Prediction of the Flow Accelerated Corrosive-Inner Wall Surface Regions of CANDU Reactor Feeder Pipes Conveying Two-Phase Coolant

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1. Introduction

Feeder piping is an integral part of the CANDU Primary Heat Transporting System (PHTS), carrying pressurized heavy water to and from the reactor fuel channels to remove heat produced by the fission of uranium fuel [1].

From the results of the in-service inspection (ISI) measuring the wall thickness of outlet (hot-leg side) lower feeder pipes performed at two CANDU reactors, Point Lepreau and Gentilly-2 in 1995 and 1996, respectively, the wall thinning degradation of feeder pipes at the bend part was unexpectedly found to be much severe. It has been well known that such wall thinning of feeder pipes is caused by the flow-accelerated corrosion (FAC) which is one of the mechanical-chemical degradation mechanisms affecting the integrity of piping systems. Especially, intensive studies to understand the parameters affecting FAC have been performed [2] and some commercial codes such as CHECWORKS [3] to monitor and predict the FAC rate of piping systems/components have been developed. For the Wolsung unit 1, the wall thickness measurements have been performed during every overhaul period since 1996. The wall thinning rates at the bends of outlet feeder pipes were assessed to exceed the design value.

Up to the present, the inspection of feeder pipe wall thinning has been focused on the central extrados surface area of feeder pipe bend part where is generally considered to be the initially most thinned area resulting from the manufacturing bending process of feeder pipe.

The preliminary study [4] on the prediction of potential for the mechanical damage of thinning due to the flow-accelerated corrosion on the wall of CANDU feeder pipe was performed, where the primary coolant was assumed to be a single-phase saturated liquid. It was found that the connection region of straight and bend pipe near the inlet part of the bend intrados is predicted to be the worst region susceptible to wall thinning due to FAC.

In the meantime, at the CANDU reactor under consideration herein the primary coolant at the exit of pressure tube containing fuel maintains a quality of zero during the condition of reactor power less than about 80% beyond which however, the quality increases linearly up to about 4% (it corresponds to the void fraction of 33.5%) as the reactor power rises to 100 %.

In this study, the two-phase flow field inside feeder pipes has been analyzed as realistically as possible and the shear stress distributions have been calculated to predict the local region of feeder pipe wall highly susceptible to FAC-caused thinning. Based on the results mentioned above, a guide to the selection of the weakest position (location) where the measurement of wall thickness should be performed has been provided for the establishment of preventive measures.

In this research, the computational fluid dynamics (CFD) analysis has been performed to address the present problem.

2. CFD Analysis

CFD calculations are performed for the simplified 2.5 inch feeder pipe model where the 1st and 2nd spans of feeder pipe lie on the same plane. Feeder pipes are categorized into two groups: type A and type B. Type A feeder pipe is the case where the 1st bend winds in the upstream direction of pressure tube. On the other hand, type B feeder pipe is the case where the 1st bend winds in the downstream direction of pressure tube.

The coolant is heavy water in two-phase. Reference pressure is equal to 10 MPa and reference temperature is equal to 310 ^{o}C. Inlet condition is that mass flow rate is equal to 24 kg/s and outlet condition is that average relative static pressure is equal to 0 Pa. And no slip condition is applied on the wall. These conditions are referred to FSAR [5]. Mesh type is tetra-prism mesh, and about 900,000 nodes are used. Simulation type is steady state and turbulent flow is simulated numerically using the standard $k-\varepsilon$ turbulence model [6]. Especially, for the calculation of pipe internal two-phase flow, the inhomogeneous two-fluid model is used. And a convergence criterion is that RMS residuals of major parameters are less than 10^{-4}.

3. Results and Discussion

The CANDU reactor system considered herein is designed such that the quality of primary coolant flowing into the feeder pipes from the outlet of pressure tube containing fuels has a value ranging from zero to about 4 % which is equivalent to the void fraction of about 33.5%. Thus, to investigate the effects of void fraction of coolant on the shear stress distribution on the inner wall, calculations have been performed for the 4 different cases where the void fraction of coolant entering the feeder pipes has 0.1, 0.2, 0.3 or 0.4 while the same 1st and 2nd bend angle and the lengths of 1st and 2nd straight pipes are fixed for 70°, 0.65 in, and 1.5 in, respectively.

3.1 Type A feeder pipes: Effects of the void fraction $\underline{\alpha}$ of fluid at the inlet

Figure 1 displays the local positions of the feeder pipe inner wall surface subjected to the maximum fluid shear stress for the 4 different cases where $\alpha = 0.1$, 0.2, 0.3 or 0.4. As can be seen from the figures, the fluid shear stress distribution on the feeder pipe inner wall surface as well as the local position of the feeder pipe inner wall surface subjected to the maximum fluid shear stress hardly changes even though the void fraction of coolant entering the feeder pipe varies in the specified range considered in the system design. In addition, the weakest positions subjected to the maximum wall shear is located at the 2nd bend intrados surface area for all cases and between the inlet part of the 2nd bend and mid part of the 2nd bend like results for single phase [5].

