EXPERIMENTAL MODELING OF EDDY CURRENT INSPECTION CAPABILITIES

W. R. Junker and W. G. Clark, Jr.

Metal Systems Department
Westinghouse R&D Center

ABSTRACT

An experimental modeling technique based on the use of liquid mercury samples containing artificial discontinuities has been examined to establish the applicability of this approach to the assessment of eddy current inspection capabilities. Results show that the mercury modeling concept provides an accurate, rapid and inexpensive approach to the calibration and characterization of eddy current inspection techniques. Data are presented which clearly show the impact of defect size, type and location on the eddy current response developed with a surface riding "pancake" probe. The potential of mercury modeling to enhance the understanding of eddy current inspection techniques and also to guide the development of rational analytical modeling is discussed.

INTRODUCTION

Eddy current nondestructive inspection techniques are used extensively for the examination of relatively thin metal structures or as high sensitivity tests for near surface discontinuities in heavy section components. Despite the high sensitivity inspection capabilities, the accurate sizing and characterization of discontinuities by eddy current methods is particularly difficult. Specifically, the impact of many variables (material structure, surface finish, proximity effects, etc.) create significant signal interpretation problems. The conventional approach to the resolution of eddy current defect characterization problems is to fabricate a large number of test standards
containing well characterized artificial discontinuities and to establish a reference log of eddy current response versus discontinuity type and size. As one might expect, if the eddy current signals developed during an inspection vary significantly from the calibration standard results, the accurate characterization of discontinuities becomes increasingly difficult. Under these conditions, the standard practice is to prepare even more calibration specimens in an attempt to reproduce the actual inspection results and thus, identify the source of eddy current signals. This approach can be very expensive and in some cases, it is difficult if not impossible to prepare suitable samples (subsurface discontinuities, branched cracks, etc.) Such experimental difficulties plus the absence of widely applicable analytical models currently limit the value of eddy current testing to accurately characterize discontinuities.

This paper examines the experimental modeling of eddy current inspection capabilities based upon the use of liquid mercury samples designed to represent metal components containing discontinuities. First proposed in the 1940's by Forster(1) and more recently used successfully by Blitz and Rowse(2) and Aldeen and Blitz(3), the mercury model can be used to accurately characterize the interaction between discontinuities and eddy current response.

A brief summary of past work with mercury modeling plus a detailed discussion of recent experiments designed to further evaluate the technique are included in this paper. Recommendations for further work and suggestions for the practical application of mercury modeling are discussed.

MERCURY MODEL CONCEPT

The mercury model concept proposed for the experimental evaluation of eddy current nondestructive inspection capabilities is based on the assumption that the nature of an eddy current field induced in a liquid mercury sample is essentially identical to the field produced in a fine grain, nonmagnetic structural metal. Operating under this assumption, it is then possible to fabricate liquid mercury test samples containing artificial discontinuities which accurately represent similar discontinuities in a solid structural metal. This approach not only provides a rapid, inexpensive method of specimen fabrication but virtually any conceivable defect type can be imbedded in the test sample. In addition, artificial discontinuities can be moved during the test to permit the detailed evaluation of eddy current probe-discontinuity interactions. This feature is critical to accurate defect characterization and probe design considerations. The liquid nature of the test medium also permits the convenient
evaluation of the effect of changes in specimen geometry on eddy current response.

An additional feature of the mercury modeling concept is the fact that geometrical scaling of the probe size and specimen dimensions can be used to create models which accurately represent smaller scale inspection problems. The mercury test medium can also be used to represent other nonferromagnetic electrical conductors by normalizing the eddy current response in terms of electrical conductivity parameters.

The earliest experiments conducted to substantiate the mercury modeling concept involved simple apparatus and configurations such as that illustrated in Figure 1. Later, more sophisticated instrumentation was developed which permitted the detailed evaluation of the impact of defect size, position and orientation on eddy current response. Figure 2 shows the apparatus designed by Aldeen and Blitz to control the position and orientation of an axial discontinuity in the wall of a tubing simulation sample. Results developed with this equipment showed that it was not possible to distinguish between the size and orientation of a simulated crack. However, crack depth in the radial direction could be accurately determined. The inability to characterize crack size and orientation is attributed to the limitations of an encircling coil probe. Aldeen and Blitz suggest that improved discontinuity resolution may be possible with a surface scanning probe. The experiments described in this paper were designed to address the defect characterization and sizing capabilities of a surface riding "pancake" eddy current probe.

Figure 1 - Mercury model for measuring eddy current fields within a cylinder (after Forster)
EXPERIMENTAL APPROACH

Figure 3 presents a schematic representation of the simple experimental technique used in this investigation. A rectangular plastic box is used to form the mercury sample and a nonconducting plastic rod is used to represent a drilled hole. The "hole" depth is accurately measured and controlled by attaching the rod to a standard dial gage. A "pancake" coil (copper wire wound circumferentially around a non conducting core) eddy current probe is spring loaded against the bottom of the specimen. Experiments can be conducted with the coil held stationary while moving the "flaw" or by moving the coil with the "flaw" held stationary. All experiments involved in this investigation were conducted with a set up similar to that shown in Figure 3. The mercury sample size was maintained at 6.0 in. × 10.0 in. (15.24 cm × 25.4 cm) and involved various thicknesses to 1 in. (2.54 cm). Laboratory grade mercury with a purity level of 99.9% was used in all cases. All data were generated with a 2.0 in. (5.08 cm) diameter eddy current probe used in conjunction with a state of the art NORTEC NDT-25L test instrument operating at 0.5 kHz. Experimental data were developed to demonstrate the effect and interaction of discontinuity size, type, and depth.
Figure 3 - Experimental set up for mercury sample modeling of eddy current NDE capabilities

