Proceedings of ICFDP7:
7th International Congress on Fluid Dynamics and Propulsion
December 18-20, 2001, Cairo, Egypt

ICFDP7-2001068

A MEASUREMENT OF VELOCITY UNDER PULSATING FLOW CONDITIONS IN A PIPE WITH AN ORIFICE

Ema TAMURA
Department of Mechanical Engineering,
Tokyo Denki University, 2-2 Kanda-Nishikicho,
Chiyoda-ku, Tokyo, JAPAN 101-8457
Tel: 81-3-5280-3374, Fax: 81-3-5280-3574
E-mail: ema@cck.dendai.ac.jp

Junjiro IWAMOTO
Department of Mechanical Engineering,
Tokyo Denki University, 2-2 Kanda-Nishikicho,
Chiyoda-ku, Tokyo, JAPAN 101-8457
Tel: 81-3-5280-3374, Fax: 81-3-5280-3574
E-mail: iwamoto@cck.dendai.ac.jp

Key words: Pulsating Flow, Orifice, LDA, Jet Boundary Layer

ABSTRACT

A pulsating flow in a pipe with an orifice plate is studied experimentally. Velocities and turbulent intensity are measured by a hot-wire anemometry and LDA (Laser Doppler anemometry). The hot-wire used in the present study can not detect flow direction. But, it is found that a reattachment length can be estimated using hot-wire. The measurement of the distribution of the instantaneous flow velocities in radial and axial direction shows the oscillation of the jet boundary. It is found that the behavior of the flow in the neighborhood of jet boundary is different for different pulsating frequency. It may be considered that this difference is due to the interaction between the fluctuating jet boundary starting from the orifice edge and the pulsating waves generated by the rotary valve.

INTRODUCTION

The flow in pipes used in the industrial plants is found to be mostly unsteady. Since the unsteady flow can cause some difficulty in dealing with the practical problem such as measurement of flow rate, the effective technique of measurement in dealing with unsteady flow is not yet well established. It may be approximately treated as quasi-steady or steady flow using the time-averaged values of flow variables.

Mottram[1] gives a comprehensive study of pulsating flow through the orifice meter. Mottram indicates that theoretically derived correction factors, which depend on Reynolds and Strouhal number, and on acoustic response of a pipeline system can be very inaccurate. Jungowski et al.[2] measure time averaged velocity by using I-type hot wire, but not instantaneous velocity.

In the present study a final goal is to clarify the factor which causes the errors in the flow rate measured by using an orifice plate under the pulsating flow conditions experimentally. In order to do that, a knowledge of the detailed flow pattern in the flow field is needed.

In this paper the velocity profiles in the pipe with an orifice plate are measured by using hot-wire anemometer and LDA.

NOMENCLATURE

d : Orifice diameter mm
D : Internal diameter of pipe mm
f : Pulsation frequency Hz
H : Step height of orifice mm
m : Orifice/pipe area ratio
Δp_s : Pressure difference across orifice mmAq
r : Radial coordinate mm
R : Radius of pipe mm
R_e : Reynolds number
T : A period of one cycle of pulsation sec
L_R : Reattachment length mm
u : Flow velocity m/s
U_0 : Time-averaged velocity on the centerline at station A(see Fig. 3) m/s
x : Axial coordinate with origin at orifice mm
β : Orifice/pipe diameter ratio
θ : Angle of rotary valve degree

Subscript:
p **:** Conditions in pipe 2
s **:** Conditions in pipe 1

EXPERIMENTAL APPARATUS

The experimental apparatus is shown in Fig.1. The air is sucked through pipe 1, surge tank 1, pipe 2 and surge tank 2 by a Roots vacuum pump and then discharged into the atmosphere. The internal diameters D of the pipes 1 and 2 are 53.00mm, orifice/pipe diameter ratio β being 0.4347 (orifice/pipe area ratio m = 0.1913). By the rotary valve of the butterfly type a pulsating flow is generated. It is located 535 mm downstream of the orifice plate in pipe 2. The flow in pipe 1 is steady since the pulsating components of the flow are eliminated by surge tank 1(volume 200 l). Hence the flow rate calculated from the differential pressure Δp_s across the orifice plate in pipe 1 can be considered to be reference flow rate.

The experimental conditions are as follows;

1) In case of the pulsation frequency f = 0Hz, the error of the flow rate between pipe 1 (calculated using the differential pressure Δp_s) and pipe 2 (using Δp_d) is within 2%.

