

**NUMERICAL INVESTIGATIONS ON VORTEX GENERATED
OSCILLATIONS OF A PAIR OF CYLINDERS ALONGSIDE**

Dr. Nirmal Kumar Kund

Associate Professor, Department of Production Engineering
Veer Surendra Sai University of Technology, Burla 768018, India

Abstract— *The current investigation is motivated towards vortex generated oscillations and vortex shedding because of elastically fixed pair of cylinders. Various non-dimensional key process parameters such as mass ratio, Reynolds number, transverse gap ratio, frequency ratio and reduced velocity, pertaining to the current problem are recognized and their comparative significance are also witnessed. The studies are carried out at various frequency ratios and reduced velocities by taking the flow to be laminar and incompressible. The numerical model includes governing transport equations of continuity and momentum in two dimensions. The model practices finite volume method (FVM) with pressure based SIMPLE algorithm to perform numerical simulation for obtaining the associated flow fields. The oscillations initiated from the interacting vortices through a pair of cylinders are entirely studied in terms of cylinder trajectory and vibration frequency/amplitude.*

Keywords— *Numerical simulation, Reduced velocity, Frequency ratio, Trajectory, Amplitude, Shedding.*

I. INTRODUCTION

Stability study owing to wake around cylinder is examined by Barkley and Henderson [1]. Numerical solutions of linear systems of equations are also given away by Trefethen and Bau [2]. The rudiments of CFD has also been explained by Versteeg and Malalasekera [3]. The basics of fluid mechanics is also elucidated by Kundu and Cohen [4]. Fluid flow over porous cylinder with incessant suction/blowing is expounded by Fransson *et al.* [5]. Effects of traveling wave on von Karman vortex street about a cylinder is explicated by Wu *et al.* [6]. Influence of synthetic jet on wake around cylinder is detailed by Feng and Wang [7]. The interference of synthetic jet with wake vortex shedding nearby a cylinder besides its decomposition analysis is further expanded by Feng *et al.* [8, 9]. In addition, synthetic jet usage on separation control near cylinder is also extended by Feng and Wang [10]. The suction flow practice for diminishing vortex induced vibration of cylinder is also added by Chen *et al.* [11]. Also, the suction flow technique on unsteadiness reduction around the cylinder is further experimented by Chen *et al.* [12].

From the abovementioned literature, to the best of authors' understanding, it is quite obvious that there is no such exhaustive computational analysis relating to the influences of reduced velocity and frequency ratio on cylinder vibration in terms trajectory of cylinder centre together with the amplitude, frequency and deflection of cylinder. With this standpoint, the present research aims primarily at the computational investigations of the above stated intents (apart from the fluid flow behavior) around a pair of cylinders in abreast position. The current numerical model practices finite volume method (FVM) with pressure based SIMPLE algorithm to carry out simulation for getting the desired flow fields. Lastly, the computational results are analyzed and compared for realizing the expected physical feel and sagacity. The predictions of the model concerning various non-dimensional key process parameters are along expected lines. In addition, for comparison of results, an in-house experimental setup is also planned for the future.

II. DESCRIPTION OF PHYSICAL PROBLEM

The physical problem encompasses the fluid flow with velocity U over a pair of elastically fixed cylinders of diameter D each. The fluid flow is assumed to be incompressible and the problem concerns with two degrees of freedom (relating to oscillations along both x and y directions). A two dimensional rectangular computational domain is chosen in order to save simulation time. Transverse gap ratio (T/D) chosen to be 3. In addition, the details about the physical problem with computational domain are illustrated in Fig. 1.

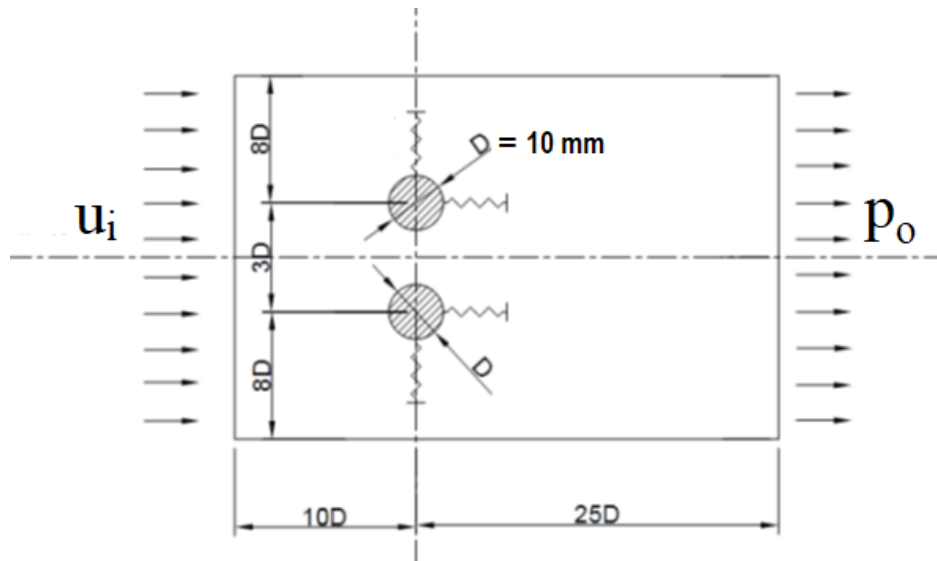


Fig 1. Physical problem with computational domain

III. MATHEMATICAL FORMULATION

A. Governing equations

The dimensionless form of the governing transport equations of continuity and momentum pertaining to the present physical problem are as mentioned below.

