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AC High Magnetic Field Generator Using Multilayer Eddy-Current Type Coil

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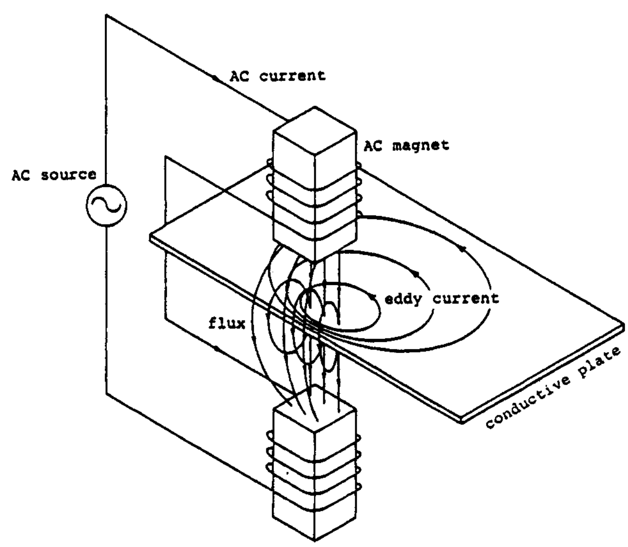
Abstract

This paper described the performances and features of a new high magnetic field generator proposed by the authors, that is, H-shape cylinder type and multilayer eddy-current type AC high magnetic generator. The magnetic field distribution of the generator is analyzed by the finite element method. Further, the equipment and the improvement in performance are also discussed.

1. Introduction

The fundamental principle of the high magnetic field generator is that the eddy currents in the conducting plate by AC excitation yield the magnetic shield as shown in Fig. 1(a). The first attempt, based on two- or four-conducting plates configurations, has been already done and we have reported the details of the generator as well as results [1–3]. Figure 1(b) shows that the configuration of the four-plate type device. As the results seemed to be promising, the authors work out the new device using special conducting cylinder with slit. The paper is devoted to this approach.



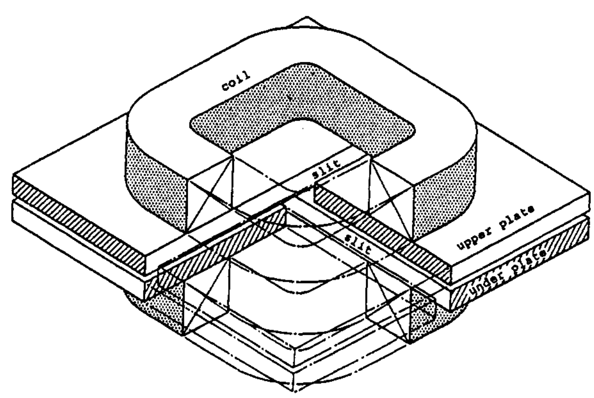


Fig. 1. Magnetic shielding effect. (a) One conducting plate. (b) Four conducting plates.

2. Consideration the shape of a shielding coil on the AC high magnetic field generator

2.1. *H-shape shielding coil*

We have confirmed the generation of a high magnetic field by the AC generator. In order to improve further the concentration effect, the H-shape shielding coil for magnetic shield is proposed. The H-shape shielding coil as shown in Fig. 2 has the structure of a solid copper material. The hole is located at the center and a slit is cut in the radial direction. The exciting coil is wound around the coil.

2.2. *Analysis of magnetic field by FEM*

The structure of the shielding coil without the slit is cylindrically symmetric. As a exciting current is applied, it can be assumed that eddy currents are induced cylindrically as shown in Fig. 3. But it is clear that the eddy currents flow in the radial direction near the slit. In order to apply the two-dimensional FEM, a r–z plane away from the slit is chosen as the analytical plane. In the r–z plane, both the applied current and the eddy currents have only the θ-direction component. For a θ-direction current, the magnetic vector potential A_θ also has only a θ component. We assume that the material

