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Suppression of vortex-induced vibration in low mass-damping circular cylinders using wire meshes

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ABSTRACT

The effectiveness of wire meshes in suppressing vortex-induced vibrations (VIV) is investigated experimentally in this work. Geometries are inspired by the results of a recent study in which the sensitivity of VIV to localised perturbations in the wake of a cylinder free to oscillate, was investigated. A series of square wire meshes with different densities and sizes have been tested. The work focuses on the VIV response description as well as on the analysis of the drag force associated with the device. The physical mechanisms that lead to the VIV attenuation are also described after the analysis of the wake dynamics.
Total suppression of VIV (more than 95%) is shown for reduced velocities up to more than 13. The suppression is achieved with drag reductions of 20% inside the lock-in region. In general most of the meshes investigated are able to attenuate partially VIV without increasing drag forces.

1. Introduction

The study of vortex-induced vibrations (VIV) of bluff bodies is a classical problem in engineering. Marine structures and ocean systems exposed to currents are prone to suffer vibrations induced by the hydrodynamic forces generated by the separated flow in their wake. Deep water drilling and production risers and other slender structures experience fatigue during their life span because of VIV. Vortex-induced motions are also typical of structures such as spar buoys in oil rigs or those found more recently in marine energy harvesting devices and floating wind turbines. In general, when systems are characterised by low mass (if compared to the fluid displaced mass) and low damping, VIV becomes a persisting problem and the structures tend to exhibit large amplitude vibrations in a wide range of operating conditions. General reviews on the nature of VIV can be found in Refs. [4,20,23].

There has been an increased interest in devices to attenuate VIV in the last decades as a result of the industrial demand of such systems. Blevins (1990) [5] describes and compiles the most common systems used in order to mitigate VIV response of cylindrical bluff bodies. One of the major industrial demands in relation to the VIV problem is to reduce the response of the structures, while keeping hydrodynamic forces contained. It must be done for all types of flow and omni-directionally. Helical strakes are very extended and have a good VIV reduction performance, but they considerably increase drag, with all the drawbacks associated to it [10,16,19,21,26]. They are also expensive to manufacture and to install. Systems that streamline the structures are also industrially extended, examples are fairings and splitter plates [1,11] which are known not only to reduce VIV but also drag. The main problem of those is that they are directional and if not, they can be extremely dependent on maintenance and on their ability to align with the flow [2]. Other suppression systems have been proposed in the past, for

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example the use of tripping wires [9], control rods [17,25] or suppression bumps investigated by Owen et al. (2001) [18] and Huera-Huarte (2006) [12]; or the gap dissecting part of the bluff body proposed by Baek and Karniadakis (2009) [3]. Flexible meshes with inserts have been used recently studied [7,15] with the aim to mitigate VIV responses in deep water risers.

The system devised here consists of a wire mesh that is wrapped around the circular cylinder at certain distances. The idea is not new in the sense that it is very close to the shroud concept or the axial slats reported by Ref. [5]. The novelty relies in the fact that their design is not based on a trial and error process, typical of most of the suppressors available, but inspired in the VIV sensitivity study recently conducted by Jiménez-González and Huera-Huarte (2017) [14]. The work presented here also describes the mechanisms that lead to the VIV suppression. The size (diameter) of the mesh is systematically varied in order to meet positions in the wake with high sensitivity, while keeping the system omnidirectional. The effect of the mesh density is inferred by testing two different mesh porosities.

2. Experimental methods

2.1. Facility and cylinder model

Experiments were conducted in the Free Surface Water Channel (FSWC) of the Laboratory for Fluid-Structure Interactions (LIFE) at Universitat Rovira i Virgili (URV) in Tarragona. The water channel has a cross-section of 1×1.1 m^2 downstream a 6 to 1 (cross-sectional area) three-dimensional contraction, and it is able to deliver over 0.7 m^3/s. The flow is generated by two axial pumps controlled by two frequency sources, and the profile in the working section is characterised by a very low velocity variability, with a maximum deviation in velocity of 1.58%. An schematic view of the facility appears in Fig. 1.

The circular cylinder model consisted of a rigid transparent acrylic tube with and immersed length $L = 0.5$ m and with an external diameter $D = 0.05$ m (aspect ratio $L/D = 10$). The model had a transparent end-plate attached to its bottom end in order to prevent three-dimensional effects. Two springs were connected to the model providing restoring forces to the system, that hung from a one-degree-of-freedom air bearing rig. The only motions allowed to the cylinder were those in a direction perpendicular to the flow direction or cross-flow (y). The Cartesian system of reference used throughout the document has its centre 0.25 m below the free surface (at the middle of the submerged part of the cylinder) with the positive x in the direction of the flow. The z axis is coincident with the axis of the cylinder in its equilibrium position with its positive part pointing to the free surface from below. A load cell was installed linking the cylinder model to the air bearing carriage, allowing direct measurement of the drag force acting on the cylinder. The experiments were conducted by sampling at 2 kHz the displacement and force signals during a period of time of 90s, ensuring more than 90 cycles of oscillation per run.

Decay tests in air showed a very low damping, with a value of only $\xi = 0.0054$ (0.54% if expressed as a percentage of the critical damping). The total weight of the system, including the air bearing carriage, the load cell, the cylinder model and the parts used to connect all of them, yield a mass ratio $\left(m^* = \frac{4m}{\rho \pi L D^2}\right)$ of 2.38. The combined mass-damping parameter $m^*\xi$ was as low as 0.013. The displacements of the cylinder in the y direction along the air bearing rig, were measured using a non-intrusive laser displacement sensor. Details of the experimental arrangement appear in the schematic shown in Fig. 2.

The Reynolds number based on the cylinder model diameter $Re = UD/\nu$, where U and ν are respectively the free-stream velocity and the water kinematic viscosity, ranged from 7000 to 23000. The ratio between the free stream velocity in the channel and the average velocity of the cylinder (based on its natural frequency in water f_n) is defined as the reduced velocity $U^* = U/f_nD$.

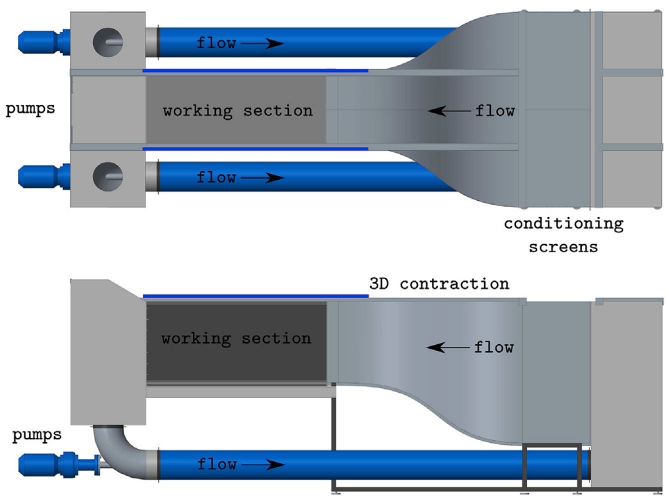

Fig. 1. Schematic views of the Free Surface Water Channel (FSWC).