Electromagnetic Reinforced Carbon Fiber Composite Case and Its Electromagnetic Pulse Protection Performance

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Abstract: We adopt the technology of electromagnetic strengthening carbon fiber composite material to improve its electromagnetic protection ability, and use it to prepare the sample of carbon fiber composite cabinet, through the test, it has good electromagnetic pulse protection performance. Based on the carbon fiber composite structure design and electric connection design of the interlamination and gap electromagnetic enforcement. The HEMP protection performance was tested under the GB/T18039.10-2018 standard and the results showed that the HEMP shielding efficiency were above 65 dB. The carbon fiber composite cabinet had the lightweight ,high strength， HEMP shielding and anti-severe environment characteristics. The carbon fiber composite cabinet has a project value and application prospect.

Keywords: Composite Materials; HEMP; Carbon Fiber Composite Cabinet

Introduction

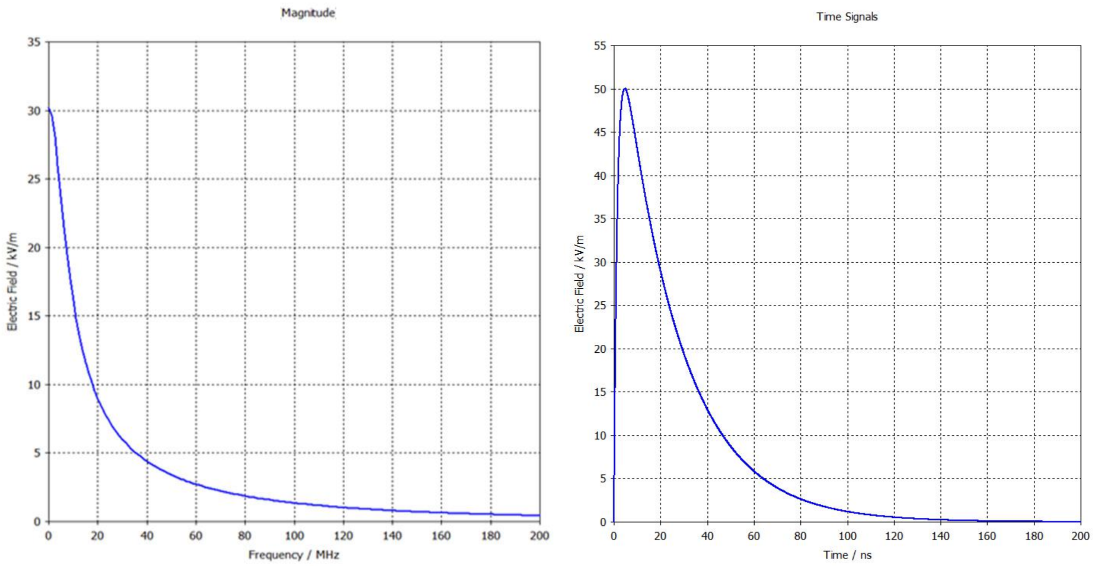
Electromagnetic pulse attack, especially HEMP is one of the biggest electromagnetic pulse interference sources faced by electronic equipment. The main characteristics of HEMP are high field strength, wide spectrum and wide coverage area of high field strength. For large-equivalent nuclear explosion. the peak field strength of HEMP field can reach 10^5 V/m [1]. Thus, posing a serious threat to shipborne electronic equipment within its range. As the basic unit of electronic control system, the reliability of standardized chassis of carrier-borne aircraft directly affects the security and stability of each system. Due to its excellent environmental corrosion resistance and weight reduction effect. composite materials have been applied more and more in weight reduction design of carrier-borne aircraft equipment. However, due to its own material factors, the traditional carbon fiber composite chassis does not have the electromagnetic pulse protection ability or has poor protection ability. Therefore, improving its electromagnetic pulse protection ability has become a research hotspot and difficulty in this field. Detailed research on HEMP is conducive to targeted equipment protection work [2].

This article will to a certain type of aircraft with a standard power supply chassis as the research object, the CST studio software is used for chassis protective properties of the composite design review, in weight loss when the design adopt the method of integrated structure, replacing the original Mosaic structure of traditional metal chassis structure. with nickel plating carbon fiber, magnetic extending network and conductive leads to material as base material. Manufacturing a carbon fiber composite chassis based on an integrated structure. In terms of manufacturing process, the advantages of integrated manufacturing of composite materials are fully utilized to avoid the influence of weight and protective effect brought by the splicing of the original metal chassis [3-4]. The shielding efficiency of the manufactured carbon fiber composite chassis under HEMP is tested and verified, and its electromagnetic pulse shielding efficiency is tested.

