Abstract

The flow past a circular hollow cylinder of fine screen gauze was investigated by means of a 2D LDV. The flow behavior depends significantly on the solidity of the screen gauze. There can be found no region of flow reversal just downstream of the cylinder, irrespective of the open area ratio, but a recirculating region does appear in several diameters downstream of the cylinder except for the case with the smallest mesh number of 30; the open area ratio is 0.50. Just downstream of the cylinder, the flow is nearly uniform and has a very small fluctuating intensity. Between the co-flowing uniform flows with the low turbulence, free shear layers are developing, which eventually roll up to discrete vortex streets at several diameters downstream of the cylinder, forming an isolated, slender recirculating region along the center line. Both the mean streamwise velocity and the turbulent intensity increase rapidly at the distance proportional to the open area ratio of screen gauze. Further downstream, the mean center-line velocity approaches asymptotically to the same value as in the wake of the normal cylinder.

1 Introduction

The non-slip and non-penetrate conditions at the wall has a decisive effect on the behavior of the flow past a blunt body. Many attempts have been devoted, therefore, to control the flows by manipulating some or less these conditions. It is very interesting, therefore, to know what will happen when the wall of a “blunt body” has permeability. We can find several kinds of such obstacles in the practical purpose, for example, tall towers for a telecommunication relay station. Newly designed buildings often have some louver-like porous “fence” for both practical and aesthetic reasons. The flow past a cylindrical structure with permeable walls has also a close relation to the wind dynamics of trees and hence to a useful method for wind dumping device, especially in an urban area.

Permeable walls are realized by screen gauze in this study. Screen gauzes are well known devices to reduce turbulence and flow irregularity in many practical and experimental apparatus. A lot of studies have been performed concerning the characteristics of flow past screen gauze equipped crossing the whole section in a conduit (1). But the flow past obstacles made of screen gauze has not been studied so far. A related similar flow was referred in the review paper by Perterson et al. (2). Higuchi and Takahashi (3) studied the wakes behind two-dimensional flat- and curved-grid wind tunnel models concerning the parachute inflation problems. Flow past porous plate was also studied by the discrete vortex point method by Inoue (4).

The aim of this study is to clarify fundamental characteristics of the flow past a permeable, cylindrical obstacle in a uniform flow.

2 Experimental apparatus and method

A permeable wall was realized by fine screen gauzes with mesh number of 30, 50, 80 or 120; the open area ratio is 0.50, 0.42, 0.47 or 0.39,
respectively. The screen gauze is attached around 6 circular frame-rims which are fixed through their centers by a circular cylinder of 6 mm in diameter, as shown in Fig. 1. Each frame-rim has a slit at the trailing edge and a 0.5 mm x 2 mm filler gauge goes through the slits parallel to the frame axis. A strip of rolled screen gauze was closed by gluing it on this filler gauge. The outer diameter of the hollow cylinder is nominally 50 mm and a length of 500 mm. The permeable cylinder thus constructed is not strictly circular where there are no frame-rims and elongated slightly to the flow direction.

The hollow cylinder was placed vertically in the center plane of a 0.5 m x 0.5 m square test-section with 1.2 m length, all made of a transparent plexi-glass, connected to the exit nozzle of an Eiffel type wind tunnel. The streamwise position of the cylinder is 300 mm from the nozzle exit. A definition sketch of the flow field, the coordinate system and several symbols used are shown in Fig. 2.

Velocity measurements were carried out using a four-beam two-color LDV system (DANTEC) with a controlling and processing hardware (57N21 and 57N35) and a software (BURST ware ver.3.20). A 2-D fiber probe (60X63) with 300 mm focal length and 38 mm beam separation has a control volume of approximately 0.09 mm in diameter and 1.4 mm in length and is carried on a 3-D traversing mechanism with the positioning accuracy of 4 µm (y and z-axes) and 50 µm (x-axis). The beams are 40 MHz frequency shifted by Bragg cells (57N14).

The flow is seeded with liquid particles having an average diameter of nearly 1 µm generated by a fog generator (SAFEX) at the inlet of the wind tunnel. By adjusting the fog concentration and the hardware parameters, most LDV data were taken under the bursting rate of about 1 kHz. Either 20 x 10^3 data acquisition or 25 seconds time elapsed is used for the completion of data acquisition at a point.

In this study, no meaningful measurements could be done inside the cylinder because of the size of the cylinder and the laser beam separation.
The Strouhal number of rolling-up vortices was obtained from FFT analysis of a hot wire signal. A constant temperature hot-wire anemometer (DANTEC 90C10) with a standard I-probe (DANTEC 55R02) was used. The hot-wire probe was placed at positions in the cylinder wake where it was confirmed from the LDV velocity histograms that no flow reversal takes place instantaneously.

3 Results and discussion

As explained in the preceding section, the permeable cylinder is slightly distorted transversely. First of all, therefore, the two-dimensionality of the flow was checked. Fig. 3 shows the variation of the streamwise mean velocity and fluctuating intensity in the symmetry plane of the cylinder with a 50-mesh screen under a free stream velocity of 10 m/s, compared with each other for those obtained at several z-positions. The distributions in different transverse sections coincide fairly well and the flow can be considered practically two-dimensional. The flow situations for cylinders with other screen gauzes show nearly the same tendency.

