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An Analysis of Design Characteristics of ECT Bobbin Probe for S/G Tube

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1. Introduction

The bobbin probe technique is basically one of the important ECT methods for the steam generator tube integrity assessment that is practiced during each plant outage. The bobbin probe is one of the essential components which consist of the whole ECT examination system, and provides us a decisive data for the evaluation of tube integrity in compliance with acceptance criteria described in specific procedures. The selection of examination probe is especially important because the quality of acquired ECT data is determined by the probe design characteristics, geometry and operation frequencies, and has an important effect on examination results. In this study, the relationship between electric characteristic changes and differential coil gap variation has been investigated to optimize the ECT signal characteristics of the bobbin probe. With the results from this study, we have elucidated that the optimum coil gap is 1.2~1.6mm that give the best result for O.D. volumetric defects in ASME calibration standards.

2. Experimental preparation

Figure 1 shows the bobbin probe used in experiments of this study. This probe has fixed number of turns and cable length. The probe is composed of two coils; one on the fixed body and the other one on the movable part. Thus, the coil gap (the gap between the two coils) can be adjusted by shifting the movable part. The minimum achievable coil gap of this probe is 0.4 mm. For the experiments, it is desired to have tube samples with flaws on which information is available a priorty. For this purpose, we have adopted two standard tubes; the ASME standard tube and the notch standard tube described in EPRI guidelines [1] as shown in Figure 2. The ASME standard tube has 5 defects with different depths and diameters; a 100% through-wall hole (TWH), and four flat bottom holes (FBH) with the depths of 80%, 60%, 40% and 20% of wall thickness. The notch standard tube has the axial and circumferential ID notches of 60 % of wall thickness, and 9.5 mm in length and 0.15 mm in width. The notches locate at the same axial position, but at the opposite side circumferentially. These standard tubes are made by non-magnetic Inconel 600.

3. Signal analysis setup

In order to acquire and analyze ECT signals from the specimens, an experimental system as shown in Figure 3 has been set up. The experimental system included a Miz-30 eddy current instrument and an Eddynet software developed by Zetec Inc. In addition, the experimental system also had an automated linear translation scanner that can move the probe with a constant speed of 24 inch/second. The primary operation frequency of the experimental system was 550 kHz which is currently adopted for inspecting the KSNP SG tubes.

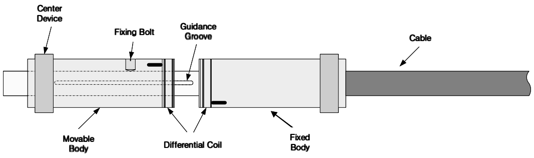


Figure 1. Bobbin probe for experiments

Figure 2. ASME and notch standard tubes

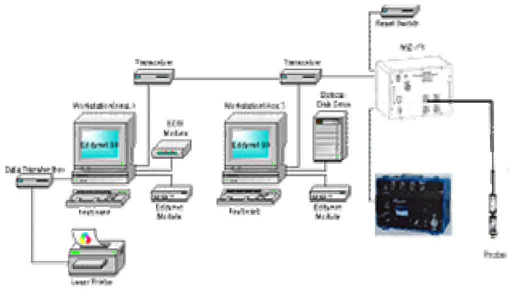
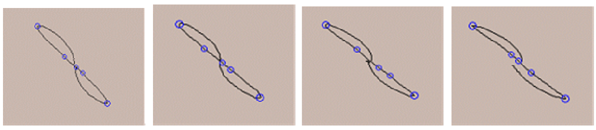


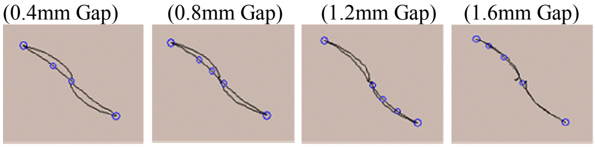
Figure 3. Test system configuration for eddy current characteristic measurement

4. Experimental results

Figure 4 shows the experimental signals acquired from the TWH in the ASME standard tube with various coil gaps. One of the desired characteristics of ECT signals obtained by a differential bobbin coil probe is that the "center line" connecting the two peaks of the impedance plane trajectory (which is quite often called as Lissajous signal) is straight. As shown in Figure 4, when the coil gap is less than 1.2 mm the center lines of the signals are not completely straight but slightly convex. For the gap sizes of 1.2 mm and 1.6 mm, the center lines are straight. However, as the coil gap increases to 2.0 mm and above, the center lines become concave. From these experimental results, one can determine that the optimal values of the coil gap (at this specific example) would be between 1.2 mm and 1.6 mm.



