International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 32, No. 1, March 2022, pp. 74–80; https://doi.org/10.17736/ijope.2022.ts24

http://www.isope.org/publications

Experimental and Numerical Investigation of Fluid-structure Interaction for a Submerged Oscillating Cylinder in a Lock-in Region

Hassan el Sheshtawy, Mohammed Youssef, Ould el Moctar and Thomas E. Schellin
Institute of Ship Technology, Ocean Engineering and Transport Systems (ISMT), University of Duisburg-Essen
Duisburg, Germany

Vortex-induced vibration of a flexible cylinder located in a circulating water channel was investigated experimentally and numerically. The cylinder was subject to a reduced velocity flow of 5.18 at a subcritical Reynolds number of 5×10^4. Discretization errors of numerically simulated response predictions were analyzed and validated against experimental measurements. The coupled dynamic normalized transverse response of the cylinder was measured and compared with numerically simulated responses. A particle image velocimetry (PIV) technique measured the wake's flow topology. In general, the numerical simulations yielded nearly the same behavior as the experimental PIV measurements. However, using computational fluid dynamics, the computed flow separation region from the cylinder started earlier than the PIV-measured separation angle. The presented experimental and numerical results provided reliable benchmark data suitable for numerical validation of the associated fluid-structure interaction phenomena.

INTRODUCTION

The lock-in phenomenon occurs when the vortex shedding frequency is close to a natural frequency of the vibrating cylinder. When this happens, large damaging vibrations may result (el Sheshtawy, Tödter, et al., 2021), leading to a considerable reduction of the cylinder's fatigue life. Many engineering structures, such as offshore oil risers, offshore wind turbine towers, heat exchanger tubes, bridges, and factory chimneys, among others, are subject to lock-in phenomena.

For marine structures, fluid flows around pipes or tubes generate substantial structural stresses. Owing to the significance of this problem, extensive numerical and experimental investigations of flow-induced loads have been conducted to examine the wake behind a cylinder and the associated vortex-induced vibration (VIV). However, these phenomena are not completely understood scientifically.

Khalak and Williamson (1996) designed and developed an experimental procedure to test a rigid cylinder fixed at the top of a flow channel. They measured displacements and lift and drag forces for different inlet flow velocities. Khalak and Williamson (1997, 1999) used the same procedure to test the behavior of an elastic cylinder.

Structural dynamics of a cylinder in a flow of water is influenced not only by the cylinder's elasticity but also by its free end condition, be it fixed or free to move (Prastianto et al., 2009). Fujarra et al. (2001) investigated the dynamic behavior of an elastomeric cantilevered cylinder, restrained in the flow direction by a thin aluminum plate. The objective was to increase the stiffness in the inline flow direction compared to the transverse flow direction. The free end of the cylinder was fixed at the top. They compared their results with the dynamic behavior of a flexible cantilevered cylinder having the same flexibility in both directions (Fujarra et al., 2001) and rigid cylinders (Khalak and Williamson, 1999). Prastianto et al. (2009) measured the dynamic behavior of and the forces acting on a flexible free-hanging cantilevered cylinder. Their cylinder was mounted vertically, and it was clamped at its top. They used the same setup as Prastianto et al. (2009). XK Wang et al. (2017) studied the effect of VIV on a horizontally aligned cylinder, which was fully submerged and free to move only in the transverse flow direction. The associated damping remained constant. They studied the effects of different flow velocities and used particle image velocimetry (PIV) to measure the velocities and to monitor the related vortex structures. Shaharuddin and Darus (2012) tested a horizontally and a vertically orientated aluminum pipe in a small tank and compared their results with published data. Govardhan and Williamson (2000) and Sarpkaya (1995) documented a comprehensive literature review covering experimental and computational studies of VIV of cylinders in water.

Recent research of Tödter et al. (2019, 2021) experimentally studied VIV of both a fully and a partially submerged hollow cylinder situated in a circulating water channel. The two tested cylinders were made of polyvinyl chloride. They compared their results with measured accelerations obtained via a three-dimensional digital image correlation method.

Only a handful of researchers considered strongly coupled fluid-structure interaction (FSI) problems by treating the structure as a flexible entity and solving the governing equations of a discretized structure using the finite element method and the fluid flow equations using the finite volume method. As a subclass of FSI problems, VIV focuses on understanding the complex physics between a moving bluff body and the vortex shedding process, whereas FSI is a vital issue in a range of fields, such as aerodynamics, hydrodynamics, biomechanics, and flow control. The efficient numerical simulation of FSI is essential for a realistic simulation of problems of this kind. To our knowledge, only a limited number of FSI studies considered for flow past a cylinder used a continuous system method to investigate the effects on the structure. E Wang et al. (2017), Khan et al. (2017), and Jin et al. (2020), for example, performed such studies by treating the structure as a mass-spring system. Rao et al. (2012) considered this approach to be a discrete structural simplification.

Received August 17, 2021; updated and further revised manuscript received by the editors November 3, 2021. The original version (prior to the final updated and revised manuscript) was presented at the Thirty-first International Ocean and Polar Engineering Conference (ISOPE-2021), Rhodes, Greece (virtual), June 20–25, 2021.

KEY WORDS: Vortex shedding, lock-in, fluid structure interaction, particle image velocimetry measurements, oscillating cylinder, vortex-induced vibration.