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Specific power input: Comparison among rigid and flexible models

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ABSTRACT

The specific power input imparted by the blowing wind to an oscillating circular cylinder is a key topic in calculating aeolian vibrations of overhead transmission lines using the energy balance principle, i.e. the most common methodology used to design new lines and to dimension fittings and damping devices.

The specific power input as function of the vibration amplitude was measured, during the last decades, by different research groups using different models. The obtained curves show a large dispersion of the results increasing the uncertainties in determining the vibration amplitudes.

Aim of this paper is to describe the results obtained during experimental campaigns carried out at Politecnico di Milano Wind Tunnel using both flexible and rigid sectional model and to highlight the differences among the two cases in terms of vortex induced vibrations with particular reference to specific power input.

1. Introduction

Analysing literature data concerning specific power input due to VIV on circular cylinders (Transmission Line, 1979; Kawai 1993), it can be noted that two different classes of models were used to perform wind tunnel tests: some data collected in different experimental campaigns are reported in Fig. 1. The first class of models collects rigid sectional ones suspended on springs (typically made up by tensioned wires) with only one degree of freedom, i.e. the displacement in cross-flow direction (Belloli et al., 2005a, 2005b; Farquharson and McHugh, 1956; Diana and Falco, 1971; Williamson and Roshko, 1988). The second class collects flexible models able to vibrate according to their modal deflected shape under wind excitation, (Belloli et al., 2003; Diana et al., 2005; Brika and Laneville, 1996; Rawlins, 1983). This kind of experimental models are made up by a tube, mounted horizontally in the wind tunnel test section, normal to the flow direction: wind tunnel walls confine the flow and external constrains are realized as hinges. In the most of the performed researches, only the first mode was excited, (Brika and Laneville, 1996; Rawlins, 1983).

The large dimensions of the boundary layer test section of Politecnico di Milano wind tunnel allowed to test large models both flexible and rigid. Flexible models were characterized by very high aspect ratios, respectively $L/D = 227$ (Belloli et al., 2003) and $L/D = 416$ (Diana et al., 2005), where D is the cylinder diameter and L is model length. Moreover the length of the models (12.5 m) permits to excite, in the tested wind velocity range, their higher natural modes, up to mode nine. When high modes are excited, the deflected shape is characterized by more than one loop making possible to measure the dynamics of the cylinder in correspondence of nodes and antinodes and also to characterize the wake in different points along the model axis.

The rigid model set-up was realized using a large cylinder equipped by pressure taps to measure pressure distributions on the cylinder surface in correspondence of two different sections, (Belloli et al., 2005a, 2005b; Zasso et al., 2008; Belloli et al., 2012; Zasso et al., 2006; Belloli et al., 2015). By means of pressure data integration, it was possible to calculate the aerodynamic forces exerted by the wind on the cylinder while it is vibrating: this permits to directly define the instantaneous power input as wind force times cylinder's velocity. The specific power input on the rigid model was also calculated by means of the displacement approach, proposed by Farquharson (Farquharson and McHugh, 1956), and normally used when only the kinematics quantities are available. The specific power input values obtained by applying the two methods were compared. Power input rigid models has been compared with the values obtained from flexible cylinders and all the experimental data were then compared against literature data.

The measurements performed on the rigid model highlighted how the wind introduces energy into the system while the vibration amplitudes are growing, giving information both on model dynamic and on aerodynamic forces. In particular, it was pointed out that the fluid-structure interaction strongly differs at low and high vibration amplitudes: this can justify the differences between rigid cylinders, where all the sections experience the same amplitudes, and flexible cylinders where each

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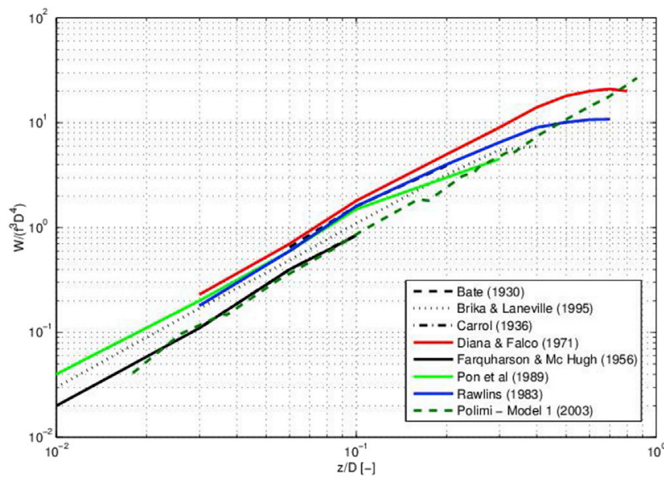

Fig. 1. Specific power input as function of vibration amplitude (Transmission Line, 1979).

section has its own displacement according to the mode locked-in. The experimental set-up of rigid and flexible models were then completed by hot-wire anemometers and multi-hole pressure probes placed downstream the cylinders. The so realized high frequency measurements were very useful to monitor the wake, in terms of harmonic content and relative phase between anemometers signals and cylinder displacement. This phase is strictly correlated to the phase between the lift force and cylinder displacement and through this kind of analysis it is possible to understand force-displacement relationship at a given cylinder section (Belloli et al., 2012, 2015; Zasso et al., 2008; Zasso et al., 2006).

