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Effect of Tube Spacing on the Displacement Amplitude of Flow past an Inline and Staggered Tube Array

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Abstract: *Arrangement of tubes plays an important role in many engineering applications like in heat exchanger, radiator, evaporator, nuclear power plant and thermal power plant. Type of arrangement and tube spacing are decided on the basis of the Fluidelastic instability, but the phenomenon of vortex induced vibration is random in nature. Tube spacing also plays a critical role in different types of arrangement. Tube spacing differs for different type of application and the range of tube spacing vary is from 1 to 6. Vortex Induced Vibration in cross flow around the inline and staggered arrangement of the tube arrays is experimentally studied for varying P/d (tube spacing) ratio. It is observed that with the increase in the velocity, the amplitude displacement increases. As the pitch over diameter ratio is increased from 2 to 4, the amplitude displacement of the tube reduces. It is also observed that between inline and staggered arrangement, the amplitude displacement of staggered arrangement is more compared to inline arrangement for same tube spacing.*

Keywords: *Vortex Induced Vibration, inline arrangement, staggered arrangement, load cell, strain indicator.*

1. INTRODUCTION

Flow around an array of cylinders is very often encountered in engineering applications. The flow around an array of cylinders is very rich in fluid dynamics phenomena. Due to its practical importance, flow around the cylindrical structures has been studied. There has been intensive research activities aimed at both understanding the underlying governing mechanisms, and creating theoretical models for the prediction of structural response to fluid excitation. The understanding of flow excitation mechanisms in tube arrays is vital for the design of heat exchangers, to eliminate instabilities which may lead to catastrophic failure. Hardik R Gohel et. al. [3] studied flow induced vibration around Triangular Array of Circular Cylinders with two-degree of freedom. Cylinder was allowed to vibrate in the cross-flow and in-line directions with the help of numerical methods. The computations were carried out at high Reynolds number range with multi-cylinder and varying pitch at 1.5*D* and 2*D*. The effects of Reynolds number on flow parameters such as drag coefficient lift coefficient, Strouhal number, lift and drag forces and vorticity. F. J. Huerta-Haurte et. al. [4] carried out laboratory experiments of two vertical cylinders with a side-by-side arrangement having high aspect ratio (length over diameter) and low mass ratio (mass over mass of displaced fluid) cylinders which pin-jointed at the ends and vibrating at low mode number in a free-surface water channel. T. K. Prasanth et. al. [5] investigated vortex induced vibration of a pair of equal sized circular cylinders for tandem and staggered arrangement in laminar flow regime. Cylinders were free to oscillate in transverse direction as well as inline direction. To obtain high amplitude of oscillation the structural damping is set to zero and cylinders of low non dimensional mass are considered. E. Longette et. al. [8] investigated the numerical methods for numerical identification of flow induced vibration effects affecting tube bundle motion in single phase cross-flow. Their main aim was to provide a numerical method for estimating the critical flow velocity for the occurrence of the fluid elastic instability without carrying out experimental investigation [8]. There are many papers, experimental and numerical analysis, on the flow around two cylinders. However, much fewer researches have been carried out for array of cylinders. T.L. Morse et. al. [11] studied effect of end conditions on an elastically mounted rigid cylinder. In the experimental setup, they have considered a vertical cylinder which is immersed in the water channel. The vertical cylinder was mounted at the top of the channel with the help of a carriage system. The upper end of the cylinder remained free while the lower end conditions were varied giving rise to three different conditions, namely - an attached endplate, an unattached endplate fixed to the channel floor (with a variable gap between cylinder and plate) and a condition of no endplate at all. They concluded that the free vibration response for both the cases attached as well as unattached end plate, were almost identical. Over the entire response plot, the vibration amplitude is markedly higher in the absence of an end plate, while the peak amplitude remained nearly unchanged. Alternate vortex shedding from the first few tube rows in staggered arrays is believed to be the source of flow periodicity. P.A. Feenstra et. al. [9] carried out experiments on a tube bundle of normal square array of 12 tubes with outer diameter 7.11 mm and a pitch over diameter ratio of 1.485. In the experiments the aim was to find out the flow induced vibration response and Fluidelastic threshold of the tube bundle which was subjected to a cross flow of refrigerant 11. As we observe that P. A. Feenstra et. al. studied the phenomena for large number of tubes but they carried out the experiments for single pitch over diameter ratio. The aim of this paper is to present the effect of higher tube spacing on the array of tubes. Also the effect of tube spacing is carried out for both the inline and staggered arrangement.

