ANALYSIS OF A NOVEL LAMINATED COIL USING EDDY CURRENTS FOR AC HIGH MAGNETIC FIELD

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ABSTRACT

The paper describes the performance and analysis of eddy-current type laminated coil for ac high magnetic field. It is difficult to obtain an ac high magnetic field by using an air-gap coil because of eddy currents. For our device, we can obtain an ac high magnetic field by means of the magnetic shielding effect of eddy currents. Two kinds of a new type of coil are proposed in order to construct the apparatus easily. The field distributions were analyzed by the two-dimensional finite element method.

INTRODUCTION

Until now very few papers on the ac high magnetic field generation were reported. It is difficult to generate an ac high magnetic field by the air-gap coil because of eddy-current problems. On the other hand, we reported the AC High Magnetic Field Generator by using the effect of the magnetic shield of the conducting plate[1]-[3]. In the generator, the effect of the eddy currents acts as the main principle and the eddy currents generate an ac high magnetic field.

In this paper, new coils for the ac generator are proposed in order to improve the construction and are analyzed by the finite element method.

THE EDDY-CURRENT TYPE GENERATOR

The concentration of the magnetic flux in the ac high magnetic field generator is based on the magnetic flux shield in the ac magnetic field. For concentrating the magnetic flux by using the magnetic flux shield, it is necessary to set up a slit in the radial direction as shown in Fig.1. The eddy currents flow around the hole due to the slit. Therefore, the magnetic flux is shielded in a copper plate, and the induction magnetic field which has the same direction as the applied magnetic field can be induced in the hole. The magnetic flux density becomes higher.

In order to realize the principle of the ac generation, we constructed the multilayer eddy-current type generator in Fig.2. The magnetizing coil and the conductor for eddy currents are closely packed in Fig.2(a). The multilayer coil is assembled in the generator as shown in Fig.2(b). The shaded portion of the apparatus is section of the coil and the poles. The yoke is added as part of the magnetic circuit in the generator. Figure 3 shows the flux distribution obtained by the two-dimensional finite element method.

The characteristics of the multilayer eddy-current type generator are shown as in Fig.4. The coil produces an ac flux density of 16 T at 60 Hz[3]. Comparing with the plate-type conductor in Fig.1, these coils offer excellent performance characteristics. It is clear that the concentration effect can be improved considerably.

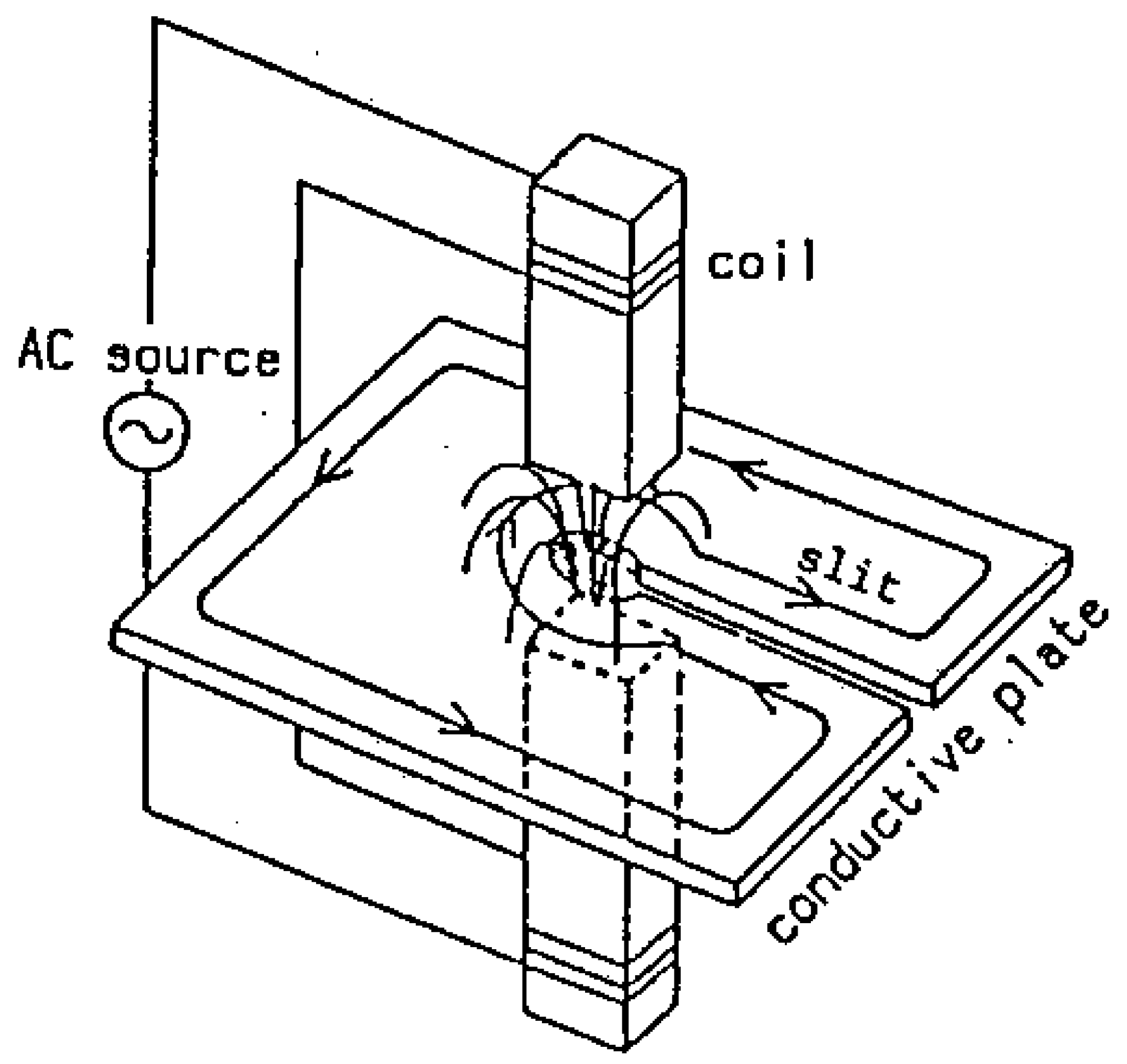
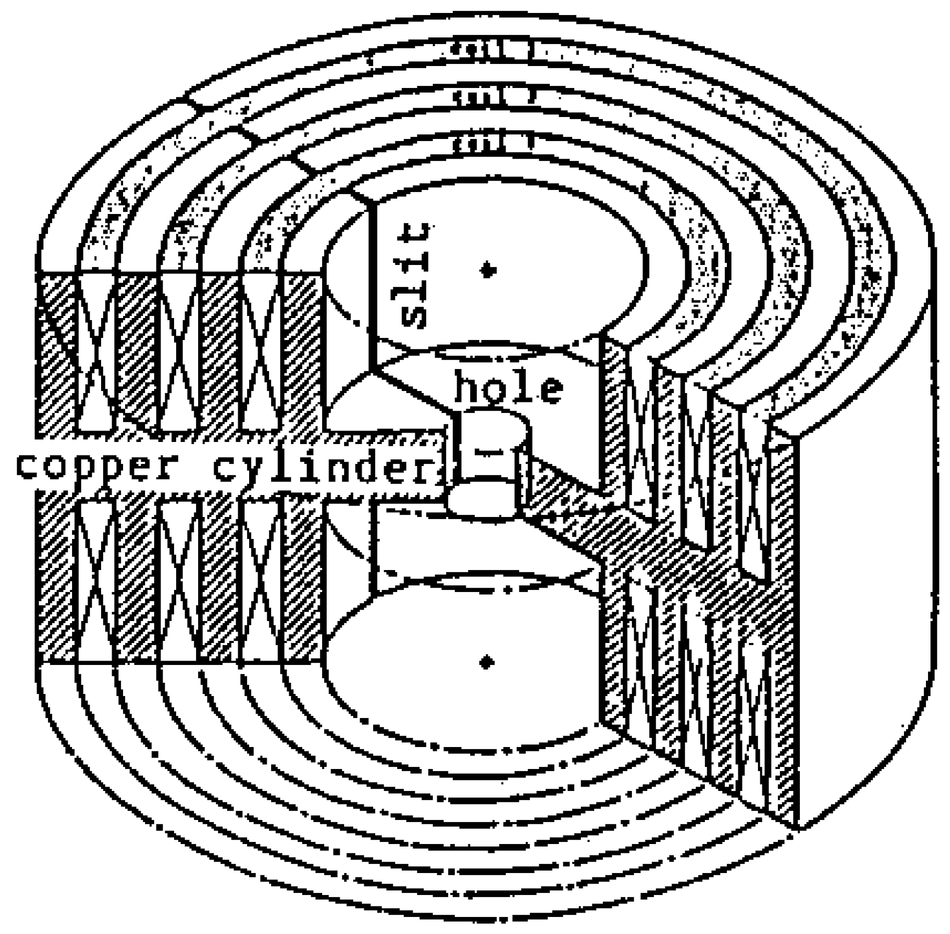


