Electromagnetic Shielding by a Spherical Shell Having a Hole (2)

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Electromagnetic shielding by a spherical shell having a hole is studied relying on the relaxation technique. Unlike the former paper (RIKITAKE, 1992a), the time-dependent magnetic field given to the shell is perpendicular to the direction connecting the shell center to the hole center.

Only the shells which are perfectly conducting are studied. The shielding power becomes somewhat smaller than that of an external magnetic field which is parallel to the direction connecting the shell center to the hole center, as studied in the former paper.

Similar study of electromagnetic shielding for thin cylindrical shells having a defect is also made in Appendix.

1. Introduction

RIKITAKE (1992a, hereafter called Paper (1)) studied electromagnetic shielding by a conducting spherical shell having a hole placed in a time-dependent magnetic field. The external field is assumed to be parallel to the direction connecting the shell center to the hole center. It is the aim of this paper to evaluate the shielding effect when the applied field is perpendicular to the said direction in a similar fashion.

Only shells of infinitely high conductivity will be studied in this paper because it was shown in Paper (1) that the shielding power is largely affected by the shell conductivity rather than by the aperture size. As shown in Paper (1), it is tedious to discuss the shielding by a finitely conducting shell. Meanwhile, it is important for practical use to estimate the shielding by a conductor of high conductivity.

Equi-potential lines around spherical shells of finite and infinitesimally thin thicknesses will be shown for various sizes of aperture in a manner similar to Paper (1). Changes in shielding ratio as the aperture size changes will also be examined.

In Appendix, the distribution of magnetic lines of force around imperfect cylindrical shells of infinitely high conductivity will be presented. The shells are assumed as infinitely long. As it is not possible to see the magnetic flux distribution for an imperfect spherical shell, the demonstration for a cylindrical case may be of some use for seeing the behaviour of magnetic lines of force. The direction of inducing field studied here is perpendicular to that treated in Appendix of Paper (1).

All through the study, the relaxation technique is used for solving the differential equations satisfied by magnetic potential or magnetic flux function in a similar manner developed in Paper (1).

2. Perfectly Conducting Spherical Shell of Finite Thickness

RIKITAKE (1990, 1992b) studied shielding of a static magnetic field applied to magnetically permeable spherical shells having a hole of various aperture sizes. As pointed out in Paper (1), it is clear that the electromagnetic induction in a perfectly conducting shell of similar shape is solved by assuming that the magnetic permeability, μ , is equal to 0 because the normal component of the field should vanish at the shell boundary.

The equi-potential lines of magnetic field are, therefore, readily obtained by making use of the

Fig. 1. Equi-potential lines around perfectly conducting spherical shells of finite thickness having a hole of various sizes. The ratio of the inner radius to the outer one amounts to 0.8.

computer programme developed in RIKITAKE (1992b). In Fig. 1 are shown the potential lines in a plane containing the shell center and parallel to the external field for a shell of which the radius of inner boundary amounts to 0.8 of the outer boundary. Illustrations are made for aperture radii $\theta_0 = 0^\circ$, 10° , 30° , 60° and 90° . The external field is perpendicular to the direction connecting the shell center to the hole center.

Fig. 2. Changes in the shielding ratio for various hole apertures. Crosses and asterisks indicate shielding ratios for finite-thickness and infinitesimally thin shells of perfect conductivity as shown in Figs. 1 and 3, respectively.

It is clearly seen in the figure that the equi-potential lines, which are completely expelled when the shell is perfect or $\theta_0 = 0^\circ$, invade the shell interior to a larger extent as the aperture becomes larger. Such a conclusion is much the same as that presented in Paper (1) although the extent of shielding is somewhat weaker for the present case than that for the field configuration studied in Paper (1). The ratio of the field at the center of the shell to that of the uniform field applied from outside is defined as the shielding ratio as before. The shielding ratios for various aperture sizes are shown in Fig. 2 with crosses.

3. Perfectly Conducting Shell of Infinitesimally Thin Thickness

In Paper (1) is shown that the relaxation scheme for electromagnetic induction in an infinitesimally thin shell of perfect conductivity can easily be compiled. The relaxation technique thus developed is here applied to the case when the inducing field is perpendicular to that studied in Paper (1).

Figure 3 shows the equi-potentials for such shells when θ_0 is assumed as 0° , 10° , 30° , 60° and 90° , respectively. It is seen in the figure that the potential distributions are much the same for shells of finite thickness shown in Fig. 1. The magnetic field at the center, which is directed to the same direction of the applied field, is readily obtained by numerical differentiation. The shielding ratios are plotted together with those for the shells of finite thickness in Fig. 2 with asterisks for $\theta_0 = 10^\circ$, 30° , 60° and 90° , respectively. They take on almost the same values as those for the shells of finite thickness except for the case of extremely small aperture size.

It appears that the external field becomes as small as one-hundredth even the shell has a hole of which the aperture radius amounts to 30° . However, we see that the shielding power for the present case is somewhat smaller than that for the field configuration studied in Paper (1).

4. Conclusion

As a result of studying magnetic potential distributions around infinitely conducting spherical shells of finite and infinitesimally thin thickness, the extent of electromagnetic shielding is clearly brought out for shells having a hole of various sizes. The magnetic field applied to the shell from outside is perpendicular to the direction connecting the shell center to the hole center. The direction is also perpendicular to that studied in Paper (1).

It turns out that the smaller the hole size is, the weaker becomes the field at the shell center. However, the shielding power is somewhat smaller than that for the field configuration studied in Paper (1). The field becomes as small as one-hundredth of the external one even the aperture size amounts to 30° or thereabout.

Fig. 3. Equi-potential lines around perfectly conducting spherical shells of infinitesimally thin thickness having a hole of various sizes.

Appendix: Electromagnetic Shielding by a Thin Cylindrical Shell of Perfect Conductivity Having a Defect—A Two-Dimensional Problem

As pointed out in Paper (1), it is not an easy matter to obtain the distribution of magnetic lines of force in a spherical problem. In order to see how the magnetic lines of force are distributed, it is of some use to study electromagnetic induction in infinitely long thin shells of cylindrical shape. The shells, which are

perfectly conducting, have a defect of various sizes.

The differential equation satisfied by the magnetic flux function is the same as that solved in Appendix of Paper (1). The function becomes zero on the shell. In contrast to the case studied in Paper (1), the applied field is perpendicular both to the cylinder axis and the direction connecting the shell center to the defect center. The relaxation programme is readily compiled in a manner similar to that for Paper (1).

The magnetic lines of force thus estimated are distributed around the shell as shown in Fig. A1 for various sizes of shell defect. It is observed in the figure that the magnetic lines of force intrude fairly deeply

Fig. A1. Magnetic lines of force around thin cylindrical shells of perfect conductivity with a defect of various sizes.

Fig. A2. Changes in the shielding ratio for various half widths of defect.

when the defect is wide. The magnetic field at the shell center is easily evaluated by numerical differentiation. The ratios of the intensity of magnetic field at the shell center to that of the external one are shown for various defect sizes in Fig. A2. We see that the shielding rate is considerably smaller than that for Appendix of Paper (1). Such a result is readily expected from the fact that the magnetic lines of force invade fairly deeply into the shell interior.

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