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Fluid-Elastic Instability of U-Tube Bundle in Two-Phase Cross-Flow

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1. Introduction

The U-bend region of nuclear steam generator tubes which undergoes high flow two-phase flow condition is highly susceptible to flow-induced vibration. In various flow-induced vibration mechanisms, it is generally known that fluid-elastic instability is the main cause of fretting wear of U-tubes.

Since 1980s many experiments have been performed to investigate the fluid-elastic instability in two-phase cross-flow [1~7]. Most of the previous experiments were performed with cantilever tube bundles.

However, the vibration mode shapes of U-bend tube are quite different from those of cantilever tube, and moreover vibration of U-bend is excited by non-uniform velocity field.

The purpose of the present study is to experimentally investigate the fluid-elastic instability characteristics using U-bend tube bundles under air-water two-phase cross-flow.

2. Experiments

2.1 Test Apparatus

The present experimental facility consists of a test section, water & air supply systems, measurements and control systems. Figure 1 shows the schematic of the test section of the present experimental facility. The test section has a total of 39 U-tubes of row number 34~44, line number 71~77. U-tubes and egg-crates are the same specifications with those of actual nuclear power plant.

The diameter of U-tube is 19.05mm, U-tubes are arranged in rotated square array with p/d is 1.633. However, due to the limitation of space, the vertical length of U-tube is reduced to be supported by only one full egg-crate in contrast to eight full egg-crates in the actual steam generator. To confirm the effectiveness of reduced vertical length of U-tubes, modal analysis was performed to check the natural frequencies and vibration mode shapes of reduced height U-tube and full height U-tube. The analysis was done by ANSYS 5.53, and the results showed that the reduction in the vertical length had negligible effect on the vibration characteristic of U-bend and horizontal region of U-tubes.

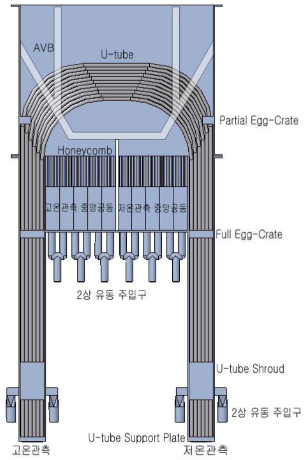

Figure 1. Schematic of test section (front view)

The vibration response of U-tubes were measured by miniature 3-axis accelerometers which were installed inside the U-tubes of row number 34~38 and 41. The validity of using accelerometer to measure the vibrational displacement of U-tubes were confirmed from separate calibration test where the displacement measured by accelerometers were directly compared with the displacement measured by LVDT.

2.2 Experimental Results

Experimental results of fluid-elastic instability of U-tubes were obtained for the homogeneous void fraction of 70~95%. The AVBs (Anti-Vibration Bar) were not installed for this stage of experiments.

The most dominant vibration direction was Y direction that is the direction of out-of-plane vibration mode. The vibration in X direction that is the direction of in-plane horizontal vibration mode was about third to half of the vibration in Y direction. The vibration in Z direction that is the direction of in-plane vertical direction was negligibly small. Therefore the critical velocity of the fluid-elastic instability was evaluated from the vibration response of Y direction. Figure 2 shows the RMS vibration displacement of U-tubes at the void fraction of 95%.

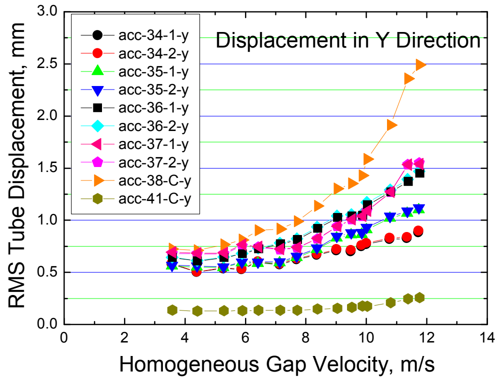

Figure 2. Vibration response of U tubes in Y direction at homogeneous void fraction of 95%

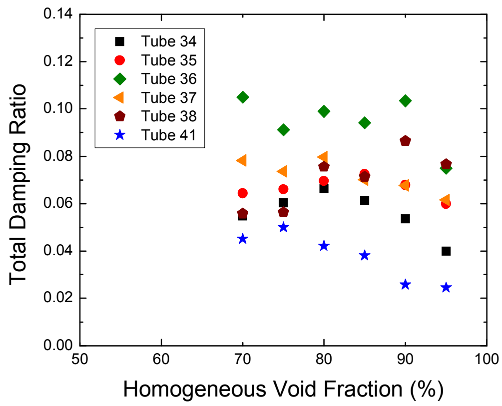

Figure 3. Total damping ratio of U-tubes

Total damping ratio was evaluated using half power frequency band method. Power spectral density (PSD) function was obtained from 30 min record of time domain vibration waveforms.

Figure 3 shows the total damping ratios of U-tubes in two-phase flow. The damping ratios of U-tubes were about 5% higher than those obtained in cantilever tubes, and had the maximum at the void fraction of 70~80%.

The most general method to predict the fluid-elastic instability would be Connors' relation which can be formulated in terms of dimensionless "reduced velocity" and "mass damping parameter" as the following equation:

$$\frac{V_{g,c}}{fD} = K\left(\frac{2\pi\zeta m}{\rho D^2}\right)^n \qquad (1)$$

In the case of U-bend tube where the velocity and density of flow are not uniform over the length of tube, the effective gap velocity should be used. However, the effective velocity was evaluated using some practical assumptions for the velocity and density profile over the U-tube.

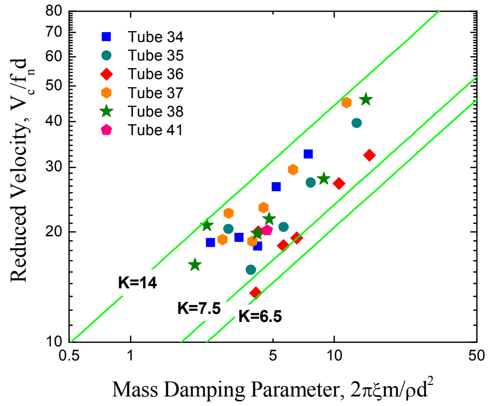

Figure 4. Fluid-elastic instability results of U-tubes

Figure 4 shows the fluid-elastic instability results of the present experiments. The minimum instability factor (K) was 7.5 in most cases.

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