1. Nuclear electromagnetic pulse (HEMP) characteristics and protection design

1.1 Analysis of HEMP characteristics

Comprehensive electromagnetic radiation generated by the interaction of air medium molecules. HEMP has a variety of expression standards in different periods and different countries. At present, the standard IEC61000-2-9 formulated by the International Electrotechnical Commission is the most widely used. Therefore, this article selects the HEMP frequency domain and time domain expression standards specified by the standard for research [5], as shown in Figure 1.



a) HEMP time domain waveform (b) HEMP frequency domain spectrogram

Fig. 1 Time domain waveform and frequency domain spectrum of HEMP

According to Figure 1, the frequency coverage of HEMP is 0~200 MHz, and 96% of the energy is concentrated in the frequency range of 0.1~100 MHz. The HEMP pulse waveform has a rise time of 2.5 ns, a pulse width of 23 ns, and a maximum field strength of 50 kV/m.

1.2 Carbon fiber composite material power supply chassis structure

The object of this paper is a certain type of power supply chassis. The chassis is divided into three parts: the fuselage, the upper top plate and the lower top plate. As shown in Figure 2, the size of the chassis is: 225mm×225mm×503mm.The main material of the chassis is T700 carbon fiber reinforced epoxy resin composite material.

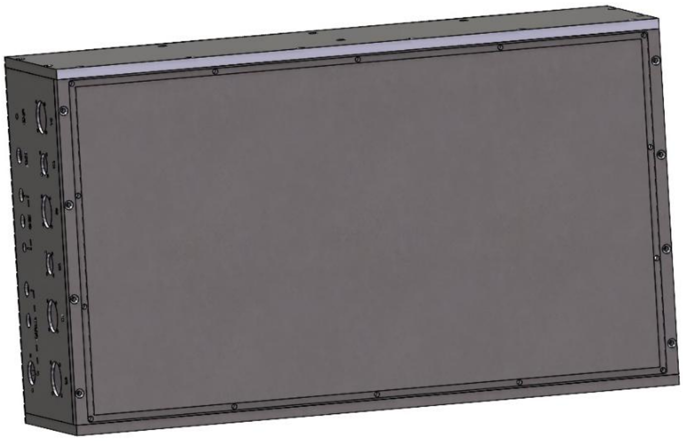


Fig.2 Schematic diagram of the carbon fiber composite cabinet structure

1.3 Carbon fiber composite material chassis HEMP protection design

1.3.1 Chassis material

According to Schelkunoff (Schelkunoff) electromagnetic shielding theory, the shielding effectiveness (SE) of the shielding material is composed of absorption loss A, reflection loss R and internal loss B. The shielding effectiveness is [6]:

$$SE = A + R + B \quad (1)$$

$$A = 1.314t\sqrt{f\sigma_r\mu_r} \quad (2)$$

$$R = 168 - 10\lg(f\mu_r/\sigma_r) \quad (3)$$

Where: f is the frequency of electromagnetic waves; t is the thickness of the material; μ_r is the relative permeability; σ_r is the relative conductivity. Therefore, when t and the incident electromagnetic wave frequency f are constant, the electromagnetic shielding effectiveness of the material is mainly related to μ_r and σ_r. According to the above principles, the constituent materials of the carbon fiber chassis need to consider ways to increase the reinforcement materials μ_r and σ_r. At the same time, according to the requirements of the composite material manufacturing process, the reinforced material needs to meet its manufacturability. Therefore, the materials to be selected for the electromagnetic enhancement layer are: metalized carbon fiber and expanded metal mesh. In order to ensure the protection requirements of the material at low frequency, the selected metal is metallic nickel, and its electromagnetic parameters are shown in Table 1.

Table 1 Electromagnetic properties of materials table

Serial number	Material	μ_r	σ_r
1	Carbon Fiber	1	0. 001
2	Nickel-plated carbon fibe	200	0. 1
3	Nickel Mesh	20000	1

At the same time, considering the skin effect (electromagnetic wave penetration depth) of the chassis material at the frequency of use (100kHz~100MHz), the minimum thickness design at this frequency is required, according to the requirements of skin depth and protective shielding effectiveness (dB) Calculation formula:

$$\delta = \frac{\chi}{10\lg e\sqrt{\pi\sigma_r\mu_r f}} \quad (4)$$

In the formula: δ is the skin depth; χ is the shielding effectiveness. Based on the 40 dB protection target in the

100kHz~100MHz frequency band, the skin depth is about 0.3 mm. Therefore, if the design of the chassis reaches the 40 dB protection target, the thickness of the shielding layer of the shielding material must be greater than 0.3 mm.

