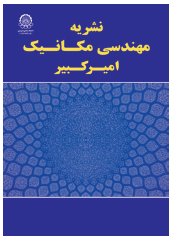

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Numerical Study on Laminar Flow Over a Cylinder and Its Rotating Controllers for Suppressing the Vortex Shedding

M. Goodarzi*, E. Khalili Dehkordi

Department of Mechanical Engineering, Bu-Ali Sina University, Hamedan, Iran

ABSTRACT: Vortex shedding exerts the dynamic and periodic forces on cylindrical structures and increasing the FIV and even the resonance. Controlling the flow over the cylinder and delaying the separation, reduces the vortex shedding and achieves the longer lifetime. Among different passive and active methods of flow control, using the flow controllers is a highly practical method. Two small rotating cylinders, near the main cylindrical structure, can be actively used for this purpose. The effects of the geometrical parameters on the oscillatory response of a particular main circular cylinder have been numerically studied for a particular laminar flow regime. The finite volume based on SIMPLE algorithm has been used for simulating the unsteady flow field. The procedure of finding the correct position to controllers is surveyed. The reduction indexes are defined for calculation the effectiveness of controllers. It is shown that there is an optimum position for the proposed condition in which the variation of lift ad drag forces for the cylinder and two rotating controllers are the minimum one and the vortex shedding is suppressed, too. Moreover, the mean drag coefficient is reduced significantly in the prescribed position for the main cylinder and two rotating controllers.

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1- Introduction

Flow over a cylinder concerns with vortex shedding and oscillations of the lift and drag forces in the wide range of Reynolds numbers [1]. Williamson [2] studied the different modes of vortex shedding within the wake of a circular cylinder at low Reynolds numbers.

Flow controllers are usually small objects that can reduce the variations of the lift and drag forces. Mittal and Raghuvanshi [3] explained the mechanism of controlling the vortex shedding using a rotating controller in the wake region. The position of the rotating controllers substantially affect the rate of the fluctuation suppression. This article concerns with finding such an optimal position of the rotating controllers.

2- Problem Description

Fig. 1 shows a schematic description of the present problem. There is a laminar uniform flow passing over a main cylinder and two rotating controllers. The fluid is supposed to be viscous and Newtonian and flow is incompressible. Small rotating controllers inject the momentum into the wake region of the main cylinder. The lower controller rotates counter clock-wise while the upper one rotates clock-wise. Positions of rotating cylinders are defined by dimensionless radial distance, (r_D=r/D), between the centers of the rotating and main cylinders, and also angular distance, θ, measured from the wake centerline. Rotating cylinders are symmetrically placed around the wake centerline.

3- Mathematical Formulation

Flow field is two dimensional in the horizontal plane. There is no external force such as electrical or magnetic fields. Therefore, transient forms of the continuity and momentum equations describe the flow field. Dimensionless rotational speed indicates the angular velocity of each rotating controller as follows:

$$\alpha = \frac{\omega D}{2u_\infty} \tag{1}$$

where ω is angular velocity of the rotating controller. Four reduction indices are introduced in this article for quantitative representation of controller effectiveness. The lift reduction index for the lift amplitude of the exerted lift force on the main cylinder is defined as:

$$I_{A_L} = \frac{A_L - A_{L,c}}{A_L} \tag{2}$$

where A_L is the oscillation amplitude of the lift coefficient in the absence of controllers, and $A_{L,c}$ is the same parameter at the presence of controllers. The reduction indices for drag coefficient are straightforwardly defined as I_{A_D}, I_{C_L} and I_{C_D}. These indices can be used to compute the amount of decrease of the same parameters over the rotating controller at the presence of the main cylinder in comparison to the cases that the main cylinder is not present.

4- Numerical Method

Governing equations were numerically solved using the finite volume method. A set of appropriate boundary conditions are needed to solve the governing equations. Second order upwind scheme was used to interpolate convective fluxes on the cell faces, while central scheme was used for diffusive

