Test and Response Analysis of Shielding Performance of The Cable Under HEMP Irradiation

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Abstract. The shielding efficiency of coaxial cable is characterized by its anti-interference ability in electromagnetic environment. The testing methods include three-axis method, GTEM chamber method, line injection method, power absorption clamp method, reverberation chamber method and so on. In practical application, it is found that the shielding performance of the cable under high altitude electromagnetic pulse (HEMP) does not accord with the shielding efficiency measured by the cable. While a typical multi-layer shielded cable is selected as the test object, a test method is designed and tested under electromagnetic simulator, and then the test results are verified and extended by CST simulation. Finally, the reason of this phenomenon is analysed theoretically, which has important reference significance for the prediction and testing of shielding efficiency of cable in HEMP environment.

Keywords: Shielding efficiency, shielding performance, HEMP, CST simulation.

1. Introduction

With the update of science and technology, cables for various purposes are becoming more and more optimized, and the structure is becoming more and more complex. Coaxial shielded cable is widely used because of its good shielding effect, especially in some key applications, such as aircraft, military equipment and so on. The shielding ability of cable to electromagnetic pulse can be characterized by shielding efficiency. In practical application, it is found that the shielding performance of cable under high electromagnetic pulse (HEMP) does not accord with the shielding efficiency measured by cable [1, 2]. Based on this situation, a typical coaxial multi-layer shielding cable is used to design a kind of shielding efficiency test method which is close to the real application scene, and the test is carried out under the HEMP simulator, and then the data processing analysis is carried out. Then the electromagnetic simulation software CST is used to simulate and verify the correctness of the test [3, 4, 5], and the regularity of the phenomenon is studied. Finally, the reason of this phenomenon is analysed theoretically, which provides reference for the prediction and testing of shielding performance of coaxial shielded cable under HEMP irradiation.
2. Test method and results analysis

2.1. Test Design and Implementation

A kind of multi-layer coaxial shielding cable is selected in the test. The length of the cable is 1 m. Both ends of the cable are connected to the custom shielding shell, and the inner core of the cable is connected to the shell through the resistance of 50 omega to simulate the matching application scene. The coupled current on the cable skin port, the middle part of the skin and the core wire were measured with the current probe. The connection between the cable and the shield shell is shown in Figure 1 [6].

![Figure 1 Connection between cable and shield shell](image)

In the experiment, the "Spring Thunder" vertical polarization bounded wave electromagnetic pulse simulator developed by Northwest Nuclear Technology Research Institute was used. The simulator can produce a double exponential electromagnetic pulse environment which is 2.5±0.5 ns, half height width is 23±5 ns, and the peak range of electric field is 2 kV/ m ~ 100 kV/ m [7]. The environment is in accordance with IEC 61000-2-9 standard. The "Spring Thunder" simulator and its typical electric field strength time domain waveform are shown in Figure 2.

![Figure 2 The "Spring Thunder " simulator and its time domain waveform](image)

The cable and measuring equipment are connected as shown in Figure 1, and the cable is placed on vertical in the test area, the shielding shell is supported by wooden stool, and the layout of test is shown in Figure 3. Three tests were carried out at 50 kV/ m field strength.
The test results are shown in Table 1. The number of the test and the peak value of the coupled current of the cable subjected to HEMP irradiation are given. The formula for calculating the shielding performance of cable is:

$$SE = 20 \times \log\left(\frac{I_{\text{skin}}}{I_{\text{core}}}\right)$$  \hspace{1cm} (1)

among this, $I_{\text{skin}}$ represents the coupled current of the outer layer of the cable under the electromagnetic pulse, and $I_{\text{core}}$ represents the coupled current on the inner core of the cable. The test results show that the coupling current on the cable’s outer skin is in order of 100 amperes, and the current in the middle of the cable is slightly larger than that of the port. The core current coupled to the cable is about a dozen mA. The shielding efficiency of this type of cable is greater than 78.73 dB in the irradiation field around 50kV/m.

Table. 1 Test results of cable shielding performance

| Test number | 190996 | 190997 | 190998 |
|-------------|--------|--------|--------|
| Electric field (kV/m) | 52.91 | 51.97 | 52.89 |
| Skin current of terminal (A) | 119.22 | 116.86 | 114.23 |
| Skin current of middle (A) | 120.17 | 120.19 | 122.60 |
| Core current (mA) | 14.38 | 14.19 | 12.08 |
| Shielding performance (terminal /dB) | 78.37 | 78.31 | 79.51 |
| Shielding performance (middle /dB) | 78.44 | 78.56 | 80.13 |
| Average (terminal /dB) | 78.73 | 78.73 | 79.04 |
| Average (middle /dB) | 79.04 | 79.04 | 79.04 |

