

Development of a new type flow metering system using UVP - (1) Principle, Configuration, and Laboratory experiments -

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1. INTRODUCTION

The flow velocity profile measurement by the ultrasonic-Doppler velocity profile(UVP) method⁽¹⁻⁴⁾ exhibited an outstanding potential in an accurate measurement of flow rates because of the advantage of the UVP method instantaneously measuring a spatiotemporal velocity profile over the flow channel. The conventional ultrasonic measuring techniques are based on a spatially averaged fluid velocity measurement, the fact of which causes inaccuracy in flow rate measurements due to the inevitable assumption of the flow velocity profiles. This paper summarizes the measurement methods of the velocity profile and flow rate using UVP, and its characteristics of ultrasonic wave propagation through the metallic wall to place the transducer on the outside wall of the pipe for industrial application. Using a small pipe test stand, we showed the UVP method to be very feasible in order to measure the transient flow rate with high accuracy and with fast response. We also performed the measurement of flow rates using larger stainless steel pipes with transducers located on the outside wall of the pipe and compared the measured results of the transient flow by UVP against the measured ones by conventional measurement devices.

2. ULTRASONIC BEAM STUDY FOR APPLICATION TO METALLIC WALL

2.1 Theoretical discussion on the transmission of ultrasonic waves

The transmission of ultrasonic beams through a metallic wall was examined to clarify the effects of the ultrasonic basic frequencies against the wall thickness to enable the measurement of the flow velocity profile and flow rates from the outside surface of a metallic wall^(5,6). There occur reflection, diffraction, and absorption of the ultrasonic wave at the boundary of two materials of the different acoustic impedance. When the wall thickness is in the same order of the wave length, there occurs a sort of resonance transmission of the wave. Immersed in a fluid, a transmission coefficient of the wave is described as following:

$$D = \frac{1}{\sqrt{1 + \frac{1}{4} \left(m - \frac{1}{m}\right)^2 \sin^2 \frac{2\pi d}{\lambda}}} \quad (1)$$

where $m = Z1 / Z2$; Z : acoustic impedance; d : wall thickness; λ : wave length.

Due to its trigonometric characteristics, it changes as d/λ periodically, as shown in Fig.1 with two examples of Plexiglas and steel. For Plexiglas, the amplitude of oscillation is rather small between 80 and 100% and its width is pretty broad. Whereas for steel, the resonance peak is very strong and narrow. However it is promising that for the resonant wall thickness, the transmission is 100%. It is found that the maximum transmission occurs at :

$$d/\lambda = 0, 1/2, 2/2, 3/2, 4/2, \quad = n/2 \quad (2)$$

and the minimum (maximum reflection) at :

$$d/\lambda = 1/4, 3/4, 5/4, \quad = (2n+1)/4 \quad (3)$$

We selected wall thickness of stainless steel using the wave length unit at a room temperature. The wall thickness was determined using 2 and 4MHz of basic frequencies. The total Doppler powers are shown in Fig. 3. It shows clearly that a high transmission is attained for a half-wave length of 2MHz. It is very promising that 1/2 wave length be a realistic wall thickness and would give us a solution for the measurement of the flow rate by the ultrasonic Doppler method by placing the transducer outside wall of a pipe

3. FLOW MEASUREMENT IN INDUSTRIAL STAINLESS-STEEL PIPE

3.1 Experiment

The test sections are A250 whose inner diameter is 250 mm, and A400 whose inner diameter is 400 mm stainless steel pipes connected in parallel. The length of the test section is about 10m. The smaller pipe of A250 is equipped with the orifice flow meter and the electromagnetic flow meter. The larger pipe of A400 is equipped only with the orifice flow meter.

The adopters are inclined by 5 deg., 8 deg., and 12 deg. to the normal line of the pipe axis. One adopter has a bore hole where the transducer directly contacts with water. The second adopter has a wall whose thickness is adjusted to the basic frequency but its surface is parallel to the wall. This means that the wall thickness is not constant over the total active area of the transducer. The third type has a wall of constant thickness over the active area of the transducer.

Cavitation gas bubbles were used as a reflector. Since the loop has several bent and valves, cavitation bubbles were generated when the loop is not pressurized. Hydrogen gas bubbles were also possible to use as a reflector.

