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Eddy-Current Inspection for Steam Generator Tubing Program Semiannual Progress Report for Period Ending June 30, 1984

C. V. Dodd
W. E. Deeds
J. H. Smith
R. W. McClung

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U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
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METALS AND CERAMICS DIVISION

EDDY-CURRENT INSPECTION FOR STEAM GENERATOR TUBING PROGRAM SEMIANNUAL PROGRESS REPORT FOR PERIOD ENDING JUNE 30, 1984

C. V. Dodd, W. E. Deeds, J. H. Smith, and R. W. McClung

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EDDY-CURRENT INSPECTION FOR STEAM GENERATOR TUBING PROGRAM
SEMIANNUAL PROGRESS REPORT FOR PERIOD ENDING
JUNE 30, 1984

C. V. Dodd, W. E. Deeds, J. H. Smith, and R. W. McClung

SUMMARY

Eddy-current inspection is the most suitable method for rapid boreside evaluation of steam generator tubing. However, small flaws can be masked by the effects of harmless variables, such as tube supports. To identify the critical properties accurately and reliably in the presence of extraneous signals caused by variations of unimportant properties, sufficient information is needed to identify harmful variations and to reject harmless ones. For this reason we are developing instrumentation capable of measuring both the amplitude and phase of the eddy-current signal at several different frequencies and computer equipment capable of processing the data quickly and reliably. Our probes and test conditions are also computer-optimized. The most recent probe design embodies an array of small flat "pancake" coils and improves the detection of small flaws and the rejection of tube support signals. We adapted our new IBM System 9000 computer to take and process the larger amounts of data required by additional variables, such as copper coating and intergranular attack. We also completed construction of the hand-wired versions of the 8- and 16-coil arrays and the multiplexing circuitry and computer codes to handle the data.

INTRODUCTION

This program was established to develop improved eddy-current techniques and equipment for the in-service inspection of steam generator tubing. The purpose is to separate the effects of relatively harmless variables such as denting, probe wobble, tubesheets, tube supports, and conductivity variations from critical ones such as defect size, defect depth, and wall thickness variations.

PROGRESS DURING PERIOD ENDING JUNE 30, 1984

As many as 3000 or 4000 combinations of properties may occur in steam generator tubing because many variables must be included. For each combination, at least 16 numbers must be stored in the computer memory, and still more memory is required to perform a least-squares fitting of such large mathematical arrays. The memory capacity of our ModComp IV minicomputer limits it to about 1200 combinations of properties. Our new IBM System 9000 microcomputer is able to handle about 30,000 combinations, which are needed for including the effects of additional variables (such as iron oxide or copper deposits on the tubing) to "train" the computer to recognize and measure or ignore such variables.

We have assembled and tested a position controller that interfaces with the new IBM System 9000 computer and will allow us to make our readings directly from that computer rather than from the ModComp. However, we encountered problems in interfacing the IBM System 9000 with the position controllers. Superior Electric and IBM have now resolved the differences between the IEEE-488 bus drivers in the IBM System 9000 computer and the Modulynx motion controllers, and new software was shipped to ORNL to correct the problem.

The computer will now position the scanners in the correct position and take the readings over the IEEE-488 bus. The motor control system drives indexers that allow automatic comparison of the actual motor position, as measured by encoders, with the number of pulses sent to the motor. An automatic correction is performed on command from the computer.

We also had to modify the ModComp programs to run on the IBM computer. In particular, we modified the program BIGRDG to control the probe positioner and take the readings from the three-frequency eddy-current instrument over the IEEE-488 bus. The ModComp program BIGFIT also had to be modified to enable the IBM computer to process the larger amounts of data acquired with the BIGRDG program.

Another main developmental effort was to interface the three-frequency eddy-current instrument with the multicoil arrays of the small pancake coils. One array may have as many as 16 coils, so connecting each coil to a separate instrument would be impractical. Therefore, we started developing a multiplexer that can take readings from each of the coils in sequence. As described earlier, we had found that a certain amount of time was required for the reading from a given coil to "settle down" after the current to it was switched on. To save time and increase the inspection speed, we decided to have the computer take readings from one coil while the preceding coil was being switched off and the following coil was being switched on.

Both the 8- and 16-coil arrays have two rings of coils around the inner circumference of the tube, separated by a short axial distance. The circuits switch on one coil from each ring alternately to protect the coil being read from transient effects that may occur when a nearby coil is being switched on or off.

