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Experiments with flexible shrouds to reduce the vortex-induced vibration of a cylinder with low mass and damping

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ABSTRACT

Experiments employing a low-mass-damping cylinder have been conducted to determine the vortex-induced vibration (VIV) response of four suppressors of the flexible-shroud family. The VIV suppressors were inspired in the concept of the *Ventilated Trousers* (VT), a flexible shroud composed of a flexible net fitted with three-dimensional bobbins. Reynolds number varied between 5×10^3 and 25×10^3, while reduced velocity varied from 2 to 26. The VIV dynamic response showed that the VT suppressed the peak amplitude of vibration down to 40% of that of a bare cylinder. Other flexible shrouds also achieved suppression, but not as efficiently. Drag was reduced during the VIV synchronization range, but remained above the value for a bare static cylinder thereafter. Spectral analysis of displacement and lift revealed that, depending on the geometry and distribution of the bobbins, the flexible shroud can develop an unstable behavior, capturing energy from the wake and sustaining vibrations for higher reduced velocities. PIV measurements of the wake revealed that the entrainment flow through the mesh is necessary to extend the vortex-formation length of the wake; this mechanism only occurs for the VT mesh.

1. Introduction

The vibration induced by the external flow past slender structures poses a problem to submarine and offshore cables, flexible pipes, drilling and production risers and other elastic structures exposed to sea currents. The excitation has its origin in the shedding mechanism of alternating vortices occurring in the wake of bluff bodies, so the hydroelastic phenomenon is called vortex-induced vibration (VIV). Flexible lines exposed to vibrations for a long time may be damaged by structural fatigue [1]. The amplification of drag due to the vibration of the body is also of considerable concern, since it increases static and dynamic loads at the joints, platform and other fixtures.

One way to mitigate the effects of VIV is the installation of suppressors along the riser, or at least on the length of the line where currents are most intense. Helical strakes and fairings, for example, have been widely employed by the industry as VIV suppressors [2]. On one hand, significant VIV suppression of light structures requires wider strakes, which increases drag. Fairings, on the other hand, tend to be more efficient in suppression as far as drag is concerned, but may suffer from hydroelastic instabilities [3]. With the improvement of molded plastic, helical strakes and fairings have indeed become sturdy contraptions, but they still take considerable time to install and occupy large areas on the deck. Other devices based on the disruption of the wake by interfering control surfaces (as explored by Silva-Ortega and Assi [4], for example) may suffer from the same problem.

During the last decades many devices have been investigated and offered as commercial products. Following the industry demand for more efficient, robust and easy-to-install devices, the technological development for suppressing VIV has been under pursuit by both the scientific and industrial communities.

In this context, All Brown Universal Components, a technology company based in the UK, created an interesting new device for suppressing VIV of drilling risers called the *Ventilated Trousers*, or simply VT [5]. Composed of a net of flexible cables holding an orthogonal array of bobbins (solid elements fitted on the net), the VT suppressor is, in the words of the inventors, “a loose fitting sleeve in the form of a light flexible net with integral bobbins in a special arrangement. It is omni-directional, rugged, and made from materials compatible with the offshore environment” [6]. Essentially, the VT is an improvement on the idea of wrapping the drilling riser in a type of flexible cover able to deform with the flow, interact with the wake and mitigate the response to hydrodynamic loads.

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The suppression effectiveness of the VT and its efficiency concerning drag reduction have been studied over the last years with promising results [7,6,8]. Brown and King [7], for example, performed experiments in a laboratory scale with flexible cylinders showing a 90% reduction of the VIV peak amplitude of displacement at a Reynolds number (*Re*) of approximately 1.4×10^5. So far, all known experiments have been performed either with flexible pipes or near real conditions at sea, especially regarding the range $Re = 3.7 \times 10^4$ to 1.2×10^6 and the structural properties of a riser [7,6]. Although this kind of experiment verifies the potential of such a device in practical applications (for being performed closer to real conditions), they are not designed to reveal the intricate hydrodynamic mechanisms by which the VT is able to achieve suppression.

1.1. Objective

In the present work we set out to understand the behavior of the VT and other similar suppressors in idealized laboratory conditions. It could be said that the VT is part of a larger family of suppressors, here called the *flexible shrouds* (also called *permeable meshes* in our previous investigations). We believe that exploring geometric variations based on the VT concept will produce siblings that could thus reveal the fundamental physical mechanisms behind the suppression.

Purely motivated by the scientific interest on the topic, the present work is part of an investigation to study the behavior of this family of suppressors at moderate *Re*, low mass and very low damping conditions. We are particularly concerned with the scientific investigation of the hydrodynamic and hydroelastic mechanisms that will explain us how this family of VIV suppressors works.

We will characterize the VIV response of the VT and three other simpler flexible shrouds derived from it. In idealized laboratory conditions all variables are under control and crucial parameters are reduced to enhance the response. The idea is to test the suppression device in the most undisturbed condition, indeed different for the real application in the ocean, but free from most of the interference that could mask the understanding of the fundamental physical phenomena. As will become clearer shortly, the differences between the models emerge from variations on the geometric parameters of the original VT, taking us step by step in understanding the physical principles.

