IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 4 Issue 8, August 2017
ISSN (Online) 2348 – 7968 | Impact Factor (2016) – 5.264
www.ijiset.com

A Study on an Ultrasonic Flow Meter

Deok-Woo Park[1] , Shang-Yoon Hwang[2] , Chungyong Kim[3] and Gyu-Sik Kim[4*]

[1,3,4] Department of Electrical and Computer Eng., University of Seoul,
Seoul, 130-743, Korea
[2] Fluid Flow Research Center of CMENTECH CO. LTD., Gyonggi-do, 13438, Korea
* Corresponding author : Gyu-Sik Kim (gskim318@uos.ac.kr)

Abstract

An ultrasonic flow meter is a type of flow meter that measures the velocity of a fluid with ultrasound to calculate volume flow. In this paper, through the test of flow meter installation effect, a very stable ultrasonic transit time 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.

Keywords: *Ultrasonic flow meter, fluid flow, transit time, square pipe, contraction with stable flow profile*

1. Introduction

An ultrasonic flow meter is a type of flow meter that measures the velocity of a fluid with ultrasound to calculate volume flow. Using ultrasonic transducers, the flow meter can measure the average velocity along the path of an emitted beam of ultrasound, by averaging the difference in measured transit time between the pulses of ultrasound propagating into and against the direction of the flow or by measuring the frequency shift from the Doppler effect. Ultrasonic flow meters are affected by the acoustic properties of the fluid and can be impacted by temperature, density, viscosity and suspended particulates depending on the exact flow meter. They vary greatly in purchase price but are often inexpensive to use and maintain because they do not use moving parts, unlike mechanical flow meters.

There are three different types of ultrasonic flow meters. Transmission (or contra-propagating transit-time) flow meters can be distinguished into in-line (intrusive, wetted) and clamp-on (non-intrusive) varieties. Ultrasonic flow meters that use the Doppler shift are called Reflection or Doppler flow meters. The third type is the Open-Channel flow meter.

Time transit flow meter : Ultrasonic flow meters measure the difference of the transit time of ultrasonic pulses propagating in and against flow direction. This time difference is a measure for the average velocity of the fluid along the path of the ultrasonic beam. By using the absolute transit times both the averaged fluid velocity and the speed of sound can be calculated.

Doppler shift flow meters : Another method in ultrasonic flow metering is the use of the Doppler shift that results from the reflection of an ultrasonic beam off sonically reflective materials, such as solid particles or entrained air bubbles in a flowing fluid, or the turbulence of the fluid itself, if the liquid is clean. Doppler flow meters are used for slurries, liquids with bubbles, gases with sound-reflecting particles. This type of flow meter can also be used to measure the rate of blood flow, by passing an ultrasonic beam through the tissues, bouncing it off a reflective plate, then reversing the direction of the beam and repeating the measurement, the volume of blood flow can be estimated. The frequency of the transmitted beam is affected by the movement of blood in the vessel and by comparing the frequency of the upstream beam versus downstream the flow of blood through the vessel can be measured. The difference between the two frequencies is a measure of true volume flow. A wide-beam sensor can also be used to measure flow independent of the cross-sectional area of the blood vessel.

Open channel flow meters : In this case, the ultrasonic element is actually measuring the height of the water in the open channel; based on the geometry of the channel, the flow can be determined from the height. The ultrasonic sensor usually also has a temperature sensor with it because the speed of sound in air is affected by the temperature.

There have been a lot of researches toward performance improvement of fluid ultrasonic flow meters [1-8]. In [1], it is shown that the pulse-phase bi-directionality ultrasonic flow meter integrated in a microprocessor-based electronics package can achieve very good performance. In [2], the flow visualization studies have been undertaken for the case of an in-line, ultrasonic transducer housing in a cylindrical cross-section metering duct by direct observation of injected dye and of particles illuminated by a laser sheet. In [3], the field tests were conducted at an actual hydraulic power plant using an ultrasonic pulse Doppler flow meter, and it was found capable of measuring velocity profiles in a large steel penstock with a diameter of over one meter and Reynolds number of more

