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Effect of eddy current in shielding plate and electron gun on flux distribution in CRT

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***Abstract*—The eddy current induced in an inner magnetic shield (IMS) and an electron gun affect the flux distribution of a cathode ray tube, causing a possible degrade of picture quality. In this paper, the effect of the distance between an IMS and a deflection coil on the eddy-current distribution is examined. The eddy current induced in the electron gun, when the coils for velocity modulation (VM) are set near the electron gun, is also analyzed. It is found that the variation of flux distribution is mainly affected by the shape of VM coil.**

***Index Terms*—Cathode ray tube (CRT), eddy current, electron gun, finite-element method.**

I. Introduction

An INNER magnetic shield (IMS) is set inside a cathode ray tube (CRT) to lessen any external disturbance, such as geomagnetism. The eddy current induced in the IMS due to the changing current in the deflection coil may affect the flux distribution in CRT. The eddy current is also induced in the electron gun [1] when coils for velocity modulation (VM) are set near the gun. Despite the importance of this phenomenon, scientific research on this topic is regarded as limited.

In this paper, the effect of eddy current in an IMS and electron gun on flux distribution in a CRT is analyzed by using the three-dimensional (3-D) finite-element method.

II. Method of Analysis

Since the shape of the deflection coil is complicated, it is not easy to discretize it and, hence, establish the appropriate mesh. To overcome this shortcoming, we utilize the $\boldsymbol{As}$ method, which does not necessarily subdivide the coil.

In the $\boldsymbol{As}$ method, the vector potential $\boldsymbol{A}$ is treated as the sum of the vector potential $\boldsymbol{As}$ produced by the source current and the reduced vector potential $\boldsymbol{A}r$ [2], [3] as follows:

$$\boldsymbol{A} = \boldsymbol{As} + \boldsymbol{A}r. \tag{1}$$

$\boldsymbol{As}$ is calculated using the Biot–Savart's law as follows:

$$\boldsymbol{As} = \int \frac{\mu_0 I}{4\pi r}\, d\boldsymbol{s} \tag{2}$$

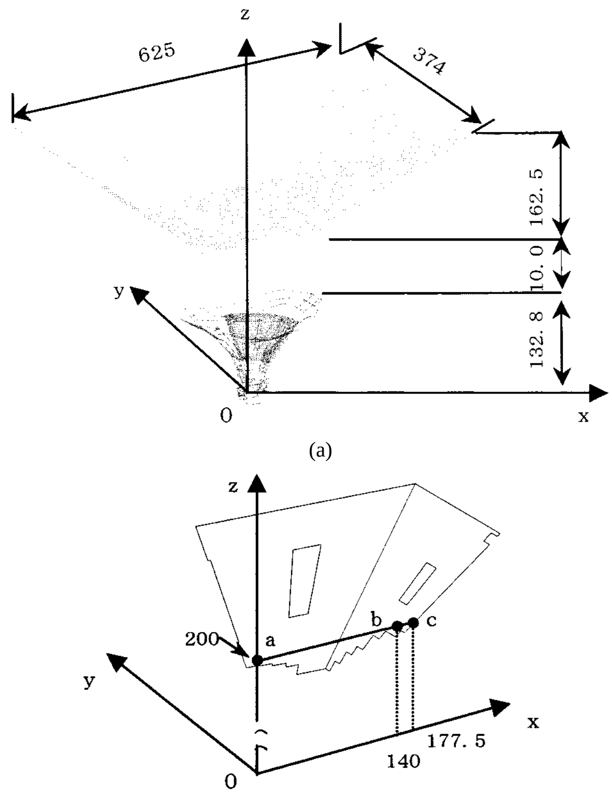

Fig. 1. Model of shielding plate. (a) Whole view. (b) Examined points.

where I is the source current and r is the distance from the line segment $d\boldsymbol{s}$ to the field point. The basic equation of the $\boldsymbol{As}$ method is given by

$$\mathrm{rot}(\nu\,\mathrm{rot}\boldsymbol{A}r) = 0 \tag{3}$$

where ν is the reluctivity.