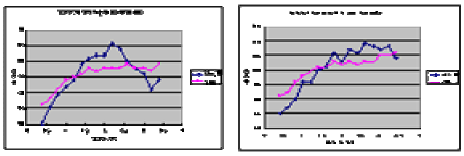
(0.4mm Gap) (0.8mm Gap) (1.2mm Gap) (1.6mm Gap)



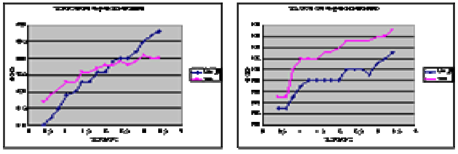
(2.0mm Gap) (2.4mm Gap) (2.8mm Gap) (3.2mm Gap)

Figure 4. Lissajous signals acquired from TWH with coil gap variation

Figure 5 shows the phase angle shift of the signals acquired from four flaws (a TWH, and three FBHs with the depths of 80%, 60% and 40% wall thickness) in the ASME standard tube. we have defined two rotational calibration factors to make the maximum rate (MxR) of TWH signals be 40° with the coil gap of 0.4 mm and normalized all the signals acquired from the other three flaws using the defined rotational calibration factors. Figure 5 shows the normalized results for the measurement of phase angles of the signals from four flaws with coil gap variation. In the measurement, we have adopted two different criteria; the peak-to-peak measurement (denoted as "Vpp" in Figure 5) and the maximum rate measurement (denoted as "MxR" in the same figure). It can be found that the phase angle increases as the coil gap increases, and the Vpp measurement showed more linear increase than the MxR measurement. Therefore, it would be better to use the Vpp measurement in the analysis of ECT signals.



(a) TWH (b) 80% FBH



(c) 60% FBH (d) 40% FBH

Figure 5. Vpp and MxR phase angle shift as coil gap variation

Figure 6 shows the phase separation at various coil gaps, which is one of the important characteristics imposed by the ASME code on bobbin coils [2]. As shown in the figure, the phases for both experiments and simulations were separated about 100° to 110° for the signals obtained from the TWH and the 20% FBH in the ASME standard tube. This result satisfies the ASME code that requires the phase separation of between 50° and 120°. Figure 7 shows the amplitude variation of the 20% FBH signal according to the coil gap. The signals with the coil gap of 0.4 mm were adjusted to be 4 volts using amplitude calibration factors and rest of the signals were normalized by applying the same calibration factors. As can be seen in the figure, the signal amplitude increased as the increase of the coil gap.

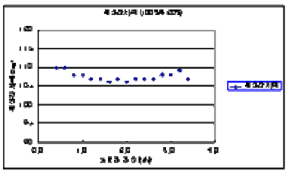


Figure 6. Phase angle separation between TWH and 20% FBH due to coil gap Variation

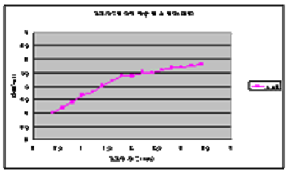
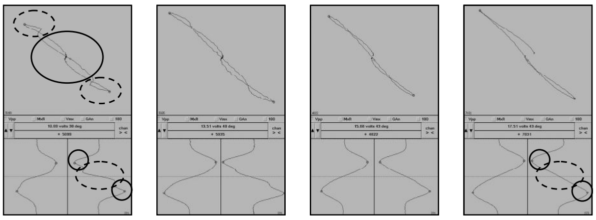


Figure 7. Amplitude change of 20% FBH due to coil gap variation

Figure 8 shows the experimental signals acquired from the notched with various coil gaps. The signals shown in the figure can be divided into two parts. The first part is identified by the solid line circles (in the figure) and corresponds to the compound signals mixed with responses from axial and circumferential notches. The second part is denoted by the dotted line circles to identify the signals form the axial notch. The signals obtained with the coil gaps shorter than 0.8 mm showed very clear separation of two signals. However, when the coil gaps were larger than 1.6 mm it was not possible to separate these two signal groups.



<0.4mm Gap> **<0.8mm Gap>** **<1.2mm Gap>** **<1.6mm Gap>**

Figure 8. Lissajous signals acquired from 60% ID axial and circumferential notches positioned circumferentially 180° with coil gap variation

5. Conclusion

In this study, we have investigated the design optimization problem of a differential bobbin coil probe with an emphasis on finding the optimal coil gap. We have fabricated a specially designed bobbin probe of which the coil gap can be adjusted, and carried out a series of experiments to acquire signals from two kinds of standard tubes with the variation in coil gap. With the results from this study, we have elucidated that the optimum coil gap is 1.2~1.6mm that give the best result for O.D. volumetric defects in ASME calibration standards.

REFERENCES

[1] EPRI, Pressurized Water Reactor Generator Examination Guidelines: Rev. 6.

[2] ASME Boiler and Pressure Vessel Code Ⅴ, Non-Destructive Examination, 1995.