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 4 Issue 8, August 2017
ISSN (Online) 2348 – 7968 | Impact Factor (2016) – 5.264
www.ijiset.com

than five million. In [4], a new technique is proposed that enables the measurement of the velocity vector in multi-dimensions on a line of the flow field. A system to achieve this goal was developed based on the ultrasonic velocity profiling by using multiple transducers. In [5], a detailed theoretical signal model describing the interaction of sound waves in random continuum and turbulent media had been presented. In [6], it describes design and development of low cost automatic water flow meter which supplies only required amount of water to the crops saving water as well as energy. In [7], it contains review on some important developments of transit time ultrasonic flow meters particularly to improve the accuracy. In [8], some experimental measurements were performed to obtain the specific values of the flow rate measurement uncertainty using the ultrasonic Doppler velocity profile (UVP) method under disturbed flow conditions.

In this paper, 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.

2. Development of a Small Diameter Ultrasonic Flow Meter

For a transit time ultrasonic flow meter, both transducers serve alternately as transmitter and receiver of ultrasonic waves. This type of meter measures the difference in travel time for pulses transmitted against the flow and pulses transmitted in the direction of the flow rate as shown in Fig. 1.

The two transducers are mounted on the outside of the pipe so that one is a known distance upstream of the other. A pulse will be transmitted by the downstream transducer, for example, and it will be detected by the upstream transducer, giving the 'transit time' for upstream flow. Then the process will be reversed and the upstream transducer will transmit a pulse to be detected by the downstream transducer, to give a 'transit time' in the direction of flow. A microprocessor is typically used to calculate the pipe flow rate based on the difference between the downstream transit time and the upstream transit time.

The flow computer was designed with low power based circuits and parts as it is required to drive in super low power and was implemented with the use of SMD (Surface Mound Device). ARM Cortex-M3 based STM32F103 was used as the main processor responsible for interface, of which block diagram is shown in Fig. 2.

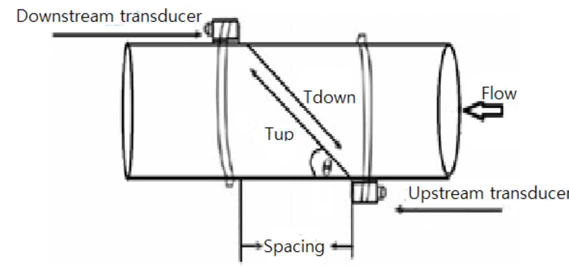

Fig. 1. Installation of a transit time ultrasonic flow meter

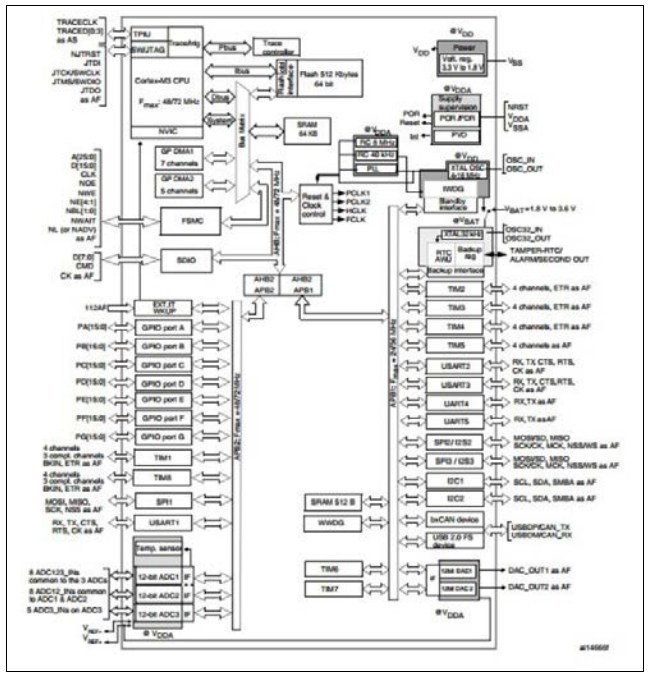

Fig. 2. Block diagram of STM32F103

Fig. 3 is the circuit diagram of the analogue turbine. 3 digital switches were used to enable choice of program from 1 circuit up to 3 circuits depending on the diameter, through which the switching within 0.2 ms was made possible. Also, by securing a model that is capable of continuous control of maximum current of 250 mA, even high power output can be responded to. The ultrasonic signal is a time domain signal. TDC(time-to-digital converter) processor called GP2 by ACAM was used in converting this signal into digital value for utilization in the microprocessor. Fig. 4 is the block diagram of TDC processor. Particularly being optimized for the measurement of ultrasonic time difference, GP2 processor is a high precision time measurement device that is equipped with a time resolution of 65 ps.

