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A Study on the Nondestructive Examination of Rod Cluster Control Assembly End Tip

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1. Introduction

RCCA(Rod Cluster Control Assembly) end-tip suffers from neutron irradiation and constant vibration due to high-speed internal flow of primary coolant during plant operation. Such operating conditions cause the RCCA end-tip crackings around the circumferential weldment of the end-tip, and in some cases, the defective end-tips were completely broken loose. However, no reliable inspection techniques for end-tip crackings were developed in the past, although some techniques exist for inspecting RCCA control rod wears. Therefore, we have developed ECT technique for the detection and the sizing of the end-tip crackings, and technique to distinguish real flaw and scratch signals. These techniques use a specially designed surface-riding probe that is able to examine circumferential crackings with an accuracy of ±5.31% RMS error. This paper describes the flaw sizing result and applied technical approaches.

2. Methods and Results

In this section, specially designed probes and techniques used to examine the RCCA end-tip are described. The examination system consists of a MIZ-30 frequency generator, multi-array probe, calibration standards, and Eddynet 98 analysis program.

2.1 Multi-Array Probe Design

Generally encircling eddy current test probe is not able to detect the circumferential cracks of circular tube with high reliability. Therefore, we designed a special eddy current probe, so called as 4*1 multi-surface riding coil probe, for the detection of circumferential cracks around the weldment of the RCCA end-tip of Reactor Control Cluster Assembly of Pressurized Water Reactor. The probe contains 8 surface coils in the inner surface of probe that is designed suitable for the detection of circumferential cracks. These coils are arrayed at a fixed distance along the inner surface of probe, and each coil is spring-loaded to minimize lift-off effect. Detailed shape of multi-surface riding probe is shown in Figure 1.

With this special ECT probe, we developed the techniques for the detection and sizing of circumferential cracks around the weldment of RCCA end-tip.

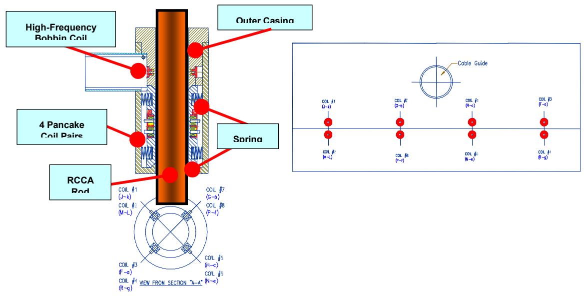

Figure 1. Schematic diagram of 4*1 multi-surface riding coil probe

2.2 Flaw Specimen Design

Flaw specimen that contains artificial crack-liked defects was designed and fabricated. Specimen was prepared from real RCCA cladding tube material in Stainless steel 304. The dimensions of RCCA tube used are 9.68mm O.D., and 1,000mm length by 0.45mm wall thickness, unirradiated. Flaws, such as circumferential notches, typical of those that can arise on the weldment of RCCA end-tip were introduced into tube sections. Detailed dimension and shape of defects of specimen are shown in Table 1. All defects on the external tube surfaces were simulated with an EDM notch with a rectangular profile.

Defect Type	Direction	Length (mm)	Depth,mm (%TW)	Remarks
Crack Like EDM Notch (Width : 0.2mm)	Circumferential	2.0 3.5 5.5 7.0 8.2	0.05(10%) 0.10(21%) 0.16(33%) 0.22(46%) 0.26(54%)	

Table 1. Artificial defects in flaw specimen.

2.3 Flaw Signal Analysis Results

Flaw signal analysis was performed based on the phase angle variation and signal formation patterns. We can distinguish the scratch signal from the wear, crack signals by observing the signal shape and formation pattern shown in Figure 2.

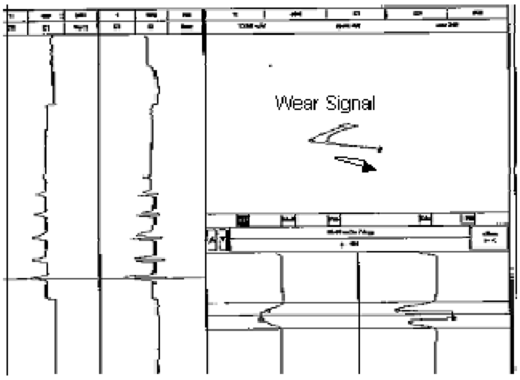

Figure 2-a, Signal pattern of wear defect at 400kHz frequencies using external differential coil.

