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# Modal Analyses of a Cylindrical Structure Partially Submerged in a Liquid Sodium Environment

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## 1. Introduction

The upper internal structure (UIS) in an SFR (Sodium-cooled Fast Reactor) system is generally attached to the rotating plug of the reactor head and cantilevered downward into the reactor hot pool. The UIS is a cylindrical structure and its upper part is exposed on the cover gas but the middle and lower parts are submerged in a liquid coolant environment for a normal operating condition[1]. Generally, the fluid contacting with the structure imposes a fluid mass on the structure and the fluid added mass may affect the dynamic characteristics of the structure. Since the UIS plays an import role in the reactor safety, its dynamic characteristics should be reflected on the component design. In this study, the modal analyses for a cylindrical structure of the UIS are carried out corresponding to the environmental conditions.

## 2. UIS Cylindrical Structure

### *2.1 General Description*

The reactor system under consideration in this study is an SFR demonstration reactor of 600MWe with a pool-type arrangement. The UIS attached to the rotating plug should satisfy the following main functions[1, 2].

- Lateral support of the control rod drivelines
- Protection of the drivelines from a sodium flow induced vibration
- Support of the above core instrumentation drywells.
- Mixing promotion of the primary sodium as it exits the core assemblies.

Figure 1 shows a schematic drawing of UIS component. Its overall length is 9.1m and its outside diameter is 3.28m. The UIS consists primarily of three vertical cylinders, which are joined by welding to horizontal plates. The upper cylinder has an outer diameter of 3.28m and a wall thickness of 2.5cm. Its upper end is welded to the bottom of the rotating plug and the lower end is terminated by a thick plate. The intermediate cylinder has an outer diameter of 2.02m and a wall thickness of 5.0cm. It is welded to the bottom of the 10cm plate and extends down to 30cm above the top of the core assemblies. By cutting large holes through the cylinder, the effective mass of the sodium contained inside will be minimized and access provided during fabrication for positioning and support of the CR driveline shroud tubes, temperature sensor drywells and the source range flux detector drywells. The UIS is made from Type 316 stainless steel.

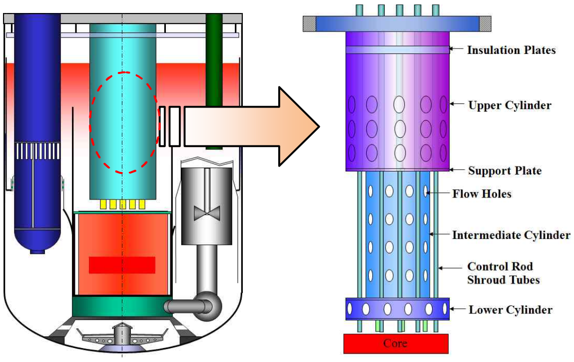


Fig. 1. Structural concept of upper internal structure for an SFR demonstration reactor of 600MWe.

### *2.2 FE Model*

The finite element (FE) model for modal analysis contains the cylindrical structure only without CRD shroud tubes. The model also simplifies the large flow holes through the cylinder. The modal analysis is carried out using ANSYS[3] program.

Two kinds of environmental conditions, air and sodium, are applied. For an air condition, the analysis model is a UIS cylindrical structure only with a support component. However, under the sodium fluid condition, the model contains the fluid volume and external vessel containing the fluid in addition to the air condition model. For the sodium environment, additional analyses were attempted of small external vessel models for the diameter and height, respectively. The element types used in ANSYS are a SOLID45 element for a structural volume and FLUID30 element for a coolant volume.

### *2.3 Analysis results*

For the air condition, the natural frequency of the 1$^{st}$ bending mode is 8.3Hz and it is not close to the frequency of the reactor building seismic isolation of 0.5Hz. For the sodium condition, the 1$^{st}$ bending mode is 5.86Hz and is about 29% lower than that of the air condition. In addition, the 2$^{nd}$ frequency for sodium condition is almost 50% of air condition. Such reduction in natural frequency is caused by the effect of fluid added mass on the structure. For the smaller diametric vessel, maintaining the same height shows an increase in the natural frequency under the fluid condition where the incremental frequency difference is only around

10%. This is mainly caused by a reduction of the fluid mass. For the small height vessel model of the sodium condition, the natural frequency is reduced about 2%. The reduction of mass for the same structure generally shows a trend to increase the natural frequency, but it is not shown in this case. From this result, the environmental fluid height below the structure affects the natural frequency of bending mode slightly, and a reduction of the frequency in this analysis is thought to be caused by the fine element meshing. Figure 2 shows the deformed shapes of the representative bending modes for all of analyses ; Table 1 summarizes the analysis results.

