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METALS AND CERAMICS DIVISION

EDDY-CURRENT INSPECTION FOR STEAM GENERATOR TUBING PROGRAM QUARTERLY PROGRESS REPORT FOR PERIOD ENDING JUNE 30, 1980

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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 of the many independent variables that affect the signals. The current development program has used mathematical models and developed or modified computer programs to design optimum probes, instrumentation, and techniques for multifrequency, multiproperty examinations. Interactive calculations and experimental measurements have been 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 computer programs for calculating the accuracy with which various properties can be measured indicate that the tubing wall thickness and the defect size can be measured much more accurately than is currently required, even when other properties are varying. Our experimental measurements have confirmed these results, although more testing is needed for all the different combinations of cases and different types of defects. We are continuing to design and construct instrumentation systems that will be used in the field.

INTRODUCTION

This program was established to develop improved eddy-current techniques and equipment for the in-service inspection of steam generator tubing. Our goal is to separate the effects of variables such as denting, probe wobble, tubesheets, tube supports, and conductivity variations from defect size, depth, and wall thickness variations. Computer design of probes, instrumentation, and techniques is emphasized.

BACKGROUND OF THE 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 multiple cylindrical conductors, we calculated the electrical signals produced in the instrument for different frequencies, probe designs, and instrument designs for many test property variations. These variations span the range of those 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 was carried out. We repeated these calculations a number of times with different coil and instrument parameters until an adequate system was obtained.

We assembled a prototype instrument from modular plug-in components. A probe was constructed, and the instrument was adjusted to conform to the design calculations described above. The instrument was connected to the parallel input-output ports of the ModComp IV minicomputer in the nondestructive testing laboratory. We made readings on preliminary tubing test samples that cover the range of anticipated test property variations. We then did a least squares fit for all the coefficients directly from the experimental data.

Once the optimum coefficients are determined the process is again reversed. Consequently, 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, tubesheets, tube supports, and thin wall regions. After the instrument successfully passes these tests, its onboard 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 contains an internal passive calibration circuit and will be tested against a set of reference standards.

We will write operating instructions and testing procedures.

PROGRESS REPORT DURING QUARTER ENDING JUNE 30, 1980

We have continued our emphasis on inspecting the tube in the tubesheet region, as shown in Fig. 1. The major concern has been intergranular attack in the crevice region, but recent experiences at the San Onofre Reactor have shown instances in which the attack extends above the tubesheet and produces circumferential cracks.

A sample from the crevice region of the Point Beach steam generator has been measured with an external reflection-type probe. The results are shown as points in the upper left region of Fig. 2, in which the magnitudes and phases have been drawn for standards with various wall

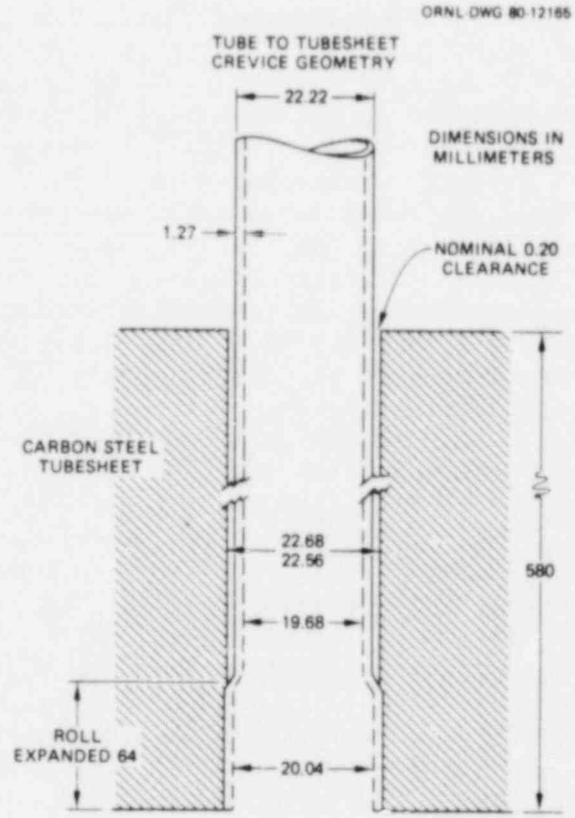

Fig. 1. Tube-to-Tubesheet Crevice Geometry.

