Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Thermal Fatigue Analysis of CANDU Feeder Pipe System

Myung Jo Jhung, Dong Gu Kang, Jong Chull Jo
Safety Issue Research Department, Korea Institute of Nuclear Safety, 19 Guseong-dong, Yuseong-gu, Daejeon
mjj@kins.re.kr

1. Introduction

ThermoFluid-Structure Interactions (FSI) occurring inevitably in operating reactor component systems can cause excessive force or stress to the structures resulting in mechanical damages that may eventually threaten the structural integrity of components. In this respect, it is very important to develop in-depth technologies in the areas of prediction, analysis, experiment and remedial measure of the FSI phenomena in reactor systems.

To solve FSI problems, results from one field (fluid-thermal) are applied as loads in other field (structural). Due to limitations of computer software and hardware, both thermofluid and structural fields were analyzed separately in the past. But a unified simulation that couples the effects of interrelated physical phenomena (physics or fields) is available now using multiphysics simulation which solves for the combined effect of interrelated physics and solves multiple single-field analyses sequentially and efficiently.

In this study, thermal stress analysis of a CANDU feeder pipe for heatup and cooldown transient is performed using a CFD code; CFX [1] and a FEM code; ANSYS [2] and the results are used for the fatigue analysis of the feeder pipe (Figure 1).

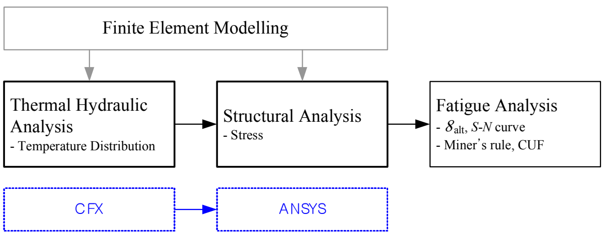


Figure 1. Procedure of FSI analysis.

2. Analysis

2.1 Finite element model

Finite element model is developed using the 3-D structural solid elements (SOLID45) for feeder pipe. SOLID45 is used for the 3-D modeling of solid structures defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The finite element model consists of 10800 elements and 14640 nodes.

The bottom nodes of the feeder pipe are fixed for the boundary conditions to simulate the contact point between feeder pipe and pressure tube. However, no boundary conditions are imposed to the top of the feeder pipe. The endcap effect is applied to the top of the feeder pipe which has no support condition. This is necessary to simulate the internal pressure during the normal operating.

2.2 Stress analysis

Stress analyses using a commercial computer code ANSYS [2] are performed to get the pressure and thermal stresses of the feeder pipe. Temperature distributions of the feeder pipe are obtained from the computational fluid dynamics (CFD) analysis and they are used as an input to the structural analysis where pressure and temperature are considered simultaneously to generate the normal operating stresses.

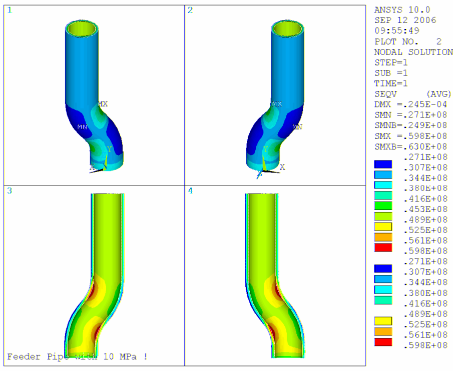
A typical heatup and cooldown transient is taken in the analysis for the thermal transient where only a total time of 180 seconds is considered because CFD analysis needed a lot of computing time. This can be expanded to the real situation in the future.

3. Results and Discussion

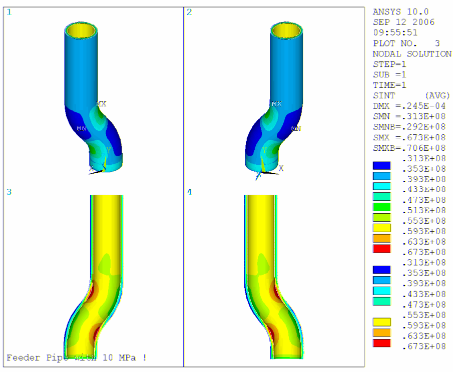
The stress analysis for the internal pressure of 10 MPa is performed to get the stress distributions in the feeder pipe. The equivalent stress and stress intensity are shown in Figure 2 where the maximum values are found in the intrados of the first or second bend. This is clear in the figure which shows their variations along the circumference of the first bend for the equivalent stress and stress intensity. Also stress component variations along the circumference verify the results. If the endcap effect is not considered, the stress variations have totally different shapes and it is evident that the endcap effect should be applied as a boundary condition. Stress variations along the radius show the inner surface is more severe than the outer one.

