Flexibility effect on flows near free end surface of finite cylinder

FLEXIBILITY EFFECT ON FLOWS NEAR FREE END SURFACE OF FINITE CYLINDER

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KEYWORDS: Flexible cylinder; Stiffness; Particle Image Velocimetry

ABSTRACT: *Flexible and deformable structures are common in nature and bio-mimetic applications. The understanding of flows around structures is essential for optimizing structural design. The stiffness of structures strongly influences the flows. In present study, the flexibility effect on the flow is experimentally observed. Cylinders having various stiffness from 0.274 to 0.582 Nmm were made by changing by changing base/agent ratios of polydimethylsiloxane (PDMS). The flow is investigated using time-resolved particle image velocimetry (PIV) technique. The cylinder motion strongly influences on flows near the free end surface, and the length of near wake are affected by the magnitude of cylinder vibration. Vortex shedding near free end surface occurs, and these flow structures only propagate downstream behind the most flexible cylinders having relatively weak cylinder motion. These results could be used as basic data in the design process of bio-inspired structural applications, and relevant CFD analyses.*

1 Introduction

The flow around structures is a typical problem both in engineering fields and in nature. The flow is strongly related to aerodynamic forces on structures. Compared to typical bluff bodies in engineering, deformability by loading is the unique characteristics of structures in nature [1. 2]. In bio-mimetic applications, flexible structures are commonly employed, and information about flows is required to optimize design parameters. Although many studies have been conducted on the flow around finite cylinders, the cylinders tested in these studies were rigid. In recent, several works about flows around flexible bodies have been conducted [2-5]. However, these studies have focused on qualitative flow information [2] or quantitative flow information behind flexible flat plates [3-5], which are quite different from those of circular cylinders. It is known that flows of flexible deformable bodies are strongly related with various parameters such as Reynolds number, aspect ratio, frontal area, mass ratio, and flexibility. In this study, flows near free end surface of finite cylinders having various flexural stiffness for investigating the effect of flexibility on flows.

2 Methods

Flow field information is obtained using a time-resolved particle image velocimetry (PIV) technique. As shown in Fig. 1, the experiments were carried out in a closed-type wind tunnel with a test section of 0.15 m (width) × 0.15 m (height) × 1.8 m (length). Cylinder models have length L = 60 mm, diameter D = 3 mm, and a corresponding aspect ratio of L/D = 20. A flexible cylinder models were made of PDMS, and the stiffness is controlled by changing base/agent ratios of polydimethylsiloxane (PDMS). Rotational stiffness (κ) varies from 0.274 to 0.582 Nmm. The freestream velocity was fixed at U_0 = 3.5 m/s. The corresponding Reynolds number (*Re*) was 673, based on the cylinder diameter.

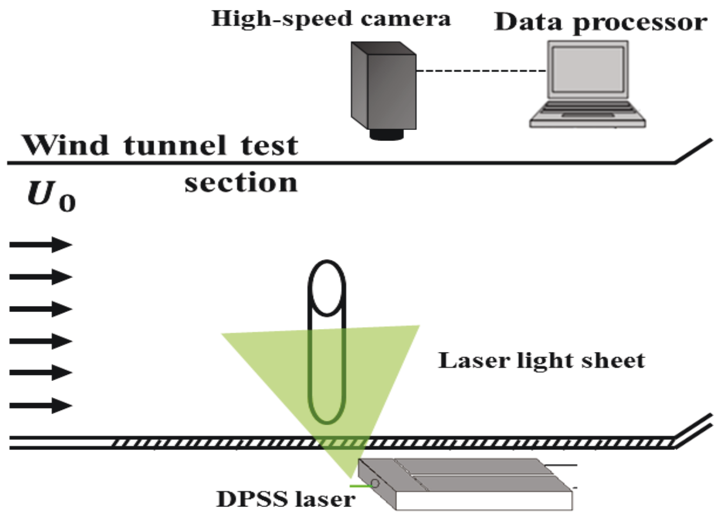

Fig. 1 Schematic diagram of experimental set-up.

3 Results

Figures 2(a) and (b) show the flow visualization results behind the rigid and flexible cylinders, respectively. The flow near free end surface is mainly governed by the downwash flow and sideways vortex shedding. For the long cylinder, the downwash flow and necklace vortex contributed to the upper and lower side regions of the cylinder, respectively. Therefore, the vortex shedding, which is similar to that which occurred behind the 2D circular cylinder, is observed at $z = -0.5L$ for both flexible and rigid cylinders. Therefore, at this spanwise position, the flow pattern behind the flexible cylinder resembles that behind the rigid cylinder. The flows near the free end surface ($z/D = -1$) of the rigid cylinder are quite different from the flows at the cylinder mid-span ($z = -0.5L$). The shedding of large-scale vortices is diminished and small-scale vortices in the near wake are observed due to the descending separated flows. As the distance from the free end surface increased, the size of the wake region grows. In contrast, small-scale vortices are not observed behind the flexible cylinder, due to weak separated downwash flows. The flow patterns behind the flexible cylinder are nearly consistent, regardless of the height

Typical instantaneous velocity vectors and streamwise velocity (U) contours at $z/D = -1$ are represented in Fig. 3. For most stiffen cylinder ($\kappa = 0.582$ Nmm), small scale vortices are observed only in the near wake. Due to higher vibration along streamwise direction causing a stronger downward flow, the wake length in moderate case ($\kappa = 0.346$ Nmm) is shortened. For the most flexible cylinder ($\kappa = 0.274$ Nmm), large scale vortex shedding occurs due to larger motion along cross-flow direction. These flow structures propagate downstream by following free stream flows. This large vortex shedding is also observed in near wake for the moderate case, but no downstream convection occurs due to relatively strong downwash flows due to higher vibration along streamwise direction.