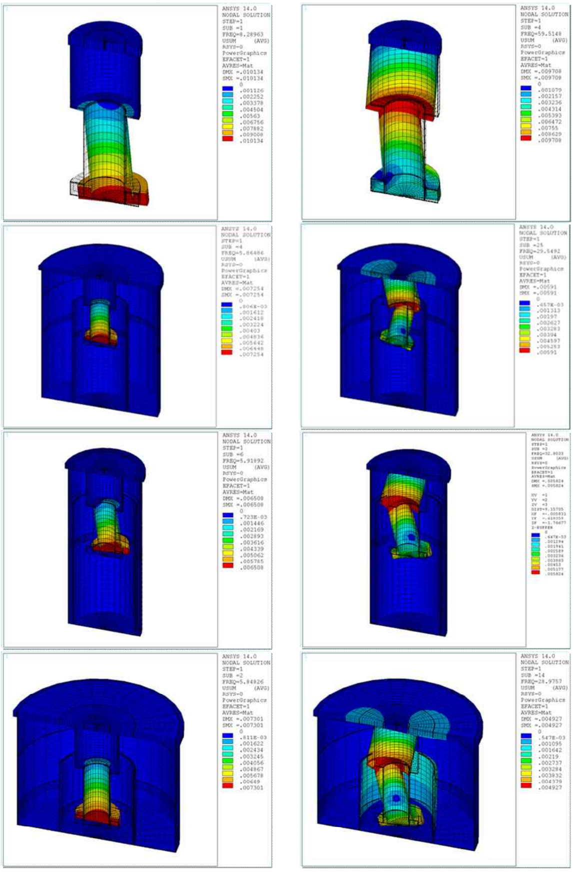

Fig. 2. Modal shapes of $1^{st}$ and $2^{nd}$ bending modes for air and sodium conditions, which are the design model, small diameter vessel model and small height vessel model in the order listed.

Table 1: Result of Modal Analyses (Hz)

| Environment | | $1^{st}$ bending mode | $2^{nd}$ bending mode |
|---|---|---|---|
| Air | | 8.29 | 59.52 |
| Na | Original | 5.86 | 29.55 |
| | Small diameter | 5.92 | 32.80 |
| | Small height | 5.85 | 28.98 |

*2.5 Sensitivity Study*

For the sodium condition, the modal analysis takes a long time compared with air condition model owing to a larger number of elements used for the modeling and fluid-structure interaction conditions. For this reason, the sodium condition model is less fine than the air condition model. However, the FE numerical analysis may be affected somewhat by the meshing geometry, element size and boundary conditions. To investigate the feasibility of the sodium condition model, a sensitivity study was conducted for two additional models, coarse and fine models comparing with the original design model in Figure 2. Table 2 shows the analysis results. The average differences for 10 initial modes are less than 2% for both models. Therefore, it is judged that the mesh size within the acceptable regime does not affect the modal results much.

Table 2: Modal Results for the Meshing Sensitivity (Hz)

| | Coarse | Model | Fine |
|---|---|---|---|
| $1^{st}$ | 5.4 | 5.1 | 4.9 |
| $2^{nd}$ | 6.2 | 6.1 | 6.0 |
| $3^{rd}$ | 29.5 | 29.1 | 28.9 |
| $4^{th}$ | 30.0 | 29.8 | 29.6 |
| $5^{th}$ | 37.1 | 36.4 | 36.1 |

### 3. Conclusions

Modal analyses for a UIS cylindrical structure for an SFR demonstration reactor with a 600MWe capacity were performed. The environments under consideration are air and sodium fluid conditions. For the sodium condition, additional analyses were attempted to study the effect of the external vessel dimensions such as the diameter and height. The fluid condition reduces the $1^{st}$ bending mode of the UIS cylinder by about 29% and is caused by the effect of fluid mass added on the cylinder. For the fluid condition, a small diametric external vessel increases the natural frequency compared with original model, but the natural frequency by a small height vessel is almost the same, and a minor difference is caused by the FE mesh geometry. These results will be reflected on the setup of test facility for UIS dynamic characteristics.

### ACKNOWLEDGEMENTS

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### REFERENCES

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