The Simulation of Fluid-Structure Interaction on Two Flexible Cylinders Subjected to an Annular Flow

Zhengang Liu [*], Yang Liu [*a)] & Jian. Lu [**]

[*] *Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong*

[**] *Department of Mechanical and Biomedical Engineering, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong*

Summary Two flexible cylinders are clamped at their two ends and located in a confined annular flow. The fluid-structure interaction in the system is simulated based on ALE N-S equations with LES turbulence model and the Euler-Bernoulli beam dynamic equation. It is found that the weak buckling with weak oscillation around the buckling state may be induced if the dimensionless velocity is large enough.

INTRODUCTION

It is very important to understand the dynamics of cluster consisting of flexible cylinders subjected to axial or annular flow in engineering. It have been found by linear analyses [1] and experiments that the system may lose stability by divergence and flutter sequentially if the dimensionless velocity, which is defined by Eq. (1), is large enough. The linear analyses can not be used to predict the vibration after the instabilities and always assume that the perturbation is based on the equilibrium state of the cylinders. Though nonlinear theories [2] have been developed for an isolated cylinder in parallel flow, however, it seems not easy to extend them to multiple cylinders. In this study, the simulation of fluid-structure interaction is carried out based on ALE N-S equations with LES turbulence model and the Euler-Bernoulli beam dynamic equation. The fluid solver is FLUENT [3] and the structure solver is integrated into the CFD solver through user-defined function (UDF).

GOVERNING EQUATIONS AND MODEL

The fluid flow governing equations are incompressible ALE N-S equations and the cylinders are model as Euler-Bernoulli beam. The flow and structure solvers are coupled by the explicit partitioned scheme [4]. Fig. 1 shows the schematic view of the model, in which two hollow flexible cylinders whose length-diameter ratios and thickness are 20 and $0.06D$, respectively, with D being their diameters, are immersed in an annular flow, confined by a cylindrical wall that has the same length as those of the cylinders and a diameter of 6 times of the cylinders' diameters. The Reynolds Re based on hydraulic diameter D_h, dimensionless velocity $\bar{U}$ and mass ratio β are defined by [1]

$$\mathrm{Re} = \frac{\rho \upsilon_0 D_h}{\mu}, \quad \bar{U} = \upsilon_0 L \sqrt{\frac{\rho A_t}{EI}}, \quad \beta = \frac{\rho A_t}{\rho A_t + \rho_b A_e}, \tag{1}$$

where υ_0 is the velocity in z direction at the inlet (see Fig. 1); ρ and μ are the density and viscosity of the fluid respectively; ρ_b, EI, L, A_t and A_e are the density, flexural rigidity, length, the total and effective cross-sectional area of the cylinders, respectively. In this study, $\mathrm{Re} = 1.13 \times 10^5$, $\bar{U} = 6.0173$ and $\beta = 0.4699$.

RESULTS AND DISCUSSION

The dimensionless x-displacement $d_x = u_x / D$ with u_x x-displacement at the mid-span of cylinder 1 is shown in Fig. 2, where the dimensionless axial coordinates $\zeta = 0, 20$ indicate upstream and downstream ends respectively and τ is the dimensionless time (see [1]). A very weak oscillation is induced, however not around the equilibrium state. From Figs. 3 and 4, it can be seen that the average and RMS values of cylinder 1 are comparable in two traverse directions, indicating a weak non-zero equilibrium state (i.e. buckling state) of cylinder 1 arises. The displacements of new equilibrium state and oscillation around it are both similar to the first vacuum beam mode. Because the oscillation around the buckling state is weak, it should be attributed to turbulence. The amplitude after the divergence, usually in the first mode, according to linear analysis [1], will increase to infinity, however, should be finite in real physical system due to the nonlinearity. The nonlinear analysis [2] shows the pitch-fork bifurcation that a non-zero equilibrium state should exist of an isolated cylinder if the dimensionless velocity is large enough. Thus the non-zero equilibrium state can be regarded as the divergence or pitch-fork bifurcation. For cylinder 2 the statements are similar. The vibration is so weak that the flow is not influenced strongly by it, as shown in Fig. 5, since the z-vorticity seems statistically symmetric with respect to x-z and y-z planes.

