

Control techniques in flow past a cylinder- A Review

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Abstract. Flow past circular cylinder is known to be one of the fundamental concepts of fluid mechanics. The fields of application where it is important to study the flow past bluff bodies are offshore and marine engineering, marine pipe lines. In structural applications like flow around chimney stacks, long span bridges, transport ships, tall buildings, towers, pillars, heat exchangers, cables etc, it is important to reduce vortex induced vibrations, drag and lift force acting on them in-order to prevent structural damage. Therefore, it is necessary to adapt control techniques in flow past circular cylinder to reduce structural damage and improve the service life of cylinder used for particular application. The various control techniques are discussed and the effect of those techniques in modifying the wake flow structure is highlighted in this work.

1. Introduction

The unsteady flow past bluff bodies has been extensively investigated in last few decades because of its use especially circular cylinder in numerous engineering applications [1]–[3][4][5]–[7]. The study of flow past a cylinder is important because the flow separation on the cylinder surface causes significant pressure drop in the wake of the cylinder which results in the drag force acting on it. This pressure gradient also results in the formation of vortices, Karman vortex, oscillating lift in the wake of the cylinder. Furthermore, if the cylinder is rotating about its own axis and when the vortex shedding frequency approaches the natural frequency of the body vortex induced vibrations are formed. Thus, if vortex shedding frequency, VIV's (vortex induced vibrations), drag force, lift force are not controlled then the body undergoes structural damage [8]. Therefore, it is inevitable to control wake flow structure in the downstream of a circular cylinder by using materials which have more damping and bare frequency or by some other control techniques. Since the material enhancement is not economical we use control techniques to modify wake flow structure. There are three different categories in control techniques, active control techniques with actuators having no sensors (active open loop control), active control techniques with actuators having sensors (active closed loop control) and passive control techniques. In the above stated methods, active control techniques need power input while the other does not require any power input.

Active control techniques include suction flow[9], oscillation of circular cylinder[10], pulsating inflow [11], moving surface boundary layer control [12], synthetic jets [13], plasma actuators [14], electromagnetic force control[15], heating the cylinder [16] etc. The techniques listed above suppress the vortex shedding frequency but need external energy inputs for their operation which is not cost effective [17]. The other control technique is passive control technique where surface modifications of the cylinder, use of control cylinders, splitter plates[18]–[22], bleed control[23], bumps on surface [24], helical strakes [25] etc reduces the vortex shedding frequency effectively. Surface modifications technique include dimples on surface [26], altering the surface roughness of cylinder by sand roughened surface[27]–[29], surface trip wire [30], roughness strips [31], screened or patterned surface [32]. Making grooves on the cylinder surface also affects vortex shedding. Usually rectangular grooves [33], U-shaped grooves [34] and V-shaped grooves [35] are employed for this purpose. Grooves are also classified depending upon their orientation. They are circumferential ring type [36],



longitudinal type [34] and helical type. The output of all these techniques is to reduce the effects that cause the structural damage so that we get more service life of the body.

Other than the above classification, control techniques can be further categorized as (i) 2-D and 3-D forcing and (ii) boundary layer control and direct wake control. In 3D forcing control technique the actuation property varies along span wise or azimuthal direction and in 2D forcing it does not happen. In case of boundary layer control or direct wake control the classification depends on whether control delays separation by modifying the boundary layer or changes directly the wake characteristics[37].

