Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22, 2009

Hot Spot Analysis around the Contact Zone between Fuel Rod and Spacer Grid

Jin Seok Lee[a*], Won Dae Jeon[b], Kwang Ho Yoon[a], Yong Hwan Kim[a], Kyeong Lak Jeon[a]

[a]*Korea Nuclear Fuel Co., Daejeon, 305-353, Korea*
[b]*CD-adapco Korea Co., Seoul, Korea*
**Corresponding author: jslee@knfc.co.kr*

1. Introduction

Fuel failure by fretting wear is still one of the complicated phenomena to be solved for the integrity of fuel rod during life time. In an effort to enhance the fretting wear resistance, various contact configurations of grid spring and dimple have been developed by fuel suppliers. The contact configurations between the fuel rod and the spring/dimple of spacer grid are able to be classified into point, line, and surface contact in terms of the shape of the contact area.

During the PSE (Pool Side Examination) and hot cell test of the irradiated fuel rods to verify the fuel performance in reactor, relatively thick corrosion layers were observed through the visual test for the fuel rod after irradiation in reactor as shown in Figure 1. Based on the results of the PSE and hot cell test on the contact surface of the fuel rod, the hot spot phenomenon around the contact surface can be one of the main causes for the thick corrosion layer.

Figure 1. Thick Corrosion Layers found at Contact Surface with Grid Spring and Dimple

In order to make a close investigation into the possibility of the hot spot at the contact surface of the fuel rod, a multiplicity of the spring contact shapes and gap conditions were incorporated into the CFD (Computational Fluid Dynamics) models including the fuel rod and the spring and dimple of the spacer grid.

In this study, it was calculated the temperature distributions around the contact zone between the fuel rod and the spacer grid to understand the effect of the gap and the grid spring shape on the hot spot.

2. Analysis Model

In order to produce the CFD model for the fuel rod and the spacer grid, the SolidWorks[1] model of the fuel rod and the spacer grid has been imported to the CFD program, STAR-CCM+[2]. Then, the polyhedral volume mesh has been created by the automatic mesh generation program. Figure 2 presents the detail polyhedral mesh configurations of the spring and dimple with the fuel rod. The model has been meshed using the polyhedral element that enables to effectively stimulate the very complicate geometry.

The polyhedral type mesh also makes it possible to enhance the calculation accuracy and remarkably reduces the number of volume mesh and calculation time compared to tetrahedral mesh generation program. The CFD model consists of approximately 2,800,000 elements which covers both solid and fluid regions.

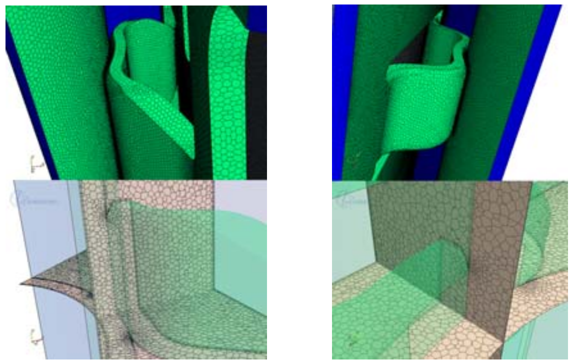


Figure 2. Mesh Configuration of Spring(left) and Dimple(right)

3. Analysis & Results

To simplify this CFD analysis, the cross flows between the adjacent cells were not included in the boundary conditions so that the only symmetry boundary conditions were applied. The initial velocity, 4.97m/s and temperature, 607.69K of the coolant were defined as the inlet conditions. In order to simulate the LHGR (Linear Heat Generation Rate) of the fuel rod, the heat flux condition of 1.11 MW/m^2 is applied at the inner surface of the fuel rod. All the boundary conditions for the simulation are shown in Figure 3.