2)The flow rate is controlled manually by the bypass valve as the differential pressure Δp_s across the orifice plate in pipe 1 is kept constant at 100mmAq.

To obtain a detailed flow pattern downstream of the orifice plate velocity distributions are measured in the neighborhood of the orifice meter in pipe 2 by hot-wire probe and LDA experimentally. A hot-wire probe is about 5 m in diameter and 1.5mm in width made from Tungsten. In LDA measurement He-Ne laser is used. That output is 10mW. A diameter of the tracer used in the measurement of LDA is about 2 m .

RESULTS AND DISCUSSION

The reattachment length

To make clear the flow pattern in the reverse flow region behind the orifice plate is important to understand the flow characteristic of a jet from the orifice. First, in the present study we used I-type hot-wire probe to measure time-averaged velocity profiles. The I-type hot wire probe has simple structure and it can't detect flow direction. In other words, the output signal from the hot-wire probe does not depend upon the flow direction when it is perpendicular to the hot wire.

When we estimate the mass flow rate by using these values of outputs from the I-type hot-wire probe, the results are different from the proper values. Fig. 2 shows the averaged velocity over cross-sectional areas along pipe evaluated from the measured velocity profiles which are obtained from the above output values of hot-wire probe. In Fig. 2 it can be seen that there is a peak near x/D = 1.3. As x/D becomes large, the averaged velocity falls and becomes constant at about x/D = 3.3, which can be considered to be the flow reattachment point.

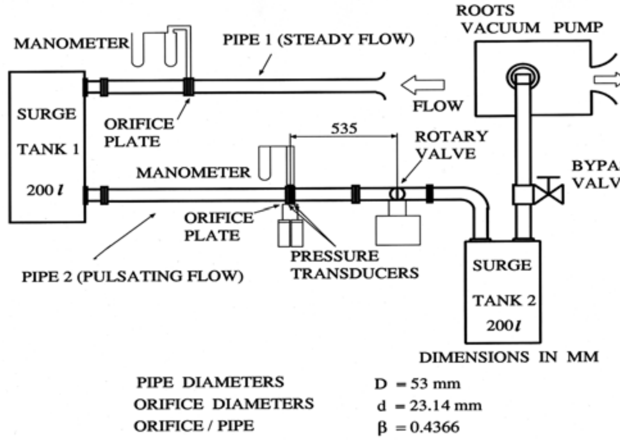


Fig. 1 Experimental apparatus

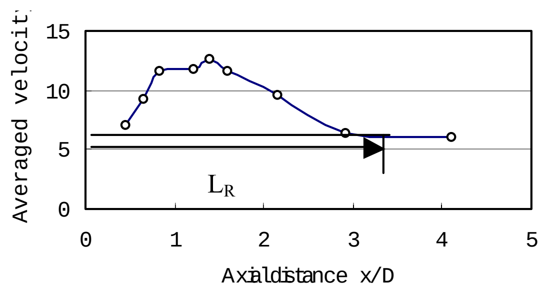


Fig. 2 Averaged velocity of an area in a pipe

Fig. 3 shows the velocity profiles measured by LDA. In the figure, the symbols A, B, C, D and E indicate the locations at x/D = -2.58, 1.32, 1.89, 2.45 and 3.02, respectively. A flow velocity u is normalized by time-averaged velocity U_0 on the centerline at station A. In this figure the solid line is the boundary between the reverse flow and the positive flow. An arrow in the figure shows a location of the point where the jet is attached to the wall, whose positions is at x/D = 3.3. Hence the reattachment length L_R is in good agreement with that estimated from the velocity profiles measured by LDA.

Ohba et al. [3] studied the flow downstream of an orifice. They are reportedly x/D = 3.25~3.37 at β = 0.375 and R_e = 25,000 (evaluated by the step height of an orifice H) by flow visualization using oil-flow method experimentally. In the present study R_e is about 40,000 when it is evaluated by the step height H of an orifice. This result is also in good agreement. As discussed, even if the flow is unsteady we can estimate the reattachment point in the above way.

