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Simulation Analysis of Crosstalk of Complex Cable Beams in High Speed EMUs

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Abstract. Based on the cable transmission line simulation method, crosstalk simulation analysis is performed on complex cable harnesses commonly used in high-speed EMUs such as power cables, DC power cables, communication cables and signal cables. Through the simulation operation, the waveform and amplitude of the crosstalk signal on the victim cable under different types of interference cables are analyzed. It is concluded that the crosstalk of the power cable to other types of cables is particularly obvious. By changing the parameters of interference signal frequency, cable spacing and cable length, the influence of the above parameters on the crosstalk of complex cable bundles is studied. The research results of cable crosstalk are analyzed and summarized, which can be used for wiring and design of complex cables in practical engineering.

Introduction

With the increasing application of high-speed EMUs, in order to ensure the safe operation of high-speed EMUs, the electromagnetic compatibility of EMU equipment systems has become more and more prominent. For high-speed EMUs, a large number of different types of complex cable bundles, such as power cables, control cables, and signal communication cables, are distributed in a limited space. The crosstalk analysis between cables has become an important part of the electromagnetic compatibility analysis of high-speed EMUs.

Research Status

At present, some scholars have studied the crosstalk of single-source and dual-source injected into one end of the cable, and obtained the waveform of the induced current [1]. Some scholars have analyzed and optimized the crosstalk of EMU cables and harnesses [2]. Some scholars have studied the electromagnetic interference problem of idle EMUs caused by crosstalk between lines, and optimized the wiring of high-speed EMUs [3, 4]. Some scholars have extended the basic theory of transmission lines for the coupling problem of EMU high-voltage cables and sensor cables, and established a crosstalk theoretical model for two commonly used shielded cables [5]. On the basis of the cable layout design of the EMU traction converter and the electrical component arrangement of the main circuit, some scholars analyzed the influence of the internal electromagnetic compatibility of the traction converter due to the components and the wiring harness, especially the problem of the electromagnetic compatibility of the cable [6].

In summary, at home and abroad, the research on cable crosstalk of EMUs mainly involves crosstalk between power cables, and less research on other types of cable crosstalk. In this paper, the crosstalk of complex cables of EMUs is studied in detail and in-depth. The research results can be used to guide the wiring and laying of complex cable bundles in practical engineering.

Cable Transmission Line Simulation Method

The cable simulation software performs electromagnetic simulation calculation on the cable based on the transmission line theory. The simulation steps are as follows:

1) Meshing. The cable harness is divided into a limited number of straight segments, and the simulation software meshes each small section of the metal cross section. In order to ensure the calculation accuracy, the grid size generally needs to be less than 1/10 of the wavelength corresponding to the highest frequency of the simulation.

2) Model extraction. The transmission line parameters R, L, and C of each small cable are extracted and input to the 2D field solver for calculation. Each small segment is converted into a transmission line equivalent circuit, and finally all equivalent circuits are connected into a complete circuit model, replacing the entire cable harness, as shown in Figure 1.

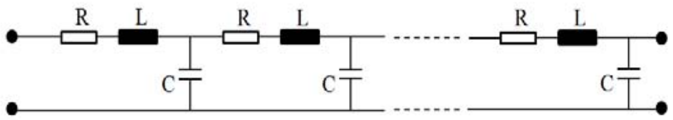

Figure 1. Schematic diagram of the equivalent circuit of the cable harness

3) Calculate the solution. Add loads and excitation sources to the cable harness and add current and voltage monitoring points to solve the time domain and frequency domain transmission characteristics of the electromagnetic energy on the cable harness. The focus of this paper is on the crosstalk of cable harnesses. Figure 2 shows the excitation source and load circuit connections for two cable crosstalk (AFDX communication cable and CAN communication cable). Among them, P1 is the voltage monitoring point on the CAN communication cable.

