Vibration analysis and experiment for a scale-down model of APR+ reactor barrel

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1. Introduction

Vibration characteristics of cylindrical shells either containing fluid or confined by fluid have been of concern in the development and design of nuclear power plants. Theoretical solutions were proposed for the free vibrations of the shells having a simple geometry, such as a cylindrical shell in confined fluid and two cylindrical shells concentrically or eccentrically submerged in fluid [1].

It is known from researches that vibration characteristics for a cylindrical shell confined by fluid are different from the shell in air. In particular, when the shell is tightly confined by a high density fluid, the natural frequency of the shell significantly decreases. The decrement of the natural frequency is very dependent on the confinement; the lower the natural frequency, the tighter the confinement [1, 2]. The damping coefficient, as well as the natural frequency of the shell, shows the same characteristic.

The APR+ design has several new features [3]. As a new concept to enhance the safety of a nuclear power plant, the ECB duct as shown in Fig. 1 has been developed, so that the vibration characteristics of the barrel with and without the duct are necessarily identified. For this reason, experimental and numerical studies were carried out for the developing APR+ barrel considering the water between the barrel and the vessel.

2. Experiment

A one fifth (1/5) scale model is built for not only hydraulic but also mechanical experiments to verify the new features of the APR+ design. For the vibration test under water, a special water tank is built, which provides 6 cm gap between the barrel and the water tank. Four sets of experiments are performed to compare the vibration characteristics of the barrel with and without the ECB ducts both in air and water. For the experiments, a free-free boundary condition is simulated by hanging the barrel. For a typical modal test, six accelerometers and an impact hammer are used as shown in Fig. 1.

Experimental results from four cases are summarized in Table 1, which are with and without ECB ducts both in air and under water

Figures 2 and 3 show two Frequency response functions (FRFs) obtained from the barrel without ECB ducts both in air and water, respectively. When the ECB ducts are not installed, the condition of the signals is much better than when the ducts are installed.

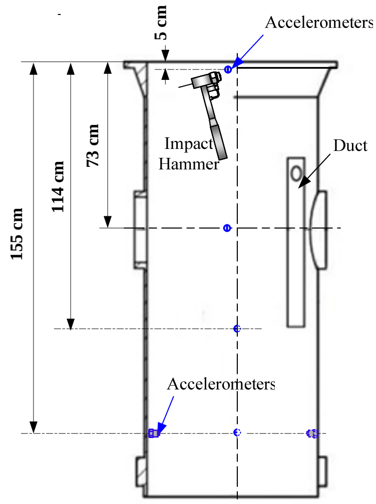

Figure 1 Test setup for vibration characteristics

Table 1 Natural frequency according to environments (Hz)

Mode	In air		In water	
	W. duct	W/O duct	W. duct	W/O duct
1	59.1	59.2	29.5/30.4	29.8/30.6
2	108.5	108.6	68.5/72.2	69.2/72.7
3	160.7	161.3	107.8	109.1
4	217.5	218.1	111.6	113.6

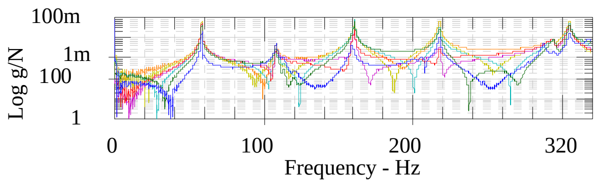

Figure 2 FRF obtaining from the barrel without duct in air

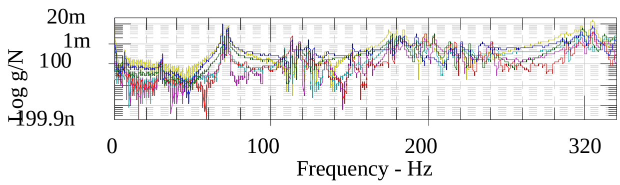

Figure 3 FRF obtaining from the barrel without duct in water

In the air test, the FRFs of all channels are clearly seen as shown in Fig. 3. Even though the FRFs in water are not seen very well as shown in Fig.4, it is not difficult to identify modes. The lower four modes in

