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Flow Control Effects of Active Suction through a Structured Porous Surface on Cylinder Wake

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SUMMARY:
A series of wind tunnel tests were conducted to investigate flow control effects of active suction through a structured porous surface on cylinder wake. The Reynolds number *Re* based on the cylinder diameter was set to 10 000, which located in the subcritical region. The structured porous surface embedded in the cylinder wall was made by 3-D printing, and holes were uniformly distributed on the leeward part of the cylinder. Various non-dimensional suction coefficients C_μ were set for active suction control. Coefficients C_μ were affected by the suction flow rate and the total surface area of holes. Wake flow measurement was achieved by a 2-D particle image velocimetry (PIV) system. Experimental results show that the control method combing active and passive strategies can change instantaneous and time-averaged cylinder wake flow characteristics, reduced-order model (ROM) properties and the Kármán vortex shedding process. Vortex shedding periods and shear-layer interaction patterns in the cylinder wake are changed.

Keywords: cylinder wake, flow control, structured porous surface

1. INTRODUCTION

Flow-induced vibration (FIV) of a circular cylinder is a common phenomenon in the field of wind engineering. FIV can cause fatigue or damage for cylindrical components of wind-susceptible structures (Derakhshandeh and Alam, 2019). For almost all engineering structures immersed in the regular wind environment, the Reynolds number (*Re*) locates in the subcritical region. In this *Re* region, the cylinder wake flow is unstable and sophisticated. Specifically, there is a series of periodically shedding vortices, known as the Kármán vortex street. It is of necessity to control FIV of the cylinder, especially the periodical vortex shedding process (Choi et al., 2008). Recently, coating a cylinder with porous media has been developed as a useful passive flow control method. Some researches focused on flow control effects of *randomized* porous media. However, it is inconvenient to modify and optimize porous parameters and investigate flow control mechanism. Arcondoulis et al. (2019) utilized 3-D printing technique to produce porous media with *structured* holes distributed inside the porous section of a cylinder. It was found that this method can control tonal noises and the vortex shedding process in the cylinder wake.

In this research, we focus on flow control effects of active suction through a structured porous surface with various suction momentum on a circular cylinder by wind tunnel tests. The wake flow measurement was achieved by a 2-D particle image velocimetry (PIV) system. Instantaneous, time-averaged and reduced-order model (ROM) flow characteristics are analyzed and compared with the baseline case, i.e. the uncontrolled cylinder.

2. EXPERIMENTAL SETUP

The experiment was conducted in a closed-circuit wind tunnel (SMC-WT1) in the Joint Laboratory of Wind Tunnel and Wave Flume, Harbin Institute of Technology, China. The length of the test section was 1000 mm and both the side lengths of width and height were equal to 505 mm. The incoming flow velocity U_∞ was fixed at 3.0 m/s and the corresponding turbulence intensity was less than 0.30 %. An overview of the cylinder test model and the detail of the structured porous section produced by 3-D printing are illustrated in Fig. 1. The cylinder included three parts: two hollow plexiglass tubes on the lateral sides and a porous section in the middle. The spanwise length of the cylinder was $L = 504$ mm and that of the porous section was $L_0 = 64$ mm. The active suction control was achieved by an external draught fan through an air vent. The cylinder outer diameter was $D = 50$ mm and the inner diameter was $d = 25$ mm. The porous section thickness was $t = 25$ mm and the thickness-diameter ratio $t/D = 0.5$. The structured porous surface was located on the leeward half part of the cylinder and the porosity was 30.2 %. The Reynolds number was $Re = 10000$ that located in the subcritical region.

The active suction was controlled by the fan and the suction flow rate Q ranged from 24 to 216 L/min. Corresponding non-dimensional suction coefficient C_μ ranged from 0.0034 to 0.2773, which was defined as:

$$C_\mu = \left(\frac{Q}{S_\mathrm{h} U_\infty}\right)^2 = \left(\frac{U_\mathrm{h}}{U_\infty}\right)^2, \tag{1}$$

where S_h was the total surface area of holes and U_h the mean suction velocity at each hole.

