Simultaneous Two-Axis Force and Displace Measurement Techniques for Vortex Shedding in SMART100 Heat Exchanger Tube Array

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1. Introduction

Flow induced vibration (FIV) is an important factor in high-performance fluid systems like nuclear reactors, since cost of plant shutdowns and repairs, and potential for safety hazards are particularly enormous [1]. Because of the concern, licensing for a brand new nuclear reactor design calls for thorough assessments in FIV [2].

We performed structural integrity assessment experiments for SMART100 heat exchanger design in terms of FIV. SMART100 heat exchanger have coiled type heat pipes to fit inside the unique compact-sized reactor vessel. Since this design is largely different from conventional LWR type reactors, which usually adopted U-tube type heat pipes, a new assessment was needed for design licensing. As a part of the project, we have developed test section for simulating the flow inside heat exchanger channel and techniques to quantitatively measure vibration of the tube bundles. We will introduce the design and calibration methods for measuring flow induced force and displacement of the heat exchanger tubes.

2. Methods and Results

2.1 Test Section

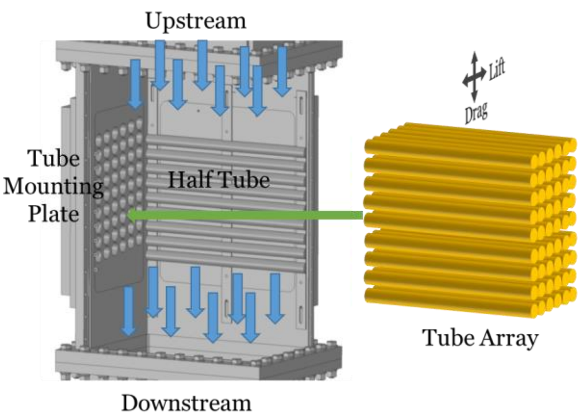

Fig. 1. Schematics of the test section. Crossflow flows over the horizontally attached tube array from the top side.

Schematics of the test section to simulate flow inside the heat exchanger is shown in the Fig. 1. Tube bundles simulating heat pipes inside the heat exchanger were installed in horizontal direction. Water flow through from upside to downside to simulate crossflow over the tube bundles. The tubes were fixed on single side, making cantilever boundary conditions for the tubes. Outer diameter and P/D ratio of the tubes were set as same as the reference heat exchanger pipe.

2.2 Measurement Tubes

Schematics of the measurement tube is shown in Fig. 2. “Slender part” near the connector has flexible geometry to promote elastic deformation of the tube. Natural frequency of the tube can be adjusted by changing dimension of the slender part. Four strain gages per tube was attached on the slender part in axial direction, 90 degrees apart. The strain gages were configured in half bridge, paring gages on opposite direction to enhance sensibility of the strain gages. Wires were connected through the inner hole and waterproof coatings were applied thoroughly over the gage surface and holes.

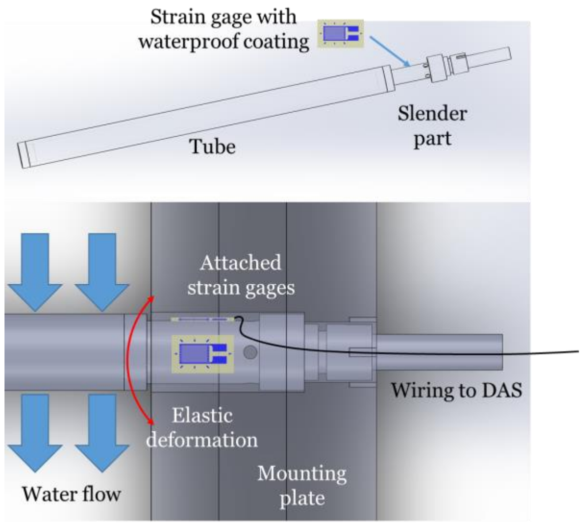

Fig. 2. Schematics of the measuring tube. Four strain gages per tube was attached at the slender part to measure elastic deformation of the tube due to fluid force. .

2.3 Calibration method

A picture of tube calibration is shown in Fig 3. Assuming velocity of the main flow is uniform over the tube, sum of fluid force applied over a tube is equivalent to concentrated force at the center of the tube. Therefore, we applied a load by weights on the center of the tube and related to the strain on an axis for force calibration. Also, we measured displacement at the end of tube while the weight load was applied to establish force-strain-displacement relationship. Fig. 4 shows the relationship of the three parameters are linear with in calibration range. Calibration process was taken twice per tube; for drag and lift direction to simultaneously measure in two axes.

Fig. 3. Picture depicting the tube calibration. Strain at the slender part and displacement at the end tip was measured simultaneously while weight with known mass was hung at the center.

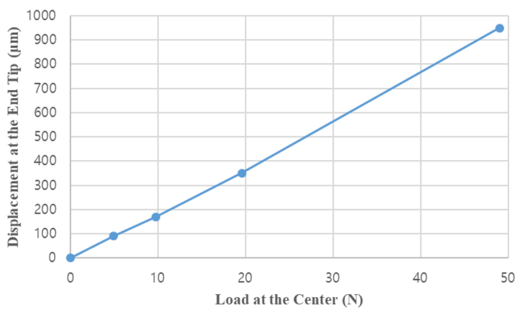

Fig. 4. Relationship between the load at the center and displacement at the end tip. Measured value shows good linear relationship.