Fig. 4 shows the transverse distributions of mean velocities U, V and fluctuating intensities u', v' in the cross-section just downstream of the cylinder with a 50-mesh screen. There can be found no region of flow reversal, even instantaneously in this region, which can be confirmed only by the instantaneous velocity histogram at each measuring position. In the central portion of the wake, the mean flow is nearly uniform and has very small turbulence intensity. As can be seen in the distributions of u' and v' near the center, the effect of the frame axis appears as small peaks, which become more evident for the case with a 30-mesh screen and less for a 120-mesh. The over-all flow character is not affected by the presence of the axis even for the case with a 30-mesh screen.

Fig. 5 shows similar distributions at x/D=4 for the same cylinder. A small but clear negative mean streamwise velocity near the center line can be observed, together with the very large transverse fluctuation intensity.

Figs. 6 (a), (b). Variations of mean velocity (a) and fluctuating intensities (b) along center line, Mesh 50.
Figs. 7 (a), (b), (c). Vector plots of mean velocity field and streamwise velocity histograms.
The character of the flow past screen-gauze cylinder can be well described by the variations of the mean streamwise velocity and turbulent intensity along the center line, Figs. 6 (a), (b), together with the aids of the mean velocity vector diagrams obtained at various x-sections, Figs. 7 (a), (b), (c), (d) which include the instantaneous velocity histograms at typical positions on the center line. In Figs. 6, the corresponding results of mean velocity and fluctuating intensity for a normal circular cylinder are indicated by solid curves.

A great difference in the wake of the permeable cylinder from the normal one is clear, i.e. the flow does not form the separated recirculating region just downstream the cylinder. The flow penetrated through the permeable cylinder co-flows with the free stream over several diameters downstream. The velocity decreases almost linearly further downstream and the flow reversal does occur in a relatively small slender region near the center line, rather suddenly. Velocity histograms at corresponding points show evidently the reverse flow.

In the course of the linear velocity decrease, the fluctuating intensities $u'$ and $v'$ remain to very small levels downstream the cylinder. They begin to grow rapidly in accordance with the onset of flow reversal.

These associated phenomena can be consistently understood only from the behavior of the rolling-up of the surrounding shear layers into an isolated vortex.

It is very interesting to know that though the maximum intensity is significantly smaller than that for a normal cylinder, the streamwise turbulence intensity approaches nearly the same asymptotic value. It should be also noted that the approaching potential flow upstream of the cylinder is decelerated considerably in the range of a few x/D.

The effect of screen gauze solidity on the flow character is shown compared in Figs. 8 (a) and (b). As can be found in the figures, the flow changes considerably with the solidity, though it varies only from 0.39 to 0.50. The penetrated positive mean velocity becomes smaller with proportional to the solidity and the onset of flow reversal.
reversal moves progressively upstream position, but the extent of flow reversal does not change so much both in magnitude and scale.

The magnitude of transverse fluctuation $v'$ in the wake of a normal cylinder is roughly twice the streamwise counterpart, as is shown in the figure. A similar relation can be found for the 50- and 80-meshes, but not for the 30- and 120-meshes, indicating a complex effect of solidity on the rolling-up process of the shear layer.

In contrast to the wake region, the flow upstream of the cylinder would not be affected by the solidity of the screen gauze and also by the free stream velocity, as shown in Figs. 9 (a), (b) which show the effect of the free stream velocity on the variation of mean velocity along the center line for the cylinder with 120- and 50-mesh screens, respectively. As can be seen in these figures, the rolling-up position moves progressively downstream with increasing the free stream velocity, and the magnitude of flow reversal becomes less intensive, but the over-all flow structure does not change for the free stream velocities from 8 m/s to 18 m/s.

The rolling-up frequency of the shear layer was obtained from the FFT analysis of hot-wire signals at several positions where it was confirmed from the LDV velocity histograms that no flow reversal occurs at all even instantaneously.

The Strouhal numbers thus obtained in the wake of the cylinders with various screen gauze are shown plotted against the free stream velocity in Fig. 10. The dependence of Strouhal number on the free stream velocity seems to be slight but indicate a complex nature as seen for 120- and 50-mesh screens. The dependence on the solidity is not monotonous and seems to be affected by the turbulence character.

4 Concluding remarks

The flow past a permeable hollow cylinder in uniform flow was investigated by means of a 2D LDV under mainly a free stream velocity of 10 m/s.

The on-coming flow goes through a permeable hollow cylinder and no flow separation on a large scale occurs in the whole flow field. Just downstream of the cylinder, no recirculating region nor instantaneous flow reversal can be observed. It was found that the flow behavior depends significantly on the solidity of the screen gauze and that the region of flow reversal downstream of the cylinder.
does occur in several diameters downstream of the cylinder except for the case with a 30-mesh screen.
The process of rolling-up depends both on the solidity and free stream velocity. The flow details in the wake of the screen gauze is thus governed by the instability process of the shear layer between the co-flowing nearly uniform flow with very small turbulence. Further studies are needed to elucidate the flow mechanism.

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References