Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Dynamic Characteristic Test for a Cylindrical Structure with Flow Holes Submerged in Water

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1. Introduction

A cylindrical structure is usually applied in industrial equipment such as a storage tank and plant equipment of pressure vessel and internal structures. A structure immersed in a liquid generally shows a gain in mass from a viewpoint of the dynamic characteristic and thus it causes a decrease of its natural frequency. The dynamic characteristics of a cylindrical structure in contact with liquid have been of great concern in the engineering design. [1-3]. An Upper Internal Structure (UIS) is a typical cylindrical structure in a Sodium-cooled Fast Reactor (SFR). Unlike a Pressurized-Water Reactor (PWR) system, the UIS in a pool-type SFR is partially immersed in a coolant and the immersion level is dependent on the operation condition. The UIS cylinder has hundreds of flow-holes to promote the mixing of primary sodium as it exits the core assemblies. A perforated cylindrical structure causes a change in natural frequency compared with a simple cylindrical structure owing to changes of mass and bending rigidity. In this study, experimental tests for a perforated cylindrical structure were carried out to assess the dynamic characteristics related to the immersion level in water.

2. Test Facility and Measurement

2.1 Test Facility

The UIS made of Type 316 stainless steel in an SFR provides lateral support and protection for the control rod drivelines and instrument guidelines against the flowing sodium condition. In addition, it also promotes the mixing of primary sodium as it exits the core assemblies and thus is one of the key components in the reactor internals [4-5].

The test facility for the dynamic characteristics of a cylindrical structure with flow holes is mainly composed of a test model, support structure, water chamber, and measurement equipment. The test model is a perforated cylindrical structure simulating the UIS cylinder, which has hundreds of flow holes. It also has a concentrated mass at the low end of the cylinder to simulate the mass of the detectors and thermocouples in the UIS. The test model is made of stainless steel and its outer diameter and thickness are 165.2 mm and 2.8 mm, respectively. The overall length of a cylinder and the thickness of thick circular plate for a concentration mass are 0.8 m and 0.1 m, respectively. 216 flow holes are machined in the cylinder and a concentrated mass is welded to the perforated cylinder as shown in Fig. 1. A seamless pipe was used for a cylinder to exclude the longitudinal welding effect and enhance the machining precision. The upper end of the perforated cylinder is welded to the fixture, which is placed on the support plate and bolted together.

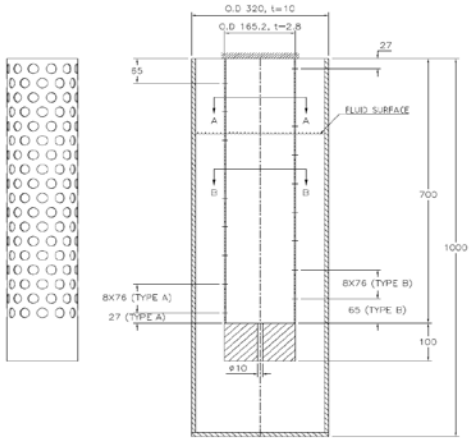


Fig. 1. Dynamic characteristic test model for a cylindrical structure with flow holes

The UIS is welded to the bottom of a rotatable plug installed on the reactor head and cantilevered downward into the reactor core without any horizontal support. Therefore, the boundary conditions of the upper and lower ends of the UIS are the fixed-end and free-end, respectively. To apply this boundary condition in this test, a typical support structure was prepared. It is composed of a horizontal support plate and a vertical column. The test model is supported by the support plate and they are fastened with bolts.

A water chamber used to provide the liquid immersion conditions was prepared and placed inside the support structure. There is a seal nozzle for a stinger transporting the excitation motion from the shaker to the test model. It provides horizontal movement of a stinger and also assures leak tightness during excitation. Its inner diameter is 0.3 m and it is made of stainless steel. The test equipment is shown in Fig. 2.

2.2 Measurement System

Because the test was performed in a fluid condition as well as in an air condition, immersible integral cable type accelerometers (Dytran 3217A) were applied. A force shaker (Modal Shop 2060E) is attached to the structure through a stinger, which is intended to transmit force only in the direction of the thrust. Accelerometers and a force transducer (PCB W208C02) were mounted on the test model and connected to the Front-End device (LMS SCADAS Mobile SCM02). The excitation signal from Test.Lab is fed to the shaker system (shaker and power amplifier). The test data are collected in the PC system through the Front-End device. The LMS Test.Lab (Rev.13A) software was applied to control the Front-End device, generate the input signal for the shaker and analyze the collected test data for natural frequency, mode shape, and so on. The measurement system for a dynamic characteristic test is shown in Fig. 2.

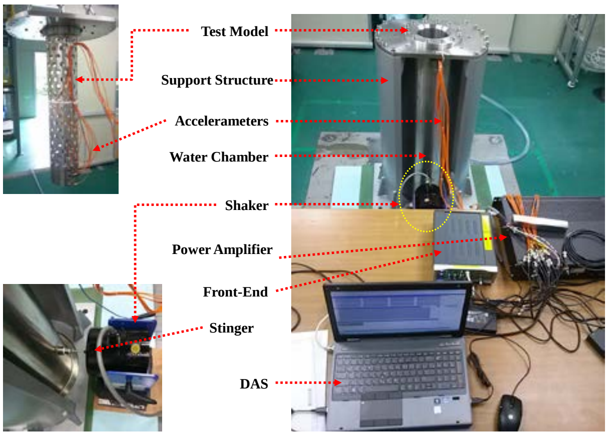


Fig. 2. Test facility of dynamic characteristic tests for a perforated cylindrical structure submerged in water chamber.