$$\nabla' \cdot \mathbf{u}' = 0 \quad (1)$$

$$\frac{\partial \mathbf{u}'}{\partial t'} + \nabla' \cdot (\mathbf{u}' \mathbf{u}') = -\nabla' p' + \frac{1}{Re} \nabla'^2 \mathbf{u}' \quad (2)$$

Where, Re (i.e. $\rho U D / \mu$) is the Reynolds number, μ is the dynamic viscosity, D is the reference length, U is the reference speed, u this is the velocity field, t is the time, p is the modified static pressure and ρ is the density.

B. Boundary conditions

The specified velocity boundary condition is used at the inlet. However, the specified pressure boundary condition is considered at the exit. The lateral boundaries are introduced with symmetry (i.e. far field) boundary conditions (i.e. both x-velocity gradient and y-velocity are taken as zero at lateral boundaries). And also, the no-slip boundary condition is taken at the surface of the cylinders.

C. Parameters

In the present investigations, the numerical simulations are carried out for fluid flow over a pair of freely oscillating cylinder. The fluid considered is air with invariable density and viscosity of 1 kg.m^{-3} and $0.001 \text{ kg.m}^{-1}.\text{s}^{-1}$, respectively. The diameter of each cylinder is taken as 0.01 m . The flow over the pair of cylinders is set at inlet velocity of 1.6 m/s corresponding to Reynolds number of 160. In other words, the flow is considered to be laminar. The cylinders are unrestricted to vibrate along transverse and in-line directions. The mass ratio is taken to be three. The damping coefficient is set as zero for attaining high amplitudes due to vibrations. The reduced velocity ranges between 4 and 10. Three different frequency ratios of 1.0, 1.5 and 2.0 are taken into considerations.

IV. NUMERICAL METHOD

The present numerical model uses finite volume method (FVM) with pressure based SIMPLE algorithm to carry out simulation for getting the desired flow fields. Second order upwind with first order implicit scheme is applied for the present physical problem formulation. The grid independence test reveals the optimum grid size that corresponds to grids with 160 nodes on the circumference of each cylinder. Likewise, the time independence test also ensures solution stability with a sound simulation time. The meshing inside the computational domain along with the enlarged view of meshing near cylinder surface is illustrated in Fig. 2.

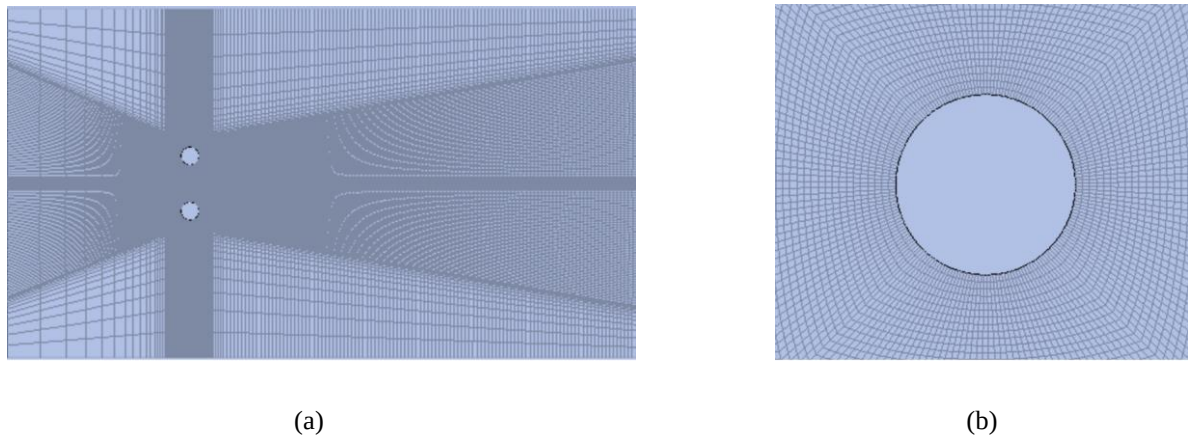


Fig 2. (a) Computational domain with meshing (b) Enlarged view of meshing near cylinder surface

V. RESULTS AND DISCUSSIONS

Numerical simulations are carried out (for flow around a pair of cylinders in abreast position), to investigate the effects of reduced velocity and frequency ratio on cylinder vibration in terms trajectory of cylinder centre along with the amplitude, frequency and deflection of cylinder.

