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H. Tsuboi
Okayama University

T. Misaki
Okayama University

T. Kikuta
Osaka Gas Coporation Limited

COMPUTATION OF THREE-DIMENSIONAL ELECTROMAGNETIC FIELD IN THE EDDY-CURRENT TESTING OF STEEL PIPES

H. Tsuboi and T. Misaki
Department of Electrical and Electronic Engineering,
Okayama University, Okayama 700, Japan

T. Kikuta
Research Center, Osaka Gas Co.,Ltd.,
Osaka 554, Japan

Abstract - This paper describes the computation of three-dimensional electromagnetic field distributions in the eddy-current testing for detecting defects of steel pipes. The boundary element method using vector variables was used for the computation of three-dimensional distributions of eddy current and magnetic flux density. The computation results of the phase of the magnetic flux density on the inner surface was compared with the experimental results of that, and then the mechanism of detecting defects of steel pipes became clear by the computation results.

INTRODUCTION

Eddy-current nondestructive testing has been discussed in some papers[1]-[5] by using experimental data and/or numerical analysis. This paper describes the computation of three-dimensional electromagnetic field distributions in the eddy-current testing for detecting defects of steel pipes. The boundary element method using vector variables[6],[7] is used in order to compute three-dimensional distributions of eddy current and magnetic flux density.

Three-dimensional steel pipe model of eddy-current testing is chosen as a computation model. In the model, there are some holes to be detected, and they are detected by magnetic flux due to an exciter coil placed at some distance. The computation results of the phase of the magnetic flux density on the inner surface is compared with the experimental results of that. The mechanism of detecting holes in the steel pipe is discussed by using the computation results of eddy current and magnetic flux.

BOUNDARY ELEMENT METHOD

The boundary element method using vector variables[6],[7] is used for the computation of three-dimensional distributions of eddy current and magnetic flux density. In the boundary element method, electric field and magnetic flux density are defined as unknown vector variables.

Electric field $\vec{E}_i$ and magnetic flux density $\vec{B}_i$ at any computation point i in the region V, which is enclosed by the surface S, are obtained by using the vector Green's theorem based on Maxwell's equations as follows[6]:

$$\frac{\Omega_i}{4\pi}\vec{E}_i = \int_S \{ j\omega(\vec{n}\times\vec{B})\phi - (\vec{n}\times\vec{E})\times\nabla\phi - (\vec{n}\cdot\vec{E})\nabla\phi \} dS - \int_V j\omega\mu\vec{J}_s\phi\, dv \tag{1}$$

$$\frac{\Omega_i}{4\pi}\vec{B}_i = -\int_S \{ j\omega\mu(\varepsilon - j\sigma/\omega)(\vec{n}\times\vec{E})\phi + (\vec{n}\times\vec{B})\times\nabla\phi + (\vec{n}\cdot\vec{B})\nabla\phi \} dS + \int_V \mu\vec{J}_s\times\nabla\phi\, dv \tag{2}$$

where Ω_i is the solid angle subtended by S at i,
$\vec{n}$ is the unit normal vector at source point,
ϕ is the fundamental solution.

The boundary surfaces between two materials are divided into a number of triangular elements on which electric field and magnetic flux density are assumed to be constant. The shape of the triangular element is defined by a linear function of coordinates. After introducing boundary conditions of electric field and magnetic flux density to the equations formed at the boundary surfaces by Eqs. (1) and (2), final simultaneous equations are set up. The eddy current in the conductor and the magnetic flux density at any point are computed by using electric field and magnetic flux density on the boundary surfaces.

COMPUTATION RESULTS

Figure 1 shows a three-dimensional steel pipe model of eddy-current testing, and Fig. 2 shows the arrangement of triangular elements; the number of elements is 648. The model shown in Fig. 2 is symmetrical with respect to x-y plane, x-z plane and y-z plane, and there is a hole at z=0.3 and $\theta=\pi/4$ in each one eighth part of the model. And then, a exciter coil applied 1 A(A.C. 30 Hz) is placed at z=0 on x-y plane. The relative permeability and the conductivity of the pipe is 400 and 3.3×10^6, respectively. Figure 3 shows the computation results of amplitude and phase of magnetic flux density on the inner surface of the pipe. The phase of magnetic flux was measured by a pick-up coil and was compared with the computation results. As shown in Fig. 3(a), the shape of the polygonal line of measured phase is similar to that of the computed phase, but there is some difference between the two polygonal lines in their levels.

Figures 4 and 5 show the distributions of eddy current on x-y plane at z=0.3 and z=0.15, respectively, and Figs. 6 and 7 show the distributions of eddy current and magnetic flux density on the inner surface of the pipe. It became clear from the figures that (1)eddy current consists of minor loops between the holes on x-y plane including the holes, (2)as the result, the phase difference and the amplitude difference of magnetic flux density arise on the x-y plane including the holes because of the changes of the eddy-current paths, (3)the peak values of the amplitude and the phase arise by the concentration of eddy current to the holes.