The paper is organized as follows. Section 2 provides details on the arrangement of the tube array and setup arrangement. Section 3 presents the results obtained from the experiments performed and discussion on the results obtained for the inline and staggered arrangement of tube array and finally Section 4 summarizes the main findings of this work and its conclusion.

2. EXPERIMENTAL CONSIDERATIONS

Phenomena of vortex induced vibration are very complex and many parameters affect the vibration amplitude of the tube. Experiments have been performed to find the amplitude displacement of the flexible tube for vortex induced vibration phenomena. In this paper, effect of tube spacing, i.e. pitch over diameter ratio, is found out experimentally. Experiments were conducted on wind tunnel where maximum attainable velocity was 25 m/s. Effect of pitch over diameter ratio has been found out for both the inline and staggered arrangement. The pitch over diameter has been selected 2, 3 and 4 since many applications of engineering lie below the ratio 6.The tube end is supported at the top surface of the test section of wind tunnel and the other end is free. Cantilever tube bundles are subjected to air flow. The support has been taken cantilever because natural frequency of cantilever tube is very less as compared to the other type of end supports and hence its stiffness. Thus the less difference between the natural frequency of the tubes and the forcing frequency would be maintained.

2.1. Sample Tested

The sample tested in the tunnel is an array of circular hollow cylinder 275 mm long with a diameter of 10 mm and its inner diameter is 9.5 mm. Material of tube is Copper. The sample has been transversely placed with regard to the wind direction from the top section of the tunnel. The sample contains of an array of 9 cylinders placed in a 3x3 configuration for inline arrangement and an array of 8 cylinders arranged in staggered configuration to form a staggered arrangement. Of all the nine cylinders, only the cylinder in the center of the first row is flexible while the other cylinders are made rigid for inline arrangement and one of the tubes in the middle row for staggered arrangement.

2.2. Arrangement of Tubes

Two different types of arrangement are mainly used for carrying out the experiments namely staggered and inline arrangement. In present case, experiments are carried out on an inline arrangement. The sample contains of an array of 9 cylinders placed in a 3x3 configuration. Of all the nine cylinders, only the cylinder in the center of the middle row is flexible while the other cylinders are made rigid. For inline arrangement, readings are taken at the center tube which is flexible. For staggered arrangement, one of the tubes in the middle row is kept flexible; amplitude displacement is measured at this flexible tube.

2.3. Experimental Setup

Block diagram of the wind tunnel is as shown in figure 3. The wind tunnel has a cross section 30 cm wide and 30 cm high**.** The global length of the tunnel, from the inlet to the end of the tunnel, is about 1000 cm. The values of the velocities are obtained with the help of Pitot tube and anemometer arrangement. The maximum velocity attainable is 25 m/s. For the experiments carried out, velocity was varied from 0 – 20 m/s.

