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# FSI Analysis of Mixing Tee for Thermal Fatigue

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## 1. Introduction

Thermal fatigue is a significant long-term degradation mechanism in nuclear power plants. In particular, as operating plants become older and life time extension activities are initiated, operators and regulators need screening criteria to exclude risks of thermal fatigue and methods to determine significant fatigue relevance. In general, the common thermal fatigue issues are well understood and controlled by plant instrumentation at fatigue susceptible locations. However, incidents indicate that certain piping system Tee connections are susceptible to turbulent temperature mixing effects that cannot be adequately monitored by common thermocouple instrumentations.

Therefore, in this study thermal fatigue evaluation of piping system Tee-connections is performed using fluid-structure interaction (FSI) analysis. From the thermal hydraulic analysis, the temperature distributions are determined and their results are applied to the structural model of the piping system to determine the thermal stress. Using the rain-flow method the fatigue analysis is performed to generate fatigue usage factors. The procedure for improved load thermal fatigue assessment using FSI analysis shown in this study will supply valuable information for establishing a methodology on thermal fatigue.

## 2. Analysis

### *2.1 Problem Definition*

A shutdown cooling system is connected to the reactor coolant system in parallel to eliminate the decay heat during plant shutdown, taking coolant in the hot leg and circulating it into the cold leg. This system for Ulchin 3 and 4 starts to operate when the coolant temperature is 177°C and its pressure 3 MPa until the temperature becomes 60°C with the cooling rate of 41.7 ~ 16.7°C/hr.

The area to be analyzed in this study is the mixing tee area where the main pipe conveying coolant of high temperature meets the branch line pipe carrying coolant of low temperature passing through the heat exchanger. In this area, the thermal fluctuation and/or stratification appears due to the high-low temperature mixing flow, which causes thermal fatigue.

### *2.2 Thermal Hydraulic Analysis*

Using ANSYS CFX 13.0 [1], a thermal hydraulic analysis is performed for the piping system with mixing tee junction. The fluid region inside the pipe is modeled by ANSYS Design Modeler. The transient analysis is performed for the 300 seconds with the time step of 0.1 second.

A hexagonal mesh with about 540,000 elements is generated. The number of nodes is determined based on the sensitivity study to increase the accuracy of the solution.

A sufficient length of pipe is included in the model to develop the flow fully as shown in Figure 1. The results of sensitivity study show that the length of 20 meters in the upstream of the main piping system is sufficient for the fully developed flow.

The flow profile of the downstream shows that the velocity changes at the junction are significant but the flow tends to remain stable at the outlet region.

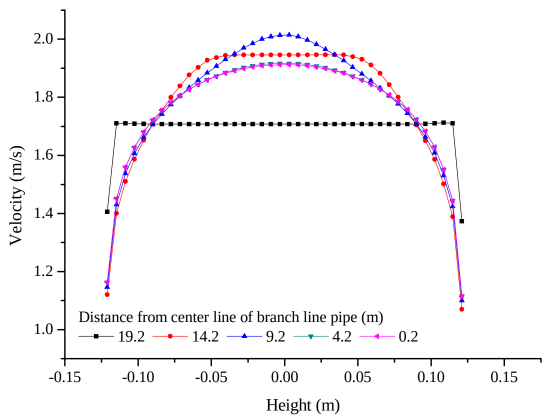


Figure 1. Flow profile at upstream locations

### *2.3 Stress and Fatigue Analysis*

The stress analysis is performed to get the thermal stress distributions in the pipe using the finite element model taken directly from the CFX model. The model uses 3-dimensional 8-node structural solid elements (SOLID185) and it has 560,341 nodes and 543,180 elements [2]. The fixed boundary conditions in the axial and circumferential directions are applied at inlet ends of the pipe and no axial movement at the outlet location is applied.

Fatigue analysis of the mixing tee is performed for which rain flow method of cycle counting is used [3].

## 3. Results and Discussion

Figure 2 shows the transient temperature distributions at the wetted wall surface at several elapsed times after the beginning of mixing flow. Figure 3 displays the transient temperature distributions at the several cross-sections of the main pipe down stream at the elapsed time of 100 seconds after the beginning of mixing flow.

