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Development of a new flow metering system using UVP

- (2) Comparison with weight measurement at NIST -

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1. INTRODUCTION

A new flow metering system using ultrasonic Doppler method (UVP) has been developed by Takeda et al.^[1-7] In this system, a flow rate is obtained by an integration of instantaneous velocity profile measured by UVP over a pipe diameter. This system has a many advantages. One is that pressure loss is not caused because the transducer can be set outside of the wall and other one is that can be applied to opaque liquid, and so on. Especially, it is not necessary the process of interpolation or averaging which using other ultrasonic flow meter because a flow rate be estimated directly by using instantaneous velocity profile.

Kikura et al.^[2] clarified a characteristic of ultrasonic propagation through the metallic wall and indicated that a flow rate can be measured from the outside of the stainless steel when the basic frequency of the ultrasonic pulse is carefully selected. Mori et al.^[3] reported the result of a flow rate measurement in the stainless steel pipe (250A and 400A) which is more realistic configuration. The error rate that obtained by compare a flow rate measured by this method with that by other flow meter (orifice flow meter and electric flow mater) was less than 0.2% at steady flow condition. Taishi et al.^[4] was indicated that this method has a good sensitivity for a transient flow rate. Thus, it is suggested that this method can be applied to flow metering system with a high accuracy.

For the realization this method, it is necessary the more information of the accuracy. Especially, it is necessary that the accuracy that compared absolutely flow rate is obtained. At the NIST (National Institute of Standard and Technology) in USA, there is the system that can be measured weight flow rate. In this paper we report the result that compared absolutely flow rate measured by this new method with that measured by weight flow rate by the NIST standard calibration system.

2. EXPERIMENTAL APPARATUS

The water facility of the NIST standard calibration system that consists of a reservoir, pump, meter runs and weight tank is shown in Fig. 1. The system is usually operated as a constant flow facility over the test section. The junction that switches the flow channel to the weight tank or the reservoir is set at the downstream of the test section. An operation that the junction is switched does not affect to the flow condition. Flows up to 38m³/min (10,000gal/min) can be provided and maximum Reynolds number is about 4M when the pipe 254mm in diameter is used. The weight tank capacity is about 20m³ and weight of water inside it can be measured. The method of flow rate measurement is below. Water thorough the test section is stored in this tank in some period

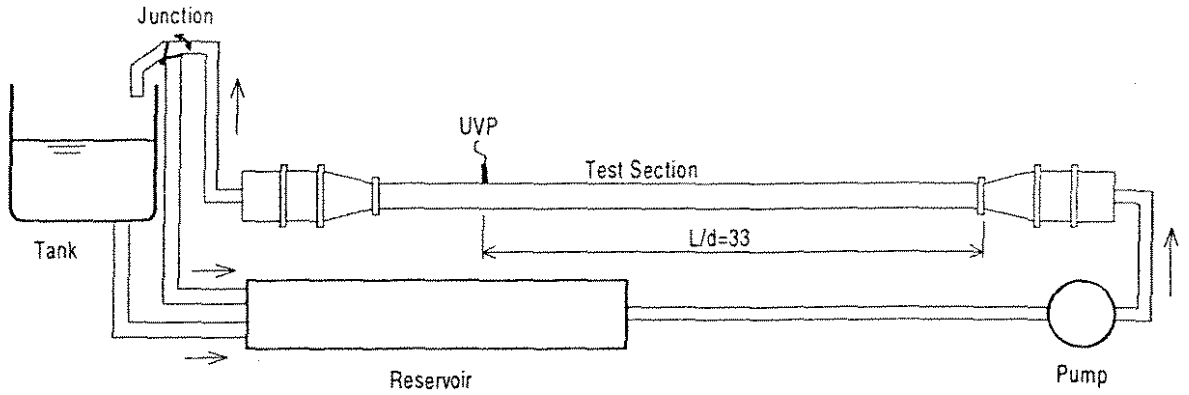


Fig. 1. Schematic of the experimental apparatus - NIST calibration standard system-

