MICRO-BLOWING EFFECT ON TWO COUPLED WAKES BEHIND TWO SQUARE CYLINDERS

Shengjin Xu[* a)], Pengchuan Zhang[**] & Weiguo Zhang[***]
[*]*Department of Engineering Mechanics, Tsinghua University, Beijing, 100084, China*
[**] *Department of Mathematical Sciences, Tsinghua University, Beijing, 100084, China*
[***] *China Aerodynamics Research & Development Center, Mianyang, Sichuan, 621000, China*

Summary A micro-blowing rig was designed to control two coupled wakes formed from two side-by-side square cylinders with T/h = 1.8, where *T* was the center-to-center spacing of the two cylinders, *h* was the side length of the cylinders. The up-surface of one cylinder was designed to vibrate in approximated sinusoidal manner. A micro-blowing flow was generated from the two upper edges of the cylinder in one cycle of the vibration. The micro-blowing flow generated a series of vortices, which influenced the widths and vortex shedding frequencies of the wakes. As the blowing was growing up, another cylinder wake became into narrow. The corresponding frequency of the wake was increased. A coupled and forced Stuart-Landau equation was modeled for this control process. The equation can qualitatively predict the change of the coupled wake.

SHORT PAPER

Experiments were carried out in a wind tunnel with a square working section (0.6 m × 0.6 m) of 2.4 m long. The velocity can be adjusted from 0.3 ~ 50 m/s. The longitudinal turbulence intensity in the free stream is less than 0.1 %. Two square cylinders made of aluminum ally were horizontally mounted in the mid-plane and spanned the full width of the working section. They were arranged side-by-side. The cross section area of each cylinder is 0.0152 × 0.0152 m^2 (*h* × *h*). A maximum blockage resulted is about 5.1% and the aspect ratio is 39.5. The upper surface of the lower cylinder was activated (the excitation frequency f_e = 45 Hz) to yield a transverse vibration (the max-amplitude A ≈ 0.35 mm) using three Thunder TR-8 PZTs. A micro-blowing flow was generated from the two upper edges of the cylinder in each cycle of the vibration (Figure1). A Dantec standard PIV2100 system with 532 nm illuminated system was employed to record velocity field behind the two cylinders. The flow pattern was also imaged by Laser-induced fluorescence (FIL) flow visualization function of the PIV system in order to investigate qualitatively the perturbation effects on the flow structures. The recording interval between a pair of successive images was 0.25 s, i.e., 4 frames per second. More than 100 images were taken for each record. The vortex shedding frequencies of two cylinders were measured using two hotwires. The typical sampling frequency was 3.5 kHz for each measurement. The duration of each record was about 30 sec. All measurements were conducted at *T/h* = 1.8 at a fixed Reynolds number of Re = 3500 (Re = $U_\infty h/\nu$, where U_∞ is free stream velocity and ν is kinematics viscosity).

Without any perturbation, the wakes of two side-by-side cylinders at *T/h* = 1.8 are characterized by a narrow wake and a wide wake, which exchanges each other in some duration at random. The vortex shedding frequency ratio between the wide wake (15.2 Hz) and the narrow wake (45 Hz) is about 1:3 (Figure 2a). The gap flow is biased towards the narrow wake at this moment as shown as the photograph obtained from FIL flow visualization measurement (not shown in the short paper), in agreement with previous experiments[1-2]. As the vibration increased, the narrow wake and the wide wake can be exchange each other. The wake frequencies and the wake widths are significantly changed (Figure2 &3). To verify this change caused by the micro-blowing flow, a coupled and forced Stuart-Landau equation can be modeled as:

$$\frac{dA}{dt} = (r + iw)A - (c_R + ic_I)\left|A\right|^2 A + \eta(1 + c_k)(B - A) \tag{1a}$$

$$\frac{dB}{dt} = (r + iw)B - (c_R + ic_I)\left|B\right|^2 B + \eta(1 + c_k)(A - B) + Fe^{i\omega_e t} \tag{1b}$$

Assume, $A = \rho_A(t)e^{i\phi_A(t)}, B = \rho_B(t)e^{i\phi_B(t)}$, after a tedious deduction, one may obtain

$$0 = r - \eta - c_R\rho_A^2 + \eta\frac{\rho_B}{\rho_A}(\cos\delta - c_K\sin\delta) \tag{2a}$$

$$\omega_e = w - \eta c_K - c_I\rho_A^2 + \eta\frac{\rho_B}{\rho_A}(c_K\cos\delta - \sin\delta) \tag{2b}$$

$$0 = r - \eta - c_R\rho_B^2 + \eta\frac{\rho_A}{\rho_B}(\cos\delta - c_K\sin\delta) + \frac{F}{\rho_B}\cos\tau \tag{2c}$$

[a)] Corresponding author. Email: xu_shengjin@tsinghua.edu.cn.

$$\omega_e = w - \eta c_K - c_I \rho_B^2 + \eta \frac{\rho_A}{\rho_B}(c_K \cos\delta - \sin\delta) + \frac{F}{\rho_B}\sin\tau \tag{2d}$$

Where, $r = (\mathrm{Re} - \mathrm{Re}_c)/\mathrm{Re}_c$. Eqs(2) show that, in the two coupled wakes, an increased F results in an increased ρ_B but a decreased ρ_A. That is, the wake of the upper cylinder becomes more and more narrow.

