Vibration Analysis of a Dual-Cooled Fuel Rod

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1. Introduction

A nuclear fuel element should be designed not only to maintain its structural integrity under any operating condition including the postulated accidents, but also to ensure that the natural frequencies of the fuel element are mismatched with all of the external excitation frequencies in the core during the reactor operation [1, 2]. A dual-cooled nuclear fuel compatible with the conventional PWR reactor core (OPR-1000) should also meet the above requirements unless the core internals or plant's operational condition can be changed. There was a study [3] on the optimal number of spacers in a PWR nuclear fuel bundle with respect to flow-induced vibration using a semi-analytical approach. In this study, vibration characteristics (natural frequency and mode shape) of two types of the dual-cooled fuel rod according to the number of support are investigated. The number of support whose a dual-cooled fuel rod has similar dynamic characteristics to the conventional PWR fuel rod is then proposed.

2. Analysis Methods and Results

2.1 Analysis model for the dual-cooled fuel rod

Fig. 1 shows schematic cross section of the present PWR fuel rod and the dual cooled fuel. The dual-cooled fuel which has inner and outer flow channel is expected to uprate a reactor power considerably (e.g. 30~50 %), to reduce the possibility of fuel meltdown by decreasing fuel's centerline temperature and to make the spent fuel more proliferation-resistant. The cross sectional dimensions of the dual-cooled fuel in Fig. 1 are the preliminary design of the previous study [4]. The supporting condition for the dual cooled fuel rod is assumed to be the same as those of the conventional PWR fuel rod. But the present supporting concept should be changed to meet the new functional requirement as a rod supporter. The fuel rod usually has 8~11 spacers along its length depending on the reactor type. To investigate effect of the number of support on vibration characteristics of the fuel rod, the number of support here is confined to four cases with respect to two fuel types listed in Table I.

The analysis model for vibration of the dual-cooled fuel rod was based on the model, which is proposed by Kang [5] and Lee [6], for the conventional PWR fuel rod which is thoroughly verified with the test results. A commercial FEA code, ABAQUS, is used for FE modeling and analysis. A planar beam element (beam 21) is used for the plane vibration of the fuel rod with annular cross section and three spring elements with equivalent stiffness are used for two springs and four dimples in each grid cell. For the numerical modal analysis, the Lanczos method is used to extract eigenvalue and eigenvector of the fuel rod. The radial stiffnesses of a spring and a dimple are obtained by the real-size model test using universal test machine. The bending rigidity, EI, of the dual cooled fuel rod is assumed 20 % higher than that of an empty Zr-4 annular tube [7]. The damping and the effect of the friction between a fuel rod and a spacer grid are ignored here because they are difficult to handle in this preliminary analysis stage.

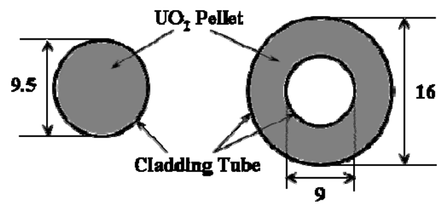


Fig. 1 Comparison of the Fuel's Cross Section; left one is conventional fuel rod and right one is dual-cooed fuel rod.

Table I: Number of supports, shorter and longer span length

ID(SP-)	Number of support	Shorter span length (m)	Longer span length (m)
K1/W1	12/9	0.327/0.458	0.368/0.544
K2/W2	11/8	0.36/0.522	0.4/0.62
K3/W3	10/7	0.401/0.606	0.451/0.72
K4/W4	9/6	0.452/0.723	0.509/0.86

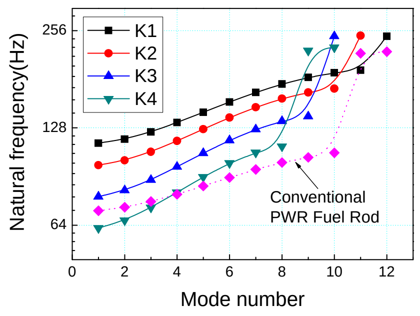
Note) Fuel length is 4.1 m for K type and 3.85 m for W type, respectively. K2/W2 has the same number of support to the conventional PWR fuel rod.

