Investigation of Natural Frequencies of the Bottom Nozzle of APR 1400 Fuel Assembly

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1. Introduction

APR1400 Fuel assembly (fuel bundle, fuel element) consists of 235 fuel rods (long, slender, metal tubes containing pellets of fissionable material, which provide fuel for nuclear reactors) [1], 4 outer guide tubes, 1 center instrumentation guide tube, 11 spacer grids, lower end fitting(bottom nozzle), and upper-end fitting (top nozzle). Fuel assemblies shall meet the design criteria for non-operational, normal operational, AOO, and postulated accident loads. The lower end fitting, upper-end fitting, 4 outer guide tubes, spacer grids form the structural frame of the assembly and hold fuel rod in place.

One of the parts of the nuclear fuel assembly is bottom nozzle. The bottom nozzle consists of an adapter plate with flow holes, a support leg at each corner (total of four legs), four skirt plates, and a cylindrical instrument guide. The adapter plate filters foreign materials with an Inconel protective grid. The support legs align the lower end of the fuel assembly with the alignment pins in the core support structure. Each alignment pin positions the corners of the four bottom nozzles [2].

A center post is to aid insertion and support of the bottom mount in-core instrumentation. The upper portion of the plate prevents excessive downward movement of the fuel and poison rod. The bottom nozzle is attached to the debris-resistant Inconel grid. The functional requirements of bottom nozzle areas the structural support of the fuel assembly, provisions for seating and locating the fuel assembly, serve as a seating and restraint surface for the fuel rod, provide sufficient coolant flow area, protecting fuel rods from debris.

Thus, most previous studies have been focused on the integrity of the bottom nozzle. Because the main function of the bottom nozzle as the structural support of the fuel assembly, thus we must be considered to reflect the structural effects of the bottom nozzle when applying a mass come from of weight a nuclear fuel assembly. In other words, the mechanical characteristics of the bottom nozzle such as stress, strain, and deformation also are considered.

Besides that, to determine frequencies and mode shapes of a structure they are also required if we want to perform a spectrum or a mode superposition harmonic or transient analysis of bottom nozzle [3]. Therefore, the objective of this study is to know the intrinsic dynamic characteristics of the 3D bottom nozzle using ANSYS modal analysis and investigate of natural frequencies and mode shapes of the bottom nozzle of APR 1400 fuel assembly.

2. Method and Result

Some data was needed as input for ANSYS software. This chapter describe method and results of the bottom nozzle modeling, setting up boundary conditions and interpretation of analysis results.

2.1 Design condition in bottom nozzle structure

In order to assess the structural integrity of bottom nozzle structure, a 3D model of bottom nozzle was modelled in 3D in ANSYS. There are input parameter for design loading condition in ANSYS software are presented in Table 1.

Table 1. Design loading condition

Loading/ Condition	Value [kg]
F.A. weight without lower end-fitting (approximately)	642
F.A. hold-down spring force (approximately)	151
Total mass	793

The material property of bottom nozzle structure made by stainless steel 304. Stainless steel 304 has excellent corrosion resistance in a wide variety of environments and when in contact with different corrosive media. Pitting and crevice corrosion can occur in environments containing chlorides [5].

Stress corrosion cracking can occur at temperatures over 60°C. Stainless steel 304 has good resistance to oxidation in intermittent service up to 870°C and in continuous service to 925°C. The mechanical properties of bottom nozzle are presented in Table 2.

Table 2. The mechanical properties of SS 304 [6]

Grade	Value	Unit
Tensile Ultimate Strength	562	MPa
Tensile Yield Strength	252	MPa
Density	7954	kg/m^3
Modulus of Elasticity	193	GPa

2.2 The Results of Static Structural

The F.A. is installed on and contacted to and supported by the lower support structure. There are 5 Guide Tubes in the nuclear fuel assembly. It consists of four outer guide tubes and one center guide tube. The functional requirements of four guide tubes are for CEA passage and form a structural member of the fuel assembly. The loadings of F.A. consists of weight of fuel and coolant flow drag which acts in opposite direction. Therefore, in this case, the weight of fuel rod masses are applied to the guide tube inner hole surface of the bottom nozzle of 643 kg and together with hold-down spring assembly force of around 151 kg, so the total force of weight as assembly force in vertical direction downward is 793 kg. In the figure 1, it shows the boundary condition of the bottom nozzle used for static analysis.

