ACTIVE CONTROL OF VORTEX SHEDDING FROM A CYLINDER

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ABSTRACT

This paper describes, experimentally, the control of vortex shedding from circular cylinder at Reynolds number 400 using an active control system to stabilize the wake instability. The investigation has been carried by, quantitatively, hot-wire to measure the mean and fluctuating velocities and, qualitatively, by using smoke-wire flow visualization technique to examine the formation of the flow field downstream of the cylinder. It has been found that active control is able to shift the frequency of vortex from the nominal vortex shedding frequency. Also, it is influence the rate of entrainment from main flow into the wake flow.

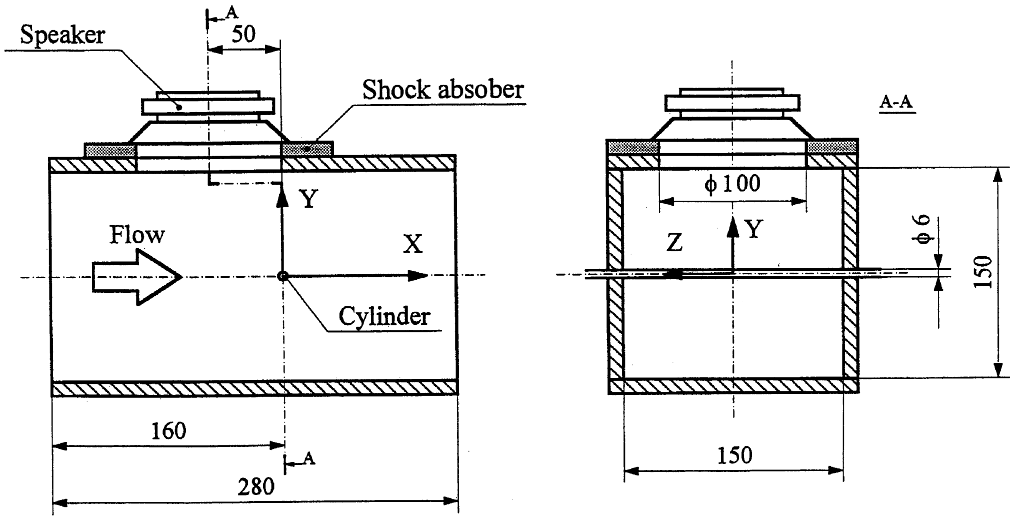
INTROUDCTION

Vortex shedding from bluff bodies is of great interest because of its practical importance from an engineering point of view in the evaluation of wind load acting on building, and the lateral vibrations due to the formation of vortices on sides of bluff bodies. The Karman vortex street in the wake of a circular cylinder has been widely studied (Roshko, 1954; Bloor 1963; Schlichting 1968). Many of these studies have considered methods of altering the wake structure. The wake is often turbulent and chaotic but supports large eddy structures of varying degree of order. This depends on Reynolds number, surface roughness and turbulence level.

The understanding of vortex shedding from bluff bodies has advanced greatly in the recent years. The shedding of vortices from alternate sides of bluff bodies is associated with strong periodic transverse forces that can damage structures. It is clear that the movement of the point at which the flow separates from the surface of the body is a determining feature of the process (Nigim 1997, Nigim and Batill 1997). Blevins (1985) studied the influence of a transverse sound wave on vortex shedding from a rigid circular cylinder. Blevins reported that the frequency of vortex shedding could be shifted by sound applied above or below the nominal vortex shedding frequency.

Although more research has been carried in the area of active control of various unstable fluid mechanical systems, the evolution of the vortex shedding is still not fully understood. Ffowcs Williams and Zhao (1989) considered the potential for suppressing vortex shedding using active control. They suggested that if vortex shedding was limited cycle of an initial linear instability then active control, suppressing instability, should prevent vortex shedding. They performed experiments to test this hypothesis, using a hot wire sensor and a single actuator, their sensor was located in the near wake; their actuator was a loudspeaker in the wind tunnel wall. They observed that at Reynolds numbers between 400 and 10000control significantly reduced the vortex shedding frequency components of the hot wire signal. In addition they presented results indicating that the vortex-street was suppressed significantly throughout the wake. Their results were preliminary and they did not claim to understand the control mechanism.