Table 1 are believed to be shell modes. As expected, the duct effect to natural frequency is insignificant. An interesting observation is that the added mass effect by water seems to be so significant that the natural frequency plummets to a half of that in air. When it comes to shell modes, since shell shape is not symmetrical in all directions due to two hot legs, two different modes could appear with respect to the two different axes. In air, the two different modes are apparently not identified. In water, however, the two similar modes are clearly measured, which are shown in Table 1.

3. Numerical simulation

An ANSYS commercial code [4] is utilized to simulate the vibration test, to compare the results with the experimental ones and to verify a gap effect; the gap between the barrel and outer vessel. By virtue of the Chen [1] report, it is generally accepted that as the gap becomes narrower, the added mass and fluid damping increase exponentially. A solid element (SOLID45) and a fluid element (FLUID80) are used for modeling the barrel and water, respectively. Fig. 4 shows the FE model for the barrel with the four ECB ducts.

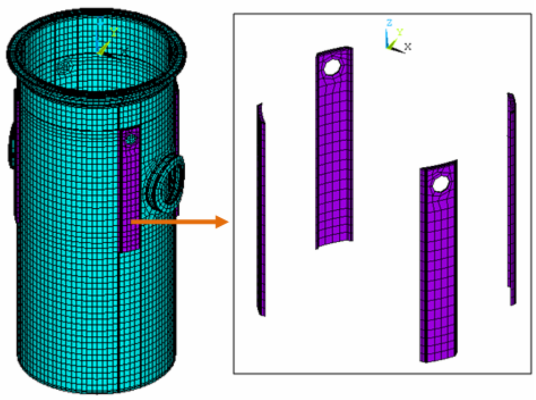

Figure 4 Finite Element model for barrel with ducts

Simulation results are summarized in Table 2.

In contrast to the experiments, even in air, two similar shell modes are obtained; 61.3 Hz/ 62.1 Hz with ducts and 61.1 Hz/ 61.5 Hz without ducts, respectively, for the first modes.

Table 2 Natural freq. obtained from FE simulation (Hz)

Mode	In air		In water	
	W. duct	W/O duct	W. duct	W/O duct
1	61.3/62.1	61.1/61.5	30.8/30.8	30.2/30.7
2	108/108	108/108	63.2/65.4	62.9/63.2
3	164.7	163.8	92.9	90.7
4	176.5	175.8	94.7	94.6

Generally, it turned out that the duct has an insignificant effect on the dynamic behavior of the barrel. The natural frequencies in water are predicted to decrease down to approximately one half of those in air regardless of the ducts.

4. Discussion

As briefly mentioned in the introduction, narrow-gap effects in dense fluid are not necessarily small. The vibration characteristics of the barrel would be influenced much more significantly by narrow confinement than by the infinite boundary as reported by Chen and Yang [1, 2]. When a narrow gap of 60 mm is considered, the added mass ratio becomes larger than eight as shown in Fig. 5, so that the added mass effect can be magnified by more than eight times. When 8 times the added mass ratio for the APR^+ barrel is factored in, the fluid mass exceeds the stainless steel barrel mass. That is the reason why the natural frequencies obtained from a water environment are so low.

5. Conclusion

Free vibration experiments and numerical simulations have been carried out for the APR^+ barrel with and without ECB ducts to see if any non-negligible effects occur from the view point of vibration characteristics.

Not only the experiments but also the simulations yield that the fluid in a narrow-gap plays a significant role in the change of vibration characteristics; natural frequency with respect to the narrow-gap water is a half of that in air.

Nevertheless, the duct effects such as duct mass, duct stiffness and fluid mass by adding the ducts to the vibration characteristics of the APR^+ barrel are insignificant even considering water in narrow confinement.

ACKNOWLEDGMENTS

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