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Vortex-Induced Vibrations and Jump Phenomenon: Experiments with a Clamped Flexible Cylinder in Water

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ABSTRACT

Vortex Induced Vibrations experiments have been carried out with a clamped, lightly damped and long, flexible, circular cylinder suspended from a towing tank carriage. The lock-in phenomenon has been observed through bending strain measurements taken along the tube span, within a range of speeds — Reynolds number varying from $6{\times}10^3$ to $4{\times}10^4$ — fully exciting the first flexural eigenmode. Experimental results clearly show 2 resonance branches, in accordance with similar experiments performed in water with rigid cylinders mounted in linearly elastic supports (Khalak and Williamson, 1996; Parra, 1996), or in air (Feng, 1968). But now, an upper overlapping branch of oscillation appears at higher reduced velocities than in the case of rigid models. For the first natural mode of flexural vibration the nondimensional mass-damping parameter in water, $(m^*+C_a)\zeta_a$ in Khalak's and Williamson's 1996 work, takes the value 0.016 if only the structural damping in water is considered. This value has the same low order of magnitude observed by those authors. As could be expected, a jump phenomenon, from the lower to the upper branch, has been experimentally observed. This jump takes place at a reduced velocity value close to $V_r \cong 8.30$, giving further evidences of a nonlinear scenario, as discussed, e.g., by Bearman (1984), Brika and Laneville (1993), Khalak and Williamson (1996) and first addressed by Feng (1968).

INTRODUCTION

The self-exciting vibration phenomenon of elastically mounted rigid cylinders, or else flexible cylinders, acted on by a steady current, although being one of the most important examples of the general Vortex Induced Vibrations (VIV) problems in fluid mechanics, is far from being fully understood. A considerable amount of research work has been done, either experimental or theoretically, the latter through nonlinear-oscillator modelling approaches and, recently, also through Computational Fluid Dynamics (CFD) techniques. The important work of Feng (1968), Iwan and Blevins (1974), Griffin (1981,1985), Griffin and Ramberg (1982), Bearman (1984), Williamson and Roshko (1988) and Brika and Laneville (1993) are just a few to be mentioned. One of the most significant and practical striking points is the existence of 2 branches of resonance, in the lock-in region, as reported, e.g., by Khalak and Williamson (1996) and Parra (1996) and previously discussed by Feng (1968), Williamson and Roshko (1988) and Brika and Laneville (1993). Khalak's and Williamson's and Parra's work deals with experiments in water, with linearly, elastically mounted rigid cylinders, the main difference between them being the values taken by the system damping. In the experimental apparatus used by Khalak and Williamson damping is very low. Instead, as explicitly mentioned by Khalak and Williamson, although Feng's work deals with low damping, his experiments were performed in air. The same holds true for the work by Brika and Laneville (1993), though a flexible cylinder was studied in this latter case. On the other hand, CFD work has systematically reported only the lower branch of resonance, e.g., Newman and Karniadakis (1995), Meneghini et al. (1997) and Saltara et al. (1998). Very recently, Newman and Karniadakis (1997) succeeded in numerically obtaining a one-diameter response amplitude, for a cable at Reynolds number 200. Also recently, from experiments with a cantilever in air, Kitagawa et al. (1997) reported free-end condition effects, namely tip-generated vortices, giving rise, at high velocities, to another sort of auto-sustained vibration pattern.

This paper presents results on VIV experiments performed in water with a smooth, lightly damped and long flexible cylinder, clamped in and suspended from a towing tank carriage. The dynamic behavior showed similarity to the cases of cylinders in air or elastically mounted cylinders in water. No end-cylinder or end plate has been used. The lock-in phenomenon has been observed by means of bending strain measurements along the tube span, within a range of speeds — Reynolds number varying from $6{\times}10^3$ to $4{\times}10^4$ — that fully excites the first vibration mode. No flow visualization has been performed, however.

EXPERIMENTAL ARRANGEMENT AND CALIBRATION

The structure is composed of an inner circular solid rod, rigidly attached to an external pipe by means of equally spaced annular rings; all are made up with standard structural aluminum alloys. The immersed span length is L = 3 m, the external diameter, $D = D_{ec}$ = 31.75 mm. Other geometrical and material properties are shown in Table 1.

Strain measurements have been taken internally, on the inner

Pipe	Aluminum Alloy: Alcoa: TR-058
External diameter, D_{ec}	31,75 mm
Internal diameter, D_{ic}	25,40 mm
Mass density, ρ_c	2710 kg/m^3
Internal Solid Rod	Aluminum Alloy: Alcoa: VR-016
Diameter, D_a	19,33 mm
Mass density, ρ_a	2710 kg/m^3

Table 1 Geometrical and material properties

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KEY WORDS: Vortex-Induced Vibrations (VIV), flexible cylinder, lock-in, jump phenomenon, strain-gages.