Flowing Water Damping Characteristics for PLUS7^{TM} Fuel Assembly

Sang-Youn Jeon [a*], Heon-Jeong Ha [a], Hak-In Lee [a], Il-Kyu Kim [a], Yong-Hwan Kim [a]
Nam-Gyu Park, Jae-Hoon Jeong [a], Chang-Sok Cho [a]
[a]KNF, Nuclear Fuel Engineering Dept., 242, Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, 34057
[*]Corresponding author: syjeon@knfc.co.kr

1. Introduction

The fuel assembly structural evaluation for the seismic and LOCA loads was performed for BOL(Beginning of Life) condition based on the SRP(Standard Review Plan) 4.2 Appendix A. In SRP 4.2 Appendix A, it is assumed that the increase in yield and ultimate strength due to irradiation offsets the EOL(End of Life) effects on grid strength[1]. In June 2012, NRC issued Information Notice 2012-09 which challenged approved assumptions based on Beginning of Life(BOL) in seismic and Loss of Coolant Accident (LOCA) analysis[2]. The relaxation of grid springs and resulting gap between fuel rod and grid support feature may lower the grid crush strength and fuel assembly stiffness resulting in lower frequencies which may impact the dynamic analysis results. Due to the irradiation effects, the fuel assembly natural frequencies and grid crush strength can be reduced at End of Life(EOL) condition. By using fuel assembly flowing water damping(higher damping value) instead of still water damping(lower damping value for previous analysis), the margin lost due to EOL condition can be regained. To evaluate the PLUS7^{TM} EOL fuel assembly structural performance for the seismic and LOCA loads, the grid and fuel assembly mechanical and damping tests have been performed.

In this paper, the details of PLUS7^{TM} fuel assembly damping tests are described. The EOL grid cell sizes are determined considering irradiation induced spring relaxation, grid growth and cladding creep-down. The EOL conditions are simulated by increasing the grid cell sizes. A series of fuel assembly damping tests were performed to get the damping characteristics of PLUS7^{TM} fuel assembly. The EOL fuel assembly damping test results are used to determine the damping coefficient of the fuel assembly for seismic and LOCA load analysis.

2. Fuel Assembly Damping Tests

The fuel assembly damping tests were performed in air, still water and flowing water conditions. The in air pluck test was performed to determine the natural frequency of the PLUS7^{TM} fuel assembly in air condition. After the in air test, the still water and flowing water tests were performed to generate the fuel assembly damping coefficient for still water and flowing water conditions. The still water tests were performed for several temperatures and displacements and the flowing water tests were performed for several temperatures, velocities and displacements. The still water test data were evaluated to determine the natural frequency and damping coefficient of the PLUS7^{TM} fuel assembly in still water condition. The flowing water test data were evaluated to determine the damping coefficient of the PLUS7^{TM} fuel assembly in flowing water condition.

The EOL fuel assembly damping tests were performed using a simulated EOL fuel assembly to generate fuel assembly damping coefficient. The fuel assembly was positioned vertically in a closed isothermal hydraulic loop and restrained at the top and bottom nozzles with core plate simulators. The test system consists of a test vessel, pumps, heat exchangers, heater, air separator and an expansion tank. De-ionized water was used as the fluid medium. The fuel assembly motion was monitored with Linear Variable Displacement Transducers(LVDTs). A total of six LVDTs were mounted at the elevations of grids 4, 5 and 6. The fuel assembly damping was obtained by conventional pluck tests. The fuel assembly pluck test was performed by displacing the fuel assembly with a known amount and releasing the fuel assembly permitting a free vibration with no initial velocity. The decay method can be used to assess the first mode damping ratio of an under-damped system. The response of an under-damped system represents that of a decaying exponential.

3. Fuel Assembly Damping Characteristics

The fuel assembly damping coefficients in air and still water can be reasonably obtained by the logarithmic decay method. However, the damping coefficients in flowing water are difficult to obtain by using the conventional decay method because the fuel assembly damping in the flowing water becomes much higher than in air and still water. Fig. 1 and Fig. 2 shows typical fuel assembly displacement histories for still water and flowing water conditions, respectively.

Since the flowing water damping is so high, the fuel assembly oscillation decays quickly and even the first vibration cycle is hard to recognize. To obtain accurate damping coefficients for high damping cases, R. Y. LU et. al.[3] developed the initial displacement and first response method based on classic vibration theory. Equation (2) is a special case of classic vibration theory when the natural logarithm of the ratio of the initial displacement to the first half cycle amplitude is used[3].

