Transition of Natural Frequencies of a Fuel Rod during Its Lifetime

Hyeong Koo Kim*, Kyou Seok Lee , Jeong Ha Kim , Sang Yoon Jeon
Korea Nuclear Fuel, Reactor Core Technology Dept., P.O.Box14, Yuseong,Daejeon,305-600
**Corresponding author: hkkim@knfc.co.kr*

1. Introduction

The natural frequencies of a Pressurized Water Reactor (PWR) fuel rod are dependent on the geometrical and mechanical properties of fuel rod itself and its supporting conditions provided by spacer grids. By the way, these environmental parameters suffer remarkable change due to the plant operating conditions such as burnup, temperature, system pressure, and so on. It is inevitable, therefore, to be changed the natural frequencies of the fuel rod during its lifetime.

In this paper, the transition of natural frequencies of the fuel rod for OPR1000 plants has been investigated considering fuel conditions associated with fuel life time. Basically for this investigation, three analysis models have been proposed representing beginning-of-life (BOL) condition, middle-of-life (MOL) condition and end-of-life (EOL) condition including spacer grid supporting conditions.

With these models, several modal analyses have been performed and the results have been compared with those of the test which has been carried out for verification of the analysis model. With these analyses and test, the changing vibration behavior of the PLUS7 fuel rod for OPR1000 during its life time has been discussed.

2. Models and Results

The fuel rod would suffer significant dynamic characteristics change due to the in-reactor conditions such as irradiation, temperature and pressure. In general, it can be assumed that the cross sectional configuration of the fuel rod is changing like Fig.1 from no contact to hard contact during its life time. And the basic configuration of the fuel rod models can be expressed as shown in Fig.2 [1]. Based on these considerations, three kinds of fuel rod vibration models are suggested according to the following life time condition. The analysis has been performed using ANSYS code.

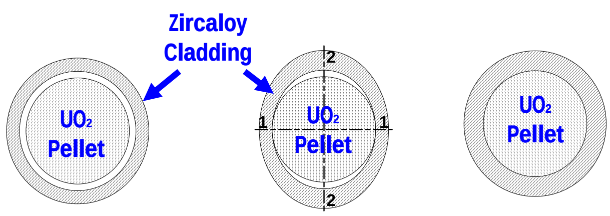

Fig.1 Configuration of fuel pellet/cladding contact

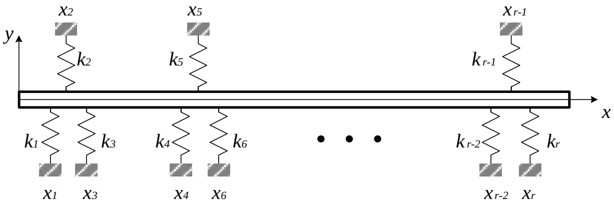

Fig. 2 Schematic configuration of fuel rod model with discretely spaced spacer grids

2.1 BOL Model

At the BOL condition, since there is a gap between fuel cladding and UO2 pellets in the fuel rod(see Fig.1 a), it is considered that the fuel rod excluding mass and rigidity of pellet is supported by multiple translational springs which represent un-irradiated spacer grid spring. In this case, the fuel rod can be modeled as a beam considering just tube density only [1]. Table 1 shows the natural frequencies of the BOL model.

Table 1. Natural frequencies of the BOL model

Mode	BOL (Air Cold) (Hz)	BOL (Water Hot) (Hz)
1	164	125
2	169	128
3	178	134
4	190	143
5	204	153

2.2 MOL Model

After BOL condition, the fuel rod configuration is changing to the line contact (see Fig.1 b). With this change, the mass of the pellets can be contributed to the vibration of the fuel rod but not the pellet rigidity [1]. Table 2 shows the natural frequencies of the MOL model. In the Table 2, case 1 and 2 represent hollow ellipse cases, case 1 for vertical and case 2 for horizontal, respectively.

Table 2. Natural frequencies of the MOL model

Mode	MOL (Case1) (Hz)	MOL (Case2) (Hz)	MOL (Irr. Spring) (Hz)
1	59	58	103
2	61	60	103
3	65	64	103
4	69	68	103
5	74	73	103

In case of elastic supports, the natural frequencies of the fuel rod in hot water condition varies from about 58 Hz to 74 Hz for first 5 modes, while in case of simply supported condition they show almost constant 103 Hz.

