Study on the Dynamic Characteristics of High-slenderness Ratio Components of Sodium-Cooled Fast Reactor

Seong-Hyeon Lee, Jae-Han Lee and Chang-Gyu Park

KAERI(Korea Atomic Energy Research Institute)

Abstract

The prototype generation IV sodium−cooled fast reactor (PGSFR) which is being developed by Korea Atomic Energy Research Institute (KAERI) is composed of several high−slenderness ratio components. In general, the frequency characteristics of the seismic load that may occur have a high response in the low frequency range. Since the frequency range of these seismic loads is likely to be in the natural frequency range of high−slenderness ratio components of PGSFR, there is a possibility that resonance may occur. In this study, high−slenderness ratio components of PGSFR were selected and the dynamic characteristics were analyzed through modal analysis and resonance possibility check.

Introduction

- The main components of the sodium−cooled fast reactor (SFR) assembly should be designed to maintain structural integrity against horizontal and vertical seismic loads.
- The frequency range of these seismic loads is likely to be in the natural frequency range of main components with high−slenderness ratio (HSR) installed in SFR.
- Thus, there is a possibility of resonance between the frequency of the seismic load and the natural frequencies of the structures.
- Therefore, it is necessary to identify structures that are expected to be vulnerable to seismic loads through dynamic characteristics analysis of major HSR components.
- In this study, HSR components were selected from the prototype generation−IV sodium−cooled fast reactor (PGSFR), and the dynamic characteristics of the selected HSR components were analyzed through modal analysis.
- In addition, the possibility of resonance between the frequency of the seismic load and the natural frequency of the selected high−slenderness ratio components was analyzed.

High-slenderness Ratio Component and Analysis Model

- **High−slenderness Ratio Components Selection**
  - In case of HSR structures like primary heat transfer system (PHTS) pump, intermediate heat exchanger (IHX), and decay heat exchanger (DHX) as shown in Figure1, there is a high possibility of structural weakness because the seismic load in the low frequency range and the natural frequency of the structure coincide with each other, which can cause resonance.
  - The value representing the level of slenderness of the structure is the slenderness ratio (SR) λ, as following [1].

$$\lambda = L/r = L/\left(2a\sqrt{I/A}\right)$$

(λ=slenderness ratio, L=structure length, r=minimum radius of gyration
I=section moment about the centroid axis, A=section area)

  - As shown in Table 1, the SR of PHTS pump, IHX, and DHX all showed a high value of 40 or more, so these components were selected as the main HSR components.