From (1) and (3), the following equation is obtained:

$$\mathrm{rot}(\nu\,\mathrm{rot}\boldsymbol{A}) = \mathrm{rot}(\nu_0\,\mathrm{rot}\boldsymbol{As}) \tag{4}$$

where ν_0 is the reluctivity of vacuum.

As it is not necessary to generate a mesh for the coil by using the $\boldsymbol{As}$ method, the mesh becomes simple and, moreover, it is not necessary to calculate the current vector potential in the modified coil at each iteration in order to evaluate the current vector potential in the coil.

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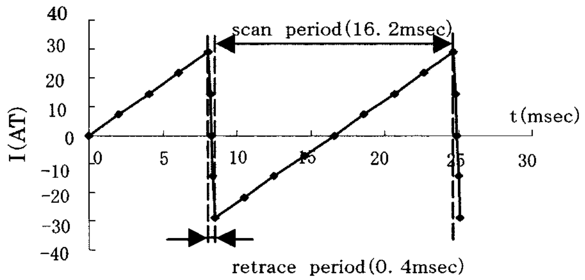
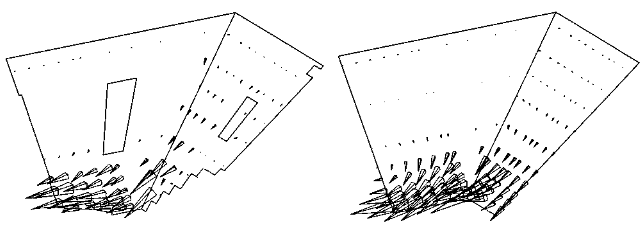


Fig. 2. Sawtooth current.



(a) (b)

Fig. 3. Effect of slit on eddy-current distribution ($t = 41.7$ ms). (a) With slit. (b) Without slit.

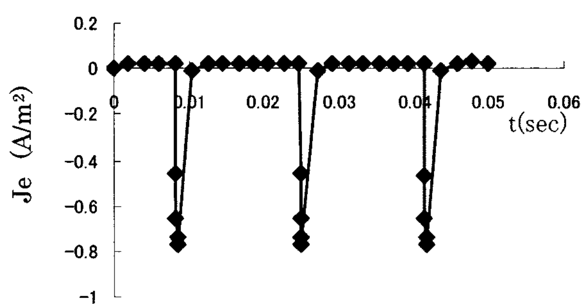


Fig. 4. Eddy-current density at point c.

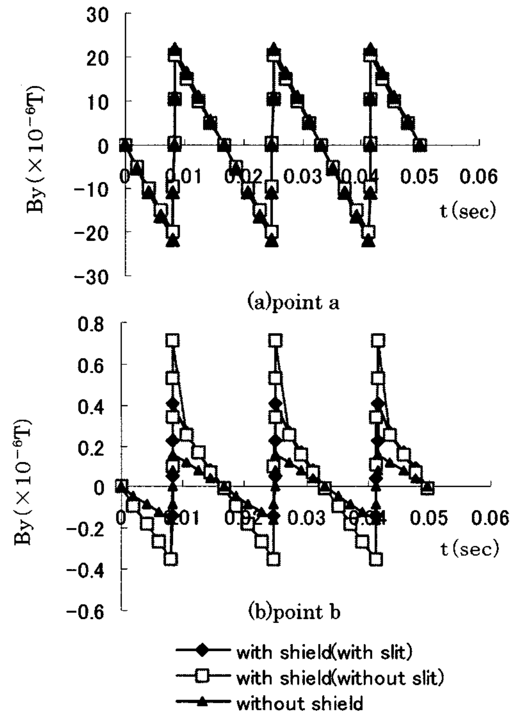
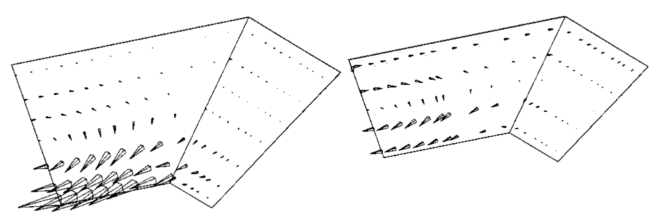


Fig. 5. Waveforms of flux density.