Fig.1 Concentration of a magnetic flux by eddy currents

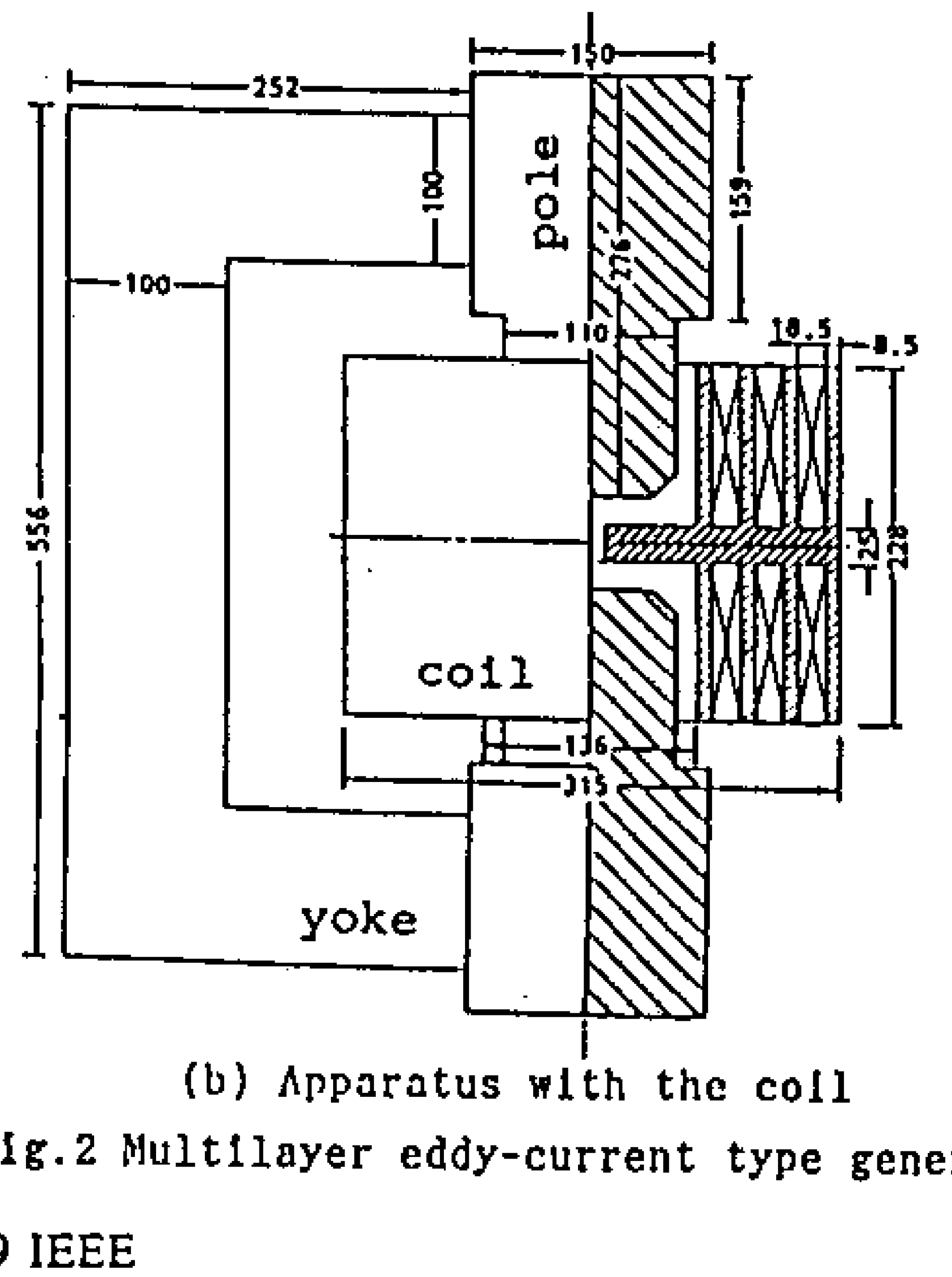
STRUCTURE OF THE LAMINATED TYPE COIL

Disc-type coil

It is difficult to construct the Multilayer Eddy-Current Type Coil because the conductor is solid copper. To improve the coil in construction, we propose two types of the laminated type coil. one of



