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CFD Application to the Regulatory Assessment of FAC-Caused CANDU Feeder Pipe Wall Thinning Issue

Dong Gu Kang, Seon Oh Yu, Myung Jo Jhung, Jong Chull Jo*
Safety Issue Research Department, Regulatory Research Division, Korea Institute of Nuclear Safety
*19 Guseong-Dong, Yuseong-Gu, Daejeon, Korea, *jcjo@kins.re.kr*

1. Introduction

From the results of the In-Service Inspection (ISI) measuring the wall thickness of outlet (hot-leg side) feeder pipes performed at two Canadian nuclear power plants, Point Lepreau and Gentilly-2 in 1995 and 1996, respectively, the wall thinning degradation of feeder pipes at the bend part was found to be much more severe than expected. 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. 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. However, for the Wolsung units 2, 3 and 4, the wall thinning rates of all the outlet feeder pipes were assessed not to exceed it. The reason is because the content of Cr in the material of feeder pipes of Wolsung units 2, 3 and 4 is higher than that of Wolsung unit 1 [1].

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. However, the potential local areas where are expected to be the most susceptible to wall thinning due to the flow-accelerated corrosion mechanism have not been evaluated (identified). In addition, the accuracy of UT measurement which has been utilized is known to be unacceptably low. Thus, the present practice of feeder pipe wall thinning inspection may result in the excessive exposure of inspection personnel without getting effective outcomes. In this regard, it will be very important to identify the local areas where are the most susceptible to the FAC-caused thinning and to determine the essential local points on which the thickness of wall needs to be measured to achieve the main objectives of inspection.

2. Analysis

The factors affecting the FAC mechanism are water-chemistry, temperature, velocity, composition of pipe material, etc. Most factors except hydrodynamic factors uniformly affect the whole inner surface of piping system through which the fluid flows. On the contrary, the hydrodynamic factors such as fluid velocity and shear stress vary with local position of piping system through which the fluid flow does not maintain its velocity profile uniformly. Therefore, the high shear stress which means steep velocity gradient in the direction of normal to wall surface near the pipe inner surface will be one of the most dominant factors affecting the FAC-caused local thinning of the feeder pipe.

Because the geometries of the feeder pipes connected to the pressure tubes are very complex, analytic solutions to obtain the flow field are not available, and experiments are very costly and difficult to conduct, the computational fluid dynamics (CFD) analysis has been chosen as the best practical approach to address the present problem.

Therefore, in this study, the flow field inside feeder pipes has been analyzed as realistically as possible using computational fluid dynamics 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.

3. Results and Discussion

It is known that both 1st and 2nd bends of outlet lower feeder pipes are the parts vulnerable to the FAC-caused wall thinning. The outlet lower feeder pipes are grouped into 20 types according to length and bend angle of feeder pipes [1]. Twenty types of feeder pipes are grouped into two categories by the direction of the 1st bend outlet. One is the geometry where the 1st bend winds in the upstream direction of pressure tube. The other is the geometry where the 1st bend winds in the downstream direction of pressure tube.

The CFX code is used for the CFD analysis with mesh type of tetra-prism and about 900,000 nodes. The CFD schemes used to simulate the flow situation in the CANDU feeder pipes in this study have been verified by comparing the investigation results for the failed feedwater pipe at Surry unit 2 plant with the CFX code calculations [2].

Sensitivity studies of the three geometrical parameters such as angles of the 1st and 2nd bends, length of the 1st span between the grayloc hub and the 1st bend, and length of the 2nd span between the 1st and the 2nd bends have been performed. The results can be summarized as follows [3];

- Pressure drop increases as the 1st or 2nd bend angle increases.
- The magnitude of maximum shear stress exerting on the intrados surface area increases as the 1st or 2nd bend angle increases.
- Pressure drop increases as length of the 1st or 2nd straight pipe increases except for the case where the 1st bend winds in the downstream direction of pressure tube because of high friction due to turbulence.
- The magnitude of maximum shear stress exerting on the intrados surface area decreases because the flow is developed as length of the 1st or 2nd straight pipe increases.
- In case where the 1st bend winds in the upstream direction of pressure tube, the connection region of straight and bend pipe near the inlet part of the 2nd bend intrados is predicted to be the worst region susceptible to wall thinning due to FAC.
- In case where the 1st bend winds in the downstream direction of pressure tube, the connection region of straight and bend pipe near the inlet part of the 1st bend intrados is predicted to be the worst region.

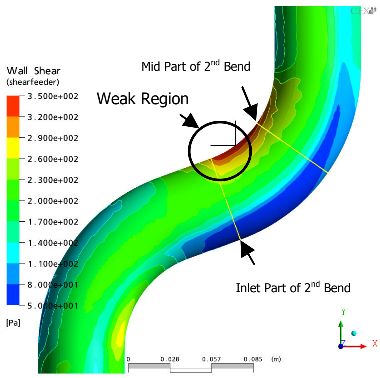

Fig. 1 Weak region due to FAC in case where the 1st bend winds in the upstream direction of pressure tube

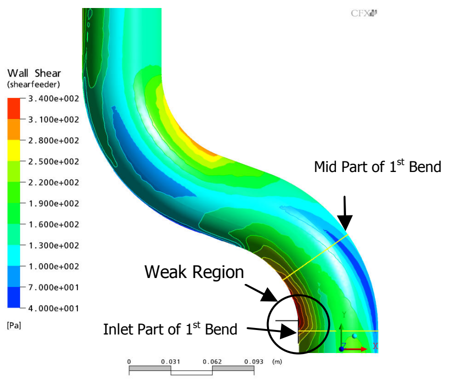

Fig. 2 Weak region due to FAC in case where the 1st bend winds in the downstream direction of pressure tube

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. 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 by 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.

In this study, the possibility was raised that the location of monitoring points on which wall thickness of feeder pipe has been measured might not be appropriate. Furthermore, it was confirmed that FAC rates on bend intrados were more significant than bend extrados through the technical meeting with AECL staff [4]. Considering all these factors, regulatory action has been taken that wall thickness measurement on 1st and 2nd bend intrados of outlet lower feeder pipes should be included in the current inspection system since the 19th Wolsung unit 1 ISI performed in November, 2006.

4. Concluding Remarks

Flow fields inside feeder pipes have been simulated numerically using a CFD code to predict the local regions of feeder pipes highly susceptible to FAC-induced wall thinning.

It is found that the local regions of feeder pipes of Wolsung units in Korea, on which the wall thickness measurements have been performed so far, are not coincident with the worst regions predicted by the present CFD analysis which are the connection region of straight & bend pipe near the inlet part of the bend intrados.

Based on the results of the present CFD analysis a guide to the selection of the weakest local positions where the measurement of wall thickness should be performed with higher priority has been provided.

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