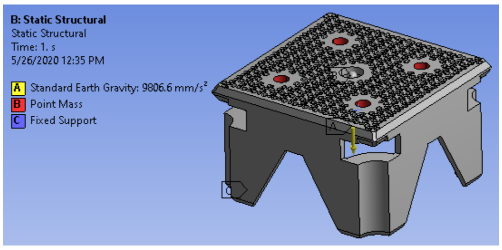

Fig.1 Static structural boundary condition

The result of maximum principal stress distributed on the bottom nozzle is presented in figure 2 and total deformation is presented in figure 3.

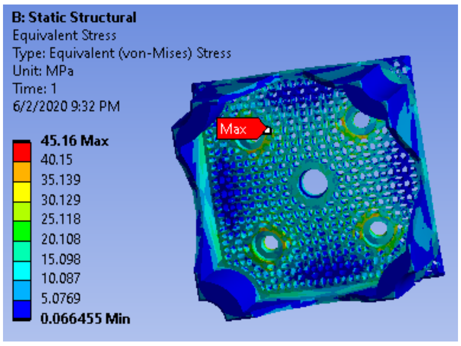

Fig.2 Maximum equivalent stress

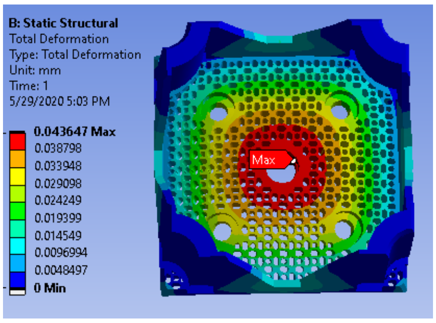

Fig.3 Total deformation

From table 2, the tensile yield strength is 252 MPa of the bottom nozzle. Whereas in the figure 2 the maximum principal stress of the bottom nozzle is 48.475 Mpa. It's mean the principal stress of the bottom nozzle is lower than from tensile yield strength. In the figure 3, we know that the maximum of total deformation is 0.043647 [mm].

2.3 Modal analysis of the F.A. bottom nozzle

For Modal analysis, three cases were considered, one for free loaded and one for weight only and the last for weight and assembly loading. A fixed support condition is applied at the bottom surface of the bottom nozzle for the modal analysis that requires the system to be linear. In this cases, there are three type of cases natural frequencies. The first case are combination of the force of hold down spring and the mass of fuel assembly. The second case is the mass of the fuel assembly except lower end-fitting. The third is without any loaded (none). The total number of force and mass are presented in table 1.

In figure 4 shows the boundary condition of the bottom nozzle of case 1, where as in figure 5 shows the boundary condition of the bottom nozzle of case 2, and in figure 6 shows the boundary condition of the bottom nozzle of case 3.

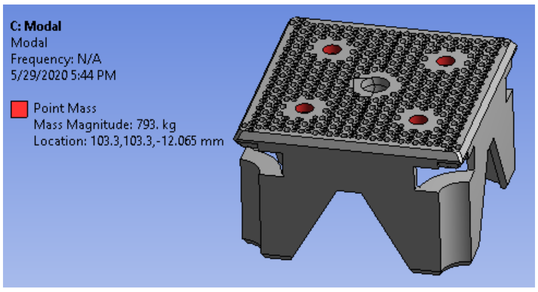

Fig.4 Case 1 (loaded by fuel rod weight + hold-down spring force)

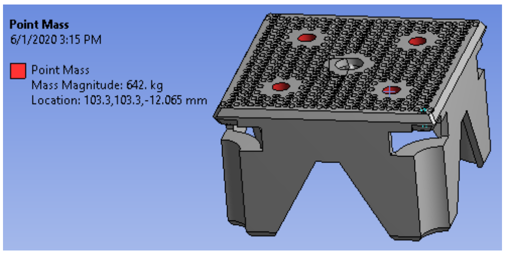

Fig.5 Case 2 (loaded with fuel rod weight only)

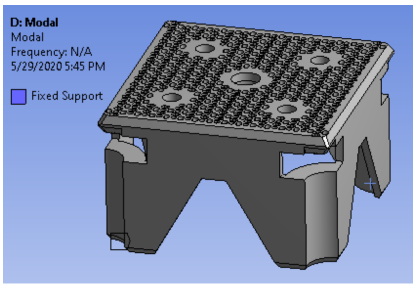

Fig.6 Case 3 (unloded)