Roussopoulos (1993) studied the control of vortex shedding from circular cylinders at low Reynolds numbers by using feedback to stabilize the wake instability. Roussopoulos found that feedback control is able to delay the onset of wake instability, rendering the wake stable at Reynolds numbers about 20% higher than otherwise. In addition Roussopoulos duplicated the experiments of Ffowcs Williams and Zhao with their original and other equipment. He concluded that control strategy adapted by Ffowcs Williams and Zhao does not suppress vortex shedding at higher Reynolds numbers.



(Dimension in mm)

Figure 1: Details of the test channel and coordination system

In this paper experimental results are reported to indicate a way of actively controlling vortex formation. Here, the implemented active control system is consisting of hot-wire probes, constant-temperature anemometer together with linearizer, a phase shifter and a power amplifier. The wake of a circular cylinder was sampled with a hot-wire anemometer, the signal processed and fed into a loudspeaker mounted in the roof of the wind tunnel and the vortex wake examined with a secondary hot-wire system.

EXPERIMENTAL APPARATUS AND INSTRUMENTATION

The experiments were conducted using an open-circuit blowing wind tunnel of 280mm length and a square (150mm x 150mm) testing section; shown in figure 1. This tunnel has a convergent section with 3:10 contraction ratio at the inlet of the testing section. Air velocities could be obtained in the range of 0.5-5 m/s. Three mesh grids of different sizes together with a fine screen were used to reduce free-stream r.m.s. turbulence levels to less than 0.1%. A solid brass cylinder of 6mm diameter and aspect ratio 25 was used for all experiments at Reynolds number 400; based upon the cylinder diameter.

The measurements of the mean-time velocity profiles and the fluctuating turbulent quantities in the flow-field were made with two Dantek miniature hot-wire probes and constant-temperature anemometry equipment. Each hot-wire anemometer (Dantex Elektronik, CTA BRIDGE 56N16, LINEARIZER 56N21 and RMS UNIT 56N25), of nominal length 2mm and having a 10-µm tungsten wire mounted to the probe axis. One of the hot wire was used as the actuator for the control loop; the

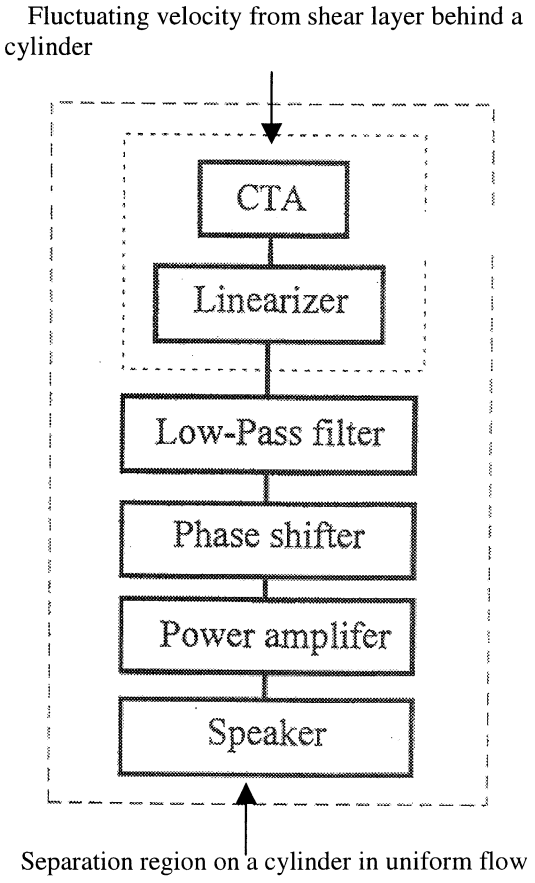


Figure 2: Diagram of active flow control system

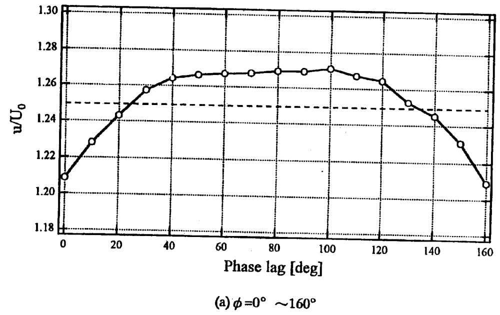
other was used for investigating the wake at other locations. The hot wires were conditioned with constant–Temperature anemometer bridges. The determination of the velocity components and the turbulence quantities were obtained from sums and differences of the voltage recorded by the hot wire and from the calibration velocity vs. an output-voltage relationship.