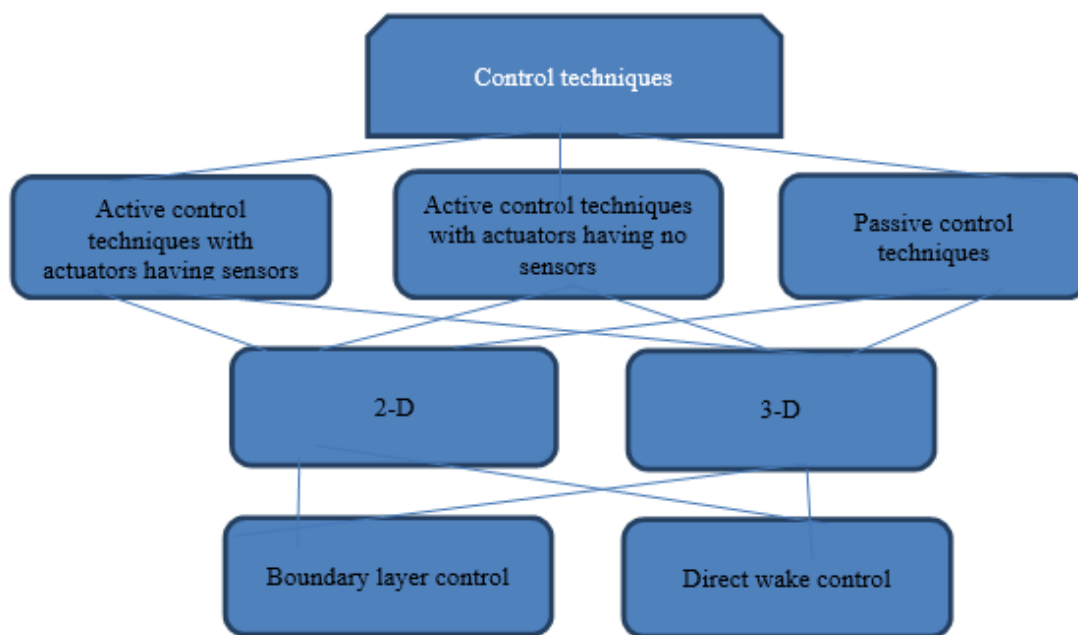


Figure 1. Classification of control techniques

Some of the parameters that affect the wake flow structure are separation angle, Reynolds number, blockage ratio, surface roughness of cylinder, the walls of the channel through which flow takes place, geometry of bluff body, viscosity of the fluid, inlet velocity of the fluid etc. The present study discusses various control techniques which can be used to modify wake flow pattern that affects vortex shedding

2. Active control techniques

Muddada et al[38] used an active control technique to control the wake flow structure. The authors developed a control equation and sensors were used to detect the flow pattern. These sensors send a signal to algorithm which then decides to actuate the rotating actuators placed around the cylinder. Thus, these rotating cylinders modify wake flow structure.

Karman Vortex Street was replaced by symmetric 2S vortices or sometimes no vortex shedding as a result of which lift coefficient and the drag reduced. This result was obtained by Wang et al [39] using synthetic jets. Amitay[40] et al also reported similar results but there was an increase in fluctuating lift of cylinder as the jet was installed only on one side of cylinder.

Sun et al [41] effectively controlled vortex shedding frequency by the effect of heating cylinder. Heating different parts of cylinder had different control effects on vortex shedding. The stabilisation effect had more strength when leeward side of cylinder was heated and it was weaker when windward side was heated. A destabilizing effect was reported when lateral sides of the cylinder were heated.

Heating the wake of cylinder is one of the other techniques in controlling wake flow pattern. Noto et al[42] reported that Karman vortex shedding is suppressed by heating near wake and this is because

when heated the density of water in the near wake decreases and suppresses the local absolute growth rate which results in less drag and fluctuating lift on the cylinder.

Oscillations of cylinder was proved to be another successful active control technique which was adopted by Berger [43] to suppress vortex shedding. It was observed that there was an effective suppression of vortex shedding when the cylinder was oscillating with harmonic forcing frequency of 1.8 times the natural shedding frequency.

3. Passive control techniques

The effect of splitter plate length on the vortex shedding frequency was investigated by Liu et al [17] who reported that even in the presence of splitter plate of shortest length affected the wake flow structure and as the length of the splitter plate increased the vortex shedding frequency decreases.

The analysis of flow structure around a perforated cylinder in shallow water by Pinar et al [44] resulted in a conclusion that porosity (ratio of open area to the whole surface area of cylinder) has a significant effect on the wake flow in the downstream of the cylinder. This was because the jet like flow which is coming through the holes on the cylinder prevents the formation of well-organized Karman vortex when compared to bare cylinder. For this to take place the authors proposed an optimum range of porosity of 0.4 to 0.8.

The effect of presence of radial fins on circular cylinder during a flow was studied by Bouzari et al [45]. The results of the experiment showed that the increase in fin's height decreases the strouhal number but increases the drag coefficient.

