Flow Characteristics behind Two Unequal Circular Cylinders in Tandem Arrangement

Yangyang Gao, Stephane Etienne, Dingyong Yu and Soon Keat Tan

a, College of Engineering, Ocean University of China, Qingdao, Shandong, China
b, Mechanical Engineering Department, Ecole Polytechnique de Montreal, Montreal, Canada
c, DHI-NTU Centre, Nanyang Technological University, Singapore

ABSTRACT

Flow characteristics behind two tandem circular cylinders with unequal diameters have been investigated based on both experiments and numerical simulations. Time-averaged patterns of velocity, vorticity, normalized Reynolds stress contours and streamline topology have been obtained by the particle image velocimetry technique (PIV) to elucidate different flow patterns. In order to give a better understanding, finite element method has been used to simulate the flow around unequal diameters cylinders placed in tandem. Three flow regimes were identified based on the time-averaged and instantaneous field, such as single-wake shedding regime, reattachment regime and co-shedding regime. In addition, force coefficients and Strouhal number are also discussed in this work to identify the flow characteristics.

KEY WORDS: Tandem Circular cylinder; unequal diameter; particle-image velocimetry, finite element method; flow pattern.

INTRODUCTION

Flow around two circular cylinders in tandem configuration are relevant to engineering applications, such as offshore platform, tube bundles in heat exchangers, bridge piers and chimney stacks. Most of the investigations on two tandem configuration refer to two cylinders of equal diameter (Zdravovich, 1977, 1987; Bearman and Wadcock, 1973; Williamson, 1985; Mittal et al., 1997; Sumner et al., 1999, 2000; Meneghini et al., 2001; Lin et al., 2002; Jester and Kallinderis, 2003; Alam et al., 2003; Sharman et al., 2005). Three regimes have been identified based on the behavior of spacing ratio for two equal circular cylinders in a tandem arrangement by Zdravovich (1977, 1987). For pitch ratios in the range of 1 <L/D<1.2-1.8 (where L is the distance between centers of the cylinders and D is the cylinder diameter), the cylinders behave as a single bluff body and the shear layers shed from the front cylinder do not reattach onto the second one. For 1.2-1.8 <L/D=3.4-3.8, the shear layers shed from the front cylinder reattach to the face of the second cylinder and vortex-shedding occurs only in the wake of the second cylinder; for pitch ratios L/D>4.0, vortex-shedding occurs both in the gap formed between the cylinders and behind the second cylinder.

Many experimental investigations were concentrated on the vortex shedding frequency based on the hot-wire measurement (Hori, 1959; Oka et al. 1972; Igarashi, 1981; Igarashi et al. 1984; Xu and Zhou, 2004). Some studies reported using the particle image velocimetry technique to analyze the flow characteristics around the two tandem cylinders. Sumner et al. (1999) identified three types of fluid behavior based on the longitudinal pitch ratio L/D: single bluff-body behavior when L/D=1; constrained streamwise growth and lateral expansion of the gap recirculation zones at small and intermediate L/D; and at larger L/D, formation of recirculation zones similar to that of a single circular cylinder.

In addition, only a handful of studies have been carried out to investigate the flow characteristic behind two tandem circular cylinders of unequal diameters. Igarashi (1982) carried out an experiment to investigate the flow characteristics of a flow around two circular cylinders of different diameters arranged in tandem. Sumner et al. (1999) and Dalton et al. (2001) investigated the suppression of vortex shedding or lift force on a circular cylinder by introducing a second smaller circular cylinder next to it. Other numerical studies, for example Zhao et al. (2005 and 2007) had been carried out to investigate the effect of the small cylinder on the flow around and forces on the two cylinders were investigated for different gap ratios and position angles. Through their laboratory investigation, Alam and Zhou (2008) showed that with decreasing d/D (where D is the downstream cylinder diameter and d is the upstream cylinder diameter), the width of the wake between the cylinders appears to narrow, and the time-averaged drag on the downstream cylinder increases, due to the less stagnant fluid or larger dynamics pressure between cylinders.

The purpose of the present study is to (1) investigate the dynamic characteristics of flow past two unequal circular cylinders in tandem configuration based on both experiment and numerical simulation; (2) establish the characteristic flow patterns based on the time-averaged flow field at different centre-to-centre spacing ratios.

EXPERIMENT SET-UP

Experiments have been conducted in the 6m long, re-circulating open