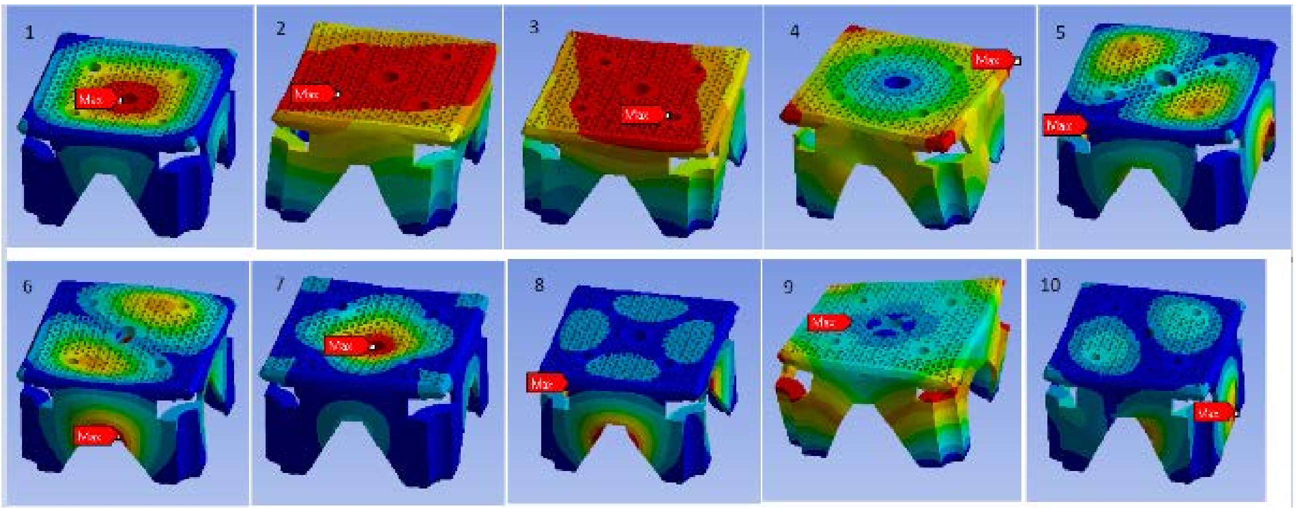

Fig. 7 Mode shape of the 10 natural frequencies of the bottom nozzle on case 1

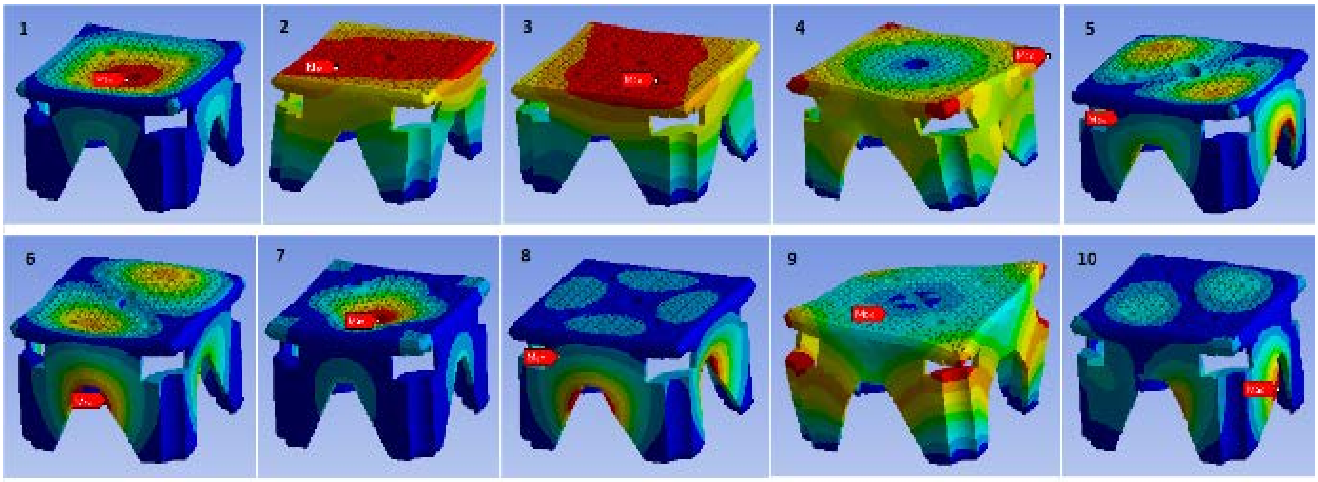

Fig. 8 Mode shape of the 10 natural frequencies of the bottom nozzle on case 2

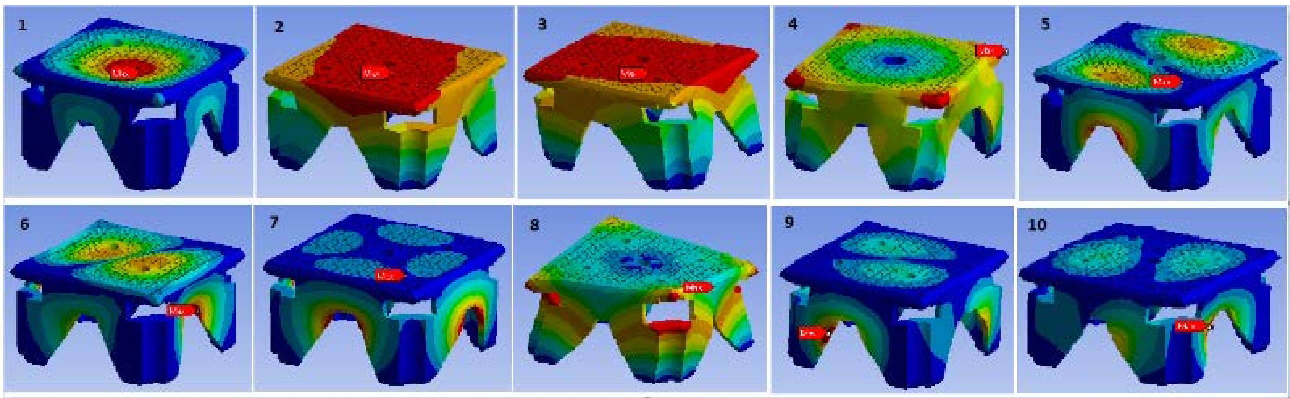

Fig. 9 Mode shape of the 10 natural frequencies of the bottom nozzle on case 3

2.4 The results of modal analysis

In this section, a modal analysis of the bottom nozzle was done to check the characteristics of the dynamic response of the system. Table 3 presents the results of the natural frequencies found for the model. In figure 7, figure 8, and figure 9 are show the mode shape of the 10 natural frequencies of the bottom nozzle on case 1, case 2 and case 3.

Table 3. The bottom nozzle natural frequencies results.

The number of mode	Case 1 (Hz)	Case 2 (Hz)	Case 3 (Hz)
1	95.158	105.75	1583.8
2	127.9	142.08	1809.3
3	127.94	142.13	1809.6
4	3079.5	3079.7	3079.7
5	3109.4	3109.9	3140.7
6	3110.6	3111.1	3141.9
7	3234.2	3235.4	3425.
8	3424.4	3425.	3750.3
9	3750.1	3750.3	4099.3
10	4092.4	4092.9	4102.5

The results showed that the first 3 modes, the modal frequencies decrease as greater compressive loads are applied. Especially fundamental frequency showed considerable differences between loaded and unloaded cases. Above mode 4, there are little change in modal frequencies. Figures 7 to 9 showed mode shape plots. Despite significant differences in mode 1~3, the mode shape of 3 cases show little difference. Overall mode shapes are similar for all cases. This is due to the similarities of loading case1 and 2 in which the direction of loading didn't change and they are applied in the direction of out-of-plane, i.e. perpendicular to the lower end-fitting upper surface.

3. Conclusion