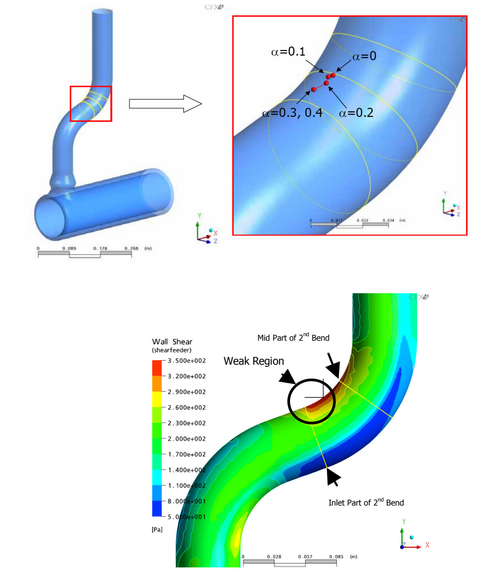

Fig. 1 Effects of the void fraction on the local positions of the feeder pipe A inner wall surface subjected to the maximum fluid shear stress

3.2 Type B feeder pipes: Effects of the void fraction α of fluid at the inlet

Figure 2 displays the local positions of the feeder pipe inner wall surface subjected to the maximum fluid shear stress for the 4 different cases where $\alpha = 0.1$, 0.2, 0.3 or 0.4. As can be seen from the figures, for the cases where the void fraction has a value not greater than 0.2, the fluid shear stress distribution on the feeder pipe inner wall surface as well as the local positions of the feeder pipe inner wall surface subjected to the maximum fluid shear stress located at the 1st bend intrados surface region between the inlet part of the 1st bend and mid part of the 1st bend hardly changes. However, if the void fraction becomes equal to or greater than 0.21, the weakest positions subjected to the maximum wall shear shifted to the 2nd bend intrados surface area between the inlet part of the 2nd bend and mid part of the 2nd bend for all cases and slightly changes as the void fraction increases up to 0.4.

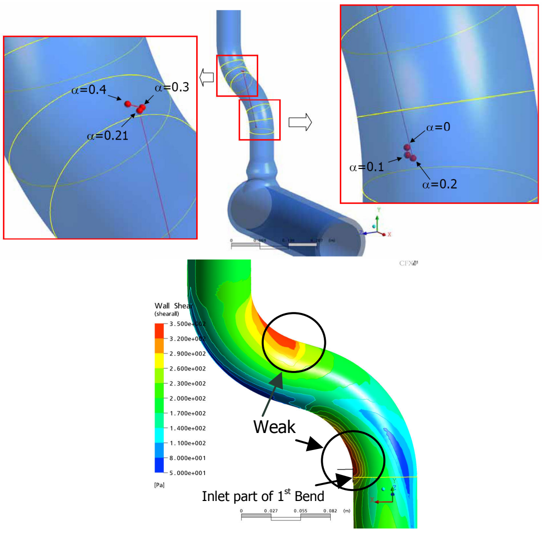

Fig. 2 Effects of the void fraction on the local positions of the feeder pipe B inner wall surface subjected to the maximum fluid shear stress

4. Concluding Remarks

Two-phase flow fields inside feeder pipes have been simulated numerically using a CFD code to calculate the shear stress distribution which is the most important factor to be considered in predicting the local areas of feeder pipes highly susceptible to FAC-induced wall thinning.

The results can be summarized as follows;

For the type A feeder pipe of which the 1st bend winds in the upstream direction of the pressure tube, the fluid shear stress distribution on the feeder pipe inner wall surface as well as the local position of the feeder pipe inner wall surface subjected to the maximum fluid shear stress hardly changes even though the void fraction of coolant entering the feeder pipe varies in the specified range considered in the system design. In addition, the weakest positions subjected to the maximum wall shear is located at the 2nd bend intrados surface area for all cases and between the inlet part of the 2nd bend and mid part of the 2nd bend like previous cases.

For the type B feeder pipe of which the 1st bend winds in the downstream direction of the pressure, when the void fraction has a value not greater than 0.2, the fluid shear stress distribution on the feeder pipe inner wall surface as well as the local positions of the feeder pipe inner wall surface subjected to the maximum fluid shear stress located at the 1st bend intrados surface region between the inlet part of the 1st bend and mid part of the 1st bend hardly changes. However, if the void fraction becomes equal to or greater than 0.21, the weakest positions subjected to the maximum wall shear shifted to the 2nd bend intrados surface area between the inlet part of the 2nd bend and mid part of the 2nd bend for all cases and slightly changes as the void fraction increases up to 0.4.

By comparing the present monitoring points with the result of CFD analysis, it is seen that the present wall thickness measurement points (wall integrity monitoring points) of the feeder pipes of Wolsung unit 1 are not coincident with the worst region predicted by the CFD analysis.

Therefore it is recommended that the results obtained from the present CFD analysis based on the knowledge of FAC mechanism should be applied to the feeder pipe management system. Finally, based on the results of the present CFD analysis a guide to the selection of the weakest local positions (locations) where the measurement of wall thickness should be performed with higher priority has been provided for the establishment of preventive measures.

REFERENCES

[1] John C. Jin, Tom Viglasky, Andrei Blahoianu, 2005, "Canadian Regulatory Perspective on Degradations of CANDU feeder piping," 2005 ASME Pressure Vessels and Piping Division Conference, Denver, Colorado USA.

[2] B. Chexal, et al., 1998, Flow-Accelerated Corrosion in Power Plants, EPRI-TR-106611-R1, Electric Power Research Institute.

[3] EPRI, 1997, CHECWORKS™ Computer Program Users Guide, EPRI-TR-103198-P1, Electric Power Research Institute.

[4] Jo, J.C. et al., 2006, Development of Regulatory Technology for Integrity assessment of CANDU Feeder Pipes, KINS/RR-444, SIRD-5, Korea Institute of Nuclear Safety.

[5] KHNP, Wolsung Unit 1 Final Safety Analysis Report, Korea Hydro & Nuclear Power.

[6] ANSYS, 2005, CFX-5.10 Manual, ANSYS, Inc.