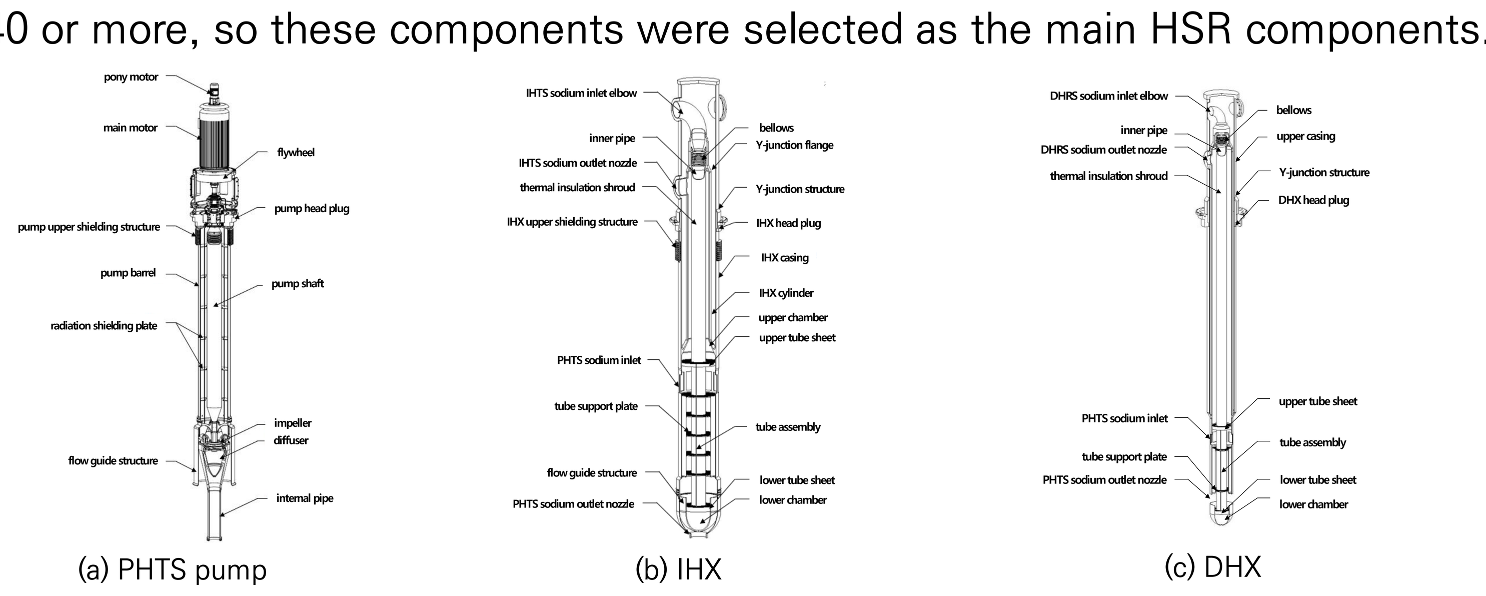

Fig. 1 Selected HSR components (PHTS pump, IHX, and DHX)

Table. 1 The SR of PHTS pump, IHX, and DHX

	PHTS pump	IHX	DHX
L [m]	16.47	18.57	12.16
r [m]	0.180	0.367	0.179
λ	103.17	44.82	68.05

- **Analysis Model**
  - The finite element analysis models of PHTS pump, IHX, and DHX for analyzing dynamic characteristics and boundary conditions are shown in Figure 2 and 3 [2].

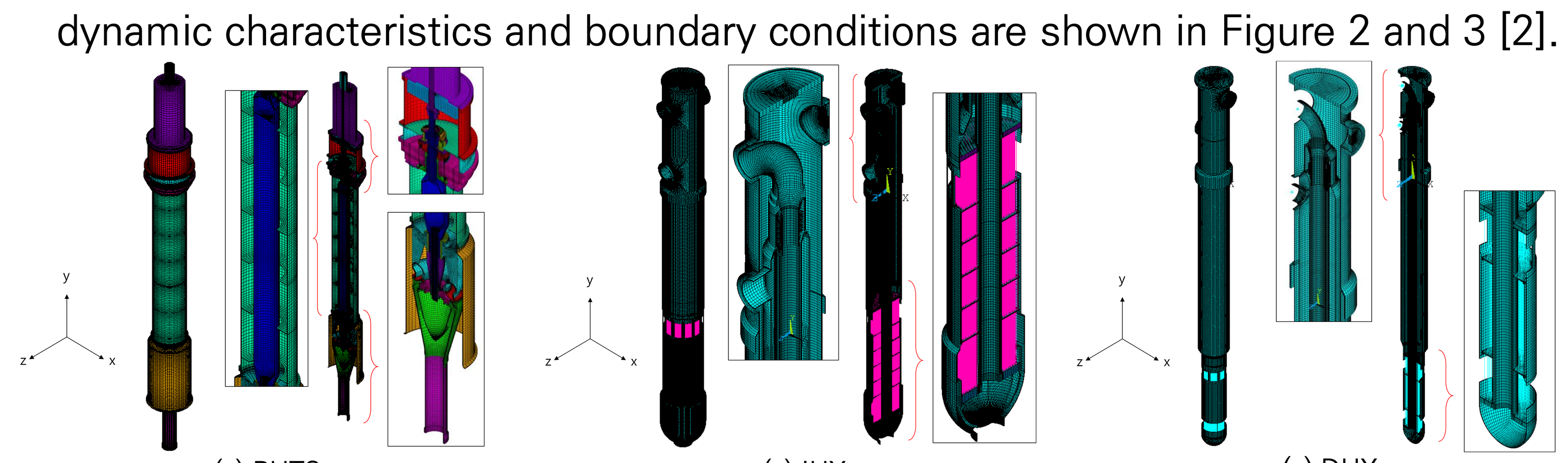

Fig. 2 Finite element analysis models (PHTS pump, IHX, and DHX)