The multiplexing circuits for the 8- and 16-coil arrays are constructed on a narrow strip that fits inside a 13-mm-diam (1/2-in.) tube. They were first tested with the multiplexing circuit of the multifrequency eddy-current instrument by using light-emitting diodes (LEDs) in place of the coils to ensure the proper switching sequence. Then the multiplexing circuits for both the 8- and 16-coil arrays were tested with small copper shims over the coils to verify the proper switching sequence of the constructed probes. The circuits are now installed in 8- and 16-coil arrays.

The microcomputer program to transfer data to the IBM System 9000 computer over the IEEE-488 bus was rewritten to transfer the data at higher rates. The initial version took 150 ms for three frequencies, with the improved versions taking 28 ms for transmission of ASCII data. A version to transmit the data in binary only takes 15 ms, but it may not work on all types of computers. The IBM computer has a delay of 6 to 16 ms after the data are transmitted; the delay contributes to much of the reading time. We shall also try another driver that was written by IBM and is faster for data transmission.

The eight-coil array was tested on the eddy-current instrument in the first multiplexed mode. The readings were correct for the ASCII data transmissions, but a small error occurred for the binary data transfers. We tested a variable delay after the array is switched from one coil to the next before the reading is made to determine how long it takes for the voltage to become stable. The readings settle to within about 10 mV of the final reading when the system operates at a rate of 40 readings per second.

Figure 1 shows the sixteen-coil multiplexing circuit breadboarded with the LED indicators. Figure 2 shows a probe with an eight-coil array. Each of the eight pancake coils is behind one of the inverted-V black plastic bulges, which are pressed outward against the inner wall of the tube. The white nylon whiskers keep the probe body centered in the tube. The conical nose cone facilitates insertion of the probe into the tube, and the multiplexing circuitry is contained in the gray housing at the right.

ORNL-PHOTO 2517-84

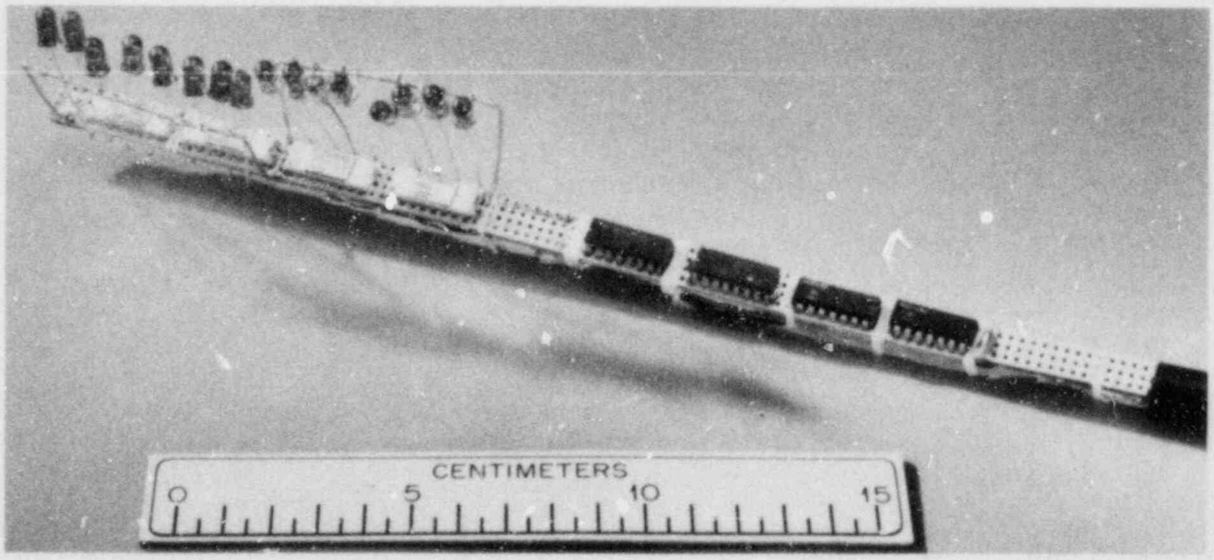

Fig. 1. Breadboarded sixteen-coil multiplexing circuit with temporary light-emitting diode indicators.