(a) Multilayer coil



(b) Apparatus with the coil

Fig.2 Multilayer eddy-current type generator them is the disc type coil shown in Fig.5. This coil is made of both the disc coil for the magnetizing current where a slit is set up in the radial direction, and the conductor disc plate where a fan-shaped slit is designed for eddy currents. These two types of the disc coil and plate are piled up alternately as shown in Fig.5(a). These disc coils are connected at the slit as a series magnetizing coil. The disc plates with insulators are inserted between disc coils. Figure 5(b) shows the flow of the magnetizing current in the disc coil and the eddy current in the disc plate when an ac current is applied.

In our small experimental model for testing, the device is made of copper. The outer diameter of the disc coil is 200 mm and the width is 30 mm. The outer diameter of the disc plate is the same as that of the disc coil.

Spiral-type coil

In the other device, the spiral coil in Fig.6 is used for magnetizing current coil instead of the disc coil. It has a structure similar to the disc type coil.

Comparing with the former, the spiral-type coil is more suitable for high voltage and small current. It may be used in the low frequency range. The former can be used for low voltage and high current.

CHARACTERISTICS

We have conducted experiments with a test model of the disc-type laminated coil. Figure 7 shows the characteristics of magnetic flux density in the hole with the number of coils. The condition of measurements is that the applied voltage for one magnetizing coil is constant. The applied voltage is 40 mV at each coil in Fig.7. The flux density increases linearly with applied voltage. We can observe the concentrating effect of magnetic flux when the disc plate is put in.

Figure 8 shows the characteristics of magnetic flux density with the thickness of a disc plate when the applied voltage of one coil is kept constant. The maximum value is at 5 mm. We consider that this value corresponds to the skin depth of the disc plate.

