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Design and Modal Analysis of the FTP and FTP Adapter in PGSFR

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1. Introduction

The fuel transfer port (FTP) and FTP adapter should be used to withdraw core assemblies from reactor in prototype gen-IV sodium-cooled fast reactor (PGSFR). Because PGSFR uses sodium as a coolant and sodium aerosol is generated, the FTP and FTP adapter should be completely sealed during refueling. During the reactor operation, the FTP plug is installed in the lower adapter fixed to the reactor head and sealed. During the refueling, the FTP plug is removed and the upper adapter is installed to provide the passage for the fuel transfer. The transportation of the core assemblies from the inside of the reactor vessel to the outside is performed through the FTP suspended to the reactor head. The location of the FTP is shown in Fig. 1.

The FTP adapter is composed of the upper and lower adapter as shown in Fig. 2. The lower adapter is designed to be fixed to the reactor head semi-permanently. The upper adapter is connected to the lower adapter and used during the refueling [1]. The purpose of this study is to design the FTP and FTP adapter by considering the fuel transfer basket and perform the modal analysis. As a preliminary stage of the seismic analysis, a modal analysis is carried out on the shape and dimension of the FTP and the FTP adapter in PGSFR. The scope of this modal analysis includes the FTP, the FTP adapter, and the gate valves. FTP adapter and gate valves are structures that are installed during refueling. Therefore, the analysis considers the configurations of the structures during refueling.

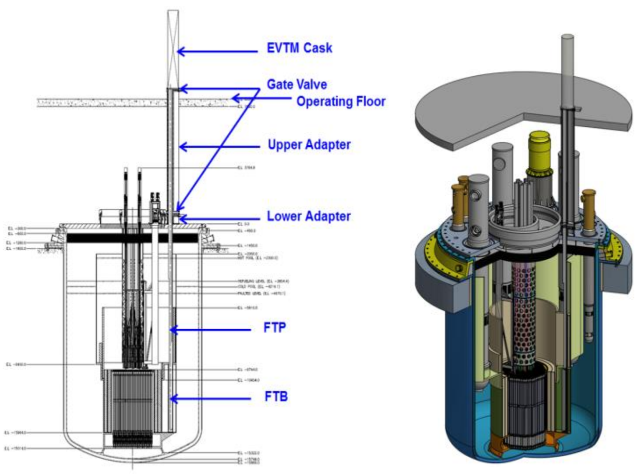

Fig. 1 Location of the FTP and FTP adapter in PGSFR

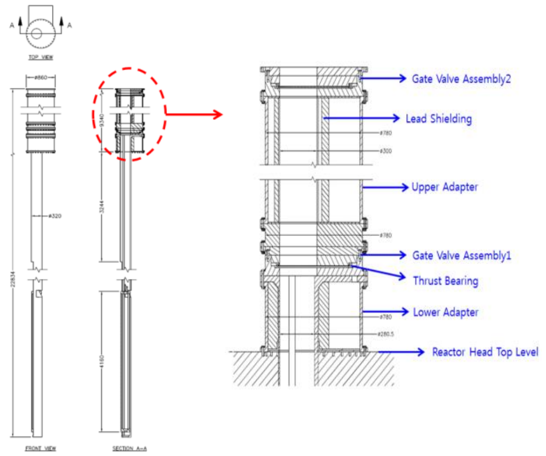

Fig. 2 Design of the FTP adapter in PGSFR

2. Design Characteristics for the FTP

The fuel transfer basket moves up and down inside the FTP. Fig. 3 shows the configuration and the free body diagram of the fuel transfer basket. As shown in this figure, the center of gravity for the fuel transfer basket and the steel wire pulling the basket are not in line because of the interference with the in-vessel transfer machine. Thus, we can assume the accident that the fuel transfer basket is jammed by the occurrence of the moment during the movement inside the FTP.