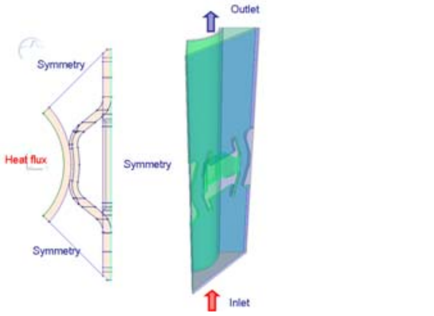


Figure 3. Boundary Conditions of CFD Analysis Model

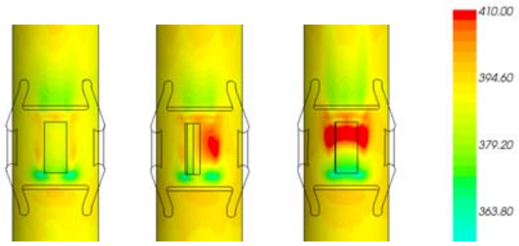
The standard k-ε model was applied to simulate the turbulence model and the UPWIND numerical scheme was used as the calculation method. It took 20~24 hours to calculate each case with the 3G RAM, 2.4 GHz CPU of Itanium Workstation 4 CPU in parallel processing.

Table 1. Input Values for Boundary Conditions

Boundary Conditions	Value	
	British unit	SI unit
Heat flux	0.35 Mbtu/hr-ft^2	1.11 MW/m^2
Inlet Temperature	634.18 ˚F	607.69 K
Inlet Velocity	16.31 ft/s	4.97 m/s

In this CFD analysis, the boundary conditions in Table 1 were applied to the CFD models with different gap conditions and contact shapes for the sake of relative comparison.

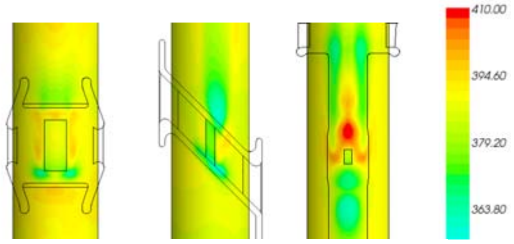
Figure 4 shows the temperature distributions on the fuel rod with various gap conditions. The same spring design was applied to all three CFD models in Figure 4. But the gap condition of each model is different from each other. The first model a) of Figure 4 has no gap. And both model b) and model c) have the 0.05mm gap between the fuel rod and the grid spring. It is observed that there are wide hot spots in case of model b) and model c) which simulate the gap (0.05mm) conditions but have same spring shape.



a) No gap b) One side gap c) Uniform gap

Figure 4. Temperature Distributions on the Fuel Rod Surface with Different Gap Conditions

The influences of the spring shape on the hot spot also were examined. In this parametric study, all kinds of the possible spring shapes were considered such as point, line and surface contacts which have been applied to the commercial fuel so far. All 3 models of Figure 5 simulate ideal contact conditions between fuel rod and grid spring.



a) Area contact b) Line conta c) Point contact

Figure 5. Temperature Distributions on the Fuel Rod Surface with Different Spring Contact Configurations

In this ideal contact conditions between the grid spring and fuel rod, the line and point contact conditions of the model b) and model c) of Figure 5, respectively have the lower temperature distributions than that of the surface contact conditions although the peak temperature of model c) is little higher than others.

4. Conclusion

Based on the CFD analysis, it is founded that the contact configurations of grid spring and dimple play a significant role in the temperature distributions on the contact surface of the fuel rod. The existence of the tiny gap between the fuel rod and the grid spring tends to increase the hot spot which may cause relatively thick corrosion. The wider area contact contributes to decrease the temperature of the fuel rod surface in the ideal contact condition, that is, when there is no gap. However if the area contact has the gap, the hot spot was sharply increased.

In the sense of the hot spot analysis on the fuel rod, the real contact conditions between the fuel rod and the grid spring should be considered to exactly predict the possibility of the hot spot. Because the area contact conditions have the higher possibility of the gapped contact than any other contact shapes.

It was estimated that the real contact conditions should be incorporated into the hot spot analysis model to simulate the conditions in reactor. And also the area contact design need to be verified to maintain the area contact during its life time with no tiny gap to minimize the thick corrosion layer at the contact surface.

ACKNOWLEDGEMENT

This work is carried out under the program "Potential Failure Mode & Effects Analysis for the improvement of Fuel Reliability".

REFERENCES

[1] SolidWorks Corporation, "SolidWorks Office (SolidWorks Essentials: Parts and Assembly)", 2008.

[2] STAR-CCM+, Version 3.06, *CD-adapco Co.*