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Implementation of a Square Pipe Ultrasonic Flow Meter

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Abstract

When the ultrasonic wave is discharged in the pipes with fluids (water, oil, etc.) flowing inside, the transit speed is affected by the fluid flow, thus transmitted at the speed of velocity of sound plus velocity of flow when flowing in the same direction and at the speed of velocity of sound minus velocity of flow when flowing in reverse direction. The measured difference of the transmission time in opposite directions is the velocity of the moving fluid, which is used to measure the volumetric flow of the fluid with the ultrasonic flow meter. The ultrasonic flow meter can be used in various applications. For example, it can be used in monitoring purpose in water and sewage areas and measurement of flow of various industrial fluids (oil, coolant, and other various petrochemical products). In this paper, the measuring pipe is designed with the contraction version of the square pipe to achieve a very stable flow measurement. This study has identified the transit time measurement effect, flow increase effect, valve effect of the contraction pipe, and the performance effect of the square pipe and round pipe.

Keywords: *Ultrasonic flow meter, fluid, round pipe, square pipe, stable flow measurement*

1. Introduction

In most heat energy supply sites, mechanical flow meter is used which is characterized by the turbine existing inside the fluid flow thus susceptible to mechanical characteristic change as well as tear and wear of such turbine. Particularly in case the characteristic change occurs gradually, it becomes difficult to determine when such change started and how significant it is.

Ultrasonic flow meter without turbines was developed as a way of settling such problems and is widely used in commercial heating especially in north Europe. Ultrasonic flow meters use sound waves to determine the velocity of a fluid flowing in a pipe. Transit time ultrasonic flow meters send and receive ultrasonic waves between transducers in both the upstream and downstream directions in the pipe. At no flow conditions, it takes the same time to travel upstream and downstream between the transducers. Under flowing conditions, the upstream wave will travel slower and take more time than the (faster) downstream wave. When the fluid moves faster, the difference between the upstream and downstream times increases. The transmitter processes upstream and downstream times to determine the flow rate.

The existing mechanical turbine caused problems such as foreign substance absorption, tear and wear of turbine until the flow measurement become impossible or result in errors and changes, which led to the civil complaints and low reliability in fare levy.

In this paper, a new ultrasonic flow meter is adopted as the alternative technology to provide solution to those underlying issues. Moreover, it has answered the demands for improvement such as not having enough force from the flow to operate the turbine that causes the turbine to stop rotating and result in drastic decrease in the measurement performance at small fluid quantity and the degrading quality after years of use.

2. Implementation of a Small Diameter Ultrasonic Flow Meter

2.1 Operational principle of ultrasonic flow meters

As the ultrasonic pulses pass through the fluids, the pulses progressing in DS (down-stream) as the fluid flow reach slightly faster than the counterparts progressing in US (up-stream), which is determined by whether there is the velocity of the moving fluid and the direction of such velocity. The amount of the fluid flowing through the pipe conduit is defined by the volume that passes the cross section during unit time.

$$Q = A \cdot V \tag{1}$$

where Q is the fluid flow (m^3/s), A and V indicate the cross section area (m^2) of the measured flow path and the average speed (m/s) of the flow, respectively.

In measuring the ultrasonic flow, the velocity measurement is commonly achieved by transit speed method, by which the ultrasonic sensors are installed in a pair in upstream and downstream each, while the measuring tube is installed along the direction of fluid stream. The sensors are placed to enable mutual reception when the ultrasonic sensor is discharged between them and to allow the incidence angle around the axis of pipe conduit. If the velocity of the ultrasonic wave discharged from oscillator and transmitted through fluid is referred to as *C*, the average speed of the fluid is referred to as *V*, and the distance between the ultrasonic sensors is referred to as *L*, then t_{AB} which is the time of ultrasonic discharged from point *A* reaching to point *B* and t_{BA} which is the time of ultrasonic discharged from point *B* reaching to point *A* are as follows. θ is the inclination angle.

$$t_{AB} = \frac{L}{C+V\cos\theta}, t_{BA} = \frac{L}{C-V\cos\theta} \quad (2)$$

The time difference ($\Delta t = t_{BA} - t_{AB}$) from the above equation (2) can be used to calculate the fluid speed, while the fluid amount can be calculated by multiplying the average fluid speed and cross section area. Formula (3) and formula (4) are deduced from formula (2). D is the diameter of a conduit.

