

Numerical Simulation of Vortex-Induced Motion of a Circular Cylinder with Low Mass-Damping

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ABSTRACT

In this paper, our in-house RANS solver, naoe-FOAM-SJTU, developed using OpenFOAM is applied to numerically simulate the VIM of a 2-D circular cylinder with low mass-damping. The response and vortex modes of an elastically mounted rigid circular cylinder constrained to oscillate transversely to a free stream are numerically investigated. Computations are carried out for reduced velocities from 1.5 to 13, corresponding to a range of 1500 to 13000 in Reynolds number. The mass ratio is 2.4 and the mass-damping is 0.013. These parameters are set to be identical with those of the benchmarking experiment conducted by Khalak and Williamson (1996). The beating phenomenon in initial branch is supported by two peak in FFT analysis. One difference in the response of cylinder between present study and experiment results from the system's tendency to keep its earlier state. The intermittent change of vortex modes at $U^*=2.9375$, which corresponds to maximum amplitude of vibration, indicates the upper branch should be described as intermittent switching between initial and lower branch. The computational results of response of cylinder and the vortex mode in the wake are in good agreement with the experimental results except for the absence of upper branch.

KEY WORDS: Vortex-induced motion (VIM); Circular cylinder; RANS; naoe-FOAM-SJTU solver

INTRODUCTION

With increased interest in deep water offshore industry, the Vortex-Induced Vibration (VIV) and Vortex-Induced Motion (VIM) of cylindrical structures, like marine risers, draw more and more attention and research interest. The VIV can cause great fatigue damage to these structures and thus lead to great casualty in ocean engineering.

Recently, many researches have been conducted on VIV of an elastically mounted cylinder at low mass damping. Among them, Prof. Williamson's group has made a series of experiments (Khalak and Williamson, 1996; Khalak and Williamson, 1999; Govardhan and Williamson, 2000). They found that for a cylinder with low mass ratio m^* and damping ratio ζ , its response has two branches of resonance, namely the upper branch and lower branch. The phase angle between lift force and cylinder response jumps approximately from 0° at upper branch to 180° at lower branch. 2S mode (two single vortices shed per cycle) was found at initial branch in the experiment, while 2P mode (two pair vortices shed per cycle) was found at lower branch. For the upper branch, 2P mode was also found, but the second vortex of each pair was much weaker and quickly disappear.

As the computer hardware and computing technology quickly develops, numerical computation has become a common method to study VIV and to predict its occurrence in ocean engineering. Although Direct Numerical Simulation (DNS) and Large Eddy Simulation (LES) can give more detail about the flow field especially near the cylinder surface compared to Reynolds-averaged Navier-Stokes (RANS), RANS can be less time-consuming and thus more applicable as design tools. Guilmineau and Queutey (2004) simulated the experiment conducted by Khalak and Williamson (1996). Pan (2007) conducted a 2-D RANS simulation of VIV of a cylinder with low mass-damping and concluded that the assumption of fully spanwise correlation in 2-D computation and the character of erasing random feature in RANS are responsible for the missing of upper branch in the simulation. Wanderley (2008) used a slightly compressible RANS code to simulate the same experiment, and got remarkable agreement with the experiment results.

In this paper, a series of simulation on the response of an elastically mounted cylinder under different reduced velocity U^* (U^* is defined as $U^*=U/f_n d$, where U is the flow speed, f_n is the natural frequency of the structure in vacuum and d is the diameter of the cylinder). Computations are carried out for reduced velocities from 1.5 to 13,