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Self-sustained Oscillation Phenomena of Fluidic Flowmeters

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***Abstract*:** In order to clarify the metering characteristics of the fluidic flowmeters employing self-sustained oscillation, the oscillating jets in a feedback oscillator and a target oscillator were visualized and the differential pressures across the jets were measured.

The experiment clarified that the fluidic oscillators could be classified into three types, i.e., feedback type, reflection type and recirculation type oscillators. The jet oscillation was caused by external feedback control pressures in the feedback type oscillator. On the other hand, the internal feedback pressure difference, produced mainly by a partly reflected jet flow from the target, sustains the jet's oscillation in the reflection type oscillator. In the recirculation type oscillator, the jet oscillation was caused by the internal feedback pressure difference produced by a jet flow recirculating along the side wall of the target oscillator under the influence of the reflected jet flow.

The jet oscillation of the target oscillator was influenced by forced pulsation of the jet flow as follows. The strength of the reversed jet flow and reflected jet flow was affected directly with the pulsation of the jet and a synchronization phenomenon appeared, in which the oscillation frequency was matched with the pulsation frequency of the jet flow.

The ranges of dimensional parameters maintaining the oscillation of the target oscillator were revealed. It was found that the target oscillator with crescent target could produce steady oscillation in a wider region of dimensional parameters.

***Keywords*:** fluidic flowmeter, feedback oscillator, target oscillator, self-sustained oscillation, pulsation flow, synchronization phenomenon.

1. Introduction

Fluidic flowmeter employing self-sustained oscillation was developed to take the advantage of fluidics, i.e., no-moving part, simple construction, easy to production and digital output signal.

Fluidic flowmeters are classified into two types, a feedback oscillator (Yamamoto et al., 1994) and a target oscillator (Yamasaki and Honda, 1979). The feedback oscillator is constructed by a fluidic amplifier with negative feedback loops connecting same side output ports and control ports each other. The target oscillator was developed for a gas flowmeter, so that the construction was simplified to reduce pressure loss through the flowmeter, then the flowmeter has not obstacles but a target opposing the nozzle.

These flowmeters produce the output frequency proportional to jet flow rate, i.e., the flow rate through the meter itself in steady flow. But, in unsteady flow, especially in periodic pulsation flow, the jet oscillation in the target oscillator is influenced by the pulsation (Yamamoto et al., 1997).

In this study, the oscillation phenomena of these two type flowmeters and the synchronization phenomena of the target oscillator were investigated by the visualization of the oscillating jet and the measurements of the differential pressure across the jet.

2. Experimental Apparatus

2.1 Feedback Oscillator

As shown in Fig. 1, the feedback oscillator under test consists of a laminar proportional amplifier, LPA, with feedback loops. Measured flow passes through a supply nozzle of the LPA forming a jet which oscillates, then spills over from a right and a left output ports alternately producing negative feedback pressure signals and flows out through vent ports.

Principal dimensions were, the width of the supply nozzle W=4.0 mm, the aspect ratio of the supply nozzle As=1.0, the width of the control nozzles Wc=1.0W, the splitter distance X=9.0W, and the width of the output ducts Wo=1.2W.

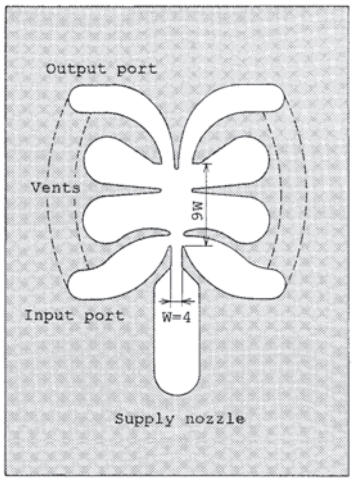


Fig. 1. LPA feedback oscillator under test.