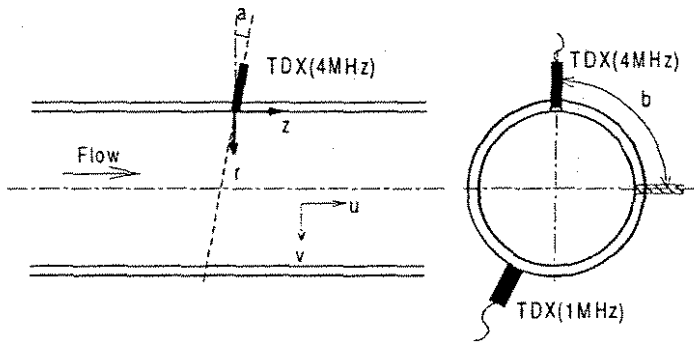


Table 1. UVP parameters

Reynolds Number	400K	2.6M
Transducer	4MHz	1MHz
Starting Depth	101mm	340mm
Channel Distance	2.22mm	1.48mm
Maximum Depth	326mm	340mm
RF gain	4,4	1,1

Fig. 2. Test section detail and coordinate system

and a weight is measured. The weight flow rate is obtained as a result that the volume of water stored in the tank divides by that time. The relative expanded uncertainty for these facilities is 0.12%. The test section has 10.15m (400in.) length and the pipe diameter is $d=253.75\text{mm}$ (10in.). The measuring region was set a downstream $L/d=33$ from the nozzle exit.

The test section with transducer setting is shown in Fig.2. Two type transducers which frequency of ultrasonic are 1MHz and 4MHz were used. The 1MHz transducer was put outside of the stainless wall and the 4MHz one was put on spatial mount made by Plexiglas which thickness is 2mm. An inclination angle of 1MHz is 5 degree and 4MHz 0-20 degree with flexibility. A particle was not used as a reflector in this experiment because there is enough small cavitation bubble that generated around the pump in water.

3.EXPERIMENTAL METHOD

Experimental procedure was according to the one of the NIST. A simultaneous measurement of flow rate by UVP and NIST system was examined five times in one running. The average flow rate was determined as the one that is averaged in each examination. A sampling of flow rate by UVP was started at the time when the junction is switched to the tank and continued over storing to the tank. The method of estimating flow rate is same one as Takeda et al^[1] has reported. Reynolds numbers are 400K and 2.6M and the transducer of the UVP was used 4MHz and 1MHz, respectively. Typical UVP parameters are shown in Table 1. A mean velocity profile of U component was measured to obtain an information of flow condition. This component of velocity can not be measured directly by UVP so that it was measured according to the method of flow mapping.

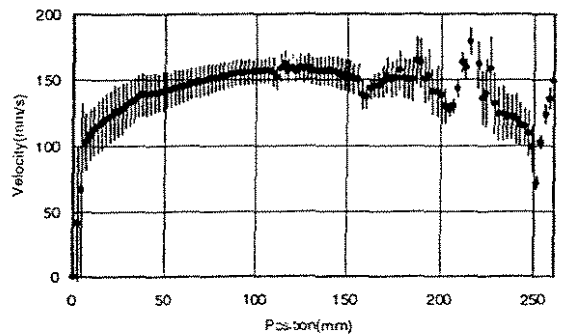


Fig. 3. Mean velocity profile ($Re=400K$)

4. RESULTS AND DISCUSSION

4.1 Mean velocity profile

The mean velocity profile in the pipe is shown in Fig.3. The frequency of ultrasonic is 4MHz and the inclination angle is 12 degree. Reynolds number is 400K. As shown in this figure, the velocity measured by UVP is disturbed by the reflection from the wall of the test section in this experiment so that it is difficult to estimate the flow rate directly. The velocity that is measured with the ultrasonic frequency of 1MHz through the stainless steel is disturbed at near side of transducer by reflection such as Kikura et al.^[5] reported. However, if a flow condition is symmetry, a flow rate can be calculated by using half side velocity profile. To obtain an information of the flow condition, we measured the U -component velocity at various positions. Mean velocity profile of U -component is shown in Fig.4. As mentioned above, the reflection is too strong to measure over a pipe diameter so that a velocity was measured two position which is 0 and 90 degree and the results are shown only half side from the wall of transducer side to the $r/d=0.5$. As shown in figure, velocity profile of U -component is in good agreement with that of the 1/7 power law in various positions so that it is suggested that the velocity distribution in the pipe is almost symmetry.

