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MODIFICATION OF THE FLOW-INDUCED VIBRATION OF A FLEXIBLE CIRCULAR CYLINDER OVER THE LOCK-IN RANGE BY A NEIGHBOURING CYLINDER OF A LARGER DIAMETER

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ABSTRACT

This paper describes an experimental investigation of the response of a flexible cylinder in the near wake of an upstream cylinder twice as large. The results suggest that the presence of the large cylinder enhances the flow-induced vibration of the flexible one in our study. Depending on the relative position of the two cylinders, three different regions of influence are observed. The original lock-in range for the flexible cylinder is either (i) disappeared, (ii) drastically widened or (iii) delayed. Drastic changes in vibration amplitude are observed for certain cylinder configurations when the vortex shedding frequency from the large cylinder coincides with the natural frequency of the flexible one.

INTRODUCTION

Flow-induced vibration of a circular cylinder in cross-flow has been studied from a variety of perspectives during the past few decades. A considerable amount of work has been done on the phenomenon of lock-in and review articles have been written by Bearman (1984) and Griffin & Hall (1991). One of the reason for this interest is the importance of knowing how the mean and fluctuating fluid forces are generated on the body due to vortex shedding. Increasing evidences show that lock-in occurs when the cylinder is subject to fluctuating fluid forces with periodicity coincident with that of the fluctuating lift or drag forces which could be induced by natural vortex shedding from the cylinder. Fluctuating fluid forces can be due to the cylinder being mounted flexibly or due to perturbation in the incoming flow. For in-line vibration, lock-in occurs when the frequency of perturbation coincides with the frequency of fluctuating drag forces due to natural vortex shedding, in this case, twice the frequency of natural vortex shedding. In the cross-flow direction, lock-in occurs when the perturbation occurs at the natural vortex shedding frequency or the frequency of fluctuating lift.

Flow perturbation on a flexible cylinder can be caused by the presence of an upstream cylinder. Most of this kind of studies have been focused on two equal sized cylinders. An upstream cylinder of larger size would produce stronger flow perturbation and there is a mismatch between the natural shedding frequencies from the two cylinders. We are interested to know in this situation, how the downstream flexible cylinder responds to the flow perturbation due to the upstream cylinder. In this paper, we shall describe the response of a flexible cylinder in the near wake of an upstream cylinder twice as large. In the absence of interference, the vortex shedding frequency of the large cylinder doubles that of the small one.

EXPERIMENTAL ARRANGEMENTS

The experiments were conducted in an open water channel with a rectangular section of 0.5 m high and 0.3 m wide. The water depth could be varied by an adjustable gate at the downstream of the channel. Throughout the experiments the water depth was kept constant at 0.35 m. Two aluminium circular cylinders of diameters D = 32 mm and d = 16 mm spanned the water channel vertically, thus having a length-to-diameter ratio of 10.0 and 20.0 respectively. The freestream time-averaged velocity, U and turbulence intensity were measured by a laser-doppler anemometer. The turbulence intensity was about 4% at the velocity of U =

0.3 m/s which was the highest velocity employed in the present experiment. The lower end of the small cylinder was pivoted on the floor of the water channel while the upper end was connected to a rigid support via two helical springs so that the cylinder could vibrate in a transverse direction to the flow. The natural frequency of the cylinder oscillation in still water was f = 1.49 Hz. The amplitude of vibration of the cylinder, a was measured by an accelerometer mounted on the top of the cylinder. Two circular end plates of 160 mm diameter were installed to ensure two-dimensional flow.

We have completed experiments with the large cylinder located at five positions as shown in Figure 1. It is well reported in lock-in experiments that higher amplitudes were achieved when the reduced velocity was increased over a certain range than when it was decreased back over the same range. In order to achieve a steady vibration state faster, the small cylinder in our experiments was first held stationary and then released from its equilibrium position after a steady flow velocity was achieved.

RESULTS AND DISCUSSION

The response of the single flexible cylinder without any interfering body was first obtained. Velocity was increased from U = 0.1 m/s to 0.3 m/s step by step. The variation of the maximum and minimum non-dimensional amplitude, a/d with reduced velocity, U/fd is shown in Figure 2. The result is in good agreement with earlier investigations where a peak with a/d = 0.25 occurred at U/fd = 6.5 and the lock-in region extended over $4.8 < U/fd < 8.5$.

