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Eddy-Current Inspection for Steam-Generator Tubing Program Quarterly Progress Report for Period Ending June 30, 1978

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Prepared for the U.S. Nuclear Regulatory Commission
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EDDY-CURRENT INSPECTION FOR STEAM-GENERATOR TUBING PROGRAM QUARTERLY PROGRESS REPORT FOR PERIOD ENDING JUNE 30, 1978

C. V. Dodd, W. E. Deeds, and R. W. McClung

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EDDY-CURRENT INSPECTION FOR STEAM-GENERATOR TUBING PROGRAM QUARTERLY PROGRESS-REPORT FOR PERIOD ENDING JUNE 30, 1978

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SUMMARY

Eddy-current methods provide the best in-service inspection of steam generator tubing, but present techniques can produce ambiguity because many independent variables affect the signals. The current development program will use mathematical models and develop or modify computer programs to design optimum probes, instrumentation, and techniques for multifrequency, multiproperty examinations. Interactive calculations and experimental measurements are made with the use of modular eddy-current instrumentation and a minicomputer. These establish the coefficients for the complex equations that define the values of the desired properties (and the attainable accuracy), despite changes in other significant variables. The final eddy-current instruments will contain on-board microcomputers for real-time data processing and interpretation. Progress is being made in addi[illegible] to the computer programs parameters for different circuit desig[illegible] Programs that allow direct interfacing between a minicomputer [illegible] the eddy-current instrument have bee[illegible] written and tested on preliminary tubing. The first modular three-frequency instrument has been constructed. We are continuing to acquire tubing standards and specimens for developing and checking the instrumentation and techniques.

INTRODUCTION

This program is established to develop improved eddy-current techniques and equipment for the in-service inspection of steam generator tubing. Its goals are to separate the effects of variables (e.g., denting, probe wobble, tube supports, and conductivity variations) from defect size, depth, and wall thickness variations. Computer design of probes, instrumentation, and techniques is emphasized.

BACKGROUND

Steam generators are a vital component in both fossil- and nuclear-fired power plants. Tube leaks in the steam generators will result in consequences ranging from loss of efficiency to plant shutdown. A method of predicting which tubes will leak and which will not during the time interval between routine maintenance shutdowns is clearly needed, and a rapid, accurate, easy-to-use inspection is an integral part of any method of prediction. Of the various nondestructive tests, eddy-current inspections most nearly meet these criteria. Present eddy-current inspections of steam generators are performed by moving a probe consisting of one or two coils through the bore of the tube. The inspection is performed with a bridge-type instrument operating at one or two frequencies. The inspections are fast, but the results are not immediate. Although it is desirable to know if a tube passes inspection before the probe is indexed to the next tube, the most common practice is to record the inspection data on magnetic tape for later playback and interpretation. The results of a test are then subject to interpretation by an operator and may be ambiguous. The reason for the potential ambiguity is the large number of test properties that can affect the examination. The test properties that may vary during the eddy-current inspection include: wall thickness, tube conductivity, tube permeability, defect size, defect location, and variations in probe-to-tube spacing and tube-to-tube-support spacing. An eddy-current instrument is capable of measuring only two test property variations per frequency, and when more than two property variations occur at the same time, the resulting signals cannot be separated. If a particular test property variations produces a uniform response as the probe is moved along the tube, its effect can be subtracted out, but this technique is not always reliable. Unfortunately, the tube is most likely to develop leaks at regions where other test properties are also changing. Even a property variation that may not impair the service of the tube, such as magnetic permeability or defect location (radially within the tube wall) must be included as a variable affecting the data, since it affects the eddy-current signal. To resolve these variations, the eddy-current instrument must make as many independent readings as there are test property variations. A multifrequency instrument can make two independent readings per frequency and a pulsed instrument can make independent readings at various time intervals along the pulse. The frequencies or time intervals should be chosen so that the response of the different test properties is different.

ORNL PROGRAM FOR IMPROVED INSPECTION

The ORNL program to develop improved eddy-current in-service inspection for light-water-reactor steam generator tubing consists of design calculations based on theoretical models, construction of optimum equipment, laboratory tests of the best design, and field tests of the equipment. Using models established for eddy-current coils in the presence of multiple cylindrical conductors, we will calculate the electrical signals produced in the instrument for different frequencies, probe designs, and instrument designs for many test property variations. These variations will span the range of variations expected in the actual tests. Next, a least-squares fit of the test properties to the instrument readings and nonlinear functions of the instrument readings will be carried out. These calculations will be repeated a number of times with different coil and instrument parameters until an adequate system is obtained.