Corresponding author, E-mail: m.goodarzi@basu.ac.ir

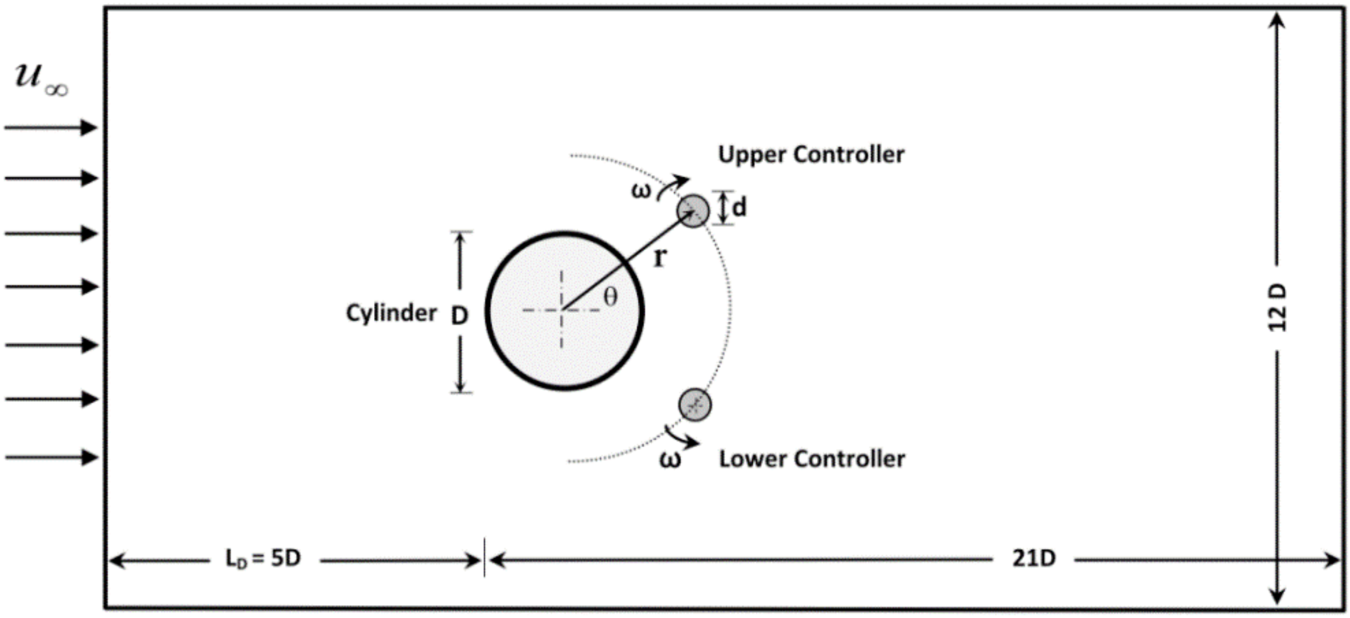


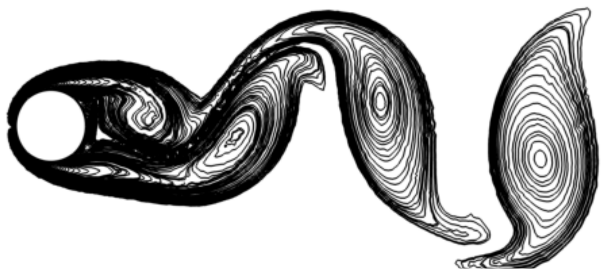
Fig. 1. Schematic description of the flow over a 2D circular cylinder at the presence of two rotating cylindrical controllers

ones. Momentum and pressure fields were coupled to each other using SIMPLE algorithm (Patankar [12]). An unstructured grid system with triangular elements was used in the present study. Grids were clustered near the rigid walls and behind the cylinders for better capturing of the high gradient dependent variables.

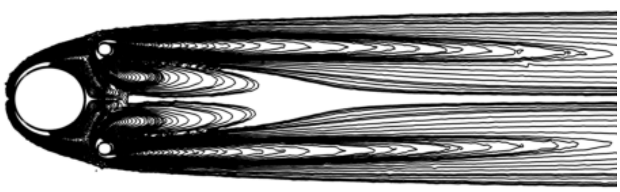
5- Results and Discussion

Present numerical modeling has been validated with previously reported results. Oscillation amplitudes of the drag and lift coefficients for main cylinder and rotating controller, controller's effectiveness and its optimal position have been computed for the specified case with d_D=0.2, α=6 and Re=150. The best position of the controller for this case has been found at (r_D=1.1 , θ=45^o).

Fig. 2 shows instantaneous vorticity contours behind the main cylinder in the absence and at the presence of the rotating controllers. It is evident that in the absence of rotating controllers a Karman Street is established in which vortices shed to the downstream with particular frequency. When twin rotating controllers are installed, vortices do not shed behind the system of cylinders and all vortices remain in contact to the cylinders rather than shedding to the downstream.



(a) In the absence of controllers



(b) At the presence of ontrollers at r_D=1.1 , θ=45^o

Fig. 2. Instantaneous vorticity contours behind the main cylinder

Controller's effectiveness can be quantitatively studied by computing reduction indices. Computed results demonstrate that oscillation amplitudes of the lift and drag coefficients are reduced by 99.828% and 99.084% at the presence of rotating controllers, respectively. At the same time, the mean drag coefficient decrease by 23.243% at the presence of rotating controllers, respectively. Computed results show that oscillation amplitudes of the lift and drag coefficients of the rotating controller decrease by 99.784% and 99.926%, respectively, at the presence of the main cylinder. Besides, the mean values of the lift and drag coefficients of the controller decrease by 10.36% and 10.741%, respectively.

6- Conclusions

Unstable laminar flow over a cylinder at the presence of twin rotating controllers was numerically studied. The impacts of the radial and angular position of the rotating controllers on the rate of vortex shedding suppression were investigated. Numerical results illustrated that there was an optimal position for installing the rotating controllers at which vortex shedding could be completely suppressed. Of course, this optimal position may be changed with changing kinematical and other geometrical flow conditions. Additionally, computed results demonstrated that when rotating controllers were installed at the optimal position, instability mechanism would be changed from vortex shedding to a simple vortex intensity fluctuation without shedding to the downstream. Simultaneous presence of the main cylinder and rotating controllers decreased unfavorable oscillatory parameters for both structures.

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