2.4 Measurements

The data was measured in a steady-state flow condition in various flow rate. The tube array was made of 6 x 9 shaped matrix with cylindrical tubes (refer the tubes depicted in the Fig. 1). Measurement tubes were placed in the first, second, third, and sixth row in center column in a rectangular tube array.

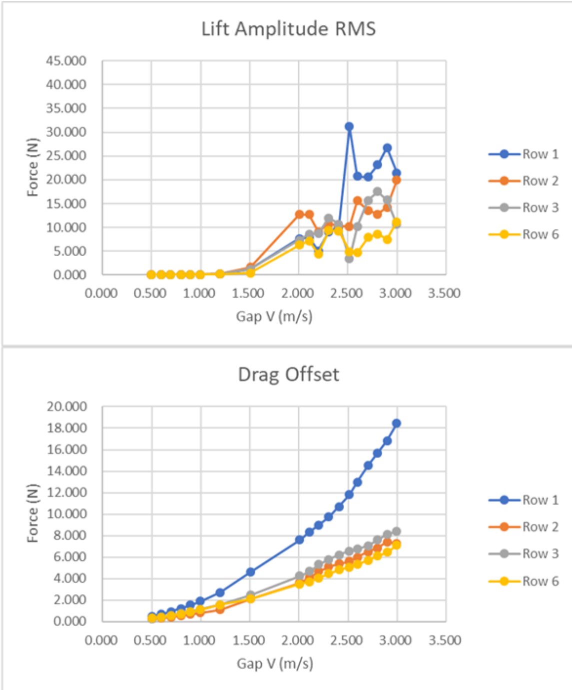

Fig. 5. Measured force in steady state with various flow rate. X axis indicates average flow velocity in the narrowest location between the tubes. Y axis indicates RMS value in the lift direction force and average value in the drag direction respectably.

Fig. 5 is an example of measurement data which shows drag and lift force applied on a tube in various flow rate. We can see the first row (blue line) shows different trend while the others are similar. This is thought to be because of characteristics of the flow boundary condition. Theoretically upstream flow for the first row is fully developed flow, while upstream flow for the other rows are highly random.

The upper graph shows RMS value of measured lift force. Each graph have four plots, which indicates position of the measurement tubes in an array. In lift force graph, we can see sudden increase in the Row 1 plot in 2.5 m/s gap velocity, which is result of resonance between structural vibration and the vortex shedding frequency. Since the resonance in vortex shedding is a concern in lift force, drag force showed stable monotonic increasing trend.

Fig. 6 is an example of measurement data, which shows power spectral density of the lift force measured in the first row in various flow rate. Highest peaks were shown in 70-90 Hz band in wide range of the flow rate. While natural frequency of the individual tubes were ~85 Hz in water, multiple peaks were found in the band, which is supposedly because of bundle effect. Shedding frequency was not clearly shown in every case in the bundle test. However we managed to derive Strouhal number within 0.4 – 0.55 range with several discernable data.

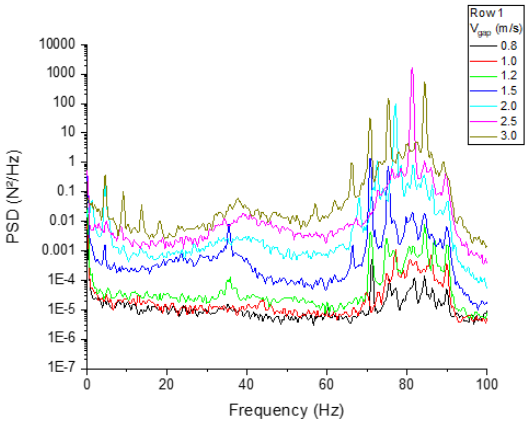

Fig. 6. Derived PSD data with measured first row lift force in various flow rate. Multiple highest peaks were shown in 70-90 Hz band, because of individual natural frequency and bundle effect. Estimated Strouhal number was in range of 0.4-0.55.

3. Conclusions

We presented an experimental setup and technique for measuring force applied on a tube under steady state crossflow using strain gages. Fluid force and displacement due to the flow was measured quantitatively with calibration, simultaneously in two axes. Data was shown in lift RMS and steady drag force measured in multiple positions in a bundle, and PSD from first row lift force. The presented technique to measure vibration of the tubes, mainly driven by vortex shedding was working fine.

REFERENCES

[1] D.S. Weaver, S. Ziada, M. K. Au-Yang, S. S. Chen, M. P. Paıdoussis, M. J. Pettigrew, Flow-Induced Vibrations in Power and Process Plant Components—Progress and Prospects, Journal of Pressure Vessel Technology, Vol. 122, 2000

[2] ASME BPC, Section III: N-1300 Applied Design, Failure Analysis and Prevention of Shock and Vibration Combo