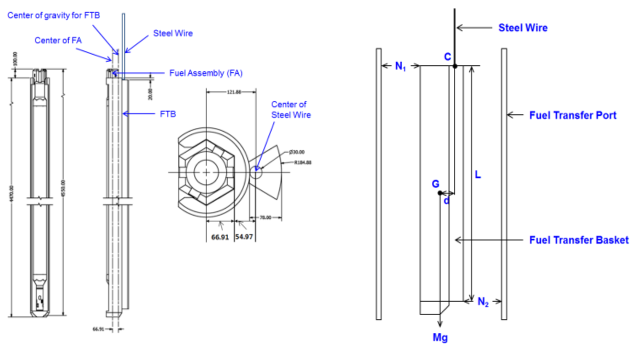

Fig. 3 Fuel transfer basket and free body diagram

Assuming that the fuel transport basket is stopped by lowering, we can take the equilibrium of moment and force against point c as shown in Fig. 3 in the free body diagram and obtain the reaction and friction forces as shown in following equations (1) ~ (6). When the fuel transfer basket moves in the direction of the gravity, the prediction for the jam of it inside the FTP can be evaluated by calculating the friction force generated between the FTP and the fuel transfer basket, and comparing it with the weight of the fuel transfer basket. The friction force inside the FTP occurs in the two positions with the reaction forces, which can be calculated as follows. Here, the frictional coefficient is expected to be very small, but conservatively, the result is as follows by applying the frictional coefficient of 0.3. From the calculation results, it can be seen that the magnitude of the frictional force (F_μ) compared with the weight of the fuel transfer basket (F_w) is very small. Therefore, even though the center of gravity of the fuel transfer basket and the steel wire pulling up the basket do not line up and make an eccentricity of about 5.5 cm, it is predicted that this will not cause a problem in the movement of the fuel transfer basket inside the FTP.

$$\sum M_c = 0,\ \ Mgd - N_2 L = 0 \quad (1)$$

$$\sum F_x = 0,\ \ N_1 - N_2 = 0 \quad (2)$$

$$N_1 = \frac{Mgd}{L} \quad (3)$$

$$d = 0.055\ m,\ \ N_1 = \frac{623.3X.8X0.055}{4.179} = 80.39\ N \quad (4)$$

$$F_\mu = 2\mu N_1 = 2X0.3X80.39 = 48.23\ N \quad (5)$$

$$F_w = (M_{fuel} + M_{FTB})g = 623.3\ X\ 9.8 = 6108.3\ N \quad (6)$$

3. Modal Analysis of the FTP and FTP Adapter

3.1 Analysis model and boundary condition

Fig. 4 shows a three-dimensional solid finite element model for the modal analysis of the FTP and the FTP ad apter [2]. The analysis model includes a FTP, a FTP ada pter, and the gate valves.

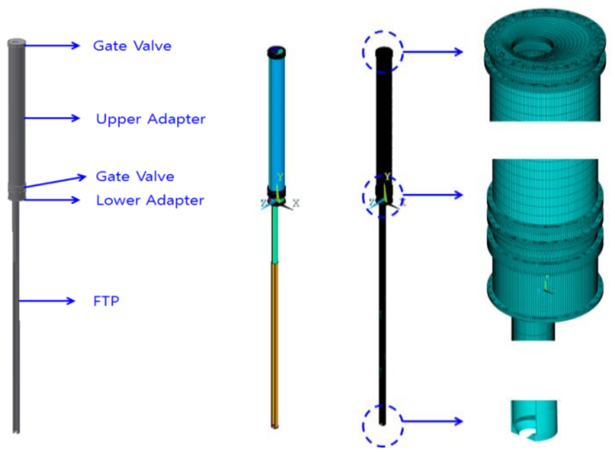

Fig. 4 FE model of the FTP and FTP adapter

In the boundary condition for the modal analysis, the inner flange of the lower adapter, which is permanently fixed to the reactor head, is completely restrained. The upper end of the upper adapter protrudes slightly above the reactor operating floor and is horizontally supported for connection to the EVTM cask, while the lower end of the FTP is horizontally supported by the reactor core shield. Also, since the thermal expansion due to the temperature difference along height must be absorbed, the lower part of the FTP is not constrained in the vertical direction.

