論文の内容の要旨

Frequency Characteristics and Fluid Flow Property of Flow-Induced Vibration with and without Resonator

（共鳴器の有無が異なる 2 種類の流体自励振動の流動特性と振動数決定機構に関する研究）

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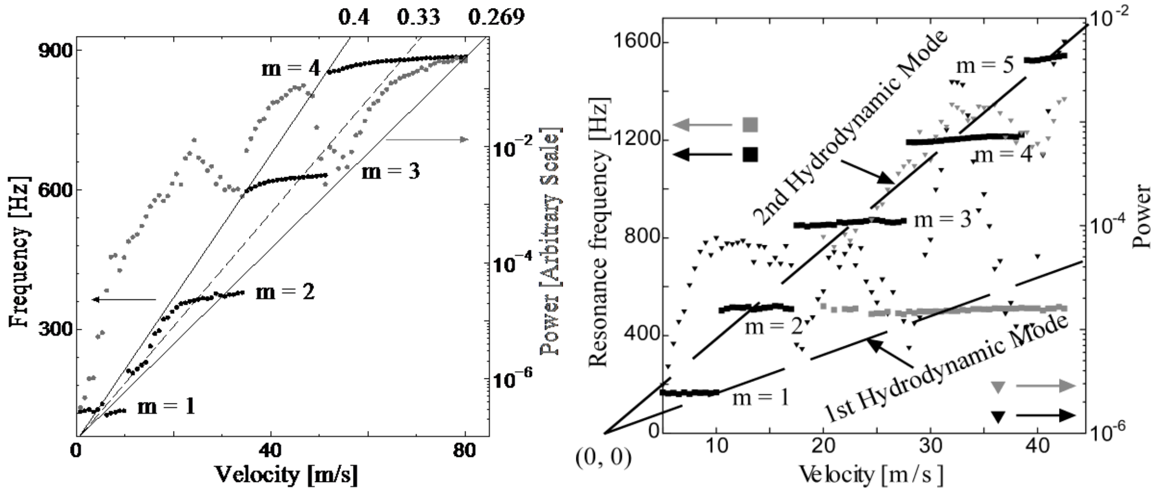
Vibration and noise problems due to fluid flow occur in many industrial plants. This obstructs smooth plant operation. These flow-related phenomena are known as flow-induced vibrations (FIV). FIV is an important source of fatigue damage of mechanical equipments.

FIV can be divided into two kinds: with resonator and without resonator. One of the most famous FIV phenomena with resonator is cavity tone, which is a kind of acoustic resonance. Flow-induced acoustic resonance of cavities and side-branch pipes, are of high interest in engineering applications, such as the piping systems of power station, chemical plants, natural gas compressor stations, the fuel vents on aircrafts or vehicle conjunction of a train. One of the typical FIV phenomena without resonator is fluid flow inside a feedback fluidic oscillator. The feedback fluidic oscillator is a device which is characterized by the absence of moving parts and can be used to enact large-scale changes in a flowfield with a relatively small control input for aerodynamic flow control applications such as cavity resonance tone suppression, fluidic actuators, jet thrust vectoring and enhancement of jet mixing. Feedback fluidic oscillator has used internal flow separation and reattachment (Coanda effect) to generate the oscillations.

The present study focused on the frequency properties of FIV, i.e. clarifying lock-in condition and flow fluctuation propagation of FIV with resonator and frequency characteristics and flow oscillation pattern of FIV without resonator. In order to find out the shear layer or jet oscillation properties, particle image velocimetry (PIV) technique was utilized to extract the two-dimensional flow fields.

