PULSED EDDY CURRENT INSPECTION SYSTEM FOR NONDESTRUCTIVE EXAMINATION OF IRRADIATED FUEL RODS

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The ability to perform nondestructive examinations of irradiated fuel rods is essential to a better understanding of fuel rod behavior in reactor safety programs. Nondestructive examination of irradiated fuel rods can provide information on microcracking, fuel-cladding interaction, surface corrosion, cladding thickness variations, and fuel rod diameter variations.

An inspection system capable of remotely scanning both Boiling Water Reactor (BWR) and Pressurized Water Reactor (PWR) irradiated fuel rods in a hot cell environment has been developed and tested. The system employs a microprocessor based control system which completely automates the scanning cycle. The system is capable of scanning fuel rods with diameters up to 1.91 cm and lengths of up to 4.06 m.

The inspection system employs three pulsed eddy current transducers capable of sensing variations in the average cladding thickness and monitoring defects within the circumferential thickness of the fuel rod. The use of the pulsed eddy current technique makes it possible to distinguish between the defects located on the inner and outer surfaces of the fuel rod. Fuel rod diameter variations are measured using two linear variable differential transformers (LVDT) and their associated signal conditioning.

Standards were fabricated for use in evaluating the systems performance. The standards include both transverse and longitudinal defects, wall thickness, and diameter variations.

SCANNING SYSTEM

The scanning mechanism is shown in Figure 1, and consists of a large aluminum base platform with an indexing chuck, a relocatable end chuck, retractable fuel rod support arms, and a scanning sensor platform.

During operation, a fuel rod lays horizontally on the retractable support arms with one end positioned in the indexing chuck and the other end supported by the relocatable end chuck. As the various sensors located on the sensor platform traverse the fuel rod, the rod support arms are retracted to allow for the continuous scanning of the supported fuel rod. Two sets of roller guides are incorporated in the sensor package to maintain the proper alignment between the sensors and the section of the fuel rod under examination.

The indexing chuck was designed such that fuel rods with various end plug designs could be supported and indexed with the scanner. The indexing chuck rotates the fuel rod in multiples of 1.8 degree steps as part of the scan cycle. The scan speed can be varied between 1.27 cm/s and 9.14 cm/s.

The heart of the scanning system is a microprocessor based control unit supplied by Integrated Microprocessors, Inc. The control system provides for both manual and automatic scanning. A large display on the control panel provides the system operator with updated information on the systems operation such as angular

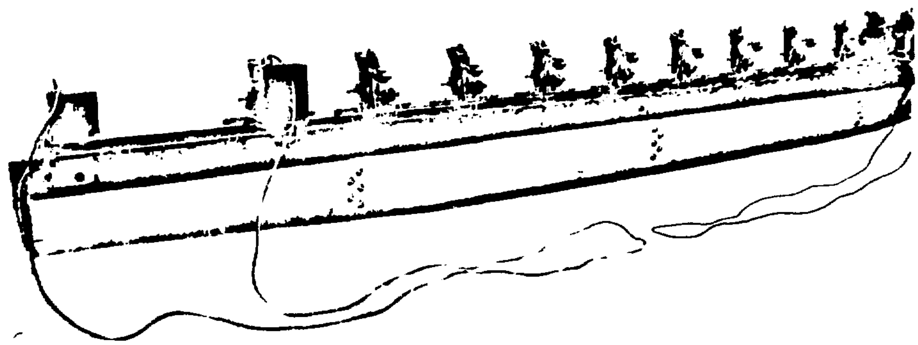

FIGURE 1--Fuel rod scanner.

orientation of the fuel rod, linear position and direction of travel of the sensor package, and certain diagnostic information for the proper operation of the scanner.

In the automatic scanning mode the entire fuel rod surface area may be examined or a detailed scan may be made of any smaller section of the fuel rod surface area.