Specially designed control system is illustrated schematically in figure2. The signal from the anemometer is a.c. coupled and amplified. This amplified signal is then either phase shifted or fed straight to the power amplifier (model KENWOOD Type COMPACT SIZE Main AMPLIFIER A-M 70). The phase shift changes rapidly with changes of frequency and can be set to any desired values. Actuation was achieved by means of a 100mm circular loudspeaker mounted on the top of the tunnel testing section. The circular cylinder was mounted horizontally and centrally in the tunnel 50mm downstream the centerline of the loudspeaker, as illustrated in figure1. Each hot wire was generally positioned near the edge of opposite sides of wake. The wires were aligned with the axis of the test cylinder. The hot wire which used as the actuator for the control loop was mounted at 1.5d downstream, 0.8d above the axis of the cylinder of diameter; location and coordinates are given in figure1. It was found that this configuration minimized the interference of the probes with each other and with the wake.

Data were acquired, analyzed and processed using an IBM personal computer and TEAC digital recorder type DR-M3. Data were sampled over a finite time interval and digitized using A to D converter (model KEITHLEY type DAS-160) and processed by an FFT (Fast Fourier Transform) analyzer to construct a frequency spectrum. The frequency resolution is a function of the time length of the data-sampling interval. For the present study the number of the data points in the sampling interval was fixed and equal to 8192 points. Thus, 50 seconds of data were sampled to construct a single spectrum of 2kHz bandwidth. Here, average spectra were constructed by continuously averaging spectra from overlapping time samples. These average spectra have no better frequency resolution than the individual spectra, but they more accurately represent the mean properties of the vortex shedding process. Further post processing was performed off-line on workstation computer together with Mathematica 2.2 for SPARC.

Smoke wire flow visualization technique was applied to study the flow field behind the cylinder. A nichrome wire of 0.1 mm in diameter was kinked by passing it through the teeth of two cogwheels of the module equal to 0.5, so that regularly spaced smoke streaklines can be produced. At 5mm downstream of the cylinder the wire was stretched vertically, at the center of the testing section, and painted with a mixture of paraffin liquid and aluminum powder. A dense white smoke was produced by passing a strong current through the wire. The maximum voltage drop across the wire was a 180 volts. The flow-field was examined by taking instantaneous photographs of the smoke streaklines from the side using an opened shutter camera and a stroboscope light. An electronic circuit to control the timing of the generation of smoke and the flash illumination was designed. To ensure reliability of the data, each experiment was repeated twice and if disagreement was reported a third set was obtained.

A. Time-mean velocity



B. Fluctuating velocity

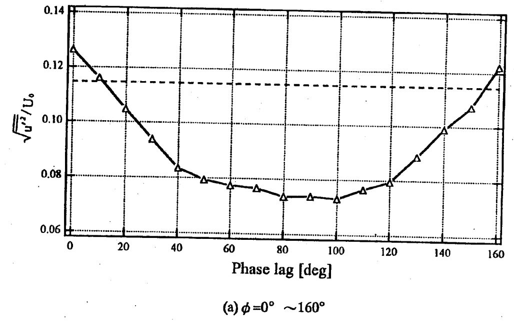
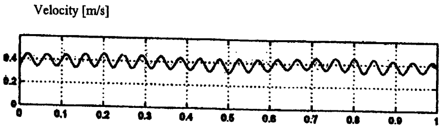


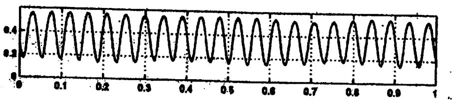
Figure 3: Distribution of time-mean and fluctuation velocities vs. phase angles

EXPERIMENTAL RESULTS

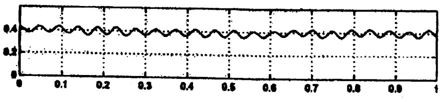
The experiments were performed on a cylinder of 6mm diameter at a speed of 1m/s, i.e. at Reynolds number 400 based upon the cylinder diameter. At this Reynolds number, it is known that there are irregular velocity fluctuations and that the shedding frequency wanders randomly about the nominal frequency. The spectral analysis of the anemometer output was carried out over an extended frequency range, the spectra showed a single well-defined peak at the vortex shedding frequency; about 35.4 Hz.