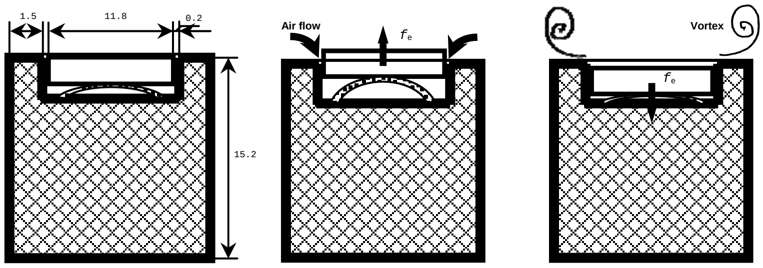

Figure 1 Cross-section sketch of the micro-blowing experimental setup.

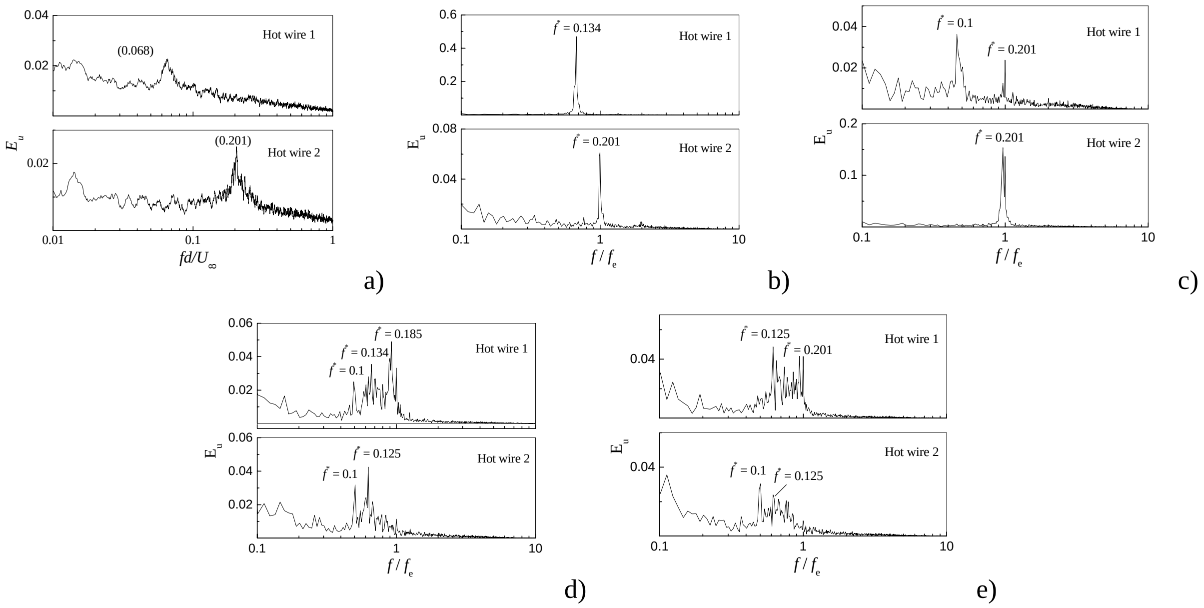

Figure 2 Power spectra of hot wire signals. From a) to e), vibration amplitude is increased from 0 to 0.35mm.

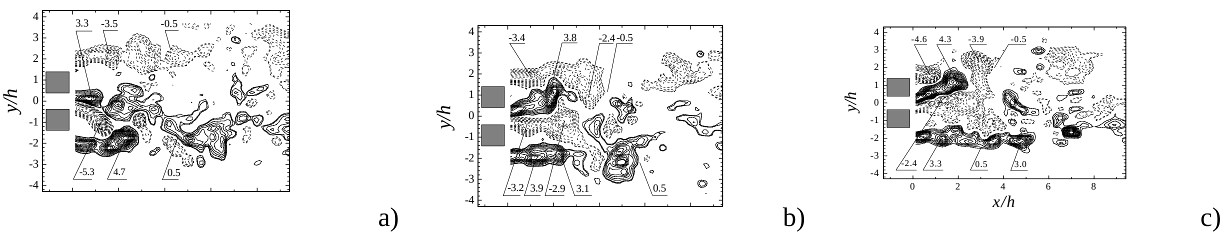

Figure 3Instantaneous vorticity contours $\omega^* = \omega h / U_\infty$ obtained from the PIV measurement. From a) to e), vibration amplitude is increased from 0 to 0.35mm.

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References

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