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Flow Regime Destabilizing Effect on Fluidelastic Instability of Tube Array Preferentially Flexible to the Flow Direction

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1. Introduction

Study on the fluidelastic instability (FEI) of a tube array is worth subject for design evaluation and failure analysis of the power and process plant equipment. Recently, some steam generator (SG) in US power plant experiences excessive tube failure from the in-plane instability at the early stage of the operation [1]. Reason-why for the SG tube failure from FEI, at that specific time against the long safe operation years is quite controversial, but can be guessed by many experts as too much fine-tolerance in manufacturing and limitation of FEI prediction model for in-plane instability. Thus, current design guideline and common model adapted for FEI prediction should be revised to cover practical case of two-phase flow tube instability problem.

U bend region of operating SG is excited by the inclined cross flow due to the gradual change of hydraulic resistance force. To study this problem using an hydraulic loop test setup, tubes to be tested should have preferential flexibility direction to vibrate and thus has ‘angle of attack’ to the flow direction. The effect of tube array’s flexibility direction on FEI is investigated by Khalvatti [2] for rotated triangular tube in single phase (air) cross flow. He showed that FEI strongly depend on the flexibility angle. Reducing bundle flexibility to the flow direction ranging from 90 (out-of-flow direction) to 0 (in-flow direction) degree has a nonlinearly-varying stabilizing effect. Joly [3] studies the same problem under high void fraction in two phase cross flow over 70 % to 90 %. With the Joly’s experimental work, there is oddly low-valued Conner’s constant in case of higher degree of angle of attack. This gives the motivation to our experimental study for fluidelastic instability of tube array in two phase cross flow.

During the short collaboration visit to BWC/AECL/ NSERC in the Ecole Polytechnique de Montreal, Canada, authors carried out the fluidelastic instability test for the tube array preferentially flexible to the flow. This paper explores reason-why for oddly dropping of Conner’s constant for the some case of preferential flexibility direction and high void fraction.

2. Methods and Results

Figure 1 shows the two phase flow test loop facility, which is located at Polytechnique Montreal. We use the same test configuration and method to Joly [3]’s experiment, except for the low void fraction measurement. 80 % and 50 % void fractions were selected to regenerate the previous test and highlight the different flow regime effect. Seven flexible tube arrays in the middle of rigid tube bundle are tested for our study as shown in the figure below.

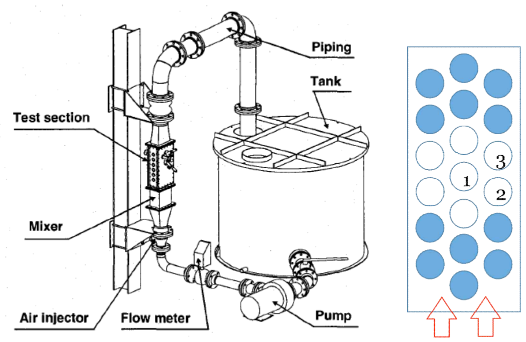

Fig.1 Test loop and tube array cross-section (open circle means flexible and solid one is fixed)

Flow rate and target void fraction were controlled independently and manually by a controller, according to the inlet pressure-corrected gas and liquid flow rate. Tube vibration was measured by the calibrated strain gauge. Void fraction was measured by the optical probe and statistical analysis. Damping and critical velocity for FEI was estimated from the measured response spectrum.

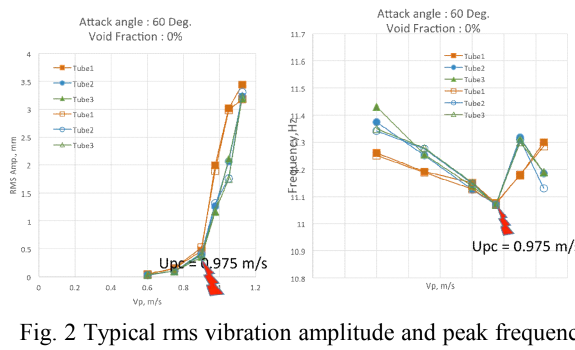

Fig. 2 Typical rms vibration amplitude and peak frequency of the tube according to the flow (60^o angle of attack and 0% void fraction, the sunder mark indicates the critical velocity).

