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

Effect of a Lumped Mass on the Natural Frequency in a Perforated Cylindrical Test Structure

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1. Introduction

Dynamic characteristic analysis of the Upper Internal Structure (UIS) in a Sodium-cooled Fast Reactor (SFR) is important in the structural design. The UIS of an SFR protects several significant components such as control rod shroud tubes and instruments guidelines and also provides flow guidance [1, 2]. To experimentally assess the dynamic characteristic of the UIS, a perforated cylindrical test model with a lumped mass, which simulates the mass of detectors and thermocouples located at the low end of the UIS, has been designed. However, understanding the effect of a lumped mass on the natural frequency of the test model should be preceded before the experiments to analyze the dynamic characteristic of the test model immersed in the surrounding liquid more clearly.

In this study, the effect of a lumped mass on the natural frequency in the test model has been investigated using the Finite Element (FE) analysis. Several perforated cylindrical structures with or without a lumped mass were considered and their dynamic characteristics such as natural frequencies and mode shapes were assessed.

2. Finite Element Analysis

2.1 Analysis model

Fig. 1 shows the perforated cylindrical structures investigated in this analysis. For simplicity, following two models (cylindrical structures without additional structures that are required to make similar boundary conditions in experiments [3]) were considered:

Model A: a perforated cylindrical structure with a lumped mass
Model B: a perforated cylindrical structure without a lumped mass

The outer diameter, thickness and height of the analysis model are 165.2 mm, 2.8 mm and 800 mm, respectively.

Two analysis models have the same porosity variation from 0% to 50% with an increment of 10% by applying triangularly patterned flow holes. Diameters of flow holes according to the porosity variation are listed in Table I. Each model has 18 rows of flow holes with an interval of 38 mm in the vertical direction and 24 columns of flow holes with an interval of 15° in the circumferential direction. The distances from the bottom of the model to centers of first flow holes in the first and second columns are 127 mm and 165 mm, respectively. The center of the bottom plate has one flow hole with an outer diameter of 10 mm and there are total 217 flow holes in the perforated cylindrical test structure. Model A has a thick plate at its bottom with a thickness of 100 mm to simulate a lumped mass condition whereas Model B has a 2.8 mm thick plate at its bottom. Material properties of a perforated cylindrical test structure used for FE analysis are shown in Table II. The commercial FE software ANSYS was used and the natural frequency and mode shape of each model were investigated [4].

Table I: Diameters of flow holes according to the porosity

Porosity (%)	0	10	20	30	40	50
Diameter of flow hole (mm)	0	14.6	20.5	25.1	29.0	32.4

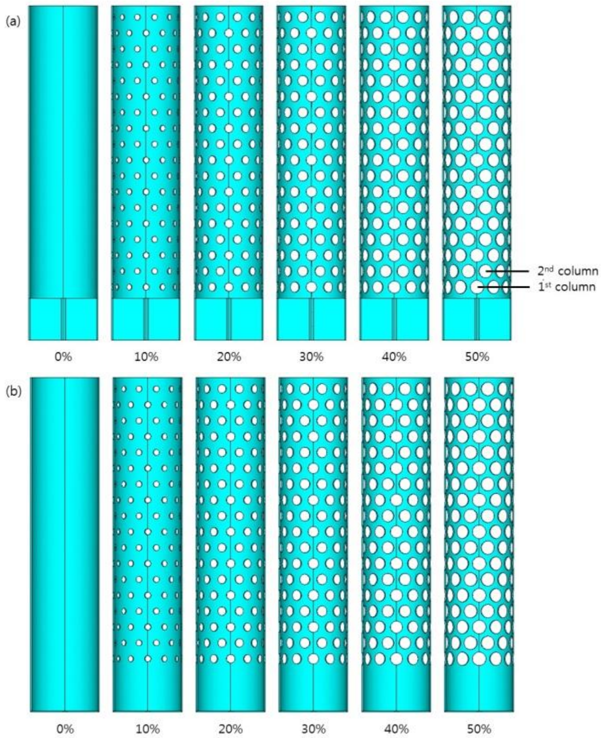


Fig. 1. Geometries of analysis models: (a) Model A and (b) Model B.

Table II: Material properties

Material	SS304
Young’s modulus (GPa)	195
Poisson’s ratio	0.29
Density (kg/m^3)	7861.9