2.2 Target Oscillator

The target oscillators under test basically consists of a supply nozzle, a target, and an output duct. One hundred and two kinds of the target oscillators with various dimensions were tested. Figures 2 (a) ~ (e) show typical target oscillators with a crescent and a rectangular targets producing the oscillation, and with a round and a wedge targets. Principal dimensions were, the nozzle width W=4.0 mm, the aspect ratio As=1.0, the target distance X=1.5~9.0W, the distance between side walls Ws=5~30W, the width of the target Wt=1.5~2.6W and the width of the output duct Wo=7.4W.

2.3 Experimental Layout

Experimental layout is shown in Fig. 3. Water supplied from a supply head tank t (Length=1.8m, Width=1.0m, Height=0.5m) flows through a pulser r, a precision needle valve e then into the oscillator q under test. The output flow of the oscillator spills over an overflow tank w (Length=1.8m, Width=1.0m, Height=0.8m) then was measured with a measuring cylinder and a stopwatch. Pulsating flow was produced by compressing and expanding a bellows with a eccentric round cam driven with a pulse motor, and was added to the supply water flow. These compressed and expanded volume of the bellows was ±3cc. The pressure ratio, Pulsating pressure/Supply pressure, was ranged from ±25% to ±50%. The jet and the flow field around the jet were visualized by the dye injection method using phenolphthalein.

