Research and Optimization of Inverter Electromagnetic Compatibility System

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Abstract. Modern electrical and electronic equipment has increasingly higher requirements on the reliability of its performance, especially the electromagnetic compatibility of the equipment. According to the working environment of the inverter cabinet and the design requirements of the cabinet, this paper widely combines the practical experience of the project, mainly from the aspects of gaps, ventilation holes, sealing, electrical layout, etc., to put forward measures to improve the electromagnetic compatibility performance of the cabinet structure design. It achieves the purpose of meeting the requirements of GJB151A, and effectively improves the electromagnetic compatibility of the inverter.

1. Introduction
The development of science and technology promotes the rapid and extensive application of high-tech achievements in the field of electrical and electronic equipment, especially the popularization of intelligent computer, which makes electrical and electronic equipment more and more intelligent and complicated[1]. As the protective shell of electrical and electronic equipment, the design quality of the cabinet directly affects the electromagnetic compatibility performance of the whole machine. Therefore, the design of the cabinet is bound to reach all the technical indexes to ensure the normal operation of the internal equipment in the complex electromagnetic environment. Therefore, the electromagnetic compatibility of the structure should be considered in the analysis and design stage, which should not only ensure the normal operation of the system in the electromagnetic environment, but also reduce the electromagnetic interference of the system to other equipment. Failure in any link will lead to interference problems when new products are put into use, so that electromagnetic compatibility is very important in the structural design of electrical and electronic equipment.

2. Electromagnetic environment of frequency converter
Any electrical and electronic equipment all acts on the specific environment under the coupling effect of various complex factors. Under the action of certain environmental factors, if there is no effective defense and protection measures, the performance of electronic components or the whole system will be greatly reduced or even invalid.

The installation space of high-speed EMU, marine frequency converter and other electrical and electronic equipment is relatively crowded, and the equipment layout is also relatively dense and crowded. In addition, the strong electric equipment, communication and navigation equipment are frequently used, and the start, stop and operation process of the equipment is very easy to produce electromagnetic interference, so the electromagnetic pollution is also relatively serious, in other words,
itself forms a closed multi-electric field interference source and multi-magnetic field interference source, and is coupled to the interfered source by electrostatic field, alternating electromagnetic field or transmission line. Therefore, we should pay special attention to this problem in the design of electrical equipment, optimize the cabinet structure of electrical equipment to obtain better electromagnetic compatibility so as to solve its interference problem, and avoid wasting a lot of manpower and material resources in debugging, or even waste all the previous work.

3. Electromagnetic compatibility theory foundation and design standard

3.1. Theoretical basis
Electromagnetic compatibility includes two major aspects: ① Compatibility between systems or devices of different kinds; ② Compatibility between a system or device and the natural electromagnetic environment. All kinds of electromagnetic interference are composed of three main elements, including interference source, coupling path (transmission medium) and sensitive equipment (receiving unit). If we want to suppress the influence of electromagnetic interference, we must start from these three aspects, make clear the interference source, coupling path and sensitive equipment, and then carry out the design. Figure 1 shows the logical relationship between the three elements.

Figure 1. Three elements of logical topological relationship of electromagnetic interference

Electromagnetic compatibility technology is mainly divided into two categories: ① From the point of view of the system itself, it should be as far as possible to choose the equipment and electrical components with the least mutual interference, and according to the demand for a reasonable electrical structure layout; ② through the comprehensive use of filtering, grounding and shielding and other technical means to effectively block and suppress the role of interference. Specific to the structural design of the cabinet, the container is mainly made of conductive materials, and the equipment and circuits that need to be isolated are all encapsulated to form a shielding cabinet to shield the electromagnetic field.

3.2. Design criteria
Frequency converter electromagnetic compatibility structure design basis GJB151A-1997 "Electromagnetic Emission and Sensitivity of Military Equipment and Subsystems". The standard provides specific requirements for electromagnetic emission and sensitivity characteristics, and specifies test procedures, test methods and acceptance criteria in GJB152A-97.

4. Electromagnetic compatibility structure design
According to the actual demand of the cabinet of frequency converter, the outer side is mainly composed of input and output power lines, signal lines and control lines, etc., and the outer interface is reserved for input and output; Power module unit is set inside the cabinet, and cooling ventilation holes are reserved outside the cabinet. Electrical components such as display screen and operation button are arranged on the outside of the cabinet; The cabinet as a whole is made up of many bending plates. Comprehensive factors lead to the existence of multiple cracks on the outside of the cabinet, and the connection of each sub-component is difficult to meet the requirement of complete sealing. The existing gaps and holes form a conductive discontinuity on the cabinet, thus causing electromagnetic leakage. In order to ensure the conductive continuity of the frequency converter cabinet, the ideal shielding cabinet should be a complete and continuous conductive body\(^2\). Therefore, how to suppress the leakage of electromagnetic energy from the above factors has become the key to electromagnetic compatibility.
4.1. Gap shielding
In the cabinet of frequency converter, there are often some joints made up of movable panels, in which the metal members cannot fully contact, but can only achieve point contact, which will form a hole array, called gap. At present, it mainly reduces the impedance of cabinet gaps to the greatest extent so as to achieve the goal of reducing cabinet gap leakage\[^3\]. The main factors affecting the impedance of the gap include: the material of the contact surface on both sides of the gap, the area or number of contact surface on both sides of the gap, the smooth roughness of the contact surface on both sides of the gap and the pressure on the contact surface on both sides of the gap. In combination with the characteristics of inverter products, the following methods can be used to reduce the gap impedance:

1. Increase gap depth (matching width of box and cover plate).
2. The frame of the cabinet adopts welding process. Full welding is required at the joint to ensure good sealing of the whole frame.
3. Add conductive pad at the contact surface or reduce the roughness value of the contact surface\[^4\], that is, reduce the gap length. The former is an economical and common method to install conductive pad on the contact surface, which can not only reduce the gap leakage, but also does not require the contact surface to have high machining accuracy.
4. Conductive coating is added to the contact surface to strengthen the electrical contact between the two sides of the contact surface. It is especially suitable for the edge contact structure of bolt connection and rivet connection. Because of the larger surface roughness of plate edge, the contact surface is in the state of point contact, while the conductive coating is characterized by fluid state. It can fully seal the gap, increase the contact area and improve the electrical contact of the contact surface. If the surface of the joint is too rough and the pores are large, the pores should be filled with conductive interstitial material first. The conductive interstitial material has the consistency of putty and can be inserted as if scraping primer. This coating can also be used to reduce corrosion on joints that are prone to corrosion.
5. When there is no conductive gasket on the contact surface, the number of bolts and rivets should be increased as much as possible to make the spacing as narrow as possible under the premise of meeting the strength and stiffness of the cabinet\[^5\]. The gap length of the contact surface can be reduced as far as possible.

4.2. Shielding of cooling vents
In order to meet the demand of ventilation and heat dissipation of power module inside the inverter cabinet, special ventilation holes should be added on the outside of the cabinet, and electromagnetic shielding devices should be added on the position of ventilation holes. On the basis of ensuring that the ventilation performance is satisfied, shielding ventilation components with high shielding performance are selected. The specific measures are as follows.

1. The outer vent of the cabinet is equipped with wire mesh. According to the structure characteristics and installation form of metal mesh, it can be divided into two categories. One is the welding process, which can effectively solve the problem of electrical contact between the wire mesh and the cabinet. However, because the wire mesh can be completely fixed by this process and cannot be replaced quickly, the later maintenance is poor, so this kind of process method is seldom used in the actual use. Another kind is the annular pressure ring through the fastening screw wire mesh installed on the shield of the vent, before the installation, should be with insulation layer, oxide layer and on the surface of the insulating material such as oil durities, and install a sufficient number of screw in short distance to get continuous contact, this way as long as handled well on the structure and process can make the metal net and get good electrical contact between shield, so more widely.
2. Use perforated metal plates as ventilation holes. It is an effective way to improve the shielding effectiveness by replacing the large-diameter ventilation holes with many small holes. Compared with the installation of metal mesh, this method can make the shielding body stable, because it does not have the problem of resistance instability caused by the contact of mesh intersections inherent in metal woven mesh. This method can be used to directly open many small holes in the shielding body, or it
can be made into perforated metal plate and installed in the ventilation hole of the shielding body separately. Directly opening small-diameter ventilation holes in the shielding wall has the advantages of simple structure, simple technology and low cost, so it is widely used in practice.

(3) Use cut-off waveguide ventilation window as ventilation hole. The first two schemes of wire mesh and perforated metal plate as ventilation holes are more suitable for the shielding effectiveness under low frequency, but the shielding effectiveness is not ideal under high frequency, especially when the aperture size of the ventilation hole is comparable to the electromagnetic wave wavelength, the shielding effectiveness of the ventilation hole will be significantly reduced. At higher frequencies, cut-off waveguide ventilator\(^\text{[6]}\), such as honeycomb waveguide ventilator, can be used to obtain high shielding performance and good ventilation. In the design, both electromagnetic shielding and heat dissipation should be taken into account. Compared with wire mesh and perforated metal plate, it has the following advantages: wide working frequency band, high shielding performance even in microwave frequency band; Low resistance to air, less loss of wind pressure; High mechanical strength, firm, not easy to deformation, strong mechanical impact resistance; The stainless steel belt is processed by special technology and is hexagonal honeycomb shape with large ventilation. Its specific structure is shown in Figure 2 and Figure 3.

\begin{figure}[h]
\centering
\includegraphics[width=0.45\textwidth]{figure2.png}
\caption{Shielding structure design of heat sink vent}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.45\textwidth]{figure3.png}
\caption{Honeycomb waveguide vent plate structure}
\end{figure}

4.3. Shield indicator light and button switch

Generally, electronic equipment can be regarded as non-solid shielding due to the installation of various leakage devices, which will leak electromagnetic energy and lead to discontinuity in the electrical equipment. In the design of the inverter cabinet, a special shielding cover\(^\text{[7]}\) is set in the interior to isolate and close the indicator light, button switches and other devices, and the combination surface with the cabinet is electrophoted with blue and white zinc to reduce the gap and improve the electrical contact, so as to realize the continuity of the cabinet's electrical.