(a) (b)

Fig. 6. Effect of distance L on eddy-current distribution ($t = 41.7$ ms). (a) $L = 30$ mm. (b) $L = 60$ mm.

III. Analysis of Eddy Current in Magnetic Shielding Plate (IMS)

A. Analyzed Model

Fig. 1 shows the analyzed model of an IMS. The analyzed region is 1/4, but $\boldsymbol{As}$ is calculated using the ampere-turns of the entire deflection coil. The total ampere-turns of a single deflection coil is 28 A. The 60-Hz sawtooth current shown in Fig. 2 is imposed on the deflection coil for vertical scanning. The thickness of the IMS is equal to 0.15 mm. The skin depth is 25.5 mm. The IMS is subdivided into four layers. 3-D mesh of the IMS of hexahedral edge element is easily generated by the pile of two-dimensional (2-D) mesh and by the transformation of coordinates.

B. Change of Flux Waveform Due to Sawtooth Current

Fig. 3 shows the eddy-current distributions at a retrace period ($t = 41.7$ ms), which are obtained using the step-by-step method. Fig. 4 shows the eddy-current density at a point c on the IMS as shown in Fig. 1. The eddy current on the IMS increases suddenly in the retrace period. Fig. 5 shows the waveforms at a middle point a, where an electron beam passes through, and a point b near the IMS. Fig. 5 suggests that the overshoot of flux density occurs due to the eddy current when there is no slit on the IMS. When a 15.1-kHz sawtooth current is applied like in the case of the deflection coil for horizontal scanning, the eddy-current effect becomes more remarkable.

C. Effect of Distance Between IMS and Deflection Coil

The effect of distance L between the edge of the IMS and the deflection coil shown in Fig. 1 on the amplitude of eddy current is examined. The distance between the top of the deflection coil and the top of the IMS is kept constant (=172.5 mm), while the bottom part is cut when the distance L is changed.

Fig. 6 shows the effect of distance L on eddy-current distribution. The figure denotes that the increase of L is also effective for the reduction of eddy-current effect.

IV. Analysis of Eddy Current in Electron Gun

A. Analyzed Model

Fig. 7 shows the analyzed model of electron gun and VM coil. The electron gun is made of stainless steel (conductivity $= 1.38 \times 10^6$ S/m). The frequency of current is 10 MHz. The position of the VM coil is changed at positions A and B as shown in Fig. 7, whereas its angle θc is depicted in Fig. 8 and takes the values of 5°, 20°, and 35°. The number of hexahedral elements is 173 999.

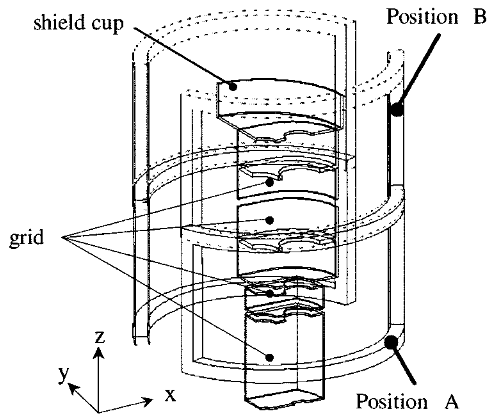


Fig. 7. Model of electron gun and VM coil.

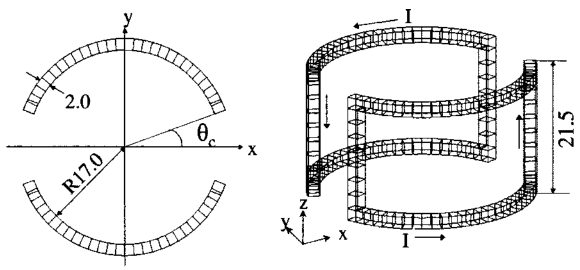


Fig. 8. VM coil.