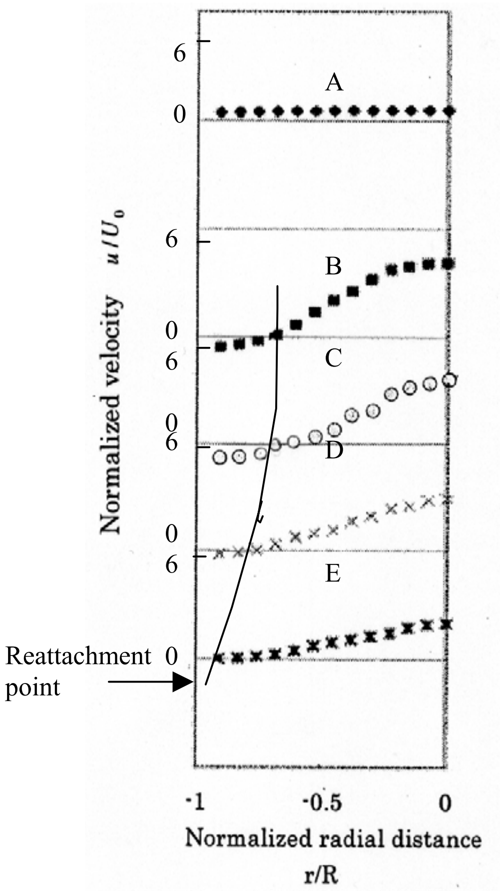


Fig. 3 Time-averaged velocity profiles by LDA

Instantaneous velocity profiles

From the measurement of time-averaged velocity by using I type hot-wire, the flow field downstream of the orifice is schematically shown in Fig. 4. The flow field downstream of an orifice is divided into two regions, i.e. a potential core domain and that without potential core.

Next, the instantaneous streamwise velocities over the radii of the pipe from x = 25mm to 50mm downstream of the orifice are measured. The measured data are phased-averaged. The output signal of the rotary encorder on the same shaft with the rotary valve triggers a start of capturing data. Fig. 5 shows the relations between the opening angle of the rotary valve and area ratio. This opening area changes with the increase in the angle in the similar curve as that of cosine. As the diameter of the rotary valve (51mm) is smaller than that of the pipe, it can not close completely. θ = 0deg denotes the instant when the signal of the rotary encorder is given. On the other hand, θ = 180deg denotes a period of one cycle of pulsation T . Since the velocity distribution is found to be symmetric with respect to the centerline of the pipe, the only a half of it is shown in the figure.

Figs. 6 and 7 show contour plots of the phase-averaged streamwise velocity. The horizontal axis is the distance measured downstream from the orifice x . The vertical axis is r/R. A color bar in the right-hand side of the figures shows the magnitude of velocity. In these figures the jet boundary can be observed between r/R = 0.2 and r/R = 0.4. The location of minimum cross-sectional area of the jet is about x = 30mm and x = 45mm at f = 5Hz and f = 30Hz, respectively. Those locations in both the radial direction and streamwise direction do not depend on the opening angle of the rotary valve. These figures show that in the region from r/R = 0.3 to 0.5 a large-scale fluctuation occurs. The amplitude of the fluctuation of the jet boundary seems to increase with pulsation frequency.