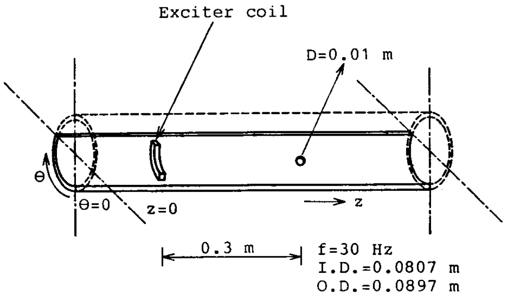

Fig. 1 A steel pipe model.

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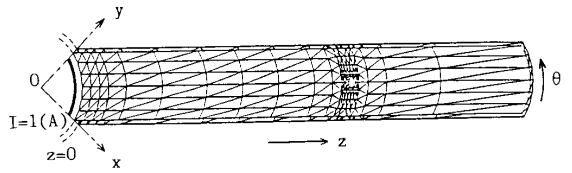
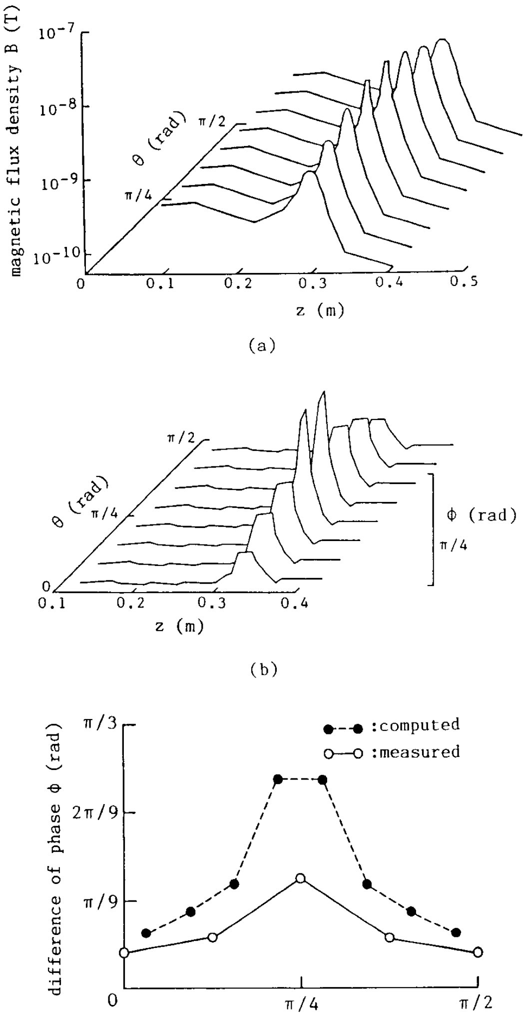


Fig. 2 Arrangement of triangular elements.

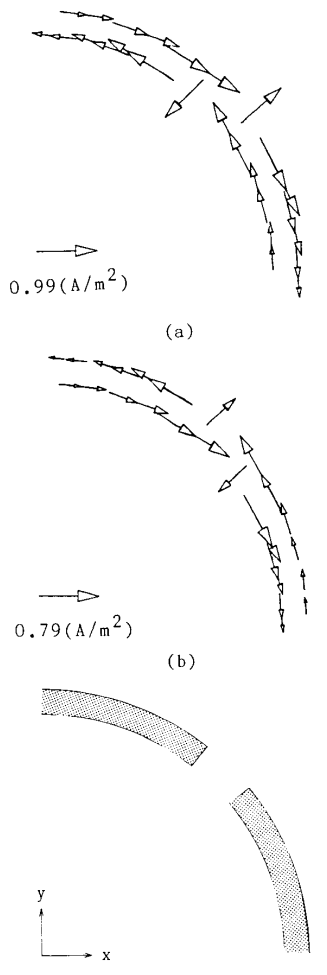


(a)

(b)

(c)

Fig. 3 Distributions of amplitude and phase of the magnetic flux density around the hole, (a) computed amplitude, (b) computed phase, (c) comparison between computed and measured phases.



(a)

(b)

(c)

Fig. 4 Distributions of the eddy current density on the cross section at z=0.3, (a) real part, (b) imaginary part, (c) the cross section.

CONCLUSION

The paper described the computation results of eddy current distributions and magnetic flux density distributions by the boundary element method. From the computation results, the mechanism of detecting holes of steel pipes by the phase difference of magnetic flux density became clear.

REFERENCES

[1] R. Palanisamy, "Electromagnetic Field Calculations for the Low Frequency Eddy Current Testing of Tubular Products," IEEE Transactions on Magnetics, Vol. MAG-23, pp. 2663-2665, September 1987.

