Fatigue Analysis of Nuclear Fuel Protective Grid

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1. Introduction

Protective grid (P-grid) is located at the lower most location of the nuclear fuel as shown in Fig. 1. It is required to perform in a reactor for not only filtering debris, but also supporting fuel rods. P-grid operating conditions in a reactor are severe in terms of considering such as high flow speed, temperature and pressure. These severe conditions might be a cause of mechanical integrity problem of the nuclear fuel. One of the critical factors, High Frequency flow-induced Vibration (HFV) is important for reliability. Because, if the P-grid is exposed to high levels of excessive vibration over a long period of time, P-grid fatigue failure could be unavoidable [1]. Furthermore, debris from P-grid fatigue failure might be added sources for the degradation of the nuclear fuel and its system.

To intensify P-grid reliability and overcome this problem, KEPCO NF has developed various improved P-grid models. Since, tendency of excessive HFV amplitude is commonly seen to appear on the top ligament of the P-grid strap, main researches were focused on decrease of the top ligament vibration amplitude. From design parametric studies and its HFV tests, A few specific designs of the improved P-grid models have shown significant responses that are decreasing HFV levels and increasing debris filtering effectiveness. To decide improved P-grid model as a commercial P-grid, it is eventually needed to estimate fatigue life. For this purpose, in the present study, we developed mean and oscillation stress corresponding to the maximum displacement of the P-grid strap using the commercial analysis program, ANSYS, and evaluated fatigue integrity in steady state condition.

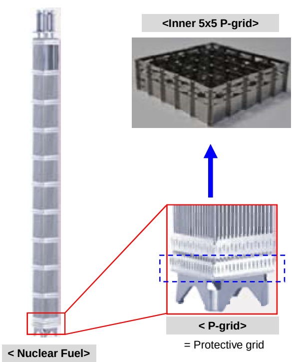

Fig. 1. General Configuration of P-grid in a Nuclear Fuel

2. HFV Test Results

2.1 Comparison of the HFV Test Results

To investigate specific relationships between configuration of P-grid and HFV characteristics, several types of the P-grids were tested in KEPCO NF INFINIT (Investigation Flow-induced Vibration) facility. Fig. 2 shows a comparison of the HFV test results whose data is the best case of improved P-grid models and existing P-grid model. The comparison amplitudes are relative value that is normalized based on the maximum amplitude on the graph. The comparison shows definitely that HFV values of improved model much lower than that of existing model.

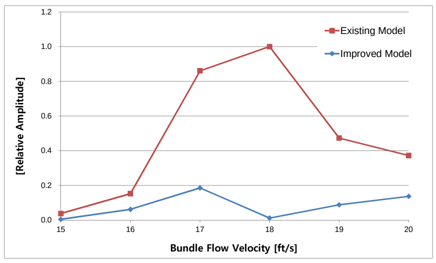

Fig. 2. Comparison of the HFV test results

2.2 Prediction of Max. Displacement at Top Ligament

For generating stress on the P-grid using ANSYS, top ligament displacement is required for input data, and herein is a maximum strap oscillation during HFV at operating condition. This displacement can be predicted by the following basic vibration equation (1).

$$v(\dot{x}) = \frac{dx}{dt} = \frac{d}{dt}(A \sin \omega t) \quad = A\,\omega \cos \omega t \qquad (1)$$

where, ω: angular velocity
v: velocity amplitude
A: displacement

From above equation, and its relations of frequency, velocity, displacements are predicted in Table 1.

Table 1. Displacement at Max. Vibration

Model	Freq. [Hz]	Disp. [μm]
Existing	4462	5.00
Improved	4435	0.93

3. Fatigue Analysis

3.1 Establishment of the Simulation Model

For ANSYS simulation as similar as possible to the actual conditions, two displacement steps and boundary conditions were applied to the set-up as shown in Fig. 3. One step is loaded by fuel rods inserting to the grid which affects to grid dimple deflection, and second step is loaded by the top ligament displacement due to the strap oscillation. Also, boundary conditions were applied as real state of the grid assembly welding.

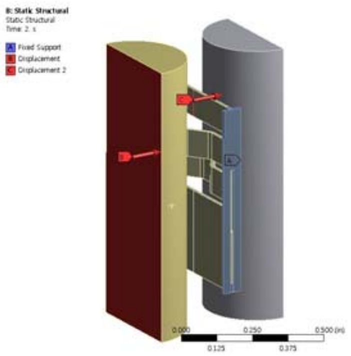

Fig. 3. Boundary and Loading Condition

3.2 Estimation of Fatigue Stress

From the ANSYS simulation, mean stress and stress amplitude due to the top ligament oscillation can be acquired. And, using Goodman fatigue equation (2), alternating stress can be calculated. These stresses are listed in Table 2.

$$\frac{\sigma_a}{S_n} + \frac{\sigma_m}{S_u} = 1 \qquad (2)$$

where, σ_m: mean stress
σ_a: stress amplitude
S_u: ultimate stress
S_n: alternating stress

Table. 2 Max. Stress on the strap

Model	σ_m [ksi]	σ_a [ksi]	S_n [ksi]
Existing	128	2.66	7.76
Improved	121	0.87	2.28

3.3 Estimation of Fatigue Life

With calculated alternating stress and referred inconel S-N curve, fatigue lives of the P-grid can be roughly evaluated. Based on the above data, both P-grid models' fatigue life are estimated on the graph as shown in Fig. 4. The graph shows both P-grids are quite low from fatigue endurance limit. It means both P-grids might be safe from fatigue failure only in case of such level of strap vibration as like in Fig. 2. Also, it is clearly concluded that improved P-grid model is a robust design than that of existing. However, it is noted that the S-N curve might be downward from current curve if modified coefficients are considered to fatigue endurance limit [2], since acquired S-N curve data from its test specimen and environments are different from P-grid condition.

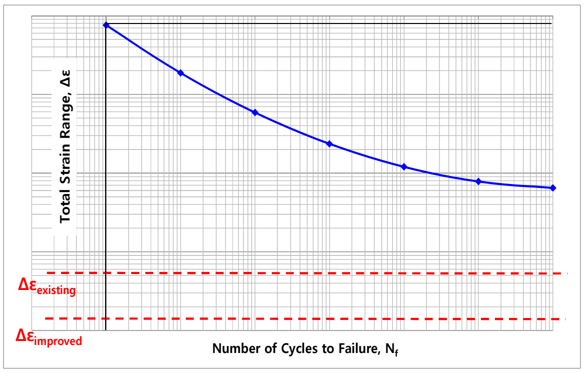

Fig. 4. S-N Curve of Inconel

4. Conclusions

Several improved P-grid models have been developed, and best case model was finally selected. Through HFV test data and a series of fatigue life evaluation such as predicting top ligament displacement, ANSYS analysis processing and estimating using S-N curve, existing and improved P-grids' fatigue life could be technically evaluated. In consequence of this study, improved P-grid model's design characteristics have shown better performance comparing to that of existing P-grid.

For more accurate fatigue analysis of the P-grid, harmonic response approach should be considered [3], since structure dynamic effect due to the external force from strap vibration could not be ignored. In the future work, it is required to study harmonic analysis of the strap vibration in dynamic state, and evaluate P-grid fatigue life from its calculated alternating stress.

REFERENCES

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