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Ultrasonic Drain Flow Measurement Using Correlation Technique

相関法を用いた排水管用超音波流量計測

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1. Introduction

With the recent escalation of environmental concerns, monitoring for the flow rates in the flumes and/or drain pipes is much demanded. Conventional ultrasonic flowmeters cannot meet the request, since much of these devices are for the filled flows such as in the closed pipe. In these situations travel time method based on the through transmission observation can be applied. On the other hand, there are few methods applicable for the unfilled fluid flows in the pipe or small open channel flume[1]. To encounter the problem, a technique[2] is investigated based on the observation of the pulse echo signals scattered from the particles in the medium. Special feature of the technique is that transmit and receive direction is perpendicular to the fluid flow direction and estimated by the correlation calculation between the repetitively excited pulse echo signals. In the present paper, simulation and experiment examinations are made to verify the precision of the flow velocity measurement for the open channel unfilled fluid.

2. Method

As shown in Fig.1, a flow measurement apparatus for the unfilled liquid medium in the pipe is considered, where the medium is flowing with constant speed v in the horizontal x direction. A single transmitter/receiver transducer is attached at the bottom of the pipe. Pulsed waves are repetitively excited at time instant $T_n = n\Delta T$, $n=1,\ldots,N$) for every time interval ΔT. Echo signals $e_n(t)$ scattered from the particles in the flow medium can then be received, where t is the time of the echo signal starting from the exciting time of the n-th excitation. Maximum correlation coefficient $R(\tau_{mn})$ between the signals e_n and e_m with respect to time t is calculated as,

$$R(\tau_{mn}) = \operatorname*{Max}_{t'} \frac{\int e_m(t-t')e_n(t)dt}{\sqrt{\int e_m(t)^2 dt \int e_n(t)^2 dt}} \qquad (1)$$

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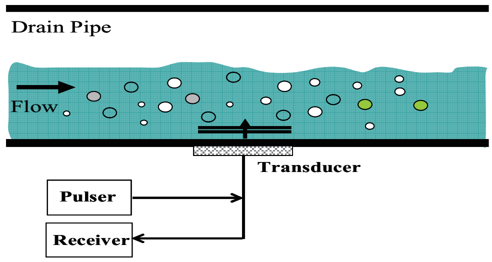


Fig.1 Schematic depiction of the ultrasound flow meter system.

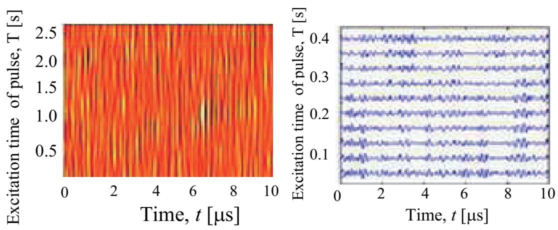
where τ_{mn} is the excitation time interval defined by $\tau_{mn}=(m-n)\Delta T$.

Note that fluid medium moves a distance $x=v\tau$ for time interval τ. For the case when the target is located at the position within the radiated acoustic beam field in the range $|x|<D_T/2$ (D_T is the diameter of the transducer), $R(\tau)$ takes peak at $\tau=0$ and decreases in proportional to $|x|=|v\tau|$. Furthermore, when the target goes beyond the acoustic beam field in the range $|x|>D_T/2$, the correlation approaches to zero. Consequently, slope of decay ($\Delta R/\Delta\tau|_{\tau=0}$) around the peak ($\tau=0$) is proportional to v (since, $|x|=|v\tau|$). In other words, flow velocity v can be estimated from the slope of the fitted regression line over the correlation curve.