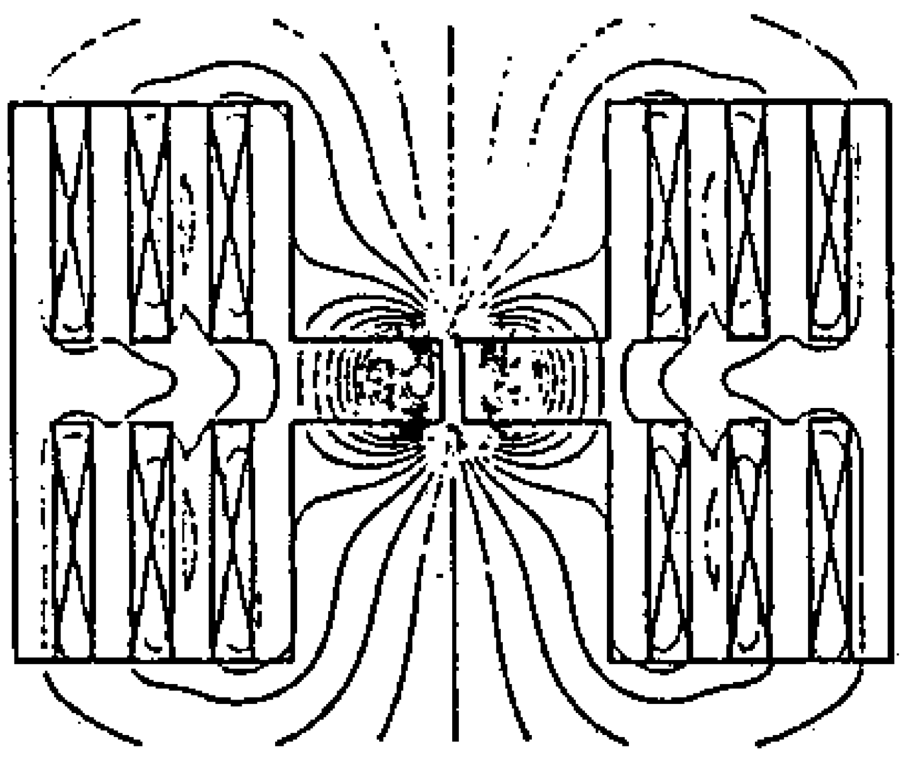


Fig.3 Flux distribution obtained by the FEM

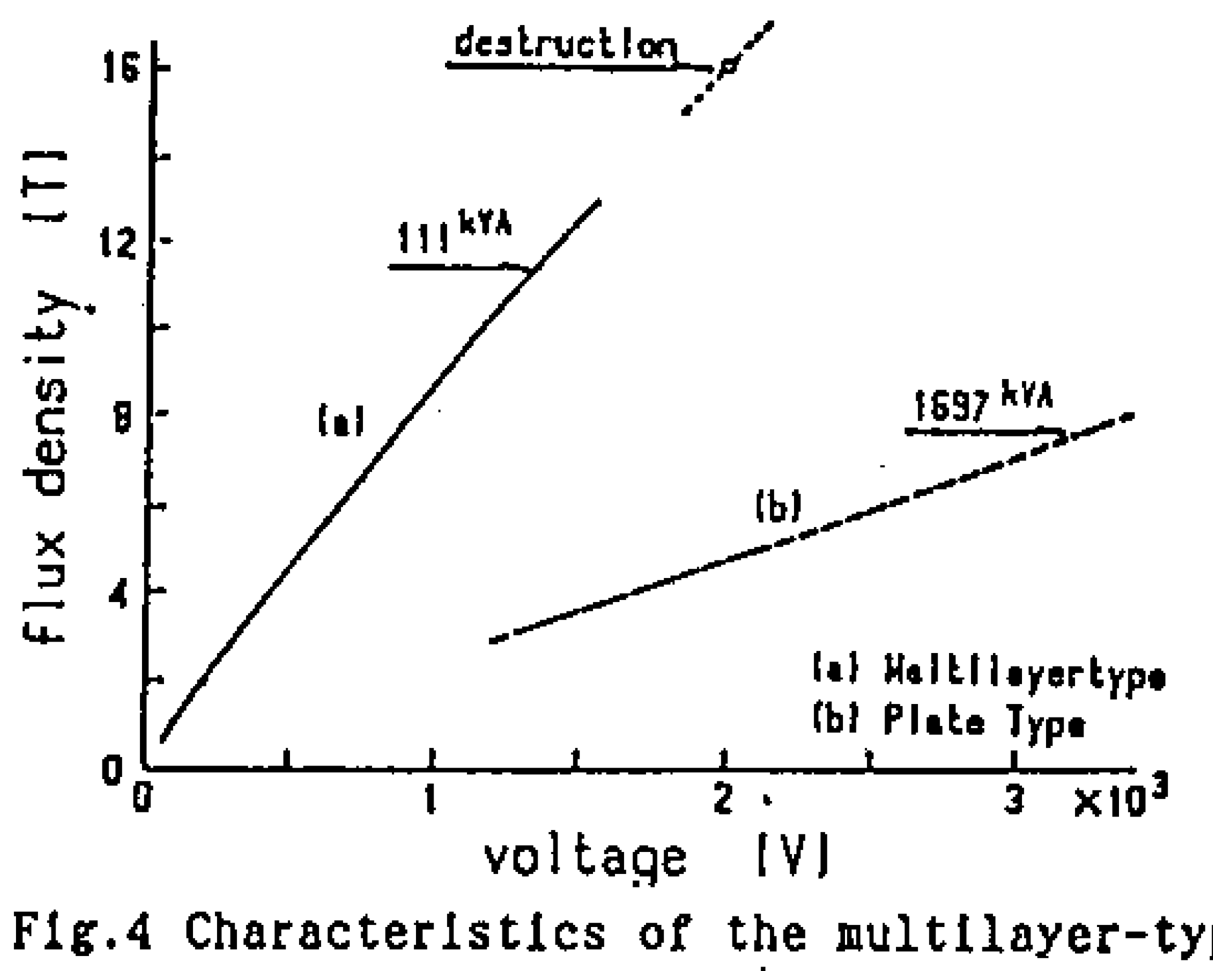


Fig.4 Characteristics of the multilayer-type generator

ANALYSIS OF THE LAMINATED COIL BY FEM

In order to analyze the flux distribution in the laminated coil, we consider the model as shown in Fig.9. The coils and plates are axisymmetric and the eddy currents flow inside the individual conductors. The technique of the FEM applied to this problem is reported in [3]. In this problem, eddy currents flow in both the magnetizing coils and the plates. Therefore, the following conditions must be satisfied as follows,

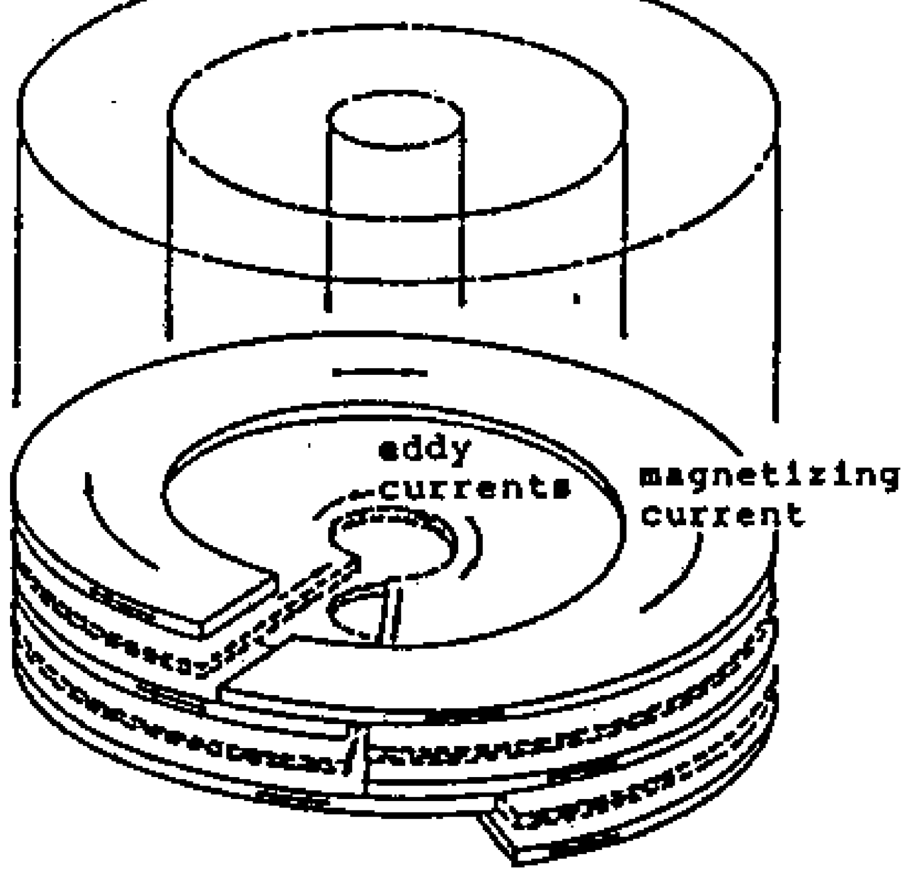
In the magnetizing coil:

$$\int_s (J_{in}+J_e)dS = I_{in} \tag{1}$$

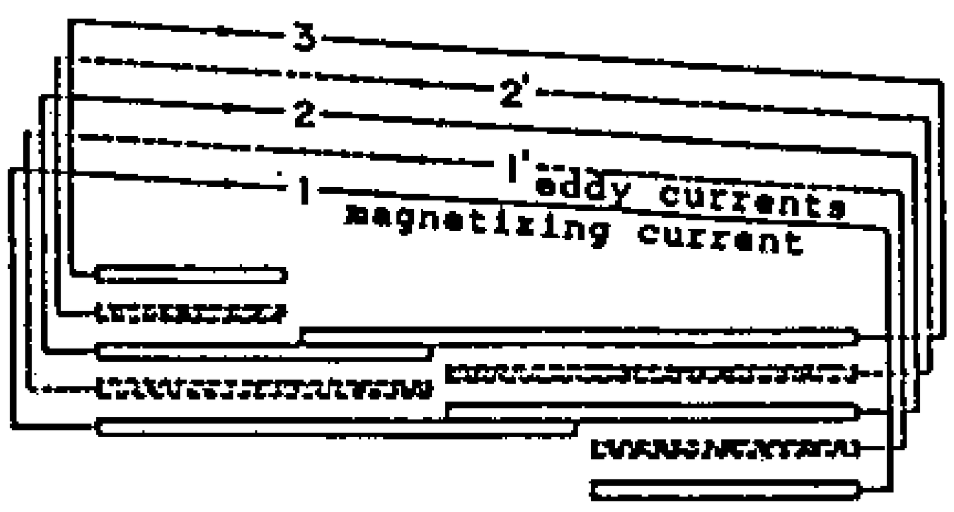
In the conducting plate:

$$\int_s J_e \, dS = 0 \tag{2}$$

where J_{in}, I_{in} and J_e are the magnetizing current



(a) Structure



(b) Connection of the coils

Fig.5 Disc-type laminated coil

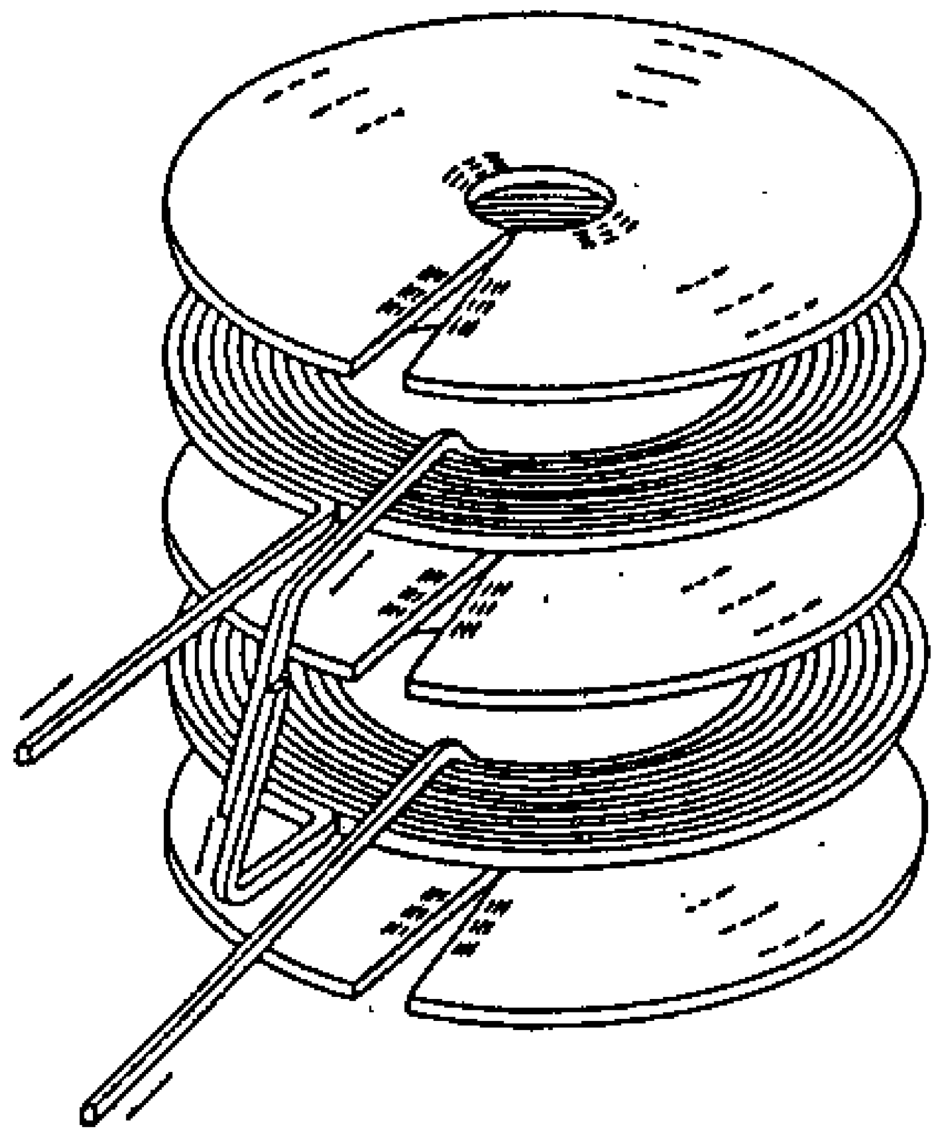


Fig.6 Spiral-type laminated coil

density, the magnetizing current and the eddy-current density respectively. The integration is made in the cross section S of the coil and the plate.

Figure 10 shows the flux distribution in the disc-type coil. When the magnetizing current density has $J_{in}\sin\omega t$, the flux density has the maximum value at the phase $\omega t=2\pi/3$ because of eddy currents.

Figure 11 shows the relation between the flux density in the hole and the number of coils. This result agrees with that in Fig,7.

CONCLUSION

The concentration of a magnetic flux by using laminated coils is discussed. These coils are suited to generating an ac high magnetic field and the structures of the coils are simpler than the former in construction. It may be used for obtaining an ac high magnetic field. It can also be applied to the induction electromagnetic pump.

REFERENCES

(1) K.Bessho, S.Yamada, M.Kooto,T.Minamitani,N.Nakano, M.Masahashi; "AC high magnetic field generator using multilayer eddy-current type coil", Proc. of Soft Magnetic Materials 8, 5-26, (1987).

(2) T.Yoshimoto, K.Bessho, S.Yamada;"Three dimensional FEM analysis of a cylinder-type flux concentration apparatus", IEEE Trans. Magn., Vol.MAG-24, No.6, (1988).

(3) K.Bessho, S.Yamada, M.Kooto, M.Masahashi,M.Nakano, :"Characteristics of multilayer eddy-current type ac magnetic coil with cooling system", J. Appl. Phys. Vol.64, No.10-8, (1988).