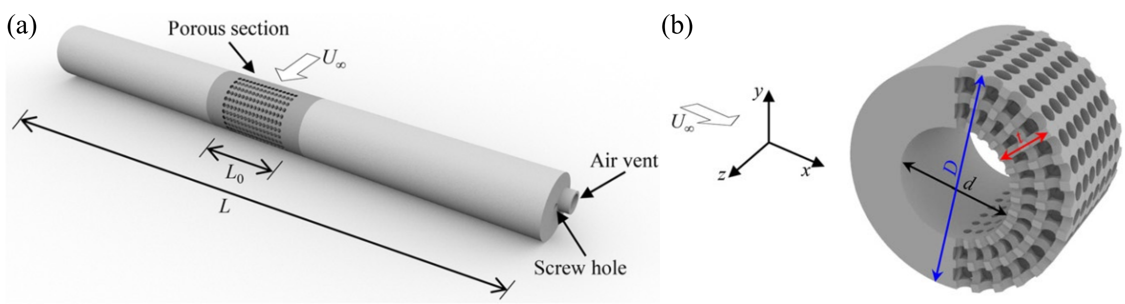

Figure 1. Cylinder test model with structured porous surface. (a) The whole circular cylinder test model with a porous section. (b) The detail of the structured porous section. (Yu et al., 2021)

The cylinder wake flow was measured by a 2-D PIV system, as shown in Fig. 2. The system included a high-speed double-shutter CMOS camera, digital delay generator and doubles-pulsed Nd:YAG laser machine. The frame rate of the camera was 200 fps (i.e. the sampling frequency $f_\mathrm{s} = 200$ Hz) and the time interval between two laser pulses was $\delta t = 0.1$ ms. The field of view (FoV) was 1480×1600 pixel and 1 pixel was equal to 0.2 mm.

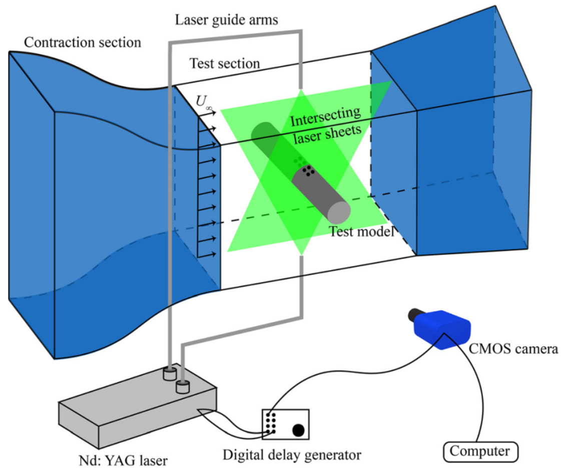

Figure 2. An overview of the wind tunnel test and PIV system.

3. RESULTS AND DISCUSSION

Figure 3 shows instantaneous vorticity distributions of typical test cases. There is a series of anti-symmetric vortices that exist in the wake of the baseline case, and form Kármán vortex streets. For the controlled case with $C_\mu = 0.0856$, the formation of anti-symmetric vortices is suppressed and the pattern of shear layers is transformed. The vortex shedding period is also changed. When the momentum coefficient C_μ increases to 0.2773, large scale vortices are invisible in the wake region and periodicity is unapparent.