$$V = \frac{\Delta t \cdot C^2}{2L\cos\theta} \quad (3)$$

$$Q = A \cdot V = \frac{\pi D^2}{4} \cdot \frac{\Delta t \cdot C^2}{2L\cos\theta} \quad (4)$$

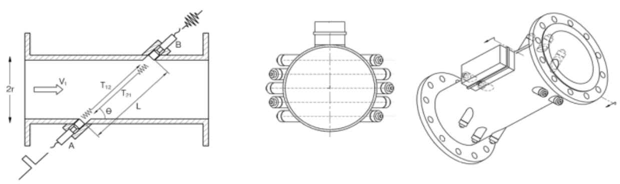

Fig. 1 Major components of ultrasonic flow meters

2.2 Development of small diameter ultrasonic flow meters

It is required to develop an ultrasonic flow meter with improved structure that provide accurate measurement of velocity, flow and calorie of fluids even in the pipe conduits of small diameters with low speed flow. As in Table 1, a flow ratio of above 25:1 is required for the distance between surfaces and the maximum flow for the purpose of domestic application. In order to settle this, the cross section of the pipe was made square as Fig. 2 to accommodate a number of circuits and to maintain the reflected ultrasonic signals. This may bring about various benefits and drawbacks at the same time. The biggest drawback is the increased pressure loss due to the narrow fluid path, which still falls below specification requirement of 10 kPa. This does not cause major issues. At the same time, it is expected the cross section interior will gain increased time difference effect as well as cleaning effect owing to the local velocity increase. Also, the reduction of the entrance from circle to square accomplishes valve effect that reduces the asymmetric velocity profile or swirl that might be witnessed in the front end portion. Such effects were specifically identified.

2.3. Evaluation of performance for single elbow pipe configuration after edge

For stable flow measurement in fluid flow, the flow effects must be overcome depending on the conditions of the straight pipe configuration that may affect the fluid flow. To achieve the valve effect of asymmetrical velocity distribution, in the single elbow pipe configuration after edge with the straight pipe configuration part of larger than 50D, the flow meters with diameter of 50, 100, 150mm each have acquired the results shown in Table 3~5. Here, maximum flow, medium flow, and minimum flow are each represented as q_{max}, q_t, and q_{min}.

Table 1. Research on characteristics of flow meter that is in need of domestic development

Diameter DN	Maximum flow q_p (m^3/h)	Distance between surfaces(㎜)	
		EN 1434	Korea Heating material specification
20	1.5	190	190
25	3.5/6	260	260
40	10	300	300
50	15	300	200
65	25	300	200
80	45	350	225
100	70	350	250
125	100	350	250
150	150	500	300
200	250	500	350
250	500	600	450

Table 2. Size conversion of flow velocity by scope of flow required for research and development

Classification	v(s)	v(p)	v(i)	v(Start)
20A	2.65	1.33	0.05	0.03
25A	7.92	3.96	0.16	0.04
40A	4.42	2.21	0.09	0.04
50A	4.24	2.12	0.08	0.04
65A	4.19	2.09	0.08	0.03
80A	4.97	2.49	0.10	0.02
100A	4.95	2.48	0.10	0.02
125A	4.53	2.26	0.09	0.02
150A	4.72	2.36	0.09	0.03
200A	4.42	2.21	0.09	0.02
250A	5.66	2.83	0.11	0.06

(Unit: m/s)

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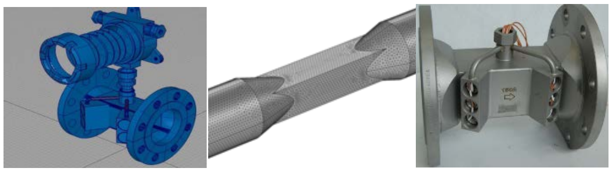

Fig. 2 Schematic diagram of the ultrasonic flow meter developed with square flow path

Table 3. Performance of a 50 mm ultrasonic flow meter (straight pipe configuration 50D)