When the larger cylinder is placed at position 1 or 2, the amplitude of vibration is very small up to U/fd = 8.5 (Figure 2). Thereafter, the amplitude increases drastically and reaches a peak value of a/d = 0.5 at U/fd approximately equal to 11.0. We also carried out flow visualisation during the experiments from which we attempt to provide explanations for these two observations, namely the disappearance of the original lock-in range around U/fd = 6.5 and the new lock-in range around U/fd = 11. There have been a number of experimental investigations on the vortex shedding mechanism in the near wake of a circular cylinder, e.g. Cantwell & Coles (1983), Perry & Chong (1982). An accepted model is that with the growth of an attached recirculating vortex on one side of the cylinder, potential flow is induced to invade the recirculating near wake region and detach the recirculating vortex at the other side of the cylinder to form a shed vortex. In our configuration of position 1 or 2, the flexible cylinder is located near to the invasion path of potential flow connected with the recirculating region of the large cylinder. Accordingly, as natural vortex shedding strives to occur from the large cylinder, the invasion of potential flow induces on the flexible cylinder a strong flow perturbation in the transverse direction. At the original lock-in range, the frequency of this fluctuating perturbation does not match with the natural vibration frequency of the flexible cylinder. This suppressed the occurrence of large amplitude vibration in the original lock-in range. We also could not observe distinct vortex shedding from both cylinders in this range. It seems that the proximity of the two cylinders destroy the supply of potential flow over both cylinders necessary for vortex shedding. At U/fd = 11, the frequency of the transverse flow perturbation coincides with the natural frequency of the flexible cylinder and large-amplitude vibration occurs at this new lock-in region. We observed that as the small cylinder undergoes rigorous lateral vibration at its natural frequency, the gap between the two cylinders is opened periodically. This seems to allow invasion of potential flow into the recirculating region behind the large cylinder and we could observe distinct vortices shed from both cylinders.

When the large cylinder is placed at position 3 (Figure 3), the lock-in range for the flexible cylinder is drastically widened. Constantly high amplitudes of vibration are observed throughout the range of reduced velocities except at the two extremes. Comparing with the single cylinder case, the peak of vibration occurred at a smaller reduced velocity (U/fd = 5.5). Figure 4 shows the responses of the flexible cylinder with the large cylinder at position 4 or 5. We observe that the start of the original lock-in range is delayed and there is a general trend of larger amplitude of vibration comparing with the single cylinder case. At $8.5 < U/fd < 11.5$, the amplitude of vibration is maintained at a constant level. The presence of the large cylinder clearly enhances the flow-induced vibration of the flexible one. With the diameter of the large cylinder twice that of the flexible one, natural vortex shedding frequency from the large cylinder is half that of the flexible one. We believe that vortex shedding from the large cylinder produces flow perturbation to the downstream cylinder. When the reduced velocity increases to U/fd = 11, vortex shedding frequency from the large cylinder coincides with the natural frequency of the flexible one. In that case there is a competition between harmonic excitation and superharmonic excitation.

CLOSING NOTE

Our preliminary experiments suggest that the relative position of the two cylinders governs the interaction of the vortex shedding mechanism between the two cylinders. Vortex shedding from the large cylinder which acts as a lateral flow perturbation seems to play a key role in influencing the lock-in phenomenon of the flexible small cylinder. We are trying to confirm this by carrying out measurements on the fluctuating pressure and fluid forces on the flexible cylinder.

ACKNOWLEDGEMENT

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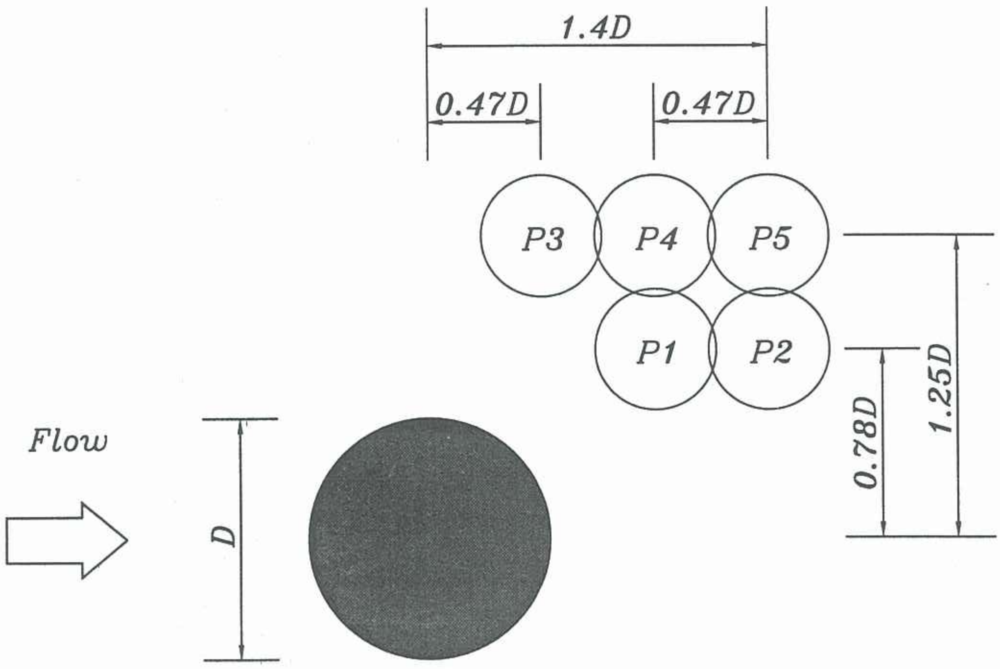

