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CHARACTERISTICS OF FLOWS AROUND A RECTANGULAR CYLINDER OF WHICH VIBRATION IS SUPPRESSED BY PULSATING JETS FROM THE LEADING EDGES

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1 INTRODUCTION

There are a number of investigations to control flow-induced vibration of structures by means of active operation to change behavior of separated flows. Among many approaches, some moving structural elements such as rotating circular cylinder or fluttering fin are devised near structural edges or corners [1, 2]. On the contrary to these mechanical approaches, the authors have conducted an experiment to stimulate the flow separation region of rectangular cylinder by pulsating jet which is ejected through thin straight slit along the leading edges [3]. Under adequate phase conditions, this method works successfully to suppress flow-induced vibration of rectangular cylinder of B/D=2.

In the present paper, in order to clarify the mechanism why such method can suppress the vibration, the flows around the cylinder are investigated by means of flow measurement and visualization. It is found that the separation shear layers around the cylinder of suppressed vibration are relatively smooth and weak in comparison with those of the fixed cylinder.

2 EXPERIMENTAL APPARATUS

Figure (1) shows the experimental setup of the present study. The duct of the wind tunnel has a cross section of 60 cm height and 30cm width. A rectangular cylinder of B/D=2 is suspended by four pairs of coil springs. The motion of the cylinder is measured by two laser linear gauges; one measures the vertical displacement of the leading edge of the cylinder while the other does that of the trailing edge. Two computer-controlled AC servomotor driven wind blowers take a role to inject air into the rectangular cylinder through two tubes.

Figure (2) shows the details of the rectangular cylinder. The mass of the cylinder is 180 g and the natural frequency of the vertical vibration is 2.89 Hz when no approaching wind blows. Thin straight slits of 0.4 cm wide gap are opened along the leading edges on the top and bottom surfaces of the rectangular cylinder. On a side wall of the cylinder, two tubes from the AC servomotor wind blowers are connected to two vertically aligned circular holes

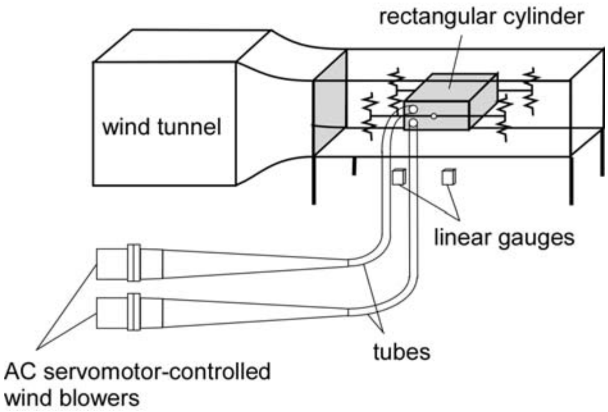

Fig.1: The experimental apparatus.

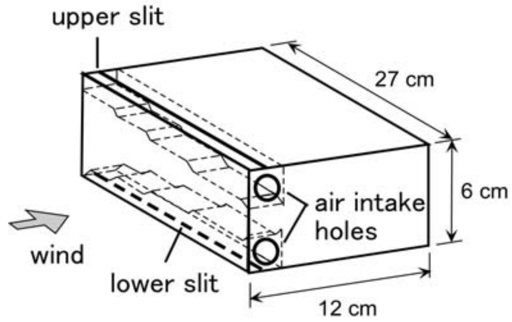

Fig.2: The rectangular cylinder specimen.

individually. The air stream generated by the AC servomotor wind blower is supplied through the circular hole into a narrow cell where the air stream is forced to change the direction and vertically spout as jet through the thin slit.

The present rectangular cylinder vibrates vertically when the approaching wind velocity exceeds 2.0 m/s. The amplitude of this vertical translational vibration increases as the wind speed increases. No rotational motion is observed.

