Research on Reliability Design of Electromagnetic Compatibility System in Power Supply System

Ming Gao [1], Zhenhua Lu [1], Changjun Rong [1], Ying Li [1], XiaoLei Fan [1]

[1] High-tech Institute, Fan Gong-ting South Street on the 12th, Qingzhou,Shandong, China

Abstract. Electromagnetic compatibility (EMC) is an important factor in power system design. In modern electronic equipment, the reliability design of the power supply system is very important to ensure the stability of the equipment. Based on this, this paper mainly studies the electromagnetic compatibility and system reliability of the power system, and analyzes the electromagnetic interference sources in the power system and their adverse effects on the system. By optimizing the design of key components such as power line, filter and grounding system, an improved design scheme of power supply system is proposed. The experimental results show that the design can significantly improve the reliability of the power supply system, and effectively reduce the impact of electromagnetic interference on the equipment. This study provides an important reference for the electromagnetic compatibility and reliability design of power supply system, and has practical significance for improving the stability of electronic equipment.

Keywords: Electromagnetic compatibility design; Airborne power supply system; Safety; reliability.

1. Introduction

Electromagnetic compatibility (EMC) refers to the ability of electronic devices to work simultaneously in the same electrical environment without interfering with each other. Electromagnetic compatibility is very important in the power supply system, because the stability and reliability of the power supply system are directly related to the working effect and safety of the whole system. However, in practical applications, the power supply system is often subject to a variety of electromagnetic interference, such as electromagnetic radiation, electromagnetic induction, etc. These interferences may come from the external environment, such as lightning, wireless signals, etc., and may also come from the interference of other internal electronic equipment. Electromagnetic interference (EMI) can cause serious consequences such as instability of power supply system, damage of components, and even fire, which brings serious harm to the operation of the system. With the rapid development of more electric aircraft technology, the number of electrical equipment on aircraft has increased significantly, and the power supply system plays an important role in aircraft flight. The airborne power supply system is usually used in the AC-DC, DC-DC, DC-AC power supply conversion work inside the aircraft, which is composed of external power socket, emergency power supply, main power supply, secondary power supply and other links. However, due to the external environment, flight altitude and other factors, a variety of auxiliary devices are used in the airborne power system, such as airborne temperature control devices, airborne charging equipment, which virtually increases the complexity of the electromagnetic compatibility design of the airborne power system. Therefore, the staff should apply electromagnetic compatibility design in the early stage of power system design, comprehensively enhance the overall anti-interference ability of the power system, ensure the reliability of the system in research and development, and extend the service life of the system [1] .

2. Overview of Electromagnetic Compatibility Design

2.1 Overview of electromagnetic compatibility

Electromagnetic compatibility (EMC) refers to the ability of different electronic devices to coexist without functional obstacles to each other and without adverse effects on the surrounding environment. Electromagnetic compatibility (EMC) is the most important technical requirement in the design of modern electronic equipment and systems, which determines the interoperability between equipment and the reliability between equipment and the environment. The concept of electromagnetic compatibility originates from the problem of electromagnetic interference. In modern society, many electronic devices exist in a relatively narrow space at the same time, such as mobile phones, televisions, computers and so on. These equipments will emit electromagnetic radiation when they work, and they are vulnerable to electromagnetic radiation interference emitted by other equipment. If no effective measures are taken, they will produce a variety of functional disorders and system failures, and even pose a threat to personnel safety and equipment stability.

2.2 EMC design standards

In order to ensure that electronic equipment can be compatible with each other and work in harmony with the environment, a series of international standards for electromagnetic compatibility have been formulated. These standards are intended to regulate the level of electromagnetic radiation and the ability of equipment to resist interference so that the equipment can effectively coexist and adapt to the environment. The most important of these is the IEC series of 61000, in which the general rules and the measurements, specifications and test methods for electromagnetic compatibility are specified in detail. With regard to electromagnetic compatibility, IEC 61000 series standards mainly include the following aspects:

1.Electromagnetic radiation: specify the limits of electromagnetic radiation emitted by equipment under normal working conditions, as well as test and measurement methods.