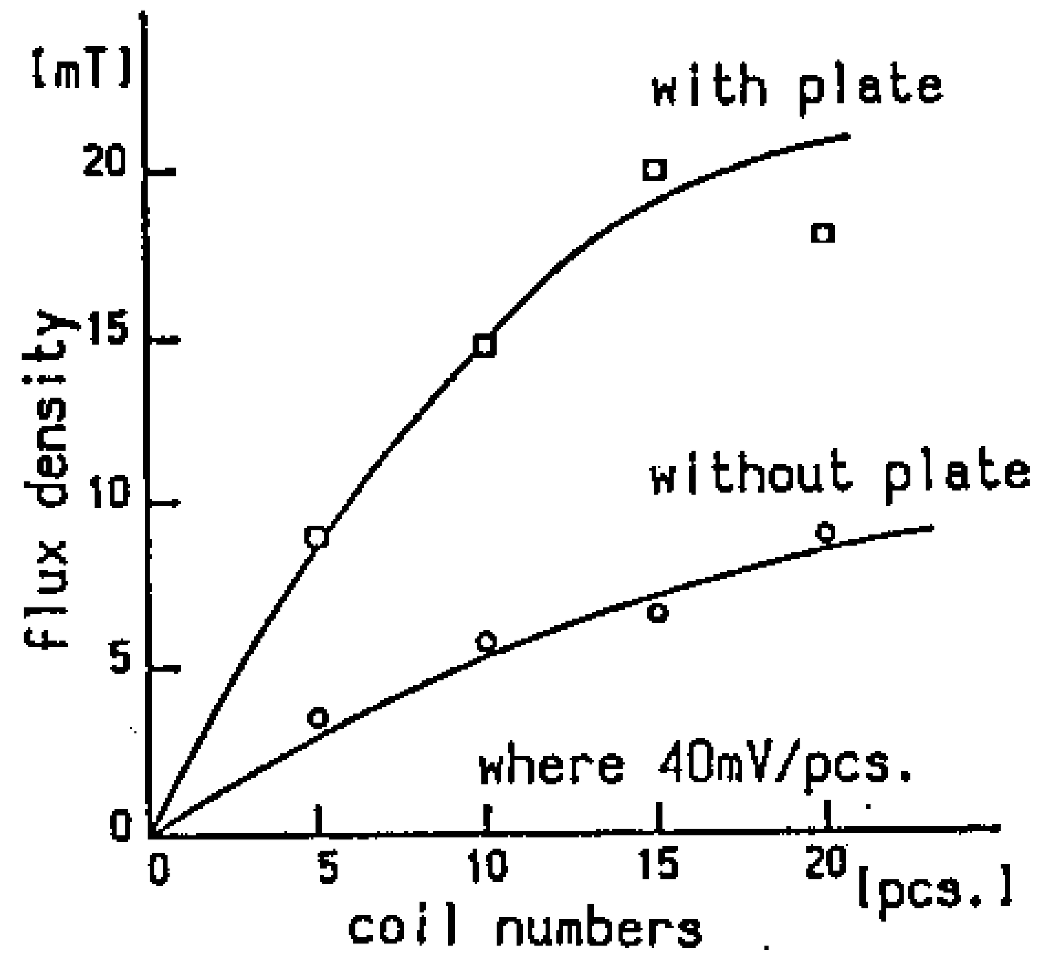


Fig.7 Relation between the number of coils and flux density in the hole

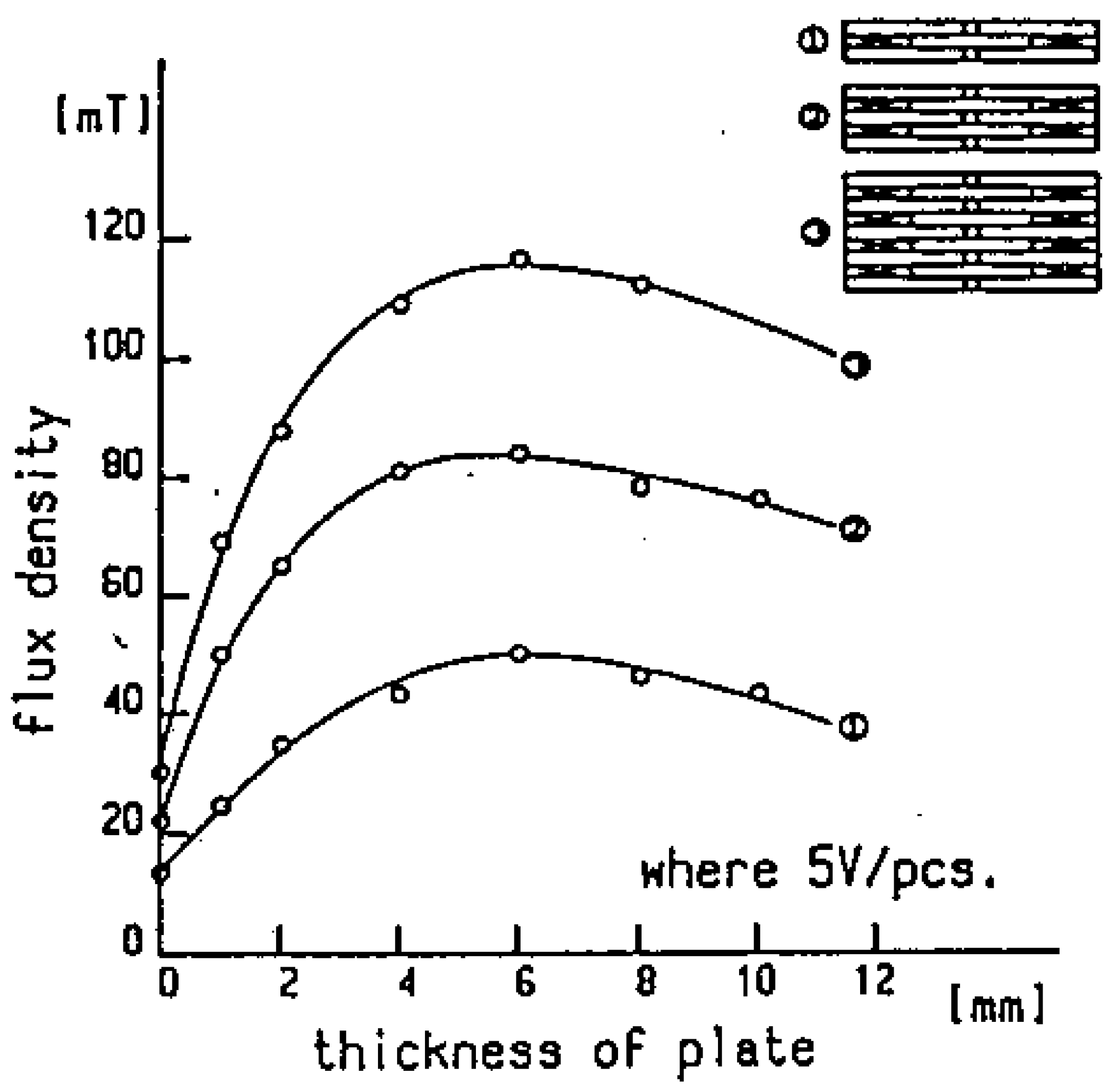


