STUDY ON INFLUENCE OF GEOMETRY ON FLUID ELASTIC INSTABILITY

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ABSTRACT

The tube bank is used in boilers, heat exchangers in power plants and steam generators in nuclear plants. These tubes sometimes vibrate violently and come to the fatigue failure due to the flow induced vibration which is caused by the cross flow. This phenomenon is that the large vibrations arise at the critical flow velocity and it is called fluid elastic instability. However the influence of tube arrays on fluid elastic instability has not been clarified yet. In this paper, the influence of tube arrays on fluid elastic instability is examined by experiments. As a result, it is clarified that the tube vibrations became large as T/D increases and L/D decreases, and the tube vibrations strongly depend on the dynamic characteristics of tubes such as the natural frequency and the damping ability.

1. INTRODUCTION

In heat exchangers in power plants, steam generators in nuclear plants, various vibrations due to the flow occur and it is experienced that these plants are forced to be stopped in operation. These vibration phenomena due to the flow are generally called flow induced vibration. Above all fluid elastic instability is one of the problems suffered through the designing and the trouble shooting.

This mechanism is investigated by many authors and the design guidelines are given in ASME. However influence of geometry of tube array on fluid elastic instability has not been clarified yet.

The onset velocity of fluid elastic instability is strongly influenced by the natural frequency, the damping of tubes and the array patterns. These effects have been investigated by many researchers. However the relation between the onset velocity and the array patterns such as pitch to diameter ratio.

Then in this paper, the test apparatus is constructed such that the various tube arrays which can change natural frequencies are set in the duct and fluid elastic instability can be occurred by blowing the wind. The eighteen experimental cases are conducted. Namely six array patterns ×three natural frequencies.

2. EXPERIMENTAL METHOD

2.1 Experimental apparatus

Fig.1 shows the duct system used in this experiment. The wind is provided from the blower set left in this figure. The tube bank is set at the position of holes made on the up and down plates of the duct. The flow velocities are measured at 25 points on the duct exit plane by the hot wire probe and the representative velocity is obtained by

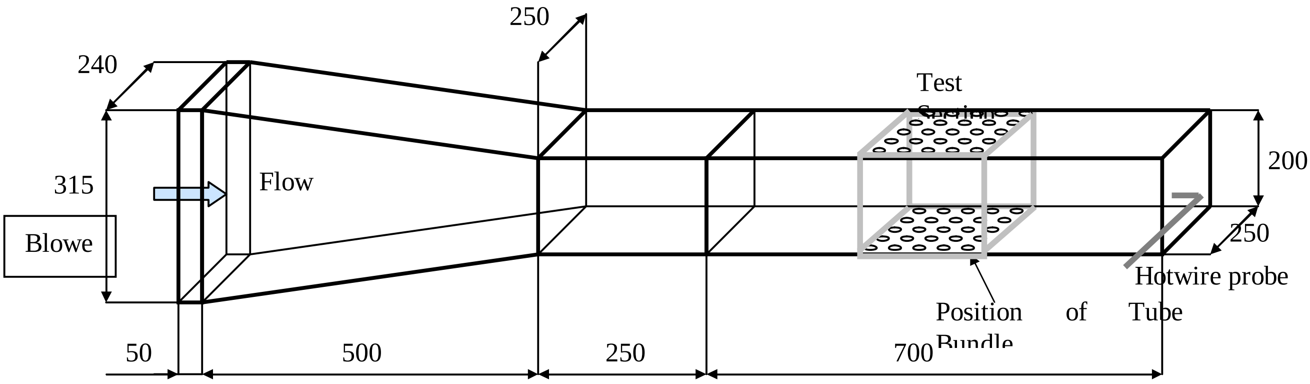

Fig.1 Experimental apparatus (Duct system)

averaging these data. The tube bank is made of rods (It is made of vinyl chloride material and it is called tube hereafter) and the rod has 25mm diameter and two M3 screws are inserted in the rod. In both ends are fixed on the rigid plates. The tube bank is set in the duct to be subjected to the cross flow. The tube length is 200mm and the cross section of the duct has 200mm height and 250mm width. The natural frequency of the tube is changed by changing the fixed position of the screw. T/D and L/D are changed by changing the fixed position of the screw. The acceleration pickup is attached to be able to measure the perpendicular direction acceleration to the flow as shown in Fig.2. The dynamic characteristics such as the natural frequency and the damping are obtained by FFT analyzing the signal of the acceleration. The range of the gap velocity is 5～50m/s and the Reynolds number based on the tube diameter is 8330～83300.