3.2 Results and discussion

The steady state flow rate can be obtained by integrating the velocity profile, which is obtained with the measuring line on the diameter. There is quite a strong influence of the wall just in front of the transducer which deteriorates the shape of the velocity profile. We decided to use only the half of the velocity profile which is beyond the center of the tube, using the following equation:

$$Q = 2\pi \int_0^R V(r) r dr / \sin\theta \quad (5)$$

where θ is the inclination angle of the transducer.

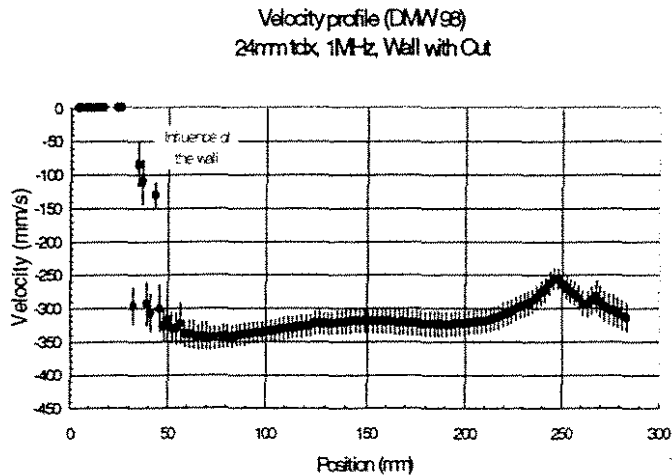


Fig. 4 Time averaged velocity profile in 250A stainless-steel pipe (1MHz, thickness of $\lambda/2$)

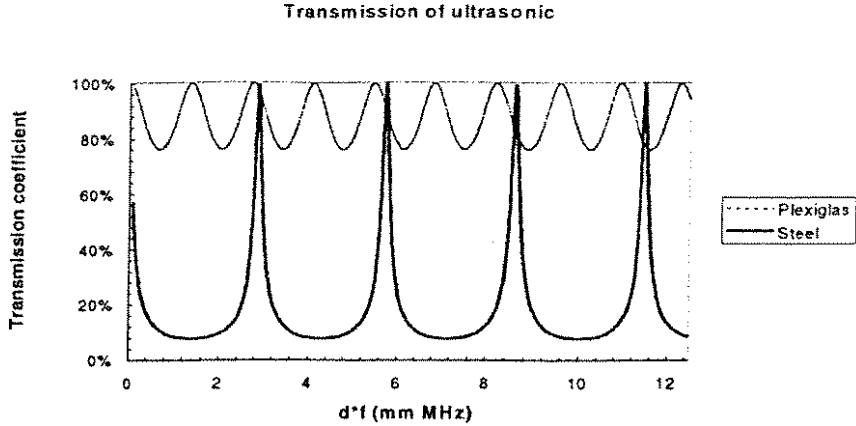


Fig.1 Transmission coefficient of ultrasonic through Plexiglas and Steel walls.

2.2 Experimental study

Fig.2 is a plot of the total Doppler power at the center of the channel with respect to the wall thickness of aluminum, whose acoustic impedance is relatively small as metals, in unit of wave length for two frequencies used here. The figure exhibits a general tendency that a large Doppler power can be observed at the wall thickness of half and one unit of wave length, the fact of which seems to enable us to have better transmission of the ultrasonic beam through metallic wall when the wall thickness is carefully selected.

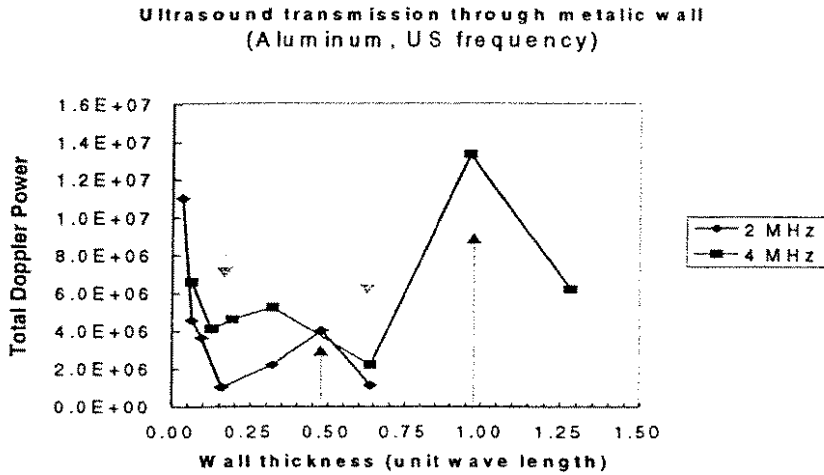


Fig. 2 Total Doppler power with unit of wave length through Aluminum wall.