ORNL-PHOTO 2518-84

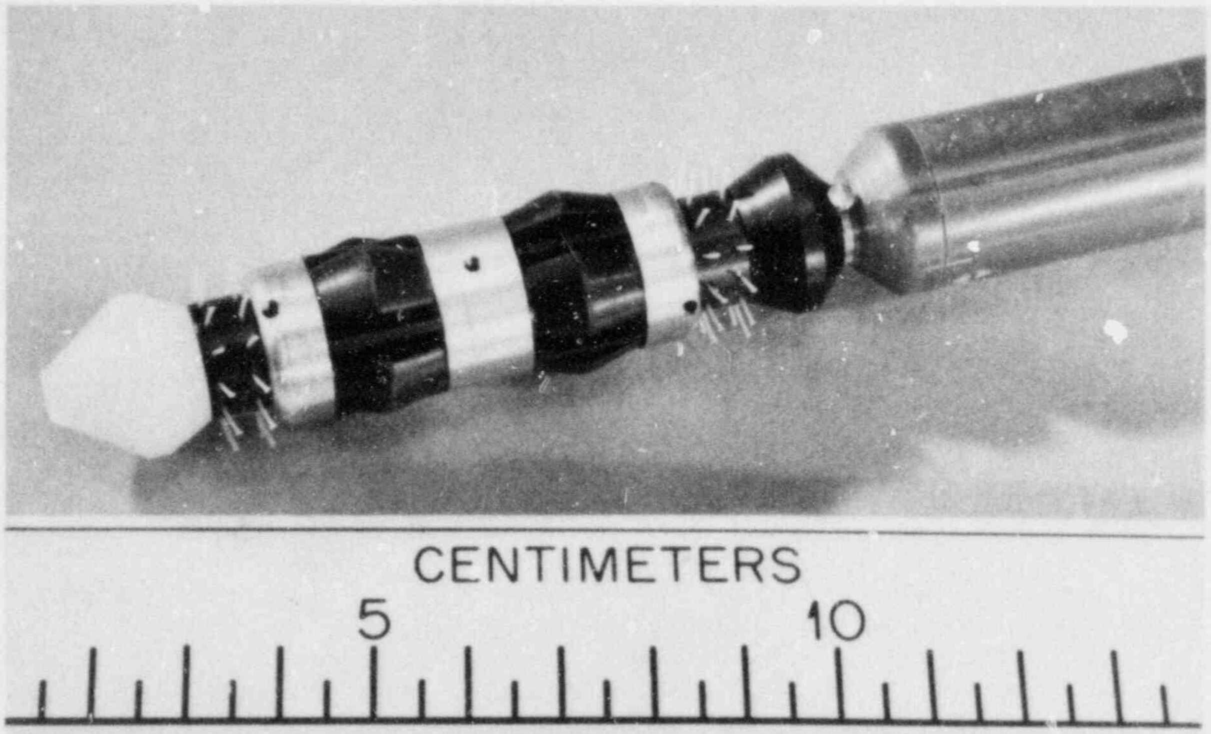

Fig. 2. Probe with array of eight pancake coils.

We also started eddy-current examination of tubes with stress-corrosion cracking prepared by Pacific Northwest Laboratories (PNL) for a round-robin test. The tube scanner for inspection of the PNL tubing was completed, and scanning of the tubing has started. The tubes were scanned for 76 mm (3.0 in.) along their length with readings every 0.6 mm (0.026 in.) in both the circumferential and axial directions. This gave 120 points around the tube and 120 points along the tube. Some of the tubing was found to have ferromagnetic regions, so a saturating magnet was constructed to fit the new scanner, and the tubes with the ferromagnetic indications were scanned again. A special scan was made of the two tubes with thinned walls. Several plotting techniques were used to display the data. The fine scan allows every defect to be pinpointed, and the data can be reevaluated after the tube is burst to determine which defect (or group of defects) caused the failure. The data are stored on 133-mm (5.25-in.) floppy disks with four tubes per disk. Figures 3 and 4 are representations of two typical scans of tubes with stress-corrosion cracking, which shows up very clearly.

