Stress Analysis of Fuel Rod under Axial Coolant Flow

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1. Introduction

A pressurized water reactor(PWR) fuel assembly, is a typical bundle structure, which uses light water as a coolant in most commercial nuclear power plants[1]. Fuel rods that have a very slender and long clad are supported by fuel assembly which consists of several spacer grids. A coolant is a fluid which flows through device to prevent its overheating, transferring the heat produced by the device to other devices that use or dissipate it. But at the same time, the coolant flow will bring out the fluid induced vibration(FIV) of fuel rods and even damaged the fuel rod. This study has been conducted to investigate the flow characteristics and nuclear reactor fuel rod stress under effect of coolant. Fluid structure interaction(FSI) analysis on nuclear reactor fuel rod was performed. Fluid analysis of the coolant which flow along the axial direction and structural analysis under effect of flow velocity were carried out under different output flow velocity conditions.

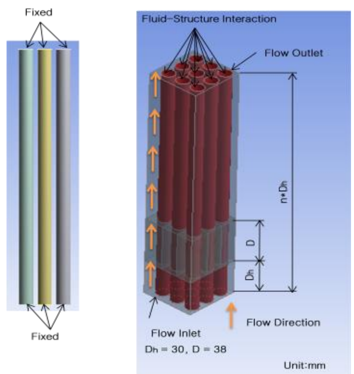

Fig. 1. Schematic of overall domain

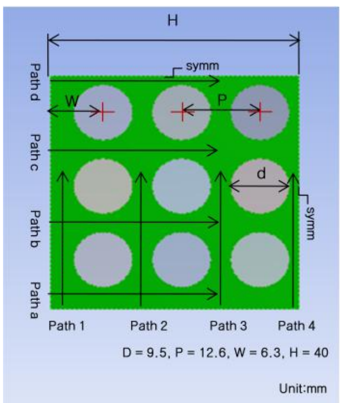

Fig. 2. Cross section of 3 by 3 rod fuel bundles an measuring location

2. Analysis Model

In this study, assume the fuel rod was fixed well by spacer grip, the coolant flow along the direction of principal axis with flow velocity range of 4~9 m/, and the inlet pressure was 1.4 atm. Fig. 1 and Fig. 2 shows the spacer grip form and size. Here, using the 6 by 6 spacer grip form and give the symmetry condition to decrease to 3 by 3 model. The part spacer grip length is D_h=30 mm, height is D=38 mm, coolant flow inlet to outlet length dimension is n* D_h=210 mm where n represent variable, housing length is H=40 mm, fuel rod diameter is d=9.5mm, spacer grid pitch is P=12.6 mm, and W=6.3 mm. Flow paths along the bottom wall and left wall are also shown in Fig. 2.

2.1 The Structure Model

The structure model was discrete with 189,123 elements by meshing package in workbench program, see Fig. 3. The material properties of the structure model were taken in the work of chen[2] were a Young's modulus of E = 98.6 GPa, a shear modulus of G = 0.3 GPa and a Poisson ration of n = 0.3.

2.2 The Fluid Domain Model

The computational fluid domain model was discrete with 539,658 elements by means of CFX meshing with temperature 25 ^{0}C, see Fig. 4. The fluid flow along the principal axial and the outlet flow velocity was 4m/s ~ 9m,/s. In this fluid domain, spacer grip was modeled with wall element as Fig. 5 shows.

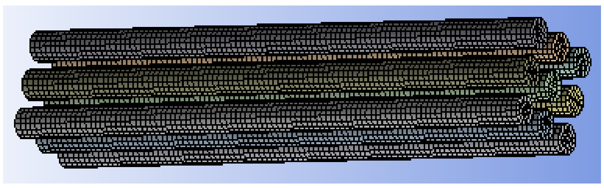

Fig. 3. Structure meshes of nuclear reactor rod

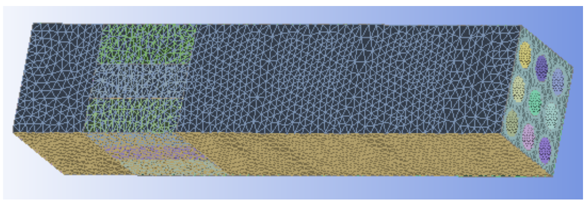

Fig. 4. Volume meshes of fluid domain

3. Simulation Results and Discussion

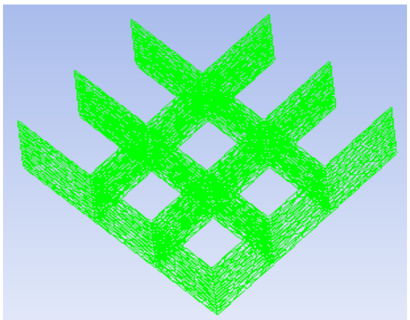

Fig. 5. Spacer grid model

Table I: Maximum flow velocity under different outlet flow velocity from path 1 to path 4