Figure 2 shows a typical RMS vibration amplitude and peak frequency of tube according to the pitch flow velocity. One can identify the critical velocity from this figure as abrupt increase of RMS amplitude and pitch velocity at the peak frequency coming together in one value. Table 1 summarizes the test results comparing with the Joly's work [3]. Conner's constant at 80 % void fraction were quite similar within 20% error bounds, considering the high uncertainty in estimating the critical velocity. From the estimated value of K at 50% void fraction for both case of angle of attack, low value of K value at both high void fraction seems to be due to the disturbances from the flow regime.

Table 1 instability test result and its comparison

AOA	β	U_{pc}	K	β	U_{pc}	K	Diff.%
60	70	1.4	**1.9**	0	0.9	**4.93**	
60	80	1.4	**1.7**	50	2	**3.38**	
60	90	1.8	**1.6**	80	1.4	**1.53**	**11.42%**
90	70	1.2	**1.7**	0	1	**6.04**	
90	80	1.1	**1.3**	50	1.3	**2.19**	
90	90	1.1	**1**	80	1.5	**1.61**	**19.47%**

(AOA:Angle of attack, K: Conner's constant)

From the visual inspection, lateral tube motion of 60^o and 90^o angle of attack seems to block the flow path periodically. It is reported that intermittent flow is characterized by periodic flooding (mostly liquid flow) followed by bursts of mostly gas flow [4]. Enlarged bubble in an intermittent flow regime can be squeezed at flow gap between tubes. Authors think that this can makes tubes to destabilize more. It is strongly recommended that flow visualization is highly needed to identify this phenomena. Figure 3 shows flow regime map based on the Grant's map [5].

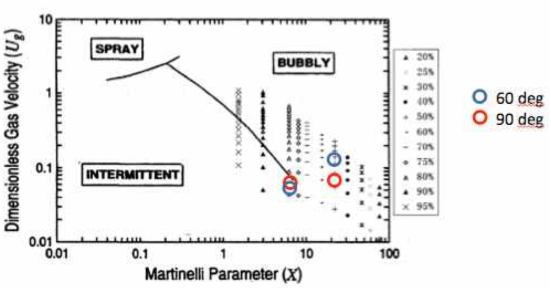

Fig. 3 Flow regime of the test condition
(Circle indicates the flow regime to be tested)

Measured void fraction is quite low compared to homogeneous volumetric void fraction because the measured value is a local property at a point. To measure the true void fraction and define the flow regime, the averaged void fraction for the cross sectional area of flow direction should be considered.

3. Summary and Conclusions

During the collaboration visit, experiment on fluidelastic instability of rotated triangular tube array with inclined preferential vibration direction were done in two phase cross flow. Test objective is to identify the reason-why for the oddly low Conner's constant at high void fraction, compared to the lowest design guideline. Two types of preferential direction (60 ^{o}, 90 ^{o}) of 7-clustered tube array were tested under 0 %, 50 %, 80 % void fraction. As the flow rate goes up, tube response was measured for each steady state flow condition by the strain gauge. Damping, peak frequency, and the critical velocity were estimated from the response spectrum.

It seems that the flow regime for high void fraction can destabilize tube array with preferential flexibility over 60 degree. Because an intermittent flow is inherently unstable compared to the uniform bubbly flow, thus out-of-flow motion of tubes can be more fragile to the unstably rising intermittent flow. From the visual inspection, lateral tube motion seems to block the flow path periodically. Enlarged bubble in an intermittent flow regime can be squeezed-up at the flow gap between tubes. Authors think that this can makes tubes to destabilize more and to lower the Conner's constant. Authors strongly recommend that flow visualization is highly needed to identify this phenomena further.

Acknowledgement

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