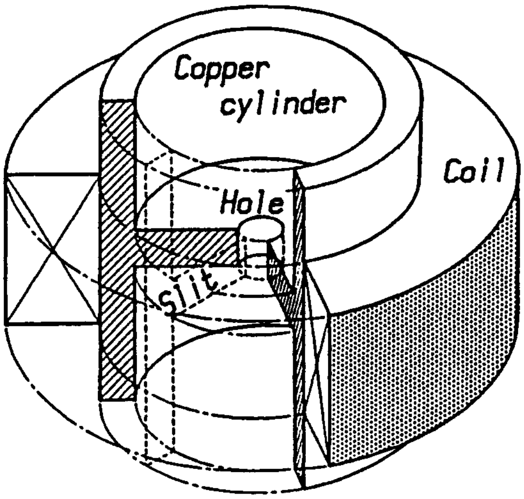


Fig. 2. H-shape cylinder type coil.

parameters are constant and the variables vary sinusoidally with time. In the two-dimensional region, the θ-direction vector potential A_θ satisfies the equation as,

$$\nabla^2 A_\theta = \mu J_{0\theta} - \mu J_{e\theta}, \tag{1}$$

where

$J_{0\theta}$ = applied current, $J_{e\theta}$ = eddy currents,

ω = angular frequency, σ = conductivity.

The eddy currents $J_{e\theta}$ are expressed as

$$J_{e\theta} = j\omega\sigma A_\theta + \frac{\sigma}{r}\frac{\partial\phi}{\partial\theta}, \tag{2}$$

where ϕ is a scalar potential. The component $\partial\phi/\partial\theta$ is constant in the r–z plane. As the cylindrical coil has the slit isolated electrically, the total value of θ-direction eddy currents in the cross section of coil is equal to zero. Therefore, the eddy currents satisfy,

$$\int_S J_{e\theta}\,dS = \int_S \left(j\omega\sigma A_\theta + \frac{\sigma}{r}\frac{\partial\phi}{\partial\theta}\right) dS = 0, \tag{3}$$

where S is the r–z cross section of the coil. The peak value of an input voltage is given by,

$$V_{in} = j\omega \int_c A_\theta\,dl + RI, \tag{4}$$

where R is the resistance of the exciting coil. As an input voltage or an input current is applied, eqs. (1) and (3) are solved by the iteration method.

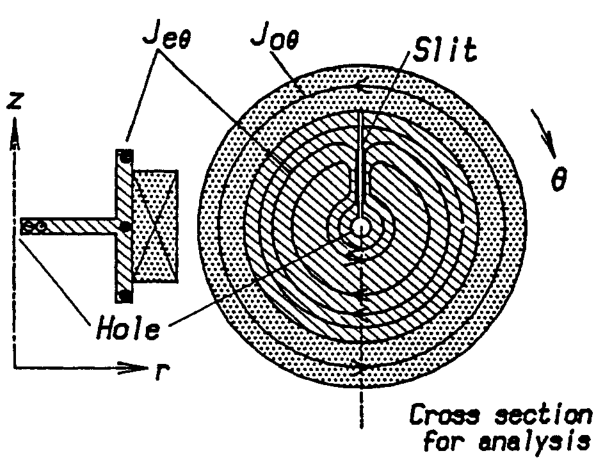


Fig. 3. Cross section for analysis and simplified path of eddy currents.

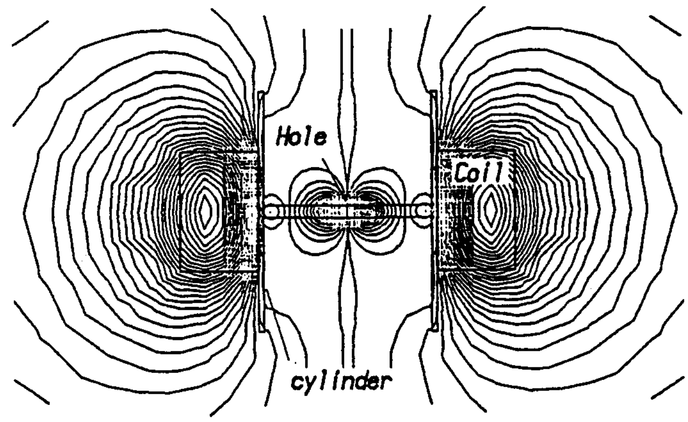


Fig. 4. Equi-potential lines.