Outlet flow velocity (m/s)	Maximum flow velocity (m/s)			
	Path 1	Path 2	Path 3	Path 4
4	4.49	4.50	4.47	4.30
5	5.46	5.56	5.48	5.34
6	6.40	6.53	6.42	6.41
7	7.45	7.57	7.42	7.43
8	8.48	8.61	8.47	8.43
9	9.54	9.64	9.45	9.44

Table II: Maximum flow velocity under different outlet flow velocity from path a to path d

Outlet flow velocity (m/s)	Maximum flow velocity (m/s)			
	Path a	Path b	Path c	Path d
4	4.51	4.50	4.40	4.44
5	5.48	5.55	5.42	5.49
6	6.43	6.54	6.42	6.50
7	7.47	7.57	7.43	7.48
8	8.51	8.63	8.44	8.49
9	9.56	9.66	9.46	9.59

In this study, fuel rod stress was calculated under Table I and Table II show the Maximum flow velocity under different outlet flow velocity at different paths. And from the results can see that at path 2 and path b got the maximum flow velocity. Because of the these flow velocity, fluid got the pressure and in the structure analysis the flow pressure was used as input data. Fig. 6 shows the fuel rod stress under different outlet flow velocity. From the results can see that among the flow velocity 4 ~7 m/s the maximum stress happened at spacer grid and at velocity 8 m/s happened near fluid outlet and at velocity 9 m/s happened at fluid outlet. Table III shows the maximum stress of fuel rod at

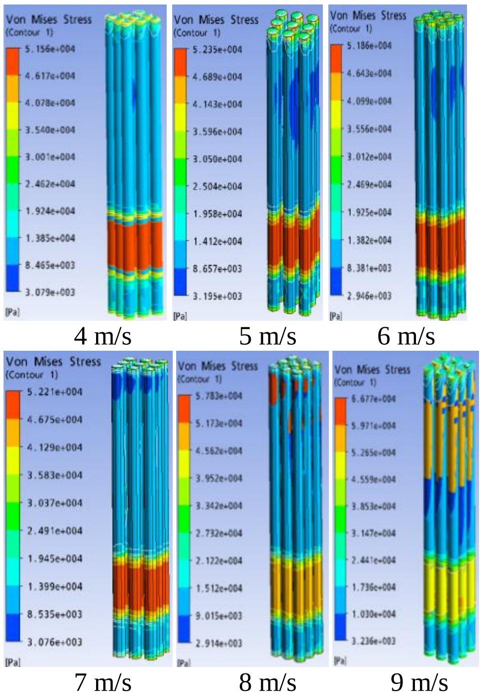

Fig. 6. Von Mises stress under different outlet flow velocity

different output flow velocity. And from the results can see that the maximum stress increased when the outlet flow velocity increased except at velocity 6 m/s and 7 /s.

Table III: Maximum flow velocity under different outlet flow velocity from path a to path d

Outlet flow velocity (m/s)	4	5	6	7	8	9
Maximum Stress (KPa)	51.6	52.4	51.9	52.2	57.8	66.7

4. Conclusions

In this study, nuclear reactor fuel rod stress under axial flow coolant was calculated using FSI method. Fuel rod stress were calculated under axial coolant flow with different output flow velocity conditions(from 4 m/s to 9 m/s).

1. The maximum flow velocity happened at path 2 and path b.
2. Among the velocity 4 ~7 the maximum stress happened at spacer grid and at velocity 8 m/s happened near fluid outlet and at velocity 9 m/s happened at fluid outlet.

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[2] Chen, S. Y., A Study on the Prediction Method of Buckling Load for the Lattic Type Plate Structure of the Fuel Assembly, Dept. of Doctoral Dissertation of Mechanical Design Engineering, Chungnam National University, 2006.