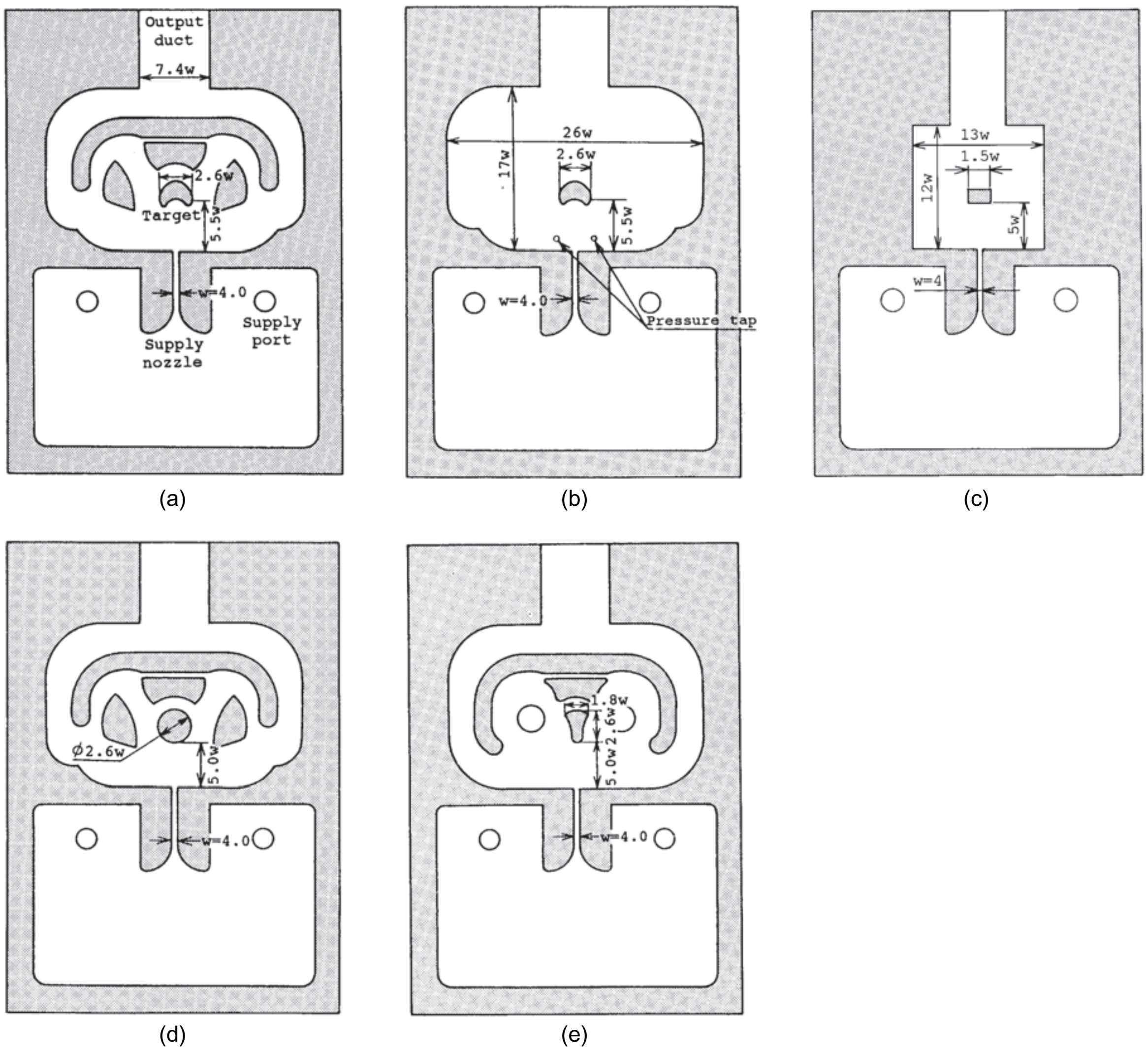


Fig. 2. Typical dimensions of target oscillators under test:
(a) Type A, (b) Type B, (c) Type C, (d) Type D, (e) Type E.

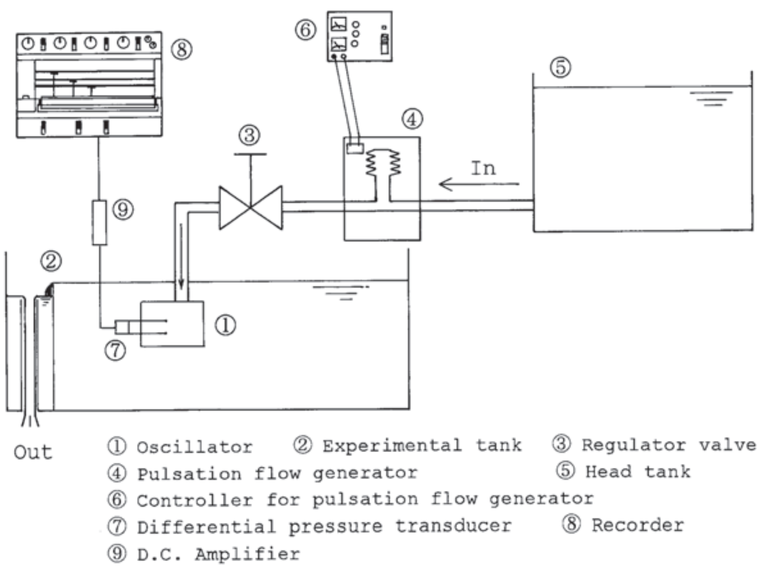


Fig. 3. Experimental apparatus.

3. Results and Discussion

3.1 Frequency-Jet Velocity Characteristics

The relationships between the oscillation frequency f and the mean jet velocity u of the feedback oscillator for steady and pulsating flows are shown in Fig. 4. The frequency of the feedback oscillator was proportional to the mean flow velocity and the linear relationship was not influenced by the pulsation of the jet velocity. Figures 5 (a) and (b) show the relationships between f and u of the target oscillators, Type A and Type C, respectively, for steady and pulsating flows. In steady flow, the relationship between f and u had linearity. On the other hand, in pulsating flow, the relationship had not linearity and the synchronization of the oscillation frequency with the pulsating frequency appeared. This synchronization phenomena appeared commonly in the target oscillators. The oscillation phenomena showed periodicity in the synchronized range, but in the other range, the frequency and the amplitude of the oscillation changed randomly.