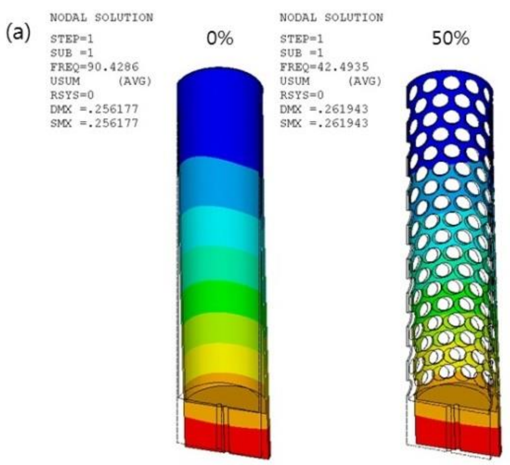
2.2 Analysis result

The modal analysis was performed by applying the fixed boundary conditions at the top of the model. The natural frequency of the 1st bending mode and the mass were obtained from the modal analysis. The result is shown in Table III and the 1st mode shapes of Model A and Model B are shown in Fig. 2. As the porosity increases, the mass of Model A varies with a decrement of about 3.2% and 15.8% decreases compared with its original mass when the porosity is 50%. And the natural frequency decreases approximately 12.9%, 10.9%, 9.9%, 9.6% and 9.6%, respectively with respect to the porosity variation. In the case of Model B, the mass varies with a decrement of about 8.3% and the natural frequency decreases approximately 11.0%, 9.4%, 8.7%, 8.7% and 9.6%, respectively. The mass of Model A is 2.6 times greater than that of Model B when the porosity is 0% and the mass difference increases up to 3.8 times as the porosity increases due to the lumped mass although the mass decrement is the same.

To clearly assess the analysis results, the rate of changes of the mass and natural frequencies of Model A and B according to the porosity variation are plotted in Fig. 3. Each value is normalized by its maximum value, i.e., the value at 0% porosity. From the figure, one can see that the rate of change of the mass of Model B shows much steeper slope than that of Model A; the difference is almost 26% at 50% porosity. In the case of natural frequency, on the other hand, the rate of change of the natural frequency of Model A shows steeper slope than that of Model B; the difference is about 6% at 50% porosity. This result mainly comes from the existence of the lumped mass. Since two models have the same geometry (flow holes and size) except the bottom part which is relatively short to the total length of the model, one can assume that their bending rigidities are not much different. For the similar rigidity, therefore, the natural frequency of Model A has the steeper slope than that of Model B because the natural frequency is inversely proportional to the mass.

Table III: Analysis result according to the porosity

Porosity (%)	Model A Mass (kg)	Model A Natural frequency (Hz)	Model B Mass (kg)	Model B Natural frequency (Hz)
0	24.58	90.43	9.36	215.48
10	23.81	78.78	8.59	191.83
20	23.04	68.88	7.82	171.56
30	22.26	59.89	7.03	152.82
40	21.47	51.21	6.24	134.08
50	20.68	42.49	5.46	114.36



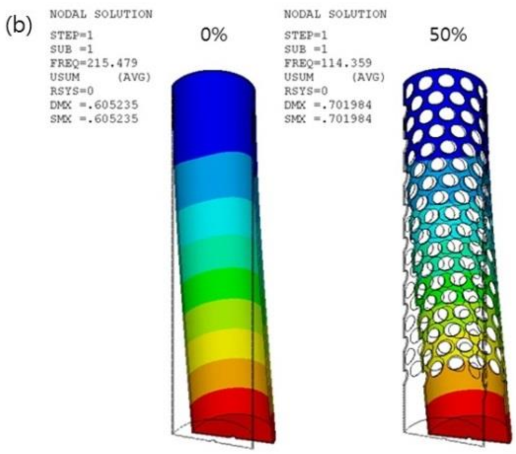


Fig. 2. 1st mode shapes of (a) Model A and (b) Model B with porosities of 0% and 50%.

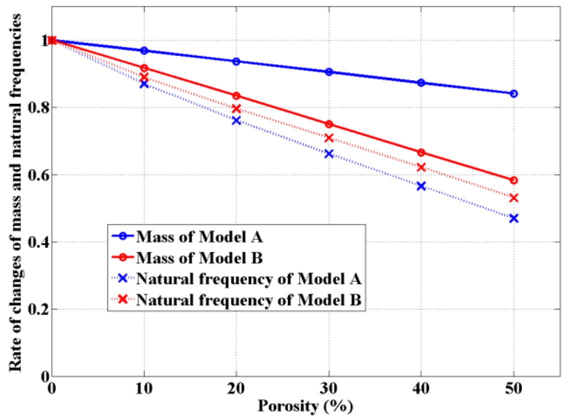


Fig. 3. The rate of changes of the mass and natural frequencies of Model A and Model B according to the porosity variation.

3. Conclusions

In order to assess the effect of a lumped mass on the natural frequency of the perforated cylindrical test structure, the FE analysis was performed with respect to various porosity conditions. And the test model without a lumped mass was also evaluated to compare the effect of a lumped mass. From the analysis result, it is observed that the lumped mass which takes relatively small portion of the structure affects not much the bending rigidity but the natural frequency of the structure; the decrement behavior of the natural frequency of the lumped mass model according to the porosity variation showed steeper slope than that of the model without a lumped mass whereas the rate of change of the mass showed the more gentle behavior.

Acknowledgement

This study was supported by the National Research Foundation (NRF: No. 2012M2A8A2025636) grant funded by the Korea government (Ministry of Science, ICT and Future Planning).

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