Figure 4 shows the equi-potential lines of vector potential A_θ. The distribution suggests that the induced eddy currents flow on the cylinder and the space inside the cylinder is shielded from the magnetic flux applied by the exciting coil. The returning eddy currents around the hole generate the high magnetic field.

2.3. *Analysis of the shielding coil*

In order to improve the magnetic concentration, we examined the shape of the shielding coil. Figure 5 shows the relation between the concentration ratio and the height of the cylinder. The concentration ratio indicates the ratio of the magnetic flux density in the hole to what without the shield. The exciting frequency is 60 Hz and the material of the shielding coil is made of copper.

The cylinder type coil clearly enables the concentration ratio to increase. We can confirm the effect of the cylinder compared with the value without a cylinder (thickness

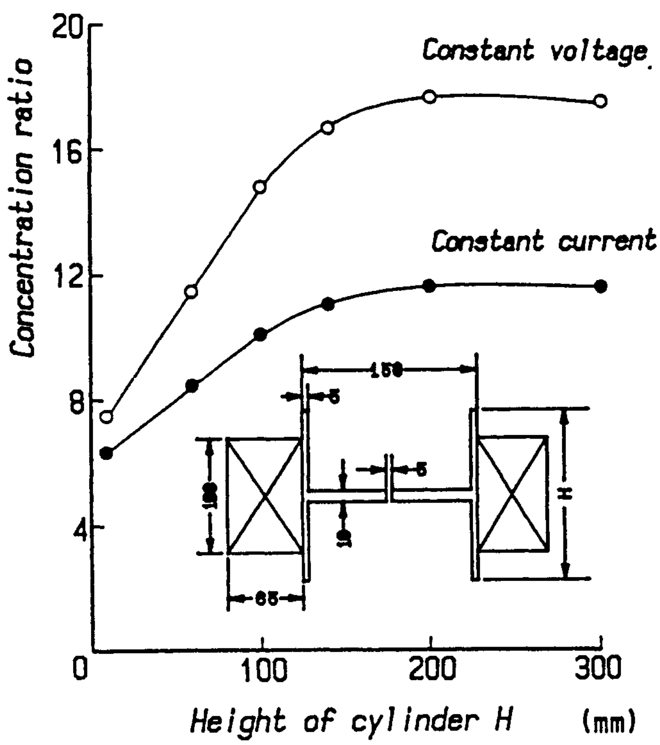


Fig. 5. Relationship between the concentration ratio and the height of cylinder.

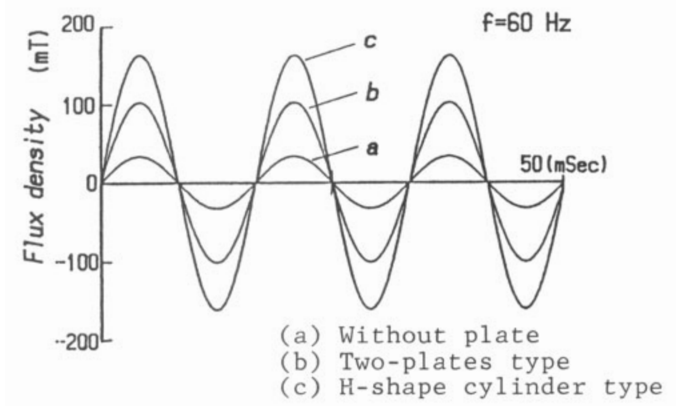


Fig. 6. Waveforms of flux density in the hole at 60 Hz. (a) Without shielding coil. (b) Only with shielding plate. (c) With shielding coil.

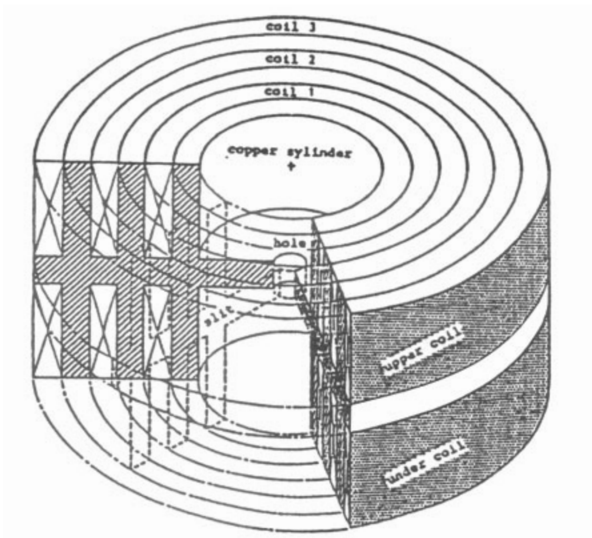


Fig. 7. Multilayer eddy-current type coil.