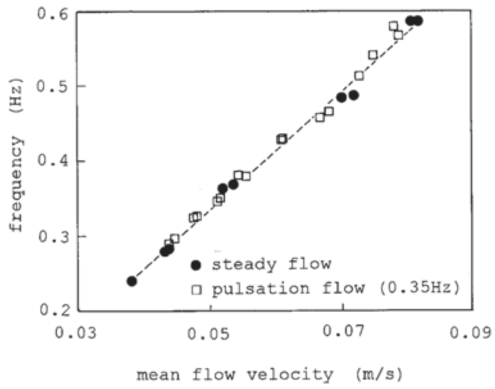
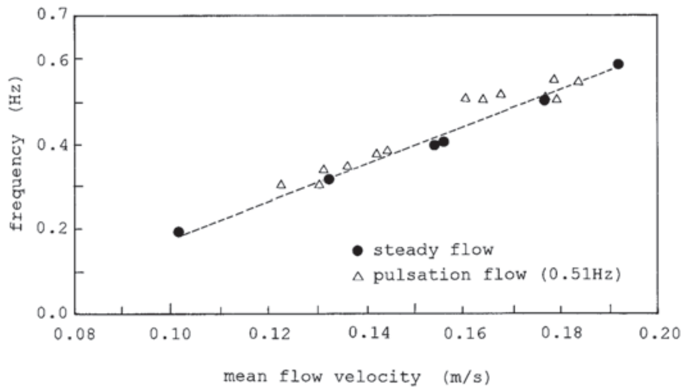
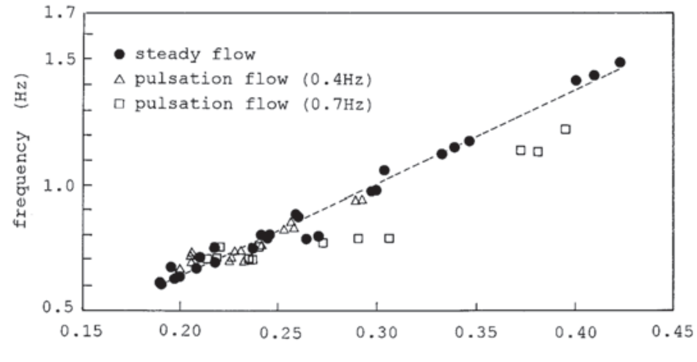


Fig. 4. Frequency vs. jet velocity characteristics of LPA feedback oscillator.



(a)



(b)

Fig. 5. Frequency-jet velocity relations of target oscillators:
(a) Type A, (b) Type C.

3.2 Oscillation Phenomena of Feedback Oscillator

The visualized flows of the feedback oscillator are shown in Figs. 6 and 7. In steady flow, as shown in Fig. 6, the jet reflected periodically right and left i.e., oscillated steadily by alternately feedback pressure signals.

In pulsating flow, as shown in Fig. 7, the jet oscillates with the same frequency as that of steady flow in spite of the expansion of the jet flow and the pulsating output pressures. This is due to the cutting off of the expansion of the jet by the vent vanes and to the damping effect of the pulsating output pressures through the feedback loops consisting of the output ports, the feedback ducts, the control ports and the control nozzle.

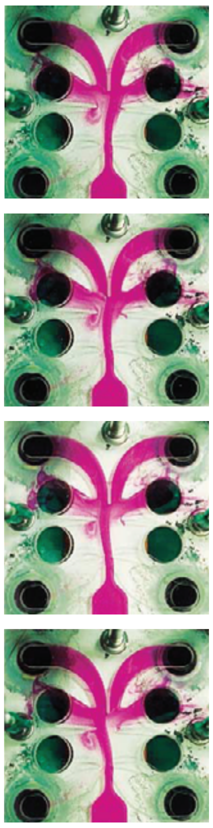


Fig. 6. Oscillating jet of LPA feedback oscillator in steady flow.

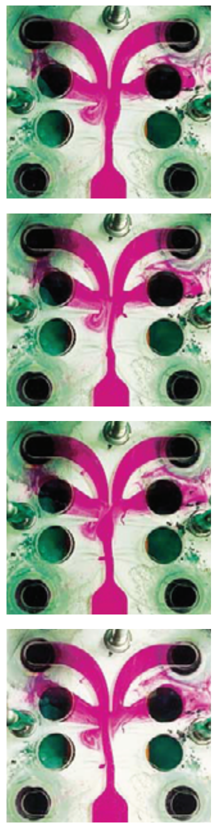


Fig. 7. Oscillating jet of LPA feedback oscillator in pulsating flow.

