INTERACTION OF A CURRENT-CARRYING COIL WITH A SLOT IN A CONDUCTING PLATE: A PROBLEM OF EDDY-CURRENT NONDESTRUCTIVE EVALUATION

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Abstract

Eddy-current methods are often used in the nondestructive evaluation of coducting structures. In the simplest procedure, a current-carrying coil is scanned over the conducting workpiece, inducing eddy-currents into the structure. If there is a defect (which could be a crack, or some other conducting anomaly), then the driving-point impedance of the coil changes slightly. The variation of the change in impedance with position of the probe coil is, in some sense, a signature of the defect.

By adopting the exciting current as the phase reference, the probe impedance, ΔZ, due to the flaw can be expressed in terms of the electric field, $\mathbf{E}^{(s)}$, scattered by the flaw as

$$I^2\Delta Z = -\int_{coil} \mathbf{E}^{(s)}(\mathbf{r}) \cdot \mathbf{J}_e(\mathbf{r})d\mathbf{r}, \tag{1}$$

where $\mathbf{J}_e$ is the exciting current density. Rather than use (1), it may be easier to use a reciprocity theorem to calculate the impedance change:

$$I^2\Delta Z = -\int_{flaw} \mathbf{E}^{(i)}(\mathbf{r}) \cdot \mathbf{J}_a(\mathbf{r})d\mathbf{r}. \tag{2}$$

$\mathbf{E}^{(i)}$ is the known electric field, due to the coil, that is incident upon the crack, and $\mathbf{J}_a$ is the anomalous current due to the flaw. We use the latter form in a code that we have developed for eddy-current problems [1,2].

The problem we are modeling is based on an experiment run by Dr. Steven Burke of Aeronautical Research Laboratories, Melbourne, Australia. The experiment is shown in Figure 1; a coil is scanned along the positive X-axis over a slot (produced by electro-discharge machining, or EDM). The coordinate axes are symmetrically placed with respect to the slot. All parameters are listed in Table 1. **You are to compute the change in impedance versus position, and plot the magnitude and phase of your results.** The experimental data, and results of one of our model computations, are shown in the next two figures.

Our model computations were based on a three-dimensional volume integral code that uses pulse functions for expansion and testing, and incorporates conjugate gradients and FFT algorithms [1,2]. We used 32 cells along the length of the slot, 8 across the width, and 8 in depth, for a total of 6,144 unknowns for the anomalous current density. We believe that the problem size can be reduced considerably by using first-order (piece-wise linear) expansion functions for the three current components, but continuing to use pulse functions for testing.

Acknowledgement

We are indebted to Dr. Burke for supplying us with the experimental data. Further information about the experiment can be obtained by contacting him.

References

[1] J. R. Bowler, L. D. Sabbagh, and H. A. Sabbagh, "A Theoretical and Computational Model of Eddy-Current Probes Incorporating Volume Integral and Conjugate Gradient Methods", IEEE Trans. Magnetics, Vol. 25, No. 3, May 1989, pp. 2650-2664.

[2] H. A. Sabbagh, J. R. Bowler, and L. D. Sabbagh, "A Volume Integral Code for Eddy-Current Nondestructive Evaluation", Journal of the Applied Computational Electromagnetics Society, Vol. 4, No. 1, Spring 1989, pp. 3-22.

Note Added in Proof

Certain data in Table 1 are incorrect; the following are the correct data:

The coil

Inner radius	: 6.15mm (not 6.05mm)
Height	: 6.15mm (not 6.35mm)
Lift-off	: 0.88mm (not 0.9mm)
Frequency	: 900Hz (not 4.00kHz)

Other parameters

Skin-depth at 900 Hz: 3.04mm

Details of the experiment will be found in S. Burke, "A Benchmark Problem for Computation of ΔZ in Eddy-Current NDE," Journal of Nondestructive Evaluation, Vol. 7, Nos. 1/2, 1988, pp. 35-41.

We thank Dr. Burke for bringing these corrections, and his paper, to our attention.