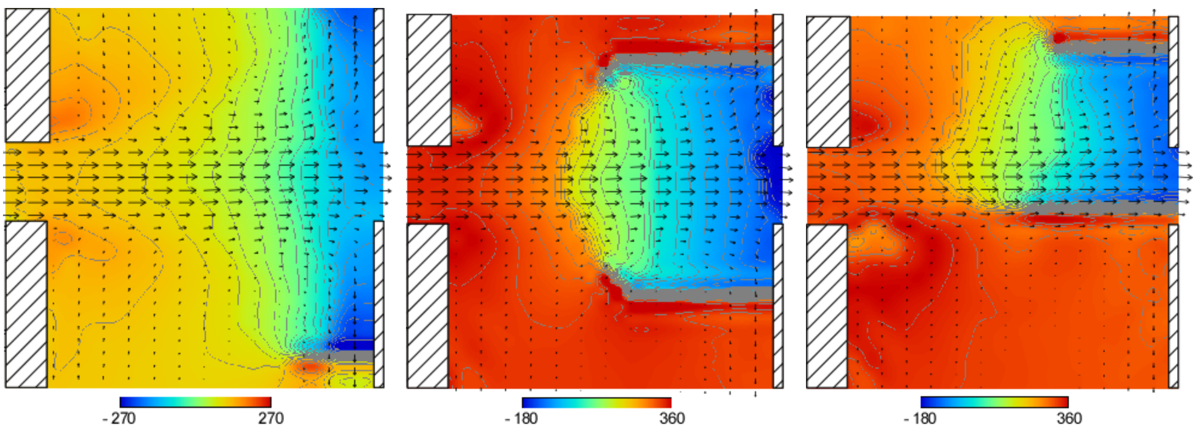
As a typical type of FIV with resonator, flow-induced acoustic resonances in a piping system containing closed coaxial side-branches with and without forced pressure fluctuation were investigated experimentally.



(a) (b)

Fig. 1 Resonance characteristics of closed coaxial side-branches system. Dashed lines correspond to hydrodynamic mode, *m* = acoustic modes number. (a) d/D = 1/4, (b) d/D = 4.

In order to excite a self-induced acoustic resonance in the piping system with closed coaxial side-branches (d/D = 1/4), a block was put at the inlet of the main pipe. For this piping system configuration, Resonance characteristics of the piping system were examined by a microphone firstly, as shown in Fig. 1 (a). The results revealed that the fluid flow fluctuations were strongly locked in corresponding to the natural frequencies of the side-branches for the flow under relative high Reynolds number condition ($Re > 1.3 \times 10^5$). However, for the relative low Reynolds number flow conditions ($6.6 \times 10^4 < Re < 1.3 \times 10^5$), the resonance was seen to be dominated by the shear layer oscillation properties, i.e. the resonance occurred at a dominant frequency based on the shear layer oscillation frequency (frequency according to the hydrodynamic mode) rather than the natural frequency of the closed coaxial side-branches.



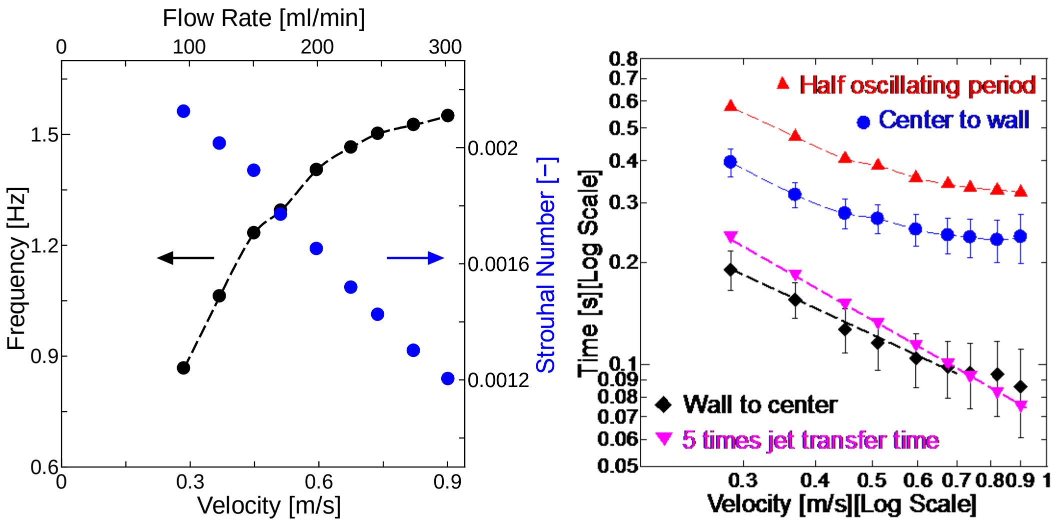
(a) Under 1st hydrodynamic mode (b) Under 2nd hydrodynamic mode (c) Under off-resonance condition

Fig. 2 Phase delay maps under resonant and off-resonant conditions.