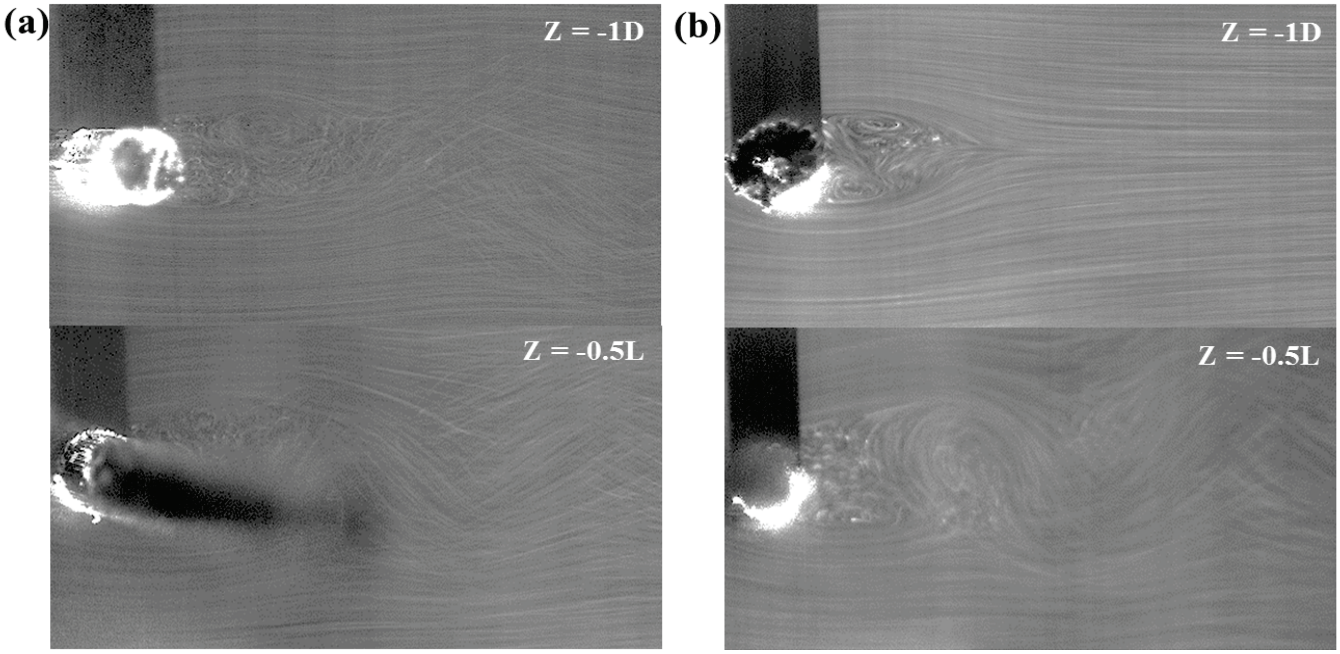

Fig. 2 Visualized flows around the (a) rigid and (b) flexible cylinders.

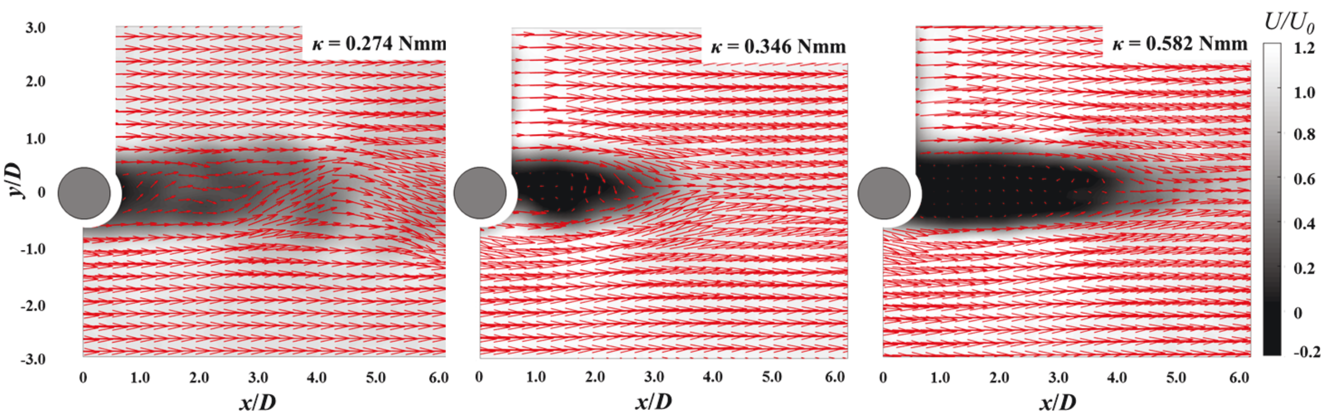

Fig. 3 Instantaneous velocity vectors and streamwise vorticity (U) contours at z/D = -1.

4 Conclusion

In this study, flows near free end surface of flexible cylinders having three different rotational stiffness are experimentally observed using a time-resolved PIV technique. Flow structures such as wake length and vortex structures near free end surface are strongly influenced by the flexibility of cylinders. As stiffness decreases, large scale vortex shedding occurs and stronger downstream convection is observed. This study would be used as the basic data for the design process of bio-inspired structures, and relevant CFD analyses.

Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (NRF-2017R1C1B5017479) and Human Resources Program in Energy Technology of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea. (No. 20174030201620).

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