The trajectory of the cylinder centre at different reduced velocities and at frequency ratio 2 is as depicted in Fig 3. It is noticed that the trajectory of the cylinder centre follows the illustrious Lissajous figure at low reduced velocity. And also, the amplitude of vibration is high at low reduced velocity. Furthermore, the amplitude of vibration decreases with the increase in reduced velocity. Additionally, with the increase in reduced velocity, the regular Lissajous figure gradually becomes irregular.

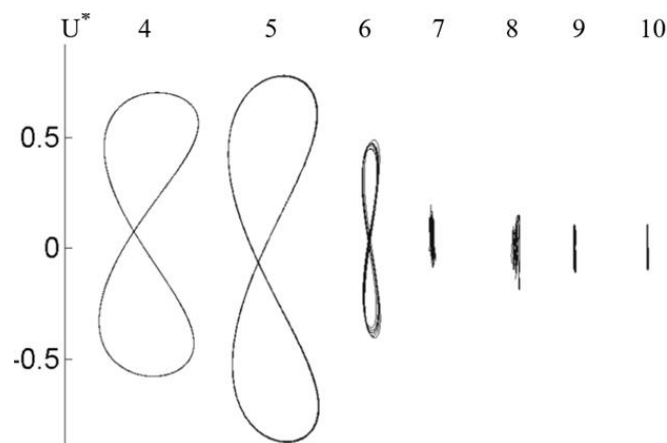


Fig 3. Trajectory of cylinder centre at different reduced velocity for frequency ratio 2

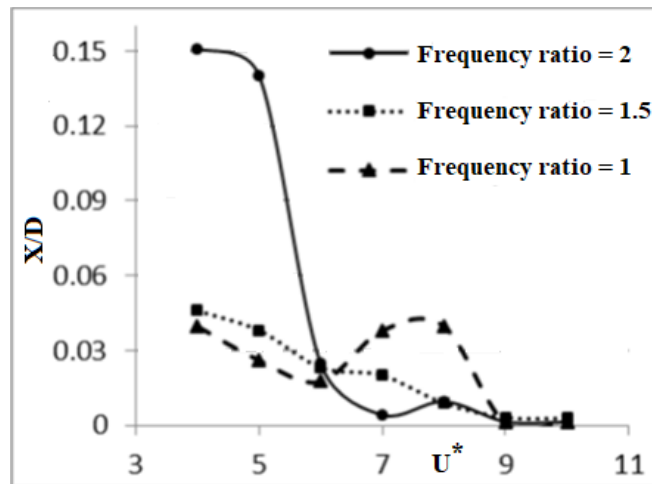


Fig 4. Ratio of rms value of amplitude in stream direction to cylinder diameter vs. reduced velocity

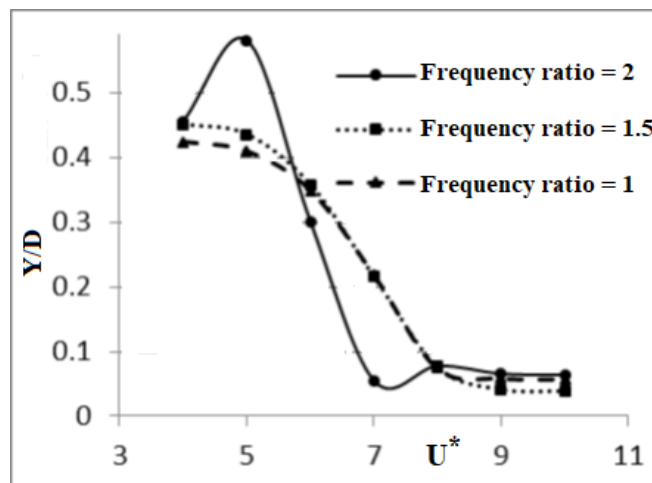


Fig 5. Ratio of rms value of amplitude in transverse direction to cylinder diameter vs. reduced velocity

Figs. 4 and 5 illustrate the dimensionless rms value of amplitude vs. reduced velocity curves at different frequency ratios. It is noticed that the maximum value of ratio of deflection in the stream direction to cylinder diameter is about 0.15. And also, the maximum value of ratio of the deflection in transverse direction to cylinder diameter is nearly 0.50. The amplitude gets decreased by an order for increase in reduced velocity from 4 to 10.

VI. CONCLUSIONS

Numerical simulations are performed for flow around a pair of cylinders alongside, to examine the influences of reduced velocity and frequency ratio on cylinder vibration in terms trajectory of cylinder centre together with the amplitude, frequency and deflection of cylinder. The current numerical model practices finite volume method (FVM) with pressure based SIMPLE algorithm to perform simulation for obtaining the chosen flow fields. Second order upwind with first order implicit scheme is used for the current physical problem formulation. The grid independence test discloses the optimum grid size and the time independence test also confirms solution stability with a sound simulation time. The predictions of the model relating to various non-dimensional key course parameters are consistent with the expectations. The assessment with a pilot-scale experimental procedure is yet to come.

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