3 SUPPRESSION OF THE CYLINDER VIBRATION BY PULSATEING JET

In order to generate pulsating jets through the slits along the leading edges, the time histories of control voltage to drive AC servomotor wind blowers are designed to feedback simultaneously measured vertical displacement of the cylinder. The applied time history of the control voltage $V(t)$ is defined in terms of the following function:

$$V(t) = a\ y(t - \tau + \theta T) + b \tag{1}$$

where $y(t)$ is the cylinder displacement history measured by the laser linear gauges, $\tau(= 0.32s)$ is the time lag between the control voltage and the jet generated through the slit. The central value of the control voltage b is set to 6.95 V (the corresponding jet velocity is 1.49 m/s) and the initial amplitude a is set 2.95 V (the corresponding velocity amplitude is 0.77 m/s). In Eq. (1), T is the measured period of the vortex-induced vibration and θ is a coefficient to adjust the phase of the control voltage. The jet from the lower leading edge keeps the phase opposite to the jet from the upper leading edge.

The amplitude of the control voltage is proportional to that of the cylinder displacement $y(t)$. Therefore, when the cylinder vibration diminishes, the fluctuation component of the pulsating jets also diminishes so that the jet flows reach to steady flows with the above velocity 1.49 m/s.

Using this feedback jet generation, we conducted four cases of the phase $\theta = 0, 1/4, 1/2, 3/4$. The results of the approaching wind velocity 3.0 m/s are shown in Fig. (3). In case of $\theta = 0$, the phase that the jet takes its peak at the instant the cylinder takes the highest position, the cylinder vibration is suppressed in just several cycles.

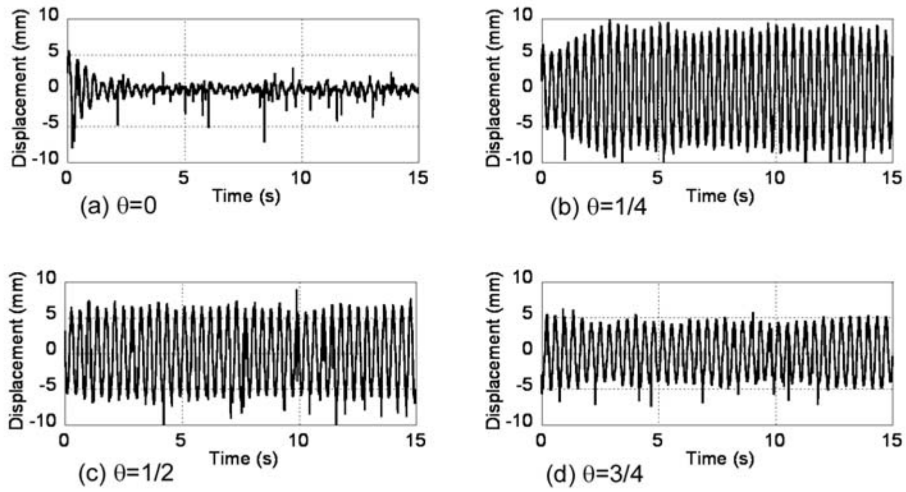

Fig.3: Cylinder displacement histories after the pulsating jet is generated at four different phase angles $\theta = 0, 1/4, 1/2, 3/4$ (the approaching wind velocity =3.0m/s).

4 MEASUREMENT AND VISUALIZATION OF FLOWS

As described above, if the separation shear layer just after the leading edge is stimulated by pulsating jet, under adequate phase conditions, the vortex-induced vibration can be suppressed. In order to investigate the mechanism of this effect, fluid velocity of the separation shear layer and the wake are measured by hot wire anemometer. The approaching wind velocity is 3.0 m/s. The three measured cases are: the fixed cylinder; the vibrating cylinder without pulsating jet stimulation; and the suppressed cylinder by the pulsating jet of $\theta = 0$.

Figures (4) and (5) are the contours of time-averaged stream velocity and the turbulent intensity. Comparing the cases of the fixed cylinder and the suppressed cylinder, even though both cylinders are stationary, the two flow fields are quite different. The flow field around the suppressed cylinder exhibits longer wake region and weaker fluctuation.