FIGURE 1. THE ARRANGEMENT OF THE CYLINDERS.

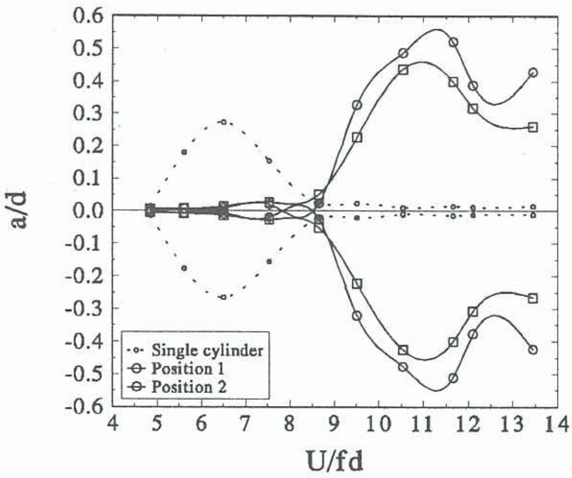

FIGURE 2. THE VARIATION OF THE NON-DIMENSIONAL AMPLITUDE WITH THE REDUCED VELOCITY (POSITION 1 AND 2).

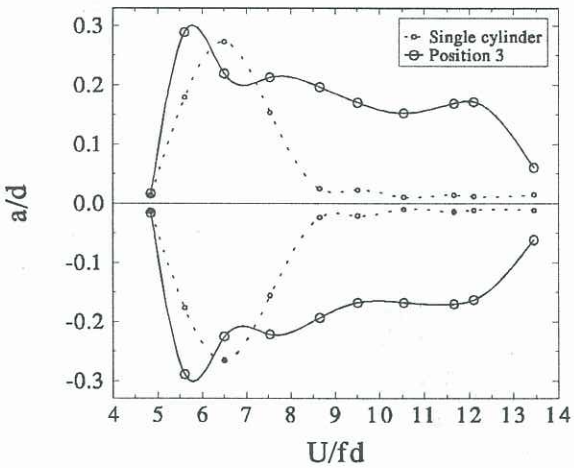

FIGURE 3. THE VARIATION OF THE NON-DIMENSIONAL AMPLITUDE WITH THE REDUCED VELOCITY (POSITION 3).

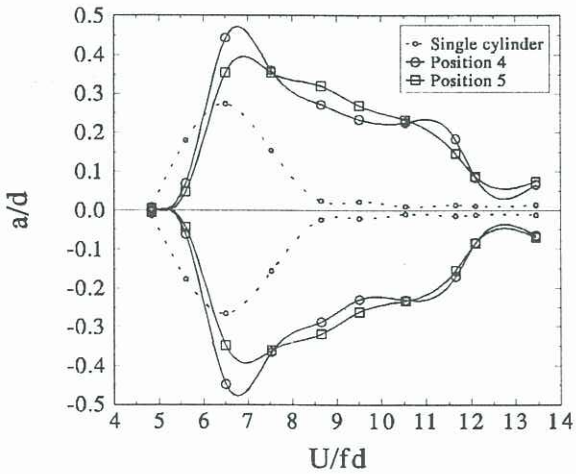

FIGURE 4. THE VARIATION OF THE NON-DIMENSIONAL AMPLITUDE WITH THE REDUCED VELOCITY (POSITION 4 AND 5).