2.Electromagnetic immunity: specify the immunity requirements and test methods when the equipment is subject to external electromagnetic interference, so as to ensure the normal operation of the equipment.

3.Coupling of ground and power circuit: specify the limit requirements and protective measures for electromagnetic interference transmitted through ground and power circuit to reduce interference.

4.Electrostatic discharge: specify the electrostatic discharge capability requirements and test methods of the equipment to ensure that the equipment can resist electrostatic interference.

In addition to IEC 61000 series standards, there are other international and national standards, such as CISPR series, EN series and so on. Together, these standards form a global framework for electromagnetic compatibility to ensure that equipment is compatible with each other on a global scale.

3. Key points of electromagnetic compatibility design for airborne power supply system

3.1 Shielding design

Shielding is the main method to cut off space radiation, which is composed of electric field radiation and magnetic field radiation. When designing the shielding body, it is directly related to the structure and material of the shielding body. The shielding effect of the shielding material is composed of reflection loss and absorption loss. The low-frequency magnetic field is the most difficult electromagnetic wave to shield. Therefore, the shielding material should be made of materials with high magnetic permeability and conductivity as far as possible to improve the absorption loss in an all-round way. However, it is worth noting that the material with high magnetic permeability has poor conductivity, which will reduce its reflection loss, so it is necessary to evenly coat a layer of material with high conductivity on the surface of the material to effectively solve the above problems. The structural design of the shield should have good grounding performance and continuous conductivity, while the vents, display windows and gaps on the chassis will affect the shielding effect, which is the main factor of electromagnetic leakage. Therefore, in order to avoid poor shielding performance of the system, conductive rubber is usually filled in the gap position to effectively solve the problem of poor contact points, thereby enhancing the shielding effect (as shown in Figure 1).

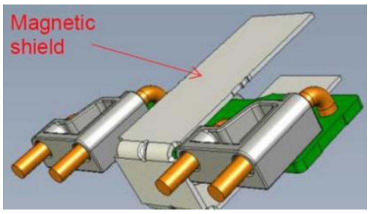

Fig. 1 Shielding Design

3.2 Filter design

In the power supply system, the filter is used to suppress unnecessary high-frequency interference in the power supply circuit to ensure the stability and reliability of the circuit. Filters commonly found in power systems include power line filters, input filters, and output filters. Power line filters are usually connected directly between the AC power supply and the equipment to prevent external high-frequency noise and interference from entering the equipment. The input filter is used to eliminate the high frequency interference signal generated by the equipment itself, so as to reduce the radiation interference to other equipment. The output filter is mainly used to filter out high-frequency noise and ripple at the output of the power supply to ensure that the current output by the device is stable and clean (as shown in Figure 2).

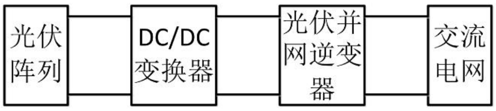

Fig. 2 Filter Design

In the filter design, it is necessary to select the appropriate type and specification of the filter to meet the EMC requirements of the equipment. Different equipment may have different requirements for EMC. When designing the filter, it is necessary to ensure that it has sufficient filtering effect, and reasonably arrange the filter components and circuits to minimize its interference with other components. Electromagnetic coupling between different components may cause interference signals to propagate in the system, so care should be taken in the filter layout to reduce the possibility of electromagnetic coupling. At the same time, when choosing the filter components, we should also consider their operating temperature range and reliability indicators to ensure that the filter can work properly in a variety of environments. In addition, a multistage filter structure is adopted to improve the performance of the filter, wherein the multistage filter structure is formed by cascading a plurality of filters, and each filter stage plays a role of filtering in a specific frequency range. This design provides better filtering and noise suppression, and reduces the impact of the filter on system performance [2] .