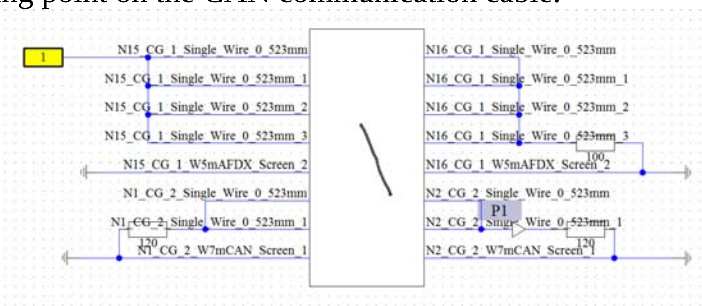

Figure 2. Schematic diagram of circuit connection of two cable crosstalk

During the simulation calculation, the change of current and voltage on the cable harness is transmitted to the 3D electromagnetic field simulation module, thereby generating electromagnetic interference to the space electromagnetic field and the adjacent cable harness. The 3D electromagnetic simulation converts the spatial time-varying electromagnetic field to the cable harness, and then simulates the time domain and frequency domain transmission on the cable harness through the 2D cable harness simulation. This field-channel joint simulation method can solve the problems of crosstalk between multiple cable harnesses, radiation emission of cable harnesses, and radiation sensitivity of cable harnesses.

Complex Cable Bundle Modeling

This article uses professional electromagnetic simulation software for simulation. The simulation model is shown in Figures 3 and 4. In the model, the cable path is complex, including a cable bundle composed of a power cable bundle, a DC power cable bundle, a communication cable, and a signal cable.

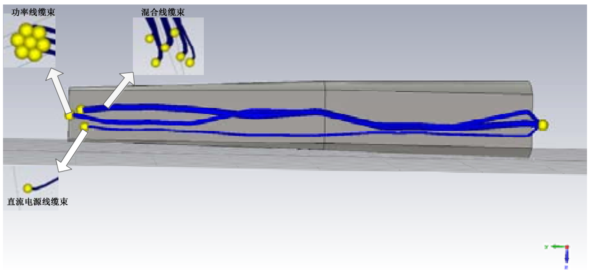

Figure 3. Cable crosstalk simulation model

According to the cable type, this section groups the cables, each group of two cables, crosstalk simulation analysis, and analyzes the crosstalk of the different groups of cables. The result of the grouping is: 1) the power cables are respectively connected to the DC power cables, communication cables, and signal cables; 2) the DC power cables are respectively Communication cable and signal cable; 3) communication cable and signal cable.

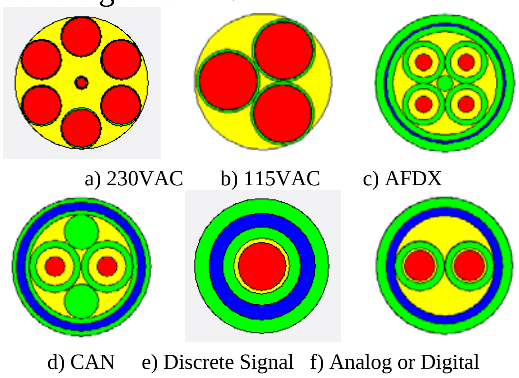

Figure 4. Cable section model

According to the above grouping, 1) Apply excitation signals and loads to the power cables that are interference cables, 230V sinusoidal alternating current, load resistance 17.7 ohms and 115V sinusoidal alternating current, load resistance 4.4 ohms; 2) Apply excitation signals and loads to the DC power cables that are interference cables, ±270V high-voltage direct current, load resistance 23.6 ohms and 28V direct current, load resistance 0.4 ohms; 3) Apply excitation signal and load to the communication cable as the interference cable, 6V, 100MHz, 50% The square wave of the air ratio is AFDX signal, the load resistance is 100 ohms, the square wave of 3V, 1MHz, 50% duty cycle is CAN signal, the load resistance is 120 ohms; 4) Apply excitation signal and load to the signal cable as the interference cable, 6V, 100MHz, 50% duty cycle square wave discrete signal, load resistance 100 ohms, 12V, 10MHz sine wave is analog signal, load resistance 50 ohm, 12V, 10MHz, 4% duty cycle square wave Digital signal, load resistance 50 ohms.