3.3 Oscillation Phenomena of Target Oscillator

3.3.1 Steady flow

Figures 8, 9 and 10 show the visualized flows of the target oscillators, Type A, Type B and Type C, respectively. As shown in Fig. 8, in the Type A oscillator, the oscillation of the jet was caused mainly by the positive effect of the reflected jet flow from the concave target. As shown in Fig. 9, the oscillation phenomenon of Type B was the same as that of the Type A. In these cases, the crescent target reflecting the impinged jet was the necessary for the oscillation. As shown in Fig. 11, this consideration was proved by the results that the target oscillators with a round target (Fig. 2 (d)) or a wedge target (Fig. 2 (e)) produced steady jet flow. These did not reflect the impinged jet and produced symmetrical flow pattern without oscillation. Then we call this type oscillator Reflection Type Oscillator.

As shown in Fig. 10, in the Type C oscillator, the rectangular target oscillator, the jet impinging on the target partly reflects and partly passes around the target and impinges on the side wall then partly recirculates acting as a internal feedback flow. The oscillation was produced by the recirculation jet flow under the influence of the reflected jet flow. Then we call this type oscillator Recirculation Type Oscillator.

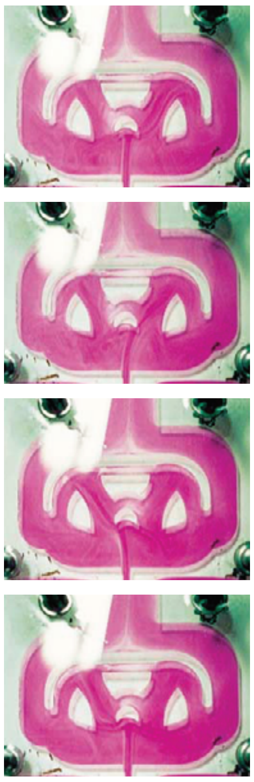


Fig. 8. Oscillating jet of target oscillator with crescent target (Type A) in steady flow.

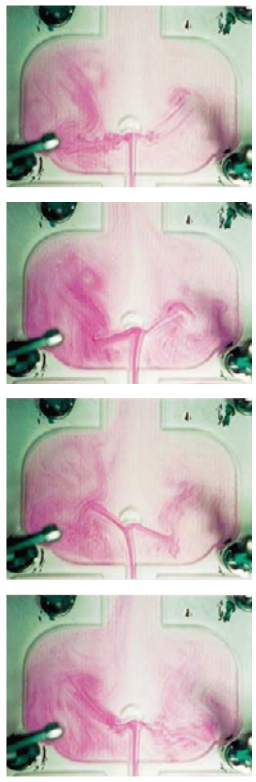


Fig. 9. Oscillating jet of target oscillator with crescent target (Type B) in steady flow.

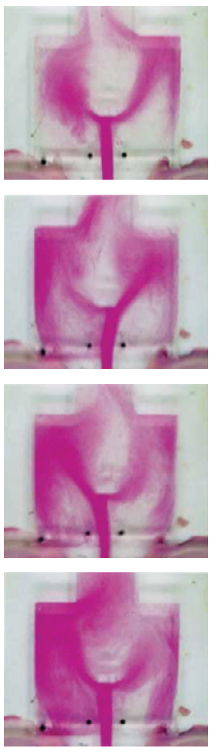


Fig. 10. Oscillating jet of target oscillator with rectangular target (Type C) in steady flow.

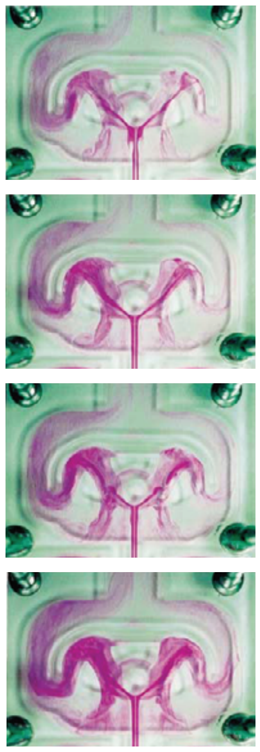


Fig. 11. Steady symmetrical flow of target oscillator with round target (Type D) in pulsating flow.