In order to induce much stronger acoustic resonance and make the resonance easy lock-in to the natural frequency of the coaxial resonator, a resonator with a width ratio of $d/D = 4$ in which acoustic radiation into the main pipe became smaller was designed and tested. Resonance characteristics of the piping system were examined by a microphone, as shown in Fig. 1 (b). In this kind of configuration, strong frequency lock-in was excited under the first acoustic resonance mode while Strouhal number $St > 0.4$. To increase the amplitude of the shear layer fluctuation and control the resonator operate under resonant and off-resonant conditions, a louder speaker was placed at the upper end side of the coaxial side-branches. Phase averaged velocity fields at eight successive 45°-wide interval phase of a typical acoustic cycle, were obtained two-dimensionally in the junction of coaxial side-branches, while the acoustic resonance was induced at the first and second hydrodynamic modes. Patterns of shear layer correspond to two hydrodynamic modes were obtained from the phase averaged velocity fields. The PIV can acquire time series velocity fluctuations, then, two-dimensional phase delay maps under resonance and off-resonance conditions in the junction of coaxial side-branches were obtained. Fig. 2 (a) (b) shows the contour map of phase difference under resonant condition, and Fig. 2 (c) shows the phase delay map under off-resonant condition. The phase delay maps under resonant condition were symmetric about the main pipe because the lower side-branch resonated with the speaker, pressure fluctuation passed down to the lower side-branch and made the two side-branches were well-tuned. For the phase delay maps under first and second hydrodynamic modes, the phase difference around the antinodes area of the shear layer became large dramatically. However, the contour lines in the junction under off-resonant condition exist only in the upper side-branch, where the loudspeaker was installed at the end, because the shear layer fluctuation disturbed the transformation of pressure fluctuation to the lower side-branch. Experimental results show that the proposed phase delay map method costs less experiment and computation time and achieves a better repetition than the phase locking technique. In addition, the phase delay map method can obtain phase difference under the different frequency components. This is extremely important when two different acoustic modes were induced in one experimental condition.

Motivating from understanding the mechanism of flow-induced vibration without resonator, characterization of periodic flow structure in a feedback fluidic oscillator under low Reynolds number water flow were investigated experimentally.

In the present study, a feedback fluidic oscillator has been manufactured and tested under low Reynolds number water flow, to clarify the flow patterns inside the oscillating chamber and the feedback channels, to figure out the oscillatory characteristics and dynamic structure of periodic jet fluctuation and the feedback flow, via PIV technique. The flow oscillations were triggered by the Coanda effect, the frequency highly increases with the Reynolds number and a non constant Strouhal number while Reynolds number ranged from 200 to 630 were obtained based on spectral analysis of the velocity fluctuations inside the feedback channels, as shown in Fig. 3 (a). The flow rate fluctuations of the feedback flows inside the feedback channels were quantitatively determined. Meanwhile, corresponding patterns of the jet fluctuation during one cycle were extracted from the two-dimensional velocity distributions. The time of jet oscillate from the center of the control volume to either of the attachment walls and that of jet oscillate from either of the attachment walls to the center of the control volume were separated and discussed by different interpretation models. The experimental results showed that the time of jet oscillate from the center of the control volume to either of the attachment walls was related to the feedback flow through the feedback channels and the time of jet oscillate from either of the attachment walls to the center of the control volume was related to the propagation time of jet traveling along the oscillating chamber, as shown in Fig. 3 (b), and this time was found approximately equal to 5 times propagation time of jet traveling along the oscillating chamber under low Reynolds water flow.



(a) (b)

Fig. 3 Frequency characteristics of the feedback fluidic oscillator (a) and characteristics time of the jet oscillation. ▲ shows the half oscillation period. ● indicates the time of jet oscillation from the center of the control volume to one of the attachment walls. ▼ represents five times jet oscillation time. ♦ signifies the time of jet oscillation from one of the attachment walls to the center of the control volume.