Mechanical Characteristic Study for Mid Grid Number Effect on Small Size Fuel Assembly

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1. Introduction

The different types of grid assemblies (top, bottom and mid, etc) perform a number of functions. First of all, the gird assemblies are part of the overall fuel assembly (FA) skeleton structure. They provide the lateral and axial structure that ties the guide tubes and the instrument tube together to form the skeleton structure between the top and bottom nozzles. And they also provide both lateral and vertical support for the fuel rods (FRs).

In this study, FA behavior with respect to the number of mid grid (MG) is evaluated with finite element analysis. Stability, modal and stress analyses are completed using the ANSYS finite element program.

2. Fuel Assembly Model

Fig. 1 shows 4-type FA configuration designed for a small-size reactor. These FAs have a 17x17 FR array, 24 Zircaloy guide tube (GT), one Zircaloy instrument tube (IT), Inconel top and bottom grids, SS-304 top and bottom nozzles and 2~5 Zircaloy MGs. Overall the FA length is about 50% of current 17x17 FA length.

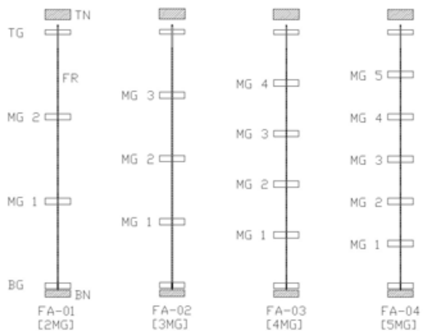


Fig. 1. FA Configuration

The grids support the FRs both laterally and axially with a spring-loaded friction grip. Each cell of the grid employs a 6-point FR support system consisting of two orthogonal sets of two dimples and a spring, as Fig. 2.

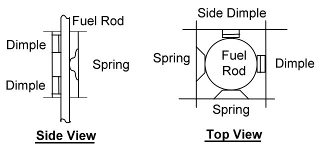
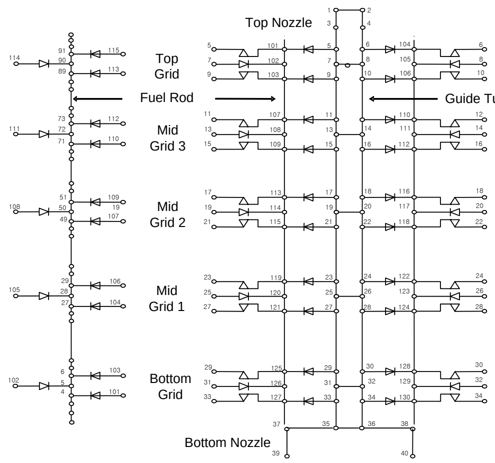


Fig. 2. FR connection with spring and dimple in grid cell

Fig. 3 shows the FR and FA detail beam model of FA-02. The FR and grid connection is simplified by 1-spring and 2-dimple elements for FR stability analysis, as shown in Fig. 3 (a). On the other hand, two slide elements are added to FR-grid connection and the FA beam model modified by equivalent two GTs and two FRs structure, to effectively evaluate FA modal and stress analysis.



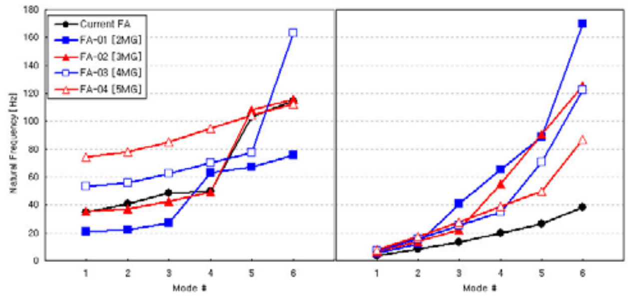
(a) FR Model (b) FA Model

Fig. 3. Detail FR and FA Beam Model

3. Simulation Results and Discussion

3.1 Modal Analysis for FR and FA

Fig. 4 shows the results of FRs and FAs modal analysis. In the 1st mode, the natural frequency (Nf) of the FRs and the FAs are respectively increased by 28~41%, 8~17% as more MGs are added. These results quantitatively show that FA becomes proportionally stiffer with an increase in the number of MGs. This is caused by the increase of the number of FR-Grid contact points and GT-Grid welding points.



(a) FR Natural Freq. (b) FA Natural Freq.

