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EVALUATION OF A PULSED EDDY-CURRENT SYSTEM
FOR SUBSURFACE FLAW DETECTION

by

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ABSTRACT

A pulsed eddy-current system was evaluated for subsurface flaw-detection capabilities in stainless steel. The standard probes, designed for flaw detection in thin specimens, were able to indicate the presence of 3-mm-diameter holes 3 mm below the surface of a stainless steel test block. A special probe was constructed in order to obtain a deeper penetration into the material. With this probe, 3-mm-diameter subsurface holes to a depth of 9 mm could be detected. No optimization of probe design parameters was attempted in the present investigation.

I. INTRODUCTION

Eddy-current inspection is a nondestructive testing (NDT) technique used in industry for the examination of round stock, coatings, and hardness. More recently, this technique was adopted for the inspection of nuclear components such as steam-generator tubes. The need to measure an increasing number of parameters during an inspection resulted in the introduction of the multifrequency or pulsed eddy-current system. A pulsed eddy-current (PEC) system was developed at Argonne National Laboratory for the examination of stainless steel breeder-reactor fuel. The system is modular in construction (Fig. 1) and contains two current pulse generators and eight adjustable sampling points for data retrieval or parameter separation. In general, two point probes of different construction are used, one for wall-thickness measurements and the other for defect detection. These point probes can be interchanged with circumferential probes, if desired.

The PEC system was chosen because of some unique advantages over conventional equipment. Commercial systems apply continuous sine waves to a driver coil and extract information from the signal generated in the receiver coil. The number of separate parameters (e.g., wall thickness, defect location, size, and lift off) that can be detected in a multifrequency eddy-current test is twice the number of test frequencies used,¹ assuming small signals and linear approximation. Thus, a system with three discrete frequencies can yield information on six parameters. On the other hand, a pulsed system contains all frequencies within a reasonably broad band, which permits the determination of a large number of parameters. The signal in the receiver coil is sampled at adjustable delay times to obtain the desired information.² Since the depth of penetration of an electromagnetic plane wave into a conductive material is governed by the relationship

$$\delta = \frac{1}{(\pi f \mu \sigma)^{1/2}},$$

various frequency components will affect different portions of the received waveform. Here f is the frequency, μ is the permeability, and σ is the conductivity. A sampling point at a particular time is therefore comparable to one frequency in the multifrequency system, and two parameters can be resolved.³ Thus, a system with two sampling points will define, for example, four parameters: relative size of inside defects; relative size of outside defects; position of defects (inside or outside surface); and minimum lift off.

From these considerations, the following unique advantages of the PEC system become apparent:

- a. The existing PEC system with eight available sampling points is comparable to an eight-frequency system, with respect to parameter determination.
- b. The electronics are much simpler, that is, crystal-controlled oscillators and accurate frequency discriminators are not needed.
- c. Selection of sampling times makes the instrument versatile and easily adaptable to particular problems.
- d. The short duty cycle (~1%) permits the construction of a sturdy probe of small dimensions.
- e. Small probe size yields good resolution at impressive sensitivity levels (0.025-mm wall thinning and 0.037 mm deep x 1.2 mm long EDM notch sensitivity in thin-wall stainless steel tubing).
- f. The short duty cycle permits high current pulses in the driving coil (10 A peak), which results in good penetration and local saturation of ferritic materials. Small surface and subsurface defects can be detected in such materials.
- g. The pulse length is not critical to the collection of desired information.

The pulsed eddy-current method also has the following advantages over ultrasonic methods: (a) An eddy-current system does not require a couplant, and (b) more parameters can be determined with a single eddy-current probe than with an ultrasonic transducer. These advantages for the PEC suggest a much wider area of application than is being utilized at present. A system such as that described above was demonstrated to representatives of KWU, Federal German Republic during their visit at Argonne National Laboratory under a cooperative GCFR Program with General Atomics. The NDT experts expressed the desirability of applying PEC to tests for subsurface voids in stainless steel components. It was agreed that ANL will evaluate the feasibility of such tests on a standard supplied by KWU, since PEC equipment is not available commercially.