The flow past a rectangular grooved cylinder (as shown in figure 2) along the length of the cylinder was studied as a function of groove size and the angular position of the groove by Canpolat [46]. The experimental arrangement was as shown in the figure and by placing the groove at different angles. It was observed that groove size and angular position of groove had a significant effect on near wake structure, vortex shedding frequency and turbulent statistics.



Figure 2. Experimental set-up and a photo of a cylinder with groove along its length. Reprinted in its original form with kind permission from Elsevier [46]

A control cylinder mechanism was employed by Kuo et al [47] to reduce the fluctuating lift and form drag on the cylinder. The vortex street for flows with Re varying from 80 to 300 over a circular cylinder was suppressed using control cylinders placed in the downstream. By using this method, the vortex street was still maintained but there was a decrease in drag and fluctuating lift. The control cylinders which are present in the downstream obstructs the oncoming flow and deflects a part of fluid in the gap between main cylinder and control cylinder which creates a downstream advancing momentum. This momentum is advantageous in two ways one is it minimizes the rotation of fluid in the immediate wake region and also delays the vortex formation which ultimately reduces the

fluctuation lift. The second advantage is it reduces the wake width thus reducing the drag acting on the main cylinder.

Figure 3 depicts that the fluctuating lift increases with increase in Reynolds number when control cylinders are not used but when control cylinders are used fluctuating lift reduces with increase in Reynolds number. In figure 4 the dependence of form drag and total drag is shown. Total drag and form drag reduces with increase in Reynolds number but they increase with increase in Reynolds number when no control cylinders are used.

An experimental investigation by Guo et al [48] of flow past a slit cylinder in which slit is made along the length of the cylinder and placed parallel to the incoming flow led to a conclusion that the slit with slit ratio 0.05 has suppressed the lift force on cylinder by 81.78% when compared with a circular cylinder without a slit. The results of an experiment by Zhou et al [31] reveal that the presence of dimpled surface weakens the vortex shedding and result in less drag compared to that of flow over a smooth cylinder.

The effect of placing dual splitter plates one in upstream and the other in the downstream on wake flow structure and vortex shedding was studied by Hwang and Yang [18] and the reports state that each of the splitter plates significantly affect the wake flow the one which is placed in the front of the cylinder reduces pressure in the vicinity of the first stagnation point with a secondary effect of increasing the base suction pressure and the splitter plate at the back vortex shedding in the near wake region. In order to modify wake flow pattern and reduce the drag acting on the cylinder lee[49] et al used control rod to achieve desired results. A control rod was installed upstream of the flow at different distances from main cylinder and different diameters of control rods are used for analysis. When compared to no control rod flow, there was a 29% reduction of drag coefficient by placing control rod of diameter ($d/D = 0.233$) placed at a distance of ($L_c/D = 2.081$) in the upstream of main cylinder. When compared with results obtained by placing control rod a reduction of 25% of drag coefficient was achieved by placing control rod of diameter ($d/D = 0.233$) at a distance of ($L/D = 1.833$) from the main cylinder in the upstream. When a control rod is installed the control rod disturbs the oncoming flow and creates a turbulent flow separation on the surface of main cylinder leading to the smaller vortex formation region and wake width when compared to no control rod case. Due to the retardation of the flow separation point the pressure on the rear surface of the cylinder is reduced which leads to the reduction of pressure drag acting on the main cylinder.

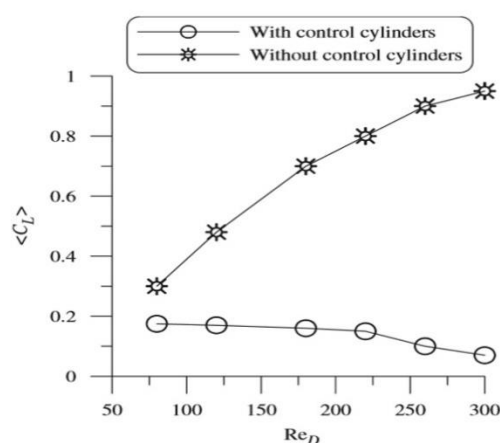


Figure 3. Dependence of coefficient of lift on Reynolds number for setup with control cylinder and without control cylinder. Reprinted in its original form with kind permission from Elsevier[47]