1.3.2 Electromagnetic simulation

The CST studio software was used to evaluate the protective performance design of the chassis composite material. CST has a unique simplified model library, using the transmission line matrix method, which can accurately calculate the electromagnetic shielding effectiveness of the chassis. This section simulates and predicts the effect of using electromagnetic reinforced materials for carbon fiber chassis. 1) The shielding effectiveness of ordinary carbon fiber (no shielding layer added) chassis. Through the test, the vertical conductivity of ordinary carbon fiber is 5 S/m, which is used as the simulation input parameter. The maximum electric field strength inside the chassis is 14.5 kV/m, as shown in Figure 3, the shielding effectiveness calculation result in the time domain is 10.75 dB; the shielding effectiveness calculation in the frequency domain is shown in Figure 4, SE≥10.61 dB (10 kHz~100 MHz). From the simulation results, the electromagnetic shielding effectiveness of ordinary carbon fiber composite cabine is weak, and the indicators cannot meet the protection requirements.

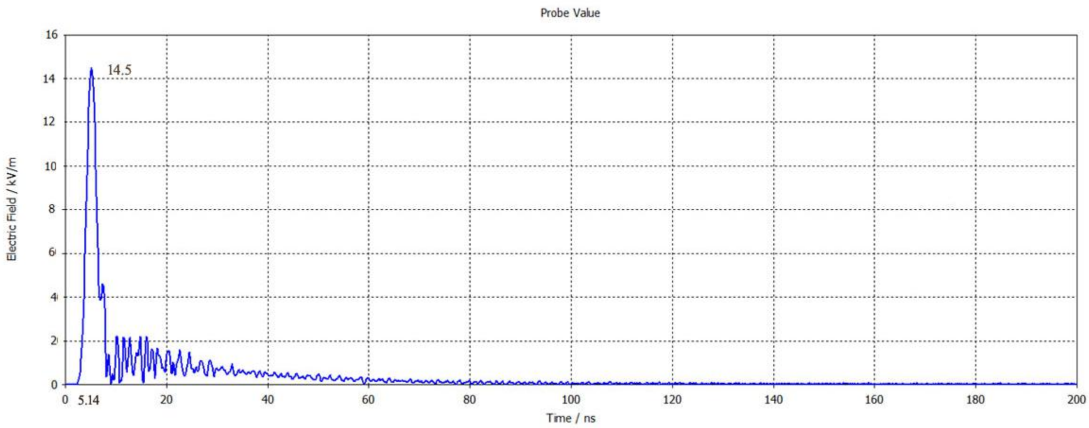


Fig. 3 Electric field intensity inside ordinary carbon fiber chassis (time domain)

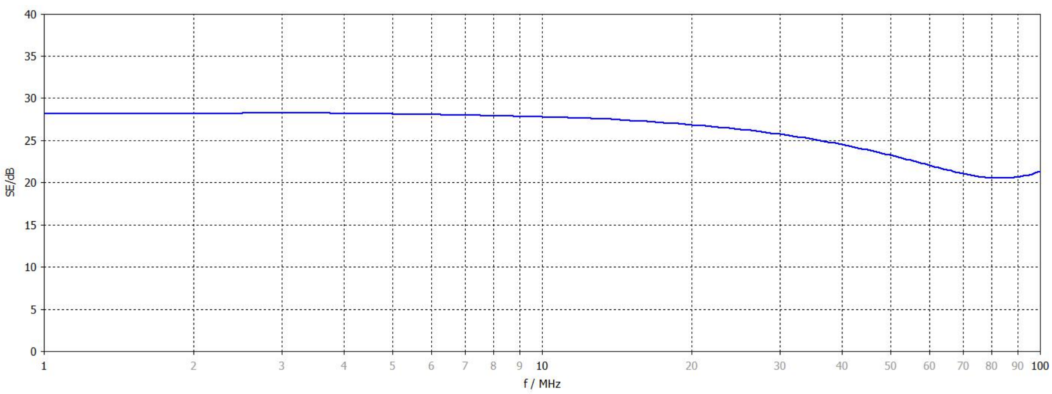


Fig. 4 Shielding effectiveness of common carbon fiber case

(1) The shielding effectiveness of the nickel-plated carbon fiber chassis.