[2] R. Palanisamy, "Prediction of Eddy Current Probe Sensitivity for the Sizing of Case Depth in Ferrous Components," IEEE Transactions on Magnetics, Vol. MAG-23, pp. 3308-3310, September 1987.

[3] T. R. Schmidt, "The Remote Field Eddy Current

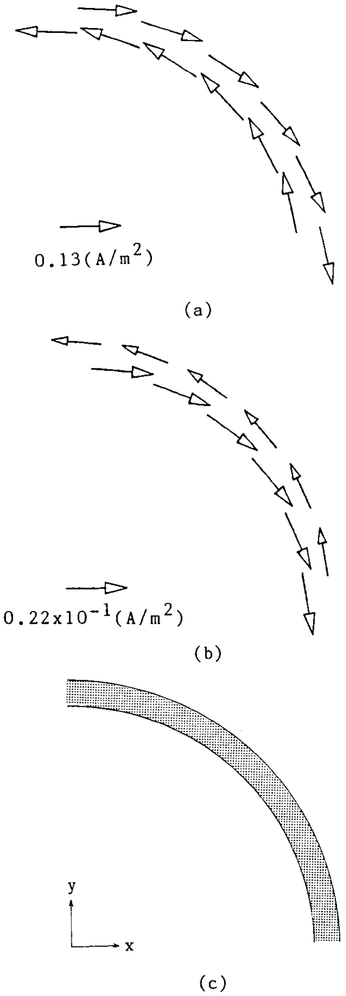


Fig. 5 Distributions of the eddy current density on the cross section at z=0.15, (a) real part, (b) imaginary part, (c) the cross section.

Inspection Technique," Material Evaluation, Vol.42, pp.255-230, February 1984.

[4] N. Ida and W. Lord, "A Finite Element Model for Three-Dimensional Eddy Current NDT Phenomena," IEEE Transaction on Magnetics, Vol. MAG-21, pp.2635 -2643, November 1985.

[5] W. Lord, Y.S. Sun, S.S. Udpa and S.Nath, "A Finite Element Study of the Remote Field Eddy Current Phenomenon," IEEE Transaction on Magnetics, Vol. MAG-24, pp.435-437, January 1988.

[6] H.Tsuboi and T.Misaki, "Three-Dimensional Analysis of Eddy Current distributions by the Boundary Element Method using Vector Variables," IEEE Transactions on Magnetics, Vol. MAG-23, pp. 3044-3046, September 1987.

[7] T. Misaki and H. Tsuboi, "Techniques for Boundary Element Analysis of Three-Dimensional Eddy Current Distribution," IEEE Transactions on Magnetics, Vol. MAG-24, pp.146-149, January 1988.

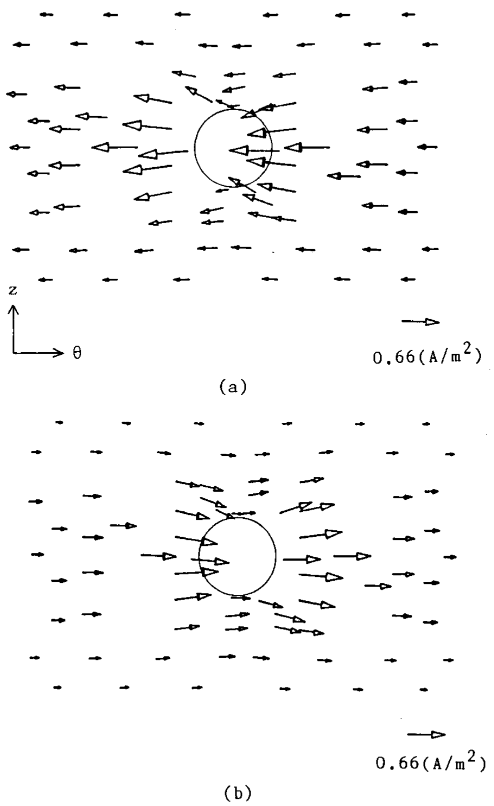


Fig. 6 Distributions of the eddy current density on the inner surface of the pipe, (a) real part, (b) imaginary part.

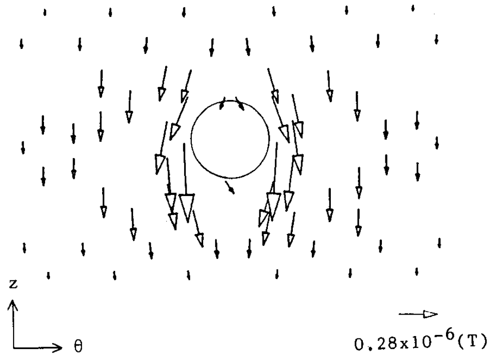


Fig. 7 Distributions of the magnetic flux density (real part) on the inner surface of the pipe.