Figure (6) shows the power spectra of the fluid velocity fluctuation at the point P in the wake shear layer. The power spectra of the fixed cylinder and the vibrating cylinder exhibit the peak frequencies corresponding to the Strouhal number and the structural natural frequency, respectively. On the contrary, the power spectra of the suppressed cylinder exhibit no such pronounced peak frequencies.

Flow visualization by using dry ice and green laser sheet are also conducted. Comparing the visualized shear layers around the fixed cylinder, Fig.(7), and the suppressed cylinder, Fig.(8), it is indicated that the shear layer from the cylinder suppressed by jet is smoother than that from the fixed cylinder.

5 CONCLUSIONS

The flow measurement and visualization suggest that the separation shear layer of the suppressed cylinder is weaker and smoother than that of the fixed cylinder. This weak shear layer does not generate sufficiently strong vortices in the wake so that the cylinder does not start vibration again. This strange situation has been reached by stimulating the separation region by the pulsating jet and sustained by keeping the jet steadily.

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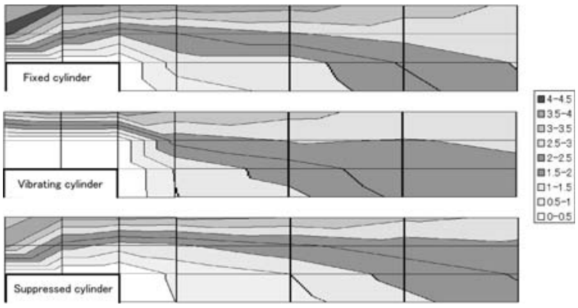

Fig.4: Distributions of the time-averaged stream velocities (from top: fixed cylinder, vibrating cylinder, cylinder suppressed by jet).

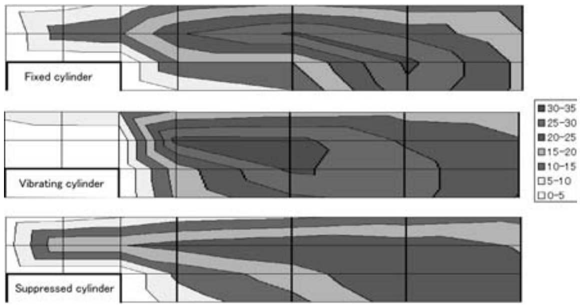

Fig.5: Distributions of the turbulent intensity (from top: fixed cyliner, vibrating cylinder, cylinder suppressed by jet).

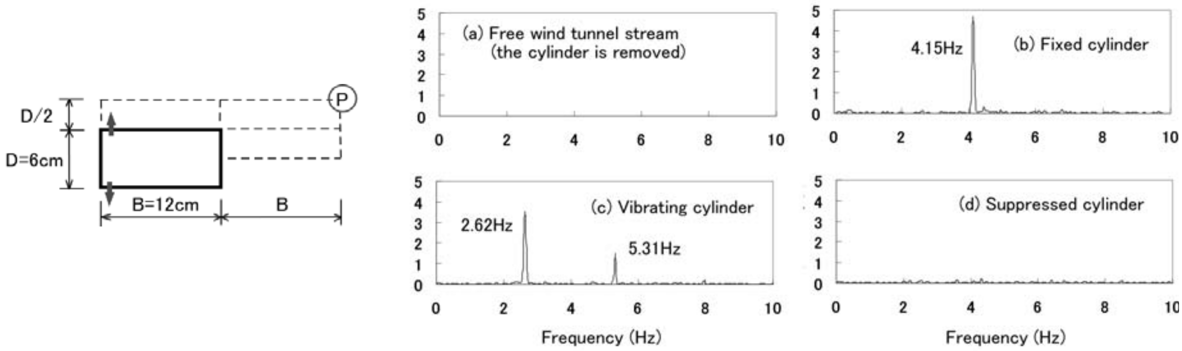

Fig.6: Power spectrum of the velocity at the measuring point P.

Fig.7: Visualized shear layer around the fixed cylinder.

Fig.8: Visualized shear layer around the cylinder suppressed by jet.