Based on the above simulation results, the carbon fiber needs to be metalized and reinforced. First, nickel-plated carbon fiber is used as the chassis material to evaluate the design of the protective performance. The vertical conductivity of the nickel-plated carbon fiber is 430 000 S/m, which is used as the simulation input parameter. The maximum electric field strength inside the chassis is 348.7 V/m, as shown in Figure 5, the shielding effectiveness calculation result in the time domain is 43.1 dB; the shielding effectiveness calculation in the frequency domain is shown in Figure 6, SE≥34.75 dB (10 kHz~100 MHz). From the simulation results, the electromagnetic shielding effectiveness index of the nickel-plated carbon fiber chassis is calculated in the time domain, and the shielding effectiveness has met the protection requirements; but calculated from the frequency domain, the shielding effectiveness SE≥34.75 dB in the low frequency band (below 2.8 MHz) is still Does not meet the design requirements.

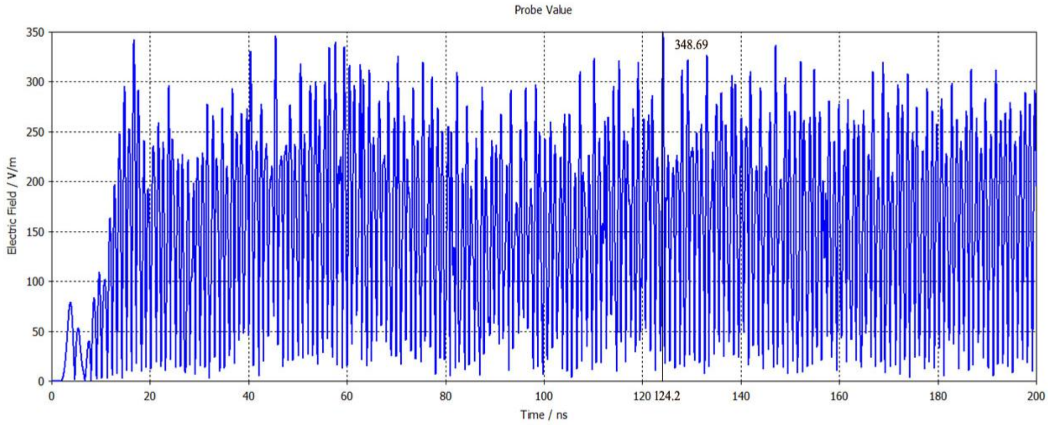


Fig.5 Electric field intensity inside the nickel-plated carbon fiber chassis (time domain)

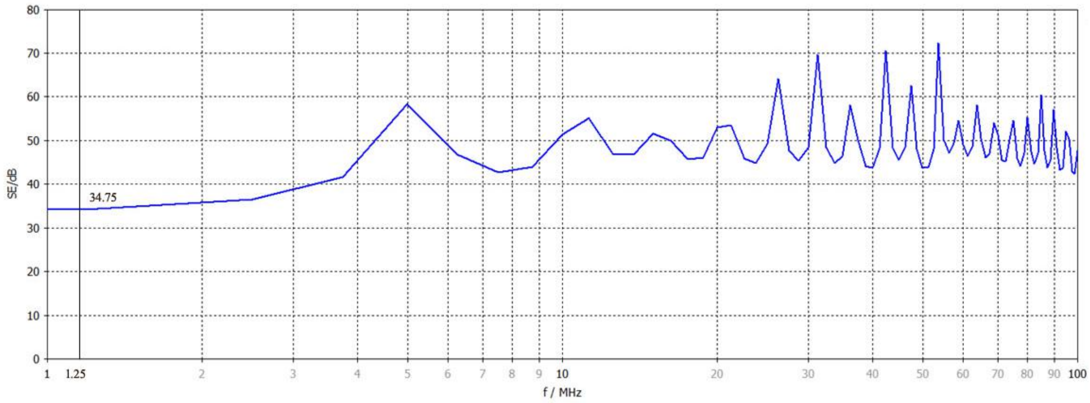


Fig.6 Shielding effectiveness of the nickel-plated in carbon fiber case

(2) The shielding effectiveness of the nickel-plated carbon fiber and metal nickel mesh composite chassis.

On the basis of the second case, the protection performance of the low frequency band needs to be enhanced. Consider using nickel-plated carbon fiber and metal nickel mesh as the main material of the chassis, and further optimize the design and evaluation of protection performance. Through the test, the vertical conductivity of the composite material is found to be 14400000 S/m, which is used as the input parameter of the simulation. The maximum electric field strength inside the chassis is 227.9 V/m, as shown in Figure 7, the shielding effectiveness calculation result in the time domain is 46.8 dB; the shielding effectiveness calculation in the frequency domain is shown in Figure 8, SE≥41.6 dB(10kHZ~100MHz). From the simulation results, it is concluded that the electromagnetic shielding effectiveness of the nickel-plated carbon fiber and nickel mesh reinforced composite chassis has met the protection requirements. Therefore, the protection enhancement design method of nickel-plated carbon fiber cloth and nickel metal mesh is finally adopted.