Simulation Result Analysis

Power Cable as Interference Cable

Cable crosstalk simulation is performed according to the grouping in Section 3. The interference signal of the power cable is a sinusoidal three-phase AC voltage signal of 230V360Hz, and the voltage waveform is as shown in Figure 5.

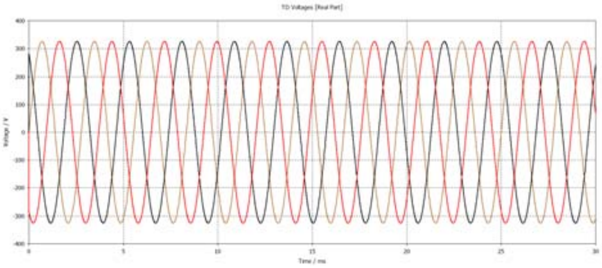

Figure 5. 230VAC360Hz sinusoidal voltage signal

The power signal is injected into the power cable using the voltage signal shown in Figure 5, and the crosstalk between the cables is calculated by the electromagnetic simulation software. The crosstalk results of the power cable to the DC power cable, the communication cable, and the signal cable are as shown in the following figure.

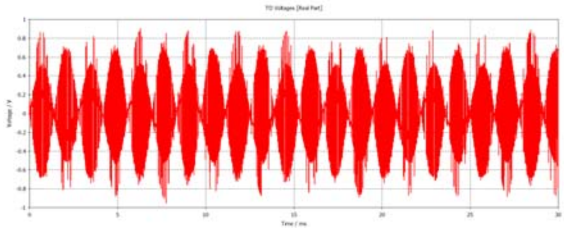

Figure 6. 230VAC to ±270V high voltage DC cable crosstalk

It can be seen from Figure 6 that the crosstalk of the 230V 360 Hz three-phase AC power cable to the ±270V high voltage DC power cable is very obvious, and the crosstalk voltage waveform frequency is similar to the interference signal waveform frequency.

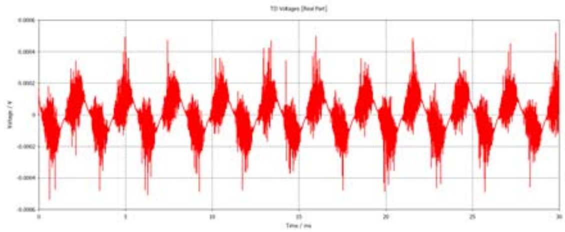

Figure 7. 230VAC to AFDX communication cable crosstalk

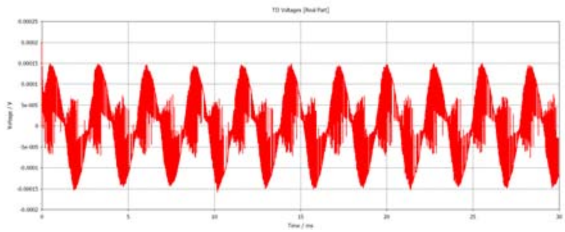

Figure 8. 230VAC to digital signal cable crosstalk

It can be seen from Figures 7 and 8 that the crosstalk of the 230 V 360 Hz three-phase AC power cable to the AFDX communication cable and the digital signal cable is small, and the crosstalk signal slightly oscillates in amplitude, the amplitude is much smaller than the interference signal, and the crosstalk signal The waveform frequency approximates the frequency of the interfering signal waveform.

According to the above results, the crosstalk result of the power cable to the DC power cable, the communication cable, and the signal cable, the amplitude of the crosstalk signal is small relative to the amplitude of the interference signal, and the waveform frequency approximates the waveform frequency of the interference signal, and Depending on the type of cable, the crosstalk signal has no oscillation and the amplitude of the oscillation is different.

DC Power Cable as Interference Cable

According to the grouping of Section 3, this section uses the DC power cable as the interference signal, and the voltage waveform of ±270V is shown in Figure 9.

