Research on the Coupling Characteristics of Electromagnetic Pulse of Electronic Equipment

Shu Wang¹, Wenwen Hu², Yue Li³

¹ Shanghai Civil Aviation College, Shanghai, 200232, China
² State Grid Anhui Electric Power Co., Ltd. Wuhu County Power Supply Company, Anhui, 241100, China
³ College of Engineering Science and Technology, Shanghai Ocean University, Shanghai, 201306, China

E-mail: ly0728_55@163.com

Abstract. The problem of electromagnetic interference is becoming more and more prominent in complex environment, and the study of coupling effect between electronic devices is very important to guide the design of electromagnetic protection. In this paper, CST electromagnetic simulation software is used to study the strong electromagnetic pulse coupling effect of the device chassis and harmonious vibration cavity, to simulate the coupling characteristics of the cavity by square hole seam area and the length of the outer cable in the cavity, and then to study the coupling characteristics of the two coupling methods at the same time through simulation and analysis of the coupling electric field and electromagnetic pulse simulation test. The results show that the larger the hole area, the stronger the field strength of coupling into the cavity, and no effect on the resonant point position in the cavity; The longer the cable, the stronger the field force coupled in the center of the cavity, the resonant frequency in the cavity is basically unchanged; When the two coupling methods exist at the same time, the size of the hole seam is small compared to the wavelength, which makes it difficult for electromagnetic waves to enter the inside of the cavity, mainly as cable coupling, and the other is mainly in the form of hole coupling.

1. Introduction

High-altitude nuclear electromagnetic pulse has the characteristics of high peak field strength, high energy intensity, wide coverage area and wide spectrum range. If the coupling current or voltage exceeds the threshold value of the component, it may cause damage to the device and affect its normal operation[1–4]. In the study of the influence of shielding cavity shape with hole on electromagnetic coupling effect, Liu Qiang and Zhan Ping Zhu [5–6] found that the electromagnetic wave coupled to the cavity near the hole has the characteristics of pulse width expansion and field strength enhancement, and the internal structure of the cavity affects the distribution of the coupling electric field. It can be seen from[7] that the influence of EMP on coupling field strength and other characteristics can be studied through different aperture gap, hole depth and aperture size, at the same time, the influence of rise time on the coupling of strong EMP is studied. Bing Cao[8] and others used the finite element method to study the relationship between the strong electromagnetic pulse and the aperture coupling, and studied the shielding effect of the machine box under different electromagnetic pulse frequencies. At present, overhead and buried cables have been widely used in power transmission projects. Feng Xu[9] solved
the problem by finite difference time domain (FDTD) method, for the coupling response of buried cables, Rui Huan[10] established a coupling model and used FDTD method to calculate the coupling characteristics of multiple electromagnetic pulses on the ground wire. For the analysis of high-altitude cables, Pei Hu[11] used CST electromagnetic simulation software to study the coupling characteristics of different types of cables under high-altitude electromagnetic pulse irradiation.

At present, the coupling characteristics of electromagnetic pulse are studied by changing the strength, pulse width, rise time, incident angle, polarization direction and slot properties[12-14], etc., lacking the study of the coupling characteristics of multiple coupling channels in the device under the actual electromagnetic pulse irradiation. This paper first studied the influence of the hole area and cables on the coupling characteristics in the cavity, and then analyze the influence of each coupling channel on the intracavity coupling characteristics according to the coupling law in the shielding cavity of electronic equipment with hole and cable channels. We also used the transmission line type bounded wave electromagnetic pulse simulator to simulate the cabi

2. Simulation research on coupling characteristics of hole and cable

2.1. Analysis of coupling characteristics of hole area
The excitation signal used in this study adopts the double exponential pulse wave specified in IEC 61000-2-9, and the waveform of its time-domain simulation is shown in figure 1. We set the double exponential pulse plane wave to simulate the nuclear electromagnetic pulse wave as the incident wave. The direction of electric field is along the positive direction of the X axis, and the electromagnetic pulse propagates along the negative direction of the Z axis, as shown in figure 2.

We chose 2cm×2cm, 4cm×4cm, 8cm×8cm, 16cm×16cm four square holes and set them in the middle of the cavity facing the incident wave surface. The cavity thickness is 0.1cm. The time-domain waveform of the positive square shielding cavity body coupling electric field is shown in figure 3.

The positive square shielding cavity body electric field frequency domain coupling function curve of different hole seam area is shown in figure 4. We can conclude that as the area of the hole increases, the field strength coupled into the cavity increases from the figure 3 and the change of the hole area will only cause the fluctuation of the
coupling field strength in the cavity, which does not affect the position of the resonant point in the cavity from the figure 4. Therefore, it's necessary to make the hole area smaller under the premise of meeting various performance requirements in the design of electronic equipment cabinet.