3.3.2 Pulsating flow

Figures 12 and 13 show the synchronization phenomena in the Type A and Type B oscillators. In these cases, the frequency of the pulsating flow was in the neighborhood of the oscillation frequency at steady flow. Regardless of the initial impinging position of the jet on the target, after several oscillation cycles, the jet came to impinge on the center of the target and the jet oscillated continuously, synchronizing with the pulsating of the flow. In the other cases, i.e., the frequency of pulsating flow was widely different from that of the oscillation frequency at steady flow, the impinging position of the jet on the target changed cycle by cycle and the period and amplitude of the jet oscillation changed randomly.

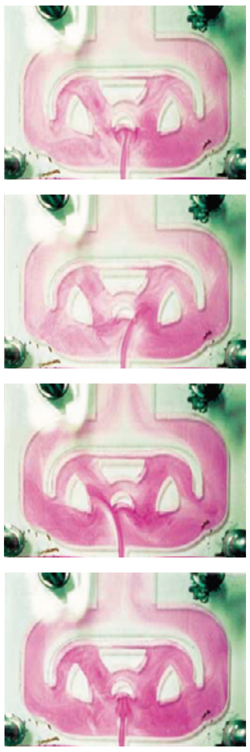


Fig. 12. Oscillating jet of Type A target oscillator in pulsating flow.

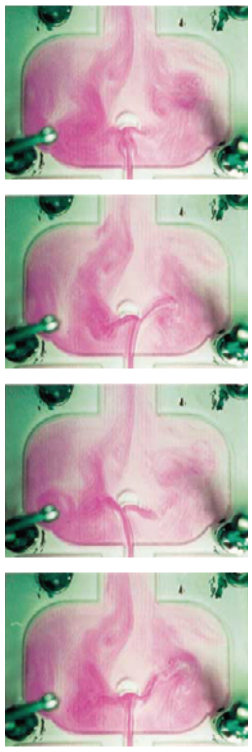


Fig. 13. Oscillating jet of Type B target oscillator in pulsating flow.

Figure 14 shows the changes of the pressure difference across the jet and corresponding flow pattern in continuous flow and following pulsating flow. In the first half, i.e., in steady flow, the pressure difference changed steadily as sinusoidal wave and the flow pattern changed periodically and symmetrically. In the latter half, i.e. in pulsating flow, the synchronization phenomena appeared. Initially, the first pulse jet impinged on the right end of the target. Then the high speed reflection flow from the target produced strong positive feedback effect, so that the jet deflected strongly to the right side so that the time needed for the jet to return to the neutral position was long. Then the second pulse jet impinged on the position closer to the center of the target. After the several repetition of this process, the pulse jet impinged on the center of the target, then the flow pattern became symmetric, the oscillation steadied synchronizing with the pulsation, i.e., the pulse jet always impinged on the center of the target. The same process was repeated regardless of the initial impingement position of the pulse jet on the target.