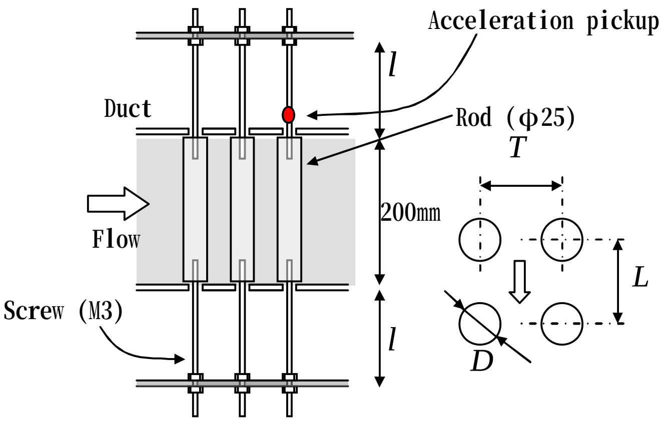

Fig.2 Experimental apparatus

2.2 Experimental parameters

Experimental parameters are shown in Table1. T/D is two kinds and L/d is three kinds, total six cases. The screw length is changed by three kinds in order to change the tube natural frequency. Namely, the lengths of screw are 100mm, 115mm and 130mm.

2.3 Measuring method

Firstly, the natural frequency and the damping of each tube are obtained by hammering test and FFT analyzing. The former is obtained from the peak frequency of the spectrum and the latter by the half power method. Secondarily, the vibration of each tube is measured by acceleration pickup attached to the tube and the signal is loaded to FFT analyzer

Table1 Experimental parameter

T/D	L/D	l [mm]	T/D	L/D	l [mm]
2	2	100	4	2	100
		115			115
		130			130
	3	100		3	100
		115			115
		130			130
	4	100		4	100
		115			115
		130			130

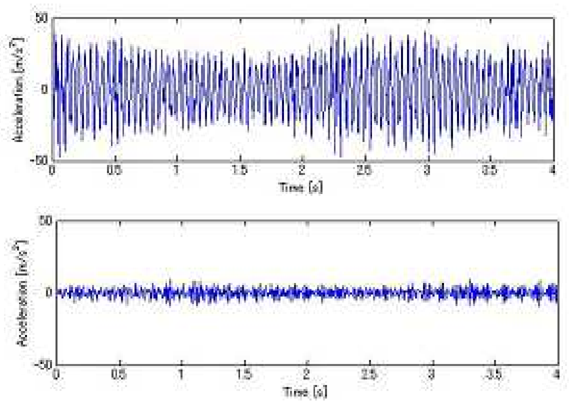

Fig.3 Wave forms of acceleration of tube

when the flow velocity is increased.

2.4 Conversion to displacement

Time histories of obtained waves are acceleration waves as shown in Fig3 (a) and Fig.3(b). Fig.3 (a) is the case of occurring fluid elastic instability clearly and Fig.3 (b) is the case of not occurring fluid elastic instability and random vibration. Here all data are obtained as RMS value in order to evaluate both displacements by the same manner. The conversion method is as follows. The acceleration data in frequency domain are converted to the displacement data by using the formula as shown in Eq. (1)

$$rms = \sqrt{\frac{1}{T}\int_0^T f(t)^2 dt} = \sqrt{\frac{1}{2}\sum_{n=1}^{N} C_n^2} \quad \cdots\cdots(1)$$

Where Cn is the displacement amplitude and T is the analyzing time. The relationship between amplitudes of acceleration An and displacement Cn is Cn=An/(2πfn)2.