4.2 Flow rate measurement

As mentioned above, the velocity profile at far side of the pipe wall can not be obtained so that a flow rate is estimated by using one of near side region at the case of using 4MHz frequency. On the other hand, the velocity profile can not be obtained at near side at the case of using 1MHz frequency because of the ringing of the stainless steel so that one of far side is used to estimate flow rate. Typical transient flow rate is shown in Fig.5. Sampling interval of flow rate is 72msec. Mean flow rate is 68.18l/s and standard deviation is 7.3%. Various frequency fluctuation can be observed and it has been clarified that these fluctuations of flow rate were in good agreement with that measured by orifice flow meter^[6].

The result of $Re=400K$ that is compared flow rate measured by UVP with that measured by NIST system is shown in Table 1. First column means data name. The value of second column is the flow rate that is measured by using UVP and the value of third column is weight flow rate by NIST system. In this table, seven data sets of measurement result that is examined five times in one experiment are shown. Especially, the number C, the average flow rate is in excellent agreement with one measured by using weight flow rate and the result is 0.00%. About other data set as shown in the table, the flow rate measured by this new method is in good agreement with the weight flow rate by the NIST system. The error rate in all experiments is only 0.18%. The result about more high Reynolds number ($=2.6M$) is shown in Table 2. The error rate is a little

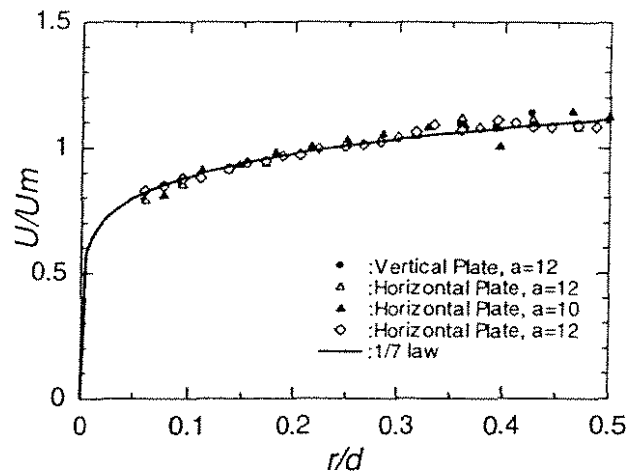


Fig. 4. U component mean velocity
 U_m is bulk velocity that measured by NIST system and "a" is inclination angle of the transducer

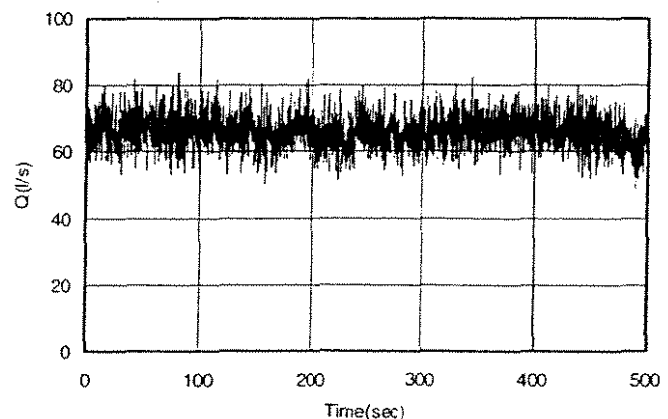


Fig. 5. Transient flow rate

larger than that of $Re=400K$ because it was measured from the outside of the stainless pipe. However, when the condition of the seeding is better, the accuracy of this method is very high as shown in the table.

In this experiment, the inclination angle of transducer for 1MHz frequency is fixed 5 degree because we aimed the measurement of high Reynolds number. As a result, the reflection was too strong to measure a flow rate, however as shown in a result. it is possible that the flow rate measures using half side velocity profile in this configuration. If we examine with flexibility of the inclination angle of transducer, it is suggested that we can measure with more high accuracy.

5.CONCLUSION

A new type flow metering system using ultrasonic Doppler method has been developed. In this presentation, we reported the result of comparison absolutely flow rate measured by this new method with weight flow rate by the NIST standard calibration system.

