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Dynamic Characteristics of Twisted Beam with Fins Submerged in Fluid

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1. Introduction

Various advanced types of nuclear power reactors are currently under development worldwide, and some of them are ready for construction. One advantage of the advanced type of reactor is the easy implementation of advanced design concepts and technology. Drastic safety enhancement can be achieved by adopting inherent safety characteristics and passive safety features. Economic improvement is pursued through system simplification, modularization and reduction in construction time.

SMART (System-integrated Modular Advanced Reactor), a small sized integral type PWR is one of those advanced types of reactors, which is being developed in Korea. All major primary components are contained in a single pressurized vessel.

The twisted beam with fins adopted for metal fuel of SMART-P, pilot plant of SMART, may have a totally different behavior from that of fuels which are used in a typical PWR. It necessitates a study on fretting-wear prediction including vibration characteristics to assure the structural integrity of the metal fuels during normal operation.

Therefore, this study investigates the vibration and fretting-wear characteristics of twisted beam with fins surrounded by fluid. Modal analyses are performed for the finite element models of fuels with various conditions. The effects of fins, boundary conditions at both ends, fluid surrounding the fuel and the number of turns are investigated on the modal characteristics of the fuel, which are expressed in terms of the natural frequency and corresponding mode shape. Also, the wear rate caused by foreign object is predicted.

2. Analysis

2.1 Fundamental Frequency

The fuel rod model is considered as the beam of length L, stiffness EI and distributed mass per unit length m vibrating with an amplitude a. At both ends a torsional spring K provides the restoring moment. The horizontal and vertical coordinates are x and y, respectively.

The differential equation for the flexural vibration of a beam is

$$EI\frac{\partial^4 y}{\partial x^4} + m\frac{\partial^2 y}{\partial t^2} = 0 \quad (1)$$

The normalized frequency is obtained as follows;

$$\frac{(\beta L)^2}{2\pi} = \frac{f_n}{\sqrt{EI/mL^4}} \quad (2)$$

where $\beta^4 = m\omega^2/EI$, and $\omega = 2\pi f_n$. K is equal to 0 and infinite for the pinned and fixed condition, which corresponds to βL of π and 4.73, respectively. Therefore the fundamental frequency is obtained as follows for the pinned and built in beams from Eq. (2), respectively;

$$f_n = 1.57\sqrt{\frac{EI}{mL^4}} \quad (3)$$

$$f_n = 3.56\sqrt{\frac{EI}{mL^4}} \quad (4)$$

The frequency of the partially clamped beam can be obtained from Fig. 1, which shows the normalized frequency with respect to 1/(1+EI/KL).

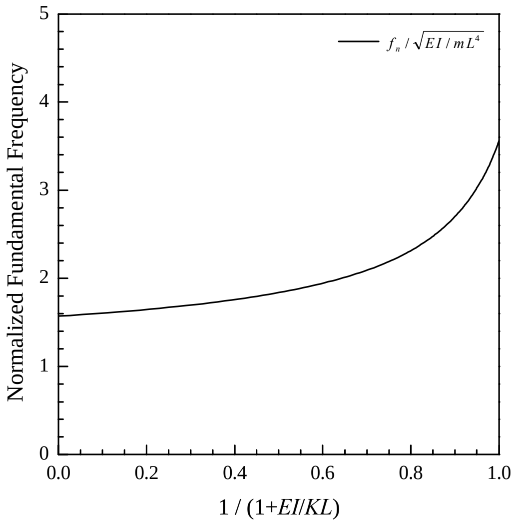

Figure 1. Frequency of partially clamped beam.

2.2 Modal Analysis by FEM

Modal analyses using a commercial computer code ANSYS 8.1 [1] are performed to find the vibration characteristics of the fuel. Several different kinds of finite element models are developed according to the fins, the number of turns and the existence of fluid surrounding the fuel (Fig. 2).

Elements used to develop models are the 3-D structural solid element (SOLID45) for the fuel meat and cladding and 3-D contained fluid elements (FLUID80) for fluid.