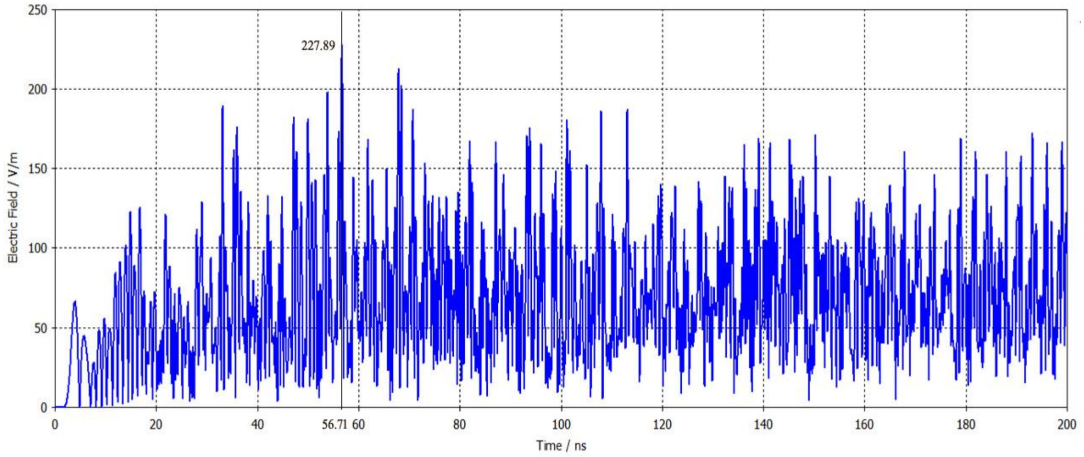


fig.7 Electric field intensity inside ordinary of the nickel plated carbon fiber and nickel screen in carbon fiber case (time domain)

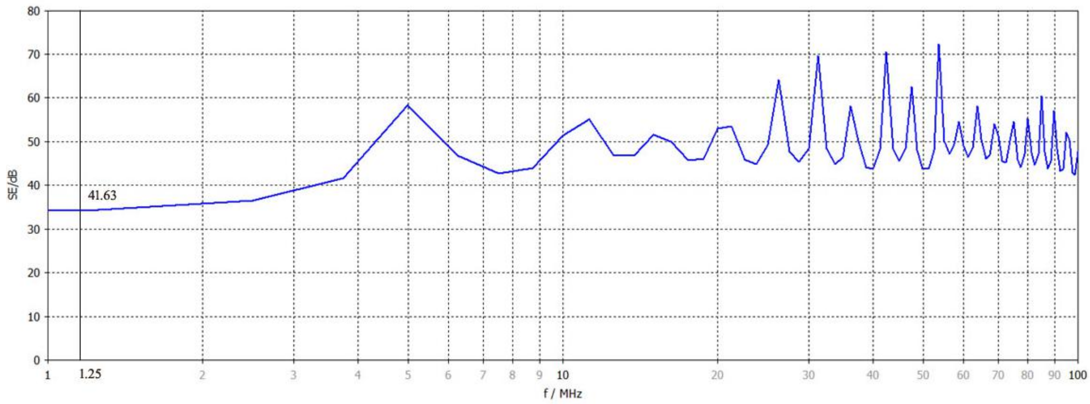


Fig. 8 Shielding effectiveness of the nickel-plated carbon fiber and nickel screen in carbon fiber case

1.4 Chassis electromagnetic pulse protection structure

Under the condition of ensuring the material's adequate electromagnetic pulse protection performance, the damage to the internal electronic equipment of the equipment by HEMP is mainly through the cable coupling and the gap coupling of the equipment shell [7]. For the case of this article, the conductive overlap structure of the case cover and the case itself is an important part to ensure the electromagnetic pulse protection effect of the case. Therefore, in order to obtain a cabinet with good electromagnetic shielding effectiveness, it is necessary to ensure the conductivity continuity inside the entire cabinet structure. The design in Chapter 1 guarantees the conductivity of the carbon fiber composite material. In this chapter, the cover plate and the cabinet box are used. The electric lap structure at the seam of the body part realizes the electromagnetic protection function of the whole box body.

As shown in Figure 9, the top plate of the chassis is made of carbon fiber, nickel-plated carbon fiber and shielded metal mesh; the box body material is made of carbon fiber, nickel-plated carbon fiber and shielded metal mesh; the edge of the chassis cover is machined to seal the groove, The groove depth is subject to the shielding metal mesh, and a conductive sealing strip is arranged in the groove (the sealing strip can be a conductive rubber sealing strip, a conductive wire mesh sealing strip, a metal spiral sealing strip, etc. but not limited to the above materials).