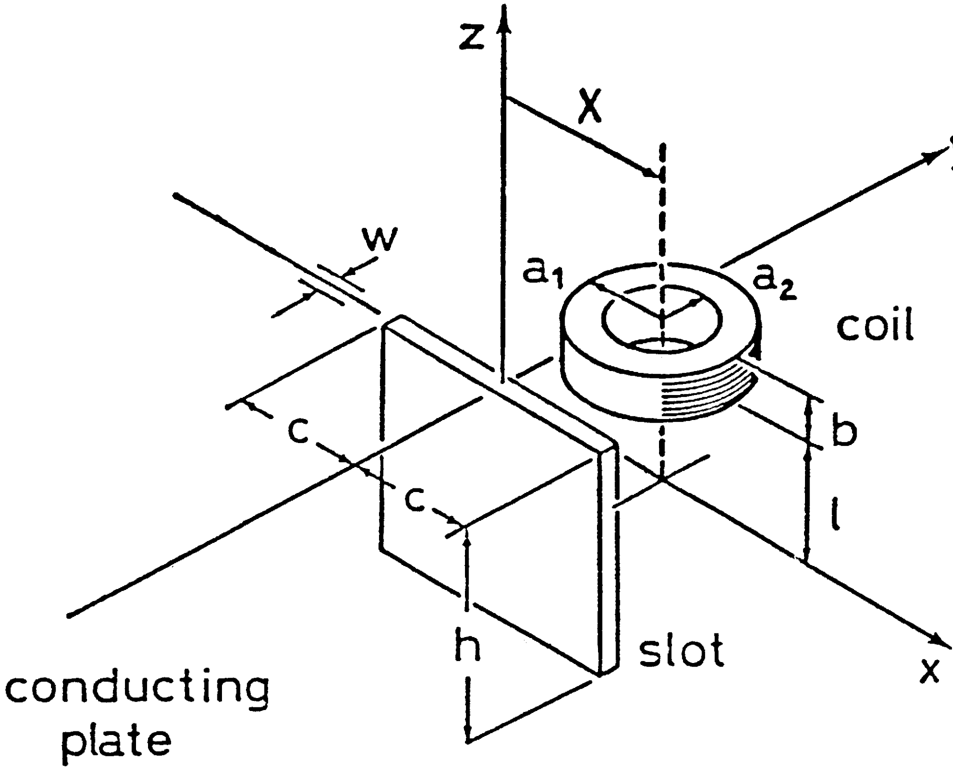


Figure 1. Schematic configuration for the benchmark experiment. The coil and slot parameters are given in Table 1.

Table 1. Experimental parameters
see also figure 1

The coil
Circular air-cored coil of rectangular cross section

Inner radius	:	6.05 ± 0.05 mm
Outer radius	:	12.4 ± 0.05 mm
Height	:	6.35 ± 0.05 mm
Number of turns	:	3790
Lift-off	:	0.9 ± 0.1 mm
Frequency	:	4.00 kHz

The test specimen
High purity aluminium plate

Plate thickness	:	12.22 ± 0.02 mm
Plate conductivity	:	3.06 ± 0.02 10^7 S/m (Measured value 4 point DC)

The defect
Rectangular EDM slot

Length	:	12.60 ± 0.02 mm
Depth	:	5.00 ± 0.05 mm
Width	:	0.28 ± 0.01 mm

Other parameters

Skin-depth at 4.00 kHz	:	1.44 mm
Isolated coil inductance	:	221.1 ± 0.1 mH
Isolated coil resonant frequency	:	26.2 kHz
Normalized reactance	:	0.704 ± 0.004 (coil on plate)