3. Test Method and Results

3.1 Test Method

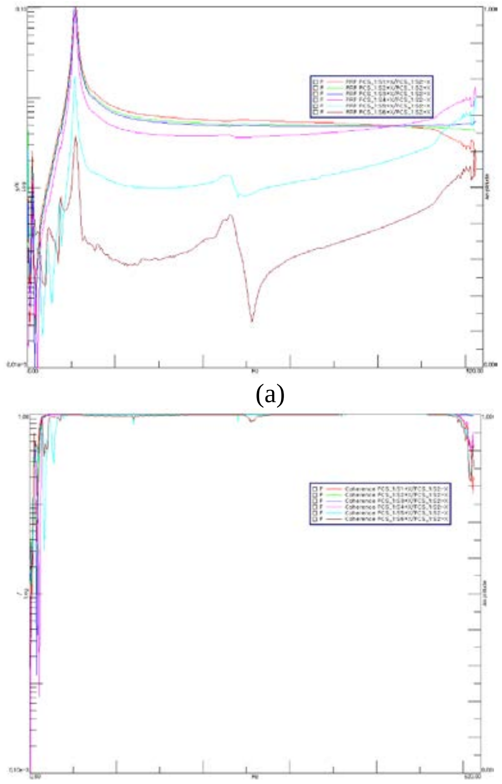
In the UIS design of the PGSFR, the area of the flow holes is approximately 30% of the UIS cylinder area. In this study, the diameter of the flow holes for the test model is 25.1 mm, which satisfies 30% of the cylinder surface area. The tests were carried out in air and various immersion conditions which are 20%, 40%, 60%, 80% and 100% in water. The dynamic responses were measured at six points along the axial direction. Table I shows the test matrix of the cylindrical structure with the flow holes.

Table I: Test Matrix for the FCS Test Model

Test ID	air	20%	40%	60%	80%	100%
FCS Φ =25.1mm	FCS -00	FCS -20	FCS -40	FCS -60	FCS -80	FCS -100

The mode shape under consideration in this test is the 1^{st} global bending mode. The 1^{st} mode was expected to be in a low frequency region of less than 100 Hz from the result of the numerical analysis. The bandwidth was 512 Hz and the input signal type was burst-random with a 60% burst time. The resultant natural frequencies were calculated by averaging the test data for 50 test runs.

Figure 3 shows the frequency response function (FRF) and coherence function of the test FCS model performed in air condition. As shown in Fig. 3, the FRF curve was distinct at a natural frequency and the magnitudes of the coherence function which verifies the reliability of this test result was almost 1.0. Other test results showed a similar tendency as Fig. 3 for the FRF and coherence function although they are not shown here.



(a)

(b)

Fig. 3. (a) Frequency response function and (b) coherence function for the FCS test model in an air condition.

3.2 Test Results

Tests were performed for six kinds of immersion level corresponding to the test matrix, and the test results are compared in Fig. 4. In Fig.4, SCS means the test results with a simple cylindrical structure without flow holes [3]. Its geometrical dimensions are the same with this test model. As shown in Fig. 4, the natural frequency of the FCS model decreases by 19.4% compared with that of the SCS model in air condition. This means that the decrement of the bending rigidity is larger than that of mass although the machining flow hole has an effect on the decrement of both the bending rigidity and mass.

The natural frequencies for both models decrease as the immersion level increases and are almost stationary for the high immersion level. The immersion level showing stationary natural frequencies for SCS and FCS was 80% and 40%, respectively. This is because the effect of the fluid added mass is greater in the SCS model owing to the larger surface area. For the fully-submerged condition, the natural frequency of the FCS model decreased by 7.2% compared with that of the SCS model. This means that the flow holes affect the decrease of natural frequency, but causes the less effect of the fluid added mass only for high immersion levels.

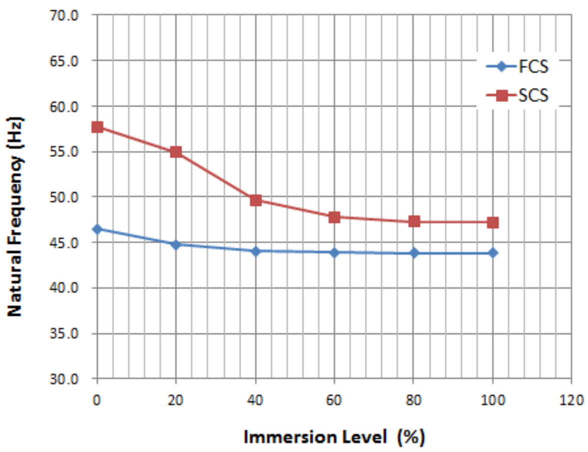


Fig. 4. Comparison of test and analysis results for the natural frequency of the 1st bending mode with respect to immersion level.

4. Conclusions

Dynamic characteristic tests for a cylindrical structure with flow holes were performed for the various fluid immersion levels. The natural frequency of the 1st bending mode for the FCS model decreases by 19.1% compared with the SCS model in air condition. The natural frequency for the FCS model decreased with an increasing immersion level, and this tendency was also shown in the SCS model. The natural frequencies in the air condition for the FCS model decreased by 13.4% compared with that in fully-immerged condition. The decrement of natural frequency in the low immersion level is greater than that in the high immersion level. The effect of fluid added mass for the FCS model was almost constant regardless of the immersion level even if the immersion level is greater than 40%. Further work on the effect of the dynamic characteristics by the flow holes diameter is in progress.

Acknowledgement

This study was supported by the National Research Foundation of Korea (NRF-2012M2A8A2025636) grant funded by the Korea government (Ministry of Science, ICT and Future Planning).

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