field-line coupling model

According to the circuit model established above, the current waveforms on the two probes are simulated.

3.2.1. The initial results. It can be seen from the figure 11 that the two lines are basically the same, indicating that the current at both ends of the load is the same, which is consistent with the analytical solution of the load response that should be obtained from the theoretical results. The formula of the analytical solution is given as follows:

\[ I(x) = [K_1 + P(x)]e^{-\gamma x} + [K_2 + Q(x)]e^{\gamma x} \]

\[ K_1 = \rho_1 e^{\gamma x_1} \frac{\rho_2 P(x_2) e^{-\gamma x_2} - Q(x_1) e^{\gamma x_2}}{e^{\gamma (x_2 - x_1)} - \rho_1 \rho_2 e^{-\gamma (x_1 - x_2)}} \]

\[ K_2 = \rho_2 e^{\gamma x_2} \frac{\rho_1 P(x_1) e^{-\gamma x_1} - P(x_2) e^{\gamma x_1}}{e^{\gamma (x_2 - x_1)} - \rho_1 \rho_2 e^{-\gamma (x_1 - x_2)}} \]

\[ \rho_1 = \frac{Z_1 - Z_0}{Z_1 + Z_0}, \rho_2 = \frac{Z_2 - Z_0}{Z_2 + Z_0} \]

\[ P(x) = \frac{1}{2Z_0} \int_{x_1}^{x} e^{-\gamma} E_x dv, Q(x) = \frac{1}{2Z_0} \int_{x}^{x_1} e^{-\gamma} E_x dv, \]

Wherein, \( \rho_1, \rho_2 \) are the reflection coefficients of the cable at the end of the cable, \( \gamma \) is the propagation constant, \( x_1, x_2 \) are the coordinates at the end of the cable, \( Z_0 \) is the characteristic impedance, and \( Z_1, Z_2 \) are the load impedance at the end of the cable.

3.2.2. Effects of simulation parameters on crosstalk. The influence of incident elevation Angle \( \varphi \) (the Angle between plane wave and xoy plane) on induced current.

Different elevation angles are selected for simulation without changing other parameters. Only the simulation waveforms of 60° and 135° are presented here, as well as the results of 30°, 45°, 60° and 90° are compared.

![Figure 9. schematic diagram of the simulation model](image1)

![Figure 10. schematic diagram of circuit connection](image2)

![Figure 11. simulation waveform of induced current at the load side](image3)

![Figure 12. simulation waveform when incident Angle changes to 60°](image4)
As can be seen from the figure, with the increasing incidence Angle, the induced current of the load all increases gradually.

The effect of cable length on induced current
After changing the cable length without changing other parameters, we get the result as shown in figure 19.

According to the simulation results, it can be seen that the current distribution within 0.07-0.2us will change with the change of length, and the overall trend does not change significantly. When the line length changes from 1m to 1.5m, the coupling peak increases, but then it increases to 2m with the line length coupling peak of 3 m, not this is due to the line length increases gradually in the process, there is a loss of a transmission line and the induced current on a transmission line transmission speed is less than the speed of light, the induction current to the load area to the \( x = 0 \) will take time, contrast when \( x = 0 \) in induced current has not been communicated to the load to the load and the reflection and transmission of load in the expression of the latter of induced current is lower than the former, so the peak value of the induced current will decrease gradually

The effect of ground height on induced current
After changing the ground height from 0.1m to 0.2m, 0.4m and 0.8m without changing other parameters, we get the result figure as shown in figure 20

It can be seen from the figure that as the height from the ground increases, the response current on the load at the same time also increases.

4. Conclusion
Using CST software, this paper established the single - coaxial line, line coupling model, through the simulation software to form the model results and change the change of the parameters of the simulation image by changing the height from the ground wire spacing and the incident Angle, length of cable grounding method of simulation analysis, the longitudinal comparison, comparing the effect of parameter change on model movements get crosstalk current coupling coefficient and the relationship between the above parametersThis experiment to verify the simulation is verified in current as the research object of the effectiveness of the crosstalk model, at the time of transmission wire and cable,
considering the crosstalk problems, within a certain range, reduce the transmission signal frequency, reduced cable refused to highly increase the distance between the cable and shorten the length of cable have good to inhibit the action of the crosstalk in shielding layer, as far as possible with double end grounding method, the shielding effect which was suppressed, the more obvious with the increase of frequency in this paper, research work for the emu anti-interference between cable and line - line, a line between the simulation model to provide certain reference and reference.

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