INSPECTION SYSTEM

The pulsed eddy current system applies a series of current pulses to a field coil to induce eddy currents in the specimen under investigation. The induced eddy currents are influenced by the specimen's characteristics - permeability, conductivity, wall thickness, surface defects, and the distance between probe and specimen. The resulting eddy currents produce a pulsed magnetic field which induces a voltage pulse in the pickup coil. The wall thickness and defect information are extracted from the induced voltage pulse using a time-sampling technique wherein a gating pulse of approximately 0.1 microsecond is used to sample small increments of the induced voltage pulse. The location of the gating pulse, that is, the sampling point location, is adjustable over the entire time duration of the induced voltage pulse. Only outer surface defect information appears in the early portion of the voltage pulse, while both outer and inner surface defect and wall thickness information appear toward the end of the voltage pulse.

The pulsed eddy current inspection system employs both an encircling coil transducer and two point probe transducers. EG&G Idaho, Inc., developed the encircling coil transducer making it possible to scan the entire fuel rod surface for inside and outside diameter defects during a single scan. The direct coupled output from the encircling coil defect transducer also contains average wall thickness data. Argonne National Laboratory supplied the pulsed eddy current electronics, one point probe transducer capable of measuring wall thickness, and another point probe transducer for monitoring surface defects. The point probe transducers provide detailed inspection capability.

The inspection system was also designed to provide information on fuel rod diameter variation. The outputs from two LVDTs were conditioned to provide this data.

The output data from the various signal conditioners are recorded on both a strip chart recorder and an analog magnetic tape. Techniques are being developed to use a computer system to aid in data reduction.

INSPECTION RESULTS

The basic operation of the fuel rod scanning system was checked out using various calibration standards. Two defect calibration standards were fabricated using zircaloy fuel rod cladding with an outside diameter of 1.43 cm with wall thicknesses of 0.081 cm and 0.094 cm. Each of the defect calibration standards contained three longitudinal and three transverse defects on both the inner and outer surfaces. These defects were prepared by electron discharge machining at 5 cm intervals along the axis of the fuel rod and had the following nominal dimensions: 0.254 cm long by 0.005 cm wide with depths of 0.005, 0.010, and 0.015 cm. A third standard was prepared from 1.07 cm outside diameter zircaloy cladding with a 0.061 cm wall thickness, which contained the same set of standard defects. A wall thickness standard was prepared from zircaloy with a uniform outside diameter of 1.43 cm. The inside diameter of the standard was prepared with wall thicknesses ranging from 0.0686 cm to 0.1067 cm in 0.00635 cm steps. Each step was 1.27 cm long. The diameter standard was prepared using ASTM Type 630 stainless steel and had the following outer diameter steps: 1.364, 1.402, 1.415, 1.427, 1.440, 1.453, and 1.491 cm. Each step was 1.27 cm long. The individual calibration standards were connected to make a single calibration rod containing defect standards, wall thickness standards, and diameter standards.

The sensitivity of the defect transducer depends upon the scanning speed. A series of tests was conducted to optimize the defect transducers performance. The test results indicated that a scanning speed of 7.62 cm/s provided the best transducer performance.

The test results obtained from the encircling coil transducer shown in Figure 2 indicate that it was capable of detecting outside diameter defects as small as 0.005 cm deep and an inside diameter defect as small as 0.010 cm deep on both the 0.081 cm wall and the 0.094 cm wall cladding. The defect size and orientation are noted in the figures. The defect transducer had a greater sensitivity to longitudinal defects than to the transverse defect standards. The transducers sensitivity to the variation in wall thickness can be seen by comparing the lower trace in each section of the strip chart recording. Figure 3 shows the encircling coil transducers response to the wall thickness standard. Edge effects of the various wall thickness step can be seen since each step was only 1.27 cm long; however, the transducers sensitivity to wall thickness is apparent. In evaluating the encircling coil transducer, all sampling points appeared to be sensitive to both inside and outside diameter defects.