Test flow	Reference flow rate (Y) (m^3/h)	Test flowmeter Flow rate (X) (m^3/h)	Measurement deviation (X/Y-1) %	Average deviation %
q_{min}	0.690	0.693	0.43	0.09
q_t	1.662	1.659	-0.18	
q_{max}	30.213	30.219	0.02	

Table 4. Performance of a 100 mm ultrasonic flow meter (straight pipe configuration 50D)

Test flow	Reference flow rate (Y) (m^3/h)	Test flowmeter Flow rate (X) (m^3/h)	Measurement deviation (X/Y-1) %	Average deviation %
q_{min}	2.844	2.843	-0.04	0.01
q_t	7.394	7.400	0.08	
q_{max}	70.009	69.995	-0.02	

Table 5. Performance of a 150 mm ultrasonic flow meter (straight pipe configuration 50D)

Test flow	Reference flow rate (Y) (m^3/h)	Test flowmeter Flow rate (X) (m^3/h)	Measurement deviation (X/Y-1) %	Average deviation %
q_{min}	6.220	6.227	0.10	0.11
q_t	16.300	16.329	0.26	
q_{max}	150.414	150.009	2.36	

The uniformity and performance of the velocity distribution were evaluated at single elbow pipe configuration. For this, an obstacle shown in Fig. 3 was produced as suggested by ISO 4064-2(2014). By using this, the performance of the flow meter with 150mm diameter was examined with different straight pipe configurations starting from 50D to 5, 3, 1D.

2.4 Evaluation of performance in double elbow pipe configuration after edge

The effect is more significant in the environments where the rotating component may occur such as double elbow pipe configuration or pump. The effect on the double elbow pipe configuration part was observed with a flow meter of 150 mm diameter. In fact, such flow distribution form was first identified by round multi-circuit ultrasonic flow meter.

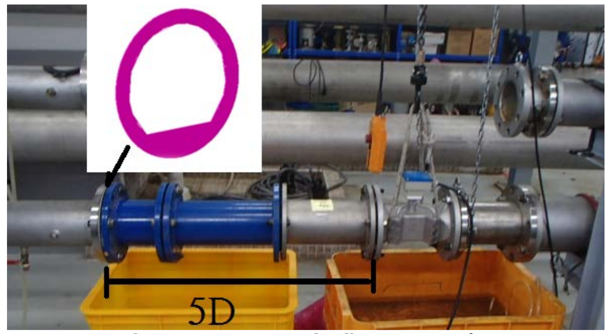

Fig. 3 Flow generator in single elbow pipe configuration (ISO 4064 example)

Table 6. Performance of 150mm ultrasonic flow meter (straight pipe configuration 1D)

Test flow	Reference flow rate (Y) (m^3/h)	Test flowmeter Flow rate (X) (m^3/h)	Measurement deviation (X/Y-1) %	Average deviation %
q_{min}	6.053	6.014	0.09	-0.64
q_t	16.367	16.300	0.26	
q_{max}	299.025	299.386	4.71	

Table 7. Performance of 150 mm ultrasonic flow meter (elbow pipe configuration 3D)

Test flow	Reference flow rate (Y) (m^3/h)	Test flowmeter Flow rate (X) (m^3/h)	Measurement deviation (X/Y-1) %	Average deviation %
q_{min}	6.153	6.124	0.10	-0.47
q_t	16.462	16.442	0.26	
q_{max}	298.550	298.321	4.69	

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Table 8. Performance of 150 mm ultrasonic flow meter (elbow pipe configuration 5D)

Test flow	Reference flow rate (Y) (m^3/h)	Test flowmeter Flow rate (X) (m^3/h)	Measurement deviation (X/Y-1) %	Average deviation %
q_{min}	6.172	6.180	0.10	0.13
q_t	16.453	16.452	0.26	
q_{max}	297.224	296.893	4.67	

Table 9. Performance of 150mm ultrasonic flow meter along the straight pipe configuration