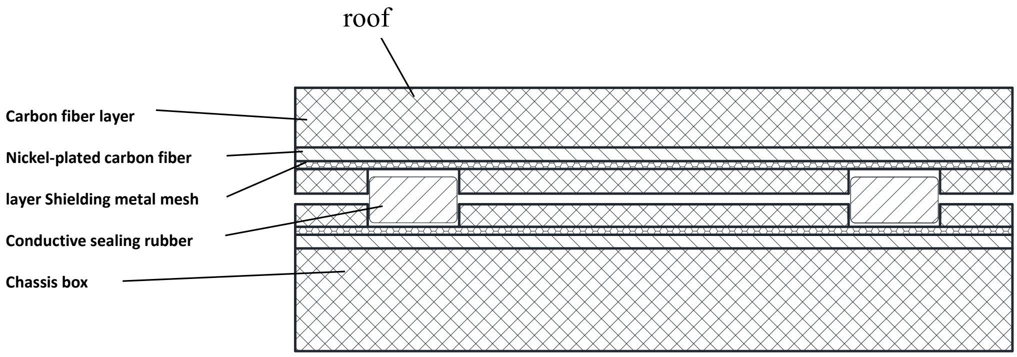


Fig. 9 Structure of sealing and electric lap of the machine box

2. Carbon fiber composite material chassis manufacturing

2.1 Forming process

The main structure of the chassis is a six-sided thin-walled facade structure, and there are multiple vertical facade structures. When designing the molding process, it is necessary to consider the molding pressure transmission of the vertical surface during integral molding. In the traditional molding process, if a greater partial pressure is achieved on the vertical mold parting surface during molding, a certain slope and greater equipment pressure need to be set. Therefore, the product shape, equipment, and molding die are all affected. There are higher requirements. Therefore, when the molding process is selected, the compression molding process or the autoclave molding process can be selected, and the compression molding requires a more complicated demolding mechanism. The molding process proposed in the plan is the autoclave molding process. The autoclave molding method is mainly to use the high-temperature compressed gas inside the autoclave to generate pressure to heat and press the composite material blank to complete the solidification molding method [8]. Due to the relatively simple structure of the upper and lower cover plates, in order to ensure the apparent quality, compression molding is used.

2.2 Molding mold design

Figure 10 shows the schematic diagram of the structure of the chassis box mold. Under the premise of ensuring the outline size, in order to facilitate quick demolding, the main mold is composed of splicing. Pre-embed the nut where the connection is needed, and leave the corresponding hole in the main body of the mold to locate the pre-embedded nut.

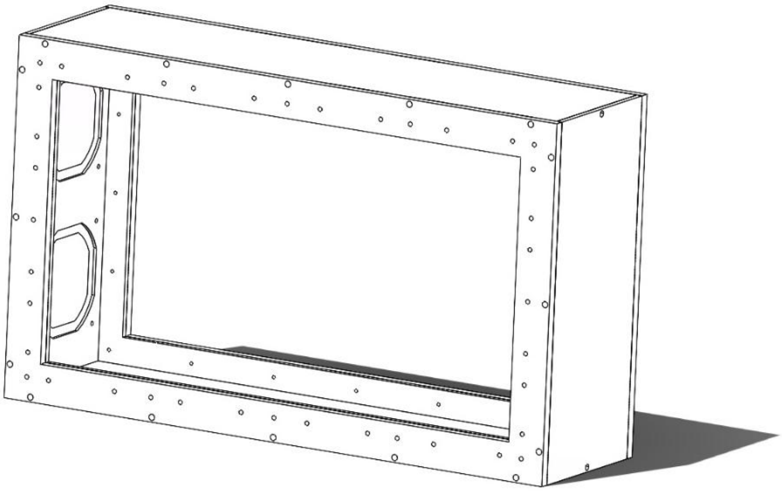


Fig.10 Schematic diagram of mold structure of the carbon fiber composite cabinet body

2.3 Lay-up design Lay-up design

Laying design is the key to ensuring the mechanical and electromagnetic properties of the cabinet. In the article, the carbon fiber composite material chassis adds a layer structure parallel to the cutting direction at the edge part of the chassis. While protecting performance, the resin is fully infiltrated at the same time.

The basic layup scheme is: carbon fiber prepreg-nickel-plated carbon fiber cloth-carbon fiber prepreg-stretched metal mesh-carbon fiber prepreg. According to the thickness of the product parts, different designs are made for the order, number of layers, materials, laps, etc. of the layup.