2.2. The influence of cable length on coupling characteristics in cavity

As is shown in figure 5, a through hole with a radius of 1 cm is opened on the upper surface of the cavity, and the cable is set as a single wire with a radius of 5mm and an outer cavity length d2 equals 10cm. We changed the length of the cable d1 in the range of 2cm, 7cm, 10cm, 12cm and 15cm to study the influence of cable length on the coupling characteristics in the shielding cavity.

![Figure 5. Shielding cavity body contains a simulation model that runs through the line.](image)

If the cube shielding cavity contains through cables, the time-domain waveforms of the coupling electric field and the field frequency domain coupling function curve when the length of the in-cavity cable changes are shown below in figure 6 and figure 7.

![Figure 6. Coupling electric field time domain waveforms when the length of the in-cavity cable changes.](image)

![Figure 7. Field field frequency domain coupling function curve when the length of the in-cavity cable changes.](image)

It can be seen that when the shielding cavity contains through cables and the length of the external cables remains unchanged, the length of the cables in the cavity will affect the coupling field strength inside the shielding cavity. The longer the cable in the cavity, the greater the coupling field strength at the center of the cavity.

It can be seen from figure 7 that the resonance frequency of the shielding cavity is about 530.25MHz. The electric field frequency domain coupling function curve in the above figure is processed in detail in the frequency range of 500MHz to 600MHz to obtain the electric field frequency domain coupling function curve of this frequency band, which is shown in figure 8.

![Figure 8. Coupling function curve of electric field in 500MHz to 600MHz frequency domain when the length of the in-cavity cable changes.](image)
When the external cable length of the cavity remains unchanged, the position of the resonant point shifts with the change of the cable length in the cavity. When the length of the internal cable is less than or equal to the length of the external cavity (d2 = 10 cm), the resonant point position shifts to the left with the increase of the length of the internal cable, which means the reduction of resonant frequency. When the length of the internal cable is longer than the length of the external cavity (d2 = 10 cm), the resonant point position shifts to the right with the increase of the length of the internal cable, which means the increase of resonant frequency.

2.3. The influence of cable length on coupling characteristics outside cavity
Supposing that the length of the cavity is a fixed value (d1 = 10 cm), we changed the length of cable outside the cavity (d2) in the range of 2 cm, 7 cm, 10 cm, 12 cm and 15 cm to study the influence of cable length outside the cavity on the coupling characteristics in the shielding cavity. Coupling electric field time domain waveforms and field frequency domain coupling function curve when the length of the outer-cavity cable changes are shown in figure 9 and figure 10.

![Figure 9. Coupling electric field time domain waveforms when the length of the out-of-cavity cable changes.](image1)

![Figure 10. Field field frequency domain coupling function curve when the length of the outer-cavity cable changes.](image2)

It can be seen from figure 9 and 10 that when the length of the cable inside the cavity remains unchanged, the length change of the cable outside the cavity will also affect the coupling field strength inside the shielding cavity. The longer the cable outside the cavity is, the greater the field strength coupled at the center of the cavity is.

The electric field frequency domain coupling function curve in figure 11 is processed in detail in the frequency range of 500 MHz to 600 MHz to obtain the electric field frequency domain coupling function curve of this frequency band as shown in figure 11.

![Figure 11. Coupling function curve of electric field in 500MHz to 600MHz frequency domain when the length of the outer-cavity cable changes.](image3)

It can be seen from the coupling function curve of electric field in figure 11 that when the cable length inside the cavity remains unchanged, the position of the resonant point does not deviate with the change of the cable length outside the cavity.
3. Simulation and Experiment Research

3.1. Simulation and analysis
Respectively deal with the three simulation scenarios of square hole size 4cm×4cm with cable length 20cm, square hole size 4cm×4cm with cable length 30cm, square hole size 8cm×8cm with cable length 10cm, and the comparison coefficient curve is shown in Figure 12.

![Figure 12. Comparison coefficient graph.](image)

By comparing the three curves in figure 12, we can conclude that at higher frequencies, there is also a phenomenon that cables near some frequencies become the main coupling channel, and as the cable length increases, these frequency points also increase. This is because the coupling of the cable itself. The cable resonance is stronger than the cavity resonance near the frequency point of 640MHz, 730MHz, and there is less leakage of energy in the cavity through the hole of the through-line than the leakage of the hole, so the cable becomes the main coupling channel near these frequency points. As the length of the cable increases, the energy coupled by the cable itself also increases, which makes the cable as the main coupling channel in a larger frequency range.

3.2. Research on nuclear electromagnetic pulse test
Comparison of simulation and test results. The comparison coefficient curve of the test calculation and simulation calculation is shown in figure 13.

