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Laboratory-scale investigation of the Ventilated-Trousers device acting as a suppressor of vortex-induced vibrations

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ABSTRACT

Experiments have been carried out with circular cylinders fitted with a suppressor of vortex-induced vibrations called the *Ventilated Trousers* (VT). Tests were performed at laboratory scale in a free-surface water channel with fixed and free-to-respond models in one degree of freedom. The oscillating tests were performed with elastically mounted cylinders with low mass and damping ($m^*\zeta < 0.009$). Reynolds number varied from 5000 to 25000 and reduced velocity varied between 2 and 15. Tests with fixed models showed that the VT increased the mean drag and practically eliminated the fluctuating lift force when compared to a bare fixed cylinder. Free-response tests showed that the VT was able to reduce 60% of the peak amplitude of vibration, thus reducing the maximum drag compared with that of a bare oscillating cylinder. Three hypotheses are proposed to explain the physical mechanism underlying the suppression by the VT: local disruption of vortex shedding; three-dimensional disruption of the near wake; and the increase of hydrodynamic damping.

1. Introduction

The phenomenon of vortex-induced vibration (VIV) may be associated with serious damage caused to offshore cables, flexible pipes and other slender structures such as drilling risers. In the pursuit of viable solutions, the technological development of novel devices for suppressing VIV has been a current topic in both scientific and industrial communities. During the last three decades many devices have been investigated and offered as commercial products, such as helical strakes, fairings, shrouds, etc. However, following the industry demand for more efficient, robust and easy-to-install devices, new ideas for VIV suppressors are still under investigation. Helical strakes, for example, may be the most widely employed suppression device of them all. Strakes became sturdy contraptions with the improvement of molded plastic, but they still reduce VIV with the cost of increasing drag, taking considerable time to install and occupying large areas on the deck.

In this context, Brown and King (Brown, 2010) created an interesting new device for suppressing VIV of drilling risers called the "*Ventilated Trousers*", or simply VT in this paper. The VT is composed of a net of flexible cables through which an orthogonal array of bobbins (with a specific geometry) is fitted. In the words of its creators, the VT suppressor is "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" (King et al., 2013). 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 and mitigate the body response to the hydrodynamic loads.

The suppression efficiency of the VT has been studied over the last years with promising results. Brown and King (2008), for example, performed experiments in a laboratory scale with flexible cylinders at $Re \approx 1.2 \times 10^6$, showing a 90% reduction of the VIV peak amplitude of displacement. (Reynolds number is defined as $Re = UD/\nu$, where U is the flow speed, D is the cylinder diameter and ν is the kinematic viscosity of water.) So far, all known experiments have been performed either with flexible pipes or near real conditions at sea, especially regarding the range of $3.7 \times 10^4 < Re < 1.2 \times 10^6$ and the structural properties of the risers (Brown and King, 2008; King et al., 2013).

1.1. Objective

Although these results are important for revealing the suppressing potential of the device, they do not shed much light on the physical mechanisms by which the VT is able to suppress vibrations. The present work is part of an investigation to study the interaction between model and flow at moderate Re and very low damping conditions. We are concerned with the scientific investigation of the hydrodynamic and hydroelastic mechanisms that make this type of suppressor effectively work.

This paper characterizes the VIV response of the VT in idealized

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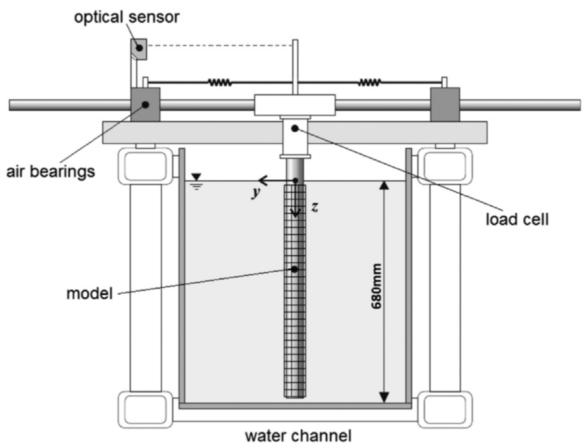

Fig. 1. Cross-section of the water channel showing the cylinder mounted on the elastic rig.

laboratory conditions, in which all variables were under control and crucial parameters were reduced to enhance response. The idea was to test the suppression device in the most pristine condition, indeed different from the real application in the ocean, but free from interference that could mask the understanding of the fundamental physical phenomena.

2. Experimental method

Experiments have been carried out in the free-surface water channel of NDF – Fluids and Dynamics Research Group – at the University of Sao 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 less than 3%, obtained from velocity and turbulence profiles measured with hot-film anemometers by Assi (2005).

