Development of Guide Thimble Stress Peaking Factor Calculation Methodology

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1. Introduction

The Nuclear Fuel Assembly for light water reactor which provides for 236 fuel rods consists of guide tubes, spacer grids, top/bottom nozzles. The guide tubes form the main structural components in conjunction with the grids, act as the main load carrying members of fuel assembly and serve as a support structure and a guide path for the control element, neutron sources and incore instruments after they are secured to upper and lower end areas. Top/bottom nozzles make the end parts of fuel assembly. And the spacer girds maintain the fuel rod array by providing positive lateral restraint to the fuel rod to the fuel rod but only frictional restraint to axial fuel rod motion. When the fuel assembly is in reactor, the tensional and compressional forces are applied to guide thimble through the top nozzle. The stresses vary with the location of guide thimble on the top nozzle plate since the different flow plate thickness between center and outer areas causes a different flexibility. The relative stress shall be considered during designing this kind of structure. And it is useful to know a coefficient to represent this relative stress difference and this value is called stress peaking factor.

2. Methodology

To identify the stress peaking factor, the fuel assembly axial stiffness test was performed, and some simple techniques are used to evaluate the test results.

2.1 Axial stiffness Test

From the test, we measured the fuel assembly axial load and deflection, and determined the strain distributions in the thimbles/inserts under axial load and also the axial stiffness characteristics of the fuel assembly. But this study focused on the strain results and the other test results are out of the scope.

The test was performed by setting fuel assembly in the test stand as shown in Figure 1. Constraints around grid #5 was taken to maintain an 0.25 inch gap on each side from the equilibrium position. The sixty (60) thimble and insert strain gages and load cell are connected to readout devices. And twenty eight (28) LVDTs are fixed to the test stand. Axial loading to the top nozzle from 0 to 5500 lbs applied by 1000 lbs. LVDTs and strain gage outputs were recorded at each state point. During the test, any fuel assembly lateral apparent set was removed by manually shaking.

2.2 Methodology of Stress Peaking Factor Calculation

Strain values were read from the several selected guide thimbles, which show the geometrical representative. Thus the stress peaking factors for each guide thimble location were produced by considering all of the guide thimbles and by converting them to equivalent one. The detailed methodology proposed in this study is as follows.

Guide thimbles can be grouped in several based on their symmetrical and geometrical propensities. In the case of 16x16 nuclear fuel assembly, 4 groups were defined and their locations were shown in Figure 1 and Table 1. Based on this concept, stress peaking factor (PF) can be developed as following equations.

$$PF = \frac{S_{GR,\,Ave}}{S_{Tot,\,Ave}}$$

where

$$S_{Tot,Ave} = GN\,\frac{\sum_{i=1}^{N}\sum_{j=1}^{M} S_{ij}}{K \cdot M}$$

$$S_{GR,Ave} = \frac{\sum_{g=1}^{g'} S_g}{M}$$

And *j(1~N)* is group number and *i(1~N)* is total guide thimble number in a group respectively. M and GN are the measured guide thimble number in each group and the real guide thimble number in each group respectively K is total guide thimble number in the fuel assembly and *g(1~g')* is same expression as *i(1~N)*.

Stress peaking factor obtained from the upper equations and the strains (S) were shown in Table 1. As shown in Table, maximum stress peaking factor appeared in the outermost and highest/lowest guide thimble locations since the thicker area of top nozzle compared to central area returns most of load to guide thimble and the fuel rod participated in sharing the load in the fuel assembly mid span. On the contrary, the fact that the central area of nozzles composed of thin plate would make it deflect rather than return the reaction load to guide thimbles. These phenomena were made sure from Fig. 2 i.e. the slopes of groups 1 and 2 in the outer locations were stiffer than that of group 4 as load increased. The nonlinear behavior occurred in the mid level span of fuel assembly due to the frictional contact between fuel rods and spacer grids thorough their spring and dimple. This general nonlinear behavior can be simply expressed as following expression.

$$EA\frac{\partial^2 u}{\partial x^2} + \sum_{i=1}^{N} \mathrm{sgn}(u)\mu k \frac{l}{2}\frac{\partial u}{\partial x}\delta(x-x_i) = p(x)\,\delta(x-x_i)$$

where E, A, μ, k, δ, l, k, u represent Young's modulus, area of guide thimble, frictional coefficient, dirac delta function, span length, stiffness of grids and axial deflection, respectively. Most of parameters governing this behavior are different in fuel assembly types and strongly impact on the fuel assembly stress peaking factor. For example, peaking factor in the top span shows slightly lower than that of the exiting similar fuel assembly since guide thimble inertia moment shows greater and more grid numbers could slightly contribute to share the load evenly. Regarding this equation, further study is going to be performed in the viewpoint of theoretical approach and the aforementioned parametric study.

3. Conclusion

In this study, guide thimble peaking factor calculation methodology was developed. Using the developed methodology, stress peaking factor was bound to be the highest in the outmost and Top/Bottom span guide thimble locations, as expected. And this factor will be used to evaluate the fuel assembly design performance conservatively and other structural integrity. In the future study, work will be focused on the theoretical analysis based on the results of this study.

[Acknowledgements]

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REFERENCE

[1] S.Y.Jeon, S. K. Lee et al., "Load Concentration Factor for Stress Analysis of Fuel Assembly Top Nozzle", 2001 Spring Proceedings of the KNS.

Table 1. Guide Thimble location and Peaking Factor

Group No.	Guide Thimble ID (Span)	PF			Remark
		Top Span	Bot. Span	Mid Span	
1	A(T,B,M), B(T,B,M), P, I, T, U(T), F, M	1.18	1.19	0.89	
2	Q(T), C(T,B,M), E(T), S(T)	1.12	1.02	1.01	
3	J, R, L, D	0.90	0.87	1.08	Ave. of Groups 2&4
4	G(T,B,M), H, N, O	0.62	0.72	1.13	

(T: Top Span, B: Bottom Span, M: Mid Span)

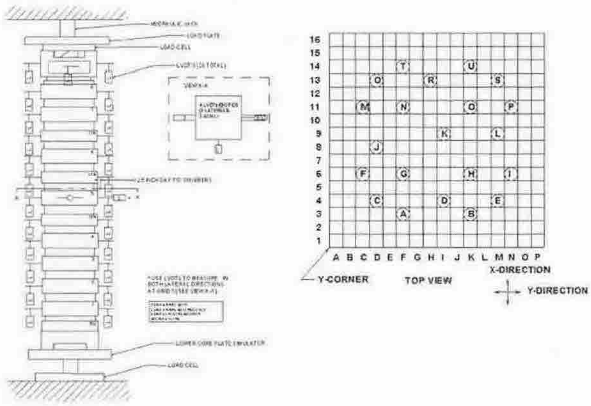

Figure 1. Test Set-up (Left) and Guide Thimble Location (Right)

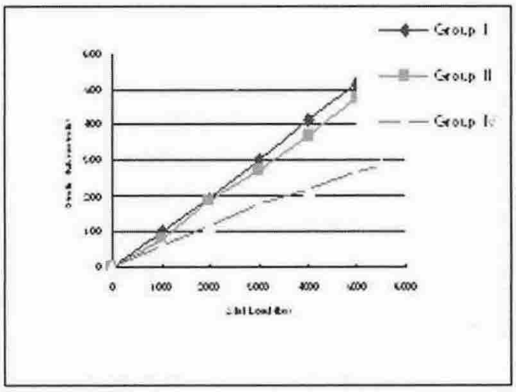

Figure 2. Applied Load vs. Strain