3. EVALUATION METHOD

3.1 Critical velocity of fluid elastic instability

The critical velocity of fluid elastic instability which is generally used by the gap velocity Vc can be obtained by the Connors expression (2).

$$\frac{V_c}{f_n D} = K\left[\frac{m\delta}{\rho' D^2}\right]^{1/2} \quad \cdots\cdots (2)$$

Where D is the tube diameter (=0.025m), m is the mass of tube per unit length (=0.715kg/m), δ is the logarithmic decrement, ρ is the fluid density (=1.2kg/m3). Coefficient K is the value obtained by experimental data of about 170 array patterns, and values such as 4.0 (mean value), 3.3 (Petigrew) and 2.4 (ASME recommended value) have been used in the tube bank design. Meanwhile the mass damping parameter mδ/ρd2 is about 50〜400.

4. EXPERIMENTAL RESULTS

Experimental results of various array patterns showing the largest vibration are presented as follows. Where only four cases are presented concerning the space.

4.1 T/D=2, L/D=2, l=130mm

4.1.1 Dynamic characteristic of tube bank

Fig.4 shows the tube array, the natural frequency and the logarithmic damping of each tube. The averages of natural frequencies and damping of all tubes are 20.7Hz and 0.138 respectively. It is found from this figure that the scatter of natural frequencies is small but that of logarithmic damping is large.

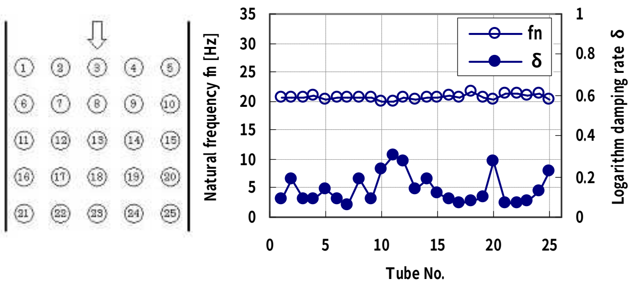

Fig.4Tube arrangement and dynamic characteristics

4.1.2 Relationship between flow velocity and tube bank vibration

Fig.5 (a) shows the relationship between the flow velocity and the amplitude of the tube ⑭ which

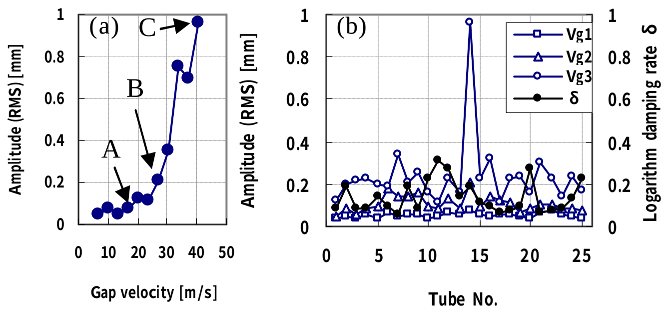

Fig.5 Amplitude of No.14 tube and amplitude of all tubes at Vg=40.8m/s

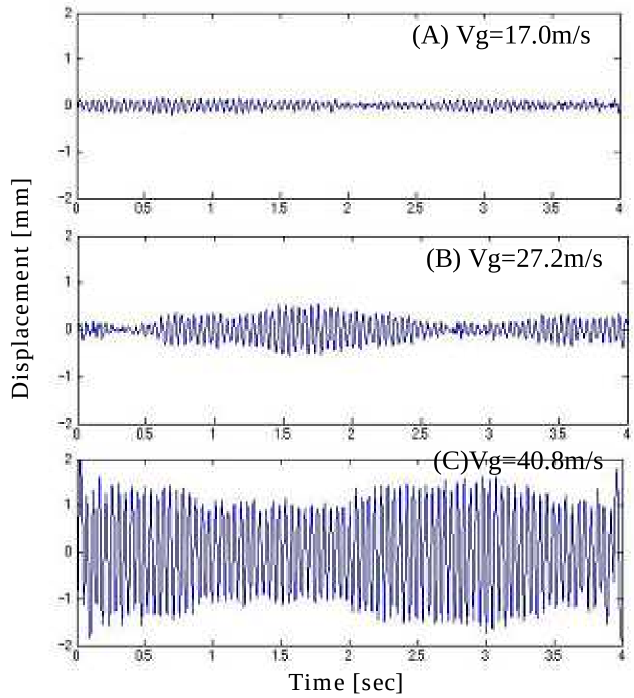

Fig.6Time histories of tube vibration at three velocities

expresses the largest vibration when the flow velocity increases. The critical velocity is Vc=23.8 m/s in this case. Fig.5 (b) shows the displacement amplitudes of all tubes at Vg1=17.0 m/s, Vg2=27.3 m/s and Vg3=40.8 m/s. Fig.6 shows the time histories of acceleration of tube ⑭ at three velocities described above. The time history when fluid elastic instability occurs is not steady but has beat in general. In Fig.5 (b), the tubes with small damping express large vibration amplitudes and the tubes with large damping express small vibration amplitudes. Namely the dynamic characteristic of each tube strongly appears in fluid elastic instability. All of the tubes are not necessary the same amplitudes but only the tube with small damping expresses a large vibration.