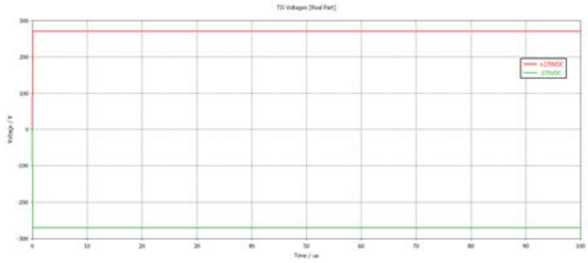

Figure 9. ±270V high voltage DC signal waveform

The DC power cable is injected into the DC power cable using the voltage signal shown in Figure 9. The crosstalk between the DC power cable and the signal cable is shown in the following figure.

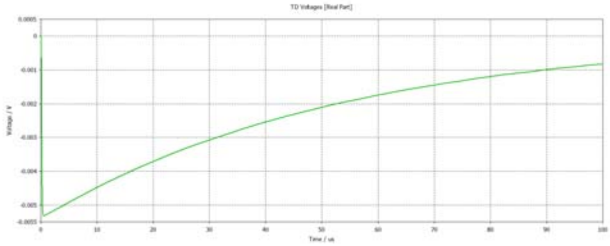

Figure 10. ±270V high voltage DC to AFDX communication cable crosstalk

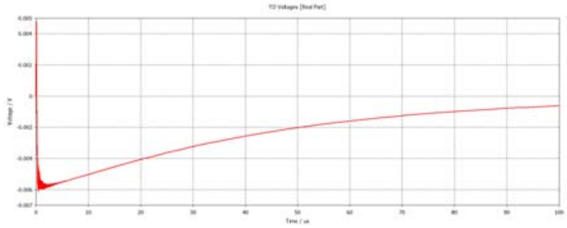

Figure 11. ±270V high voltage DC to digital signal cable crosstalk

As can be seen from Figures 10 and 11, the crosstalk of the ±270V high-voltage DC cable to the AFDX communication cable and the digital signal cable is small, the amplitude is slightly oscillated at the moment of power-on, and the waveform of the crosstalk signal gradually approaches DC signal as time increases.

Communication Cable and Signal Cable as Interference Cables

According to the grouping of Section 3, this section uses the communication cable as the interference signal, and the AFDX signal voltage waveform is shown in Figure 12.

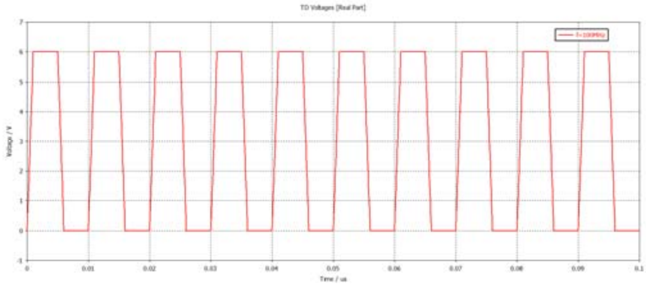

Figure 12. AFDX communication cable signal waveform

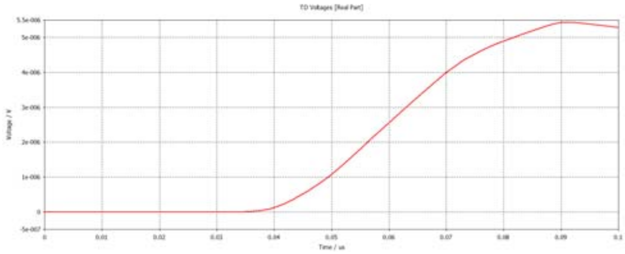

Figure 13. AFDX communication cable crosstalk to digital signal cable

As can be seen from Figure 13, the crosstalk signal amplitude of the communication cable to the signal cable is very small, only a few microvolts and the crosstalk signal is approximately zero.

According to the grouping of Section 3, this section uses the communication cable as the interference signal, and the analog signal voltage waveform is shown in Figure 14.

