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3-Dimensional Quantitative Measurement of the Geometric Changes in Steam Generator Tubes Using a Diagnostic Eddy Current Probe (D-Probe)

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1. Introduction

Occurrences of the stress corrosion cracking in steam generator tubes of nuclear power plants are closely related to the residual stress existing on the region of geometric change, that is, expansion transition, u-bend, ding, dent, bulge, etc. Therefore, the information on the location, type and quantitative size of the geometric anomaly existing in the tube is prerequisite to the activity of non destructive inspection for the alert detection of earlier crack and the prediction of further crack evolution. In this paper, a newly developed eddy current probe, which has been equipped with the simultaneous dual functions of the crack detection and the 3-dimensional quantitative profile measurement, is introduced. The proof of the probe performance including the accuracy of profile measurement and the applicability of the probe to the plant inspection is provided through the setting-up of the calibration procedure, and the comparison of the quantitatively measured data with those from the laser profilometry for the steam generator tube samples of geometric anomalies with various type and size.

2. Experimental

2.1 Diagnostic Eddy Current Probe (D-Probe)

D-Probe is a brand-new, rotary type eddy current coil probe, developed by KAERI [1]. It is designated as D(diagnostic)-Probe for its break-through function of diagnosis. The probe body is equipped with both the surface riding coil for crack detection and sizing, and the non-surface riding coil for profile measurement. Therefore, it has simultaneous dual functions of crack detection and sizing, and 3-dimenstional quantitative profile measurement with a single pass of probe movement into the steam generator tubes. By comparing the eddy current data from the crack with those from the geometric changes, the relationship between the degradation and geometric changes can be revealed. Also, it supplies the information on tube location at which cracking is most probable and thus, more alert detection of the earlier crack and the resultant increase in the possibility of detection can be expected. Moreover, the management strategy based upon the quantitative size of geometric changes can be applied to the operating nuclear power plants, by establishing the role of geometric changes on the cracking.

Fig. 1 shows the prototype D-probe, manufactured by Zetec Inc. according to the technical design by KAERI.

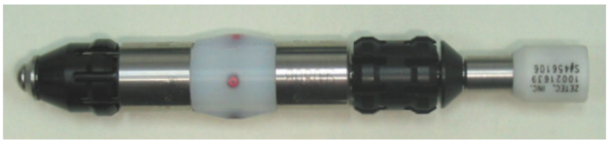


Figure 1. Photograph of a prototype D-probe.

The prototype D-probe has three eddy current coil units(two surface riding type for crack detection and one none-surface riding type for profile measurement), which are located at a circumference of the probe body. Compared to the other recently developed multi-coil array probe such as intelligent probe or x-probe [2], D-probe has a supreme advantage of measuring pure geometric changes on tube inner surface, excluding the noise from the tube outside, by the use of the exclusive eddy current coil for profile measurement optimized at the higher test frequency of 700kHz. The probe was designed to be compatible with commercial eddy current test equipments. In this work, the eddy current data was obtained using Zetec MIZ-70 digital data acquisition system, and the conditions of sampling rate, probe pulling speed, and probe rotating rate were adjusted so that each data could be obtained at distance intervals of less than 1mm in both the axial and the circumferential direction of tube.

2.2 Laser 3-D Profile Measurement

Among the existing technology for measuring the profile of the tube inside, laser profilometry is regarded as the most advanced and precise one with the highest resolution. Therefore, the laser profilometry was applied to measure the real size of the expansion/dents in the standard tube used for the calibration of D-probe profile signal, and the geometric anomalies of the tube samples. The sizes of geometric anomalies of the tube samples measured by the laser profilometry were counted as the reference standards for the comparison with those from the D-probe. LTC LP-2000 profilometry system, used for the measurement, has a rotary laser sensor with the spot size of 0.13mm and the resolution of 0.013mm. The data were obtained at the intervals of 1 degree in the circumferential direction and 0.4mm in the axial direction of the tube.

2.3 Calibration Standard Tube and Tube Samples with Geometric Anomalies

In order to set up the calibration procedure for converting the value of eddy current signal from the D-probe to the value of radius, a calibration standard tube containing the 5 segments of uniform radial changes ranged from −0.35mm to +0.35mm was manufactured. Also, tube samples with various geometric anomalies of local dent, bulge, and expansion were used to compare the accuracy of the profile measurement by the D-probe with those by the laser profilometry.

