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Vortex-induced vibrations of a circular cylinder with a pair of control rods of varying size

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We present an experimental study on the vortex-induced vibration (VIV) of a low mass-damping one-degree-of-freedom circular cylinder subject to uniform cross-flow, with pairs of control rods of varying size located in its wake. Two particular locations for control rods, selected according to recent experimental maps of VIV sensitivity to localized perturbations, have been tested for increasing control rod diameters, *d*. Important amplitude reductions are observed for all arrangements investigated, with nearly total suppression of oscillations (up to 90%) for control rods of $d = 0.4D$, where D is the diameter of the main cylinder. Force measurements have been used to describe the nature of changes observed in the wake and the mechanisms behind the VIV control. In general, the placement of control rod pairs in the near wake leads to an important weakening of the lift coefficient and alters substantially the phase between transverse force and cylinder displacement. Moreover, it is shown that, for some particular arrangements, attenuation of VIV is obtained along with a drag reduction of approximately 60% at the upper branch of amplitude response, rendering the present strategy an interesting and practical solution for VIV control when several cylinders need to be installed together.

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1. Introduction

Vortex-induced vibrations (VIV) of cylindrical structures represent a classical problem in many engineering applications, such as offshore systems, where slender components, i.e. risers, pipelines or cables; are subjected to large hydrodynamic forces, that may entail strong vibrations and increase the risk of structural damage or fatigue failure. The nature of VIV of cylindrical components has been extensively investigated in the past, providing with a vast literature on the phenomenology and prediction of VIV (see e.g. Refs. [1–7]).

Besides, the aforementioned negative structural effects of VIV have given rise to a traditional interest on the mitigation of the VIV response by means of flow control techniques, that can be either active or passive [8], depending on whether there is power input or not. Passive strategies are generally easier to implement, and are based on geometrical modifications of the bluff body or perturbation of the near wake, being generally designed to influence separation and vortex shedding. Some of such classical strategies for cylindrical bodies were collected by Zdravkovich [9] or Blevins [10], and comprise, among others, the use of plates and fairings [11,12] or helical strakes [13,14], which have been proven efficient to reduce VIV response. However, the implementation of such techniques entails the deployment of add-on devices that could be expensive to install or maintain. On

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the other hand, there are many engineering applications prone to undergo VIV that involve several circular cylinders, whose interaction may modify strongly the system dynamic response. A classical example of systems where cylindrical bodies of different size exist are the piggyback pipelines or ensemble of secondary umbilicals and flowlines present in plenty of offshore oil and gas applications, where cylindrical bodies are clamped together at fixed clearances and along longitudinal intervals. Moreover, if these intervals are short enough, the whole arrangement may be treated as a unique, rigidly linked dynamical system.

The location of secondary cylinders and the layout adopted are parameters that affect strongly the hydrodynamical forces, and therefore, system VIV response. Thus, the search for *optimal* configurations of secondary cylinders aiming at reducing VIV amplitude, has been the goal of plenty of works, where smaller cylinders are commonly denoted as control rods. Most studies have investigated the effect of varying the azimuthal angle of rods around the main cylinder, and the gap between them, for different configurations and a given ratio between the diameters of main cylinder, D, and small ones, d. These studies have dealt with arrangements with a single rod [15], two rods [16–18], triangular and squared configurations of rods [19,20], or even larger number [21], using either numerical or experimental approaches. Some of such studies have also evaluated the influence of flexibility of control rods on the VIV response, allowing to establish qualitative comparisons between rigid and flexible arrangements. For instance, the use of a symmetric arrangement with four flexible rods around a rigid cylinder was tested experimentally for turbulent flow regimes by Wu et al. [19], showing that cross-flow and in-line vibrations can be practically inhibited when the rods cover most of the main cylinder length. Similar qualitative results were numerically obtained by Zhu and Yao [21], using the same arrangement with rigid rods for a two-dimensional configuration and a similar range of Reynolds number. Thus, the use of rigid rods may simplify the analysis while providing with relevant results in terms of amplitude reduction. In general, these studies were based on a trial and error process and tackled the problem by means of parametric modifications of the arrangement, showing that the effect on the dynamic response is highly dependent on the layout and size of smaller rods, since both amplification or attenuation of VIV amplitude can be obtained.

One simple, efficient VIV control strategy consists actually in altering the vortex shedding process by placing the rods in the wake of the main cylinder, following the concept of wake control through localized perturbations. Thus, Strykowski and Sreenivasan [22] showed that the vortex-shedding behind a stationary cylinder can be effectively suppressed at low values of Reynolds numbers, if a small rod is properly placed in the regions of the wake which are more sensitive to forcing. The potential use of a control rod to cancel VIV could be inferred from the experimental works of Sakamoto and Haniu [23] and Dalton et al. [24], who showed the effectiveness of such technique to reduce the lift and drag due to vortex-shedding, by parametrically modifying the location of the rod at the wake of the main cylinder. More recently, Jiménez-González and Huera-Huarte [25] extended the concept of wake sensitivity to localized perturbations to one-degree-of-freedom VIV for an elastically mounted circular cylinder. An experimental sensitivity map of the near wake was obtained by parametrically modifying the position of a symmetric pair of perturbation rods, with $d = 0.03D$. The sketch in Fig. 1 depicts the main coherent region identified in Ref. [25], where the placement of a symmetric pair of perturbation rods leads to largest VIV amplitude reduction with respect to the uncontrolled natural VIV response of the cylinder at Re = 13400 (or reduced velocity $U^* = u_\infty/f_nD = 6.3$, being u_∞ the free-stream velocity and f_n the natural frequency of oscillation in still water). These regions were found along the cylinder's surface and in the near wake, for radial distances of $r \simeq 0.6D, 0.9D$ and $1.3D$ from the cylinder center, showing by means of wake visualizations that different stabilizing mechanisms are related to alterations in the shear layer detachment, or the vortex formation process. Moreover, the effect of perturbation size was also evaluated using cylinders of $d = 0.1D$ instead, obtaining amplitude reductions up to 66% when *optimal* locations were selected according to sensitivity maps (although the improvement

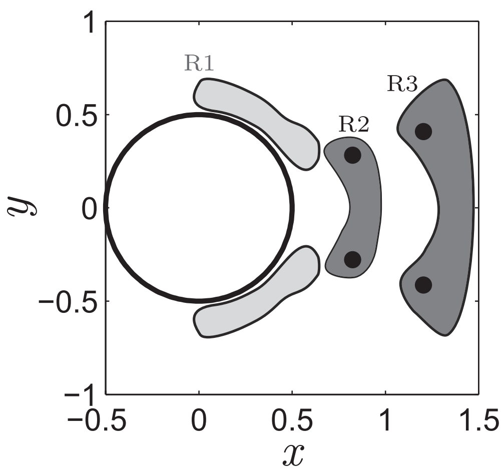

Fig. 1. Sensitivity of VIV amplitude response for a flexibly mounted cylinder at Re = 13400 ($U^* = 6.3$): sketch of coherent regions where the placement of pairs of perturbation rods provides large VIV amplitude reductions, according to [25]. The dots within regions R2 and R3 correspond to those locations leading to weaker VIV responses, which are selected for the present study.

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