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Small Amplitude Flow-Induced Vibration of a Fuel Rod in Axial Flow by Fluid-Structures Interaction Analysis

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1. Introduction

The low-amplitude vibration problem of fuel rods arises from close spacing between rod cluster and the supports of spacer grids. Thus, this vibration behavior in the long term, causing, separates from fretting, high-cycle fatigue and stress-corrosion cracking, for instance [1]. Nevertheless, this all too easily and conveniently neglected phenomenon eventually become of major concern as long period systems, such as nuclear fuel. Therefore, the flow-induced vibration of a cylindrical rod in axial flow is studied using fluid-structure interaction (FSI) analysis. This is completely defined a typical fluid-structure coupled problem. Unlikely most of the multi-physics code, the ADINA offers fluid-structure interaction capabilities in one single program for the solution of problems where the fluids are fully coupled to general structures that can undergo highly nonlinear response due to large deformations, inelasticity, contact and temperature-dependency. A fully coupled fluid-structure interaction means that the response of the solid is strongly affected by the response of the fluid, and vice versa. The fluid and solid equations are solved individually, in succession, always using the latest information provided by the other part of the coupled system. The iterative FSI coupling solution method requires less memory than the direct FSI coupling method and therefore may be more adequate to solve very large problems [2]. Because, the rod cluster structures with multi-span are composed very large problem, the former analysis scheme is used for this work. The object of a fuel rod with single span for this is shown in the Figure 1.

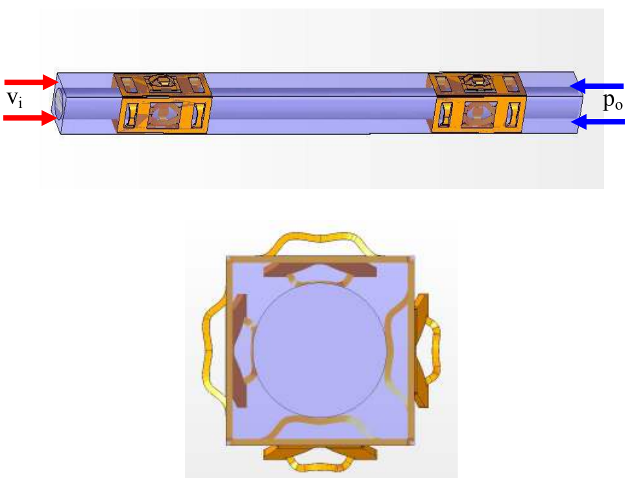

Fig. 1. Unit cell geometry of single span rod contained the coolant in axial flow

The analysis results from the FSI model are compared with those of the test method for verification of the model. After evaluating the validity of it, this FSI model will be expand with the 5 by 5 rod cluster array and multi-span structures. In this study, to propose the basic FSI analysis model of cylindrical rod cluster array.

2. FSI model

The fluid contained into single grid cell is modeled as incompressible water at the core condition. Though the fluid flows in axial direction, there exists the transverse fluid component. In fluid mechanics, the flows of practical relevance are almost always turbulent; this means that the fluid motion is highly random, unsteady and three-dimensional. Generally, a high Reynolds number characterizes turbulent flows. In this work, the Spalart-Allmaras (SA) model is chosen for turbulent flow. The wall boundary condition for the SA transport equation is called the modified eddy viscosity that has the same unit as the kinematic viscosity, namely, L^2 / t, and the others are described in Reference [3]. The supports of a spacer grid are modeled with spring element. On the other hand, the geometrical and material properties are summarized in Table 1. In addition to this, the FSI boundary condition and the initial condition for analysis are depicted in Figure 2.

Table 1: Geometrical and material properties for FSI analysis model

l	560 mm	E_{Zry}	99.3×10^{-3} N/mm^2
d	9.5 mm	ρ_{Zry}	6.56×10^{-6} kg/mm^3
k_1	233 N/mm	ν_{Zry}	0.37
k_2	654 N/mm	ρ_{water}	9.8×10^{-13} kg/mm^3
m	0.352 kg	μ_{water}	2.18×10^{-11} mm^2/s