The defect point probe used with this system was originally designed for inspection of cladding with a wall thickness of less than 0.076 cm. Figure 4 shows the response of the defect point probe to the two defect calibration standards. Data from two sampling point locations are shown for each standard. One sample point was set to be sensitive to outside diameter defect only, while the other sample point was sensitive to both inside and outside diameter defects. Because of the increase in the wall thickness of the two defect standards, only the 0.015 cm deep longitudinal inside diameter defect on the cladding with 0.081 cm wall could be detected. The point probe's depth of penetration was limited by the field coils pulse width. Figure 5 shows the wall thickness point probe's response to the wall thickness standard. Due to the edge effects resulting from the short calibrated steps, distinct wall thickness steps could not be seen.

The output of the LVDT diameter measuring system is shown in Figure 6. This signal conditioning system performed as expected.

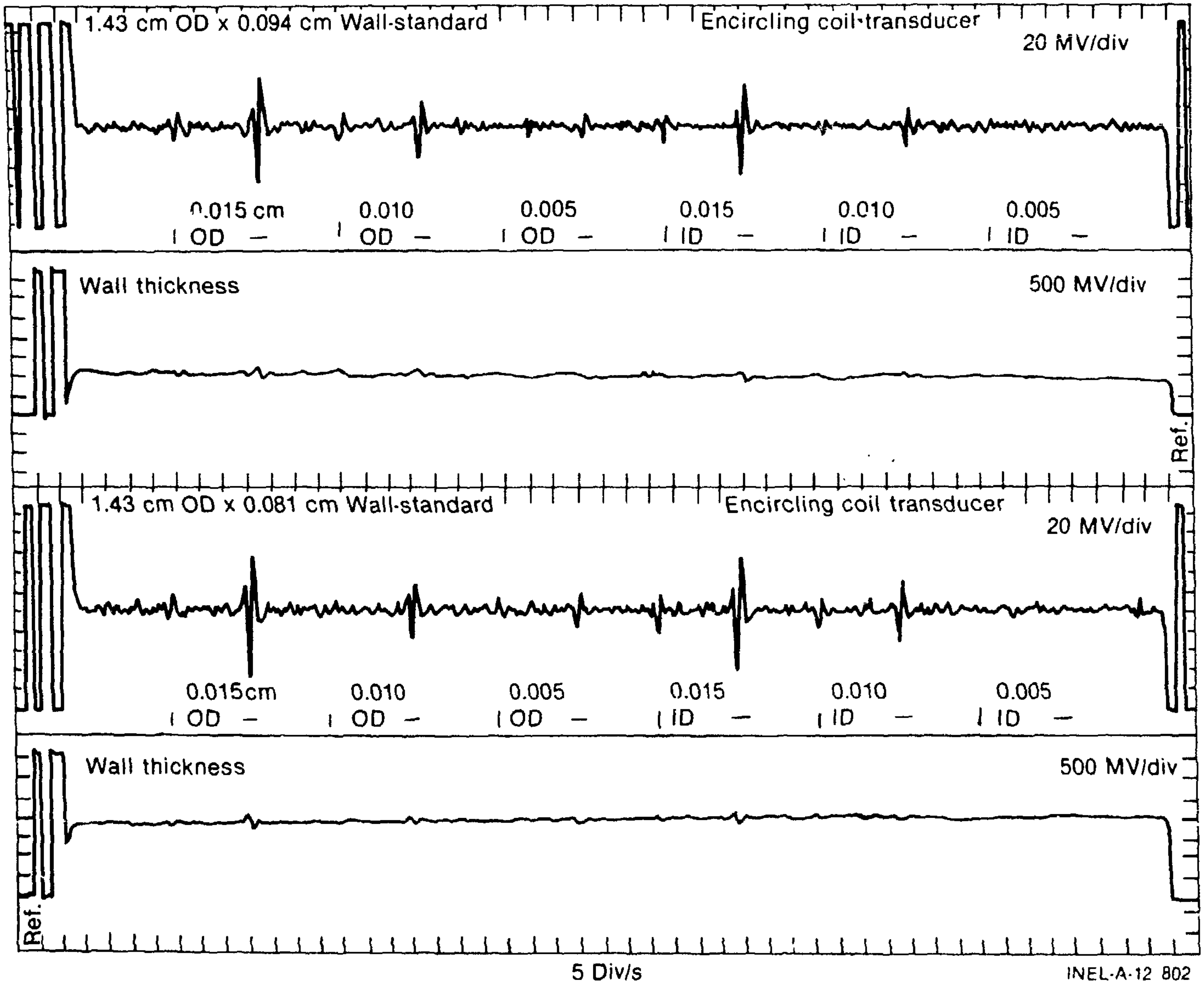

FIGURE 2--Response of encircling coil transducer to the defect standard.

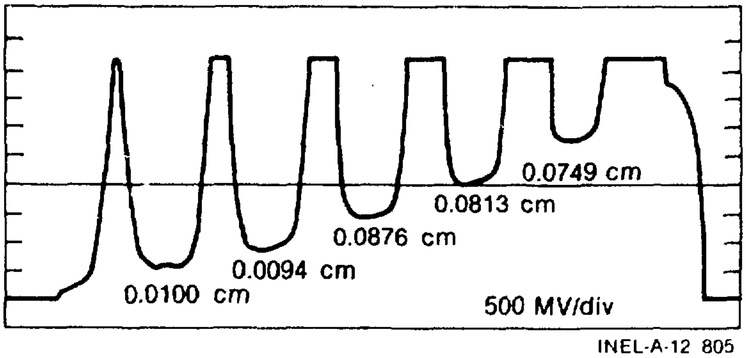

FIGURE 3--Response of encircling coil transducer to the wall thickness standard.