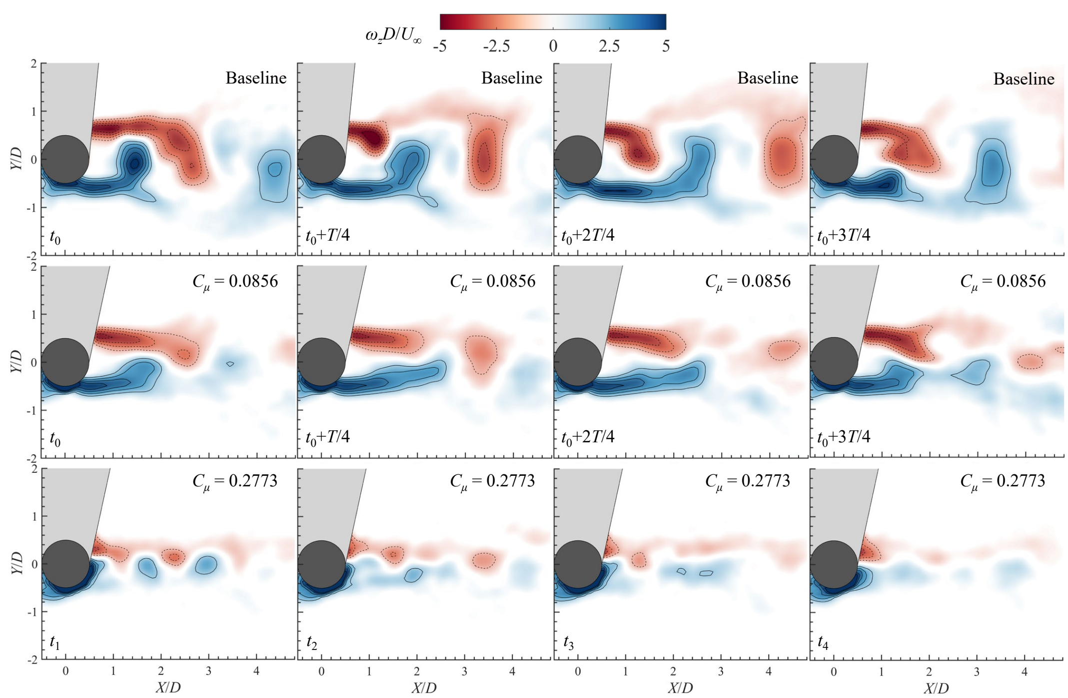

Figure 3. Instantaneous vorticity distribution within a single cycle.

Proper orthogonal decomposition (POD) is a common and useful kind of reduced-order model (ROM). Individual and cumulative energy proportions of the first 100 POD modes are shown in

Fig. 4. For the baseline case, the energy of the cylinder wake flow is mainly dominated by the first few modes. Under the control of active suction through the porous surface and with the development of C_μ, the energy proportions of the first few POD modes are suppressed and that of other modes are strengthened. It demonstrates that large-scale coherent structures of the wake flow are suppressed and small-scales structures are strengthened.

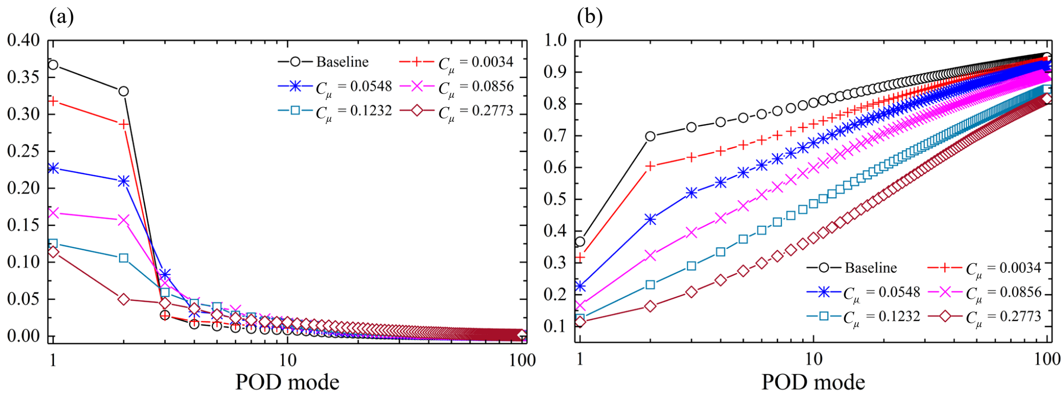

Figure 4. Individual (a) and cumulative (b) energy proportions of the first 100 POD modes.

Experimental results also demonstrate that the flow control method can modify distributions of wake velocity power spectrum, time-averaged streamlines and statistic flow characteristics such as turbulence kinetic energy and Reynolds stresses, as well as temporal and spatial POD properties. Deficits in velocity profiles are recovered and the wake flow instability is restrained.

4. CONCLUSIONS

A flow control scheme that combines passive and active methods for a circular cylinder is investigated by experiments. Control effects of active suction with different momentum coefficients C_μ through a structured porous surface made by 3-D printing are compared. POD modal energy and temporal and spatial properties are changed under the control action. Frequency-domain, time-averaged and statistic flow characteristics are also modified. Experimental results indicate that the flow control method combining active suction and structured porous surface can significantly change and modify cylinder wake properties.

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REFERENCES

Arcondoulis, E. J. G., Liu, Y., Li, Z., Yang, Y., and Wang, Y., 2019. Structured Porous Material Design for Passive Flow and Noise Control of Cylinders in Uniform Flow. Materials 12, 2905.

Choi, H., Jeon, W.-P., and Kim, J., 2008. Control of Flow Over a Bluff Body. Annual Review of Fluid Mechanics 40, 113–139.

Derakhshandeh, J. F. and Alam, M. M., 2019. A review of bluff body wakes. Ocean Engineering 182, 475–488.

Yu, H., Xu, Z., Chen, W.-L., Li, H., and Gao, D., 2021. Attenuation of vortex street by suction through the structured porous surface. Physics of Fluids 33, 125101.