3. Simulation examination

3.1 Synthesis of echo waves

As a simulation model, water is assumed to be filled up to the level h=27 mm in the drain pipe with diameter D_p=54 mm. Point scattering particles with density ρ_p=0.2 pcs/mm^3 were randomly distributed in the water medium. A circular transducer with diameter D_T=25.4 mm and center frequency f_c=5 MHz was placed at the bottom of the pipe. The transducer were excited with interval T_{prf}=10 ms. On this condition, received echo signals are calculated using the simulation software Field II. Here, the waves were emitted multiple times (number of excitations: N=250) by moving the particle position in the medium with every Δx (=vT_{prf}) step. By this means, constant laminar water flow with flow speed v =2.0 cm/s was simulated. Calculated echo waves from the particles at the



(a) (b)

Fig.**2** Simulated pulse echo signals for ρ_p=0.2 pcs/mm^3, T_{prf}=10 ms and v=2.0 m/s. (a) shows the gray scale image, (b) shows amplitude v.s. time plot .

level over the range just below the water surface z=19.5-27 mm are as shown in Fig.2. Where (a) shows the gray scale image of the echo amplitude, and (b)shows the plot of the received r.f. echo waveforms. Successive echo waves show close resemblance each other and parallely striped patterns in the gray-scale image demonstrate the degree of correlativity between the waves. When the turbulent flows are contained other than the laminar flow, the result exhibits much distorted patterns (effect of the turbulent flow was not considered in the present simulations).

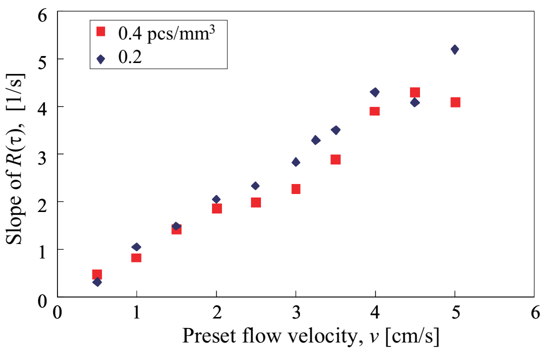


Fig.3 Simulated results of slope of correlation coefficient as a function of preset flow velocity.

3.2 Simulation result

Density of the scattering particles was set with 0.2 and 0.3 pcs/mm^3. The flow speed was changed over the range v=0.5-5.0 cm/s at every 0.5 cm/s. According to the method described in 2, correlation coefficients $R(\tau_{mn})$ were calculated between the signals for the different time excitation. Finally, as a parameter proportional to the fluid speed, slopes of $R(\tau_{mn})$ around peak were estimated from the fitted regression lines. The obtained relation between the set-up flow velocity and the measured slope of the curve was shown in Fig.4.

4. Experiment

4.1 Experiment set-up

Experiments were made under the same condition as described in the simulation. Starch powder was mixed in the water with density 0.125, 0.25, 0.5 %. The prepared solutions were circulated in the horizontally-disposed acrylic pipe (L:1m, ϕ:54 mm), where the flow velocity was controlled by changing the excitation voltage of the electric pump. Preset value of the flow velocity was measured by the vane flow meter. A piezoelectric circular transducer was attached at the bottom of the pipe. Pulser/receiver was used for the excitation and amplification of the waves. They were digitized by the digital oscilloscope and transferred to the personal computer.

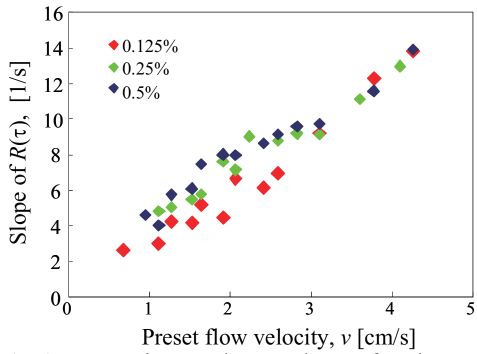


Fig.4 Experimented results of slope of correlation coefficients as a function of preset flow velocity.

4.2 Experiment result

Solutions are circulated in the pipe. Preset value of the flow velocity was changed between the range from 0.68 cm/s to 4.26 cm/s. The correlation coefficients between the echo signals for different excitations were calculated (division of the time axis was 1.2 μs). The obtained slope of the correlation R as a function of the set-up flow velocity was shown in Fig.4. It can be confirmed that the measured slope values were in good proportion to the preset flow velocity regardless of the density of the powder particles.

5. Conclusion

From the results demonstrated above, it was confirmed that the flow velocity can be measured with limited influence of the variation of various flow conditions, which is severely required for the open channel flow. In particular, it is expected that influence of the variation of water level can be avoided if the non-turbulent laminar flow condition is satisfied. The authors are proceeding with much elaborate investigations on these points.

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