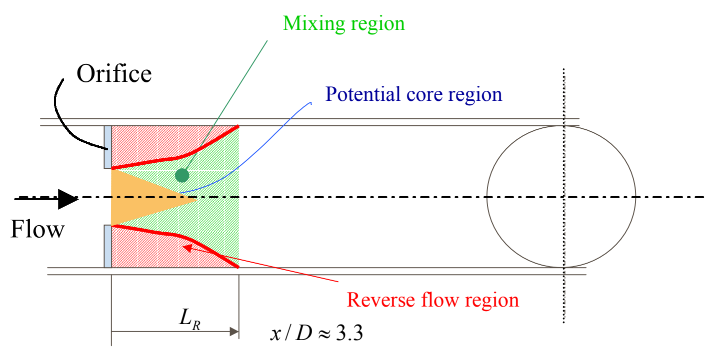


Fig. 4 Flow field downstream of the orifice

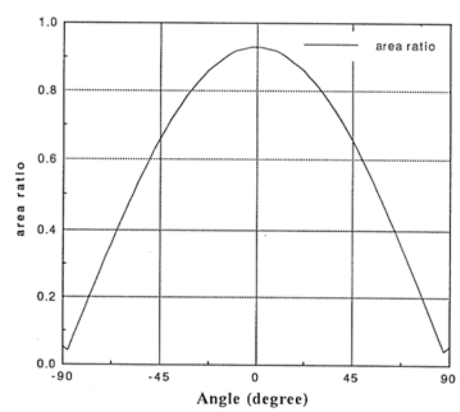


Fig.5 Area ratio of the rotary valve

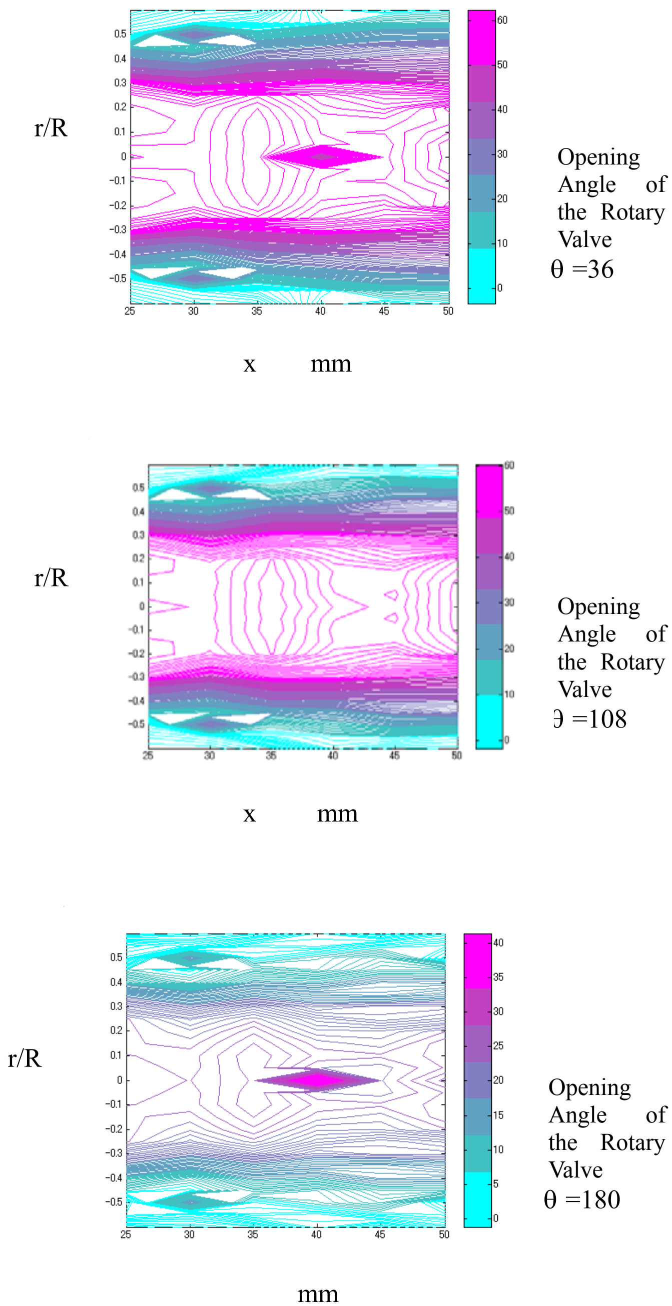


Fig. 6 Velocity contour (f=5 Hz)