4.1.3Critical velocity of fluid elastic instability

In this array, only the tube ⑭ expresses steep increasing of the vibration amplitude and the critical velocity is Vc=23.8 m/s. The non dimensional critical coefficient calculated by Eq. (2) is K=3.3.

4.2 T/D=2, L/D=3, l=130mm

4.1.1 Dynamic characteristic of tube bank

Fig.7 shows the tube array, the natural frequency and the logarithmic damping of each tube. The averages of natural frequencies and damping of all tubes are 20.5Hz and 0.154 respectively.

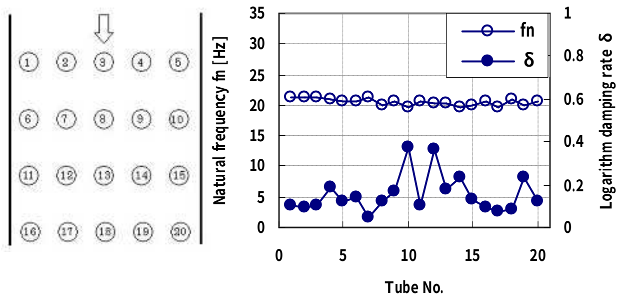

Fig.7Tube arrangement and dynamic characteristics

4.1.2 Relationship between flow velocity and tube bank vibration

Fig.8 (a) shows the relationship between the flow velocity and the amplitude of the tube ⑧ which expresses the largest vibration when the flow velocity increases. The onset velocity is Vc=23.8m/s in this case. Fig.8 (b) shows the displacement amplitudes of all tubes at Vg1=16.8m/s, Vg2=26.9 m/s and Vg3=40.3 m/s. As similar to the case of T/D=2 and L/D=2, vibrations of tubes with small

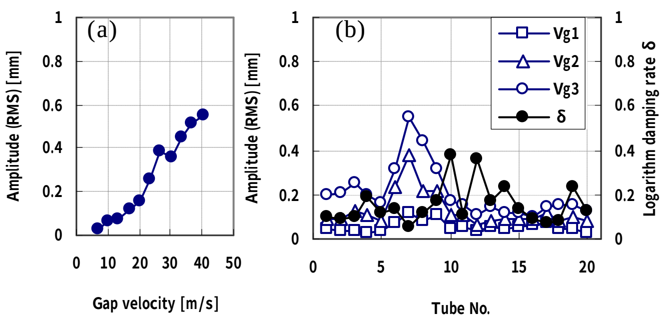

Fig.8 Amplitude of No.14 tube and amplitude of all tubes at Vg=40.8m/s

damping are almost large and those with large damping are small.

4.2.3Critical velocity of fluid elastic instability

In this array, around the tube ⑦ which vibrates largely, comparatively large vibrations were seen in the second row from the upstream. The minimum of non dimensional critical coefficient is K=3.6 (Tube ⑦).

4.3 T/D=2, L/D=4, l=130mm

4.1.1 Dynamic characteristic of tube bank

Fig.9 shows the tube array, the natural frequency and the logarithmic damping of each tube. The averages of natural frequencies and damping of all tubes are 20.7Hz and 0.117 respectively.