3.3 Grounding design

The main function of grounding design is to avoid electromagnetic interference and electrostatic interference. Static electricity and interference energy can be properly leaked through grounding. At present, common grounding methods mainly include mixed grounding, multi-point grounding, single-point grounding and other types:

Single point grounding. It refers to connecting all ground wires with the common ground wire. The single point node is divided into series single point grounding and parallel single point grounding, in which the series single point grounding structure is relatively simple, and the coupling interference between different grounding lines is easy to occur. Although parallel single-point grounding can effectively solve the above problems, it needs to use a large number of leads and the grounding content is too complex. Therefore, the staff should combine the parallel grounding and series grounding, classify the grounding circuits scientifically, put the grounding circuits which are easy to cause interference problems in different groups, apply series single-point grounding to the circuits in the group, connect the circuits between the groups through parallel single-point grounding, form a complete hybrid circuit, and effectively reduce the interference between the circuits (as shown in Figure 3).

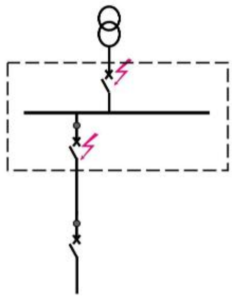
Fig. 3 Short-circuit current

（2）Multipoint grounding. This kind of grounding method is usually used in high frequency circuits and digital circuits. When the frequency is lower than 1MHZ, the single-point node shall be used; in the range of 1-10 MHZ, if the longest grounding wire is lower than 1/20 of the wavelength, the single-point grounding can be used, otherwise, the multi-point grounding shall be used; When it exceeds 10 MHZ, multi-point grounding shall be applied.

（3）0Mixed grounding. The grounding structures used at different frequencies have strong differences, so single-point grounding should be used when the frequency is low, and multi-point grounding should be used when the frequency is high. Hybrid grounding [3] can be used when multiple devices are installed.

4. Practical cases

4.1 Engineering case

In this paper, the reliability design of the airborne charging system of an airborne power system is taken as the main research object, and the application of the reliability design of the electromagnetic compatibility system in the design of the airborne power system is analyzed. The charger system is designed with 20GNC15 nickel-cadmium aviation battery pack. After completing the flight mission, the battery pack should be removed in time and transmitted to the charging station for charging and discharging. The whole operation process takes 6-8 hours, which seriously shortens the number of aircraft flights. In view of this kind of situation, this article designs the airborne charge control device, which can carry on the second charge to the storage battery group in a short time, the charge efficiency is 92%, and does not need to dismantle the battery from the airplane, has the strong self-examination function, after achieves the electromagnetic anticipated value, automatically carries on the floating charge. In addition, with the communication function, the device can be monitored through the flight control box. The above airborne charging system mainly includes signal indicator, self-check button, temperature sensor, switching power supply and other links. The number of components is large, the circuit is too complex, the wiring difficulty coefficient is high, and the electromagnetic compatibility design is difficult. In the design, the electromagnetic compatibility of the system should be considered comprehensively, and reasonable measures should be taken to solve the electromagnetic compatibility problem [4] .

4.2 Mechanical design

In the design of the shell, the aviation aluminum alloy is used, which has the characteristics of strong plasticity, good thermal stability and high rigidity. The enclosure is made of 5mm aluminum with fully enclosed structure, which can not only effectively avoid the impact of external electromagnetic environment on the product, but also avoid the radiation interference [5] from the working circuit to the outside world. At present, common metal material σr And μr As shown in the following table:

Table 1 Common Metal Materials σr And μr Value

Type of material	σr	μr
Stainless steel	0.02	200
Aluminium	0.61	1

An aluminum shielding case shall be installed at a distance of 100 cm from the enclosure, the thickness of the case shall be controlled at 0.5 cm, the frequency of the radiation source shall be 30 KHZ, and the shielding effectiveness shall be calculated as:

