Passive Control of Vortex Shedding via Screen Shroud

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Abstract. The turbulent wake of screen-shrouded cylinders were experimentally investigated using flow visualization. Screen cylinders made from screen mesh of various porosity (37\%, 49\%, 61\% and 67\%) were used as the shrouds. The main purpose of the study is to examine the effect of screen porosity, \(\beta\) and screen diameter ratio, \(d_w/D\) (wire diameter to cylinder diameter ratio) on the vortex development behind the shrouded cylinders, particularly in supressing the vortex shedding from a circular cylinder. The diameter ratio between the screen shroud and the plain cylinder, \(D/d\) was 2.0. The flow Reynolds number based on the shroud diameter, \(Re_D\) was about 1000. Results showed that the inclusion of the screen shrouds has significant impact on the wake of the circular cylinder. With larger value of the non-dimensional parameter \(\beta d_w/D\), vortex was impaired and the formation length was longer in the shrouded cylinder wake. The vortex generation mechanism was also discussed.

1. Introduction

Suppression of vortex shedding and vortex-induced vibration (VIV) has been one of the most active topics of research and patenting in fluid dynamics for many decades due to its significance in engineering applications. Previous investigations on control devices to suppress VIV have contributed significantly to the fields of buildings, bridges and marine. VIV can be suppressed by active or passive methods. Active methods involve applying energy from an external force while passive methods involve modification of the flow or structure. Each method works by disrupting the vortex shedding, either by diminishing the strength of the shear layers on either side of the cylinder or by disrupting the interaction of the shear layers. Extensive reviews of these devices can be found in available literatures [1].

Shrouds are one of the passive solutions that are less frequently employed. The used of shrouds in mitigating the impact of vortex formation have long been introduced since the work of Price in 1956. Price pioneered the work in circular holes shroud postulating that it would break up the flow into large number of small vortices [2]. The use of a screen mesh as shroud for vortex shedding suppression was first explored by Zdravkovich and Volk [3]. Zdravkovich and Vork [3] conducted experiments at high reduced velocities for three types of shroud; the square holed, circular holed and a fine-mesh gauze all having 36\% porosity. They found that the shroud made of fine-mesh gauze was the most effective one. The gauze prevented separation and affected the pressure distribution more significantly than the other two shrouds and the uniform part of the pressure distribution curve started at 120° instead of 90°. The study of screen mesh as controller of a bluff body wake has been revisited in recent years. Azmi et al.
[4, 5] found that the vibration amplitude of a bare cylinder was suppressed by about 50% and 78% using a screen shroud of 72% and 67% porosity at a shroud-to-cylinder diameter ratio of 1.25 and 2.0, respectively.

In studying the wake characteristics of a single screen body, Takeuchi et al. [6] measured the airflows around permeable cylinders made of wire mesh of 54% and 71% porosities. The flow just behind the permeable cylinders had forward velocity due to the permeability, which relaxed the near field excitation of Kármán vortex. As a result, the reattachment point behind the cylinder was delayed several times of that a solid cylinder wake. This result is consistent with Azmi et al. [7], who showed that that there exists a critical location that differentiates the screen cylinder wake into two regions where the formation of the fully formed large-scale vortices was delayed until this critical location. Gansel et al. [8] tested cylinders made from metal mesh of various porosities. The results indicated that the wake characteristics changed toward the wake characteristics of a solid cylinder at a porosity just below 75%. [9].

The various studies on perforated bodies proved that such flow cannot be easily predicted based on porosities alone, since there are multiple length scales involved such as apparent diameter, wire diameter and aperture (hole size) that govern the flow [10]. However, very limited studies have been conducted so far in understanding the effect of these parameters. The present study aims to examine the effect of a non-dimensional parameter (which is based on porosities and screen diameter ratio) on the vortex development behind a screen shrouded cylinder, paying attention to the vortex formation length. The study would certainly complement the relatively limited literature on this topic.