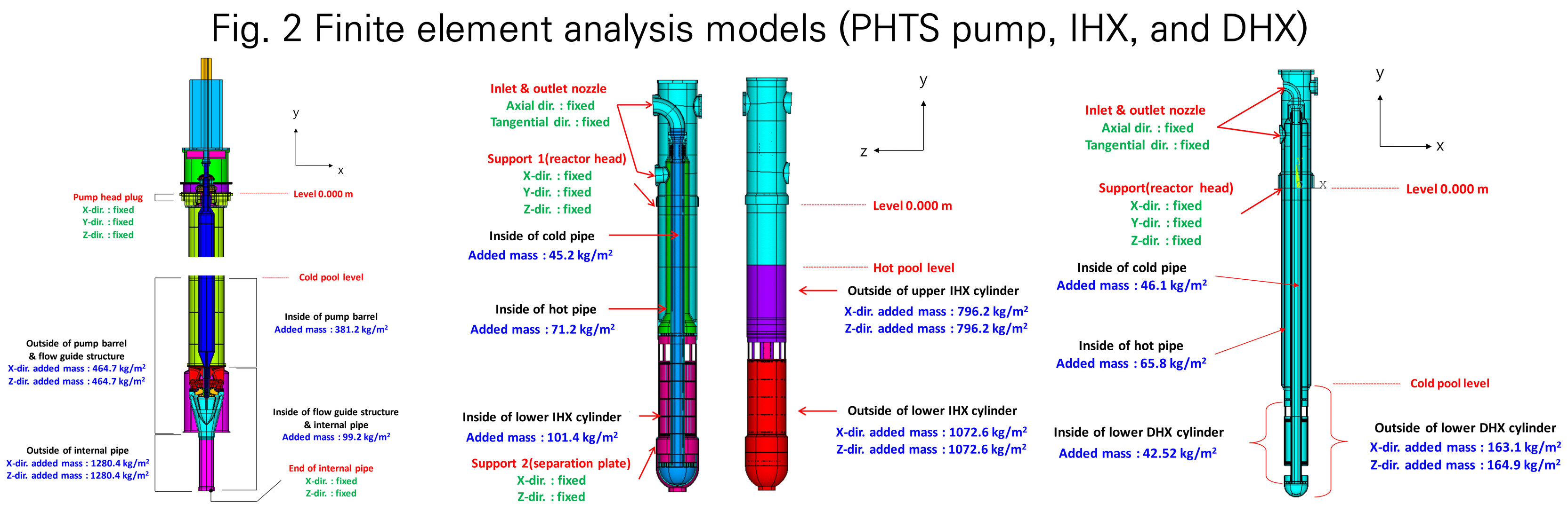

Fig. 3 Boundary conditions (PHTS pump, IHX, and DHX)

Dynamic Characteristics Analysis

- **Modal Analysis**
  - When performing modal analysis, sufficient natural vibration modes and modal parameters were extracted to include the excitation frequency range (0~100 Hz) of the floor response spectrum (FRS).
  - The major natural frequencies and modes for each direction derived from modal analysis of the PHTS pump, IHX, and DHX are shown in Figure 4.