2.4 Curing and molding

The box body is molded by autoclave molding process, and the curing and molding parameters are: curing temperature 135 ℃, curing time 2 h, vacuum degree -90 kPa, curing pressure 0.6 MPa.

3. Carbon fiber composite material chassis performance test.

3.1 Test method

The carbon fiber chassis nuclear electromagnetic pulse protection performance test is carried out using a bounded wave simulator, and a large bounded wave simulator is used to generate HEMP electromagnetic pulses. The bounded wave HEMP simulator is a simulation device for electromagnetic pulse testing of short cables or small electronic equipment. The length between the parallel plates of the simulator is 5 m, the width of the upper plate is 2 m, the width of the lower plate is 3 m, the distance between the upper and lower plates is 1 m, the field strength varies from 10 to 60 kV/m, which can simulate IEC61000-2- 9. The HEMP environment defined by different standards such as the Bell Laboratory, and the physical object of the bounded wave simulator is shown in Figure 11.

Fig.11 Bounded wave simulator

The SGE2G D-Dot electric field probe was used to measure the free field (unshielded) peak E0 in the working space of the bounded wave simulator. In this experiment, the typical HEMP waveform generated by the simulator is shown in Figure 12, the pulse front is about 2.8 ns, The half-width is about 24 ns, and the amplitude is 41.7 kV/m.

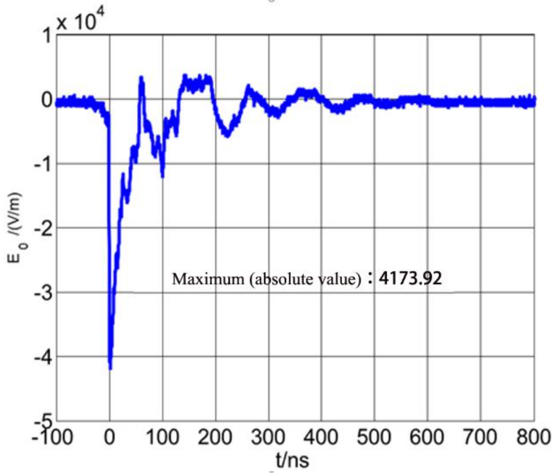


Fig.12 Simulator typical waveform

Place the tested case in the working space of a large bounded wave simulator. Use the fiber optic electric field probe to measure the pulsed electric field. When keeping the pulsed electric field in the test equipment compartment and the free field, the voltage of the high-voltage pulse source of the bounded wave simulator is equal, and the peak value of the pulsed electric field in the chassis is E_n. The test diagram of $E_1 \sim E_5$ is shown in Figure 13.

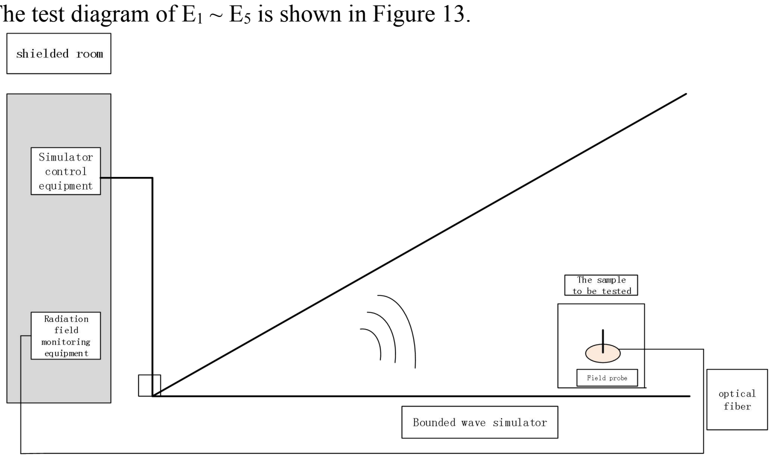
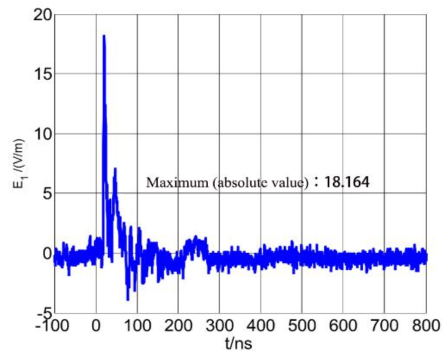


