Non Destructive Measurement of the Setup Angle between the Penetration Nozzle and the Pressure Vessel

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1. Introduction

In the pressure vessels of nuclear power plants, such as reactors or steam generators, a large number of penetration nozzles of small diameter tubes are installed for a control of the reactivity, instrumentation, and draining of the coolant. A schematic diagram is shown in Fig. 1 for an example of a nuclear reactor vessel. The inside surface of the reactor shell and the outer surface of the nozzle are joined by a weldment in a J-groove on the shell wall to secure a leak tightness.

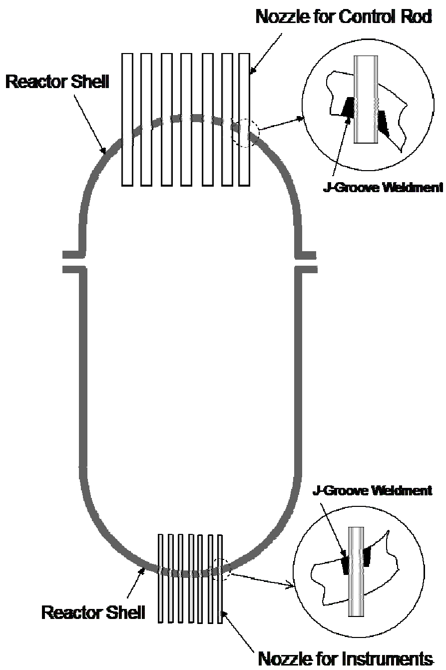

Figure 1. Schematic diagram of the penetration nozzles in a nuclear reactor vessel.

Repetitive heating and cooling of a weldment introduced by a welding process causes an expansion and shrinkage, and a resultant deformation of the nozzle. The deformation of the nozzle incurs a high residual stress, which accelerates a stress corrosion cracking of the nozzle material. It was shown that the magnitude of the maximum residual stress of each nozzle, installed on the dome of the vessel, was proportionally dependent on the setup angle between the nozzle and the inner surface of the pressure vessel, as defined in Fig. 2 [1]. Therefore, a measurement of the setup angle of each nozzle installed in the pressure vessel is essential for a precise estimation of the susceptibility to a cracking in each nozzle.

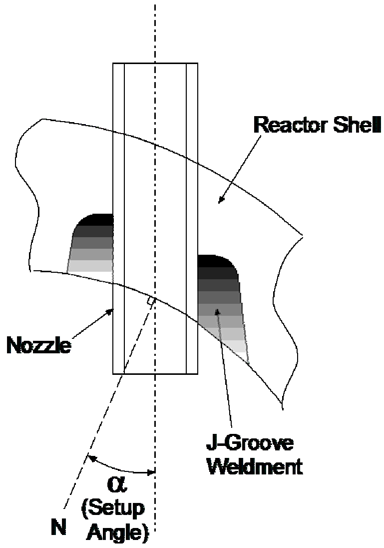

Figure 2. Definition of the nozzle setup angle (α) in a reactor vessel.

The nozzles in the nuclear reactors and the steam generators are usually made of corrosion resistant alloy, such as alloy 600, 690 and austenitic stainless steel. The local region of a nozzle in contact with a weldment is inevitably affected by the heat from the welding process, and is subject to changes in its physical properties including its microstructure, permeability and electrical conductivity.

The present study starts from this idea that the setup angle between the nozzle and the inner surface of the pressure vessel may possibly be measured by analyzing the geometry of the heat affected zone in a nozzle, where the physical properties have been changed locally.

2. Experimental

2.1 Detection of Changes in Physical Properties of Penetration Nozzle Material

The eddy current test method was chosen because the changes in the permeability and electrical conductivity could be detected non-destructively and sensitively [2]. Considering that the penetration nozzle has a tube geometry and a 3-dimensional scan of the eddy current signal along the circumferential and axial direction of a tube are needed, the eddy current test method using a motorized rotating pancake coil probe has been applied.

Zetec MIZ-70 eddy current data acquisition system and a motorized rotating 3-coil probe were used.