Because it is a typical near field, the interference field intensity is mainly based on the magnetic field, and the chassis is made of aluminum. The shielding effectiveness is as follows:

$$SE = A + R + B$$

The absorption loss is:

$$A = 0.131t\sqrt{f\mu_r\sigma_r}$$

The reflection loss is:

$$R = 74.6 - 10lg(\mu_r/f\sigma_r r^2)$$

The multiple reflection correction factor is:

$$B = 20lg[1-(Z_S - Z_W/Z_S + Z_W)^2 \bullet 10^{-0.1A}(cos0.23A - jsin0.23A)]$$

The metal wave impedance is:

$$|ZS| = 6.39\times10^{-7}\ f\mu_r/\sigma_r$$

The air wave impedance is:

$$Z_W = 2\pi\pi f_0 r$$

$$\mu_0 = 4\pi\times10^{-7} H/m$$

In the above formula, t represents the thickness of the chassis; f represents the frequency of the radiation source; R represents the distance from the interference source to the outer wall of the chassis; σr Represents the conductivity of the shield material relative to copper; μr Denotes the permeability of the shield material relative to copper.Import the data into formula to obtain $SE = A + R + B = 60.86$. It is more than 60, which meets the design requirements of military equipment for shielding.

The convex surface and concave surface between the cover plate and the case are chiseled by the milling cutter, and the groove is filled with conductive rubber to reduce the contact gap. The electromagnetic sealing gasket is added at the contact gap of the assembly surface to enhance the electromagnetic sealing of the gap and improve the shielding effect of the case [6] .

XGG22 external electrical connector shall be applied, and conductive gasket shall be set.

4.3 Circuit aspects

A power supply filter is added in the circuit to reduce power supply radiation interference. The application of enhanced differential mode AC single-phase filter can transmit 400HZ low-frequency power without attenuation, attenuate the disturbance signal transmitted from the power line, and has a high suppression effect on pulse and continuous interference [7] . At the same time, the transient suppression diode is used, and its response speed is fast and can reach nanosecond level. When the transient pulse current passes through the transient suppression diode, the voltage of the two electrodes increases from the rated voltage to the breakdown voltage, the whole diode is broken down, the high impedance in the middle of the diode is converted into low impedance, the surge pulse power is effectively released, the high impedance between the two electrodes is controlled at an expected value, and the electronic circuit element is effectively protected from being influenced by the surge pulse factor. The design parameters of the filter are the key points to suppress electromagnetic interference. It is necessary to strengthen the requirements for its installation structure, shorten the lead as much as possible, and lead the lead with shielding wire, which can effectively prevent the electromagnetic interference from the external lead and avoid the internal electromagnetic radiation, thus affecting the external circuit (as shown in Figure 4).

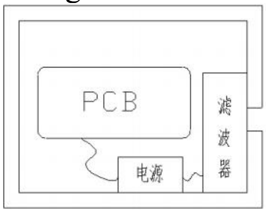

Fig. 4 Installation of Power Filter

A shielding magnetic ring is arranged on a power supply input line, and the shielding magnetic ring is made of ferrite and can provide impedance at a high frequency band and bring zero impedance at other frequency bands, thereby ensuring that useful signals pass through normally and effectively limiting the passing of high-frequency interference signals;Relay contact, diode and RC network are combined with each other, and varistor is used to absorb contact jitter, thus producing transient interference of voltage spike.The power output line and input line shall be silver-plated shielded conductor, and the shielding layer shall be single-ended grounded to separate the power ground from the signal, so as to avoid the serious impact of power radiation on the working signal and effectively limit the common-mode interference [8] of the circuit.

5. Practice test

In order to verify the correctness and reliability of the equipment test results, the working environment of the test device is changed to compare the results.