Fig.8 Relation between thickness of conductor and flux density

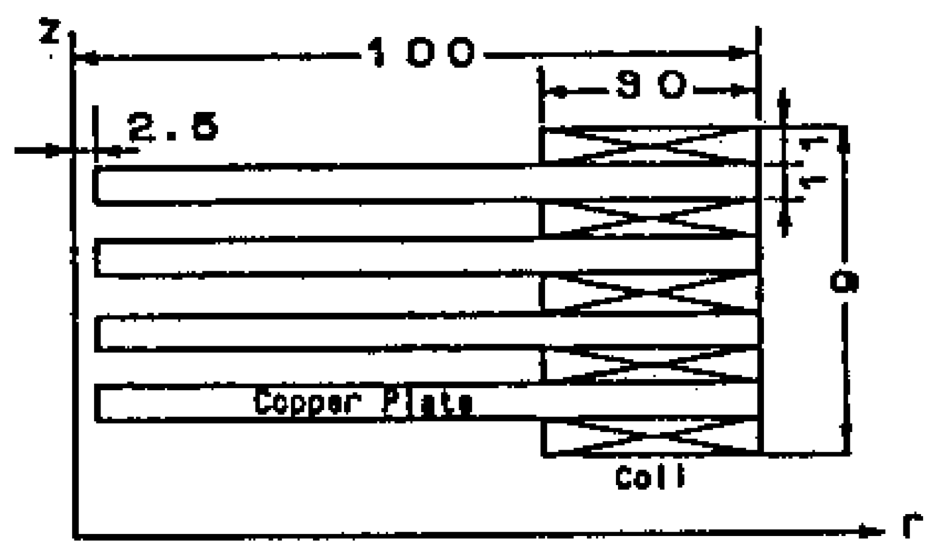
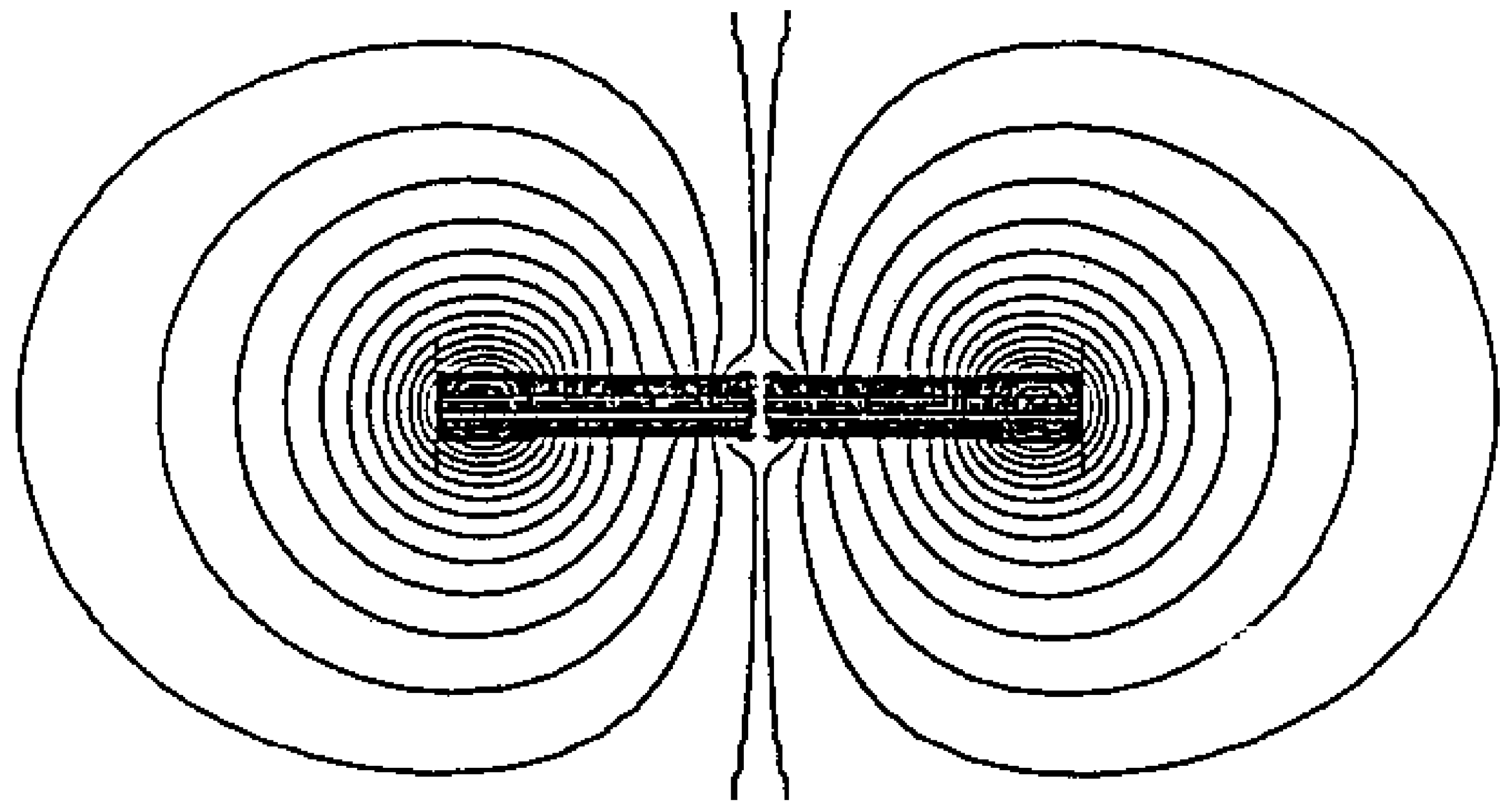
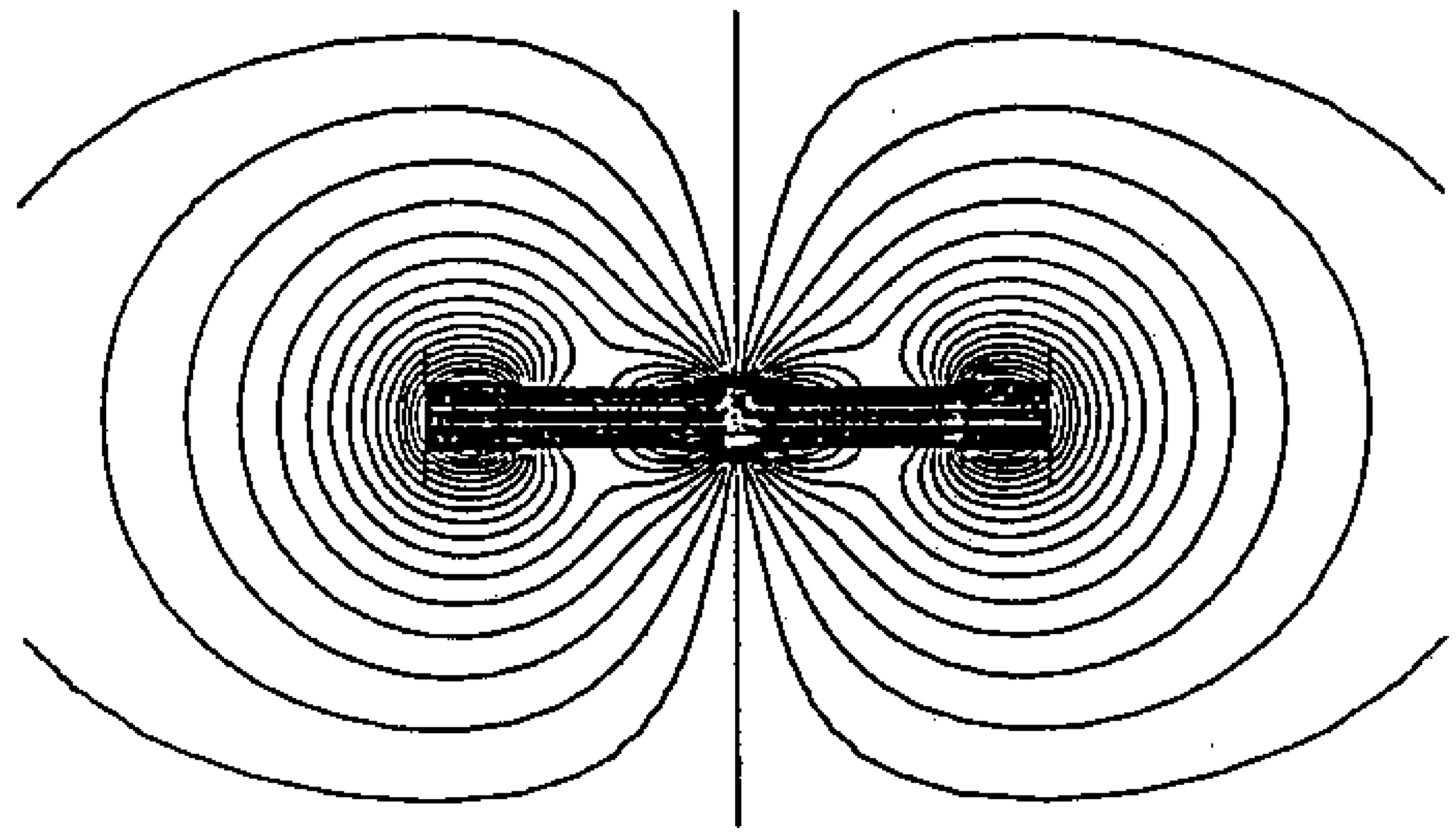