2.2 Results

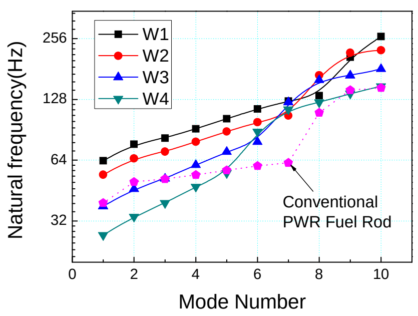
Fig. 2 shows the natural frequencies of two types of the dual-cooled fuel rod according to the number of support. They have 8~11 (K type) and 5~8 (W type) fundamental modes (usually called the fundamental mode group). Sharp increase in frequency appears at the end of fundamental modes. The number of fundamental modes increases with the number of support. The first frequency of the reference model (K2/W2) has higher than that of the corresponding solid fuel rods by 28 Hz/15 Hz because of the higher bending stiffness due to large diameter and hollow cross section. The first natural frequency of a multi-span rod with un-evenly spaced supports is strongly influenced by the longest span while other system parameters are fixed [7]. So, K type fuel with comparatively even-spaced supports has higher difference in frequency than that of W type fuel. The range of normalized (divided by the first frequency) fundamental natural frequencies of the

K and W type is about 1~1.8 and 1~2.1. So, it would be difficult to make the above range be isolated if the rods are excited in that.

Fig. 3 presents the mode shape of the dual cooled fuel rod. During a vibration of the dual cooled fuel rod in any specific mode, the deflected shapes of the various adjacent spans are considerably different. As the number of support increases, the wrinkles in the mode shape are highly developed.

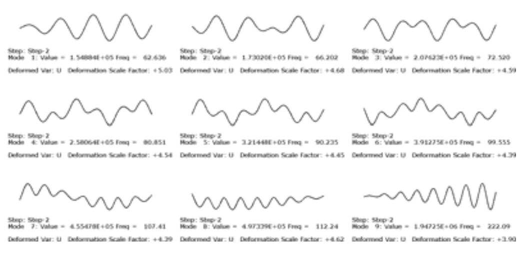


(a)

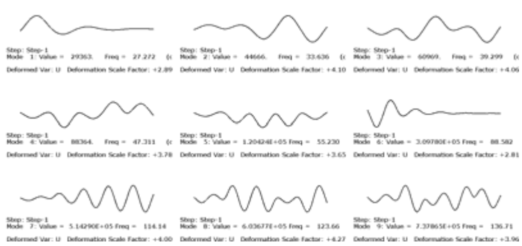


(b)

Fig. 2 Natural frequencies of the dual cooled fuel rod according to the number of supports; (a) K type, (b) W type.



(a)



(b)

Fig. 3 Mode shapes of the dual-cooled fuel rod with the least number of supports; (a) K4, (b) W4.

3. Conclusions

Vibration characteristics of two types of the dual-cooled fuel rod with changing the number of supports are investigated. K and W type dual-cooled fuel rod have 8~11 and 5~8 fundamental modes according to the number of supports, respectively. The number of fundamental modes increases with the number of support. The range of normalized fundamental natural frequencies of the K and W type is about 1~1.8 and 1~2.1. So, greater difficulties are anticipated for detuning if the rods are excited in this range. During vibration of a dual-cooled fuel rod in any particular mode, the deflected shapes of the various adjacent spans are considerably different. From the results, the reduction of the number of support of dual cooled fuel is one of the powerful option to be compatible with present reactor core. Furthermore, the reduction in the number of spacers has a significant advantage in reducing the pressure drop of a fuel assembly.

Acknowledgement

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