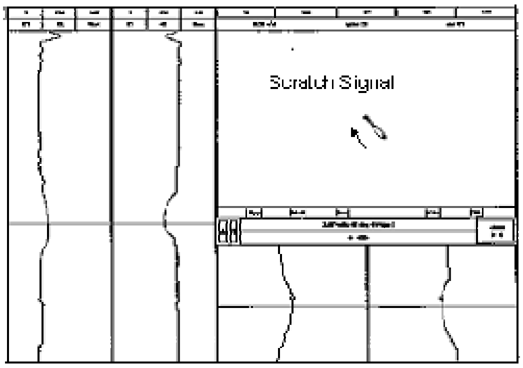
Figure 2-b Signal pattern of scratch at 400kHz frequencies using external differential coil.

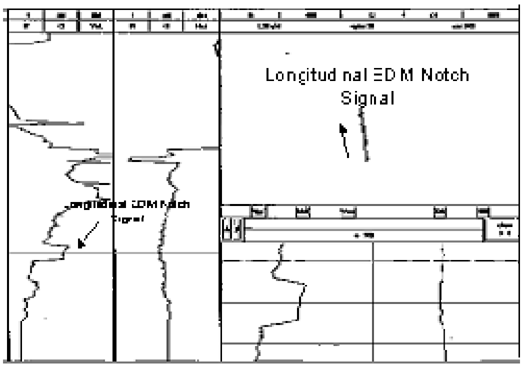

Figure 2-c. Signal pattern of crack like longitudinal EDM notch at 400kHz frequencies using the external differential coil

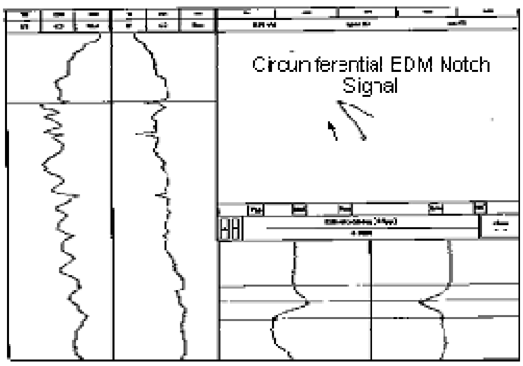

Figure 2-d. Signal pattern of crack like circumferential EDM notch at 400kHz frequencies using the external differential coil

2.4 Flaw Depth Sizing Results

Flaw sizing results are based on the sizing accuracy of artificial flaws in flaw specimen except unintentional scratches. Flaw sizing was based on phase angle versus depth correlation. The flaw sizing accuracy is shown in Figure 3, and the flaw sizing accuracy is expressed in root-mean-square(RMS) error. The accuracy of flaw sizing is determined by calculating three linear regression analysis components : regression line slope, correlation coefficient, and the root-mean-square(RMS) error. As shown in Figure 3, the RMS sizing error of 4*1 multi-surface coil is within ± 5.31% RMS in depth.

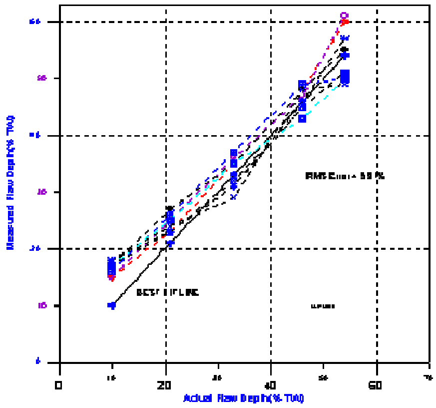

Figure 3. Crack depth sizing result of 4*1 multi-surface riding coil probe

3. Conclusion

We have designed the special ECT probe and signal analysis techniques for the detection and sizing of flaws that can be occurred on the weldment of RCCA end-tip, and elucidated the following results:

(1) The scratch signal can be distinguished from the wear, crack signals by observing the signal shape and formation pattern with high reliability.

(2) Artificial flaws in RCCA tube specimen were successfully all detected and sized. Developed examination techniques for RCCA tube provides good flaw detectability and sizing capability. The flaw sizing accuracy of 4*1 multi-surface riding coil is within ± 5.31% RMS in depth.

REFERENCES

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[2] Chalk River Nuclear Lab., Eddy Current manual(1981), pp 68~72.