A. Without control



B. Optimum controlled case (Ø = 80 °)



C. Reversed controlled case (Ø = 0 °)

Figure 4: Time histories of fluctuating velocity behind a circular cylinder

Preliminary experiments were conducted to indicate a way of actively controlling the vortex formation at the testing conditions. The wake of the cylinder was sampled by the first hot-wire, then the signal processed and fed into a loudspeaker mounted in the roof of the wind tunnel. The vortex wake examined with the second hot-wire system. The measured time mean velocity component (u) as well as the fluctuating velocity component (u'), in the wake at the vortex shedding frequency, are given in figure 3. These results were non-dimensionalized using the wind tunnel free-stream velocity (Uo) and plotted against the phase angle (ϕ). In the figures the broken line refers to the measured values when the controller is switched off. Feeding back signal from the hot-wire probe to the loudspeakers with appropriate gain and phase adjustment it was possible to reduce the vortex shedding frequency velocity fluctuations at the hot-wire location to the background noise level. In fact, by shifting the signal phase angle 80 degrees the attenuation observed at sensor is reduced by thirty decibels. Thus, the figure demonstrates that the optimum control can be achieved when the phases angle (ϕ) is 80-degree lagging. While the velocity reduced to minimum when the reverse control phase angle is zero. Also by using the microphone as the sensor for the feedback, the vortex shedding even reduced further. In the course of this investigation the classifications of those three control cases are used.

To resolve the nature of time variation of vortex shedding, time–history plots of sensor signal for the three cases were made. An example of the sensor signal with the controller turning on and off is given in figure 4. This figure shows that without controlling, the hot wire signal is dominated by elements at harmonics of the vortex shedding frequency. When the controlling loop was switched on and the loudspeaker energized, fine adjustment of the gain and phase of the controlling signal rise the virtual elimination of the fluctuation at the vortex shedding frequency. While the over all impression of each signal is of a beat produced by two interacting sinusoidal signals, close examination shows this is not the case. The larger the-amplitude pulses are relatively well defined and nearly sinusoidal, whereas in the intermediate ranges of low amplitude, the time histories are often irregular and non-sinusoidal.

Figure 5, gives the frequency spectrum where it can be seen that the harmonics typical of an oscillator in a non-linear limit cycle are eliminated together with the fundamental, an aspect supporting that interpretation of the vortex shedding process. A phase reversal of the loudspeaker signal at this condition brought an enhancement of the fluctuation and that case is also shown in the figure. Close examination reveals that the shedding frequency without control; 35.4, has changed to 33.9, in case of optimum controlling and to 34.7 in case of the reverse controlling. This new shedding mode can be regarded as the results of the positive feedback at the altered frequency and phase shift, and the potential for such positive feedback probably explains why the tuned feedback loop as never able to fully suppress vortex shedding. It is seen that the shedding amplitude is little affected, and is certainly not suppressed.

Little data have been published on regions of the flow closely behind a cylinder, which is recognized to play an important role in the determination of the vortex shedding frequency. In fact, the formation region of the vortices behind a cylinder can be used as a relative length scale for the distribution of fluctuating velocities close to the cylinder. Figure 6, shows time mean velocity and velocity fluctuations measured in both the near and the far wake downstream of the cylinder. In the near region, the wake generated by the cylinder, under the optimum control condition, is stronger than that generated without controlling. While, in case of reverse controlling the wake generation is the weakest, The rate of entrainment of flow from the main flow into the wake region is increasing due to the formation of small-scale vortices around the large-scale vortices.

In the far regions, the velocity fluctuations measured in the far wake downstream of the cylinder are altered significantly by the action of the controller. The signal measured by the sensor when it is located in the shear layer is dominated by meandering of the shear layer, which are induced by the shedding process. Roussopoulos (1993) reported that by moving the shear layer, a region of high velocity gradient, in the direction normal to the local flow would cause a sensor located in the shear layer to observe a significant change in the velocity. The control of the sensor signal is explained if the