(through the wall position) on the eddy current-flaw response. Figure 4 illustrates the four types of discontinuities studied in this investigation. Cylindrical rods, 0.25, 0.50 and 1.0 in. (0.635, 1.27 and 2.54 cm) in diameter were used to represent flat bottom holes. Flat plates of plastic 6 in. (15.24 cm) long x 0.06 in. (0.15 cm) thick were used to represent a continuous slot or crack like defect. Drilled plastic plates (0.250 in.; 0.64 cm dia. holes with .250 in.; 0.64 cm spacing) of the same overall size were used to represent a discontinuous slot and plastic spheres 0.5 in. (1.27 cm) diameter were used to represent internal pore type discontinuities. In all cases the artificial discontinuities were placed in the mercury and positioned above the test coil to yield the peak signal amplitude. Figure 5 illustrates the placement of a flat bottom hole simulator with respect to the test coil. Once the coil "hot spot" was determined with a given discontinuity, data were collected as a function of the discontinuity depth through the "wall" of the test sample. The eddy current signal amplitude and corresponding phase angle were recorded. Figure 6 illustrates the eddy current signal parameters
as determined from the test instrument display screen. The eddy current signal presented in Figure 6 represents a typical trace associated with moving an artificial discontinuity into the "hot spot" of the coil.

EXPERIMENTAL RESULTS

Figures 7 and 8 present the results of this investigation in terms of phase angle and maximum signal amplitude as a function of discontinuity depth (percent through wall), respectively. With regard to phase angle, note that the 0.25 in. (0.64 cm) and 0.5 in. (1.27 cm) diameter flat bottom "hole" as well as the 0.5 in. (1.27 cm) diameter sphere yield essentially identical results. Consequently, no distinction can be made between these discontinuities based on phase angle considerations alone. Note also
Figure 5 - Placement of discontinuities within the mercury model

Figure 6 - Data presentation scheme for eddy current modeling
that for the case of 100 percent through wall discontinuities, all of the single "point" defects group together as do the linear discontinuities (slots). As the discontinuities become more shallow the phase angle decreases accordingly however, in general, the shift in phase angle with discontinuity depth is about the same for most defect types studied.

Figure 7 - Mercury model results for various discontinuities (Phase angle response)

Figure 8 shows a wide range of signal amplitude response for the discontinuities examined. In all cases, a linear correlation exists between the discontinuity depth (percent through wall) and the log of the signal amplitude. Note that the "slot with holes" sample produced the lowest amplitude eddy current signals while the infinite slot yielded the highest signals.
DISCUSSION

The results of this investigation further substantiate the feasibility of using liquid mercury models to accurately represent eddy current inspection situations. The technique is sensitive, rapid and inexpensive as compared to more conventional calibration techniques. In addition, virtually any discontinuity type or configuration can be prepared for detailed eddy current investigation.
The preliminary experimental data generated in this study clearly demonstrate the overall sensitivity of eddy current response to a wide variety of discontinuities. The potential for using mercury models to address concerns regarding discontinuity detectability and sensitivity is clear. Questions such as: what size discontinuities of what type located where can easily be resolved. Special considerations related to probe selection and design can also be addressed. An example of the powerful potential of the mercury model approach to evaluating eddy current inspection performance is the result obtained with the drilled and undrilled infinite slot sample. Note that the signal amplitude (Fig. 8) is more sensitive to the presence of the drilled holes than is the phase angle (Fig. 7).

The simple test configuration (Fig. 3) and discontinuities (Fig. 4) examined in this investigation were selected to demonstrate feasibility and to establish overall potential. These goals having been achieved, we are now in the process of evaluating models which represent actual structures of concern (tubing). In addition, our mercury modeling plans are being integrated with our analytical effort to provide a stronger understanding of eddy current inspection capabilities.

Although the results of this investigation clearly demonstrate the value of mercury modeling, it is also important to note that such experimental techniques can serve to establish the practical limits of existing eddy current inspection methods. For example, even though the data in Figures 7 and 8 show that a "pancake" probe is very sensitive to different types of discontinuities, note that the typical data format (phase angle and signal amplitude) does not permit the accurate sizing and characterization of discontinuity type. Much more sophisticated data analysis involving such considerations as multifrequency testing, spatial analyses, etc. are required to expand the resolving power of eddy current NDE methods.

The primary disadvantages of the mercury modeling concept include the fact that mercury is toxic and must be handled carefully. Liquid mercury can only be used to represent nonferromagnetic materials and wetting and meniscus problems can distort the effective size of artificial discontinuities.

CONCLUSIONS

Pertinent conclusions associated with the evaluation of the mercury modeling concept for the assessment of eddy current inspection capabilities are summarized below.

1. Liquid mercury can be used to simulate the eddy current properties of fine grain nonferromagnetic metals.
2. Artificial discontinuities placed in a liquid mercury sample can be used to represent discontinuities in solid metallic structures.

3. Discontinuity size and type cannot be characterized from phase angle and signal amplitude data developed with a surface scanning, pancake-type eddy current probe.

4. The mercury model approach can greatly enhance the overall understanding and applicability of eddy current inspection techniques.

ACKNOWLEDGEMENTS

This work was sponsored by the Westinghouse Steam Generator Technology Division.

REFERENCES