3. Results and Discussion

3.1 Setup of the Calibration Procedure

The relationship between the values of eddy current signal from the D-probe and the values of radius from the laser profilometry, obtained by using the calibration standard tube with 5 segments of radial changes, was shown in Fig. 2. The decrease and increase of the radius value from the nominal tube radius (8.44mm) are characterized by dent and expansion, respectively. In order to obtain the equation for the optimal calibration, mathematical fitting methods were applied ant it was found that 2nd , 3rd and 4th order polynomial curves fitted well, as shown in Fig. 2. Compared to the 2nd order polynomial curve, better fit was observed for both 3rd and 4th order curves without any difference between the two. Thus, it can be concluded that the use of the 3rd order polynomial equation, fitted by 4 data points from the standard tube containing one segment of expansion and two segments of dents, is the most effective calibration procedure.

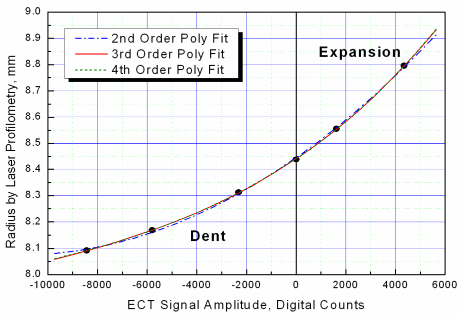
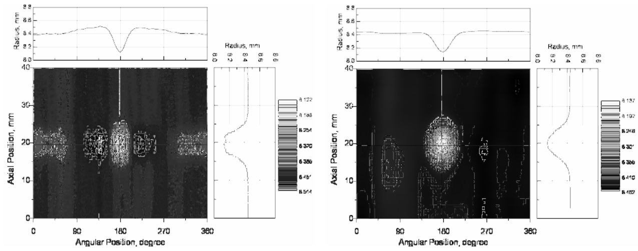


Figure 2. Relationship between the eddy current signal amplitude from D-probe and the radius values from laser profilometry, measured by using the calibration standard tube.

3.2 3-Dimensional Quantitative Measurement of Geometric Anomalies using D-Probe

In order to examine the accuracy of the quantitative profile measurement using D-probe, the results were compared with those from the laser profilometry for the sample tubes with various geometric anomalies. For the calibration of the D-probe data, the optimized procedure using the 3-rd order polynomial equation, described in the section 3.1, was applied.

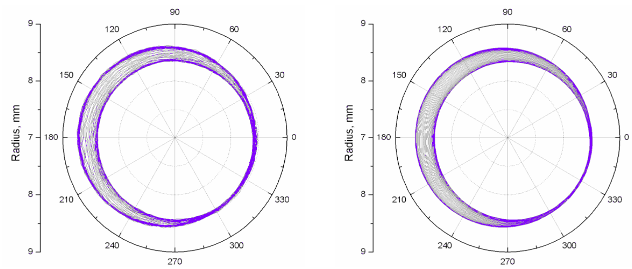
Fig. 3 shows the distribution of the radius values measured along the angular and the axial position of the tube sample with single spot dent, by the laser(Fig.3-a) and the D-probe(3-b). Almost the same results were obtained and the maximum value of the dent evaluated in the radial direction was 0.35mm in the both figures.



(a) (b)

Figure 3. Radius distribution of the tube sample with single spot dent, measured by (a) laser and (b) D-probe.

The results from the tube sample with the geometric anomaly of eccentric expansion by explosive method are shown in Fig. 4. The radius values measured in the expansion transition region of the tube were plotted in the polar coordinate. The same results are observed in the radius measurement by the laser(Fig. 4-a) and the D-probe(Fig. 4-b), and the magnitude of the maximum eccentric expansion evaluated in the radial direction is 0.35mm in the both figures.



(a) (b)

Figure 4. Radius distribution of the tube sample with eccentric expansion, measured by (a) laser and (b) D-probe.

4. Conclusion

A new eddy current probe for the 3-dimensional quantitative measurement of the geometric changes and the simultaneous detection of defects in the steam generator tubes has been developed. Through the development and application of an optimized calibration procedure, it was proven that the quantitative measuring accuracy of the geometric changes by using D-probe was comparable to that by the laser profilometry.

REFERENCES

[1] D.H. Lee et al, Korea Patent No. 562358, KAERI/KHNP, 2006.
[2] J. Kang, X-probe Experience at Diablo Canyon, 22nd EPRI SG NDE Workshop, Hilton Head, USA, 2003.