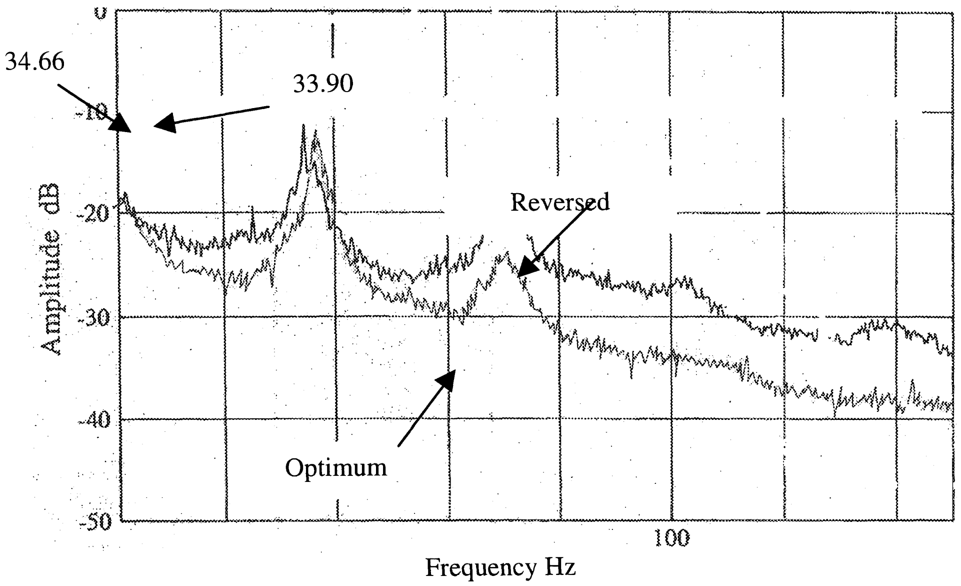
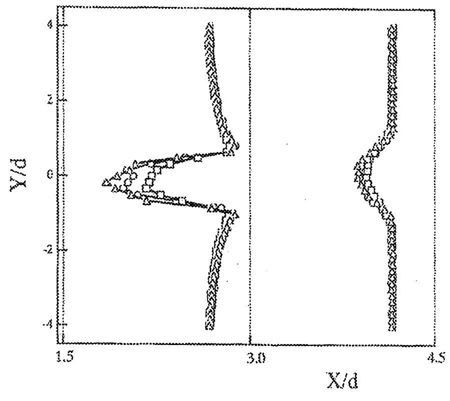
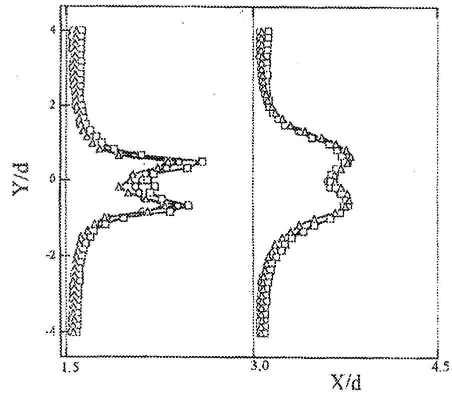


Figure 5: The spectrum of the first hot-wire signal



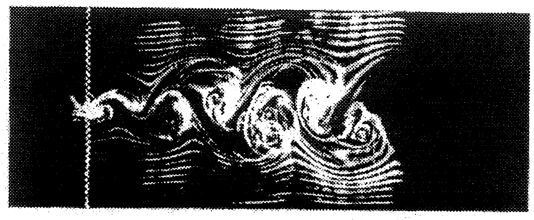
A. Time-mean velocity distribution



B. Fluctuation velocity distribution

Figure 6: Velocity distribution in both near and far wake ;
A. Time-mean velocity
B. Fluctuating velocity,
controlling O: Without,Δ: Optimum, □: Reverse

A. Without control



B. Optimum controlled case (∅ = 80 °)

C. Reversed controlled case (∅ = 0 °)

Figure 7: Smoke-wire visualization of the cylinder in the three cases

actuator is considered to move the location of the shear layer relative to the sensor.

The flow-field around a circular cylinder of 6mm diameter was examined qualitatively by using a smoke-wire flow visualization technique; example photographs are shown in figure 7. These photographs show that vortex shedding is not suppressed by the controller action. They revel that, with optimum control the rate of entrainment into the van Karman vortex street is weak. While in case of reverse control the vortex street is narrow and the rate of entrainment is high.

CONCLUSIONS

This investigation confirmed that it is possible to influence the wake instability behind a circular cylinder with an active control system operating in the frequency band about the main vortex shedding frequency. The reported control strategy was able to reduce the vortex shedding component measured by the control sensor, which was located in the separated shear layer near the cylinder. It was found, neither the wake streaklines revealed by the smoke-wire visualization, nor the velocity fluctuations measured in the far wake downstream of the cylinder, are altered significantly by the action of the controller. Though the mechanics of the process is not fully understood, the findings are interested enough to be reported.

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