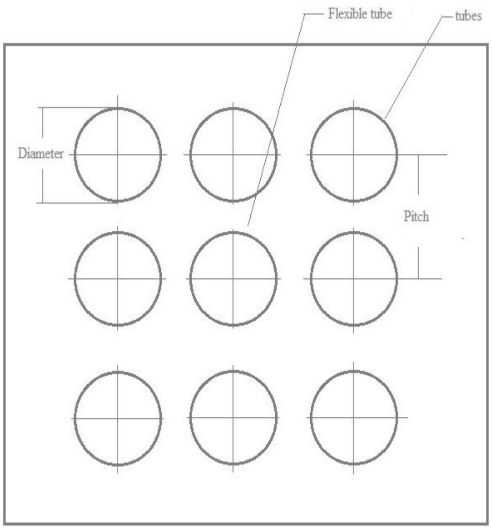

Fig1. *Inline arrangement of tube array*

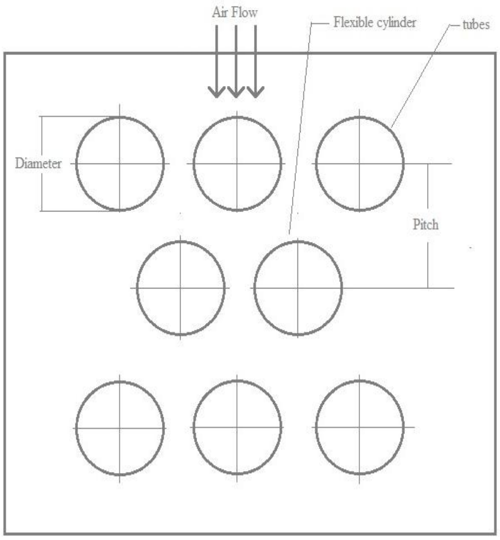

Fig2. *Staggered arrangement of tubes*

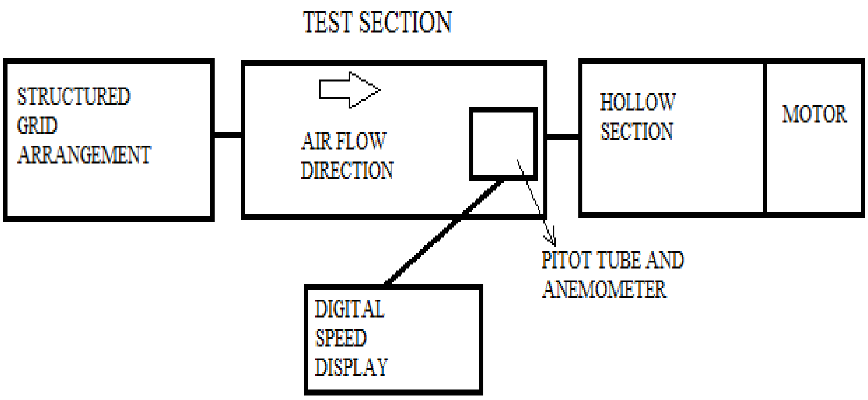

Fig3. *Block diagram of Wind Tunnel*

Table1. *Experimental readings for inline arrangement of tube array*

Parameters / S.No.	Pitch over Diameter ratio					
	2		3		4	
	Velocity (m/s)	Displacement (με)	Velocity (m/s)	Displacement (με)	Velocity (m/s)	Displacement (με)
1	5	4	5	3	5	2
2	10	7	10	5	10	3
3	15	9	15	8	15	6
4	20	13	20	11	20	9

Table2. *Experimental readings for staggered arrangement of tube array*

Parameters / S.No.	Pitch over Diameter ratio					
	2		3		4	
	Velocity (m/s)	Displacement (με)	Velocity (m/s)	Displacement (με)	Velocity (m/s)	Displacement (με)
1	5	5	5	4	5	3
2	10	7	10	6	10	5
3	15	11	15	9	15	9
4	20	15	20	12	20	11

3. Results Discussion

Experiments are carried out on inline and staggered arrangement of tube arrays. For inline arrangement, nine tubes are used and the amplitude displacement of the center tube is found out with the help of the load cell arrangement. For staggered arrangement, eight tubes are used and the amplitude displacement of the tube on the right side from the direction of the flow. Load cell is connected with the strain indicator which indicates the displacement amplitude of the tube. Results obtained from the experiments performed are as shown in the table. The data that has been collected from the experiments are represented in the form of graphs and the results are concluded from the graphs. For inline arrangement, graph of Amplitude displacement versus velocity for different P/d ratio has been shown in figure 4. As observed from the graph, for P/d ratio = 2, displacement amplitude is maximum compared to P/d ratio = 3 and P/d ratio =4. Also we can observe that with the increase in the velocity the amplitude displacement of the tube increases.

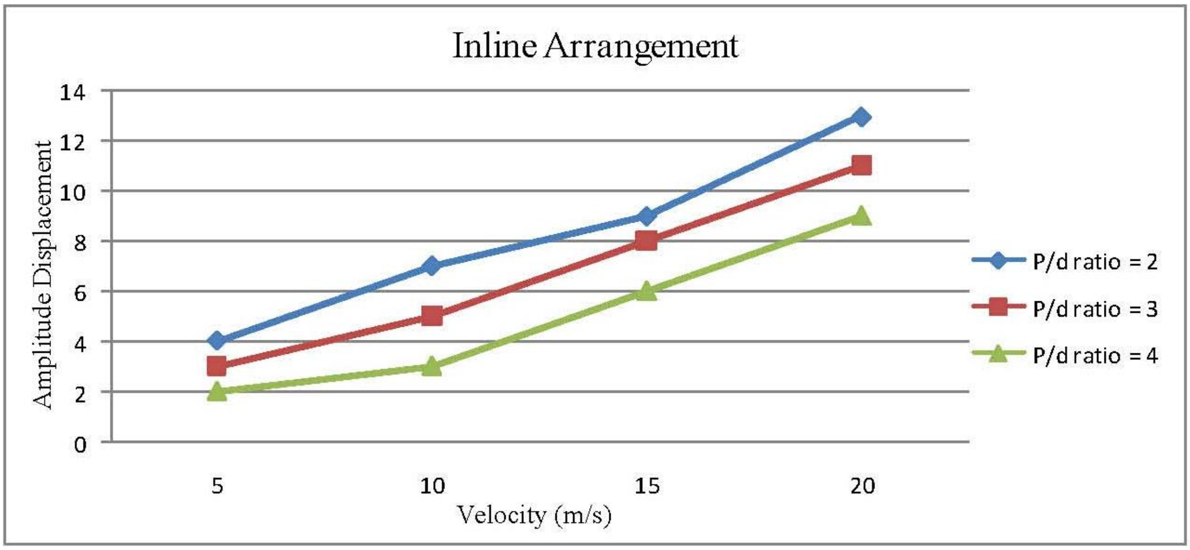

Fig4. *Displacement Amplitude of the tube for inline arrangement of array with varying P/d ratio*