2. Experimental Details
The experiments were conducted in a small open circuit type wind tunnel with a test section of 380 mm (width) × 255 mm (height) and 1.8 m (long). The free stream velocity in the test section was uniform to 0.2%, and the longitudinal turbulence intensity was less than 5%. Experiments were conducted in the wakes of both the plain cylinder and shrouded cylinder. The solid cylinder was a plain and smooth cylinder made of polished aluminium of diameter, \( d \) of 12.7 mm. The screen cylinder was of 25 mm diameter, \( D \), rolled from a stainless steel wire mesh of a square-cross-section of various porosity, \( \beta \), aperture, \( a \) and wire diameter, \( d_w \). The porosity of the screen mesh \( \beta \) is defined as the ratio of the opening area to the total area, i.e. \( \frac{a^2}{(a+d_w)^2} \). The properties of the screen cylinders are given in Table 1. The shrouded cylinder had an outer to inner diameter gap ratio of about 2.0. The plain cylinder and the shrouded cylinder had an aspect ratio of \( l/d = 29.9 \) and 15.2, respectively. Figure 1 shows the shrouded cylinder set up and one of the screen cylinders used in the study.

| Screen | Hole Size, \( a \) (mm) | Wire Diameter, \( d_w \) (mm) | Porosity, \( \beta \) (%) | Dimensionless parameter, \( \beta d_w/D \) | Formation length, \( L/D \) |
|--------|------------------------|-----------------------------|-------------------------|-----------------------------------|--------------------------|
| 1      | 0.25                   | 0.16                        | 37                      | 0.237                             | 8                        |
| 2      | 0.71                   | 0.32                        | 48                      | 0.614                             | 8                        |
| 3      | 1.6                    | 0.45                        | 61                      | 1.098                             | 14                       |
| 4      | 2                      | 0.45                        | 67                      | 1.206                             | 18                       |

Smoke wire flow visualizations were carried out using a high speed camera to obtain a qualitative understanding on the evolution of vortices in the wake of the screen shrouded cylinder. Smoke is produced from a thin (0.1 mm) steel wire coated with oil. The wire is connected as a resistor to an electric circuit. When the circuit is on, the wire heats causing the oil to generate smoke which was carried downstream by the flow to reveal the flow motion. The visualizations were conducted at Reynolds numbers of around 1000.
3. Results
For the solid cylinder wake (Figure 2), the large-scale organized vortices can be seen clearly with two rows of counter-rotating vortex structures connected by the streamwise rib-like structures. The rib-like structures are stretched due to the counter-rotating vortices. The two rows of vortices also interact with each other when evolve downstream by penetrating to the opposite side across the wake centreline. The formation length of the Kármán vortices is about 2d which is in good agreement with [11].

The screen-shrouded cylinder wake using screen 1 and screen 2 behaves quite similarly where the onset of shear layer interaction occur in the wake at about 8D as shown in Figure 3 and 4, respectively. There is an onset of transition in the shear layers and the development of turbulence in the wake further downstream. The near wake is surrounded by a laminar shear layer. An undulation of the shear layer that looks like a transition waves is evident, followed by the formation of large-scale structures which become irregular further downstream once the turbulence sets in. It can be seen in Figure 4 that the shear layer rolls up into small-scale vortices at x/D= 4. The formation length, L_f for both flow configurations using screen 1 and 2 was found to be at about 8D from the cylinder.
Figure 3. Flow visualization in the wake of a screen-shrouded cylinder (screen 1).

Figure 4. Flow visualization in the wake of a screen-shrouded cylinder (screen 2).

Figure 5 and 6 (based on screen 3 and 4, respectively) clearly shows that the undulation occurred latter in the wake and the formation length was delayed. Small-scale vortices are formed at about greater than $8D$, they do not roll up quickly to form the large-scale structures in comparison to the previous two cases. As evolving downstream, the small-scale structures become larger in size. When their sizes are large enough, they engulf the one next to them, resulting in amalgamation (Figure 5). The onset of the interaction between the two shear layers occurred at about $x/D = 14$ and 18 (not shown) for screen 3 and 4 respectively, where the large-scale structures start to form. Obviously, the shrouded cylinders wake show similar behaviour of growth of small-scale vortices and the formation of the large-scale ones further downstream, with the difference being in the formation length.