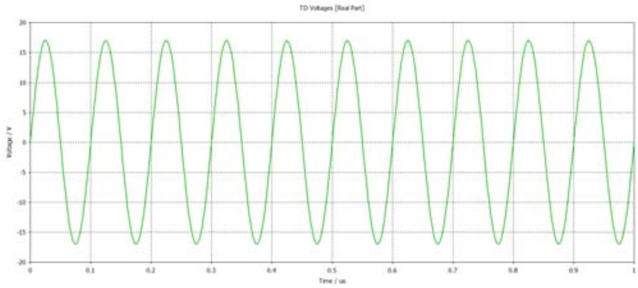

Figure 14. Signal waveform of the analog signal cable

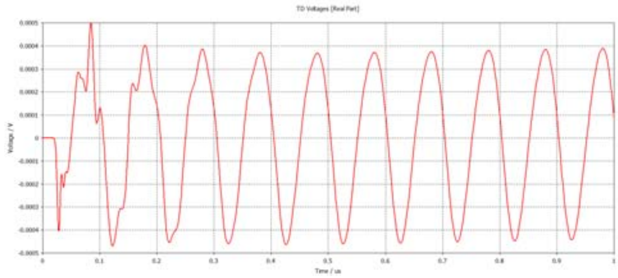

Figure 15. Analog signal cable crosstalk to digital signal cable

As can be seen from Fig. 15, the amplitude of the crosstalk signal of the analog signal cable to the digital signal cable is very small, only a few tenths of millivolts, and the crosstalk signal waveform frequency is close to the interference signal waveform frequency.

Change the Interference Signal Parameters

This section focuses on the effects of interference signal frequency, cable spacing and cable length on crosstalk.

Change the power cable signal frequency to 360Hz, 400Hz, 800Hz, respectively, and study the influence of the interference signal frequency on crosstalk. The results of the sweeping parameters are as follows.

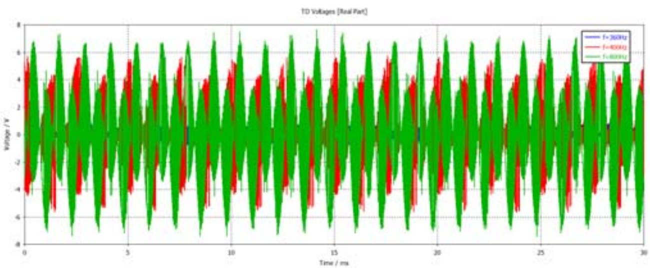

Figure 16. 230V power cable and DC cable crosstalk - change the interference signal frequency

It can be seen from Fig. 16 that the frequency change of the interference signal has a certain influence on the amplitude and frequency of the crosstalk signal. The frequency of the crosstalk signal changes with the frequency of the interference signal, and the amplitude of the crosstalk signal increases simultaneously with the increase of the frequency of the interference signal.

Change the cable spacing, the pitch varies from 10mm to 200mm, and the interval is 10mm. Study the influence of cable spacing on crosstalk. The results of the sweeping parameters are as follows.

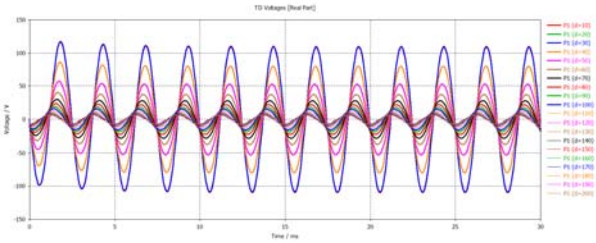

Figure 17. 230V power cable and DC cable crosstalk - change cable spacing

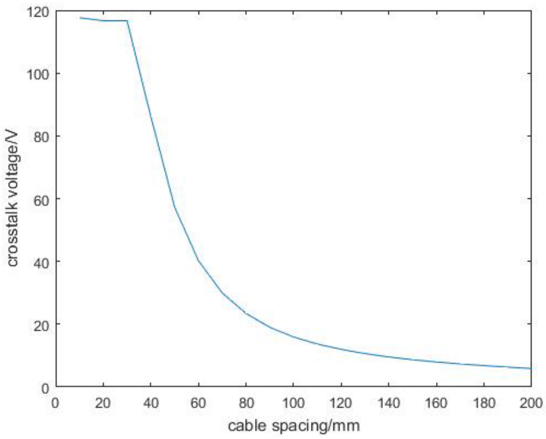

Figure 18. Curve of the crosstalk signal amplitude and cable spacing

It can be seen from Figures 17 and 18 that the cable pitch change has a certain influence on the amplitude of the crosstalk signal, and the crosstalk signal amplitude decreases as the cable pitch increases.