The CFD analysis using the CFX code [1] generates temperature distributions, and they are directly input to the structural model for the thermal stress analysis. Equivalent stress variations at heatup (30 s) and cooldown (100 s) conditions are shown in Figure 3. Comparing between heatup and cooldown conditions, cooldown is more severe than hetaup at the inner surface and vise versa for the outer surface. The maximum stresses are obtained in the intrados of the bend which is the same as in the case of internal pressure.

The thermal stresses during heatup and cooldown are obtained. Comparing stresses between heatup and cooldown, the axial and circumferential stresses of cooldown case are bigger than those of heatup one and these are added to the pressure stresses generating more stresses for the cooldown case. Therefore it is concluded that cooldown process is more severe than heatup process from the stress point of view.



(a) Equivalent stress



(b) Stress intensity

Figure 2. Stress distribution for internal pressure.

The equivalent stress histories of the typical points are generated for the fatigue analysis as shown in Figure 4. The maximum alternative stress in this case is about 19 MPa and from the fatigue curve for carbon steel [3] the number of cycles is above 10^6. Therefore cumulative usage factor is about infinite and thermal fatigue of the feeder pipe due to heatup and cooldown transient considered in this study is found to be negligible.

4. Conclusion

The analysis procedure for multiphysics simulation is setup using CFX and ANSYS, and thermal fatigue analysis of the CANDU feeder pipe due to the heatup and cooldown transient has been performed. Stress due to internal pressure has been found to be the major factor during the reactor normal operation. By comparing stresses between heatup and cooldown process, cooldown process is seen to be more severe than heatup process from the stress point of view. The equivalent stress histories have been investigated at the intrados of the first bend which is the location of the highly stressed region to get the maximum alternative stress and thermal fatigue of the feeder pipe due to heatup and cooldown transient is considered to be negligible.

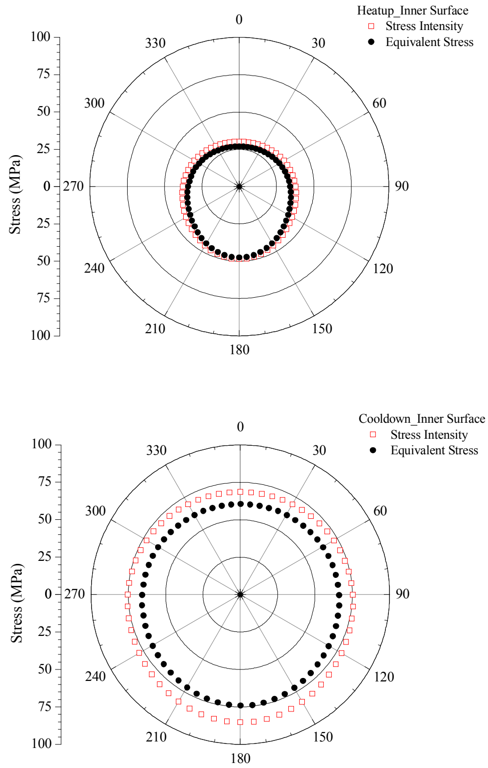


Figure 3. Stress variations along the circumference.

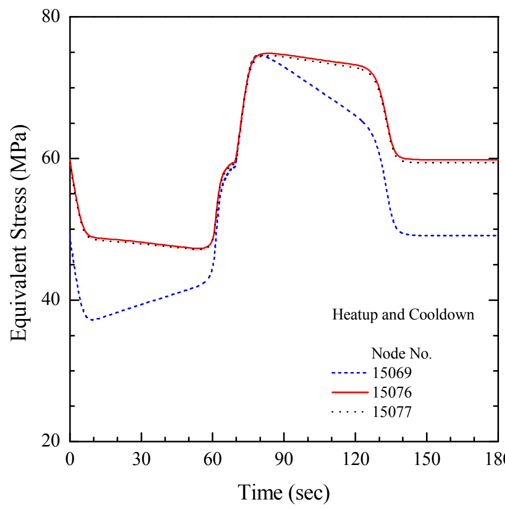


Figure 4. Equivalent stress histories.

REFERENCES

[1] ANSYS, *CFX-5.10 Manual*, ANSYS, Inc., 2005.
[2] ANSYS, *ANSYS Structural Analysis Guide*, ANSYS, Inc., 2004.
[3] ASME, ASME Boiler and Pressure Vessel Code, Section III, Appendix I Design Stress Intensity Values, Allowable Stresses, Material Properties, and Design Fatigue Curves, The American Society of Mechanical Engineers, 2004.