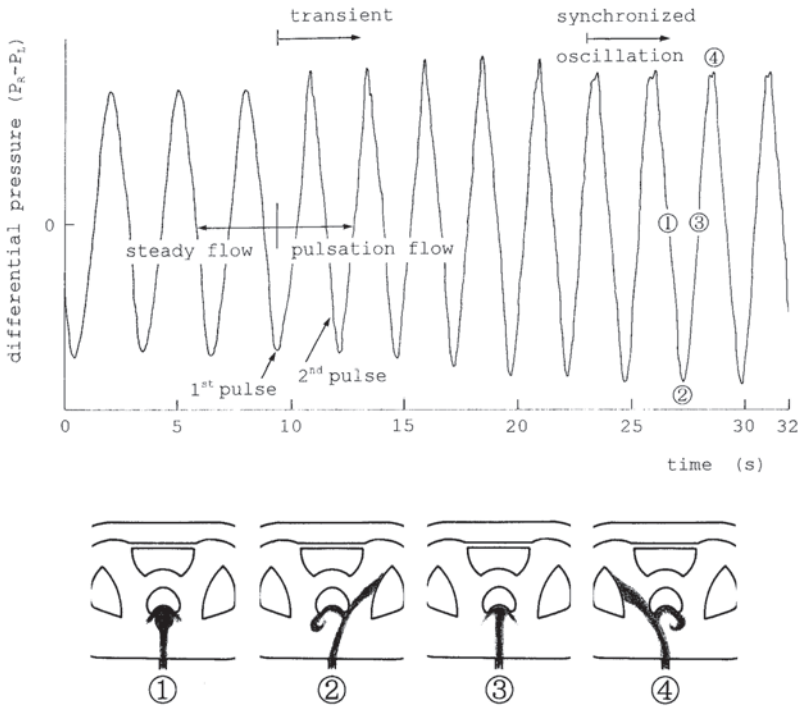


Fig. 14. Pressure difference across the jet and flow pattern in pulsating flow in case of the frequencies of pulsation and oscillation are near each other.

Figure 15 shows the changes of the pressure difference across the jet in case of the frequency of the pulsation flow was far different from that of the jet oscillation.

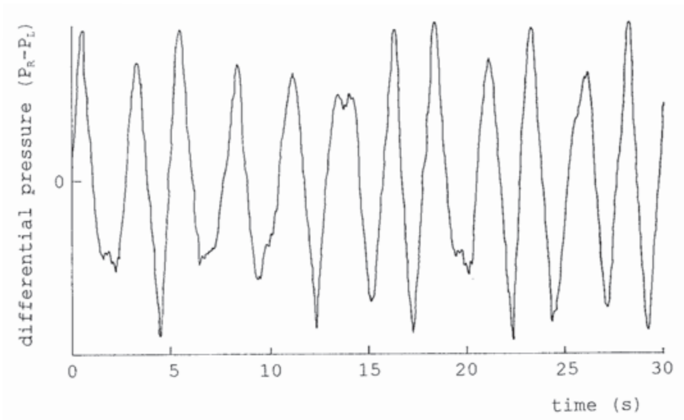


Fig. 15. Pressure difference across the jet in pulsating flow in case of the frequencies of pulsation and oscillation are far different each other.

3.4 Oscillation Phenomena

It was found that the oscillation phenomena of the target oscillator depended on geometric parameters, i.e., the target distance, the distance between side walls and the shape of the target. Figure 16 shows the effect of these parameters on the oscillation phenomena of the target oscillators (Types B and C). As shown in Fig. 16, the phenomena was classified into nine kinds between no oscillation and normal oscillation. Target oscillator with crescent target (Fig. 16 (a)) had wider dimensional area of normal oscillation due to the adequate effect of the reflecting jet flow from the concave target. The oscillation phenomena of Type A were about the same as Type B.