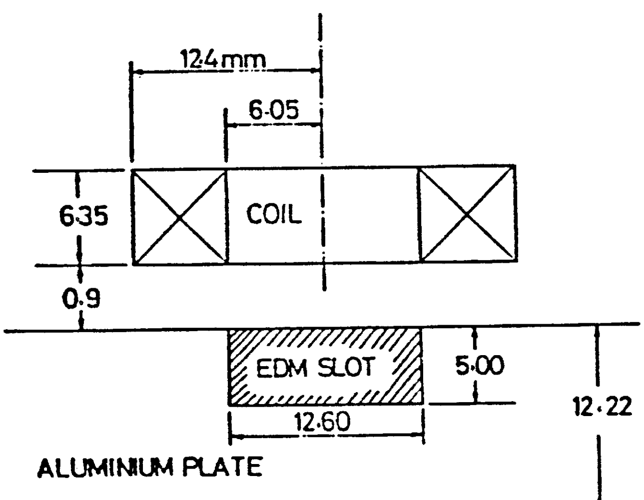
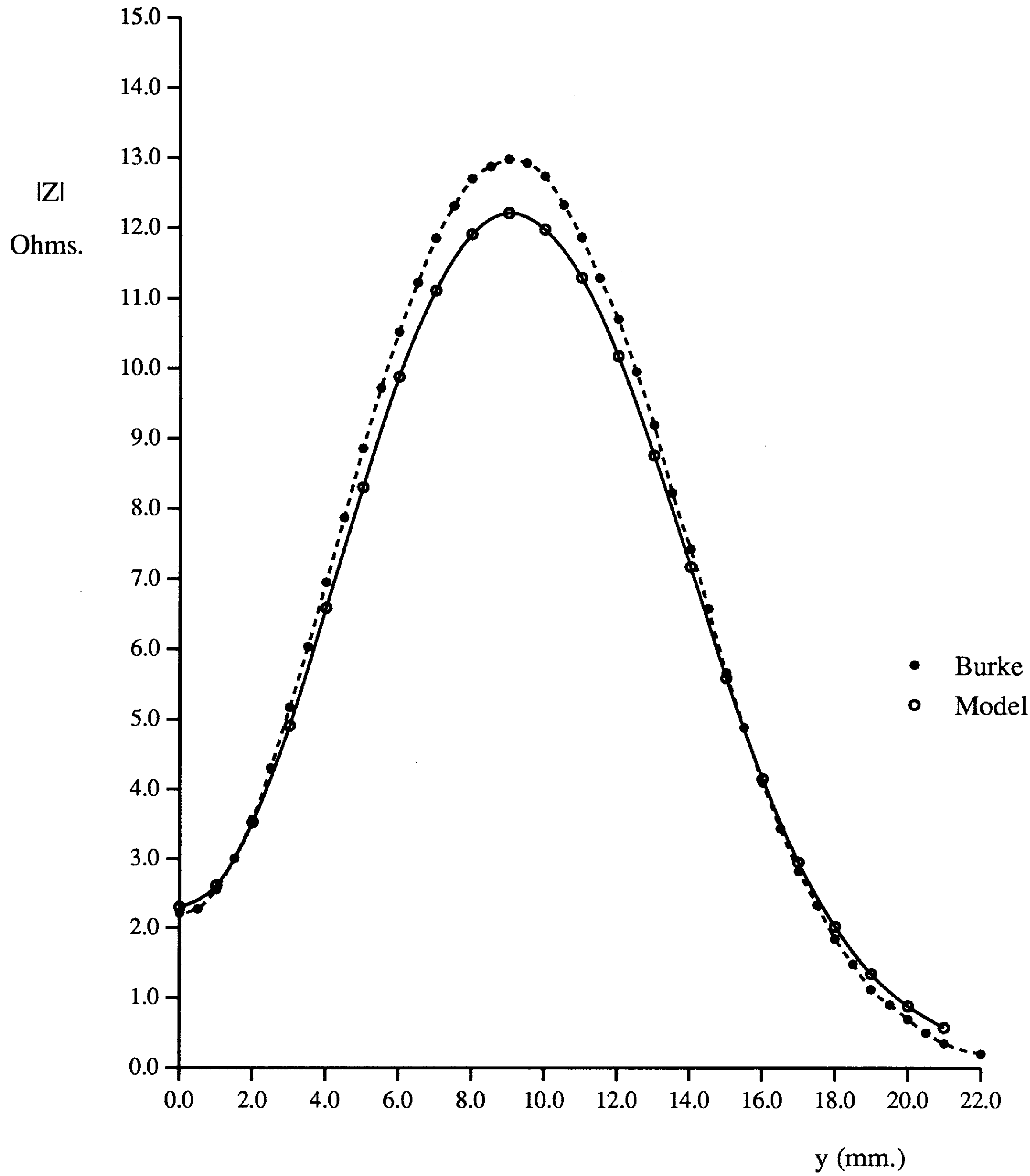


FIG. 1

Absolute value of impedance vs position.



Phase of impedance vs position.