Journal of Fluids and Structures 83 (2018) 1–26

Contents lists available at ScienceDirect

Journal of Fluids and Structures

journal homepage: www.elsevier.com/locate/jfs

Passive control of vortex-induced vibration by spanwise grooves

Y.Z. Law [a], R.K. Jaiman [b,*]

[a] Department of Mechanical Engineering, National University of Singapore, Singapore
[b] Department of Mechanical Engineering, University of British Columbia, Vancouver, Canada

HIGHLIGHTS

- A new staggered spanwise groove device for VIV control and drag reduction.
- Comparison of staggered groove with helical groove and plain cylinder.
- Mechanism of VIV suppression and drag reduction via spanwise grooves.
- Quantification of spanwise cross-correlation and three-dimensionality.
- Broadening of frequency spectra of hydrodynamic forces.

ARTICLE INFO

Article history:
Received 2 March 2018
Received in revised form 3 July 2018
Accepted 16 August 2018

Keywords:
Vortex-induced vibration
Passive control
Staggered grooves
Helical grooves
Spanwise correlation
Frequency broadening

ABSTRACT

The objective of this numerical study is to investigate the effect of spanwise grooves on the suppression of vortex-induced vibration (VIV) and the reduction of drag force. For this purpose, we consider a standard configuration of the elastically mounted circular cylinder, which is free to vibrate in both streamwise and transverse directions with identical natural frequency. We introduce a novel staggered groove configuration whose geometry is especially designed by offsetting the cross-sectional portion of the cylinder continuously along the spanwise direction. We assess the characteristic VIV responses of the proposed staggered groove configuration against the helical surface grooves for the identical dimensions and physical conditions. The staggered and helical groove configurations differ only in their arrangement of cross-section geometry along the spanwise direction. Three-dimensional coupled fluid–structure simulations are conducted at low mass and damping values with moderate Reynolds number of $Re = 4800$. The effective width and the depth of surface grooves are determined to characterize the size effects for the assessment of staggered and helical groove configurations. Results show that the staggered groove configuration is effective in suppressing VIV, wherein the net reductions of 37% in the peak transverse amplitude and about 25% in the mean drag coefficient are observed in comparison to the plain cylinder counterpart. Staggered groove configuration produces three dominant effects by introducing a continuous jump in the cross-sectional geometry along the spanwise direction: (i) reduction of the spanwise correlation, (ii) enhancement of the three-dimensional effects in the near-wake flow, and (iii) broadening of the frequency spectra of fluid forces. As a result of these physical effects, the transfer of energy from the surrounding fluid flow to the vibrating grooved-cylinder system is reduced as compared to its plain cylinder counterpart. Owing to the simplicity of mechanical design and the ease of

* Corresponding author.
E-mail address: rjaiman@mech.ubc.ca (R.K. Jaiman).

https://doi.org/10.1016/j.jfluidstructs.2018.08.004

installation, the proposed passive control concept has a potential application to deepwater marine risers and tall structures in a wind environment.

Nomenclature

μ^f	Dynamic viscosity of fluid
ρ^f	Density of fluid
ζ	Damping ratio
A_y^*	Normalized transverse amplitude
C_d	Drag coefficient
C_l	Lift coefficient
D	Diameter of cylinder
f	Oscillation frequency of cylinder
f_n	Natural frequency in vacuum
$f_{n,w}$	Natural frequency in still water
k	Stiffness of cylinder
L	Span of cylinder
L_c	Characteristic length of device
m	Mass of cylinder and fairing
m^*	Mass ratio
Re	Reynolds number
U	Far field velocity
U_r	Reduced Velocity
y^*	Normalized transverse displacement

1. Introduction

The role of vortex-induced vibration (VIV) phenomenon is well-recognized during structural designs in offshore, aeronautics and civil engineering. In particular, effective suppression of VIV and the reduction of fluid loading can lead to safer, sustainable and cost-effective structural design for a broad range of operational conditions. In the past several decades, numerous passive control techniques (Zdravkovich, 1981; Owen et al., 2001; Baek and Karniadakis, 2009; Yu et al., 2015; Law and Jaiman, 2017) have been investigated via surface modification and by adding auxiliary surfaces to modify the vortex-wake flow dynamics hence to reduce the vibration amplitude. These passive devices can be classified into two categories based on their mechanisms, namely near-wake stabilizer and surface-geometry modifier (Sumer and Fredsoe, 1997). The former device relies on the alterations of the near-wake and the shear layers around the vibrating structure, which result in the wake stabilization and the suppression of VIV. The examples of such wake stabilizing devices are the fairing (Allen et al., 2008), the splitter plate (Assi et al., 2009), the guided foil (Galvao et al., 2008), and the recently developed connected-C device (Law and Jaiman, 2017). While these devices are effective in suppressing the VIV and reducing the drag force significantly, they need to be aligned with the direction of the oncoming flow. This requires the device to rotate around the structure smoothly as the flow direction changes, which can be somewhat challenging from a mechanical design standpoint, especially for a long deepwater riser and a tall chimney, where the current or wind flow changes its direction irregularly. Owing to the mechanical design considerations, these fairing-type devices may lead to a relatively higher installation and maintenance cost for deepwater risers operating in a harsh ocean environment. These devices are also known to undergo low-frequency galloping instability at higher reduced velocity. Furthermore, the fairing-type devices are difficult to implement over square-shaped multicolumn offshore platforms (Chakrabarti, 2005) and subsea pipelines undergoing VIV in the proximity with seabed floor (Sumer and Fredsoe, 1997).

The second category of the passive control device, namely the surface-geometry modifier, suppresses the VIV phenomenon by manipulating the boundary-layer vorticity distribution and the separation points over the vibrating structure via surface variations, e.g., protrusions and grooves. The well-known examples of the such type of control devices are helical strakes (Scruton and Walshe, 1957; Zhou et al., 2011; Allen et al., 2003), dimples (Bearman and Harvey, 1993), and bumps (Bearman and Branković, 2004; Owen et al., 2001). Among these devices, helical strakes are the most common and widely used in offshore and wind engineering applications. With the helical strakes on the cylinders, flow separation positions are typically fixed at the sharp edges of the strakes, which may prevent the correlation of vortex shedding along the span. Owing to the helical profile, the performance is independent of the oncoming flow direction, thus it can be mounted on the structure without much mechanical design considerations. The simplicity of mechanical design makes the helical strakes quite economical and robust option for deepwater risers, subsea pipelines, tall chimneys and various circular cross-section