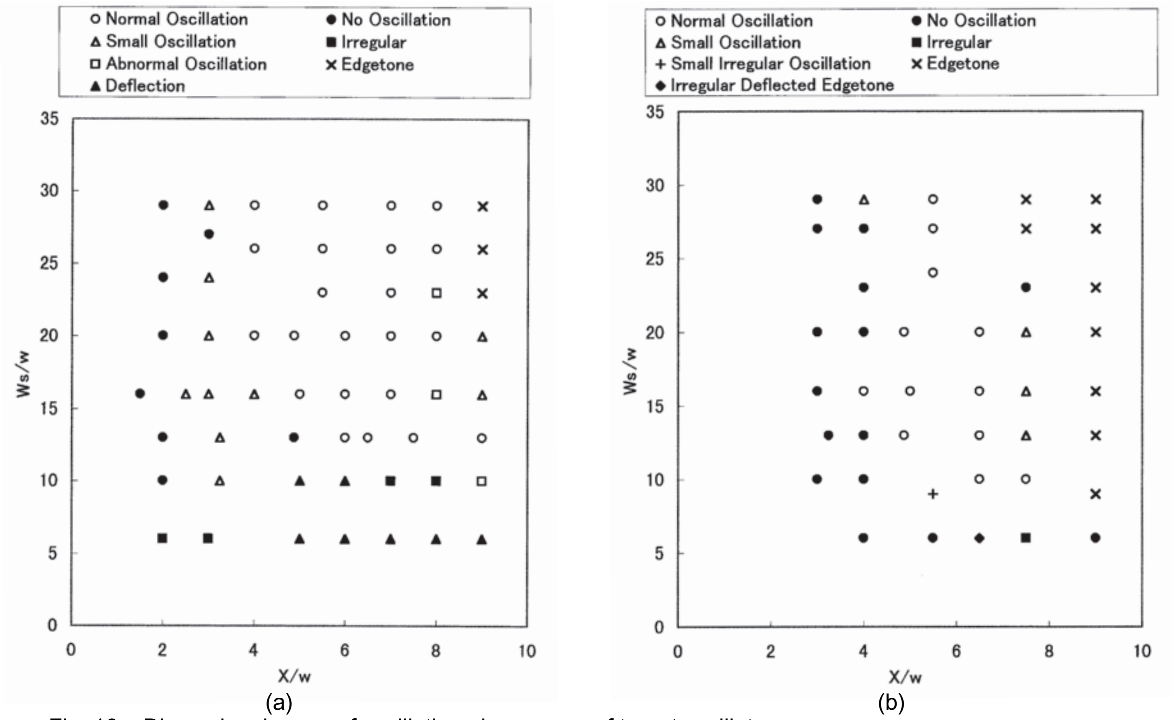


Fig. 16. Dimensional areas of oscillation phenomena of target oscillator:
(a) Type B, (b) Type C.

The nine kinds of oscillation phenomena were as follows:

1) Normal Oscillation ; Symmetrical periodic oscillation with large amplitude
2) Small Oscillation ; Symmetrical periodic oscillation with small amplitude
3) Irregular Oscillation ; Asymmetrical unperiodic oscillation
4) Small Irregular Oscillation ; Asymmetrical unperiodic oscillation with small amplitude
5) Edgetorne Oscillation ; Meandering jet flow like as edgetorne
6) Irregular Deflected Edgetone Oscillation ; Meandering jet flow deflecting irregularly
7) Abnormal Oscillation ; Jet oscillates symmetrically but stagnates around the target
8) No Oscillation ; Jet continue impinging on the target without oscillation
9) Deflection ; Jet continue deflecting

4. Conclusion

The experiments clarified that the fluidic oscillators could be classified into the following three classes according to the oscillation phenomena, the feedback type oscillator, the reflection type oscillator and the recirculation type oscillator. The oscillation was caused by feedback control signals in the case of the feedback type oscillator. On the other hand, the pressure difference mainly produced by reflected jet flow from the crescent target sustained the jet's oscillation of the reflection type oscillator. In the recirculation type oscillator, the oscillation was caused by the pressure difference produced by the reversed jet flow recirculating along the side wall of the target oscillator under the influence of the reflected jet flow.

The jet oscillation in the feedback oscillator was influenced by the pulsation of the jet flow. Nevertheless the frequency of the oscillation maintained the proportional relationship to the jet's flowrate, owing to the damping effect of the feedback loop. On the contrary, the oscillation phenomena of the reflection oscillator and the recirculation oscillator were influenced and synchronized with the pulsation since the strength of the reversed jet flow and the reflected jet flow was affected directly with the pulsation of the jet. Then the frequency of the oscillation was matched with that of the pulsation of the jet flow in the synchronization phenomenon.

The oscillation phenomena of the target oscillator was classified into nine kinds between no oscillation and normal oscillation. Target oscillator with crescent target produced steady normal oscillation in wider dimensional parameters' region.

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