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# Vortex Detection in Cross-section of a Pipe Flow Using V-Shaped Ultrasonic Probes

V 字型二測線超音波プローブを用いた円管流断面の渦検出

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## 1. Introduction

Measurement of flow velocity and volume in a pipe is important for operation control in industrial measurement fields[1)]. Flow velocity measurement using the propagation time of the ultrasound have been developed[2,3)]. Ultrasonic flowmeters of clamp-on type have advantages that it is possible to measure outside a pipe. This kind of flowmeters calculates flow volume from the mean flow velocity determined by the measured propagation time. If the velocity profile in the pipe is not always developed flow, for example, it is not axial symmetry, the measurement error occurs[4)]. In addition, ultrasonic flowmeters detect the radial components of the flow velocity as well as axial component because the propagation time is determined by all flow velocity components accumulated along propagation path. The components of the flow velocity of the radial direction cause the accuracy deterioration of flow volume measurement[4)]. Then, to reduce the effect of the in-plane components of flow velocity, we have proposed the measurement method called two orthogonal ultrasonic probes[5)].

In this previous study, it was possible to measure in-pane component of the mean flow velocity, if the flow velocity distribution was uniform. However, the mean flow velocity cannot be measured if the flow velocity has a vortex, because the measurement results varied by the setting angle of the propagation paths. Besides, it was found that the presence of a vortex might be detected by using these results.

In this paper, the purpose is detection of a vortex in cross-section of a pipe, and we propose the measurement method using V-shaped ultrasonic probes. To verify effectiveness of proposed method, we simulate fluid flow in the pipe using the Finite Element Method (FEM), and detect the vortex using proposed method by numerical simulation. By using difference of the propagation time of two propagation paths, the location and the rotational direction of the vortex is estimated.

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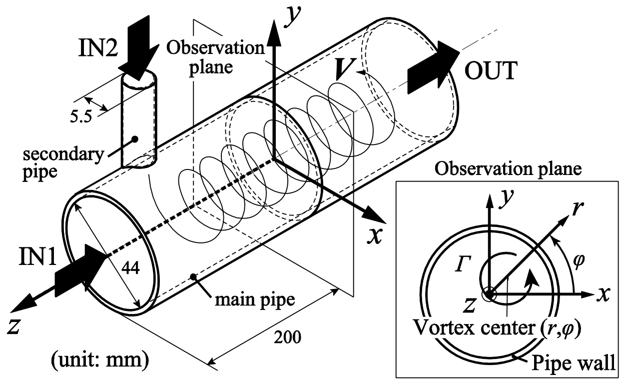


Fig. 1 Simulation model of pipe flow.

## 2. Simulation of pipe flow

**Figure 1** shows the simulation model of a pipe flow. It consists of two pipes to generate a flow with a vortex. Inner diameters of main pipe and secondary pipe are 44 mm and 5.5 mm, respectively. IN1 and IN2 are inlets and OUT is outlet. The observation plane is shown in the figure. The vortex at the location, $(r, \varphi)$ has the intensity,

$$\Gamma = \iint_S \mathrm{rot}\, \boldsymbol{V} \cdot d\boldsymbol{S}\ , \tag{1}$$

where $\boldsymbol{V}$ is the flow velocity vector on the plane, $S$ is the surface of cross-section of main pipe and, $d\boldsymbol{S}$ is the area element of $S$. If $\Gamma > 0$, the direction of rotation of the vortex is counter-clockwise rotation (CCW). If $\Gamma < 0$, it is clockwise rotation (CW). The influent flow velocity on IN1 and IN2 is 1.0 m/s. Fluid is water whose temperature is 293.15 K. The average of Reynolds number is 712 (laminar flow). This model is divided into $5.1\times10^5$ tetrahedral elements. The location of secondary pipe moves around main pipe to change the location of the vortex. Using this model, the pipe flow with the vortex is simulated.

## 3. Measurement method

**Figure 2** shows proposed measurement system. Three ultrasonic transducers, $T_1$, $T_2$, and $T_3$ put on the circumference of the main pipe on the observation pipe. The locations $T_1$, $T_2$, and $T_3$ make a

