Influence of Rotation on the Wake Development behind a Radially Deforming Cylinder

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Abstract— **The evolution of the flow past a circular cylinder superimposed simultaneously to steady rotation and a radial pulsatile motion–cross section variation–is experimentally investigated. The researched objective consists in investigating the possibility of developing a technique for increasing the cylinder fineness by combining the Magnus effect with the drag drop induced by the cross section variation. One important result consists in the fact that the cylinder pulsatile motion induces a new regime, to our knowledge not addressed before, for which the near wake–recirculating bubble–stands straight and deviation concerns only the completely detached structures from the cylinder. This feature is mentioned to persist even for the high rotating ratios. Furthermore, for the whole considered rotating ratios the one side shedding mode apparition seems to be cancelled by the pulsatile motion and the 2S mode maintains as the dominant shedding mechanism. A comparative study with literature led to the conclusion that the shedding mechanism inhibition is found to be dependent not only on the value of the rotating rate but also the value of the Reynolds number which increasingly becomes the dominant parameter..**

Index Terms— **Cylinder rotation, Cylinder deformation, Fineness enhancement , Flow control**

I. Introduction

Bluff body wakes play an important role in the design of a diversity of engineering structures and industrial applications: aerodynamics, heat exchangers, offshore structures…
Control of vortex shedding leads to decreasing the unsteady forces acting on the body and can substantially reduce its vibrations. Flow control may be executed by controlling the boundary layer separation, the shear layers structures and / or the coherent structures dynamics in the body near wake. The evolution of the flow past a circular cylinder superimposed simultaneously to steady rotation and a radial pulsatile motion–cross section variation–is considered by visualizing the flow patterns using smoke streaklines and by analyzing qualitatively the corresponding snapshots. The researched objective consists in investigating the possibility of developing a technique for increasing the cylinder fineness–the lift to drag ratio–by combining the Magnus effect generated by rotation, Coutenceau et al. [1] with the drag drop induced by the cross section variation, Oualli et al. [2], [3], [4] and [5]. The obtained results show that the flow behavior is deeply altered and new flow regimes are identified to be induced by these two dynamics combination. The von kármàn structures are progressively weakened with rotation leading to shedding mechanism inhibition when the rotating rate becomes sufficiently high. Cylinder cross section variation contributes to axially maintain the near wake with a substantial width reduction.

II. Experimental Setup

The main element of the setup is depicted in figure 1. The deforming mechanism is inserted inside the cylinder wall to generate the pulsatile motion avoiding thus any disturbance of the evolving flow. The cylinder made of PVC (Polyvinyl Chlorine) walls, figure 1, is mounted horizontally traversing the test section with the ends linked to two external motors destined to deliver rotating motion of the cylinder shaft and cylinder walls as well. The inserted mechanism consists in a cylinder shaft entrained into a rotation motion using an external motor, rotating cams transform the entering rotating motion into diameter variation movement of the test cylinder walls according the following sinus law:

$$D = Do\,(1 + As\,|\sin(2\pi\times f\times t)|)$$

Where D is the variable cylinder diameter, D0 is the initial cylinder diameter, As is the deformation amplitude set equal to 5% of the cylinder diameter, f is the cylinder forcing frequency in Hertz and t is time in seconds.

Considering the cylinder dimensions, the above relation becomes:

$$D=0.08(1+0.05\,|\sin(2\pi\times f\times t)|) \tag{1}$$

The flow behavior is thus controlled by the sinusoidal variation of the cylinder cross-section applied uniformly along the span.

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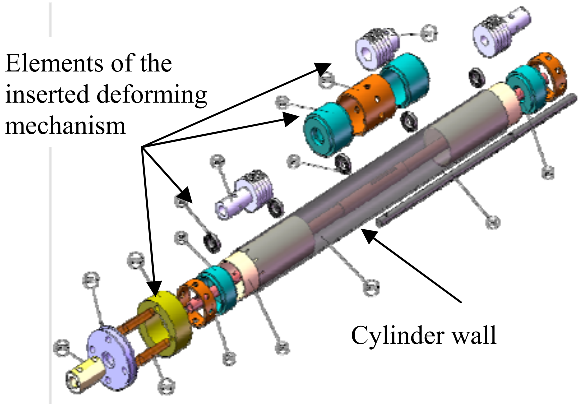