A prototype instrument will be assembled from modular plug-in components. A probe will be constructed and the instrument will be adjusted to conform to the design calculations described above. The instrument will be connected to the parallel input-output ports of the ModComp IV minicomputer in the NDT laboratory. Readings will be made on tubing test samples that cover the range of anticipated test property variations. Then the process will be reversed, and the test properties will be calculated from the readings in two ways. The first uses the original coefficients determined in the design calculations with an offset and gain correction for data channel (magnitude or phase). Next, a least-squares fit for all the coefficients will be done directly from the experimental data. The set of coefficients that matches best will be used. The first way has the advantage that with the analytical calculations, more test properties can be used and a smooth curve between the test property variations can be obtained. The second way has the advantage that constructional differences between the designed coil and actual coil are taken into account, and also certain test property variations that cannot be calculated can be included.

Once the optimum coefficients are determined, the process is again reversed so the minicomputer continuously takes readings, calculates the properties directly, and displays the results on a CRT terminal in real time. The calculated properties change in the proper manner as the probe is scanned by defects, tube supports, and thin wall regions. After the instrument successfully passes these tests, its on-board microcomputer is programmed to calculate the properties in place of the ModComp IV, and the instrument is retested. Finally, the instrument will be tested in the field under actual operating conditions. Changes will be made in the programming at this point to improve the accuracy of the tests, the ease of calibration, and the use of the instrument. The instrument will contain an internal passive calibration circuit and will be tested against a set of reference standards.

Operating instructions and testing procedures will be written.

PROGRESS ON PROGRAM DURING QUARTER ENDING JUNE 30, 1978

The batch version of the multiple cylindrical conductor problem, ENCIRM, is working now without bugs. The effect of changes in conductivity, permeability, wall thickness, tube inner diameter, tube supports, and tube defects can be calculated. The electrical circuit in the program can be either an absolute coil or a two-coil send-receive network. Other types of electrical circuits are being added to the program, and the program will be interfaced to a least-squares program, MULLSQ, to fit the properties to the readings.

The programs, TUBRDG and TUBFIT have been written. The TUBRDG program makes readings with a multifrequency eddy-current instrument, averages the readings, and stores them on disk. The TURBRDG program does a least-squares fit of the properties to the readings, continuously makes new readings, and calculates the properties.

Under separate funding these programs have been tested on ferromagnetic tubing with a three-frequency eddy-current instrument.

The wall thickness, tubing inner diameter — and therefore the clearance between the probe and the tube — and the saturating current — and therefore magnetic permeability — were varied and measurements were made. A summary of the preliminary measurements is shown in Table 1. The permeability is only estimated. Most of the errors were due to the type

Table 1. Measurement of Wall Thickness, Radial Clearance and Permeability in Ferromagnetic Tubing

	Thickness (mm)	Radial Clearance (mm)	Permeability (Relative)
Range	1.9–3.0	0.14–1.14	8–10
Fit error	0.013	0.037	0.41
Drift error	0.019	0.023	0.21
Absolute error	0.15	0.13	0.4
Repeatibility error	0.05	0.14	0.4

of saturating current drive — constant voltage rather than constant current — or to thermal heating or too small a saturating current. It is believed that these errors can be reduced with further testing and modifications. We do not expect to require magnetic saturation; during development this allows planned control of magnetic permeability.

Although there were some defects in the tubes, we did not have enough samples to do a least-squares fit of the defects to the instrument readings.

We are collecting standards so a series of readings can be made on light-water-reactor steam generator tubing. We have received three Inconel tubing reference standards from a commercial source. The tubes are 19.1- by 12.8-mm (3/4- by 0.050-in.) wall; 22.4- by 12.8-mm (7/8- by 0.050-in.) wall; and 19.1- by 10.16-mm (3/4- by 0.043-in.) wall, and each contains the reference flaws conforming to current practice for in-service inspection of steam generator tubing. Additional tubing is being ordered so that we can make standard specimens that form a complete matrix of property values.

We have redesigned our pulsed eddy-current instrument and have replaced ten of the timing integrated circuits with a single counter-timer circuit. This should make the instrument more versatile, improve its performance, and reduce its cost. We will test the pulsed instrument as well as the multiple-frequency instrument on the standard tubing.

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