Vortex-induced vibration of a fluid-conveying riser in shear flow with a diffusive wake oscillator model

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ABSTRACT

Vortex-induced vibration of marine risers has been extensively studied due to its importance in offshore engineering. The van der Pol nonlinear wake oscillator has been widely used to model the fluid-structure interaction between the oscillating riser and the time-varying hydrodynamic force on the riser due to vortex-shedding both under uniform and shear flow. The effects of internal fluid transported by the riser have also been receiving increasing attention. This work analyzes the vortex-induced vibration of a top-tensioned vertical riser transporting internal fluid in linearly shear flow using, for the first time, a diffusive van der Pol wake oscillator and the generalized integral transform technique. The transversal deflection of the riser is modeled as an Euler-Bernoulli beam with space-varying tension. The hydrodynamics force on the riser is modeled by a diffusive van der Pol nonlinear wake oscillator that includes the longitudinal variation of the vortex shedding from the riser in a linearly shear flow. The coupled system of nonlinear partial differential equations is integral transformed into a nonlinear system of ordinary differential equations in time, which is truncated at a finite order to allow numerical solutions using well-established algorithms. The effects of the sea current speed and the internal flow speed on the vortex-induced vibration of the riser are investigated parametrically. It is shown that the mode numbers of the riser vibration is predominantly affected by an increasing sea current velocity. For a given sea current velocity, the riser vibration becomes chaotic when the dimensionless internal fluid velocity increases from 0.2 to 0.4.

KEY WORDS: Marine riser; Vortex-induced vibration; Wake oscillator model; Variable riser tension; Fluid-conveying riser; Integral transforms.

INTRODUCTION

Vortex-induced vibration (VIV) of marine risers has been extensively studied due to its importance in offshore engineering (Huang et al., 2021). Nonlinear wake oscillators have been widely used to model the fluid-structure interaction between the oscillating riser and the time-varying hydrodynamic force on the riser due to vortex-shedding both under uniform and shear flow (Facchinetti et al., 2002, 2004; Gu et al., 2012). Gu et al. (2012) predicted the dynamic response of the VIV of a vertical riser using a wake oscillator model and the generalized integral transform technique. Gao et al. (2022) analyzed numerically the VIV of a marine riser with variable tension and under three types of shear current flow using a wake oscillator and the finite difference method. The effects of internal fluid transported by the riser have also been receiving increasing attention (Dai et al., 2014). He et al. (2017) analyzed theoretically the nonlinear dynamics of a fluid-conveying pipe under the combined action of cross-flow and top-end excitations. Zhang et al. (2018) investigated the VIV of a fluid-conveying marine riser under the action of harmonically varying tension using the finite element method.

Despite the wide use of nonlinear wake oscillator models in studies of VIV, the axial interaction of the flow structure has not received wide attention. The concept of a diffusive wake oscillator was first proposed by Professor Mike Gaster to interpret experimental results of vortex shedding from slender cones at low Reynolds numbers (Gaster, 1969). Skop and Balasubramanian (1995) obtained quantitative agreement between the predictions of the diffusive van der Pol oscillator and experimental data of vortex shedding in linearly shear flow. Facchinetti et al. (2002) showed that the diffusive interaction along the continuously distributed van der Pol oscillators is able to model cellular vortex shedding in shear flow. Mathelin and de Langre (2005) modeled rigid and flexible cables using a distribution of nonlinear van der Pol oscillators with diffusion. Srinil (2011) analyzed the VIV of a variable-tensioned riser in linearly shear currents with a different forcing term in the diffusive van der Pol wake oscillator. While the hydrodynamic forcing term in the van der Pol wake used by Facchinetti et al. (2002) and Mathelin and de Langre (2005) is directly proportional to the local acceleration of the riser, the hydrodynamic forcing term in the van der Pol wake used by Srinil (2011) is directly proportional to the local velocity of the riser.

The generalized integral transform technique has been increasingly used in solving fluid-structure interaction and vortex-induced vibration problems (Gu et al., 2012, 2013; An and Su, 2015, An and Su; An, Duan, and Su, An et al.; An et al., 2020). This work analyzes the vortex-induced