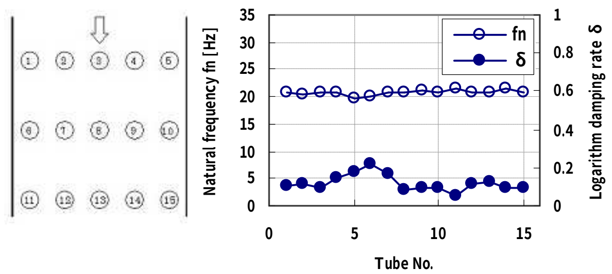

Fig.9Tube arrangement and dynamic characteristics

4.1.2 Relationship between flow velocity and tube bank vibration

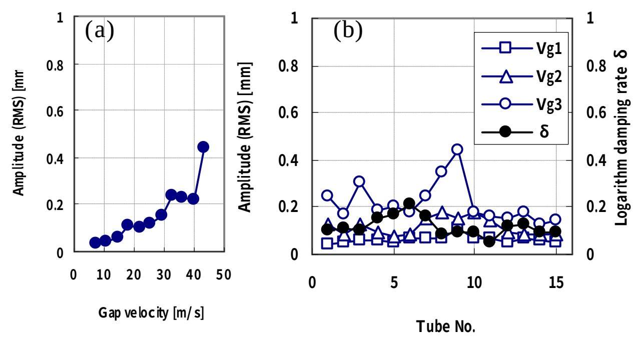

Fig.10Amplitude of No.14 tube and amplitude of all tubes at Vg=40.8m/s

Fig.10 (a) shows the relationship between the flow velocity and the amplitude of the tube ⑨ which expresses the largest vibration when the flow velocity increases. Fig.10 (b) shows the displacement amplitudes of all tubes at Vg1=18.8m/s, Vg2=30.1 m/s and Vg3=45.2 m/s. As can be seen in Fig.10 (a), this case does not show the clear feature of fluid elastic instability like Fig.5(a). Therefore when L/D is large, fluid elastic instability seems to be hard to occur.

4.4 T/D=4, L/D=4, l=130mm

4.2.1 Dynamic characteristic of tube bank

Fig.11 shows the tube array, the natural frequency and the logarithmic damping of each tube. The averages of natural frequencies and damping of all tubes are 20.8Hz and 0.130 respectively.

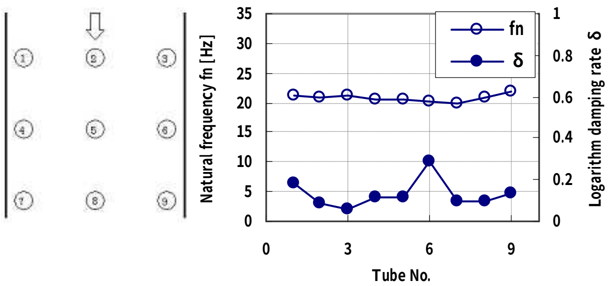

Fig.11 Tube arrangement and dynamic characteristics

4.2.2 Relationship between flow velocity and tube bank vibration

Fig.12 (a) shows the relationship between the flow velocity and the amplitude of the tube ⑧ which expresses the largest vibration when the flow velocity increases. Fig.12 (b) shows the displacement amplitudes of all tubes at Vg1=15.5m/s, Vg2=31.0 m/s and Vg3=46.5 m/s. As can be seen in Fig.12(a), this case also shows the feature of fluid elastic instability. However it is considered to be hard to occur fluid elastic instability comparing with L/D=2 and L/D=3 which cases are not described here in circumstances of the space.

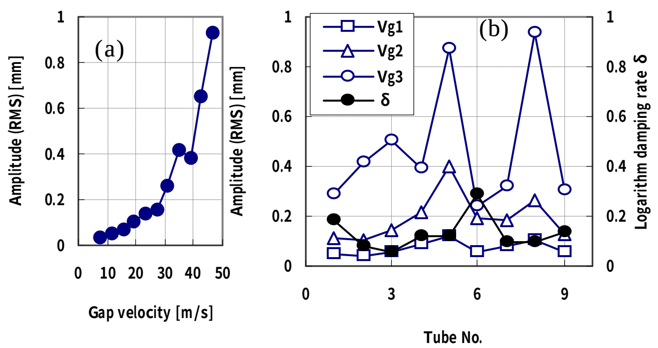

Fig.12 Amplitude of No.8 tube and amplitude of all tubes at Vg=46.5m/s

4.2.3Critical velocity of fluid elastic instability

In this array, the minimum of non dimensional critical coefficient is K=3.5 (Tube ⑤).
Summing up above results, it can be said that fluid elastic instability tends to take place with increasing T/D and decreasing L/D.