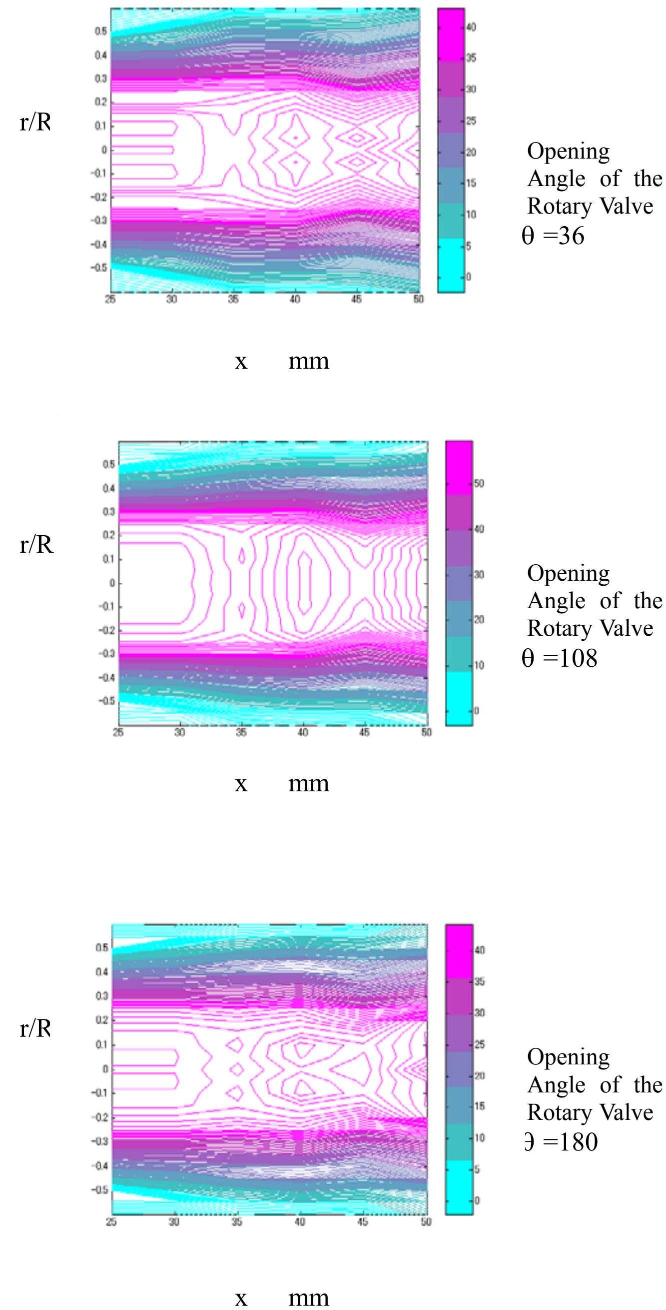


Fig. 7 Velocity contour (f=30 Hz)

Frequency Analysis Of Velocity near the Edge of the Orifice

In Figs. 6 and 7 the jet boundary is seen to fluctuate. What we have to do next is to analyze the frequency of velocity change near the edge of the orifice. Prior to the frequency analysis, we have to check the sampling frequency of the data measured with LDA. The reason for this is that the discharge condition of tracer being used with measurement of LDA into the pipe is not constant.

Fig. 8 shows the data rate which is found to be satisfactory regardless of the frequency. Although the data rate is several kHz near the wall, the flow phenomenon inside the pipe can be observed.

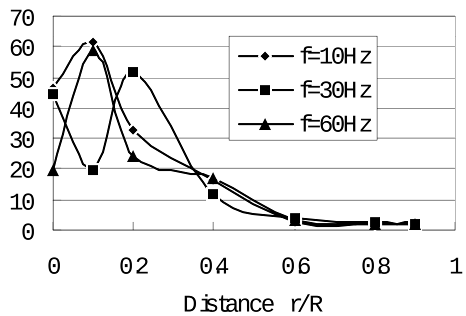
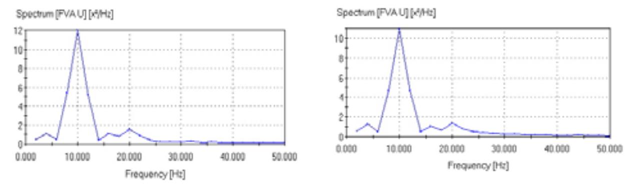


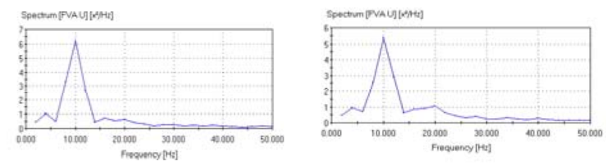
Fig. 8 Data rate

Figs. 9, 10 and 11 show the results of frequency analysis. In these figures the results from r/R = 0.35 to 0.45 are shown, where pulsation frequencies are f = 10, 30 and 60 Hz, and locations are x = 40 and 50mm. The horizontal axis is a frequency and the vertical axis the magnitudes of the each component of the frequency. In Fig. 9, as the pulsation frequency is f = 10Hz a dominant frequency is also 10Hz. The tendency remains the same even if r/R changes, expect at r/R = 0.45, where the pulsation frequency becomes dominant at r/R = 0.45, which is about 12Hz. In other words, it seems the whole jet boundary vibrates at this frequency.

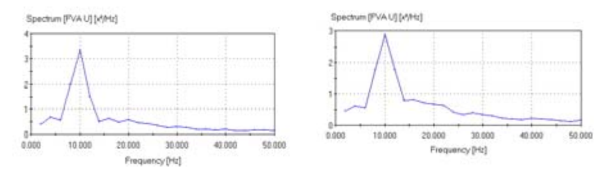
The dominant frequency is the same as the pulsation frequency except for 60Hz (See Fig. 11) where twice the pulsation frequency becomes dominant. In the velocity histories, during a rotation of the rotary valve, two similar velocity changes are observed. The resonant frequency of the flow in pipe 2 in the present study is almost equal to 45Hz. It seems that the flow behavior inside the pipe changes drastically across this value.



