Study on Energy Harvesting of Vortex-Induced Vibration of Cylinders with Different Section Shapes

Considering Nonlinear Damping

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ABSTRACT

As one of the ways to obtain ocean current energy, vortex-induced vibration (VIV) can utilize the power of ocean currents at lower velocities. In this study, the error between simulation and experiment is improved by introducing a nonlinear damping term in the simulation, which is verified by analyzing the influence of the triangular section vibrator on VIV. Combined with other scholars’ physical experiments, the effects of different cross-sectional shapes on the characteristics and energy conversion efficiency of the vortex-induced vibration are discussed. And the vortex pattern, vibration frequency, amplitude, and energy capture efficiency are analyzed. The results show that the simulation considering the influence of nonlinear damping, can significantly reduce the error between the simulation and the experimental results; The triangular-like section vibrator has apparent advantage in energy conversion efficiency. The numerical results in this research provide reliable benchmark data and a new optimization scheme for the numerical verification of vortex-induced vibration.

KEYWORDS: Flow-induced vibration; Nonlinear damping; Numerical simulation; Conversion efficiency.

INTRODUCTION

In recent years, growing concerns about energy, resources, and the environment have driven the development of renewable energy technologies. Ocean hydrokinetic energy is one of the most valued sources of potential energy. Different converters have recently been developed to harvest energy from oceans and rivers. Currently, the main form of ocean energy power generation is a hydro turbine, but the construction environment and construction cost restrict the power generation of a hydro turbine. Therefore, vortex-induced vibration power generation equipment that can extract energy in an extensive range of flow rates and has low construction costs has become a potential technology. It can bring substantial economic benefits. Regarding vortex-induced vibrations, Bernitsas, M. M (2008) summarizes many research records with clear evidence for this phenomenon. Vortex-induced vibration (VIV) and galloping are the most common FIM phenomena. VIV appears first with an increasing flow rate. Flow-induced motion (FIM) has harvested hydrokinetic energy from low-velocity ocean currents. Govardhan R and Williamson C H K. (2002) proposed the existence of a critical mass and an infinite resonance state in the VIV. They studied the VIV in the lateral direction of the vibrator without considering the structural restoring force. Khalak (1999) summarized the response range of the vibrator in the VIV region and found three branches. Williamson (1988) proposed common types of vortex leakage of VIV, such as 2S, 2P, etc. Based on these studies, the VIVACE (Vortex Induced Vibration Aquatic Clean Energy) converter was invented by Bernitsas, M. M. (2008) et al., University of Michigan. This transducer uses VIV to harness the energy of ocean currents at low flow rates. Based on this experiment, Hai Sun (2016) studied that a single cylindrical element can utilize the power of a flow as slow as 0.3946 m/s, and there is no upper limit. Khalak A (1997) and Zhang B (2018) studied the effects of different aspect ratios on FIM response and hydrodynamic energy conversion and derived the optimal aspect ratio for energy harvesting.

However, galloping is a nonlinear vibration compared with VIV, it needs to be more accurate to consider the effect of linear damping on galloping. Lau S L (1981) linearized the nonlinear vibration. The method is an incremental harmonic balance method, and each step requires a linearized equation. S. J. Elliott (2015) studied nonlinear functions of damping forces in mechanical systems. Close-form solutions with equivalent linear dampers are obtained for single-degree-of-freedom systems with low-order nonlinear dampers. Neild S A (2011) studied vibration problems that are nonlinear in nature. Using average analysis requires converting the second-order equations of motion to first-order form. A more straightforward form and improved accuracy can be obtained using second-order methods. The above research proves the necessity of considering nonlinear damping when the motion amplitude is large. At the same time, galloping, which is more severe than VIV, is a high-amplitude, low-frequency FIM phenomenon. Galloping is an instability phenomenon caused by geometrical asymmetry of the vibrator cross-section or upstream turbulence. It results in an infinite magnitude response. Therefore, it is essential to select a vibrator with a suitable shape to generate electricity by using the galloping phenomenon. Park H (2013) investigated the effect of local surface roughness on the enhancement of fluid motion of a rigid cylinder over a spring. Ding L (2015) studied the flow-induced motion and energy harvesting of blunt bodies with different cross-sections and concluded that PTC cylinders and trapezoids have better energy harvesting performance in FIM. Zhang B (2019) and Lian J (2017) studied the efficiency of vibrator VIV with different cross-sections. In the asynchronous region, the power and