Figure 5. Flow visualization in the wake of a screen-shrouded cylinder (screen 3).

Figure 6. Flow visualization in the wake of a screen-shrouded cylinder (screen 4).

Table 1 summarizes the observed trend in the formation length as a function of the screen parameter and this trend is also plotted in Figure 7. Figure 7 shows that the non-dimensional parameter seems to have significant effect on the vortex formation length. As $\beta d_w / D$ increases, the vortex formation length significantly increases, particularly for $\beta d_w / D > 0.6$, where the formation length increases exponentially. For $\beta d_w / D$ less than 0.6, the formation length seems to lie in the same range. It needs to be noted that, this result may be applicable for the studied Reynolds number range and for the cylinder gap ratio of 2.0. The flow would behave differently, for other Reynolds number and gap ratio.
4. Conclusion
Flow visualization using smoke wire have been conducted to understand the flow behaviour behind screen-shrouded cylinders. The effect of screen parameter on the vortex development in the cylinder wakes was studied. From the visualization results, it can be concluded that with higher screen parameter value, the formation length became larger. For the non-dimensional parameter of greater than 0.6, the effect was more significant, where the formation length increased exponentially. Two flow regimes have been identified i.e. the vortex merging process and the delay of the large-scale organized structures in the screen-shrouded cylinder wake. The formation length is expected to depend on factors such as the screen parameter presented here, the gap ratio as well as Reynolds number.

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References
[1] Zdravkovich MM 1981 Review and classification of various aerodynamic and hydrodynamic means for suppressing vortex shedding J. Wind Eng. Ind. Aerodyn. 7(2) 145-189
[2] Price P 1956 Suppression of the fluid-induced vibration of circular cylinders J. Eng. Mech. 82(3) 1-22
[3] Zdravkovich MM, Volk JR 1972 Effect of shroud geometry on the pressure distributed around a circular cylinder J. Sound Vibration 20(4) 451-455
[4] Azmi AM, Zhou T, Cheng L, Wang H, Chua LP 2012 On the Effectiveness and Mechanism of Vortex-induced Vibration Suppression using a Screen Cylinder The Twenty-second International Offshore and Polar Engineering Conference International Society of Offshore and Polar Engineers
[5] Azmi AM, Zhou T, Zhou Y, Chen J, Cheng L 2015 The effect of a screen shroud on vortex-induced vibration of a circular cylinder and its wake characteristics The Twenty-fifth International Ocean and Polar Engineering Conference International Society of Offshore and Polar Engineers
[6] Takeuchi H, Tasaka T, Murai Y, Takeda Y, Tezuka H, Mori M 2007 Particle image velocimetry for air flows behind permeable cylinders. Proc. of the 5th ASME–JSME Joint Fluids Engineering Conference San Diego USA vol 37035 pp. 1-8
[7] Azmi AM, Zhou T, Zhou Y, and Cheng L 2016 Statistical analyses of a screen cylinder wake Fluid Dyn Res, 49(1) 015506
[8] Gansel LC, McClimans TA, Myrhaug D 2012 Flow around the free bottom of fish cages in a uniform flow with and without fouling J. Offshore Mech. Arct. 134(1) 011501

[9] Levy B, Friedrich H, Cater JE, Clarke RJ, Denier JP 2014 The impact of twine/mesh ratio on the flow dynamics through a porous cylinder Exp. Fluids. 55(10) 1829

[10] Azmi AM, Zhou T, Cheng L 2014 On the Effect of Various Shrouds on the Wake of a Circular Cylinder. ASME 2014 4th Joint US-European Fluids Engineering Division Summer Meeting collocated with the ASME 2014 12th International Conference on Nanochannels, Microchannels, and Minichannels 2014 pp. V01BT14A016-V01BT14A016

[11] Unal MF, Rockwell D 1988 On vortex formation from a cylinder. Part 1. The initial instability. J. Fluid. Mech. 190 491-512