Proceedings of the Twenty-fifth (2015) International Ocean and Polar Engineering Conference **www.isope.org**
Kona, Big Island, Hawaii, USA, June 21-26, 2015

ISBN 978-1-880653-89-0; ISSN 1098-6189

Frequency and Moving Direction Effects on Lift, Drag and Vortex Mode for Flows Around an Oscillating Cylinder

Muyu Duan[1,2] and *Decheng Wan*[1 *]

1. State Key Laboratory of Ocean Engineering, School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai, China
2. Department of Ship and Port Eng. ,Jiangsu Maritime Institue, Nanjing, Jiangsu, China
*Corresponding author

ABSTRACT

This paper presents comprehensive study on forced oscillating circular cylinder at low Reynolds numbers. A series of numerical simulations are carried out on various situations of flow past an oscillating cylinder using OpenFOAM (Open Field Operation and Manipulation). Specifically, the cylinder is forced to oscillate in X direction, Y direction, and XY direction. Effects of oscillating frequency and moving direction on the lift, drag and vortex mode are analyzed emphatically. The numerical results of forced transverse vibration reproduce the phenomenon of "beating" and "lock in", and verify the different vortex modes of 2S, 2P and P+S, identified by Williamson and Roshko (1988). We continue to study an in-line oscillating cylinder and classify the results into three groups. Many interesting conclusions that are dramatically different from that of the transverse oscillations are obtained. Although there are many papers dedicated to the problem of a cylinder vibrating transverse to a fluid flow (Y-motion), there are few papers on the more practical case of forced vibration in two degrees of freedom (X,Y motion). Numerical simulations of XY motion are then carried out to study the similarity and difference with the Y motion. The paper helps us to understand comprehensively the behavior of the cylinder oscillating under different frequencies, amplitudes and directions.

KEY WORDS: frequency effects; moving-direction effects; flow dynamics; oscillating cylinder; lift and drag; wake analysis

INTRODUCTION

Any motion of a cylinder in a steady uniform flow clearly affects the flow field in the wake of the cylinder, and it also influences the fluid forces on the cylinder.

In the study of forced vibration of a cylinder, Williamson (1988) is a representative one. Williamson did controlled oscillation experiments, over a range of amplitudes (A^* up to 5.0) and wavelengths (λ^* up to 15.0). The results showed principally three vortex wake patterns, namely 2S, 2P, and P+S modes, which are relevant to the fundamental synchronization regime. The experiment was used as a benchmark and many researchers later verified the results by experiments and numerical simulations. The normalized wavelength $\lambda^* = U/(f_{ex}D)$ is a very important parameter based on the forced oscillating frequency f_{ex}. Flow past a stationary cylinder results in organized vortex shedding at a Strouhal frequency f_{st}. When the controlled excitation frequency f_{ex} is close to the Strouhal frequency f_{st}, it results in significant changes in both the wake structure and forces on the cylinder. The lock-in phenomenon occurs and the vortex shedding frequency alters to match the cylinder oscillation frequency. On the other hand, when f_{ex} is appreciably different from f_{st}, the time traces of the drag and lift coefficients show beating frequency. A plethora of studies on sinusoidal transverse oscillations have been reported in the literature, such as Bishop (1964), Koopman (1967), Staubli (1983), Carberry (2005), Leoniti (2006), Zheng Z.C. (2008) and Pham A. H. (2010), and the reviews of Williamson (2004) and Sarpkaya (2004).

Although the phenomenon of forced vibration of cylindrical body has been studied extensively, the vast majority of these studies have concentrated on transverse vibrations. However, an in-line component of motion has been shown to play a major role in VIV, as the drag force typically fluctuates at twice the frequency of the lift. Some studies have concentrated on forced in-line oscillating cylinder. Leontini J. S. (2011) studied an in-line oscillating cylinder, whose frequency of oscillation was kept equal to the vortex shedding frequency of a fixed cylinder. Other researches were concentrated on forcing frequencies at, or close to, twice the Strouhal frequency, such as Tandida (1973), Barbi (1986), Karniadakis (1989), Konstantinidis (2005, 2007). Forcing at these frequencies lead to synchronization of the vortex shedding to the oscillation frequency. Aside from the direct practical application to VIV, the problem of a controlled, sinusoidal, in-line oscillation can present a unique viewpoint in terms of wake control strategies.

As mentioned earlier, it is more practical for a cylinder to vibrate both transverse to and in line with the flow. Jeon and Gharib (2001) conducted experiments by forcing a cylinder to move both in the in-line and transverse directions. In their work, the frequency of the in-line motion is twice that of the transverse motion; thus the cylinder follows a trajectory resembling an "eight" figure. Their results indicate that, while the frequency of vortex shedding is still determined by the transverse motion, the streamwise motion controls the phase of shedding, and thus the phase of the instantaneous lift force, determining the energy transfer to the cylinder. There are other experimental