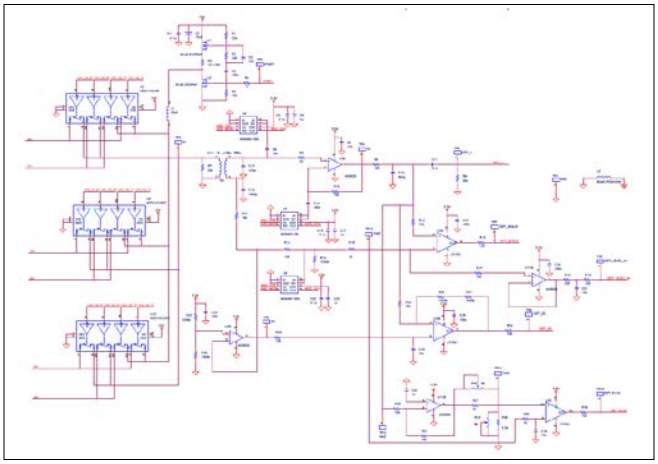

Fig. 3. Analogue driving part circuit

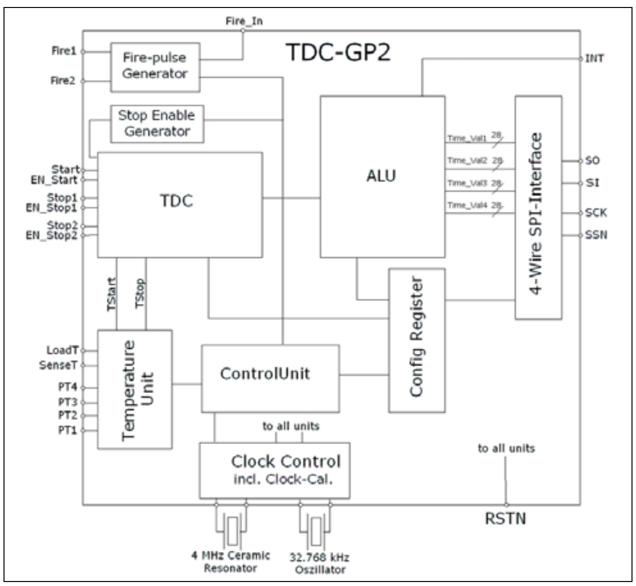

Fig. 4 TDC-GP2 block diagram

The circuit using TDC was structured as Fig. 5. The signal, pre-processed through analogue circuit, is entered into TDC processor which is then directly connected to the STM32F103 main processor for control. Through this, velocity measuring capacity at the velocity greater than 0.01 ms was tested. Fig. 5 shows the structure of circuits that operate TDC. Overall, SMD parts were used in the board production. For easy maintenance of the product, total of 3 modules were produced including process board, analogue board, and interface board, with each being connected through exclusive connectors. The actual performance was tested using the completed board and measuring tube. The flow scope was based on 25D, 50D and grade 2 deviation, and the starting flow was also examined.

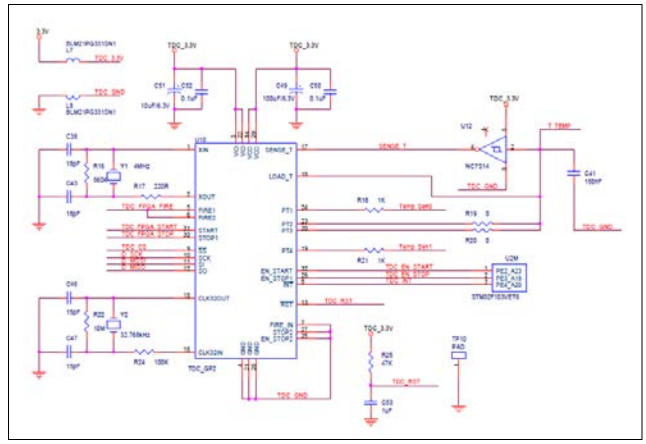

Fig. 5 TDC driving circuit diagram

3. Experimental Results

In order to evaluate the characteristics of flow part in an ultrasonic flow meter, the facilities of an internationally approved correctional institute was utilized. The scope of flow measurement was (0.06～2000) m^3/h and CMC uncertainty of the system was 0.37 % (k=2.0). Water was used as the test fluid of which temperature was kept (18～25) ℃ during use. Fig. 6 is the schematic design of the related devices.