The modal frequencies and mode shapes of bottom nozzle were evaluated and compared for loaded and unloaded cases. The modal analysis of the bottom nozzle was conducted to get reference dynamic behavior of the lower end-fitting. The results on table 3 show that the bottom nozzle of natural frequencies at 3 different loading cases.

The results of this research will be used for developing simplified fuel assembly model in which lower end fitting will be modeled by simple plate. For such simplification of model, the equality of structural stiffness and mass in the dynamics behavior should be ensured so that the simplified model will produce results that is comparable to actual model. In this case, the detailed structural and modal analyses result of lower end-fitting will be used as reference for obtaining equivalent stiffness and mass of lower end-fitting. We can conclude that our result is suitable for use in the development of F.A. seismic analysis model.

Acknowledgement

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Reference

[1] United State Nuclear Regulatory Commission. 2014. Glossary. [Online] Available at: https://www.nrc.gov/reading-rm/basic-ref/glossary/fuel-assembly-fuel-bundle-fuel-element.html

[2] United State Nuclear Regulatory Commission. APR 1400 Design Control Document Tier 2 Chapter 4. Reactor. Revision 0, December 2014.

[3] ANSYS Dynamics Solutions 11.0 Version. 2007. ANSYS, Inc. All Rights Reserved. Printed in U.S.A.

[4] APR1400 Standard SAR, 2004, KHNP

[5] Azom Sponsored by Alco - Ferrous and Non-Ferrous Metals. 2005. [Online] Available at: Stockisthttps://www.azom.com/article.aspx?ArticleID=2867

[6] ANSYS. Mechanical Properties Data Compiled by The Granta Design Team at ANSYS, incorporating various sources including JAHM and MagWeb.