V-shaped sound paths. The angle from X-axis, $\alpha$ is 15°. The direction of the measurement system, $\theta$ moves from 0° to 360° by 1°. $T_1$ and $T_2$, and $T_1$ and $T_3$ are the transducer pairs of sound paths. Each ultrasonic transducer transmits and receives a probing signal. At this time, each ultrasonic propagation time is

$$\tau_{ba} = \int_{l_{ab}} \frac{1}{c+\boldsymbol{V}\cdot\boldsymbol{t}} dl + \tau , \tag{2}$$

where $a$ is the index of the transmitter and $b$ is the index of the receiver. $c$ is the sound velocity of the liquid. $\boldsymbol{t}$ is the unit tangent vector along propagation path. $dl$ is line element of propagation path along $T_a$ to $T_b$. $\tau$ is propagation time in the pipe wall. And difference of propagation time under the condition $c^2 \gg (\boldsymbol{V}\cdot\boldsymbol{t})^2$ is

$$\begin{aligned}\Delta\tau &= (\tau_{31}-\tau_{13})-(\tau_{21}-\tau_{12}) \\ &= \frac{2}{c^2}\left(\int_{l_{12}} \boldsymbol{V}\cdot\boldsymbol{t}\,dl - \int_{l_{13}} \boldsymbol{V}\cdot\boldsymbol{t}\,dl\right),\end{aligned} \tag{3}$$

where $l_{12}$ is the propagation path of $T_1$ to $T_2$. And $l_{13}$ is the propagation path of $T_1$ to $T_3$. If there is the center of the vortex between $l_{12}$ and $l_{13}$, it is assumed $\Delta\tau > 0$ (If $\Gamma > 0$) or $\Delta\tau < 0$ (If $\Gamma < 0$). Furthermore, using $\Delta\tau$, the rotation direction of the vortex could be estimated.

## 4. Results and Discussion

**Figure 3** shows four flow velocity vector fields obtained in the plane and the results of measurement simulation. The difference of propagation time, $\Delta\tau$ change with the direction, $\theta$ and these curves are similar to each other. Moreover, In Fig.3, the curves takes two peak values. The location of larger peak value agree with the vortex location, $\varphi$. And the location of second peak value agree with the argument, $\varphi + 180°$.Thus, when the center of the vortex locate between $l_{12}$ and $l_{13}$, the $\Delta\tau$ significantly change by flow velocity of the vortex. Using its change, it is possible to estimate the argument of the vortex, $\varphi$. And then the rotation direction of the vortex is obtained by sign of the $\Delta\tau$. However, the distance, $r$ ,and the intensity, $\Gamma$, of the vortex cannot be estimated. Some mathematical model of the vortex is needed to the estimation.

## 5. Conclusion

In this study, we proposed V-shaped ultrasonic probes to detect the vortex in the pipe cross-section. The pipe flow and measurement of the location and rotation direction of the vortex was simulated. As a result, it was found that proposed method can estimate the argument in polar coordinate and rotation direction of the vortex on the pipe cross-section. Experimental verification is planned in the future.

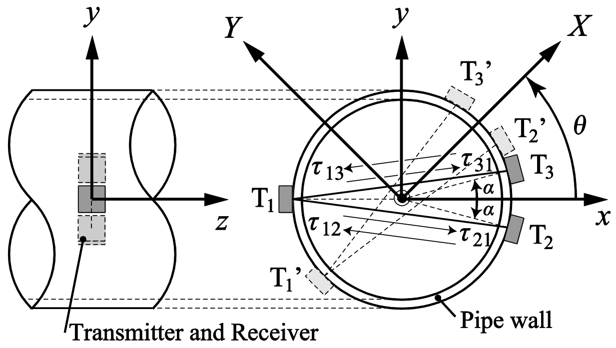


Fig. 2 Measurement system.

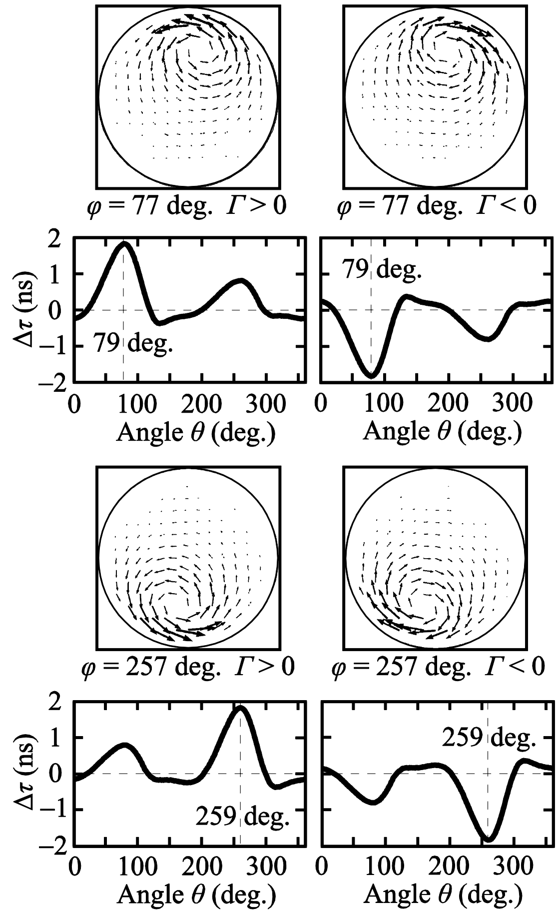


Fig. 3 Selected velocity vector fields and results of measurement simulation.

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