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IN-CORE EDDY-CURRENT MEASUREMENTS OF THE ATR FUEL ELEMENT CHANNEL SPACING

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**IN-CORE EDDY-CURRENT MEASUREMENTS
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CHANNEL SPACING**

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and

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INSTRUMENTATION AND CONTROL BRANCH

AEROJET NUCLEAR COMPANY

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ABSTRACT

During the Core I tests, or first power tests of the Advanced Test Reactor, it was necessary to measure coolant channel thickness, spacing in selected fuel elements. A nondestructive testing technique has been adapted and used successfully to make this difficult underwater measurement, restricted by small space, thermal gradients, a radioactive environment. Measurements had to be made in-core with standby coolant water flowing while the elements were still giving off a considerable amount of decay heat. These requirements imposed the following restrictions on the measuring transducer: It had to be small enough to be inserted in a channel as small as 0.055-inch thick; range up to 0.120 inch; have good resolution, low radiation sensitivity, an output independent of temperature, and produce highly repeatable measurements.

The transducer chosen was an eddy-current type using phase demodulation techniques to separate unwanted signals. The technique has proved itself in field applications and opened the way for future use of this transducer type in many severe environments.

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IN-CORE EDDY-CURRENT MEASUREMENTS

OF THE ATR FUEL ELEMENT

CHANNEL SPACING

I. INTRODUCTION

During Core I tests on the Advanced Test Reactor, it was necessary to measure the coolant channel spacing in the core fuel elements. This requirement resulted from an ATR fuel-element design that incorporated a curved cross section in the fuel plates themselves. (The fuel element length is approximately 50 inches.)

The purpose of the measurements was to detect any change in the fuel plates during the test which would reduce the coolant channel spacing and in turn lead to a tendency to burn out; changes included blistering, separation of the fuel plate, buckling of the fuel plates, oxide buildup, or distortion of the entire element. To investigate and determine these changes, a single special fuel-element assembly was designed to run at higher temperatures. The element was fabricated by Oak Ridge with two extra thick plates containing additional fuel (Figure 1). The test assembly was located in ATR position 12 (Figure 2); this section was designed to run at the equivalent of full-power reactor conditions during higher power levels of a test series in which overall reactor power would not be taken to a maximum.

The special element was instrumented with thermocouples and pitot tubes to monitor temperature and flow during a run and possibly prevent a fission break from occurring should a drastic change in conditions occur. In addition, it was required that the thickness of the instrumented channels be measured between each test of the series. Measurements had to be made in-core with standby coolant water flowing and while the elements were still giving off considerable amounts of decay heat. These requirements imposed the following restrictions on the measuring element or transducer: It had to be small enough to be inserted in a channel as small as 0.055 inch; it required a range of up to 0.120 inch, good resolution, a low radiation sensitivity, low temperature sensitivity, and measurements that were highly repeatable.

Fig. 1 Special ATR fuel element.

ANC-C-16808

Fig. 2 ATR schematic cross section.

II. THEORY OF OPERATION

The transducer chosen for the ATR-channel-thickness measurement was an eddy-current type. This choice was based upon a report by C. V. Dodd, Metals and Ceramic Division, Oak Ridge National Laboratory on eddy-current coolant channel spacing probes^[1].

The development of an eddy-current transducer can be divided into two basic parts:

- Design and fabrication of a detector to meet environmental and experimental conditions
- Design and construction of electronic circuitry needed to excite the transducer and produce a usable signal.

When an electrical conductor is placed in an alternating magnetic field, eddy-currents are induced in the conductor. The magnitude, phase, and distribution of these eddy-currents are determined by the size, shape, electrical conductivity, porosity, magnetic properties, and the presence of flaws in the material. In a test situation the magnetic field used to induce the eddy-currents is obtained by applying an ac voltage to a test coil. As the test coil approaches the sample the eddy-currents are induced in the sample. The induced eddy-currents create a magnetic field which interacts with the field of the test coil. This interaction produces an impedance change in the test coil; the change is a complex function of all the parameters which affect the eddy-currents themselves. All of these factors, including any perturbations caused by the experimental conditions, must be considered in the coil design.

To use eddy-currents as a measurement tool requires the analysis of a complex impedance problem. Impedance contains both resistive and reactive components -- hence, phase information is present, all of which may or may not vary linearly with any of the variables attributed to the sample in which the eddy-currents are induced.