2.3 EOL Model

To simulate EOL condition, we have to consider both the mass of pellets and the rigidity of pellets as well as cross sectional configuration of the fuel rod (see Fig.1 c) into the FE models. And during this period, the spacer grid spring can become inactive due to the creep down of the fuel rod as well as the irradiation relaxation of the spacer grid springs [1]. Under these considerations, EOL Model has been analyzed.

Table 3 shows the natural frequencies of the EOL model. In the Table 3, the first column represents that spacer grids provide flexural support and the second column represents simple support. The natural frequencies of the fuel rod at the EOL condition also maintain nearly constant value of 107 Hz

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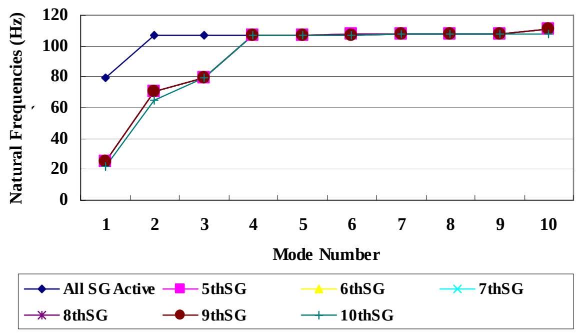
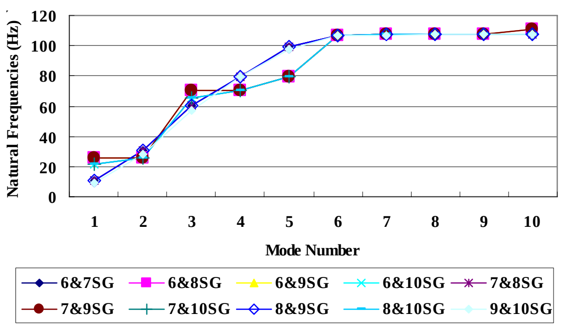
Table 3. Natural frequencies of the EOL model

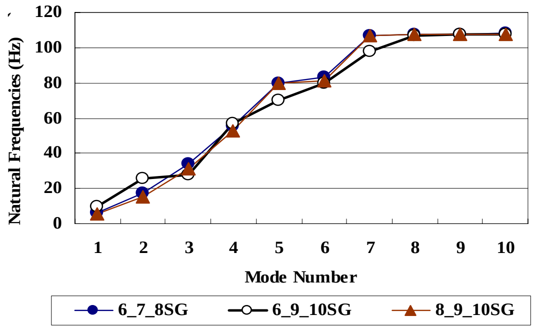
Mode	EOL (Un-Irr. Spring) (Hz)	EOL (Irr. Spring) (Hz)
1	48	107
2	50	107
3	54	107
4	59	107
5	65	108



(a) One spacer grid inactive



(b) Two spacer grids inactive



(c) Three spacer grids inactive

Fig.3 Comparison of natural frequencies for the model with inactive spacer grids

Fig. 3 represents the natural frequencies of the model with various combinations of the inactive spacer grids. The numbers showed in the legends of the figure mean the location of the inactive spacer grid from bottom.

In the case of inactive spacer grid, initial vibration modes and frequencies are decided by the span length of inactive spacer grids. And the natural frequencies of the model with inactive spacer grid are quite low compared with active case. Therefore, if there is an inactive spacer grid during plant operation, the mode shape will be presented at the span first. This mechanism is possible to become one of the main causes expediting the fuel rod fretting. At this point, the inactive spacer grid is very unfavorable for maintaining fuel rod integrity. It is quite an interesting that the models with inactive spacer grids maintain nearly the same natural frequencies regardless of the combination of inactive spacer grids when the number of inactive spacer grids is same.

3. Conclusions

In this paper, vibration behavior of the fuel rod for the OPR1000 plants which is being changed during its life time due to in-reactor irradiation condition has been investigated. For the investigation, three kinds of models have been considered according to the in-reactor condition. Since the natural frequencies of the fuel rod suffer severe changes, fuel rod and spacer grids should be carefully designed under consideration of these conditions.

ACKNOWLEDGEMENT

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REFERENCES

[1] H.K.Kim, et al, “Modal Analysis of a PWR Fuel Rod under Simulated Plant Operation Condition, Int. Conf on Noise & Vib. Sep.2008, Leuven, Belgium.