Flow rate (m^3/h)		19.6	63.8	126.0	192.4	320.2
Round pipe average velocity (m/h)		0.25	0.83	1.64	2.50	4.16
: Square pipe average velocity (m/h)		0.61	2.00	3.96	6.04	10.05
Relative deviation according to the changes in straight configuration at double elbow pipe configuration (%)	50D	0.05	-0.05	-0.08	-0.06	0.04
		0.25	0.09	0.07	0.08	0.06
	0D	0.06	0.29	0.34	0.38	0.36
	1D	-0.79	-0.26	-0.26	-0.29	-0.19
	2D	0.14	0.31	0.09	0.17	0.16
	3D	-0.48	-0.67	-0.77	-0.68	-0.72
	4D	-0.28	-0.41	-0.65	-0.56	-0.40
	5D	-1.08	-0.93	-1.13	-1.05	-0.99

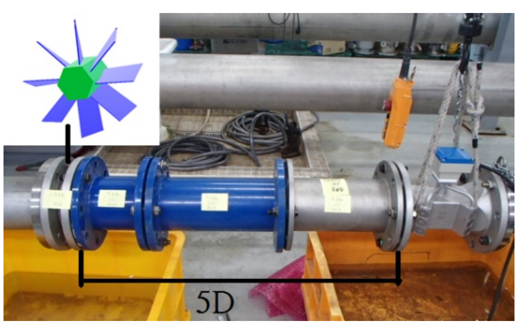

Fig. 4 Obstacle generator test at double elbow pipe configuration

The effect of obstacle was first identified by checking the velocity at the cross section of round pipe, then further identified of the valve effect upon the additional installation of square pipe.

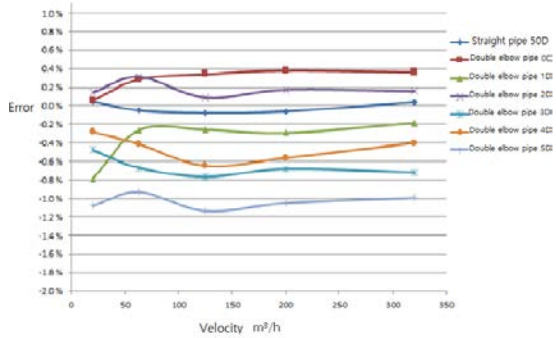

Fig. 5 Performance of ultrasonic flow meters (150 mm, double elbow pipe configuration)

At this time, a longer straight pipe configuration is regarded to be associated with a larger expanded revolution component. Performance comparison of ultrasonic flow meters in a 50mm square pipe and a round pipe (straight pipe configuration 50D) is done. As shown in Fig. 6, a comparison of errors by the velocity was made on a 50mm square pipe ultrasonic flow meter and a round pipe ultrasonic flow meter at the straight pipe configuration 50D. The round pipe showed performance of 6% error whereas the square pipe showed less than 0.2% under greater velocities.

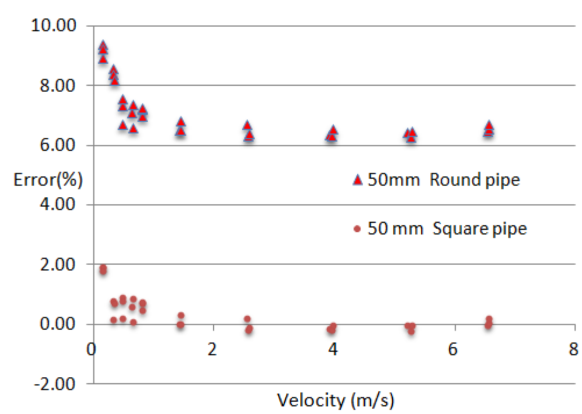

Fig. 6. Comparison of errors in a square pipe ultrasonic flow meter and a round pipe flow meter

4. Conclusions

Through the test of flow meter installation effect, a very stable ultrasonic transit measurement was achieved. Further, by designing the measuring tube as a contraction of the square pipe conduit, a very stable flow measurement was realized, of which details of contribution to the performance was confirmed through a test. The shape of the reduction pipe was naturally reduced from round to square, which brought about reduction of the valve effect caused by the changes in the ultrasonic flow meter cross section from round to square as well. This created a type of wing in the fluid flow that is assumed to perform two

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functions, which are rectification of the rotating components and the rectification of the asymmetric velocity distribution as the velocity increases. Also, a comparison test was made on the square pipe conduit and round pipe conduit, from which it was concluded that the square pipe conduit is superior in error performance in small diameter than the round counterpart.

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