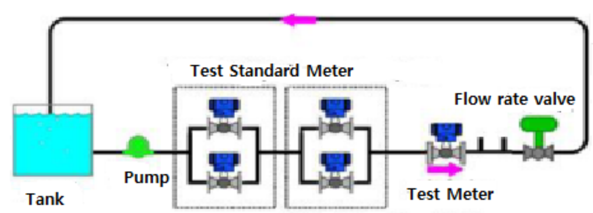

Fig. 6 Schematic diagram of liquid flow meter appliance

As one of the methods of verifying the accuracy of performance measurement of an ultrasonic flow meter, a test was conducted on velocity as it is proportional to transit time difference. Accurate and stable measurement of time is the most crucial factor of the ultrasonic time measurement method. It is inevitable that various changes are accompanied depending on factors such as signal shape, circuit noise and fluid condition in test sites. Since achieving measurement stability at the velocity suggested within ±5 % usually requires a level below 0.1～ 0.2 ns, the effect of transit time difference measurement was achieved through the circuit that was produced according to following experimental studies. 24 hour evaluation of the zero stability when the sensor was installed at 30°

angle and the velocity of sound was 1435.86 m/s was acquired, of which result is shown in Fig. 7. The result was approximately within ±0.05 ns.

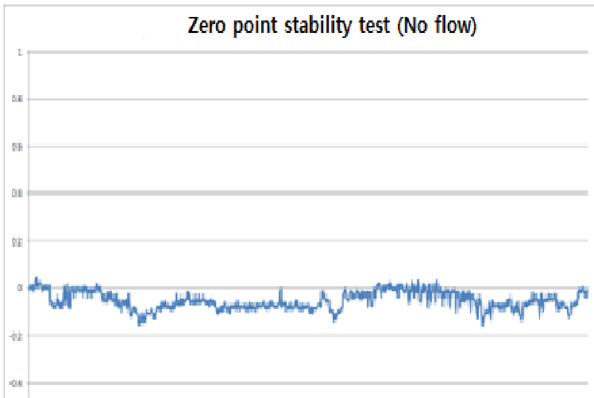

Fig. 7 Time measurement result test, Y=Δ t (ns)

The increase in the velocity value caused by the change in ultrasonic flow meter cross section was compared 1:1 with the round flow meter by letting the fluid through. It is a case of square pipe inscribed in the diameter of which flow increase effect is shown as the change from Table 1 to 2. This is greatly affected by the inevitable limitation that was intended for easy contraction from a round pipe to a square one in the initial stage of development.

Table 1 shows the velocity value calculated based on the scope of flow from Korea Heating specification. V(start), the velocity at start flow, has a value of 0.06 m/s at approximately 0.02 m/s whereas v(s), the velocity at the overload flow, increases up to approximately 5.7 m/s.

Table 1. Reference velocity calculation in 25 times magnification (Unit: m/s)

diameter	velocity (m/s)			
	start	v(i)	v(p)	v(s)
50	0.04	0.08	2.12	4.24
65	0.03	0.08	2.09	4.19
80	0.02	0.10	2.49	4.97
100	0.02	0.10	2.48	4.95
125	0.02	0.09	2.26	4.53
150	0.03	0.09	2.36	4.72
200	0.02	0.09	2.21	4.42
250	0.06	0.11	2.83	5.66

As a result of producing a contraction of the round pipe, cross section contraction and velocity increase occurred.

Table 2. Velocity increase rate according to change in cross section area by diameter

diameter	square pipe size (horizontal and vertical)	cross section contraction rate	velocity increase rate
40A	35×35 ㎜	2.52 %	2.58 %
50A		37.6 %	60.29 %
65A		63.1 %	170.80 %
80A	64×64 ㎜	18.5 %	22.72 %
100A		47.9 %	91.75 %
125A	94×94 ㎜	28.0 %	38.88 %
150A		50.0 %	99.99 %

The ultrasonic flow meter cross section gradually contracts from round pipe to square pipe. At this time, the contraction rate and contraction angle may slightly vary. However, the ultrasonic circuit is equally distributed and placed on the square contraction surface with 150 mm diameter which is large enough to safely estimate the flow distribution in order to describe velocity value by height. At this time, the circuit placement converts the flow with reflected signals so that the cosine effect components are naturally compensated.