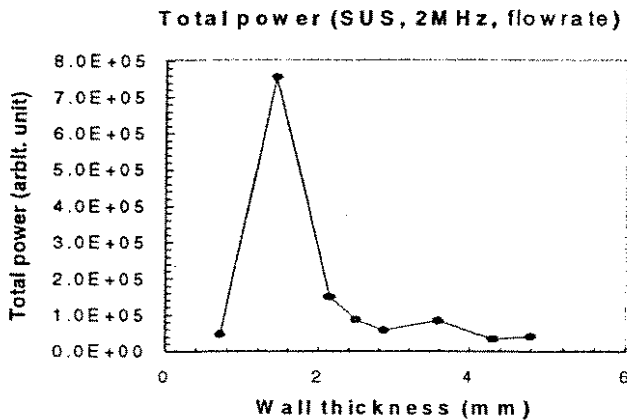


Fig.3 Total Doppler power against wall thickness of stainless steel.

Fig. 4 shows the measured results of time averaged velocity profiles of the case with 1MHz ultrasonic basic frequency.

Transient measurement means to study a response of the flow meter to the flow which fluctuates with relatively high frequency. In order to make a comparison of time-response with the orifice (ORF) and electromagnetic flow meter (EMF), these values are recorded in the computer. The results are shown in Fig. 5. It can be seen that the time response of UVP appears very good compared with the orifice flow meter, and that the transient behavior shows the exact correspondence with the orifice up to the small fluctuations not only transient period but also stationary period. Fig. 6 shows a difference of the measured flow rates between UVP and the orifice. The difference ranges up to 0.2% in steady state flow condition and about up to 5% in rapid transients.

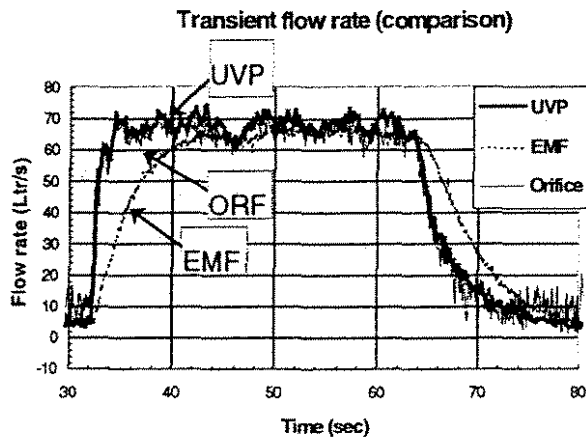


Fig. 5. Comparison of measured transient flow rates by UVP, orifice (ORF), and electromagnetic flow meters (EMF) .

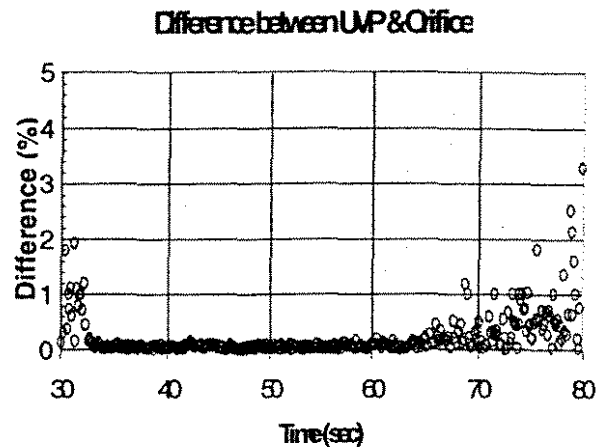


Fig. 6. Comparison of errors between measured transient flow rates by UVP and orifice flow meters.

4. CONCLUDING REMARKS

Transmission of an ultrasonic beam has been studied experimentally. The experimental results show that one half-wave length would give the most promising result for the velocity profile measurement. By one-dimensional measurement, the transient flow rate can be obtained with sufficiently high accuracy. By locating the measuring lines on the diameter at various azimuthal angles, transient flow rates can be successfully measured. Comparison with the orifice flow meter shows that the estimated flow rate is in a very good agreement with its result. The electromagnetic flow meter has a poor time response compared with other two methods.

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