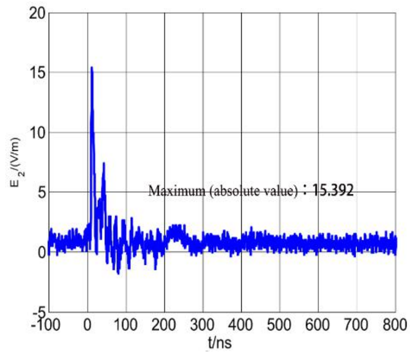
Fig.13 Schematic diagram of HEMP test

The typical HEMP pulsed electric field measurement waveform measured in the case is shown in Figure 14. The HEMP electromagnetic pulse electric field shielding effectiveness of the chassis is [9]:

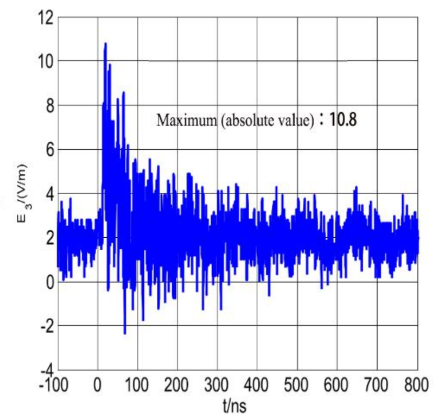
$$SE_n = 20\log_{10}\left(\frac{|E_n|}{|E_0|}\right) \qquad (5)$$

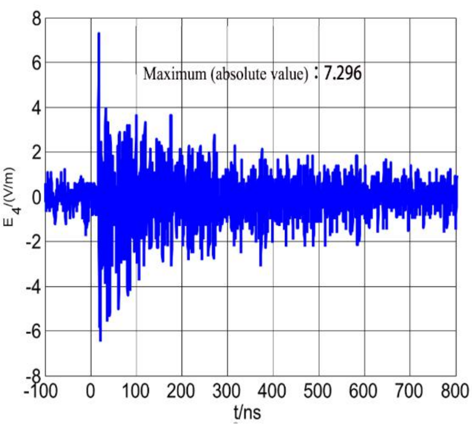
Where: SE_n is the nuclear electromagnetic pulse shielding effectiveness obtained from the nth test of the chassis; E_n is the field component measured inside the chassis.



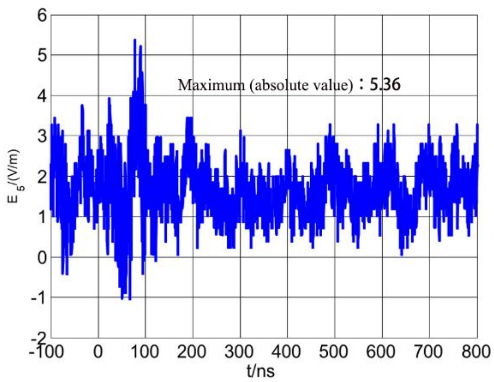


(a) 1st time **(b) 2nd time**





(c) 3rd time **(d) 4th time**



(e) 5th time

Fig.14 The waveform of HEMP pulse electric field measured in 1st - 5th time

3.2 Test results

Table 2 shows the electromagnetic pulse shielding effectiveness results of the carbon fiber composite chassis under the HEMP bounded wave simulator [10]. It can be seen from Table 2 that the shielding effectiveness of the composite case under the nuclear electromagnetic pulse reaches more than 65 dB. From the analysis of shielding theory [11], the protection frequency band of the test case is medium and low frequency (100 kHz~100 MHz). When the electromagnetic enhancement material is installed to ensure the skin depth of the material, the electromagnetic pulse protection effect mainly depends on the reflection loss R, and the reflection loss has a great relationship with the wave impedance of electromagnetic waves. The shielding effectiveness of electric field waves is much higher than that of magnetic field waves [12]. Therefore, in the design of nuclear electromagnetic pulse shielding, the case adopts electromagnetic enhancement materials with excellent conductivity and permeability. The equivalent electric and magnetic field wave protection under electromagnetic pulse is effective. At the same time, the integrated design of the case makes the case free of splicing gaps other than the cover, which is very beneficial to the improvement of shielding effectiveness.

Table 2 HEMP shielding effectiveness test data of the carbon fiber composite cabinet

n	SE_n/dB
1	67.01
2	68.66
3	71.73
4	75.14
5	77.82

4. Conclusion

This article uses nickel-plated carbon fiber and magnetic stretched mesh as the electromagnetic reinforcement of carbon fiber composite materials; optimizes the traditional spliced chassis structure, and uses the autoclave process to manufacture the integrated carbon fiber composite chassis. The test structure shows that the protection performance of the case under nuclear electromagnetic pulse (HEMP) exceeds 65 dB. The research in this article provides a reference for the application of carbon fiber composite materials in weight reduction and electromagnetic pulse protection in complex electromagnetic environments, and provides a reference for the future design of similar products to give play to the advantages of composite materials and structures.

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