In this experiment, the pipe flow of NIST system is symmetry that is fully developed so that a flow rate was calculated using by half side velocity profile because velocity profile of another half side was disturbed by the reflection. The result of $Re=400K$ is very good agreement with the flow rate measured by the weight flow rate. The error rate in all experiment is only 0.18%. The result of more high Reynolds number ($=2.6M$) is a little larger than the result of $Re=400K$ because it was measured from the outside of the stainless pipe. However, when the condition of the seeding is better, the accuracy of this method is very high about 0.6%.

As mentioned above, it is indicated that this new type flow metering system using by UVP has very high accuracy. And this method is multipurpose system because flow rate can be measured under high Reynolds number.

ACKNOWLEDGEMENT

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Table 2. Flow Rate Measurement
($Re=400K$)

		UVP (L/s)		Weight		Difference	% error
		Average	Deviation	GPM	L/s		
A	1	70.60	3.25	1109.14	69.97	-0.63	-0.90%
	2	70.24	3.22	1110.27	70.04	-0.20	-0.29%
	3	70.76	3.01	1110.30	70.04	-0.72	-1.03%
	4	70.61	3.00	1110.23	70.04	-0.57	-0.82%
	5	70.23	3.12	1110.78	70.07	-0.16	-0.23%
B	6	70.20	3.31	1110.87	70.08	-0.12	-0.17%
	7	70.36	3.41	1111.42	70.11	-0.25	-0.35%
	8	70.20	3.39	1110.32	70.04	-0.15	-0.22%
	9	69.86	3.56	1109.81	70.01	0.15	0.21%
	10	69.90	3.38	1110.72	70.07	0.17	0.24%
C	11	70.21	3.17	1113.62	70.25	0.04	0.05%
	12	70.34	3.17	1113.76	70.26	-0.08	-0.11%
	13	70.38	3.39	1113.61	70.25	-0.13	-0.19%
	14	70.30	3.40	1115.04	70.34	0.04	0.06%
	15	70.16	3.41	1114.10	70.28	0.12	0.17%
D	16	69.81	3.22	1111.90	70.14	0.33	0.48%
	17	70.12	3.12	1113.85	70.27	0.15	0.21%
	18	69.67	3.25	1113.00	70.21	0.54	0.77%
	19	69.88	3.21	1112.82	70.20	0.32	0.45%
	20	70.07	3.29	1113.73	70.26	0.19	0.27%
E	21	70.20	3.29	1101.77	69.50	-0.70	-1.00%
	22	69.97	3.20	1102.62	69.56	-0.41	-0.59%
	23	70.13	3.35	1102.90	69.57	-0.56	-0.80%
	24	70.11	3.31	1102.85	69.57	-0.54	-0.78%
	25	70.36	3.36	1103.20	69.59	-0.77	-1.10%
F	26	69.76	2.96	1103.30	69.60	-0.16	-0.23%
	27	69.67	3.19	1103.51	69.61	-0.06	-0.08%
	28	69.72	3.23	1103.49	69.61	-0.11	-0.16%
	29	69.44	3.15	1103.65	69.62	0.18	0.26%
	30	69.57	3.22	1103.44	69.61	0.04	0.06%
G	31	69.96	3.07	1101.77	69.50	-0.46	-0.66%
	32	69.70	3.21	1102.62	69.56	-0.14	-0.20%
	33	69.36	3.24	1102.90	69.57	0.22	0.31%
	34	69.54	3.13	1102.85	69.57	0.03	0.05%
	35	69.71	3.22	1103.20	69.59	-0.12	-0.17%
Average		70.03	0.13	1108.10	69.90	-0.13	-0.18%

Table 3. Flow rate measurement
($Re=2.6M$)

		UVP (L/s)		Weight		Difference	% error
		Average	Deviation	GPM	L/s		
A	1	475.35	25.66	7485.94	472.24	-3.11	-0.66%
	2	478.06	25.45	7485.60	472.22	-5.85	-1.24%
	3	475.10	25.60	7494.20	472.76	-2.34	-0.50%
	4	474.44	26.95	7478.94	471.80	-2.65	-0.56%
	5	472.01	26.38	7483.13	472.06	0.05	0.01%
Average		474.99	0.64	7485.56	472.21	-2.78	-0.59%