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**Eddy-Current Detection of Cracking
During Thermal Transients**

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by

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EDDY-CURRENT DETECTION OF CRACKING
DURING THERMAL TRANSIENTS

by

N. B. Edenborough

ABSTRACT

An eddy-current system for detection of cracking during thermal transients at about 1700°R is described.

INTRODUCTION

The Los Alamos Scientific Laboratory has been conducting a number of experiments to determine the high temperature characteristics of composite pedestals. (Figure 1 is a drawing of a pedestal.) The pedestal is a support member of the Phoebus reactor, positioned near the exit (hot) end of the reactor. Composite material is a graphite-niobium carbide mixture formed by hot pressing.

One of the characteristics of interest was the thermal gradient the pedestals could withstand without cracking. The thermal gradient tests were performed in the furnace shown in Figs. 2 and 3. This furnace was heated in a closed helium atmosphere by passing current through the graphite radiator (center cylindrical object in Fig. 3). The pedestal was centered within this radiator on a water-cooled probe. When the radiator was heated with 10,000 amperes of current, the exterior surface of the pedestal heated much more rapidly than the inner surface, producing a thermal gradient from the outside to the inside of the pedestal.

The temperatures inside the pedestal during the test were as much as 4000°R, with the maximum thermal gradient occurring at approximately 1700°R. The total test

time was typically 30 seconds. Thermal gradients varied from 0° to 500°R with the maximum occurring at approximately 13 seconds.

The Nondestructive Testing Group (GMX-1) of LASL was asked to develop a technique that would detect when a crack occurred. Otherwise, many tests would have to be run at various maximum thermal gradients bracketing that necessary to crack the pedestal. The high cost of pedestals and tests made this undesirable.

THE EDDY-CURRENT SYSTEM

Eddy-current testing methods were attempted because it was felt that this technique could work at the temperatures and gradients involved. Eddy-current testing techniques utilize a coil energized at high frequencies. If a conductive material is placed near the coil, eddy currents are produced in the material. The coil impedance changes owing to the currents flowing in the material. If some defect occurs in the material which breaks up the flow of the eddy currents, a corresponding change is produced in the impedance of the coil.

The primary feature of the eddy-current test which made it the most amenable to this problem was the probability that a coil could be made which would withstand

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the temperatures involved. Also, the wires to the coil should be fairly easy to bring out of the furnace under sealed condition. Tests were run to perfect the eddy-current techniques. These consisted of (1) cracking pedestals at room temperature to determine the electronic system necessary, the sensitivity, etc., (2) running various coil designs at high temperatures to check out their material and physical properties, and (3) actual high temperature runs with pedestals of graphite and composite material.

A coil was developed on the basis of the room temperature and high temperature preliminary tests. The coil form was made of boron nitride and wound with tungsten-26% rhenium wire. The coil was to be placed in the large bore of the pedestal. The wires had to be insulated from the pedestal yet be as close to it as possible. No high temperature insulating material was found which could easily be formed to the necessary shape; therefore the wires were wound in deep slots in the boron nitride to provide standoff.

The coil design is shown in Fig. 4, and a probe is shown in Figs. 5 and 6. The wires exit from the probe at the rear of the coil form in a relatively cool section of the furnace. From that point to the furnace exit they are insulated with ceramic sleeves and held against the cold probe. The furnace insert assembly is shown in Fig. 7.

The impedance change effects produced by heating the coil were evaluated. Figure 8 is a graph of the changing impedance of the coil as it is heated, normalized to room-temperature values. Note that the magnitude increases 50% while the phase changes 64° from ambient to 3090°F . The effect of a crack in the pedestal was determined to be approximately 5% and is also plotted on this graph. This effect was

evaluated by measuring the impedance of the coil first within an uncracked pedestal, then within a cracked pedestal, at room temperature. The electronic system should be capable of resolving a 5% change in impedance while responding to a 50% change. Note that while changing temperature produced changes in both magnitude and phase, a crack affected only the magnitude. This feature was useful in separating temperature effects from the effects of cracks.

A block diagram of the electronics system is shown in Fig. 9. The main feature of this system is the Hewlett Packard 3405A Vector Voltmeter. This device is capable of measuring the absolute magnitude and comparative phase of a voltage (B) in relation to a standard (A). The output is two dc voltages which are proportional to the full scale meter readings of both phase and magnitude. Since the signal change produced by a crack is a small step in the magnitude of the impedance, a time differentiation system was inserted to amplify the effects of this step for easy visualization. All output was recorded on a 6-in. Honeywell Visicorder.

THE CRACK-DETECTION TESTS

Five fully instrumented, high temperature runs were made. Figure 10 shows a typical coil and pedestal after a test. The insulated wires to the pedestal are for the thermocouples. Figure 11 is a close-up of this tested pedestal showing the crack that was produced. The coil form shown in this photograph had been of larger diameter; a corner was milled off for thermocouple insertion. The coil after test is shown in Fig. 12. Note that there is some relatively minor corrosion damage. Figure 13 is a typical oscillograph trace from a test. The crack indication is easily visible.

Pedestal cracking occurred at approximately 500°R thermal gradient from the

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outside to the inside of the pedestal. This gradient occurred at about 1700°R . The eddy current coil failed at approximately 3600°R . This failure was in all cases due to brittle fracture of the leads at the point where the windings turned 90° to go through the coil form. This failure would probably have been avoided if the bends had not been so sharp. However, a redesign of the coil form was not felt to be necessary since the failures occurred well after the crack initiation.

CONCLUSION

An eddy-current coil was developed which detected the occurrence of cracking in pedestals during thermal transients. The coil, a boron nitride coil form with tungsten-26% rhenium wire, was excited at 1 MHz. The typical temperature of crack occurrence was 1700°R . The coil withstood up to 3600°R ; this temperature could probably be extended if the coil form were redesigned.

Fig. 1. A pedestal.

Fig. 2. High temperature furnace used for eddy-current tests.

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Fig. 3. End view of furnace showing radiator (center cylindrical object).

Fig. 4. Cutaway drawing of high temperature eddy-current probe.

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Fig. 5. High temperature eddy-current probe.

Fig. 6. Close-up of coil on probe.

Fig. 7. Furnace insert assembly.

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Fig. 8. Impedance change, with temperature, of high temperature eddy-current coil amplitude normalized to ambient.

Fig. 9. High temperature eddy-current electronics.

Fig. 10. Pedestal and probe after test.

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Fig. 11. Pedestal after test showing crack.

Fig. 12. Probe after test.

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Fig. 13. Typical oscillograph trace of a high temperature test.

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