Table 3. Velocity distribution of 150 mm ultrasonic flow meter (Double elbow pipe configuration after edge 0D)

flow rate (m^3/h)	velocity distribution by in-pipe location (m/s)			deviation %
	V1	V2	V3	
6	0.19	0.20	0.19	±3.6
16	0.52	0.53	0.52	±1.3
300	9.38	9.42	9.31	±0.5

(a) Velocity distribution of 50D after edge

(b) Velocity distribution of 5D after edge

Figure 8. Velocity distribution of double elbow pipe configuration after edge (5D)

It was observed that, regardless of the change in flow rate, the velocity distribution status at double elbow pipe configuration after edge 0D was stable at relative deviation of ±3.6 %.

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 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.

Acknowledgments

This work was also supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2016011249).

References

[1] Bozidar Dimitrijevic, Velizar Pavlovic, "Ultrasonic fluid flow measurement methods, an overview," *Electronics and Energetics*, Vol.8, No.2, pp.299-315, 1995

[2] Neil C. Temperley, Masud Behnia, Anthony F. Collings, "Flow patterns in an ultrasonic liquid flow meter," *Flow Measurement and Instrumentation*, Vol.11, pp.11-18, 2000

[3] Kenichi Tezuka, Michitsugu Mori, Takeshi Suzuki, Toshimasa Kanamine, "Ultrasonic pulse-Doppler flow meter application for hydraulic power plants," *Flow Measurement and Instrumentation*, Vol.19, pp.155-162, 2008

[4] Hironari Obayashi, Yuji Tasaka, Seiji Kon, Yasushi Takeda, "Velocity vector profile measurement using multiple ultrasonic transducers," *Flow Measurement and Instrumentation*, Vol.19, pp.189-195, 2008

[5] R Velmurugan, P Rajalakshmy, "Ultrasonic flowmeter using cross-correlation technique," *International Journal of Computer Applications*, Vol.66, No.10, pp.19-22, March 2013

[6] Ria Sood, Manjit Kaur, Hemant Lenka, "Design and development of automatic water flow meter," *International Journal of Computer Science, Engineering and Applications*, Vol.3, No.3, June 2013

[7] G. Rajita, Dr.Nirupama Mandal, "Review on transit time ultrasonic flowmeter," *2nd International Conference on Control, Instrumentation, Energy & Communication*, 2016

[8] Sanehiro Wada, Noriyuki Furuichi, "Influence of obstacle plates on flow rate measurement uncertainty based on ultrasonic Doppler velocity profile method," *Flow Measurement and Instrumentation*, Vol.48, pp.81-89, 2016

Deok-Woo Park was born in Korea, in 1973. He received the B.S. degree in 1999 from the Dept. of Electrical Eng., University of Hanyang, Korea. He received the M.S. degree in 2006 from the Dept. of Electrical and Computer Eng., University of Seoul, Korea. He is a Ph.D. student of the Dept. of Electrical and Computer Eng., University of Seoul, Korea. He works for Korea Testing Certification Institute.

Shang-Yoon Hwang was born in Korea, in 1967. He received the B.S. degree in 1989 from the Dept. of Physics, University of Konkuk. He received the M.S. degree in 1991 from the Dept. of Physics, University of Konkuk. He works for CMENTECH Co. Ltd.

Chungyong Kim was born in Korea, in 1991. He is an undergraduate junior in the Dept. of Electrical and Computer Eng., University of Seoul, Korea.

Gyu-Sik Kim was born in Korea, in 1958. He received the B.S. degree in 1981 from the Dept. of Electronics Eng., Seoul National University, Korea. He received the M.S. degree in 1983 and the Ph.D. degree in 1990 from the Dept. of Control and Instrumentation Eng., Seoul National University, Korea. He is working as Professor in the Dept. of Electrical and Computer Eng., University of Seoul, Korea.