2. Models and experimental conditions

The reference data for this paper were collected during three different experimental campaigns, (Belloli et al., 2003, 2005b; Diana et al., 2005): two experimental models are very similar, two aluminium tubes 12.5 m long with different external diameter and different mass for unit length. These two models are flexible and they vibrate according to their natural deflected shapes. The third model is a rigid one, suspended on springs, and it is instrumented with a pressure scanner to acquire the pressure distribution on the cylinder surface. The pressure data were integrated to obtain the forces exerted by the fluid on the model due to vortex shedding.

Fig. 2 and Fig. 3 show respectively rigid and flexible models installed in the wind tunnel test section. Table 1 reports the main characteristics of the models tested in the Politecnico di Milano Wind Tunnel. Further details relative to models and experimental set-up are reported respectively in Belloli et al. (2003), Diana et al. (2005), and in Belloli et al. (2005b, 2012), Zasso et al. (2006, 2008).

Table 2 reports the experimental conditions realized while testing, the turbulence level was in all the cases lower than 2%.

In Table 2 the Scruton number was calculated according to equation (1):

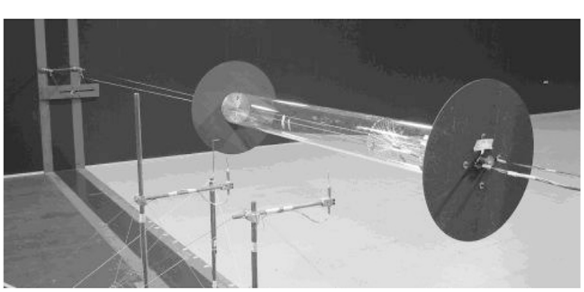

Fig. 2. Rigid model installed in the wind tunnel test section (Belloli et al., 2005b).

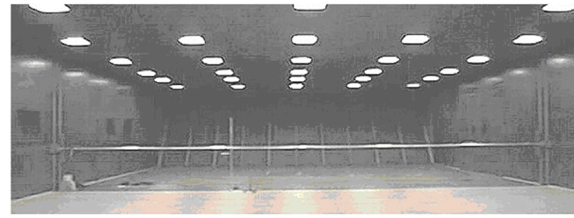

Fig. 3. Flexible model installed in the wind tunnel test section (Belloli et al., 2003; Diana et al., 2005).

Table 1
Models details.

	Model 1	Model 2	Model 3
Diameter $[m]$	0.055	0.03	0.2
Length $[m]$	12.5	12.5	2
Linear mass $[kg/m]$	0.89	0.48	5.5
Aspect ratio L/D	227	416	10
First natural frequency $[Hz]$	3.77	5	3.25

Table 2
Relevant experimental conditions.

	Model 1 (Belloli et al., 2003)	Model 2 (Diana et al., 2005)	Model 3 (Zasso et al., 2008)
Highest Reynolds number	18500	6000	50000
Scruton number (Mode 1)	0.8	1.4	1.22

$$Sc = \frac{2\pi m_L h_{st}}{\rho D^2} \quad (1)$$

where m_L is mass for unit length, h_{st} is the structural damping to critical ratio and ρ is air density. For the flexible models the non dimensional structural damping h_{st} is the one relative to the first mode ($h_{st} = 5{\cdot}10^{-4}$) measured at the maximum oscillation amplitudes obtained by means of wind excitation.

For all the tested models the displacement was obtained from accelerometers signals placed in vertical direction. Accelerometers in horizontal direction were placed to check possible along wind vibrations. The wake downstream the models was studied using hot-wire anemometers and multi-hole pressure probes, as done by Brika and Laneville (1993).

The signal coming from anemometers is useful because its relative phase respect to the cylinder vibration is correlated to the phase between lift force and cylinder displacement, (Zasso et al., 2006, 2008; Belloli et al., 2012). This phase gives important information about the fluid-dynamic cylinder conditions, especially in the flexible model cases that, due to their small diameters, can not keep inside pressure scanner devices. In particular this quantity permits to identify the different power input mechanisms that characterize the fluid-dynamic states encountered by the model, (Belloli et al., 2005b, 2012; Zasso et al., 2008; Zasso et al., 2006).

3. Specific power input evaluation

3.1. Displacement approach

The displacement approach to evaluate wind power input is based on displacement or acceleration signals measured in transient condition and treated with logarithmic decrement technique to define the non dimensional damping ratio (Farquharson and McHugh, 1956; Diana and Falco, 1971; Rawlins, 1983). More precisely the total power imparted by the