Study on Magnetic Field Shielding Effectiveness of Slotted Conductor Plate

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Abstract. In this paper, the magnetic field shielding effectiveness of slotted conductor plate is tested. According to the dominant effect of magnetic shielding at different measuring points, the slotted conductor plate is divided into edge effect area, platform area and aperture leakage area, and the change law of magnetic field shielding effectiveness in different regions is analyzed. The magnetic field shielding effectiveness of slotted conductor plates at different frequencies is tested. The results show that the shielding effectiveness increases with the increase of frequency.

1. Introduction

With the development of power grid construction and the continuous improvement of transmission voltage level, the electromagnetic disturbance caused by power electronic equipment in power grid is becoming more and more serious. These electromagnetic disturbances may cause electromagnetic interference to the equipment, cause data loss in the process of data transmission, and cause damage to the equipment and system in serious cases[1].

Electromagnetic shielding is one of the most basic means of electromagnetic interference protection[2]. By adding a metal shell to the disturbance source or sensitive equipment, the electromagnetic emission level can be effectively reduced or the anti-jamming ability can be improved[3]. Based on the existing research, a complete shield can usually obtain a good shielding effect. However, due to the needs of ventilation and heat dissipation, the shield generally has openings and gaps, and the electromagnetic field is coupled to the adjacent space through these holes, which weakens the shielding effectiveness of the shield. Therefore, the research on the perforated shield has important engineering and social significance.

The main analysis methods of shielding effectiveness of perforated shield are numerical method, analytical method and experimental method. The finite-difference time-domain method is a numerical method based on Maxwell equation. In reference[4], the finite-difference time-domain method is used to study the electromagnetic field shielding effectiveness of different hole shapes and whether there is a wire through the cavity. In terms of analytical methods, Bethe keyhole theory is the most widely used. H. A. Bethe put forward the dipole theory in 1944 to study the effect of small holes on the shielding effectiveness of shields with the help of the equivalent hole stitching field of electric and magnetic dipoles[5]. Because the electromagnetic environment is complex and the simulation conditions are usually limited, the experiment has become an important means to study electromagnetic shielding. According to the principle of measuring material shielding effectiveness by shielding chamber method, an experimental scheme of power frequency magnetic field and power frequency electric field shielding
effectiveness testing system is proposed in reference[6]. In this paper, the magnetic field shielding effectiveness at different positions of the slotted conductor plate is tested experimentally, and the changing trend of shielding effectiveness is explained. The influence of frequency on the shielding efficiency of conductor plate is analyzed.

2. Experimental platform
The structure of the experimental platform is shown in figure 1, which consists of a square conductor plate with a side length of 1 m and a thickness of 1mm, with a relative permeability of 1 and a conductivity of $3.7 \times 10^7$S/m. A rectangular gap is opened in the center of the conductor plate with a length of 20cm and a width of 1mm. The upper surface of the conductor plate coincides with the $xoy$ plane, and the central axis of the plate coincides with the $x$-axis and $y$-axis respectively. The transmitting loop coincides with the axis of the receiving loop and is perpendicular to the $xoy$ plane. The vertical distances between the transmitting loop and the receiving loop to the conductor plate are $d_1$ and $d_2$ respectively. The radius of the transmitting loop is 5cm. Wherein, the transmitting loop is connected with the low frequency power signal generator through the lead wire, and the receiving loop is connected with the EMI test receiver through the lead wire. The physical diagram of the experimental platform is shown in figure 2.

Figure 1. Experimental platform structure.

Figure 2. The physical diagram of the experimental platform.
3. Experimental results and discussion

During the experiment, the relative position of the transmitting loop and the receiving loop is kept unchanged, so that they move along the x-axis or y-axis at the same time, the range of motion is [-50cm, 50cm]. The induced voltages of the receiving loop before and after placing the slotted conductor plate are \( u_1 \) and \( u_2 \) respectively, and the shielding effectiveness is defined as equation (1).

\[
SE = 20 \log_{10} \left( \frac{u_1}{u_2} \right)
\]  

3.1. Test overview

The loops move together along the x-axis or y-axis, and the magnetic shielding effectiveness (SE) of the slotted conductor plate is measured as shown in figure 3. For a finite size conductor plate, when the measuring point is located at the edge of the plate, most of the field will leak through the edge, which is called the edge effect of the field. For this test, the edge effect area corresponds to the area of x/y<-35cm and x/y>35cm.

With the loops move toward the center of the slotted conductor plate, the proportion of the field leaking through the edge of the plate decreases, so the SE of the plate increases. When the loop moves to the critical point, the SE tends to be stable in a certain region, and the region of the conductor plate is called the platform area of the plate. For infinite conductor plates, SE calculates according to equation (2) ~ (5)[7].

\[
SE = 20 \log_{10} \left( \frac{(\eta_m + \eta_w)^2}{4\eta_m \eta_w} e^{(1+i)\frac{\delta}{\sigma}} \left[ 1 - \left( \frac{\eta_w - \eta_m}{\eta_w + \eta_m} \right)^2 e^{-2(1+i)\frac{\delta}{\sigma}} \right] \right)
\]

\[\eta_m = \sqrt{j \omega \mu_0 / \sigma}\]

\[\eta_w = j \omega \mu_0 \frac{\rho^2 + d_i^2}{3d_i}\]

\[\delta = \sqrt{2 / \omega \mu_0 \sigma}\]

In this paper, the calculated value of SE obtained by the above equation is 44.37dB, which is basically the same as the platform area SE measured by the experiment. Therefore, when the measuring point is located in the platform area of the slotted conductor plate, it can be treated as an infinite conductor plate.
When the loop continues to move closer to the center of the slotted conductor plate, the proportion of magnetic field leakage from the central slot gradually increases and leads to the decrease of SE. This effect is called aperture leakage effect, and the corresponding area is called aperture leakage area. In this experiment, when the loop moves along the x-axis, the aperture leakage area is -20 < x < 20 cm region; when the loop moves along the y-axis, the aperture leakage area is -10 cm < y < 10 cm region.

3.2. Shielding efficiency of slotted conductor plate at different frequencies

The test results of shielding effectiveness of slotted conductor plate at different frequencies are shown in figure 4. It can be seen that SE has nothing to do with frequency in the edge effect zone and aperture leakage area. In the frequency range above 20 kHz, the SE in the platform area decreases at first and then increases in the "U" shape. The critical point between the edge effect area and the platform area corresponds to the maximum value of SE, except for this point, SE increases with the increase of frequency.

4. Conclusion

(1) According to the different dominant effect, the magnetic field shielding effectiveness of different positions of slotted conductor plate can be divided into edge effect area, platform area and aperture leakage area. In the edge effect area, the shielding effectiveness increases with the measuring point away from the edge of the plate, the shielding effectiveness of the platform area is basically unchanged, and the changing trend of shielding effectiveness of the aperture leakage area is related to the direction of movement of the measuring point.

(2) The magnetic field shielding effectiveness of the edge effect area and aperture leakage area of the slotted conductor plate has nothing to do with the frequency, but the shielding effectiveness of the platform area increases with the increases of frequency.

Acknowledgements
This project is supported by the Science and Technology Project of SGCC under Grant 5200-201956058A-0-0-00.
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