The verification test is carried out at different times on the same day, and the test results are as follows: the reference values of the first four tests are 2.9979V, 3.0094V, 3.0129V and 3.0143V respectively. It can be seen from the figure below that the green diamond line represents the established standard law function, and the vacuum values 1-4 of the arc extinguish chamber represent the data measured at 9:00 am, 11:00 am, 3:00 pm and 8:00 pm respectively. The fitting curves of the four test results are basically consistent with the standard curve. The main error distribution is when the signal voltage difference is greater than 0. 1V, at this time, the vacuum degree in the arc extinguish chamber has reached 3Pa or above, and partial discharge has occurred in the arc extinguish chamber, which will interfere with the collected signal and cause the instability of the collected value. However, for the detection of vacuum degree, when the vacuum degree is greater than 3 Pa, the vacuum circuit breaker has been seriously degraded and can not be used any more.

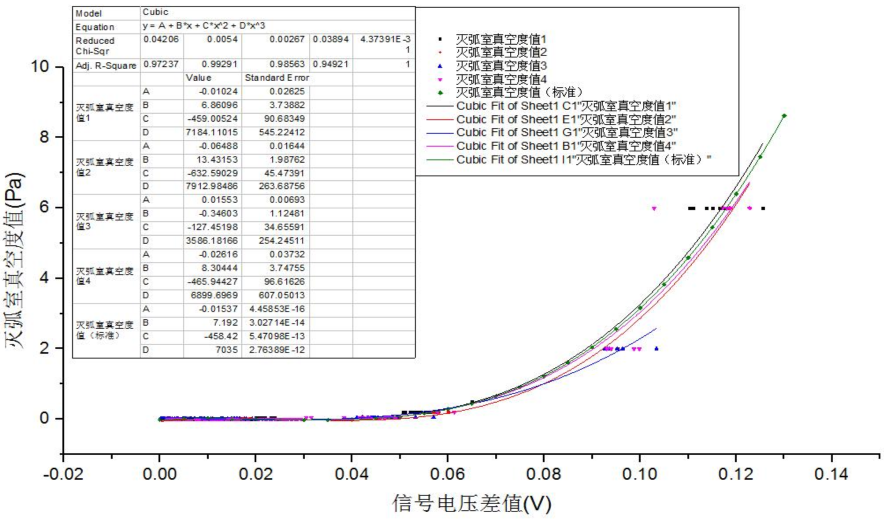

Fig. 5 Experimental results under different time conditions

Verification tests are conducted under different weather conditions on the same day, and the test results are as follows: the reference values of the first four tests are respectively 2.9902V, 3.0084V, 3.0024V and 3.0112V.

The results of the test are shown in the figure below. The green diamond line represents the established standard law function. Vacuum values 1 to 4 of the arc-extinguishing chamber respectively represent data measured at a temperature of 20 deg C/a humidity of 40%, a temperature of 24 deg C/a humidity of 50% on a sunny day, and a temperature of 10 deg C/a humidity of 60%, and a temperature of 8 deg C/a humidity of 70% on a cloudy day. The fitting curve of the test results obtained from the four tests is basically consistent with the standard curve, and the main error distribution is also after the signal voltage difference is greater than 0.1V. According to the test (1), the test results can meet the requirements (as shown in Figure 2).