(a)x=40 ,r/R=0.35, f=10 (b)x=50, r/R=0.35, f=10

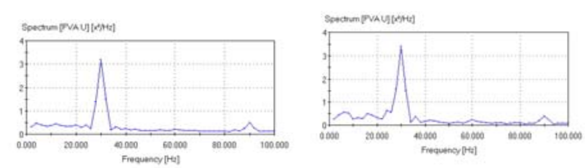


(c)x=40 ,r/R=0.40, f=10 (d)x=50, r/R=0.40, f=10

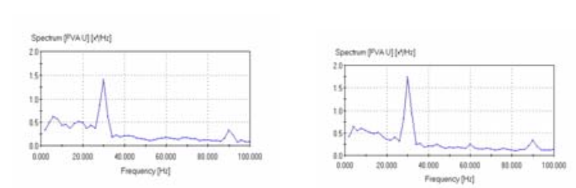


(e)x=40 ,r/R=0.45, f=10 (f)x=50, r/R=0.45, f=10

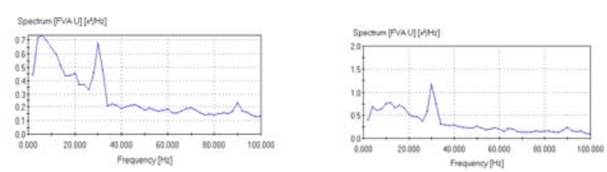
Fig. 9 Frequency (f=10Hz)



(a) x=40 ,r/R=0.35, f=30 (b)x=50, r/R=0.35, f=30

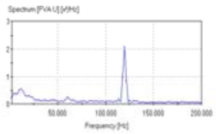


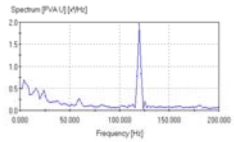
(c)x=40 ,r/R=0.40, f=30 (d)x=50, r/R=0.40, f=30



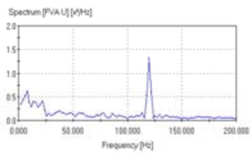
(e)x=40 ,r/R=0.45, f=30 (f)x=50, r/R=0.45, f=30

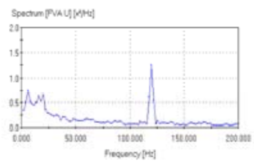
Fig. 10 Frequency (f=30Hz)



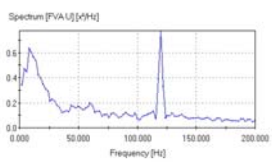


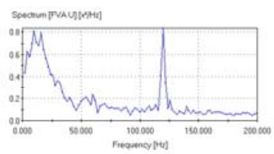
(a)x=40 ,r/R=0.35, f=60 (b)x=50, r/R=0.35, f=60





(c)x=40 ,r/R=0.40, f=60 (d)x=50, r/R=0.40, f=60





(e)x=40 ,r/R=0.45, f=60 (f)x=50, r/R=0.45, f=60

Fig. 11 Frequency (f=60Hz)

CONCLUSIONS

To understand the flow field downstream of an orifice the velocity profiles in the pipe with the orifice plate in pulsating flow are measured and the following conclusions are derived.

(1) Even in the case of a pulsating flow the average reattachment length can be determined using I-type hot-wire probe.

(2) The measurement of the distribution of the instantaneous flow velocities in radial and axial direction shows the oscillation of the jet boundary. It is found that the behavior of the flow in the neighborhood of jet boundary is different for different pulsating frequency.

(3) Although the velocity measurement downstream of the orifice plate is restricted to a certain extent in the present study, it is found that the dominant frequency at r/R=0.45 is different from the pulsation frequency.

REFERENCES

[1] Mottram, R, C., “The measurement of Pulsating Flow Using Orifice Plate Meters”, Flow its measurement and control in science and industry, 1, Part 2, pp.195 (a)-208, Instrument Society of America, 1974.

[2] Jungowski, W. M., Stuzinski and Szabo J. L., “Orifice Meter Performance under Pulsating Conditions”, 2nd International Symposium on Fluid Flow Measurement, Calgary, Alberta, June 6-8, 1990.

[3] Ohba, Rionie and Sunada, “Experimental Studies of the Flow through an Axial Sudden Expansion with Orifice”, J. Japan society for Aeronautical and Space Sciences, Vol.48, pp.82-88, 2000 (In Japanese).