Equation (2) is used in this paper to calculate the high damping coefficients from pluck tests in flowing water.

$$\delta_\pi = \ln \frac{x(0)}{x(\min.)} = \frac{\zeta\pi}{\sqrt{1-\zeta^2}} \quad (1)$$

$$\zeta = \frac{\delta_\pi}{\sqrt{\pi^2 + \delta_\pi^2}} \quad (2)$$

Where,
δ_π : logarithmic decrement
ζ : damping coefficient
$x(0)$: initial pluck displacement
$x(\min.)$: first minimum amplitude

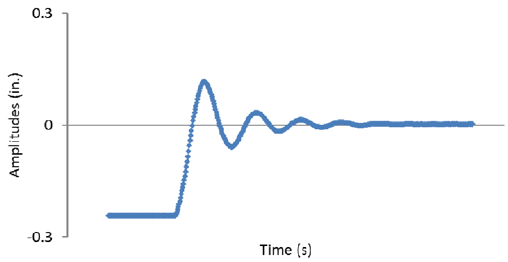

Fig. 1. Fuel Assembly Decay Motion in Still Water

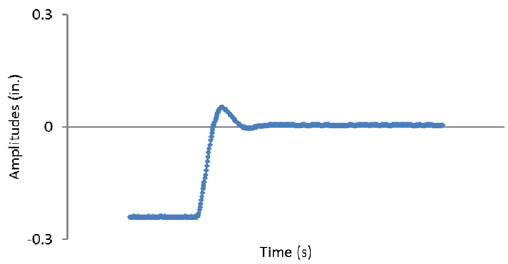

Fig. 2. Fuel Assembly Decay Motion in Flowing Water

Fig. 3 shows the normalized damping coefficients vs. bundle flow rate for still water and flowing water conditions at high temperature. Fig. 4 shows the normalized damping coefficients vs. amplitudes for still water and flowing water conditions at high temperature. Based on the test results, it is confirmed that the fuel assembly damping coefficients in still water and flowing water are strongly dependent on the flow rate and not sensitive to vibration amplitude. The fuel assembly damping coefficients in flowing water are more than two times higher than damping coefficients in still water. The still water and flowing water damping test results of the PLUS7^{TM} fuel assembly will be used for the EOL fuel assembly seismic and LOCA load analysis. It is expected that the margin lost due to EOL condition can be regained by using fuel assembly flowing water damping coefficients for the EOL fuel assembly seismic and LOCA load analysis.

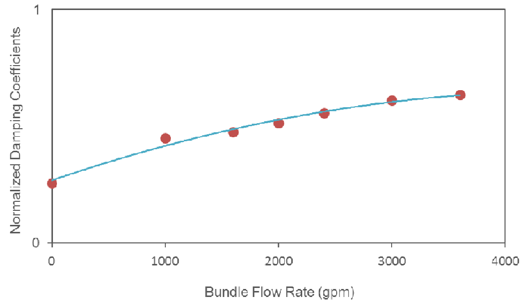

Fig. 3. Normalized Damping Coefficients vs. Bundle Flow Rate at High Temperature

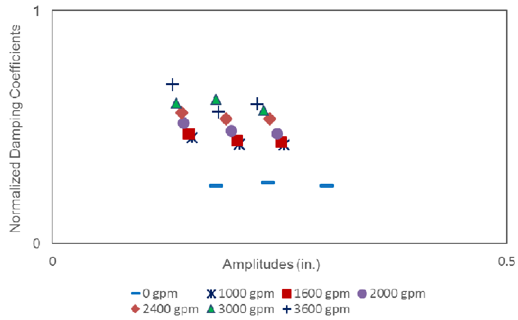

Fig. 4. Normalized Damping Coefficients vs. Amplitudes at High Temperature

4. Conclusions

A series of fuel assembly flowing water damping tests were performed to get the damping characteristics of PLUS7^{TM} fuel assembly for EOL condition. To perform the flowing water damping tests, simulated EOL grids, skeleton and fuel assemblies were manufactured. The EOL grid cell sizes are determined considering irradiation induced spring relaxation, grid growth and cladding creep-down. The EOL conditions are simulated by increasing the cell sizes.

Based on the test results, it is confirmed that the fuel assembly damping coefficients in still water and flowing water are strongly dependent on the flow velocity and not sensitive to vibration amplitude. The fuel assembly damping coefficients in flowing water are more than two times higher than damping coefficients in still water. It is expected that the margin lost due to EOL condition can be regained by using fuel assembly flowing water damping coefficients instead of still water damping coefficients.

REFERENCES

[1] U. S. NRC Standard Review Plan (NUREG-0800), Appendix A. Evaluation of Fuel Assembly Structural Response to Externally Applied Forces, Rev. 3, NRC, 2007.

[2] U. S. NRC Information Notice 2012-09, Irradiation Effects on Fuel Assembly Spacer Grid Crush Strength, NRC, 2012.

[3] R. Y. LU and David D. Seel, "PWR Fuel Assembly Damping Characteristics", Proceedings of ICONE14, Miami, Florida, USA, July 17~20, 2006.