5. CONSIDERATION OF EXPERIMENTAL RESULT

5.1 Influence of tube array on K value

In each pitch to diameter ratio, the tubes which expressed large vibrations are selected and the minimum values in each K value are showed in Fig.13 and Table2. These values are relatively small comparing with the average value 4.0 showed in the Reference(4). This is due to obtaining the minimum values in each array pattern. The average of these values is 3.4 and this value is near to the value 3.3 presented by Petigrew and is larger than ASME recommended value 2.4. The influence of array pattern on the K value is that the K value becomes small with increasing T/D and decreasing L/D. In other word, fluid elastic instability is ease to occur when T/D is large and L/D is small.

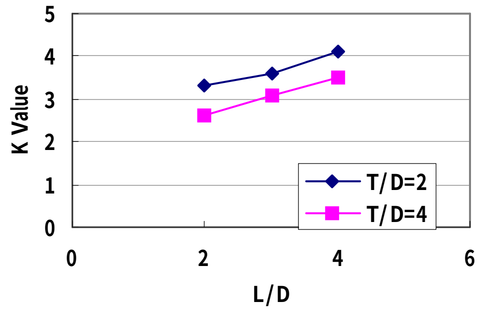

Fig.13 Relationship between pitch and K value

Table2 Minimum K values of each parameters

T/D	L/D	Tube No.	K
2	2	14	3.3
	3	7	3.6
	4	8	4.1
4	2	5	2.6
	3	5	3.1
	4	5	3.5
Mean value			3.4

5.2 Influence of tube array on fluid elastic instability

Fig.14 shows the relationship between the flow velocity and the displacement amplitude of the tubes located at the near center of the tube bank which have the natural frequency of 21 Hz and the logarithmic decrement of about 0.1 (δ=0.07-0.12). That is to say, the influence of only array pattern on fluid elastic instability will be considered. From these figures, it is found that fluid elastic instability tends to take place and the vibration becomes large with increasing T/D and decreasing L/D. Namely, the larger T/D is and the smaller L/D is, the greater the gradient of vibration amplitude to the flow dA/dV is. This is considered that when T/D becomes small the gap velocity becomes large and the separation point shifts behind the tube. As a result, the strength of vortex becomes weak. On the contrary, when L/D becomes small the interference between adjacent tubes becomes strong.

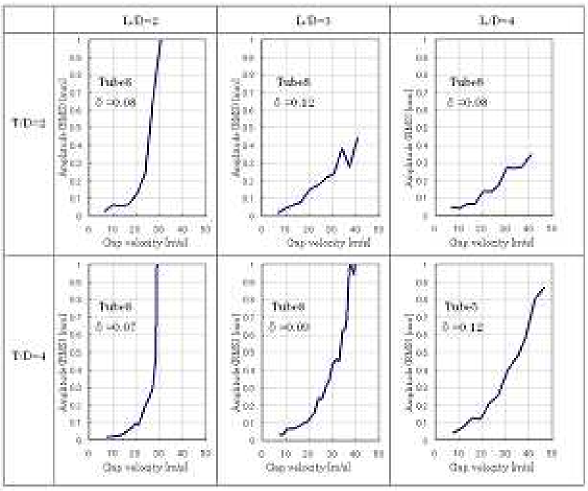

Fig.14 Effect of tube array on fluid elastic instability

6. CONCLUSION

In order to grasp the influence of tube array patterns on fluid elastic instability, the experimental apparatus was made and vibrations of all tubes were measured with varying the natural frequencies and array patterns. The results are summarized as follows.

(1) In fluid elastic instability, all of the tubes do not vibrate all together but the special tubes vibrate easily. In present tube array, the tubes located at the center of the second row from upstream vibrate easily in case of T/D=2 and the tubes located the center column vibrate easily in case of T/D=4. These tubes show large vibrations.

(2) The tubes located at the most upstream were the most hard to vibrate in all experiments.

(3) The dynamic characteristics of each tube influence strongly to the occurrence of fluid elastic instability. Even the tube located at the place to vibrate to ease vibrates small in case of large damping and fluid elastic instability is hard to vibrate.

(4) The influence of pitch to diameter ratio on the K value is that the K value becomes small with increasing T/D and decreasing L/D, and it appears the clear amplitude increasing and fluid elastic instability is ease to occur.

7. REFERENCES

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