2. Experimental method

Experiments have been carried out in the recirculating water channel of NDF Fluids and Dynamics Research Group at the University of São Paulo, Brazil. The water channel has a test section 0.7 m wide, 0.9 m deep and 7.5 m long. The flow speed (U) is variable up to 1 m/s, allowing for tests with different values of Reynolds number, with a turbulence intensity of less than 3%.

Models were attached to a one-degree-of-freedom rig which allowed the model to oscillate freely in the cross-flow direction (y), as shown in Fig. 1. The platform was mounted on air bearings to reduce friction within the system, thus ensuring very low structural damping and maximum response. A load cell installed between the cylinder and the rig measured instantaneous lift and drag forces acting on the cylinder. A pair of coil springs provided the restoration force to the system and an optical sensor measured the displacement without adding extra damping. For further details on the elastic rig, other VIV experiments employing the rig and information on the facilities please refer to [9,10].

Tests were performed with a rigid section of a circular cylinder (external diameter $D = 50$ mm, submerged length $L = 650$ mm) fitted with four different flexible shrouds. Variations of the meshes concerned the geometry of the bobbins, focusing on the main length scales of the original bobbin, and their distribution on the net.

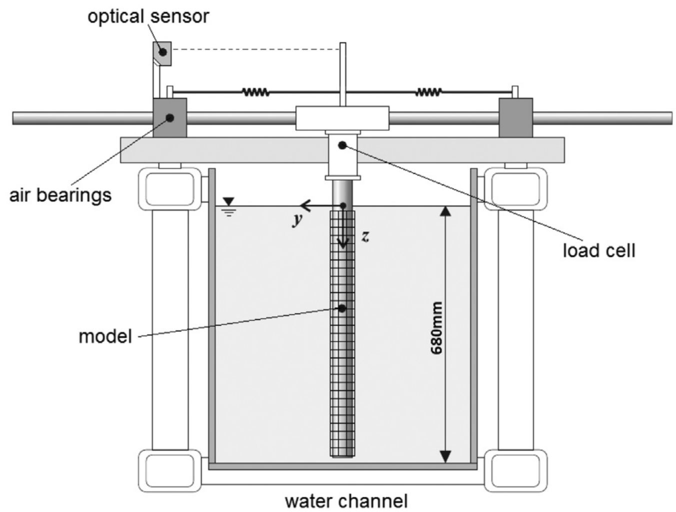

Fig. 1. Cross-view of the test section showing the elastic rig and cylinder in the water channel.

The first model is a pure reproduction of the VT device. Its main properties are the perimeter (p), the width of the mesh element (w) and a characteristic dimension of the bobbin (d), as can be seen in Fig. 2. Brown [5] provides a guide for the geometric definition of the mesh, allowing some variations on its properties: the diameter ratio, for example, must vary between $d/D = 0.08$ and 0.125. Besides that, in a previous work, Brown and King [7] verified that a mesh element width of 5 times the bobbin characteristic dimension ($w = 5d$) resulted in a more effective VT than one in which $w = 3d$. They also reported that the net perimeter must be between $p = 4D$ and $4.71D$. Following these guidelines and considering that the parameters are not completely independent, the largest possible mesh was built respecting the restrictions and recommendations proposed by Brown [5]. The final dimensions of the VT model employed in the present work are shown in Table 1.

Based on the VT mesh, presented in Fig. 3a, three other meshes with simpler geometries have been built altering the VT bobbin geometry and distribution, but keeping the same w and p. The *thick-sparse mesh*, shown in Fig. 3b, had different bobbins formed by only one circular cylinder with an external diameter of $d_{ext} = 3d$, corresponding to the outer diameter of the VT bobbin. On the other hand, the bobbin of the *thin-sparse mesh* shown in Fig. 3c, was made with a single cylinder with external diameter $d_{ext} = d$, resulting in a mesh following the thinner elements of the VT bobbin.

The VT, the thick-sparse and the thin-sparse meshes all had the same bobbin distribution, with bobbins fitted on every other mesh element. Now, the third variation resulted in the *thin-dense mesh* shown in Fig. 3d. It was built with the same bobbins used in the thin-sparse mesh, but fitting bobbins in every element of the net, resulting in a different distribution of bobbins.

In summary, all three bobbins have the same height of $5d$, but they vary in shape and how they are distributed on the mesh, as illustrated in Fig. 3 and Table 1. Again, all new bobbins are based on the main length scales found in the VT bobbin: height $5d$ and diameters d or $3d$.

By keeping the net perimeter (p) constant for all meshes and varying the outer diameter of the bobbins, the thin meshes presented a loose fit around the cylinder when compared with the other two. At first, this was not intentional, since we believed that keeping p constant would support the direct comparison of the results. However, as will be discussed later, the loose meshes had quite a significant and interesting effect in the response.