A rigid section of a circular cylinder was attached to a platform on a 1-degree-of-freedom rig, which allowed the model to oscillate freely in the transverse direction (y), as shown in a cross-sectional view in Fig. 1. The platform was mounted on air bearings to reduce friction, thus ensuring very low structural damping and maximum response. A pair of coil springs was responsible for providing the stiffness of the system and an optical positioning sensor (employing laser triangulation) measured the displacements with a resolution of 0.2 mm without adding extra damping.

A load cell installed between the cylinder and the platform measured instantaneous lift and drag forces acting on the cylinder. Because the load cell moved with the cylinder, the inertial component due to the mass of the model being accelerated was subtracted from the total force measured by the sensor. Details on the manufacturing and operation of the load cell were presented by Assi (2009). For further details on the elastic rig, other VIV experiments employing the rig and information on the facilities please refer to Cicolin et al. (2015, 2014) and Assi et al. (2013, 2010a, 2010b, 2009). Drag and lift coefficients have been reduced by dividing the fluid forces measured by the load cell by $\frac{1}{2}\rho U^2 DL$, where ρ is the specific mass of water, D is the external diameter and L is the submerged length of the cylinder.

Visualization of the flow in the near wake has been performed by the emission of hydrogen bubbles from a thin wire stretched parallel to the axis of the cylinder at about $1D$ upstream and $1D$ to the side of the centerline of the wake. A laser sheet illuminated a plane near the region where the free shear layers separated and rolled up to form vortices. A camera positioned perpendicular to the laser plane captured a field of view of almost $4D$ by $4D$ in the xz-plane.

The circular cylinder was cut from a perspex tube with an external diameter of D= 50 mm; the underwater aspect ratio was L/D = 13.4.

Table 1
Experimental parameters.

	m^*	$f_{N_{air}}$ (Hz)	$f_N \equiv f_{N_{water}}$ (Hz)	ζ_{air}	ζ_{water}
Bare cylinder	2.8	0.68	0.58	0.3%	1.6%
Cylinder with VT	2.9	0.66	0.56	0.3%	6.5%

The cylinder top end was attached to the load cell and the bottom end was closed to keep it watertight. Free-decay tests have been performed both in air and in water to determine the natural frequency and damping associated with the models. The natural frequencies were obtained from the power spectrum of displacement and the damping parameter from the logarithmic decrement of the decay response (values will be presented later when discussing the VIV response). Reduced mass m^* (defined as the ratio of total structural mas to the mass of displaced fluid) and structural damping ζ_{air} (defined as a fraction of the critical damping) were kept to a minimum in order to enhance the response. All experimental parameters are presented in Table 1.

The VT device was built with a flexible net of common polymeric twisted threads. Dozens of bobbins were manufactured out of polymeric rods, drilled through and attached to the net. All materials employed in the construction have been carefully chosen to ensure the VT was neutrally buoyant when submerged. Fig. 2 illustrates the assembly as it was ready for tests.

Some considerations must be presented concerning the geometric parameters of the VT model: The description found in the patent (Brown, 2010) allows for some variations on bobbin dimensions. The reference tests presented by Brown and King (2008), however, have been performed employing a fixed ratio between geometric variables. To allow for comparison, the same proportions for the bobbins, mesh size and bobbin distribution found in that report have been kept in the present work, as shown in Fig. 3. The mesh element width (w), net perimeter (p) and the ratio between the cylinder and the characteristic size of the bobbin (d/D) were specified.

Previously, Brown and King (2008) 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 $\frac{3}{2}\pi D$ (or $4.71D$). Besides that, the patent recommended that the diameter ratio must vary between $d/D = 0.08$ and 0.125. Following this recipe and considering that the parameters are not completely independent, the largest possible mesh was built respecting the patent restrictions and recommendations. The final dimensions of the VT model employed in the present work are shown in Table 2.

3. Results

Preliminary experiments have been carried out with fixed models in flowing water in order to measure the hydrodynamic coefficients of drag (streamwise direction) and lift (cross-flow direction) acting on the cylinder with and without the VT. The mean drag coefficient ($\overline{C}_D$) obtained for the cylinder with and without VT are shown in Fig. 4(a). The bare cylinder presented $\overline{C}_D \approx 1.1$ for the whole range of Re, as expected and in agreement with Zdravkovich (1997). On the other hand, the VT increased $\overline{C}_D$ by approximately 25% when compared with that of a fixed bare cylinder, at least in the range $10 \times 10^3 < Re < 25 \times 10^3$. This result was expected, considering that the effective diameter of the cylinder with the VT is larger than the external diameter D of the bare cylinder, thus exposing a larger frontal area to the incoming flow. (Please note that $\overline{C}_D$ was normalized employing D for both cases.) But the main observation is that the complex geometry of the VT increased the loss of kinetic energy to the wake as the flow passed around the body, at least as far as fixed cylinders were concerned.