3.2 Analysis Result

Modal analysis is performed to calculate the natural frequency of the FTP and the FTP adapter. A total of 200 modes are calculated and main modes are arranged in X, Y, and Z directions. First, we have summarized the modes that the ratio of the effective mass to the total mass is 10% or more. The main modes as shown in Table 1 are about the behaviors of the FTP adapter because the mass of the FTP adapter is much larger than that of the FTP installed under the reactor head. In the analysis results, the dominant mode in the horizontal X direction is the 3rd mode and the natural frequency is calculated as 19.1 Hz. This mode represents the bending mode of the outer cylinder of the FTP adapter.

In the horizontal Z direction, the 4th mode dominates and the natural frequency of 20.3 Hz is calculated, which represents the bending mode of the inner shield of the adapter and the outer cylinder.

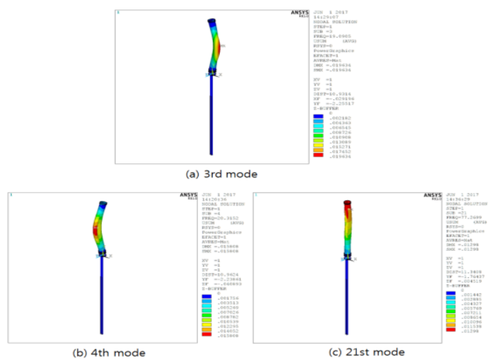

Fig. 5 Main modal shapes of the FTP adapter

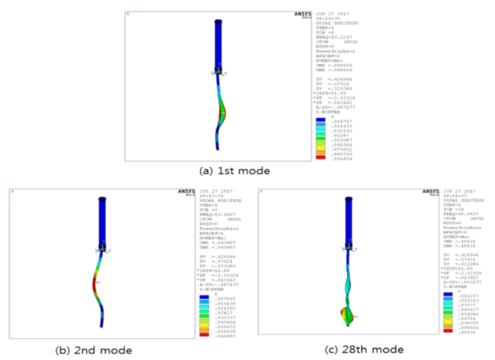

Fig. 6 Main modal shapes of the FTP

In the vertical Y direction, the 21st mode is extracted as the main mode and the natural frequency is 77.3 Hz, which indicates the torsion mode of the outer cylinder of the FTP adapter. Fig. 5 shows the main modal shapes of the FTP adapter. The FTP, which is suspended from the bottom of the reactor head, is also the main structure. In addition, the modes with an effective mass ratio of 2 % or more to the total mass are extracted. Two of the seven are combined modes for bending and torsion of the FTP adapter, and the remaining five modes are for the FTP behavior. Table 2 shows the main modal characteristics of the FTP. Three representative modes of 1st, 2nd, and 28th are shown in the table, and modal shapes are shown in Fig. 6.

Table 1 Main modal characteristics of the FTP adapter

Direction	Mode	Frequency (Hz)	Partic. Factor	Ratio	Effective Mass (Kg)	Cumulative Mass Fraction	Ratio Eff. Mass to Total Mass
X direction	3	19.091	87.45	1.0000	7646.7	0.6233	0.5369
Y direction	21	77.270	100.20	1.0000	10040.3	0.7947	0.7048
Z direction	4	20.315	90.03	1.0000	8105.5	0.6761	0.5690

Table 2 Main modal characteristics of the FTP

Direction	Mode	Frequency (Hz)	Partic. Factor	Ratio	Effective Mass (Kg)	Cumulative Mass Fraction	Ratio Eff. Mass to Total Mass
X direction	1	13.222	17.54	0.2006	307.6	0.0241	0.0216
Y direction	28	90.064	-22.47	0.2242	504.7	0.8420	0.0354
Z direction	2	13.646	20.26	0.2250	410.5	0.0325	0.0288

4. Conclusions

For the current design of the PGSFR FTP and FTP adapter, it is possible for the fuel transfer basket to move up and down without jams from the calculation results of the frictional force. In connection with the modal analysis, the main modes of FTP and FTP adapter are first evaluated, which are about the behavior of the FTP adapter. In addition, the main modes of FTP, which are the modes with an effective mass ratio of 2% or more to the total mass, are extracted and evaluated to understand the modal characteristics of FTP.

Acknowledgements

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REFERENCES

[1] FTP Adapter Design, SFR-800-DM-302-001, Rev.01, KAERI, 2017.

[2] ANSYS User's Manual for Revision 15.0, ANSYS Inc.