Figure 4 shows the measurement waveform of the coupled current on the 190998. The coupled current waveform was dealt with Fourier transform. The results are shown in Figure 5. It can be seen that the main frequency of the skin current coupling waveform on the cable is about 42 M, and the internal current has noise interference because the signal is too small, but it can still be seen that there is a peak value around 40 M, which is consistent with the skin current [8].
Figure 4 Coupling current waveform at 190998
According to the pre-detection data of the cable, the shielding efficiency of the cable is about 50 dB, which is much different from the 78.73 dB measured by experiment, which proves that the shielding performance of the cable in practical application is better than that of the cable. At the same time, it can be found that the main frequency of the coupled current on the cable has changed, which is less than the theoretical frequency of the pure cable at 150M.

3. Simulation and analysis

3.1. CST simulation

CST (Computer Stabilization Technology) software package includes seven studios, such as cable studio, electromagnetic studio, which can solve a variety of problems in different fields \[9,10\]. The test environment shown in Figure 3 can be modeled and simulated using CST, as shown in Figure 6.
The HEMP waveform generated by the simulator is added as the excitation source, and the shielding shell size is 40cm * 25cm * 10cm, at the same time the current probe is added at the middle and the port of the cable respectively. The coupled current and its spectrum are calculated when the cable is connected to the shielding shell at both ends. The current waveform and spectrum are shown in Figure 7.

![Current waveform of cable and Frequency spectrum of coupling current](image)

**Figure 7** Current waveform and its frequency spectrum by CST simulation

Compared with the experimental data, CST calculation results show that the current waveform measured by the experiment is in good agreement with the simulation. The main frequency of current spectrum is 43.5M. The waveform trend is in good agreement with the measurement results, as well the correctness of the measurement results is proved.

Because the physical structure of the cable is changed after the shielding shell is connected at both ends of the cable, the coupled current and its spectrum are different from that of the pure cable. Change the size of the shell along the cable in the simulation, and calculate its current and spectrum respectively, the result is shown in Figure 8.

![Current waveform on different size of cable and Frequency spectrum of coupling current](image)

**Figure 8** Influence of different dimensions of shell on coupled current of cable

The shielding effect of the cable varies with the shell size as shown in Table 2. The fitting curve is shown in Figure 9. The results show that the shielding shell connected at both ends of the shielding cable has influence on the coupling current and spectrum of the cable. The smaller the shell, the
smaller the coupling current on the cable, the smaller the shielding efficiency, and the closer the main frequency of the coupling current spectrum to the pure cable.

Table. 2 Shielding performance of cable with different shell size

| Shell size/cm | skin current/A | core current/mA | shielding performance/dB |
|---------------|----------------|-----------------|--------------------------|
| 40*10*5       | 96.13          | 256             | 51.49                    |
| 40*10*10      | 109.20         | 269             | 52.17                    |
| 40*10*20      | 132.03         | 297             | 52.96                    |
| 40*10*30      | 152.55         | 305             | 53.98                    |

Figure. 9 Relationship between shielding performance of cable and shell size

3.2. Theoretical Analysis
A typical scenario of shielded cables applied to a device is shown in Figure 10. The skin of the cable is connected with the shell of the equipment, and the core wire transmits the communication signal. In the irradiated environment, the shielding shell connected at both ends is equivalent to extending the electrical length of the cable, while the core wire is connected to the circuit of the shell.

Figure. 10 Shaded cable connection diagram

The results show that the coupling current on the cable outer skin increases with the increase of the shell size, but due to the shielding effect of the shell, the current on the core wire is not obvious, and the shielding efficiency value of the cable will increase continuously. What’s more, the main frequency of the coupled current will be reduced with the increase of the electric length. This is consistent with the simulation results.
4. Conclusions
In order to research the relation between the actual shielding performance and the shielding efficiency of the shielded cable, a shielding performance test method of the cable under HEMP was designed, and a typical multi-layer shielding cable was selected as the object, and the experiment was carried out under the electromagnetic pulse simulator. The experimental data are analyzed theoretically. Then the coupled current and its spectrum on the cable are calculated by CST simulation. The results are in good agreement with the experimental data. Due to the connection of shielding shell, the physical structure of the cable will change, CST is used to simulate on different shell parameters. The results show that the coupling current on the cable increases gradually with the size increase of the shell, and the main frequency of the coupled current spectrum decreases. Finally, the reasons of better shielding performance of shielded cable and decrease of main frequency of coupled current are analyzed theoretically.

The results show that when the shielding efficiency of cable is measured by irradiation method, the shielding shell should be made by the size connected at both ends when the cable is actually used to simulate the real environment, and the shielding performance of the cable will be better than that of the pure cable. When the shell at both ends of the cable is small enough, the test results will be close to the shielding efficiency of the pure cable.

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