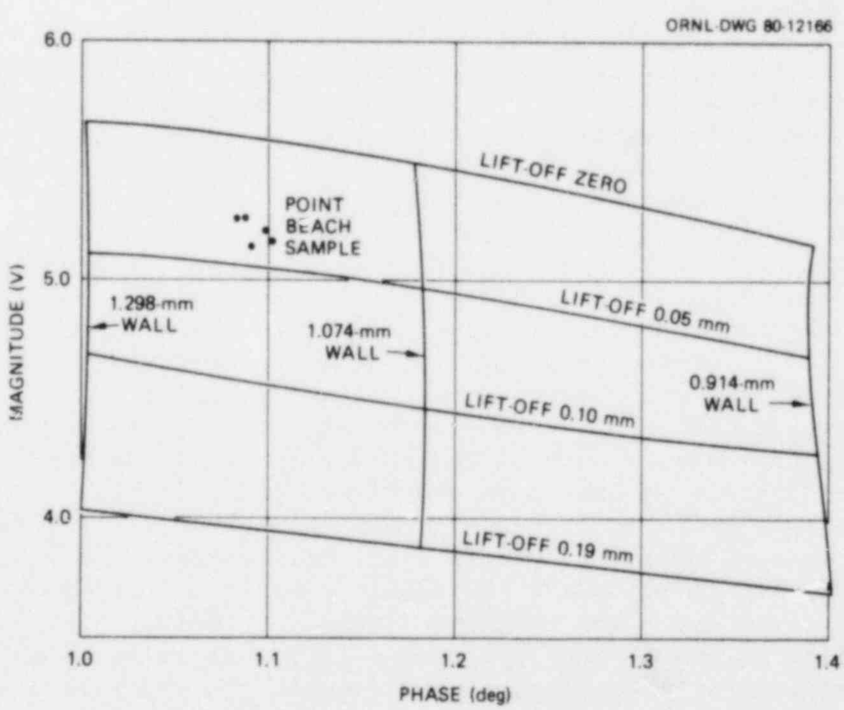

Fig. 2. Magnitudes and Phases for Various Lift-Offs and Wall Thicknesses.

thicknesses and lift-offs. The nearly vertical curved lines show the variations of magnitude and phase with various lift-offs from 0.0 to 0.19 mm (0.0075 in.). The left-hand curve is for tubes of 1.298 mm (0.0511-in.) wall thickness; the middle curve is for tubes with 1.074-mm (0.0423-in.) wall; the right hand curve is for tubes with 0.914-mm (0.0360-in.) wall. The curves slanting down to the right show the variation of magnitude and phase for a given value of lift-off — 0.0, 0.05, 0.10, and 0.19 mm (0.0, 0.002, 0.004, and 0.0075 in.) — for various values of the wall thickness. We see that the Point Beach sample measurements indicate wall thicknesses approximately midway between 1.298 and 1.074 mm (0.0511 and 0.0423 in.) [nominal thickness is 1.27 mm (0.050 in.)], and the lift-offs are approximately 40 μm (0.0015 in.), indicating some nonconducting coating on the metal. Thus, the sample showed a 99- to 124-μm (3.9 to 4.9 mil) decrease in wall thickness, with a 40-μm-thick (1.5-mil) nonconductive coating. The sample has had a definite change in its electrical and magnetic properties.

We remeasured the sample of tube using a through-transmission measurement. The tube measured 1.16 to 1.20 mm (0.0457 to 0.0472 in.), with an average value of 1.18 mm (0.0464 in.). The average reading from the previous measurements with a reflection coil was 1.19 mm (0.0467 in.). We will loan a through-transmission instrument to Westinghouse to test its other tubing samples. Westinghouse has not been making absolute wall thickness measurements on the samples in its laboratory. There is some speculation that the pulling operation may have caused the decrease in wall thickness.

Personnel of the Wisconsin Electric Power Company were contacted and permission was requested to perform a limited inspection of a few tubes during the next outage.

However, the utility refused to grant us permission to inspect the Point Beach steam generator during its July outage and suggested that we contact them later for its November outage. As a result, we are making contact with personnel at the H. B. Robinson and Robert E. Ginna plants to see if we can obtain permission to test our system on their generators. (All three plants are experiencing the deep crevice attack in Westinghouse Model 44 steam generators.)

We are in the process of installing our instrumentation and equipment in a truck so that we can transport it to a reactor site and then perform the inspection from the rear of the truck. We are continuing to modify the instrumentation so that it can be operated remotely from the back of the truck to the steam generator. We will probably use the Westinghouse probe positioner and TV system with our pusher-puller.

A switching power supply has been installed in one of the instruments. This supply has saved about 4.5 kg (10 lb) of mass, and the instrument runs about 10°C cooler than with the linear power supply.

Three tubesheet samples have been machined and will be tested with our other tube standards to generate the calibration runs needed for our probes. Additional standards are being prepared by Bob Clark of PNL.

We have rewritten the programs TUBRDG and TUBFIT to allow them to contain larger arrays. Both programs will now allow up to 1250 different sets of properties to be measured and fitted. This allows a smoother and better fit to be made to the experimental data. In addition, TUBFIT will fit specified properties from only the applicable sets of readings. For instance, the tubesheet clearance can be fitted to only those readings taken when the probe was inside the tubesheet, and the defect location can be fitted only to those readings taken while the probe is centered on the defect. The same set of calibration readings will be used for all the readings.

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