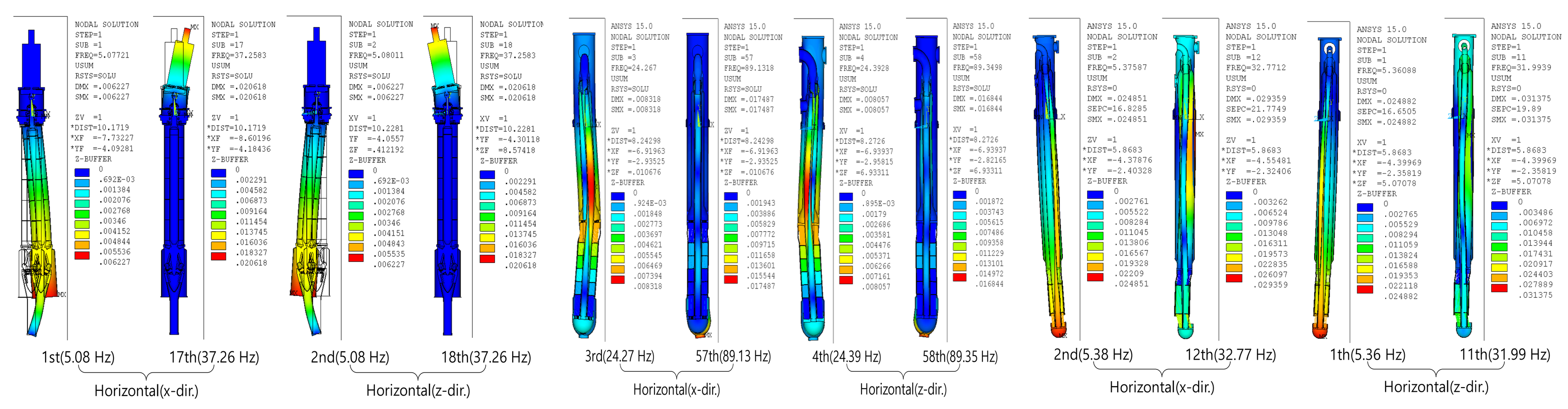

Fig. 4 Major mode shape (PHTS pump, IHX, and DHX)

- **Resonance Possibility Analysis**
  - The seismic loads are applied to the HSR components as shown in Figure 5.
  - The possibility of resonance was analyzed by comparing the FRS acting on supports of HSR components with the natural frequencies of those components (Figure 6~8) [3].
  - The possibility of resonance with the natural frequency of the PHTS pump is expected to be high in the critical frequency range of support 2−x direction (4.3 Hz to 6.0 Hz) and support 2−z direction (4.4 Hz to 6.3 Hz).

