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Experimental Study of Vortex Ring Dynamics by Using UVP

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Dynamics of a vortex ring generated from a nozzle fixed on the top of a cylindrical water tank is investigated using UVP (Ultrasound Velocity Profiler). The instantaneous velocity profiles on three ultrasound beams are obtained to reconstruct two-dimensional structure of vortex ring, which alters with changing the piston speed and the piston stroke. The translational velocity, the diameter, and the length of the vortex ring are evaluated from the two-dimensional velocity field as function of dimensionless piston stroke and Reynolds number.

1. Introduction

A vortex ring can be seen in various natural and industrial situations for handling intermittent fluid flow such as volcanic fumes, smoke rings, and fuel injection system. It is often chosen as a suitable research target to obtain fundamental knowledge on flow transition or instability caused by nonlinear phenomena. In the past the characteristic of the vortex ring, which is expressed by translational velocity, ring diameter, and ring length, were studied based on dye visualization and LDV. In this study, UVP[1)] (Ultrasound Velocity Profiler) is used to acquire those parameters directly from the two-dimensional flow field, which is measured by three ultrasound transducers. In this paper we mention on the flow reconstruction method and the difference of internal structure accompanied with changing the piston speed and the piston stroke of a vortex ring generator.

2. Principle of UVP

An ultrasound pulse emitted from an ultrasound transducer is reflected by the particles suspended in fluid and is received by the same transducer. Positional information is given by the time of flight from emission to reception of the pulse, and velocity information is obtained from Doppler-shifted frequency of the received ultrasound echo. If a number of the particles is enough, ultrasonic pulse are reflected everywhere on the passing line of the pulse. Thus, UVP can measure an instantaneous velocity profile along the line.

3. Experimental setup

3.1 Configuration

A vortex ring generator, which is composed of a cylindrical nozzle and a reciprocating piston, is fixed on the top of a water tank with 3m height and 1m width. The vortex ring is emitted downward. Diameter of the nozzle D_0 is 50mm and the piston to push out the vortex ring is connected with a stepping motor controlled by computer, so stroke S and piston speed V are variable to be controlled. We chose the experimental conditions as shown in Table 1. Measurement section was located 250mm ($=5D_0$) downstream the nozzle. Hydrogen bubble was used as fluid tracer for UVP, and generated by a water electrolysis using Pt-Al wire at 30V DC.

3.2 Definition of measurement section

Three ultrasound transducers are fixed in the water tank as shown in Fig.1. The transducer A is arranged on the axis of the nozzle so as to measure the vertical position of the vortex ring. The transducer B and the transducer C are fixed horizontally and 45degree respectively, so as to measure the inner velocity profiles of the vortex ring passing through each measurement line. Three measurement lines cross at a point located 250mm downstream the vortex ring generator The measurable radius from the point is 160mm for all the transducers.

Table 1 Experimental conditions

piston stroke : S [mm]	piston speed : V [mm/s]
30, 50, 90	100 to 700 (step 100)
110, 130, 150	100 to 400 (step 100)

(43 cases all)

4. Results and Discussion

4.1 Translational velocity

The translational velocity of vortex ring is obtained from the advection velocity of the vertical velocity profiles measured by the transducer A. Fig.2 shows a sample of time evolution of the vertical velocity profile moving downward. This profile gives instantaneous position of vortex ring. The translational velocity U is determined as the slope of linear function as shown in Fig.2.