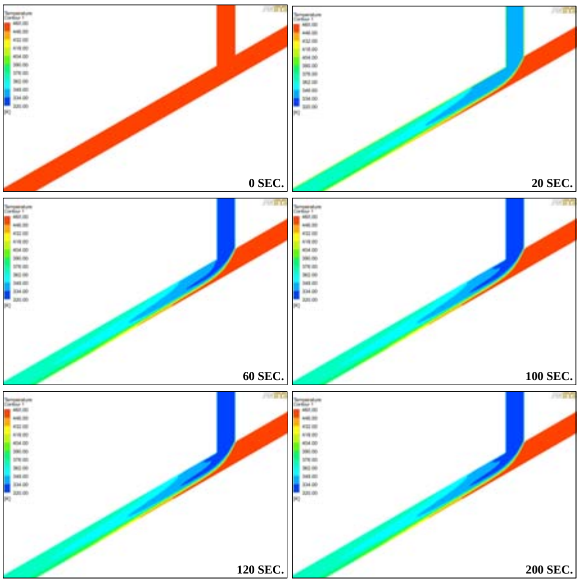


Figure 2. Temperature distributions for thermal hydraulic analysis

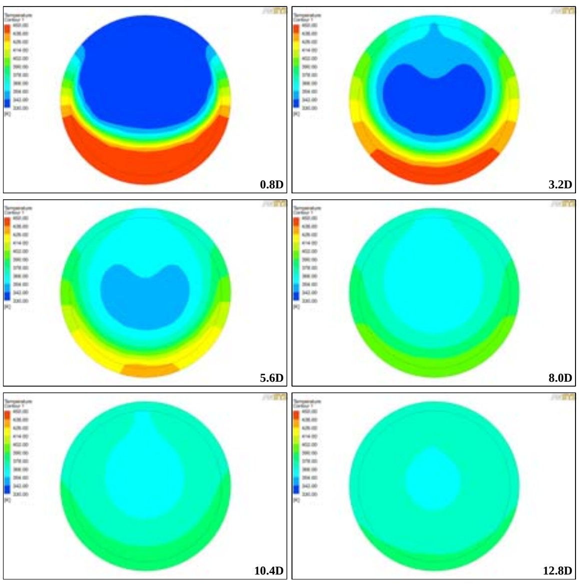


Figure 3. Cross-sections of temperature distributions at 100 seconds

The comparisons of temperature histories at several locations between three points show that the temperatures at the top point are lowered more rapidly than those at the bottom point, which means that there exists thermal stratification. Also it is found that the stable temperatures for all locations are obtained at about 100 seconds after the mixing flow begins.

The stress analysis is performed to get the thermal stress distributions in the pipe using the finite element model taken directly from the CFX model. Temperature distributions of the pipe obtained from the thermal hydraulic analysis are used as an input to the structural analysis to get the thermal stresses. And they are used to calculate fatigue usage factors.

Seven cuts are chosen from experience for calculating the fatigue usage factors. Cuts from A through D are located at the junctions of mixing tee and cuts from E through G are located at the 1/3 locations of the down stream in the main pipe.

The mean temperature variation at each cut shows that it is almost uniform after 170 seconds from the starting point when mixing flow begins. In the same way, the equivalent stress variation at each cut also shows that it is almost uniform after 100 seconds as expected.

The fatigue usage factors calculated at inside and outside of the cut points for the cycles of 5.8E10 are summarized. The usage factors are almost the same for all locations because the stress intensities due to thermal mixing are almost negligible and the allowable numbers of cycles from the design fatigue curve are almost the same for all locations.

## 4. Conclusions

A detailed CFD analysis involving conjugate heat transfer analysis is performed to obtain the transient temperature distributions in the wall of the mixing tee subjected to high-low temperature mixing flow during plant shutdown using a commercial CFD code. The thermal loads from CFD calculations are transferred to ANSYS Multiphysics which is employed for the thermal stress analysis. From the thermal stress analysis, the response characteristics of the T-junction subjected to mixing flow are investigated, and the fatigue analysis is ultimately performed. Using the rain flow method for cycle countings, fatigue usage factors are calculated for locations concerned and are found to be very low.

## REFERENCES

[1] ANSYS, Inc., 2010, ANSYS CFX-Solver Theory Guide and ANSYS CFX-Solver Manager User's Guide, Canonsburg, PA.

[2] ANSYS, Inc., 2010, Theory Reference for ANSYS and ANSYS Workbench Release 13.0, Canonsburg, PA.

[3] Bannantine, J.A., Comer, J.J., Handrock, J.L., 1989, *Fundamentals of Metal Fatigue Analysis*, Prentice Hall, New Jersey.