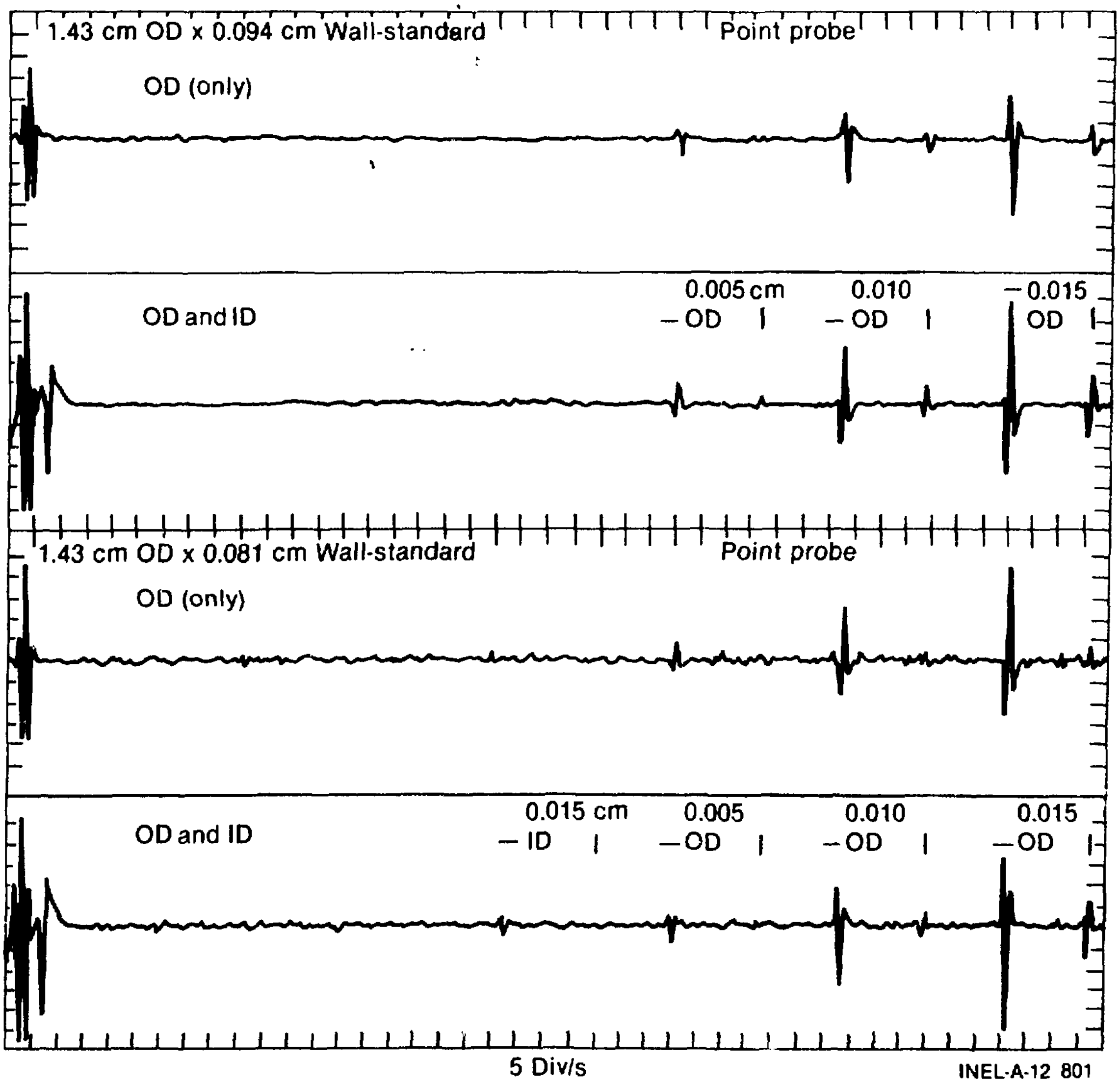

FIGURE 4--Response of point probe defect transducer to the defect transducer.

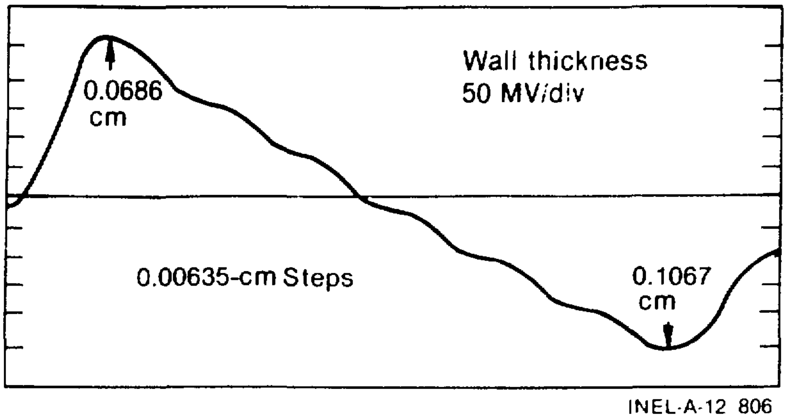

FIGURE 5--Response of point probe wall thickness transducer to the wall thickness standard.