ORNL-DWG 84-1924

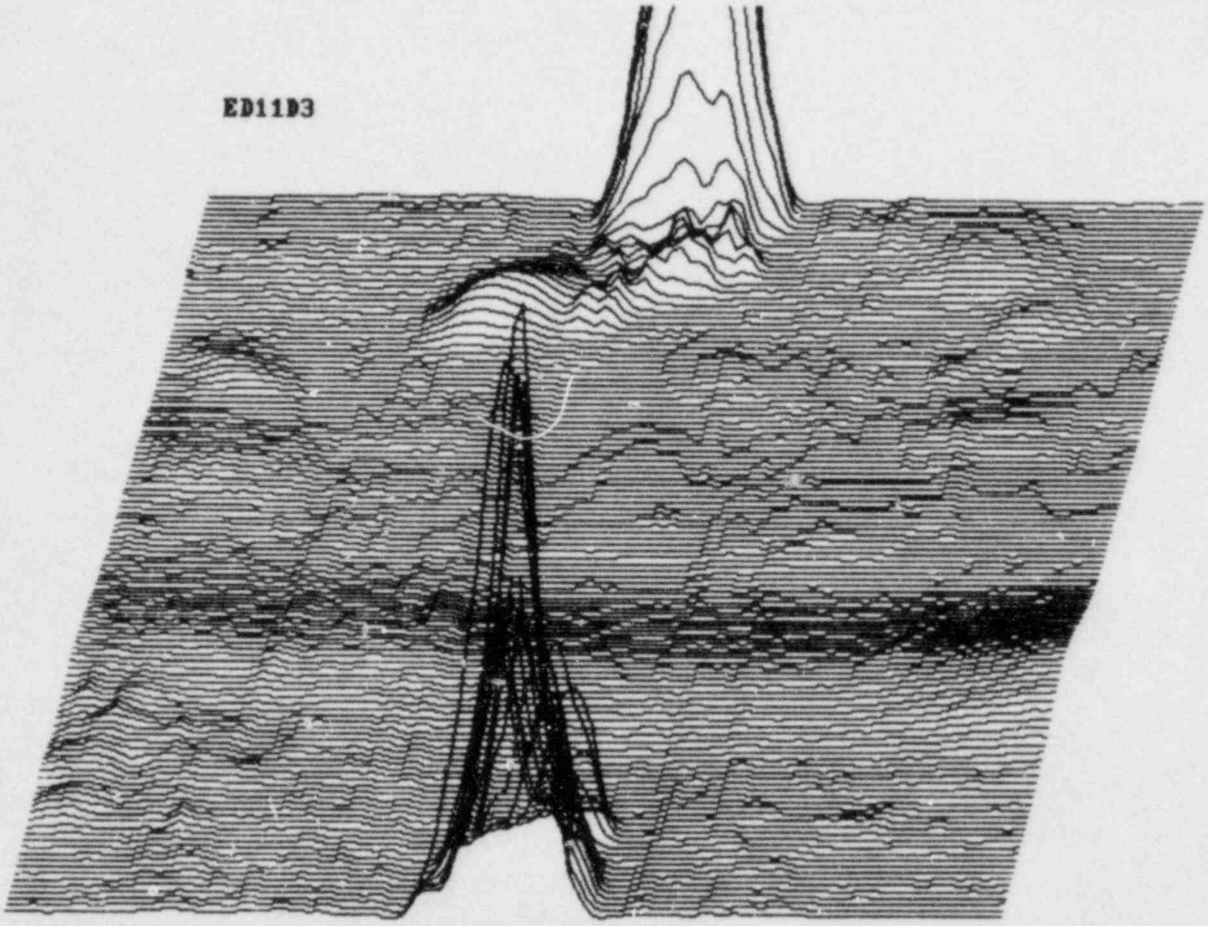

Fig. 3. Scan of tube with stress-corrosion cracks.

MEETINGS AND TRIPS

In January 1984, C. V. Dodd met at ORNL with A. Birks, D. Lessor, and J. Prince of PNL to discuss transfer of a three-frequency instrument and the associated technology to make it useful to PNL.

On January 10, R. W. McClung attended a meeting of the Subgroup on Surface Examination of the *ASME Boiler and Pressure Vessel Code*, Sect. V, on Nondestructive Examination. This subgroup has cognizance over documentation for eddy-current examination of steam generator tubing.