Fig.9 Model of the laminated coil



(a) $\omega t=0$



(b) $\omega t=2\pi/3$

Fig.10 Flux distribution calculated by the FEM

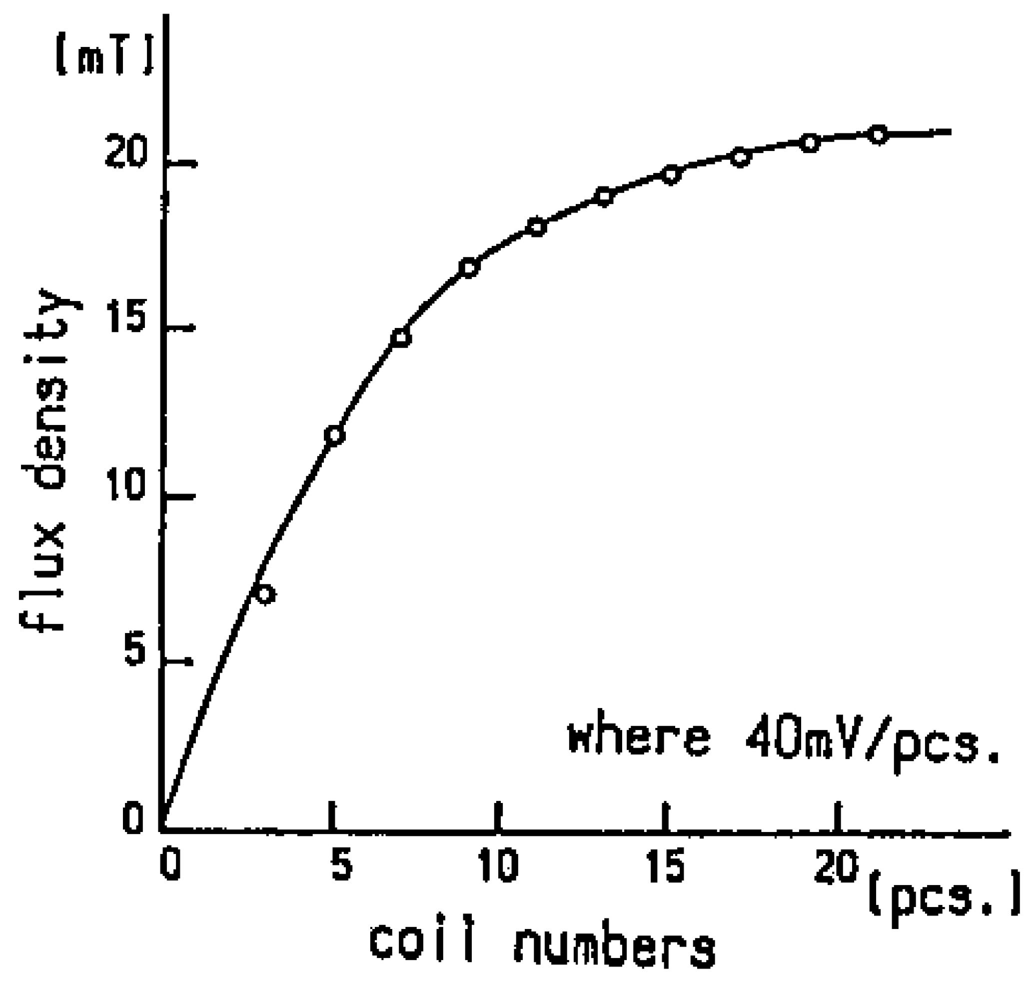


Fig.11 Relation between the number of coils and flux density by the FEM