ATR measurements were to be made over a long period of time during which oxide buildup could continually change the characteristics of the channel walls. This meant that the eddy-current transducer must not "look" at the channel wall but rather at some other target whose properties did not change with time but whose physical position did follow variations in channel spacing. The physical dimensions dictated the use of a flat, thin coil; the final design was a rectangular, helical coil on a printed circuit material (Figure 3). This coil was sandwiched between two phosphor bronze leaves of a buggy spring arrangement. The coil then "looked" at the phosphor bronze. The frequency of operation of the transducer was chosen high enough so that eddy-currents were induced in the spring only and not in the channel walls. Although, this is not actually possible in practice, a frequency can be chosen such that the amount of eddy-currents induced in the channel wall and their effect on the overall measurement is negligible, if the transducer is calibrated under suitable conditions. The depth of penetration, δ , for eddy-currents is a function of frequency. A standard depth of penetration is defined as the depth at which the magnetic field intensity has decreased by $1/e$. At the frequency used in this application, δ was equal to 0.0068 inch. Further design considerations (later discussed more thoroughly) were governed by physical dimension limitations.

Consider the flat, rectangular, helical coil between two phosphor bronze spring surfaces. The coil and springs are arranged to permit either spring to follow the contour of

Fig. 3 Printed circuit coil.

the channel wall. When the channel spacing decreased, the distance from coil to spring decreased; when spacing increased, the distance from coil to spring increased. As the distance from coil to target changes, the reflected coil impedance changes. In eddy-current terminology, this distance or spacing from coil to target is called "lift off".

Other factors, previously mentioned, which affect coil impedance can be controlled by properly selecting design materials and concepts. The only other variable which cannot be eliminated by design techniques is electrical conductivity. Because the measurements were made at different temperatures, an electrical conductivity change with temperature occurred in the target. This meant that in addition to coil impedance changing due to "lift off" or distance from target, another change related to electrical conductivity would also occur.

Fortunately, both variables produce changes in impedance that are phase separable. For instance, if the impedance of a test coil is measured as a function of "lift off" and electrical conductivity changes, an impedance diagram related to these variables can be created as shown in Figure 4^[2]. The solid lines indicate lines of constant distance, with varying electrical conductivity, while the dashed lines designate lines of constant conductivity, with varying distance ("lift off").

To obtain the desired information related to the pertinent variable (in this case distance), it is only necessary to look in some direction in the complex impedance plane where the undesirable variables are eliminated or minimized and where the test parameter has a large component of variation. This is accomplished electronically through phase sensitive demodulation techniques.

A block diagram of the electronic circuit used to accomplish phase sensitive detection is illustrated in Figure 5. Excitation is provided by a 1.0 MHz crystal controlled oscillator buffered by a power amplifier driving a coil drive amplifier and a phase shift reference amplifier. The output of the coil drive and reference amplifiers drives six different channels of signal conditioning electronics. Each channel consists of a ring bridge demodulator fed through an isolation amplifier with phase adjustment control. The coils are driven through an isolation amplifier followed by two stages of gain into the ring demodulator. The guard shield is driven through another amplifier with amplitude and phase adjustments to enable the line to be balanced and, thereby, prevent capacitance losses. The output of the ring demodulator is amplified and recorded on an oscillograph.

Fig. 4 Normalized impedance diagram.

Fig. 5 Block diagram of electronics.

III. MECHANICAL DESIGN

In order to measure the coolant channel spacing, the transducer had to be long enough to traverse the full length of a fuel element and thin enough to pass through the channel. The transducer finally used was a probe 70 inches long x 9/16 inches wide x 0.046 inches thick. Figure 6 is a photograph of some of these probes. Probes were fabricated from 3/8 inch OD x 0.010 inch wall, 304 stainless steel tubing. The tubing was rolled to 0.046 inch thickness with a "window" milled in one end; the clamping bars were welded on, wires strung through, the transducer assembly installed in the "window", the tip rounded, TIG welded, polished, and finally vacuum potted full of high strength epoxy. The two lead wires were connected at the end of the probe to a small coaxial lead cable, potted, and enclosed in a welded end cap. Figure 7 is a photograph of the parts and assembly showing the detailed assembly of the transducer in the probe end.

It was desired to make measurements six at a time in order to reduce reactor downtime; probes were mounted in a fixture which could be placed over a fuel element and all six probes simultaneously inserted or withdrawn. Problems were compounded by the desire to take measurements at different horizontal locations in the fuel element. The fixture used was designed so the probes had to be shifted only once to make all desired measurements for a single run. These positions are shown in Figure 8.