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a) Corresponding author. Email: mmyliu@polyu.edu.hk.

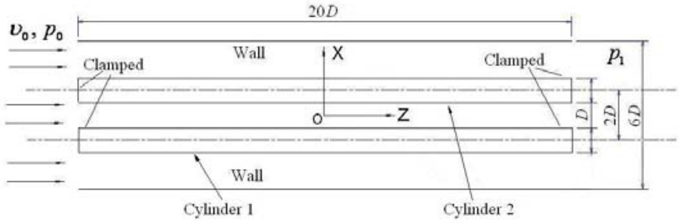

Fig. 1 The sketch of the model

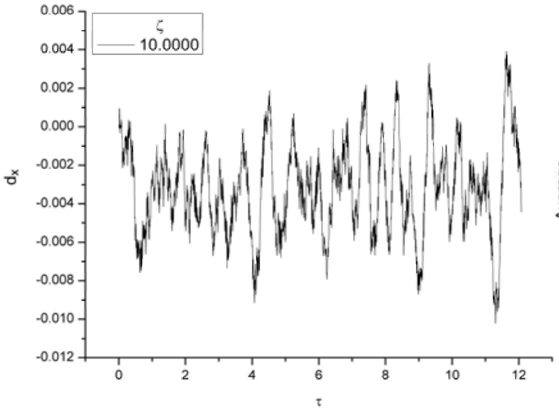

Fig.2 the mid-span displacement of cylinder 1

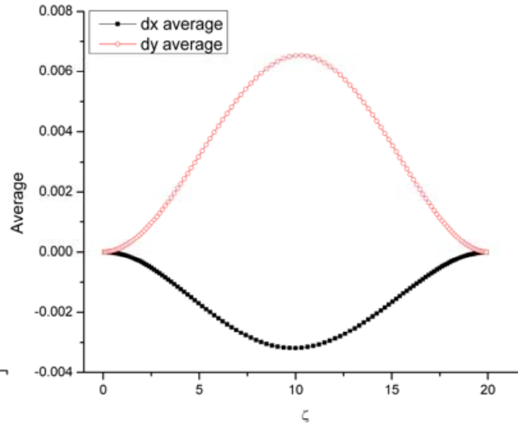

Fig. 3 the averages of displacements of cylinder 1

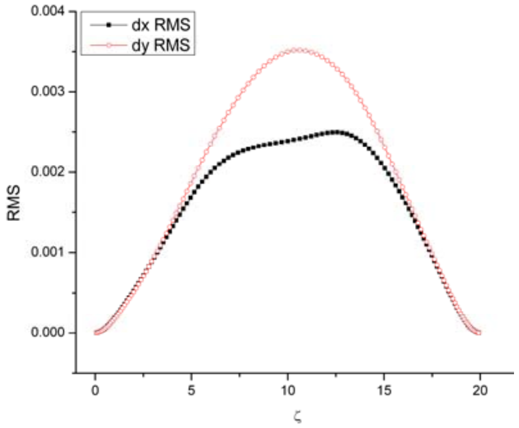

Fig. 4 the RMS of displacements of cylinder 1

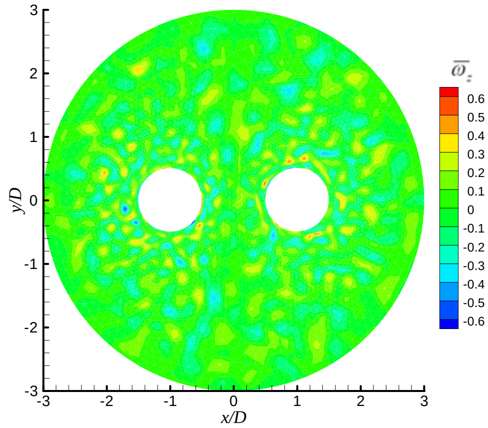

Fig. 5 the dimensionless z-vorticity at the mid-cross section of whole fluid domain

CONCLUSIONS

The fluid-structure interaction for a cluster consisting of two cylinders subjected to an annular flow is simulated and it is found that the weak buckling with weak oscillation around the buckling state may be induced if it the dimensionless velocity is large enough.

ACKNOWLEDGEMENT

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