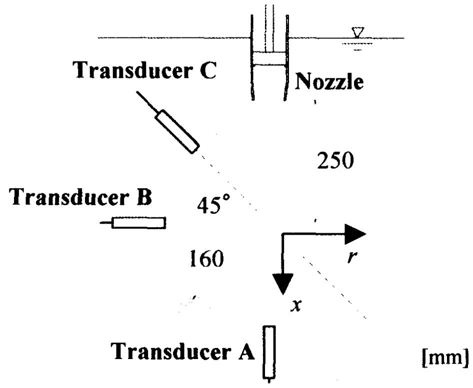

Fig.1 Definition of measurement section

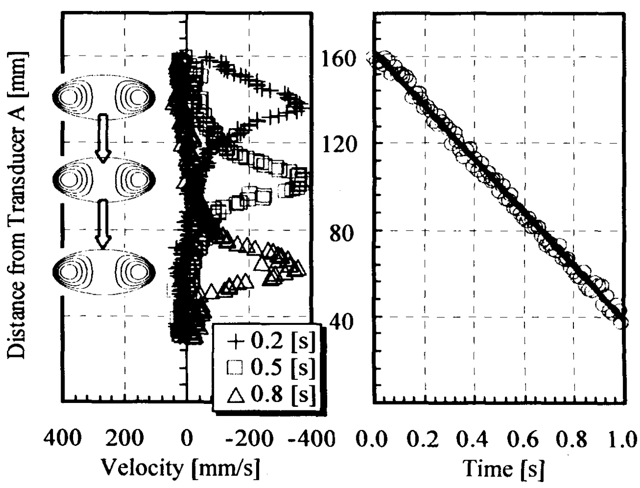

Fig.2 Translational velocity

Fig.3 shows the contour map of the dimensionless translational velocity $U^{*}(=U/V)$ as the function of the dimensionless piston stroke $S^{*}(=S/D_0)$ and Reynolds number Re, where Re is defined as $Re=VD_0/\nu$. The color map expresses larger U^{*} as white while smaller as the black. U^{*} increases almost linearly with S^{*} and also with Re at $Re < 2.0\times10^4$ while U^{*} becomes almost constant at $Re > 2.0\times10^4$. This implies that, 1) vortex ring is undeveloped at $Re < 2.0\times10^4$, and is developed enough at $Re > 2.0\times10^4$ in the measurement position, 2) the translational velocity relative to piston speed reaches around 0.5 only in certain optimum condition while it has smaller value in case of small S^{*}.

4.2 Two-dimensional flow field

Fig.4 shows four cases of the two-dimensional flow field of the vortex ring calculated from two componential velocities measured by transducer B and C. (a) is the result of short stroke and low speed, (b) just longer stroke, (c) just higher speed and (d) longer stroke and higher speed than (a). The result tells us that the increase of piston speed makes the structure of vortex ring clear and its circulation becomes strong while its size hardly changes. On the other hand, as the piston stroke increases, the diameter of the vortex ring becomes large.

4.3 Diameter and length of vortex ring

Representative parameters of the vortex ring are defined as following. The diameter; D is defined by the distance between the two points, at which the axial component of the local velocity relative to translational velocity corresponds to zero. The length; L is defined by the distance between the two points on the central axis, at which the axial component of the relative velocity is zero. These values are determined from the vector map of the vortex ring as shown in Fig.4. Fig.5 shows the contour map of the dimensionless diameter $D^{*}(=D/D_0)$ and Fig.6 shows that of the dimensionless length $L^{*}(=L/D_0)$ as the function of the dimensionless piston stroke S^{*} and Re. Each contour map expresses larger D^{*} and L^{*} in white, while smaller in black. In Fig.5, D^{*} increases with S^{*}, and the increment ratio becomes gradually small. D^{*} depends strongly on S^{*} but D^{*} depends weakly on Re. This tendency is similar to earlier study[2)]. In Fig. 6, L^{*} increases with respect to S^{*}, and decreases as increasing Re except the dump between $1.5\times10^4 < Re < 2.0\times10^4$. The length increases with respect to piston stroke. This fact implies that the initial axial vorticity distributes more widely to the nozzle axis by increase of the volume pushed out from the nozzle. The existence of the dump in L^{*} map indicates that vortex ring is stabilized in particular conditions.

5. Conclusion

The flow structure of the vortex ring has been successfully measured using UVP with 3-measurement lines. The basic characteristics of the vortex ring including translational velocity, diameter and length, are discussed. Through this experimental research, we confirm that: 1) the translational velocity increases approximately in proportional to the piston speed in case of developed vortex ring. 2) The diameter depends strongly on piston stroke, but weakly on Re. 3) The length increases with piston stroke and decreases as increasing Re.

