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Design Concept of Array ECT Sensor for Steam Generator Tubing Inspection

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1. Introduction

The eddy current testing, which is one of the nondestructive examination methods, is widely used for the inspection of heat exchangers including steam generator tubing in the nuclear power plant. It uses electromagnetic induction to detect flaws in conductive materials. This method may offer a relatively low cost approach for high speed, large scale testing of metallic materials in high pressure and temperature engineering systems. Two types of eddy current probes are conventionally used for the inspection of steam generator tubing according to the main purpose. One is the bobbin probe technology and the other is the rotating probe. During the inspection, they have restrictions for the flaw detection or the inspection speed. An array probe can be alternative to the bobbin and rotating probes. The design concept of array coils with high sensitivity is described in this paper. It is expected that the eddy current testing using this type of array sensors may provide high detectability and resolution for flaws in steam generator tubing.

2. Inspection Methods

The steam generator tubes have different shapes and lengths depending on the design of the steam generator. The tubes are welded at either end and expanded partially inside a thick plate called a tubesheet. They are held in place by different support structures such as tube support plates along their straight sections or by anti-vibration bars in the bent sections. The inspection area corresponds to the complete length of the tube from the end of the tubesheet at one leg to the end of the tubesheet at the other leg. In the case of low row U-bends, the tube can be inspected from both legs with sufficient overlap to ensure total length coverage. The goal of the inspection of steam generator tubing is to detect, characterize and size indications attributable to tube wall degradation. Two types of eddy current probes, such as the bobbin and rotating probes, are currently used for the inspection of steam generator tubing in Korea [1].

2.1 Bobbin Probe Technology

The bobbin probe used for the inspection of steam generator tubing has a self-comparison differential coil arrangement as shown in Fig. 1. Two narrow coils wound opposite to each other compare different sections of a tube during the examination process.

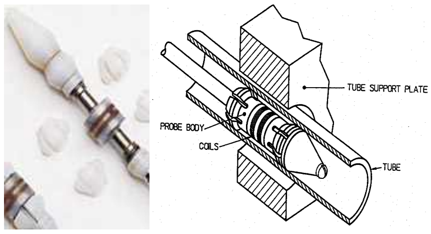

Fig. 1. Bobbin coil arrangement

As the probe is withdrawn, any differences detected by each coil are reflected as changes in coil impedance and are displayed as eddy current signal responses on a screen. Fig. 2 shows an example of eddy current signals detected by a bobbin probe. This probe is excellent for detecting small localized flaws and axial cracks, but it is relatively insensitive to circumferential cracks due to the direction of the induced eddy current. The entire tube length can be quickly examined using the bobbin probe.

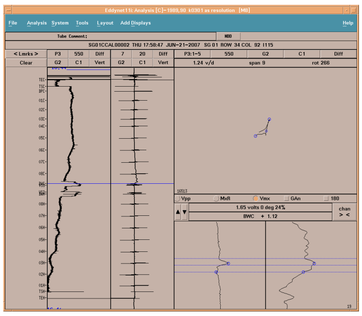

Fig. 2. Eddy current signals from a bobbin probe

2.2 Rotating Probe Technology

The rotating probe is normally used for the inspection of a tube's circumference. The surface riding coils of this type of probe ensure maximum signal-to-noise performance. Three coils, one is pancake coil, another is circumferential indication coil and the other is axial indication coil, are arranged in 120 degrees intervals in a circumference of probe body as shown in Fig. 3.

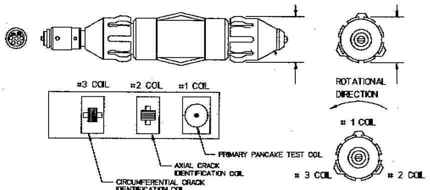

Fig. 3. Rotating probe coil arrangement

The motorized rotating probe coil(MRPC^{TM}) developed by ZETEC, Inc., is widely used for this purpose [2]. The MRPC™ probe has two pancake coils, which one is mid-range and the other is high-range, and one plus point coil. It excels in finding not only axial and volumetric flaws but circumferential flaws in critical areas such as roll transition and regions affected by deposits in steam generator tubing. Fig. 4 shows an example of eddy current signals from the MRPC™ probe. However, the rotating probe technology is limited to use for the inspection of long range of a tube due to its very low inspection speed.