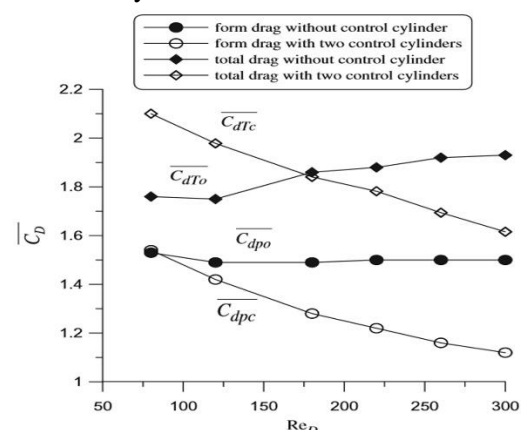


Figure 4. Coefficient of drag versus Reynolds number. Reprinted in its original form with kind permission from Elsevier[47]

Helical strakes on the surface of the cylinder can significantly reduce the vortex induced vibrations. Zhou et al [50] used helical strakes to suppress the vortex induced vibrations by 98 % when compared

to circular cylinder without helical strakes. The bare cylinder had a maximum vortex induced vibration amplitude value of 0.51. In case of bare cylinder, we can see the formation of well organised Karman vortex which can interact with each other and increase the drag on the cylinder. In case of cylinder with helical strakes the vortex is not well organised which reduces the drag (figure 5).

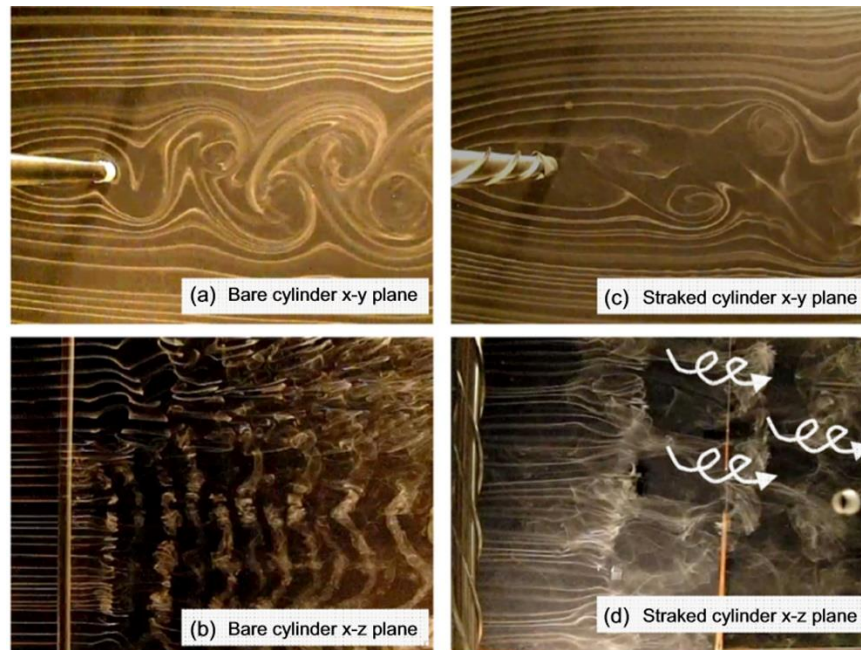


Figure 5. Flow visualisation of bare and straked cylinder wakes on different planes. The arrows indicate direction of swirling flow. Reprinted in its original form with kind permission from Elsevier [50].

4. Conclusion

Control techniques classification is based upon the use of external energy. Techniques which use external energy input are classified as active control techniques and the techniques which does not use any energy input but are used with surface or geometrical modification are considered as passive control techniques. Vortex shedding, Karman vortex formation, vortex induced vibrations results in structural damage. This damage can be controlled by the use of control techniques. Among active and passive control technique, the research carried out on active control technique shows predominant decrease in the formation of wake past bluff bodies. Several authors had suggested various active control techniques such as developing a control equation, using sensors to detect the flow pattern, heating the cylinder and making the cylinder to oscillate. Among all these techniques, heating the surface of cylinder shows considerable decrease in the wake flow structure. Although this technique shows considerable decrease in the formation of wake, it is found that only very few authors have taken this study. Much more research work is needed in the technique- heating the surface of the cylinder- for better understanding of the phenomenon in which it reduces the formation of wake

5. References

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