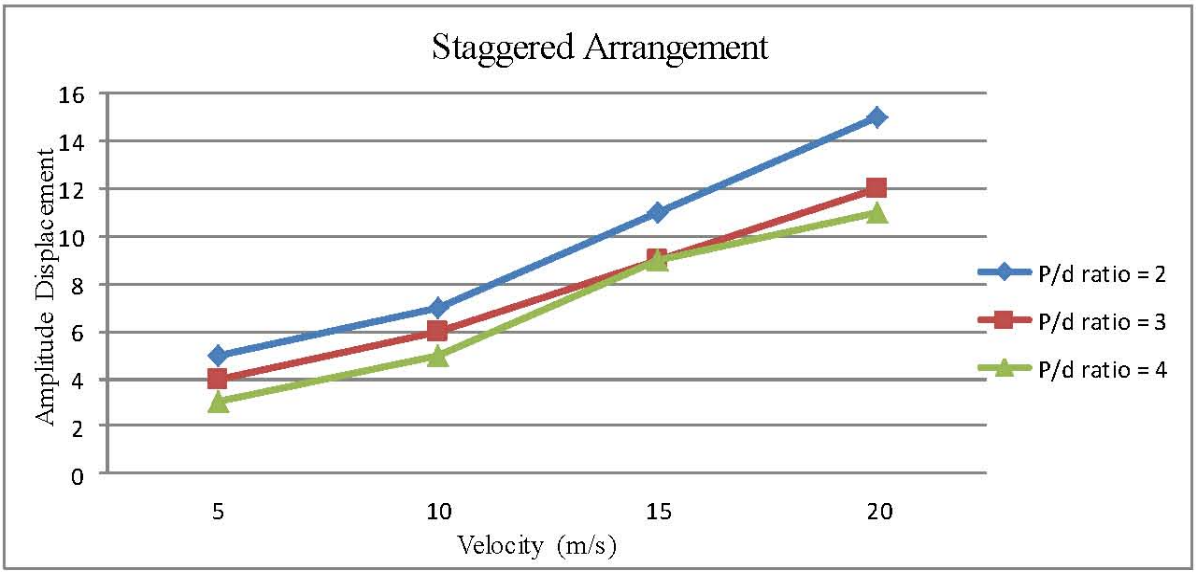

Fig5. *Displacement Amplitude of the tube for staggered arrangement of array with varying P/d ratio*

For staggered arrangement, graph of Amplitude displacement versus velocity for different P/d ratio has been shown in figure 5. As observed from the graph, for P/d ratio = 2, displacement amplitude is maximum compared to P/d ratio = 3 and P/d ratio =4. Similar conclusions can be derived from this graph, but the amplitude displacement of staggered arrangement is more compared to inline arrangement.

4. CONCLUSION

Experiments are carried out on inline and staggered arrangement of tube arrays. For inline arrangement, nine tubes are used and the amplitude displacement of the center tube is found out with the help of the load cell arrangement. For staggered arrangement, eight tubes are used and the amplitude displacement of the tube on the right side from the direction of the flow is considered. For both, inline and staggered arrangement, amplitude displacement is measured for three different pitches over diameter ratios (p/d), which are 2, 3 and 4.

Following results are concluded based on the results of the experiments conduced

1. For inline arrangement, maximum amplitude displacement is measured for the p/d ratio equal to 2. The value of amplitude displacement goes on decreasing as the value of p/d ratio increases from 2 to 4.
2. For staggered arrangement, results similar to inline arrangement are observed i.e. the maximum value is measured for p/d ratio equal to 2 and the value of displacement goes on decreasing as the p/d ratio increases from 2 to 4.
3. When the results are compared for staggered and inline arrangement, the value of displacement amplitude for staggered arrangement is more compared to that of inline arrangement. As seen in the table, for P/D ratio = 2, the maximum value of displacement amplitude is 15 με for staggered arrangement while for inline arrangement the maximum value is 13 με.

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