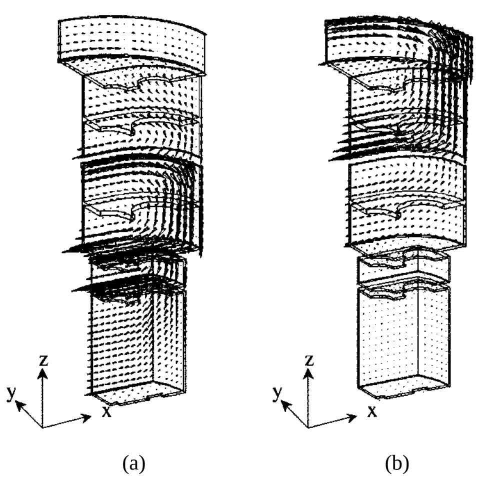


Fig. 9. Eddy-current distributions ($t = 0.225$ μs). (a) Position A. (b) Position B.

B. Effect of Shape of VM Coil

Fig. 9 shows the eddy-current distributions on the surface of electron gun in the case of positions A and B. Fig. 10 shows the flux distributions in the y–z plane with and without eddy current. The flux inside the electron gun, where the electron beam passes through, is considerably affected by the eddy current.

Finally, Fig. 11 shows the effect of eddy current and coil shape on the distribution of flux density By along the z axis. The flux distribution is considerably affected by eddy current. By is increased when θc is decreased. The CPU time for 30 steps is 44 490 s (computer used: VT-Alpha 6000, SPEC 95:27.0).

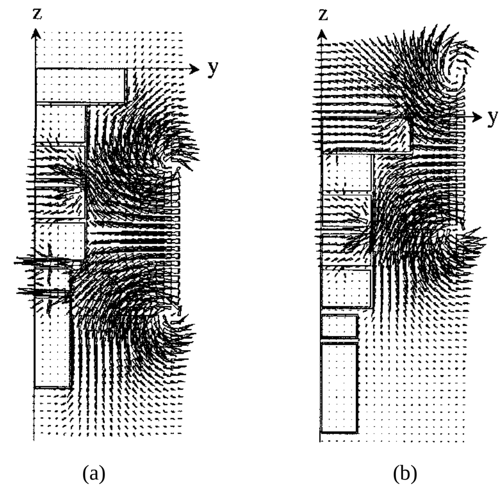


Fig. 10. Flux distributions ($t = 0.225$ μs). (a) Position A. (b) Position B.

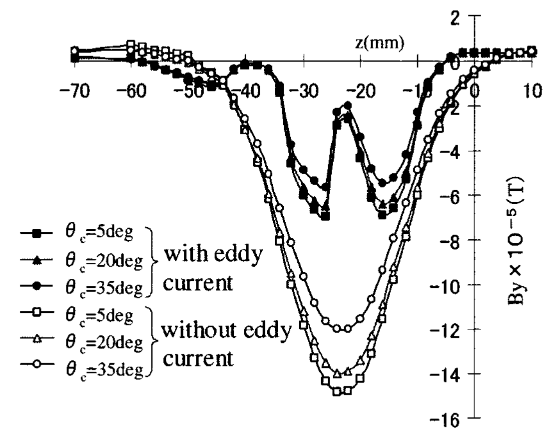


Fig. 11. Effect of coil shape on flux distribution ($t = 0.225$ μs).

V. Conclusion

The obtained results can be summarized as follows.

1) The flux waveform near ISM under sawtooth current excitation is considerably changed due to the eddy current. The effect of eddy current is also changed by the distance between the ISM and the deflection coil.
2) The flux distribution along the path of electron beam is largely affected by the eddy current and the shape of the VM coil.

The optimal design of the IMS and VM coil system will be carried out by combining the eddy-current analysis shown in the paper and the analysis of electron beam orbit in the future.

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