Fig.1. Exploded view of the circular cylinder maquette

III. Important Results

The flow regime considered in this study corresponds to the moderate Reynolds number range (Re ≤ 3000). The non-dimensional steady rotating rate considered in this study, α= ΩR/U∞, with Ω is the motor speed, R is the cylinder radius and U∞ is the infinite flow speed, increases from 0 to 10 and the length along which the wake is tackled extends on more than 10 times the cylinder diameter. The considered radial pulsating to the cylinder natural shedding frequency ratio fs is in the range of 0 to 8 with the pulsating amplitude As fixed equal to 5% relatively to the cylinder diameter. The details of the response mechanism of both the near wake and the von Karman eddy street are particularly examined and the flow asymmetry induced by the cylinder rotation is found to be mitigated by the pulsatile dynamic effect, figures 2 and 3. Hence, the existence of two regimes has been confirmed with the creation or non-creation of alternate eddies after an initial primary one. When deviated by rotation, the cylinder near wake width is found to reduce by an amount of 34% relatively to its natural value. In addition, the cylinder pulsatile motion induces a new regime, not addressed before, for which the near wake−recirculating bubble−stands straight and deviation concerns only the completely detached structures from the cylinder, figure. 4. This feature is mentioned to persist even for the high rotating ratios. Furthermore, for the whole considered rotating ratios the one side shedding mode apparition seems to be cancelled by the pulsatile motion and the 2S mode maintains as the dominant shedding mechanism. A comparative study with Coutanceau et al. [1] led to the result that the shedding mechanism inhibition is found to be dependent not only on the value of the rotating rate α but also on the value of the Reynolds number which increasingly becomes the dominant parameter. In the case of the present study the shedding mechanism is completely inhibited for α=5, figure 5, while Coutanceau et al. [1] and Werlé [6] reported the value of α≈2.5.

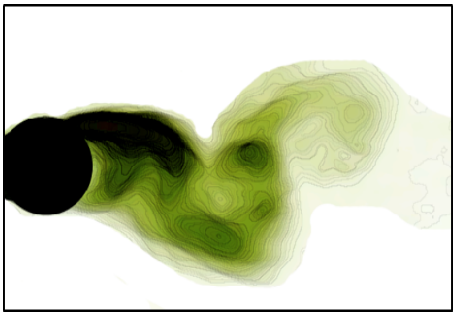

Fig.2. Flow around a circular cylinder / natural evolution, Re=2700.

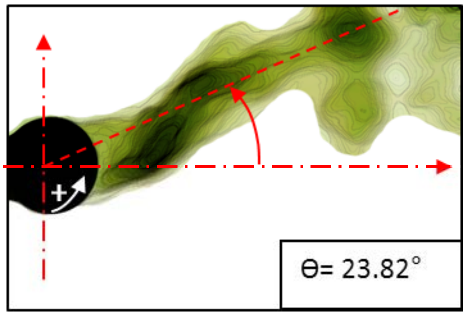

Fig.3. Flow around a rotating cylinder, α=2.26 and Re=2700.

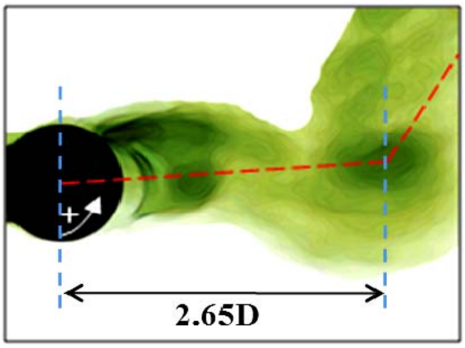

Fig.4. Flow around a rotating and radially deforming cylinder, α=2.26, f_s=3.34 and Re=2700.

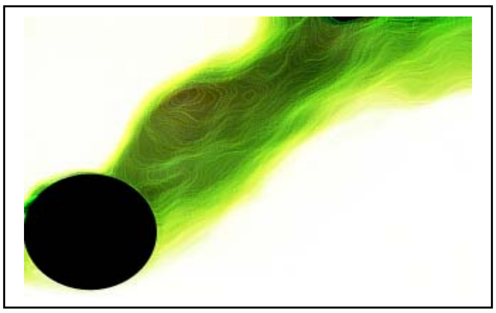

Fig.5.Shedding mechanism inhibition, α=5 and Re=2700.

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IV. Conclusion

The present study analyses the flow response around a circular cylinder superimposed to simultaneous uniform spanwise cross-section pulsatile motion and steady rotation. It is established that the flow topology is deeply altered in terms of the near wake and the global von Karman eddy street behavior. The Shedding mechanism suppression is delayed by radial deformation and the near wake width shrinks up to 34% compared to the natural dimension value expecting thus important drag coefficient drop accompanied by a substantial increase in the cylinder fineness. These observations call further investigation using PIV and anemometry techniques in order to precisely quantify the flow response. This is the subject of a study in current development.

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