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Experimental examination of open channel flow measurement by the ultrasound correlation method

超音波相関法による開水路流量計測の評価実験

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1. Introduction

Monitoring of the flow rates in the flumes and/or drain pipe is much demanded[1]. However, conventional ultrasonic flowmeters cannot meet the request, since much of the devices are for the filled flows such as in the closed pipe based on the through transmission travel time observation. Hence, there are few methods applicable for the unfilled fluid flows in the pipe or small open channel flume1. To encounter the problem, a technique[2-4] is investigated based on the observation of the pulse echo signals assuming the existence of scattering particles in the drainage water. Particularly, sound waves are emitted from the bottom of the pipe with its direction normal to the fluid flow direction. Flow velocities are then estimated from the correlation between the repetitively excited pulse echo signals. In the present paper, examinations are made to examine the precision and/or durability of the flow velocity measurement in the actual situation suffered by the water surface fluctuations.

2. Method

As shown in **Fig.1**, a drainage pipe is considered where the unfilled scattering fluid medium is flowing with constant speed v in the horizontal x direction. To measure the flow velocity of the fluid in the pipe, a single transmitter/receiver transducer is attached at the bottom of the pipe. Pulsed waves are repetitively excited at time instant $\tau = nT_{prt}$ (n=0,1,2...) for every time interval T_{prt}. Echo signals $e(t;\tau)$ scattered from the particles in the flow medium are then observed, where t is the elapsing time starting from each excitation time τ. Correlation coefficient $R(\tau)$ between the target signal $e(t;\tau)$ and the reference signal $e_0(t;\tau=0)$ is considered. It is then expected that flow velocity can be estimated from the correlativity between the successive echo signals. To eliminate the effect by the turbulent fluctuation of the flows, echo signals were divided in the depth direction and calculations are carried out for each divided interval. To this end, we denote the subdivided echo signals as $e(t_k;\tau)$, where t_k is k-th subdivided time interval having span Δt. Average correlation coefficients $R(\tau)$ for each intervals is used as a final value, that is,

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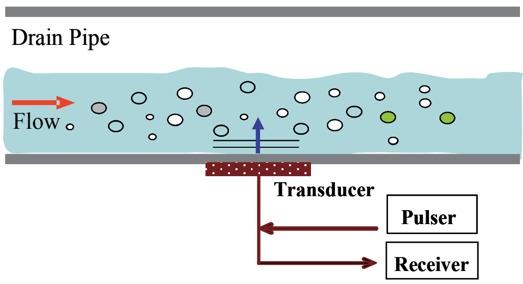

Fig.1 Schematic of the open channel ultrasound flow meter system.

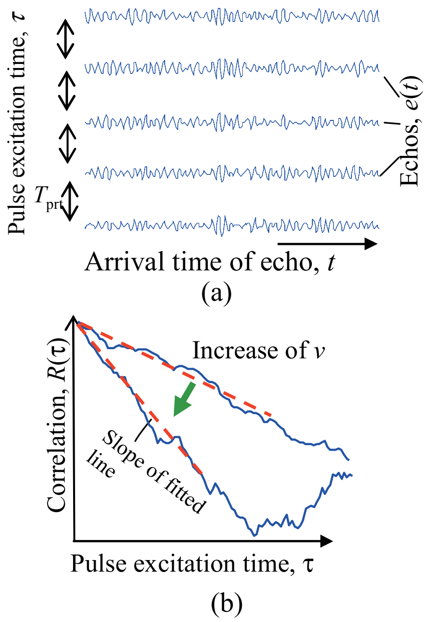

Fig.2 Procedure of flow speed estimation, (a) pulse echo signals, (b) variation of the correlation coefficient.

$$R(\tau) = \frac{1}{K}\sum_{k=0}^{K-1}\mathrm{Corr}\left[e(t_k,\tau), e_0(t_k;\tau=0)\right] \qquad (1)$$

where Corr[a,b] denotes the correlation of signals a and b. It is noted that time t is related with the water depth z through the relation: z=0.5ct where c is the sound speed in the fluid medium.

Suppose that pulse echo signals as shown in **Fig. 2**(a) are repetitively observed. Procedure for obtaining the flow speed from the correlation of the pulse echo signals is then explained as follows. That is, variation of the correlation values with respect to the excitation time τ beginning at that of the reference signal are depicted in **Fig.2**(b). As the target particles move away from the initial positions, correation $R(\tau)$ decreases in proportion to the moving distance $|x|=|v\tau|$ with its peak at $\tau=0$. Based on this situation, regression line is fitted over the correlation curve, flow velocity v is finally estimated from the slope of the fitted regression line.

