International Journal of Heat and Fluid Flow 34 (2012) 15–27

Contents lists available at SciVerse ScienceDirect

International Journal of Heat and Fluid Flow

journal homepage: www.elsevier.com/locate/ijhff

Reduction of fluid forces and heat transfer on a square cylinder in a laminar flow regime using a control plate

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ARTICLE INFO

Article history:
Received 19 September 2010
Received in revised form 23 October 2011
Accepted 24 December 2011
Available online 20 January 2012

Keywords:
Reduction of fluid forces
Control plate
Flow pattern
Heat transfer
Square cylinder
Vortex shedding
Laminar flow

ABSTRACT

This study focuses on the reduction of the fluid forces acting on a square cylinder in a laminar flow regime by a passive control, i.e. a flat plate placed upstream of the cylinder. The Reynolds numbers based on the width of the square cylinder (W) and the inlet flow velocity are selected from Re = 50 to Re = 200. The width of the control plate (h) is varied from $0.1W$ to $0.9W$ and the distance between the control plate and the cylinder (S) is chosen within the range of $1.1–7W$. In these ranges of h and S, the different flow patterns and the magnitude of the reduction of the fluid forces in order to identity the optimum conditions are studied. The results of the heat transfer from a cylinder in the presence of a control plate are also provided for $S = 1.1–7W$, $h = 0.5–0.9W$, Re = 160, Pr = 0.71.

The results show that the optimum position and width for the control plate are a distance of $3W$ away from the cylinder and a width of $0.5W$, respectively, where the almost maximum reduction of the fluid forces and the minimum reduction of the heat transfer are provided.

It is also found that the total Nusselt number of the cylinder in the presence of the control plate decreases for different gap spacings, except for $S/W = 1.1$.

1. Introduction

There is usually a massive unsteady wake region downstream of a bluff body which leads to considerable fluctuating fluid forces and susceptibility to flow-induced vibration. The wake and the separated flow region can be reduced by the flow control which, in turn, reduces unsteadiness and the forces on the object. An effective flow control can save energy, increase the propulsion efficiency and also reduce the induced vibrations of the body. The flow around the chimneys, parallel suspension bridges, the vibrations of radar masts, heat exchanger pipes, and high structures are applications of flow control in industry. In general, the flow control methods used to suppress the aerodynamic forces are classified into two categories:

1. Active control methods in which the flow is controlled by supplying external energy through means such as forced fluctuations and jet blowing (Fransson et al., 2004; Fujisawa et al., 2005).
2. Passive control methods in which the flow is controlled by modifying the shape of the body or by attaching the additive devices such as a control rod or plate or roughness elements onto the body (Darekar and Sherwin, 2001; Hwang and Yang, 2007; Lim and Lee, 2004; Tamura and Miyagi, 1999).

Active control generally requires complex mechanical devices that supply external power to the flow. Therefore, compared with the active flow control, the passive control is simpler, easier, and possibly less costly to implement.

Many attempts have been made to suppress or reduce vortex shedding and fluid forces acting on the bluff bodies by control of the fluid. A review and a classification of the various aerodynamic and hydrodynamic means for suppression of the vortex shedding are carried out by Zdravkovich (1981). He classified these means into three categories:

a. Surface protrusions for control of the boundary layer, which affect the separation lines and/or separated shear layers, e.g. tripping wire, fin, etc.
b. Shrouds, which affect the entrainment layers to supply fluid necessary for the growth of vortices, e.g. axial rod, axial slat, etc.
c. Near wake stabilizers, which prevent interaction of entrainment layers, e.g. splitter plate, guiding van, etc.

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doi:10.1016/j.ijheatfluidflow.2011.12.008