4.4. Screen shielding

The display of frequency converter is the main source of electromagnetic leakage, so it is very important to deal with the electromagnetic shielding of the display. The original design is to connect the display to the cabinet as a whole, and maintain electrical continuity. If the cathode-ray tube shielding cover is made of ferromagnetic material, electromagnetic shielding can be realized effectively, so that the displayed image is not affected by the stray magnetic field around it. For the terminal display of the information processing equipment, it is necessary to prevent the information from leaking to the outside through the opening of the display screen. Therefore, it is far from enough to adopt the above shielding measures, and corresponding measures must be taken to shield the display screen. The measures taken must ensure that the shielding layer has a certain degree of light transmission and does not affect the screen observation. There are two common methods:

(1) The screen is covered with conductive glass or plastic, so that the conductive layer covering the conductive material has continuous electrical contact with the cabinet. This method is more effective for shielding electric field and plane wave field, but has little shielding effect on magnetic field.
(2) Screen covered with wire mesh or conductive glass and wire mesh composite layer. It is required that the wire mesh does not affect the observation. In order to improve the shielding effectiveness, it is better to connect the intersections through welding. The metal mesh and conductive glass composite layer can not only shield the magnetic field, but also the electric field and plane wave field.

4.5. Cabinet door seal design
The connection between the cabinet door and the cabinet body is made of finger-shaped reed made of beryllium copper alloy with high electrical conductivity, abrasion resistance and corrosion resistance[8]. The finger-shaped reed is fixed on the side of the cabinet through its own barbs. The contact surface of the cabinet is electroplated with blue and white zinc without spraying paint, so as to form a conductive body and ensure good sealing and electromagnetic shielding performance of the cabinet, as shown in Figure 4.

![Figure 4. Partial sectional view of the cabinet door seal](image)

4.6. The layout design
Inverter limited space on the high pressure high-power high-frequency interference source equipment, and has a lot of high sensitivity are susceptible to interference of sensitive equipment, the overall layout, should avoid interference sources and sensitive equipment too close, very serious interference sources must be far away from sensitive sensor[9], and USES the input and output isolation on the space, the principle of heavy current and weak current isolation, such as input on the left side of the input and output on the right way is used in the main electrical, control electric in the box body upper, lower high voltage is located in the enclosure, the middle through the metal plate isolation block.

4.7. Cable and filter processing
In order to reduce the conductive transmission of the filter, the input power supply of the device is usually EMI filter in series[10], and the filter housing must form a continuous conductor with the case housing. The smaller the contact resistance, the better. This requires that the case housing in contact with the bottom surface of the filter should not be painted or painted with conductive paint. In addition, the input line is generally wired with a shielding layer, whose shielding layer shall ensure good contact with the chassis 360°. In order to prevent interference from the front-end cable of the filter, the distance between the filter and the cable entrance of the box body shall be guaranteed to be the shortest.

5. Electromagnetic compatibility test
The frequency converter equipment was tested in the relevant approved electromagnetic compatibility test room. The first designed box was used to test the 50cm of magnetic field radiation RE101. The test process and results are shown in Figure 5.
It can be seen from the test results that the equipment exceeds the standard seriously in the range of 1~10kHz and does not meet the requirements of GJB151A-1997. The optimized test results are shown in Figure 6 through the above optimization method.

According to the test results, the device also exceeded the standard seriously in the RE102 (10kHz~30MHz) test, which did not meet the requirements of GJB151A-1997. The optimized test results were shown in Figure 8 after passing the above optimization method.

After testing the remaining contents of RE102, through observation and analysis of the test results, it is shown that the improved box has better electromagnetic compatibility and meets the requirements of GJB151A[11].
6. Conclusion
Electromagnetic compatibility (EMC) is an important bottleneck in system design. The EMC performance directly affects the reliability and stability of the whole system equipment. Based on the frequency converter cabinet work environment and the specific design requirements of cabinet, according to enhance and improve the electromagnetic compatibility cabinet, combined with practical engineering experience, the gap, vents, light switch, screen shielding, cabinet door seal, cable and filter processing completed cabinets overall design and layout, and the related test, results show that the design improvement of frequency converter box has good electromagnetic compatibility, can be used in high speed emu, Marine and other electrical and electronics equipment.

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