Fig. 4. FR and FA Modal Analysis (FR: BOL hot water condition, FA: cold air condition)

3.2 Fuel Rod Stability Analysis

Fluid flow across an array of elastic tubes can induce a dynamic instability that can result in very large amplitude vibrations once a critical cross flow velocity is exceeded. The flow of fluid over these tubes results in both fluid excitation and fluid-structure coupling forces on the tubes.

Previous studies show that the onset of instability is governed by the following dimensionless groups: the mass ratio $m_t / \rho D^2$; the reduced velocity V / fD; the damping ratio ξ_n; the pitch to diameter ratio P / D; the array geometry and the Reynolds number. The relationship between the parameters can be investigated theoretically or experimentally. One general form that has been used to fit experimental data is:

$$\frac{V_c}{f_n D} = C \left(m_t \frac{2\pi \xi_n}{\rho D^2} \right)^a \qquad (1)$$

where,

V_c : Critical cross flow velocity

f_n : Natural frequencies of the immersed tube

D : Cylinder diameter

m_t : Total mass per unit length of tube

ρ : Fluid mass density

ξ_n : Fraction of critical damping for n th mode

C, a : Functions of the tube array geometry

$$V_e^2 = \frac{\int_0^L V^2(x)\, \phi_n^2(x)\, dx}{\int_0^L \phi_n^2(x)\, dx} \qquad (2)$$

where,

V_e : Effective velocity

$V(x)$: Cross flow velocity at each axial location of the tube.

ϕ_n : n th vibration mode shape

When the ratio of effective velocity to critical velocity (V_e / V_c) is less than 1, the FR will be stable [1].

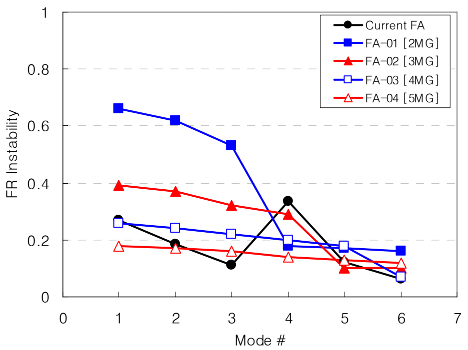


Fig. 5. FR Instability at BOL Hot Water Condition.

Fig. 5 shows that every FR is stable in each mode. All of the V_e/V_c ratios are less than 1. These results are evaluated under the following assumption: the cross flow value is 1/3 of the cross flow in current nuclear reactors and at BOL hot water conditions. Instabilities of the FA-04 FRs are 1/3 less than the FA-01 FRs at 1st mode. In this analysis, it is assumed that the boundary conditions of the contact elements are not changed during the evaluation.

3.3 Fuel Assembly Stress Analysis

When a center MG (MG 2; FA-01 & FA-02, MG 3: FA-03 & FA-04) is deflected by 0.5 inches in a lateral direction, the stresses generated on the FR and GT are shown in Fig. 6. The results show that the stress on a FR and GT is raised by about 20% and 35% respectively as the MG span length is reduced by 1/2. Because deflected MGs of FA-01 and FA-03 are not located in the center of FA, their stress values higher than the others.

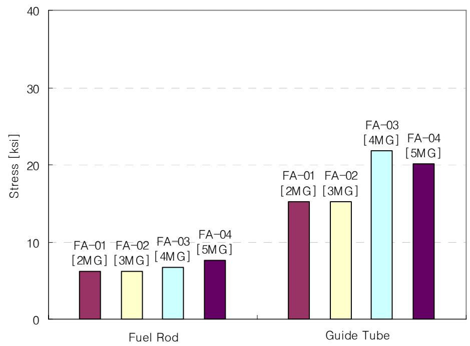


Fig. 6 Stress on FR and Guide Tube

4. Conclusions

Stability, modal and stress analysis are performed to evaluate the effect of the number of MGs on FA mechanical characteristics. It is generally known that the greater the number of grid assemblies within an FA, the stiffer the FA becomes. In this study, this phenomenon was evaluated through a series of numerical analysis.

Modal analysis results of FRs and FAs show that their 1st mode Nfs are increased by 28~41%, 8~17% respectively as more MGs are added.

It is evaluated in stability analysis that instabilities of FA-04 FRs are 1/3 less than FA-01 FRs at 1st mode. And the results of stress analysis show that the the stress on the FRs and GTs is increased by about 20% and 35% respectively as the MG span length is reduced by 1/2.

REFERENCES

[1] ASME Section III Boiler Pressure Vessel Code, Appendix N, Dynamic Analysis Metohds