Change the cable length, the length varies from 50mm to 1500mm, and the interval is 50mm. Study the effect of cable length on crosstalk. The results of the sweeping parameters are as follows.

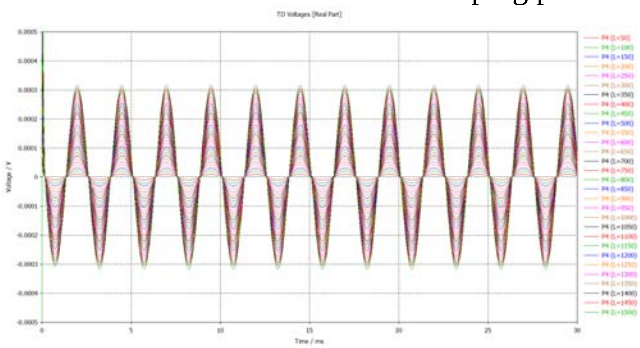

Figure 19. Crosstalk between 230VAC and analog signal cable - change cable length

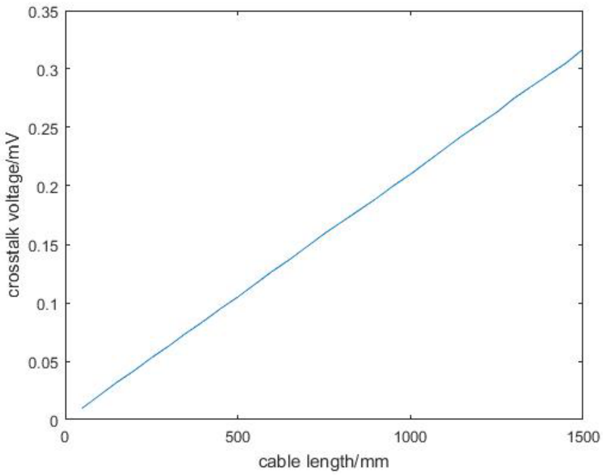

Figure 20. Curve of crosstalk signal amplitude versus cable length

As can be seen from Figures 19 and 20, the cable length change has a certain influence on the amplitude of the crosstalk signal, and the crosstalk signal amplitude increases as the cable length increases.

In summary, by changing the parameters of the interference signal frequency, cable spacing, cable length and other parameters, the following conclusions are studied and summarized: 1) changing the cable length, the amplitude of the crosstalk voltage is little affected; 2) changing the line Cable spacing, the most significant impact on the amplitude of the crosstalk voltage; 3) change the frequency of the AC signal, the frequency and frequency of the crosstalk voltage change, and the higher the frequency, the greater the crosstalk of the crosstalk.

Conclusion

In this paper, the common power cables for high-speed EMU complex cable bundles are used to establish the simulation model of interference signal, cable structure and load end, and the crosstalk between different types of cables is studied. Through research and analysis, it can be seen that the DC power cable has less influence on the communication cable, the signal cable; and the communication cable has less influence on the signal cable; and the signal cable has less influence on the signal cable; however the influence of the power cable on the DC power cable, the communication cable, and the signal cable is significant, and the waveform of the crosstalk signal is a waveform whose direct frequency approximates the interference signal. By changing the interference signal frequency, cable spacing and cable length, the following conclusions are drawn: 1) the amplitude and frequency of the crosstalk signal increase as the frequency of the interference signal increases. 2) the amplitude of the crosstalk signal decreases as the cable pitch increases. 3) the amplitude of the crosstalk signal increases as the length of the cable increases. The conclusion of the complex cable bundle crosstalk obtained in this paper can provide some theoretical support for the laying of EMU cable bundles.

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