$D = 10$ mm). The height of the cylinder is related to that of the coil. The height of the cylinder should be larger than that of the coil.

Based upon the results, we have measured the flux density at the hole on the tested model. Figure 6 shows the waveforms of flux density on the hole. The peak value of the flux density on the model with cylinder coil is 1.58 times more

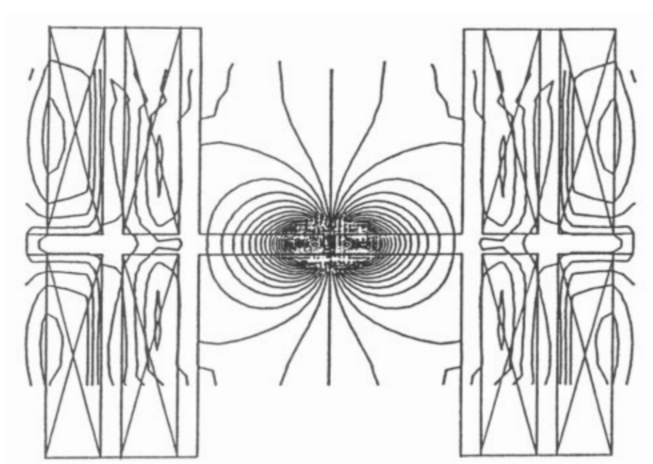


Fig. 8. Equi-potential lines (two layer type).

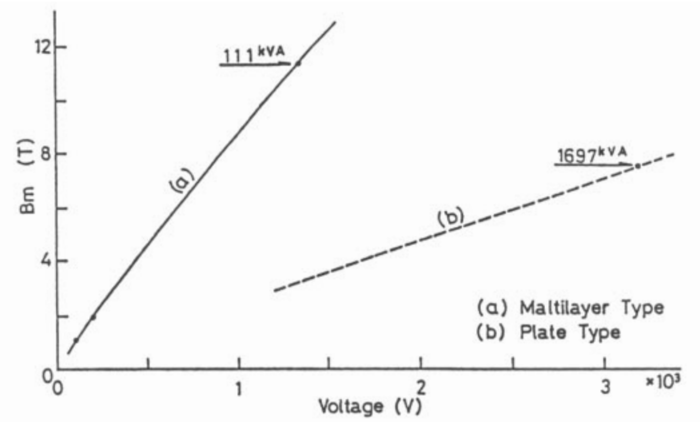


Fig. 9. Relation between the AC voltage and the maximum flux density.

than that without two plate type. The concentration ratio measured on the tested model is less than the calculated value. The error occurs because the magnetic effort of a slit is eliminated in the analysis.

3. Multilayer cylinder type

Recently, a new model of the high field generator as shown in Fig. 7 has been introduced. The exciting coils are placed within many layers. The device is named by the authors "Ohyama coil". The equi-potential lines for the two-layer device are shown in Fig. 8 and it is seen that the concentration ratio considerably increases.

The effect of field concentration has been also checked experimentally. The three-layer generator was supplied with input voltage 1350 V and frequency 60 Hz. Then an AC flux density of 11.2 T was obtained with an input electric power of 111 kVA. In order to compare the results, the plate-type device as shown in Fig. 1(b) was tested and the results are far worse: applying the voltage 3400 V and input power 1697 kVA, a flux density of 7.4 T was obtained. In Fig. 9 the concentrated flux density for two types of generator as a function of input voltage is presented. This numerical and experimental analysis shows very clearly that the multilayer device gives much better results than the former ones.

4. Conclusion

The paper presents a method of AC high magnetic field generation. The very high efficiency is especially seen when using multilayer device. The authors believe that this way of high magnetic field generation has a very promising future. In order to obtain longer duration, we must solve the important problem of cooling because the cylinder was destroyed by the high temperature and the strong magnetic force at a field of 16 T.

References

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