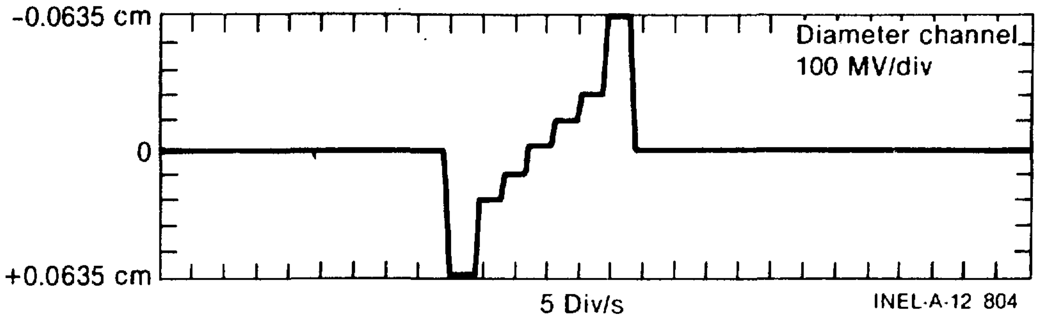

FIGURE 6--Diameter calibration data - LVDT system.

With the existing performance capability several BWR fuel rods have been scanned using both the encircling coil transducer and the point probe transducer. Figure 7 shows defect data obtained scanning a 28 cm section of a fuel rod. The top trace is data obtained from encircling coil transducer, while the lower trace was obtained from the point probe transducer scanning at the zero degree orientation. Since the point probe was not sensitive to inside diameter defects, it can be concluded that these indications represent outside diameter surface defects. Detailed metallographic examination has not been performed to verify the exact nature of the defects.

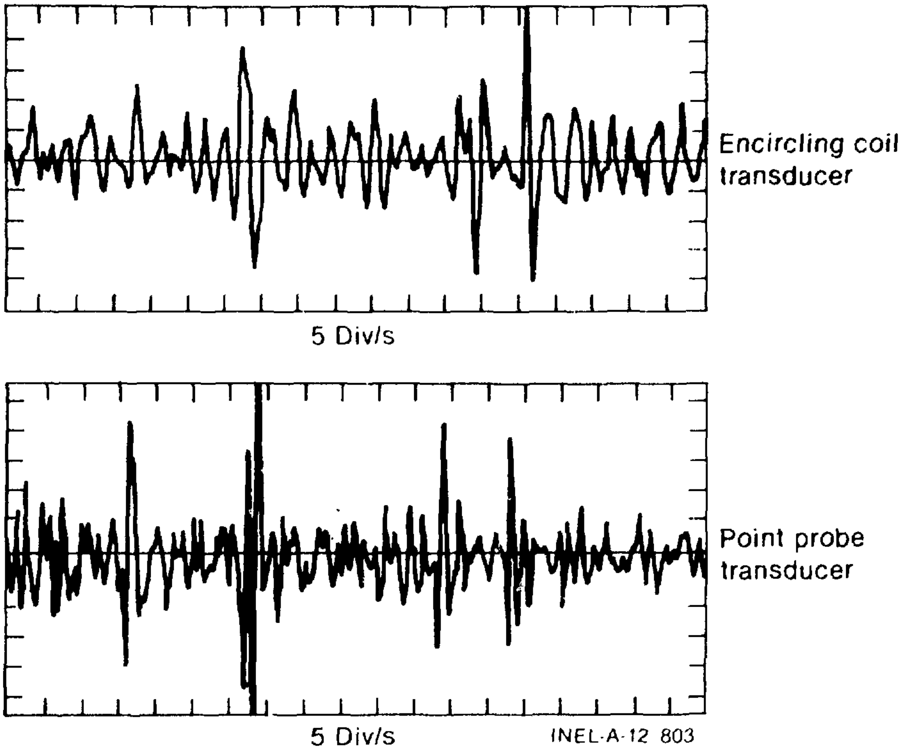

FIGURE 7--Actual fuel rod scan showing possible defects (fuel Rod ID-DA2999).

SUMMARY

The newly developed scanning system will greatly facilitate the remote inspection of irradiated fuel rods.

All of the sensing systems performed adequately with the exception of the defect point probe transducer. Two improved point probe transducers have been fabricated with field coil pulse widths comparable to that of the encircling transducer. The increased pulse width should improve the transducers sensitivity to inside diameter surface defects. It has not been possible to evaluate the performance of the new probes due to a hot cell remodeling program.