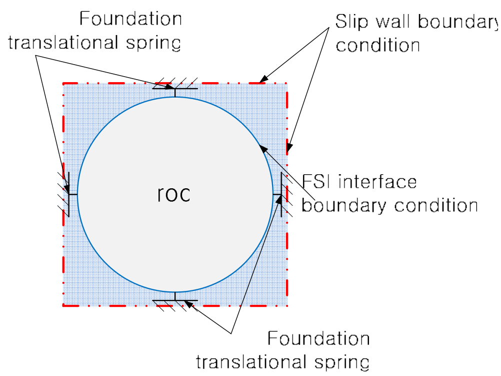

Fig. 2. FSI boundary condition of unit cell of single span rod contained the coolant in axial flow

The axial flow velocity at inlet of the coolant is defined 1.0 to 10.0 m/s, the pressure at outlet is 0.1 kg/mm^2, the Reynolds number of it is about 30,000. Total analysis time is set 2.0 sec, and the control time step is 1×10^{-5}. Therefore, the total number of increment is 20,000.

3. The results of analysis

The translational displacements in Y and Z direction from FSI analysis were very good agreement with those of the experimental method. The maximum displacement behavior of the center node was biased in Z-directional dof, which was shown in Fig. 3. The Y-directional vibration amplitude by turbulence fluid flow was nearly zero value; however, the Z-directional value was much higher than that. The maximum vibration amplitude in Z-direction was shown the peak value and then decayed as time.

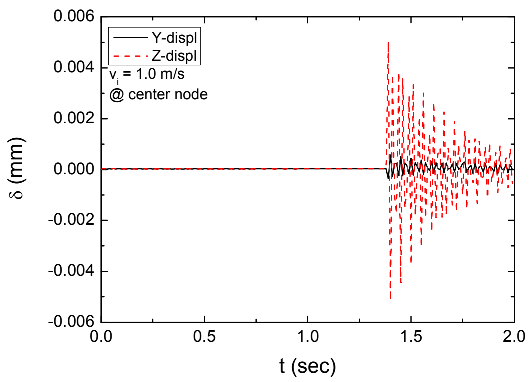

Fig. 3. The Y and Z directional vibration amplitude of a center node (No. 28) at the axial inlet flow velocity 1.0 m/s from FSI analysis

In addition to this, the orbit of the solitary rod was shown random vibration motion as Ref. [2], which was displayed in Fig. 4. It had predicted the circular orbit; the actual orbit was shown in diagonal or nearly one directional motion. This vibrational motion was closely related with the fretting fatigue and wear of fuel rod. Of course, the maximum displacement as the velocity of the coolant was increased, but that had not linear behavior. As described in introduction, the purpose of this work was to develop the fluid-induced vibration analysis model of the rod cluster structure, therefore the developed reliable FSI model will be expanded the multi-span and the rod cluster structure. In contrast with this, the bottom and the top nodes of a rod were shown much smaller displacements with the center node values due to the translational constraints at those points. These vibrational motions of fuel rods will be examined as the inlet flow velocity.

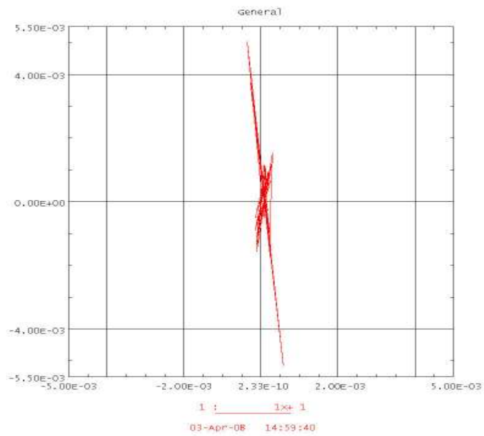

Fig. 3. The vibration amplitude of a center node (No. 28) at the axial inlet flow velocity 1.0 m/s from FSI analysis

After the validity of the FSI model is verified, the effect of the boundary condition for a rod will be examined. Finally, the FSI model to evaluate the fluid-induced vibration will be compared the experimental method by FIVPET facility.

4. Conclusion

A fluid-structure interaction analysis of a fuel rod with single span in axial flow was executed with the commercial code, ADINA. This FE model and the procedure were applied by using a fluid-structure coupled algorithm. The coolant was modeled with incompressible fluid, and a fuel rod surrounded grid straps were supported with grid spring or dimple. The analysis results from FSI model were compared with the other results. After the verifying procedure, this FSI analysis model will be expanded with multi-span and rod cluster structure. It may be supposed to developing means for predicting the vibration amplitudes. The wear rate strongly depends on vibration, and wear is serious concern. Therefore, this FSI analysis model will be supply a key sense for the fretting wear behavior without the actual scaled FIV test.

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