II. LABORATORY EVALUATION AND RESULTS

A test block with side-drilled 3-mm (0.125-in.)-diameter holes at various distances from the surface (Fig. 2) was obtained from KWU to evaluate the detection capability of the PEC system. In the first attempt, a standard wall-thickness coil was mounted in a square Teflon block, with the coil touching the surface to be examined. The assembly was then moved by hand across the surface of the stainless steel block, while the output of the PEC instrument was recorded on a strip chart. Figure 3 shows the trace of the strip-chart recorder for the scan over holes 1 to 3 mm (0.04 to 0.125 in.) below the surface. No indications were obtained from holes greater than 3 mm in depth. This was anticipated, since the 1.6-mm (0.063-in.)-diameter coil was designed for thin-wall tubing. A rough calculation of the penetration depth, with the applied pulse length (Fig. 4), yields a value of $\delta \approx 1$ mm. In the calculation, it was assumed that the lowest frequency in the pulse equals the initial trace excursion until the pulse decays to 1/3 of the maximum value. For the short pulse, the lowest frequency is thus ≈ 150 kHz, the conductivity is 1.4×10^6 mho/m, and the permeability is $4\pi \times 10^{-7}$ A/m. At a depth of 3 mm, the intensity has therefore decreased to $e^{-3} = 0.05$, which is the limit of detectability for the instrument.

An increase in penetration depth can be achieved by lengthening the pulse duration, which decreases the lowest frequency component present in the pulse. The pulse is generated by discharging a capacitor through the probe coil, and the discharge time is therefore determined by the coil impedance. It was necessary to construct a new probe to achieve the desired pulse lengthening. The construction of this probe was the same as the first, except the coil has a diameter of 6.35 mm (0.25 in.). The achieved pulse lengthening is shown in Fig. 5. The lowest frequency component can be estimated at ≈ 25 kHz, which would yield a depth of penetration $\delta = 2.7$ mm. Therefore, holes up to a depth of ≈ 9 mm should be detectable. The longer pulse duration necessitated a resetting of the sampling points for best results. A hand scan of the stainless steel test block resulted in the strip-chart recordings shown in Fig. 6. All holes up to a depth of 9 mm (0.354 in.) were detected. The larger probe size affected the output generated by holes close to the surface. When the probe is positioned directly above holes that are close to the surface, the output signal is reduced because the induced current is not affected by the hole. The desired output should be as indicated by the dashed line in Fig. 6a. These preliminary results indicate the feasibility to detect deep subsurface voids by the PEC system.

III. DISCUSSION

The evaluation of the PEC system indicates a wider range of possible applications. Although no effort was made to optimize the probe design or modify the electronics for this evaluation, such an endeavor will further increase the usefulness of the instrument. During the test, it became obvious that the larger the probe size the larger the effect when the probe approaches the edges of the block. It is also more difficult to hold the probe flat to the surface of the specimen, which results in a wobbling neutral line on the strip-chart trace. This could be avoided by the use of mechanized equipment.

A stronger current pulse, limited in the present instrument by the power supply, will improve the signal-to-noise ratio and ease the sample-point setting. The problem generated by voids close to the surface can be eliminated by using a double probe in a single housing. Finally, a combination of various sampling points into mathematical networks can also facilitate interpretation of results. These features were not addressed during this exploratory investigation.

REFERENCES

1. H. L. Libby, "Multiparameter Eddy Current Concepts," in Research Techniques in Nondestructive Testing, Chapt. 11, Ed. R. S. Sharpe (Academic Press, London, 1970).
2. D. L. Waidelich, "Pulsed Eddy Current," in Research Techniques in Nondestructive Testing, Chapt. 12, Ed. R. S. Sharpe (Academic Press, London, 1970).
3. C. W. Cox, "Data Handling Techniques," in Research Techniques in Nondestructive Testing, Chapt. 7, Ed. R. S. Sharpe (Academic Press, London, 1970).

Fig. 1. Pulsed Eddy-current System.

Fig. 2. Stainless Steel Test Block.

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Fig. 3. Strip-chart Recording of Standard Probe (Holes 1 to 3 mm below Surface).

Fig. 4. Pulse of Standard Probe.

Fig. 5. Pulse with Special Probe.

Fig. 6. Strip-chart Recording of Special Probe.