![Figure 13. Test results vs. simulation.](image)

Combining the comparison curve of the experimental calculation and the simulation calculation in the above figure 13 (a), (b), (c), it can be seen that the simulation and test curves are consistent in general change trend, and have a good agreement. The amplitude fluctuations at each frequency point are obvious, mainly because the simulation work is to study the high-altitude nuclear electromagnetic pulse coupling characteristics of the electronic equipment shielding cavity under ideal conditions. The surrounding environment includes the pulse waveform generated during the test. There are differences between them. These practical factors have caused the test results to fluctuate sharply, but this does not affect the overall law. Therefore, the test verifies the accuracy of the simulation work.

4. Conclusion
This paper analyzed the coupling characteristics of the cavity through the simulation of the area of the hole and the length of the inner and outer cables, using simulation and experiment to study the coupling characteristics of the two coupling channels at the same time. The following conclusions can be drawn
(1) The larger the hole area, the stronger the field strength of coupling into the cavity, and no effect on the resonant point position in the cavity;
(2) The longer the cable, the stronger the field force coupled in the center of the cavity, the resonant frequency in the cavity is basically unchanged;
(3) When the two coupling methods exist at the same time, the size of the hole seam is small compared to the wavelength, which makes it difficult for electromagnetic waves to enter the inside of the cavity, mainly as cable coupling, and the other is mainly in the form of hole coupling.

5. References
[1] Phan Duy Tung, Jung Chang Won. Optically transparent and very thin structure against electromagnetic pulse (EMP) using metal mesh and saltwater for shielding windows[J]. Scientific Reports, 2021, 11(1).
[2] Li Bing, et al. "Influence of Electromagnetic Pulse on Electromagnetic Relay by Using Equivalent Circuit Model". Proceedings of the 26th International Conference on Electrical contacts and the 4th International Conference on Reliability of Electrical Products & Electrical Contacts. Ed., Institution of Engineering and Technology, 2012, 204-9.
[3] Lei Hong, Li Qingying. Electromagnetic Pulse Coupling Analysis of Electronic Equipment[J]. MATEC Web of Conferences, 2017, 139.
[4] Baozhou Du, Yazhou Chen, and Erwei Cheng. "Strong Electromagnetic Pulse Comprehensive Protection Methods Research for UAV". Proceedings of the 2nd International Conference on Mechatronics Engineering and Information Technology (ICMEIT 2017). Ed., Atlantis Press, 2017, 15-8.
[5] Liu Qiang, Qian Baoliang, Zhu Zhanping. Numerical study on coupling of microwave pulses into different shaped cavities through slots [J]. High Power Laser and Particle Beams, 2009, 21(12): 1859-65.
[6] Zhan-Ping Zhu, Hong-Gang Wang, and Biao-Liang Qian. Numerical Simulation of Microwave-Slot Coupling into a Rectangular Cavity with an Interior Structure[C]. IEEE, 2011: 1-4.
[7] Liu Chenglong School of Mechanical Engineering Nanjing University of Science and Technology Nanjing, China Cao Bing, Jiang Wencan School of Mechanical Engineering Nanjing University of Science and Technology Nanjing, China. "Analysis on Couplings of Strong Electromagnetic Pulse to Computer Box with aperture arrays". Proceedings of 2011 World Congress on Engineering and Technology (CET 2011) VOL06. Ed.. Institute of Electrical and Electronics Engineers, Inc., 2011, 521-4.
[8] Bing Cao, Xuchao Pan, Chenglong Liu, Maolei Zhang, Wencan Jiang. Simulation research on shielding effect of computerized boxes with electromagnetic pulse hole based on finite element analysis[J]. Cluster Computing, 2019, 22(6).
[9] Feng Xu, Chen Liu, Wei Hong, et al. Fast and Accurate Transient Analysis of Buried Wires and its Applications[J]. IEEE Transactions on Electromagnetic Compatibility, 2014, 56(1): 188-199.
[10] Rui Huan, Cheng Liao, Zhihong Ye, Jie Luo. A time domain hybrid method for the coupling of two wires above the ground excited by electromagnetic pulses[J]. Microwave and Optical Technology Letters, 2020, 62(3).
[11] Pei Hu, Xiao-Dong Mu, Zhao-Xiang Yi, Shao-Chong Wang. Effect of Wiring Method on Coupling of Cables Under HEMP Irradiation[J]. IOP Conference Series: Earth and Environmental Science, 2018, 186(5).
[12] Li, Xuan, et al. "Analysis on electromagnetic pulse cable coupling inside enclosure with aperture based on BLT equation". Proceedings of the Seventh Asia-Pacific Conference on Environmental Electromagnetics (CEEM’2015). Ed. , 2015, 299-301.
[13] Gai Hong Du, Yang Meng Tian. The Coupling Effect of Electromagnetic Pulse and Computer[J]. Applied Mechanics and Materials, 2014, 3072.
[14] Ruirong Hao, Xiaodong Zhang, Huai Gao, Haodong Wu, Jianchun Cheng, GuannPyng Li. A novel high-altitude electromagnetic pulse (HEMP) protection circuit for RF applications[J]. Microelectronics Journal, 2018, (84): 1-8.