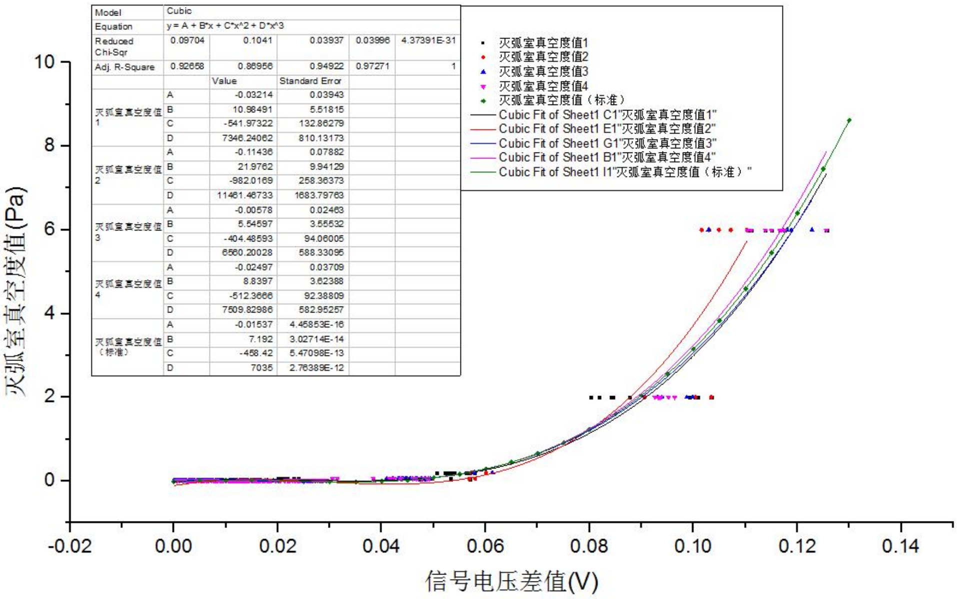

Fig. 6 Experimental results under different weather conditions

6. Conclusion

To sum up, the power supply system plays an important role in modern society, and its stable and reliable work is very important for all walks of life. But in the process of power supply system design, we are often faced with electromagnetic compatibility (EMC) problems, which may lead to system failure and interference. Therefore, in order to ensure the stable operation of the power supply system, it is necessary to design and study the reliability of the electromagnetic compatibility system:

Understand the concepts and principles of electromagnetic compatibility. Electromagnetic compatibility (EMC) refers to the ability of different electronic devices to coordinate and coexist without interference in the electromagnetic environment. In a power supply system, rapid changes in current and voltage generate electromagnetic radiation and can cause interference with other equipment. Therefore, a series of measures should be taken to reduce the electromagnetic radiation and improve the anti-interference ability of the system.

Pay attention to the wiring and grounding design of the power system. Good wiring and grounding design can reduce electromagnetic radiation and interference. First of all, we should avoid sharing the same path between the power line and the signal line, because the mutual interference between them will cause electromagnetic compatibility problems. In addition, we should ensure that there is enough distance between the power line and the signal line to reduce cross interference.

References

[1] YANG Huarong, HU Shuanghu, WANG Hongguang, et al.Discussion on electromagnetic compatibility test of ship system in land joint commissioning [J].Communication Power Supply Technology, 2021, 38 (16): 89-92.

[2] LI Wan-Research on Interference Avoidance Measures of Ship Communication System Based on Electromagnetic Compatibility Interference Factors [J].Science and Informatization, 2021 (18): 14,16.

[3] LIU Ruihua, LI Yin, ZOU Ling.Simulation and analysis of electromagnetic compatibility between Cn-band satellite navigation signal and microwave landing system [J].Signal Processing, 2022,38 (2): 384-394.

[4] LIU Yan, CHen Ruixun, sun Gong.A system-level electromagnetic compatibility analysis method for spacecraft based on single-machine EMC test results [J].Spacecraft Environmental Engineering, 2021, 38 (4): 395-400.

[5] Sun Gong, Wang Wei, Liang Ke, et al.Analysis method of electromagnetic compatibility of RF system between manned spacecraft and satellite [J].Chinese Journal of Space Science and Technology, 2020,40 (2): 49-53.

[6] Jin Qi. Research on Electromagnetic Compatibility Simulation Analysis and Optimal Wiring of Electronic System Interconnection Cable [D]. Jiangsu: Nanjing University of Science and Technology, 2022.

[7] Ai Xiaohua, Zhou Mei, Jiang Haitao, et al.Design and test analysis of a new T-BOX EMC test system [J].Safety and EMC, 2021 (4): 53-57.

[8] Beijing University of Aeronautics and Astronautics. A decomposition method of system electromagnetic compatibility index of 10 kHz-18 GHz electric field radiation emission: CN 202111004076.8 [P]. 2021-11-