3. Test examination

3.1 Experiment set-up

As a drainage mimicking water, flour powder mixed water with density 0.125, 0.25 and 0.5 % was prepared. The solutions were circulated in the horizontally arranged acrylic pipe with length L=1 m and diameter D_p=54 mm. The flow velocity v was controlled by changing the excitation voltage of the electric pump. Preset value of the flow velocity v was measured by the rotating vane flow meter. A piezoelectric circular transducer with center frequency f_c=5MHz and diameter D_x=25.4 mm (Panametrics:V307) was attached at the bottom of the pipe. Pulser/receiver (Panametrics: 5058PR) was used for the excitation and amplification of the ultrasonic waves.

3.2 Test result

Flour mixed water was circulated in the pipe. Preset value of the flow velocity v was changed over the range from v=0.68 cm/s to 4.26 cm/s. Pulse echo waves were observed repetitively with repetition T_{prt}=10 ms. As described in section **2**, depth intervals between z=19.5 mm and 27 mm were subdivided with every Δz=0.9 mm (Δt=1.2 μs) spacing. The correlation R was calculated according to eq.(1). **Figure 3** shows the correlation R as a function of the excitation time τ for different preset flow velocity. Here, fitted regression lines are shown with dashed lines. As expected, the correlation decays linearly at the beginning of the excitation time instant. The slopes of the fitted lines were compared with the preset flow velocities as shown in **Fig.4**. The results demonstrate that they have good proportionality with the preset flow velocities in the fluid.

4. Conclusion

From the results demonstrated above, it was confirmed that the flow velocity can be precisely measured in the presence of the moderate water surface fluctuation conditions. However, quantitative evaluation of the durability against the turbulent flow is remained for the future investigations. The authors are proceeding with much elaborate investigations on these points.

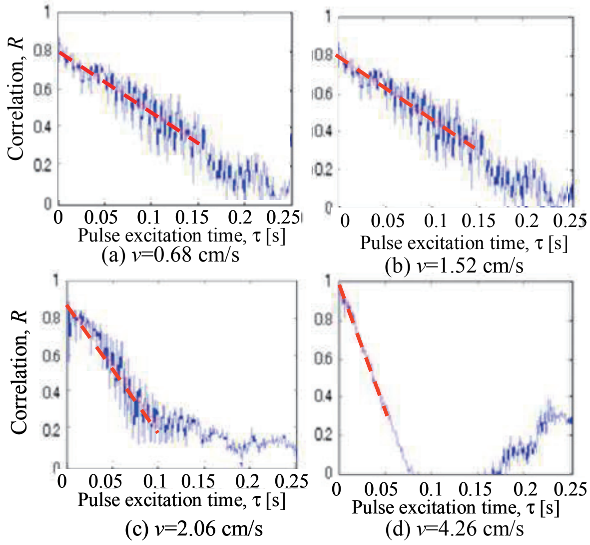

Fig.3 Experiment results of the correlation coefficients R as a function of pulse excitation time τ for different preset flow velocity v. Fitted regression lines are shown with dashed line in the curve.

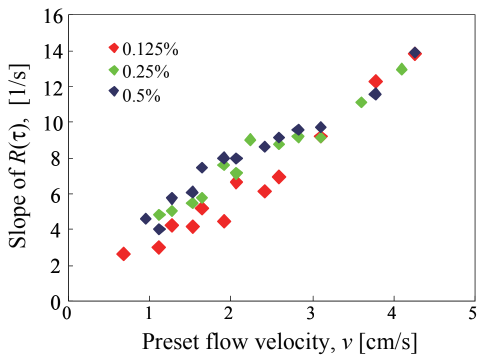

Fig. 4. Experiment results of slope of correlation coefficients as a function of preset flow velocity.

References

1. U. S. Dep. of Interior Bureau of Reclamation, “Water Measurement Manual”, http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/
2 M.Uchida, A.Yamada, “Development of a Ultrasonic Flow-meter for Drain Fluid”, Spring meeting of Acoust. Soc. Jap., 1-p-4, pp.977-978, 2005.
3 M. Uchida, A. Yamada, K. Oda, “Open Channel Ultra-sonic Flowmeter Using Correlation Technique”, Autumn meeting of Acoust. Soc. Jap., 3-p-23, 2005.
4 I. Nishimura, A. Yamada and M. Uchida, ”Ultrasonic Drain Flow Measurement Using Correlation Technique”, Proc. Symp. Ultrason. Electronics, vol.30, pp.41-42 (Nov. 2009).