2.2 Penetration Nozzle Specimens

The penetration nozzle specimens were prepared by heating the alloy 600 tubes locally with electric band heaters in order to simulate the geometry of the heat affected region by the welding process. Three kinds of specimens were simulated to have a setup angle of 0, 15 and 21 degrees, by using the band heaters with the corresponding geometry of the setup angle, respectively.

3. Results and Discussion

3.1 Changes in Physical Properties and Eddy Current Signal

Fig. 3 shows the result of 3-dimensional distribution of the eddy current impedance from the specimen which is simulated to have a setup angle of 0 degree. It is clearly seen that the heat affected region, where the value of the impedance have increased, can be clearly distinguished from the eddy current signal. The changes in the impedance signal are thought to reflect the changes in the electrical conductivity caused by the microstructure changes in the heat affected region.

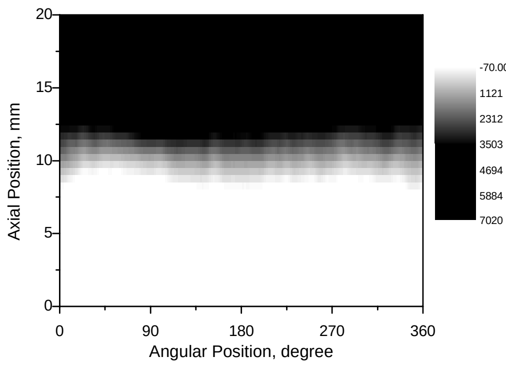

Figure 3. 3-dimensional distribution of the eddy current impedance from the specimen with a setup angle of 0 degree.

3.2 Measurement of Setup Angle

Fig. 4 shows the result of 3-dimensional distribution of the eddy current impedance from the specimen which is simulated to have a setup angle of 15 degree. From the definition of the setup angle shown in Fig. 2, the setup angle can be calculated using the following equation,

$$\text{Setup Angle (a)} = \tan^{-1}\{(A-B)/D\}$$

where, A and B represent the maximum and the minimum values of the axial position where the impedance begin to increase, respectively, and D is the value of the inner diameter of the nozzle specimen.

From the equation above, the setup angle was calculated to be 14.9 degrees, which was coincident with the value of 15 degrees in the condition of the specimen preparation.

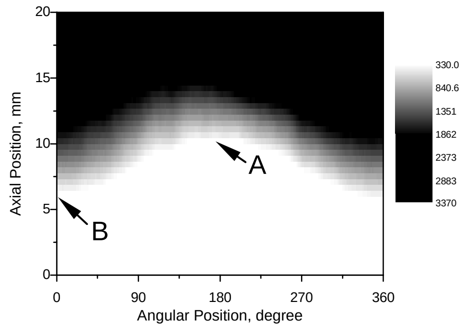

Figure 4. 3-dimensional distribution of the eddy current impedance from the specimen with a setup angle of 15 degrees.

The result of the 3-dimensional distribution of the eddy current impedance from the specimen which is simulated to have a setup angle of 21 degrees is shown in Fig. 5. The value of the setup angle was calculated to be 21 degrees, which was also the same as that in the condition of the specimen preparation.

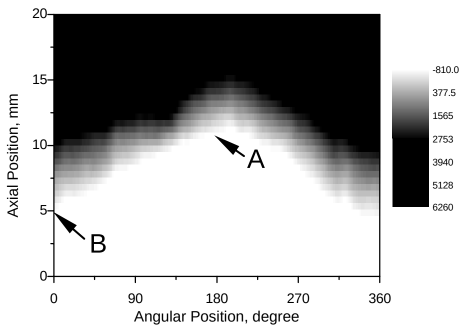

Figure 5. 3-dimensional distribution of eddy current impedance from the specimen with a setup angle of 21 degrees.

4. Conclusion

The setup angle between the nozzle and the inner surface of the pressure vessel could be measured exactly, by analyzing the geometry of the heat affected zone in the nozzle, where the physical properties were changed locally.

REFERENCES

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[2] D. J. Hagemaier, “Fundamentals of Eddy Current Testing,” ASNT, 1990