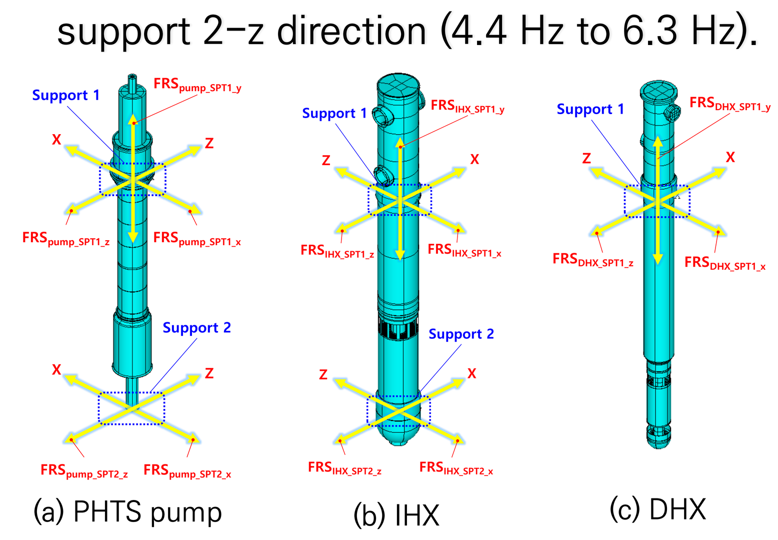

Fig. 5 Seismic load direction and location acting on each component

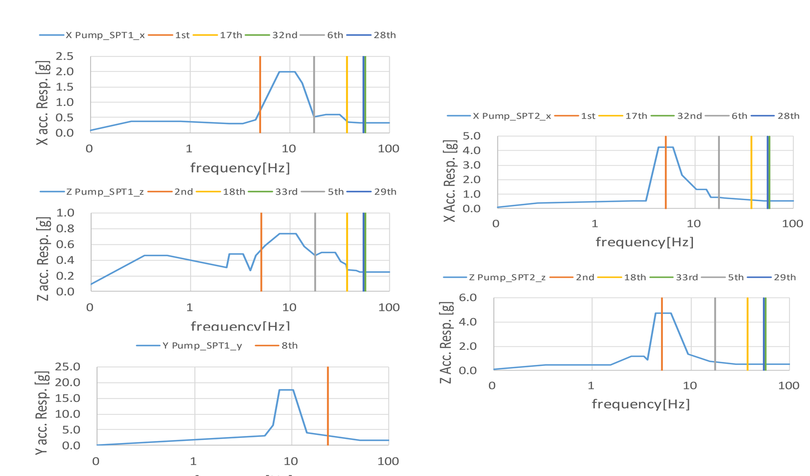

Fig. 6 Comparison of the natural frequency and FRS of the PHTS pump

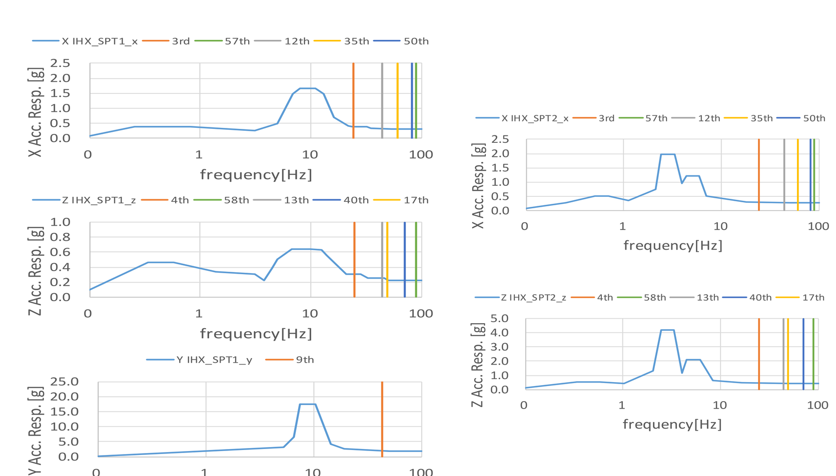

Fig. 7 Comparison of the natural frequency and FRS of the IHX

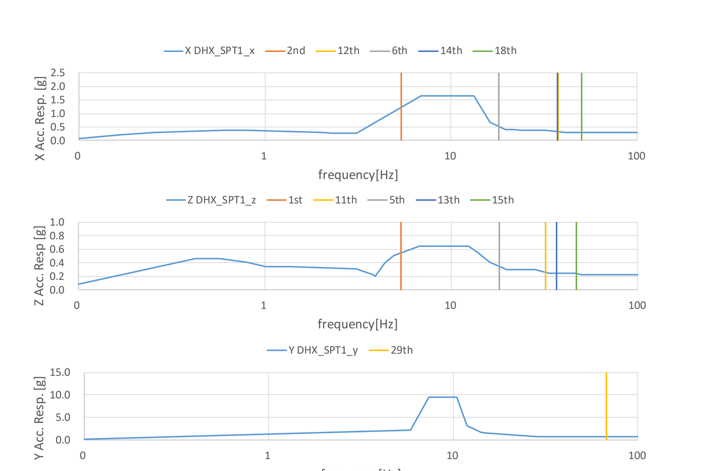

Fig. 8 Comparison of the natural frequency and FRS of the DHX

Conclusions

- In this study, the PHTS pump, IHX, and DHX, which are expected to be vulnerable to horizontal seismic load, among the major components constituting the PGSFR reactor assembly were selected based on the slenderness ratio.
- Modal analysis was performed to analyze the dynamic characteristics of the components selected as high−slenderness ratio structures, and modal parameters such as natural frequency and participation factor obtained as a result of the modal analysis were calculated.
- In order to evaluate the seismic risk of each component, the possibility of resonance between the seismic load frequency acting on each component and the natural frequency of each component was analyzed.
- As a result of the analysis, in the case of the PHTS pump, it was expected that the critical frequency range of the horizontal seismic load acting on support 2 and the natural frequency of the PHTS pump would be highly likely to resonate.

References

[1] J. M. Gere and S. P. Timoshenko, "Mechanics of materials", 4th edition, PWS Publishing company, 1997.

[2] G. H. Koo and J. H. Lee, Development of FAMD Code to Calculate the Fluid Added Mass and Damping of Arbitrary Structures Submerged in Confined Viscous Fluid, KSME International Journal, Vol 17, No.3, pp. 457−466, 2003..

[3] G. H. Koo, "PHTS Design Response Spectra", KAERI internal document, 2017