Numerical study on suppression for wake galloping of parallel circular cylinders by helical wires

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ABSTRACT: This paper investigates the mechanism of reduction in the wake galloping amplitude of parallel circular cylinders by helical wires using 3D Large Eddy Simulation (LES). A numerical mesh system for cylinders with helical wires is proposed, and the performance of this numerical model is validated by comparing with experimental data. Thereafter the suppression effect for the amplitude of wake galloping by using helical wires with different diameter ratios is studied. Finally the suppression mechanism of helical wires for the wake galloping of parallel cylinders is clarified through the analysis of lift forces, correlation of forces and flow fields.

KEYWORDS: wake galloping, parallel circular cylinders, helical wires, vibration suppression, Large Eddy Simulation.

1 INTRODUCTION

The phenomena of wake-induced galloping are often of primary concern in bridge engineering, offshore industry, aerospace, power transmission, energy extraction, and many more applications, which greatly affect the performance and fatigue life of the structures (Assi et al., 2010). Helical wire is one of the most proven and widely used control measures in various industrial and offshore applications to suppress flow-induced vibration (Zdravkovich, 1981). It is considered to be of great practical significance because of the ease of installation on a cylindrical structure and the insensitivity of flow direction with helical pattern, and the wires of rounded section will not increase the drag coefficient dramatically as sharp-edged rectangular strakes (Weaver, 1959). However, although it has been used on the isolated cylinder, yet its performance for reducing wake galloping of parallel circular cylinders have not been fully understood. This study aims to provide an effective numerical method to predict the characteristics of wake galloping of parallel wired circular cylinders and to clarify the mechanism of wake galloping suppression for parallel cylinders by helical wires.

2 NUMERICAL MODEL

2.1 Numerical method

The 3D unsteady LES filtered Navier-Stokes equations are solved in this study using the control volume method. Smagorinsky model (Smagorinsky, 1963) is adopted to model the subgrid-scale turbulent viscosity with Smagorinsky constant \( C_s \) set as 0.032. The second-order central difference scheme is employed to the convective and viscosity terms, and the second-order implicit scheme is used for the unsteady term. SIMPLE (semi-implicit pressure linked equations) algorithm is employed for solving the discretized equations. The sliding mesh technique is employed to analyze the structural response of 1DOF system. The equation of motion is solved by 4th order Runge–Kutta method.
2.2 Geometry and boundary conditions

The geometries used in this study are elongated circular sections with and without helical wires. The computational domain is shown in Fig. 1 whose width and depth of domain are $57D$ and $30D$ respectively, where $D$ is the diameter of cylinder. The spanwise length of the domains in this paper is $4D$. The cylinders are of tandem arrangement and the center-to-center distance is $4D$. The upstream cylinder is fixed and the downstream one can move transversely combining with dynamic laying mesh and sliding mesh technique. To check the effectiveness of helical wire with different diameters, wire diameters $d=0.02D$ and $0.1D$ are studied. The helical wires have a configuration of 4 starts with pitch $P=8D$. A rotated mesh around the surface of cylinders with helical wires is generated and connects with the outer mesh using interface as shown in Fig. 2. Uniform velocity condition is specified at the inlet boundary, and zero diffusive condition is used at the outlet boundary. Symmetric condition is used for top, bottom and side surfaces of the domain.

![Computational domain](image1)

![Numerical mesh around cylinders](image2)

3 RESULTS AND DISCUSSION

3.1 Validation of numerical model

For the prediction of fluid-induced vibration, the force on cylinder should be simulated accurately. For that purpose, it is necessary to show that the calculation is reliable by verifying the accuracy of pressure distribution with experiment results. The isolated cylinder is firstly simulated and the result shown in Fig. 3(a) agrees with experimental data (Kubo et al., 2012). The parallel cylinders with the angle of attack $\alpha=0^\circ$ and $15^\circ$ are simulated and the results are given in Fig. 3(b) and (c). The calculated values also agree well with the experimental values (Yagi, 2003), which prove the accuracy of current numerical model for fluid force.

![Wind pressure distributions](image3)
3.2 Effect of helical wires

The displacement time history of the downstream cylinder is simulated by the unsteady simulation, and the amplitudes of vibration are shown in Fig. 4, compared with the experimental results. The amplitude is calculated using the mean value of peak displacement after the vibration reaches stable state. The predicted vibration amplitude of bare cylinder agrees with experiments (Assi et al., 2010). The amplitude is negligible when $U/fD<3$. It keeps increasing with the reduced velocity and shows a trend of divergence, which is similar to the feature of general galloping. When the wires are attached to the surface of cylinders, the effects of suppression depends on the diameter of wires. The wires of $d/D=0.1$ suppress the amplitude significantly while the wires of $d/D=0.02$ are not such effective. The mechanism of suppression is discussed in the following section.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig4.png}
\caption{Variation of vibration amplitude of cylinders with the reduced velocity}
\end{figure}

3.3 Mechanism analysis

The suppression effect of helical wires is mainly reflected in its influence on the fluctuating lift force, which is the main cause of vibration. Therefore, the lift force coefficients are analyzed for wired cylinders with different diameter ratios. It can be seen in Fig. 5 that the Root Mean Square (RMS) values of lift forces coefficients on cylinders decrease with the increasing of wire diameters, which explains the fact that the vibration suppression effect is better with larger wires. In addition, the correlation of the lift force coefficient are also compared in Fig. 6. The correlation length of lift force coefficient is reduced by wires of $d/D=0.1$, while the thin wire of $d/D=0.02$ doesn’t change the correlation distribution apparently, which support the previous analysis.

\begin{figure}[h]
\centering
\begin{subfigure}[h]{0.5\textwidth}
\centering
\includegraphics[width=\textwidth]{fig5a.png}
\caption{Variation of the RMS values of lift force coefficients with different diameter ratios}
\end{subfigure} \hfill
\begin{subfigure}[h]{0.5\textwidth}
\centering
\includegraphics[width=\textwidth]{fig5b.png}
\caption{The correlation factors of lift force in the span direction for different diameter ratios}
\end{subfigure}
\end{figure}
The flow pattern is also used to clarify the mechanism of galloping suppression. Fig. 7 shows the visualized flow around the bare and wired cylinders. It can be seen that the helical wires apparently change the vortex separation points. The separation line is almost straight for the bare cylinder but skewed by the helical wires. In the case with larger helical wires, the separation lines are skewed more strongly, which helps to understand that the suppression effect are more significant with larger helical wires.

![Flow patterns around (a) a bare cylinder and (b) a wired cylinder](image)

Fig. 7. Flow patterns around (a) a bare cylinder and (b) a wired cylinder

4 CONCLUSION

LES numerical simulation with dynamic mesh is used in this study to investigate the mechanism of wake galloping suppression for parallel circular cylinders by helical wires. A valid numerical model is proposed and verified by experimental data. The fluid force and vibration amplitude of cylinders compared to identify the suppression effect. The flow pattern and characteristics of lift force are analyzed to explain the suppression mechanism of helical wires for the wake galloping of parallel cylinders. It shows that the helical wires can reduce the fluctuating lift force efficiently by skewing the vortex separation line of cylinder. The vibration of cylinder is more likely to be suppressed with larger helical wires.

5 REFERENCES

3 J. Weaver, Experimental investigation of wind-induced vibrations in antenna members (No. GR-75-4), Massachusetts Institute of Technology: Lincoln Laboratory (1959).