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Frequency of a Standing Wave Generated by a Jet in a Vessel

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1. Introduction

In a fast reactor using sodium as a coolant, a free surface exists in the upper plenum of the reactor vessel where the sodium coolant contacts with a cover gas. Fluctuation of this free surface causes two important phenomena, which are a thermal striping on a vessel wall and a gas entrainment at a free surface. An experimental study has been performed to investigate the frequency of a free surface fluctuation in a vessel. There are two dominant frequency regions which are generated by a standing wave and a jet. In this paper, the frequency of a standing wave is studied as a function of the vessel diameters.

2. Experiment

Figure 1 shows the test section used in the experiment. The water enters from the bottom of the tank and flows out at the side nozzles. Five types of vessels with different diameters (d_V), 0.38m, 0.48m, 0.68m, 0.78m, and 1.0m were prepared. Also five types of inlet nozzles with different diameters, 0.038m, 0.048m, 0.058m, 0.078m, and 0.1m were prepared. Mean water level was varied for four cases, 0.87m, 1.07m, 1.27m, and 1.47m from the inlet nozzle. Four outlet nozzles were located at a 0.74m elevation from the bottom with a 90 degree, whose diameter was 0.046m. The range of the flow rate was 1×10^{-3}~15×10^{-3} m^3/sec in the experiment.

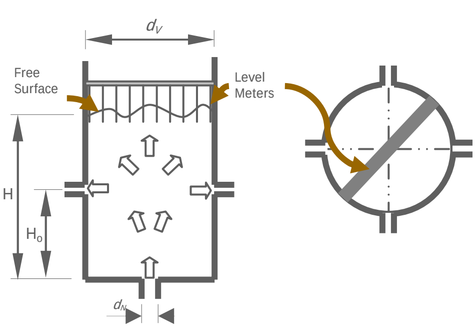

Figure 1 Test section for the free surface fluctuation experiment

The free surface fluctuation was measured by a wire level sensor at ten locations in a test section. The wire sensor was made of a 0.025mm diameter nickel wire. Experimental data were obtained at 556 experimental conditions with a 200Hz sampling rate. The frequency characteristics of the data were extracted by the FFT method and statistically analyzed by a program developed in the study. A dominant frequency regularly appears below 7Hz, and appears irregularly at a very high frequency in the range of 10~50Hz with a very low power spectral density. Therefore, the frequencies above 7Hz were excluded by a digital low pass filter. And a 0.05Hz digital high pass filter was applied to cut off the DC bias and the system frequency noise.

To extract a dominant frequency from the result of the FFT analysis of each level sensor data, the frequency was divided into several frequency groups based on the distribution of the power spectral density. Among the frequencies with the maximum power spectral density in each group, five frequencies (f_i) were extracted in order (i) of the higher value of a power spectral density, and also the corresponding power spectral densities (A_i) were extracted. After this, the extracted power spectral densities were normalized in order to make the sum 1 for each level sensor data set. It was used as the reference data set to analyze a dominant frequency of a free surface fluctuation.

3. Result and Discussion

When the wave length is very small compared with the depth of water, the frequency (f_{st}) of a standing wave is also given by Lamb[1]:

$$f_{st} = \frac{1}{2\pi}\sqrt{g\kappa} \tag{1}$$

where g is a gravitational acceleration constant and κ is the wave number. If the fluid is bounded with a distance L by two vertical planes, the condition at both ends provides $\sin(\kappa L)=0$, or $\kappa L=m\pi$, where m is an integer. When a vessel diameter is applied to the relation instead of L for a circular vessel, the frequency of a standing surface wave is given as:

$$f_{st} = \sqrt{\frac{mg}{4\pi d_V}} \quad (2)$$

According to a detailed examination of the tendency of the data, the dominant frequency by a standing wave appears above about 0.75Hz. When the frequency is less than 0.75Hz, the frequency is nearly independent of the vessel diameter, and the data is more scattered according to the condition of the jet. Figure 2 shows the distribution of the power spectral density according to the frequency. As shown in this figure and in most of the data, the power spectral density shows a skewed distribution below about 0.75Hz.

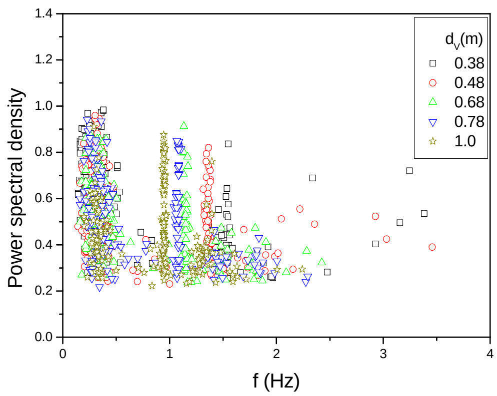

Figure 2 Maximum power spectral density distribution according to the frequency for the experiment

The frequency can be nondimensionalized with the frequency of a standing wave for the first mode (m = 1) in Eq. (2), and the dimensionless frequency (f_{st}^*) by a standing wave is described as:

$$f_{st}^* = f\sqrt{\frac{4\pi d_V}{g}} \quad (3)$$

Figure 3 shows the distribution of the power spectral density according to the dimensionless frequency. The dimensionless frequencies for the first mode converge well at f_{st}^* =1.07, and those for the second mode (m = 2) appear at nearly f_{st}^*=1.07×$\sqrt{2}$ =1.51. The dimensionless frequency for the first mode appears at 1.07 instead of at 1. It can be considered that the vessel diameter is used instead of the distance between two parallel planes in Eq. (2). Therefore, the first mode dominant frequency by a standing wave appears as the following formula for a circular vessel:

$$f\sqrt{\frac{4\pi d_V}{g}} = 1.07 \quad (4)$$

Several frequencies appear with a lower spectral density when the dimensionless frequency is large, which is considered to be due to the frequencies coming from the higher modes and a resonance with a frequency lower than 0.75Hz.

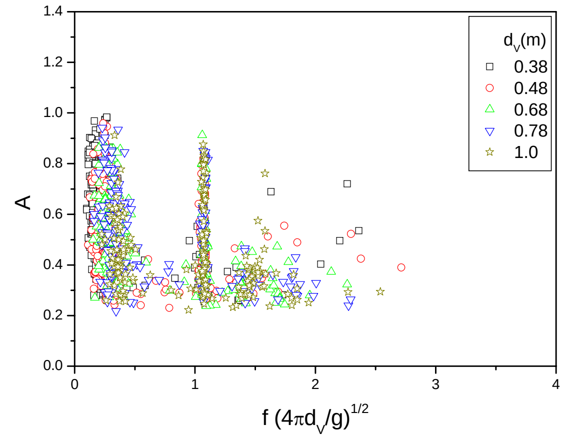

Figure 3 Maximum power spectral density distribution according to the dimensionless frequency

4. Conclusion

There are two dominant frequency regions. One is distributed dependently of a vessel diameter above 0.75Hz, it is well defined by the standing wave, and the value of the dimensionless frequency (f_{st}^*) is 1.07 for the first mode. But the opposite phenomena take place by a jet bellow 0.75Hz.

Reference

[1] H. Lamb, 1945, "Hydrodynamics," 6th edition, Dover Publications, pp. 363-475.

Acknowledgement

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