6. Reference

1) Y.Takeda : Instantaneous Velocity Profile Measurement by Ultrasonic Dopper Method, *JSME. series B* Vol.38 (1995) No.1.

2) T. Maxworthy : The structure of vortex rings, *J. Fluid Mech.* 51 (1972) 15-32.

3) T. Maxworthy : Some experimental studies of vortex rings, *J. Fluid Mech.* 81 (1977) 465-495.

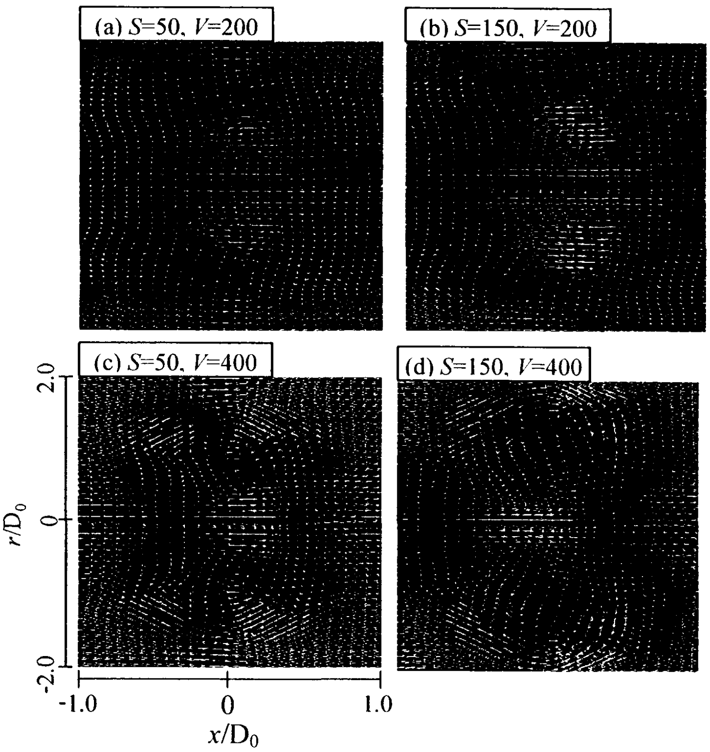

Fig.4 Two- dimensional flow field of vortex ring

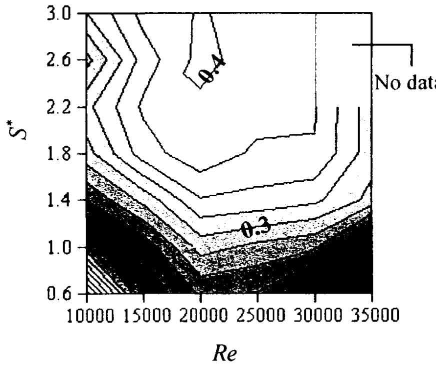

Fig.3 Dimensionless translational velocity U*

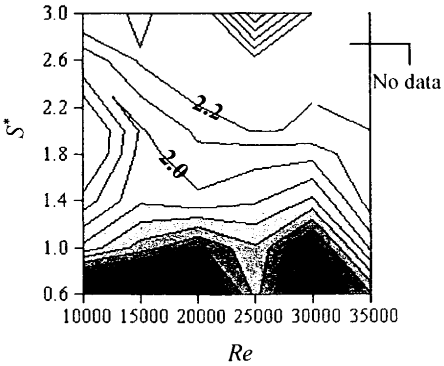

Fig.5 Dimensionless diameter D*

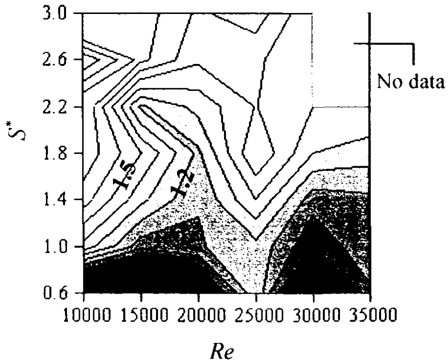

Fig.6 Dimensionless length L*