The boundary conditions at both ends of the fuel are fixed or simply supported. The fluid movement at top and bottom is considered to be constrained in the vertical direction to simulate the bounded surface fluid case. The vertical velocities of the fluid element nodes adjacent to each surface of the wetted solid coincide to those of solid by coupling the corresponding degrees of freedom.

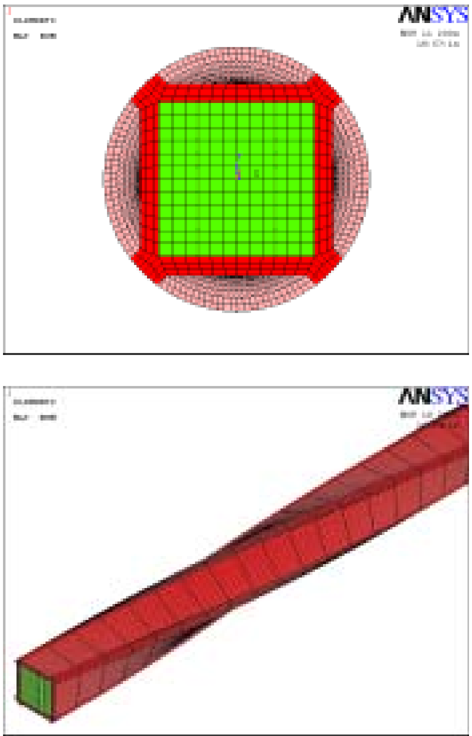

Figure 2. Finite element model of twisted beam with fins.

3. Results and Discussion

The comparison of the frequencies is made and the normalized frequencies of 0 turn with respect to 2 turns are found to be almost the same, which indicates that the effect of twist is not significant on the modal characteristics and therefore the straight beam instead of twisted beam is recommended to be used in the future modal analysis.

The effect of fins on the frequencies is investigated. The normalized frequencies of without-fin with respect to with-fin case are compared and the frequencies for with-fin case are higher than those of without-fin case by about 2 %, which is usually found from the conventional design by attaching strip or ring to the original component to increase the stiffness[2].

Finally the effect of the boundary conditions at the ends of the fuel is investigated. The normalized frequency of the simply supported case with respect to the fixed case is exactly the same as the value calculated from Eqs. (3) and (4), which is 0.44 for the fundamental frequency.

From the above preliminary study it is recommended to use the straight beam without fin to simplify the analysis considering computer execution time. And therefore the fluid surrounding the fuel rod is included to the case of straight beam without fins. Two cases of with- and without-fluid are analyzed to investigate the effect of fluid and the comparison of frequencies for the first 10 modes is made. The inclusion of fluid decreases the frequencies by about 5 % which can be expected from the fact that the fluid increases the added mass and therefore decreases the frequencies [3].

The end fixity is not clearly defined in the design of the fuel rod and is assumed to be between simply support condition and fixed condition. Therefore it is necessary to investigate the effect of the end fixity on the modal characteristics. The limits of βL are π for pinned beam and 4.73 for built-in beam, corresponding to $K = 0$ and $K = \infty$. The actual range of fundamental frequency of the beam will be located between pinned and built-in conditions.

The time required to wear into a beam can be predicted as a function of modal analysis results, that is, natural frequency, modal participation factor and modal deflection. Because the natural frequencies are so small compared with those of steam generator tube or PWR fuels, the problem of the fretting wear for these twisted beams with fins may not be significant [4]. Of course the other parameters such as wear coefficient or normal force between surfaces should be considered to finalize the wear characteristics of the fuel rod considered in this study.

4. Conclusion

(1) The effect of twisted condition is not significant on the modal characteristics of the metal fuel.

(2) With the inclusion of the fins, the natural frequencies increase but the changes are less than 2% compared with those of without-fins.

(3) The end fixity of the fuel changes the fundamental natural frequency by the ratio of 0.44 for the simply supported condition comparing with the fixed condition.

(4) The inclusion of the fluid surrounding the fuel rod decreases the natural frequency by the ratio of about 5 % for the first 10 modes due to the added mass effect.

(5) The fretting wear of the metal fuel is less significant than those of steam generator tubes or PWR fuels, but which needs to be investigated in detail to predict the remaining life of the fuel considering wear coefficients of materials used for metal fuels etc.

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