ORNL-DWG 84-1923

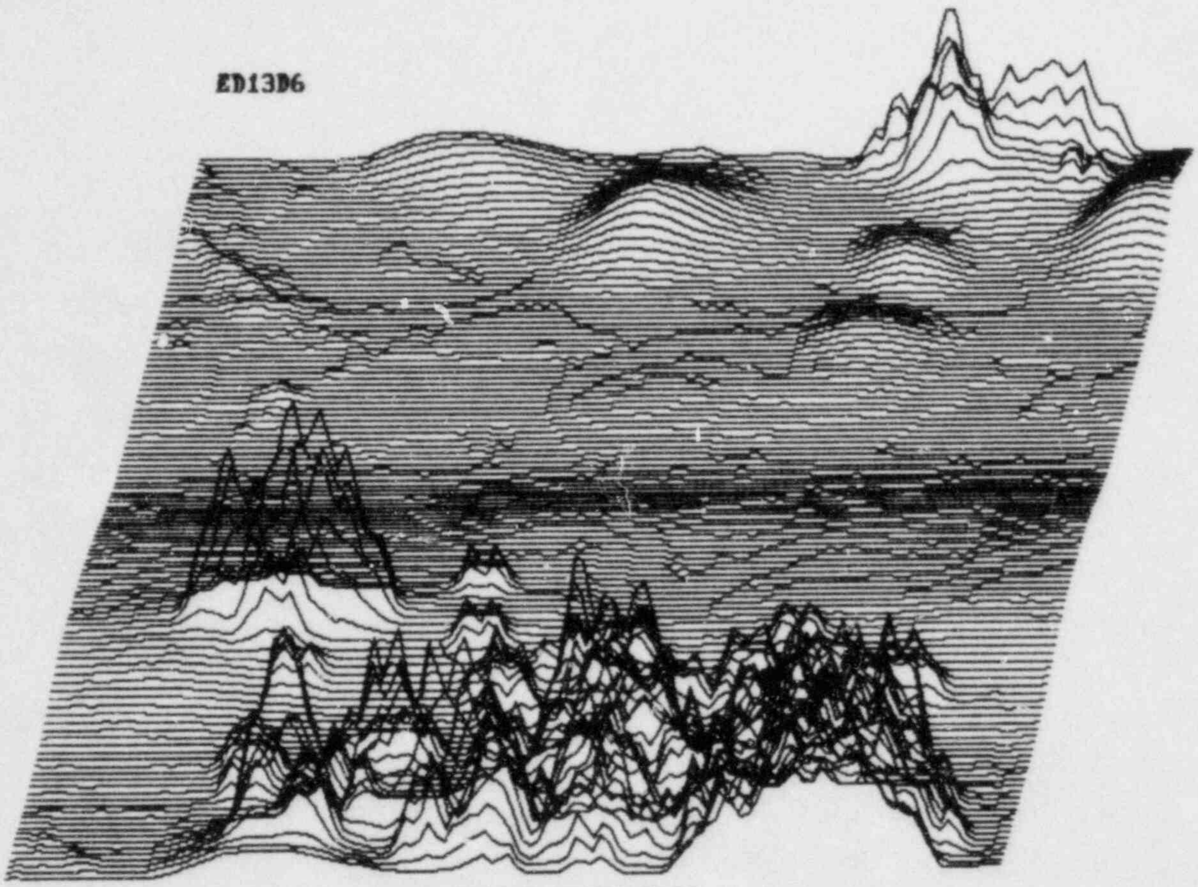

Fig. 4. Scan of tube with stress-corrosion cracks.

On April 5, C. V. Dodd traveled to Rockville, Maryland, to participate in a workshop on the Surry steam generator.

On April 10, the Surry Steam Generator Project Technical Advisory Group traveled to ORNL for a tour and presentation of the eddy-current program.

On April 25, R. W. McClung attended a meeting of the Subgroup on Surface Examination of the *ASME Boiler and Pressure Vessel Code*, Sect. V, on Nondestructive Examination, for preliminary discussions on gaining code approval for use of the ORNL multifrequency eddy-current system.

On May 25, C. Z. Serpan of the Nuclear Regulatory Commission visited ORNL for a brief discussion of the eddy-current program.

On June 26, C. V. Dodd participated in the Third Annual Steam Generator Workshop in Charlotte, North Carolina.

REPORTS, PAPERS, AND PUBLICATIONS

On June 26, C. V. Dodd presented a paper, "Improved Eddy-Current Inspection of Steam Generator Tubing," at the Third Annual Steam Generator Workshop in Charlotte, North Carolina.

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16. ABSTRACT (200 words or less)

Eddy-current inspection is the most suitable method for rapid boreside evaluation of steam generator tubing. However, small flaws can be masked by the effects of harmless variables, such as tube supports. To identify the critical properties accurately and reliably in the presence of extraneous signals caused by variations of unimportant properties, sufficient information is needed to identify harmful variations and to reject harmless ones. For this reason we are developing instrumentation capable of measuring both the amplitude and phase of the eddy-current signal at several different frequencies and computer equipment capable of processing the data quickly and reliably. Our probes and test conditions are also computer-optimized. The most recent probe design embodies an array of small flat "pancake" coils and improves the detection of small flaws and the rejection of tube support signals. We adapted our new IBM System 9000 computer to take and process the larger amounts of data required by additional variables, such as copper coating and intergranular attack. We also completed construction of the hand-wired versions of the 8- and 16-coil arrays and the multiplexing circuitry and computer codes to handle the data.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Eddy Current   Steam Generator   Multiple Frequency   Tubing Inspection

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