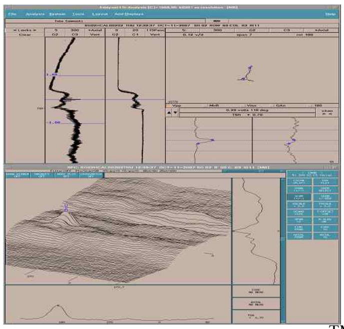

Fig. 4. Eddy current signals from the MRPC™ probe

2.3 Array Probe Technology

Array probe technology is high speed alternative to rotating probe and high circumferential sensitivity alternative to bobbin probe. The sensing part of the probe consists of multiple coils arranged around the probe circumference operating in transmit-receive mode. Mechanical rotation is replaced by a rotating field which rotates much faster enabling pulling speed comparable to the bobbin coil examination. The rotation of the field is provided by activating the transmission and the reception at known predefined circular patterns as shown in Fig. 5. Electric current injected in the transmit coil creates a magnetic field that establishes an eddy current in the test material creating a magnetic field that opposes the original one. Eddy currents are read by the receive coil. In the case of discontinuities or property changes in the test object, the flow of eddy currents is disrupted which is interpreted as variations of phase and amplitude in the voltage plane as shown in Fig. 6.

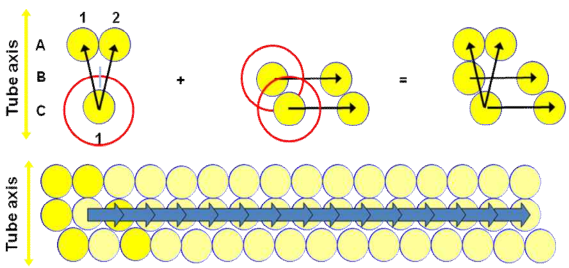

Fig. 5. Transmit-receive coils and rotation of the field by activating the transmission and the reception

Transmit-receive coils offer directional sensitivity with clear separation of circumferential and axial indications in the case of intersecting flaws. As mentioned above, eddy currents are generated by electromagnetic coils in the test probe, and monitored simultaneously by measuring probe electrical impedance. Amplitude drops off exponentially with distance and eddy current flow increasingly lags in phase both with depth and with axial distance from the coil. Also, discontinuities can be most easily detected when the eddy currents are perpendicular to the major plane of the discontinuity. Therefore, when the circular shape of the coil is replaced with octagonal shape or rectangular type with round edges as shown in Fig. 6, much more sensitivity of the signal can be obtained. Fig. 7 shows an example of eddy current signals from an array probe.

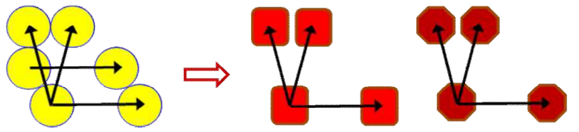

Fig. 6. Design concept of array probe coils with high sensitivity

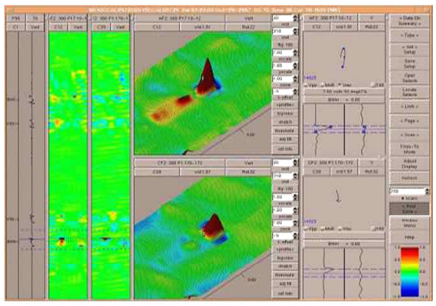

Fig. 7. Eddy current signals from an array probe

3. Conclusions

Eddy current technology has some barriers for the inspection of steam generator tubing in the nuclear power plant. Bobbin probes offer poor circumferential crack detection and rotating probes are time and money consuming due to the mechanical rotation. Array probe inspection technique can replace bobbin and rotating probe techniques due to its sensitivity for flaw detection and inspection speed. In general, circular-shaped coils are considered in an array eddy current probe. However, rectangular coils with round edge or octagonal-shaped coils may provide more sensitivity than circular-shaped coils, considering intersection angles between the eddy currents and the various discontinuities on test materials.

REFERENCES

[1] C. H. Cho, H. J. Lee, M. W. Nam, and H. J. Yoo, Development of Eddy Current Analysis Program for Steam Generator Tubing Data, Transactions of the Korean Nuclear Society Spring Meeting, May 17-18, 2012.

[2] Zetec, Eddynet®98 MRPC Analysis User Guide, Zetec Inc., Washington, 1999.