Figure 9 is an overall view of the probe-mounting fixture used. A cross section of this fixture had the same outside dimensions as a fuel element and contained telescoping supports to prevent buckling of the probes as they were driven into the element; the fixture also contained a drive screw which carried a block to which the upper ends of the probes were attached and incorporated a movable attachment to change the probes from the X_1 to the X_2 position.

Figure 10 is a detailed view of the guide block at the end of the fixture with probes in the X_2 position and extended to the approximate position where the springs enter the fuel channels. In order to change the probes from one position to the other it was necessary to remove the fixture from the reactor, completely retract them, move the locating fixture, and advance the probes into the new position in the guide block.

A drive mechanism using an electric motor, SCR speed control, reduction gear box, and friction clutch was connected to the fixture by means of a flexible drive to insert or withdraw the probes. This drive also was connected through reduction gearing to a ten-turn precision potentiometer that recorded a position-reference data trace to give a correlation between the measurements and distance from the end of the fuel channels.

Fig. 6 Completed probe assembly.

ATR CHANNEL THICKNESS MEASURING PROBE

PHOSPHOR BRONZE FOLLOWER SPRING

EDDY CURRENT COIL

PROBE LENGTH - 70.5 INCHES

Measurement Range - 0.050 in. to 0.120 in.
Resolution - ± 0.001 in.
Total Probe Thickness - 0.046 in

Fig. 7 ATR channel thickness probe.

Fig. 8 Measurement positions X_1 , X_2 .

Fig. 9 Probe fixture with probes.

Fig. 10 Guide block assembly.

IV. OPERATING PROCEDURES

Making a measurement involved many details; only the major points are covered here. In order to make a measurement the reactor had to be shut down, an allowance made for an appropriate cooling off period, the water pressure dropped to atmospheric, the water level lowered, and a top access hatch cover removed.

The measurement system was prepared by setting the probes at a reference point in the guide block to adjust the output to midscale on the recorder. The probes were then extended and a calibration block with 0.010 inch steps from 0.056 to 0.120 inch was used to calibrate each probe individually. A short record of each step on each probe was recorded as a calibration reference. The probes were then returned to the reference point in the guide block and checked for return to the midpoint. With the probes in this position the fixture was placed in the reactor and the end of the guide block inserted into the end box of the fuel element. Figure 11 is a photograph of the fixture in position to make a measurement. The probes at this time were still in the reference position and a short record was made to show that water, temperature, handling, or other extraneous variables had not changed the output. If the output remained unchanged, the system was then considered ready for the first measurement.

Probes were extended to the bottom of the fuel element by hand, the position pot set on zero, the recorder was switched on, and the drive started. The drive and recorder were stopped when the probes were completely out of the element. The probes were returned to the reference position and a short record of output was made to observe any changes. This completed the first measurement.

The fixture was removed from the reactor, the probes moved to the X_2 position, a reference point reading made, and the fixture replaced in the fuel element. The reference point reading was again checked and the second measurement taken. When the fixture was removed from the reactor after the second measurement, a final calibration was made.

Measuring procedures provided a check on zero shift, sensitivity, and calibration which could be relied upon throughout both measurements and which were permanently recorded with the data for future reference at any time. The above procedural steps are not necessarily in order of accomplishment, as some could be done concurrently.

Fig. 11 Probe fixture in position for measurement.

V. RESULTS

From a measurement point of view, the data proved satisfactory. In general, the system showed a repeatability of ± 0.002 inch over a range of 0.050 to 0.120 inch with temperatures varying over a range as great as 100°F -- starting with a cold element, warming through the test period, and ending with a hot element. It took several weeks to complete measurements on both elements in-core.

A typical measurement run as recorded on the oscillograph was photographed and is shown in Figure 12.

The data were not used as an absolute measurement but as a comparative measurement. After the element was inserted in the reactor core and before any operation, a first measurement was made. This established a baseline value against which all future measurements were compared. These baseline measurements were also checked against measurements made by a mechanical technique on the element before insertion. Agreement was quite good between the two. The criteria applied on additional measurements was that any changes in fuel-channel spacing in excess of 0.015 inch from the baseline were grounds for terminating the test. No such changes were found during the measurements.

END

Fig. 12 Typical measurement data.

VI. REFERENCES

1. C. V. Dodd, *Design and Construction of Eddy-Current Coolant-Channel Spacing Probes*, Microtecnic Nuclear Physics, Vol. 18, No. 6.
2. Ibid, (Diagram used by permission of C. V. Dodd).