The Portable Ultrasonic Flowmeter "PORTAFLOW-X"

Toshihiro Yamamoto

1. Introduction

An ultrasonic wave can be transmitted in all substances, i.e. a solid, liquid or gas. An ultrasonic flowmeter utilizes this property of the ultrasonic wave. It can be installed on the outside of a pipe without making any opening in the pipe wall, measuring flow rate within the pipe. This means that the ultrasonic flowmeter has unique capabilities for a portable flowmeter.

Fuji Electric developed in 1982 the portable flowmeter PORTAFLOW, the first to be marketed in the world. Since then, PORTAFLOW has earned domestic as well as worldwide acclaim . In the process, we have accumulated a wide range of experience in many fields.

On this occasion, we have developed and put on the market our newest flowmeter PORTAFLOW-X.

The converter for the PORTAFLOW-X uses the latest digital signal processing. This processing has achieved handy compact size and easy operation, and the sensor also has become lightweight and highly reliable. The sensors are classified according to a series, i.e. small sensors, large sensors, small pipe diameter sensors and high temperature sensors. This sensor series and new measurement system are very useful in obtaining a wider range of measurement specifications and high accuracy.

The new PORTAFLOW-X is introduced below.

2. Features of the PORTAFLOW-X

(1) Compact size and light weight

By using the latest electronics and digital signal processing, the size of the converter has been reduced to 1/7 and mass has been reduced to 1/5 as compared with our old product.

(2) Increasing of the allowable bubble content in the fluid.

By using digital signal processing, a large increase in the allowable bubble content in the fluid is possible.

(3) Excellent operability and easy handling

Setting of the PORTAFLOW-X can be easily accomplished with a page selecting system that has very few keys. An integral graphic printer is optional.

(4) High accuracy

Accuracy is very high, within ± 1.0 %.

The new sound velocity measurement system is not affected by temperature or pressure, and it can be adapted for a fluid with an unknown sound velocity.

(5) Quick response

By using a 32 bit microprocesser suitable for digital signal processing, response time is less than one second.

(6) Wide variety of sensors

Small to large diameters (ϕ13 to ϕ6,000) and low to high temperatures (–40℃ to +200℃) can be accommodated.

(7) Battery drive

The PORTAFLOW-X can be operated with the battery continuously for five hours and can be recharged in two hours by the power supply adapter.

3. Measuring Principle of the PORTAFLOW-X

3.1 New sound velocity measurement system

The principle of the measurement method used in the PORTAFLOW-X is a transit time difference technique. That is, piezo-oscillators are installed on the upstream and downstream of a pipe. The ultrasonic wave is transmitted diagonal to the direction of the flow of the measured fluid, and is then carried by it. As a result, a time difference will be evident in the transit time. The sensor detects this time difference.

If T_1 is the transit time from upstream to downstream and T_2 is from downstream to upstream, the volume flow rate Q of the fluid which flows in the pipe is proportional to the time difference ΔT ($=T_2–T_1$) in the transit times. Also, flow rate Q is calculated by the following equation.

$$Q = \frac{\pi D^2}{4} \cdot \frac{1}{K} \cdot \frac{D}{\sin 2\theta_f} \cdot \frac{\Delta T}{(T_0 - \tau)^2} \quad \cdots\cdots\cdots (1)$$

here D : inner diameter of the pipe

K : flow profile compensating factor

θ_f : angle of incidence to measured fluid flow

T_0 : transit time in still fluid

τ : transit time in the pipe wall and sensor

The measuring principle is shown at Fig. 1.

Fig. 1 Measuring principle of the ultrasonic flowmeter

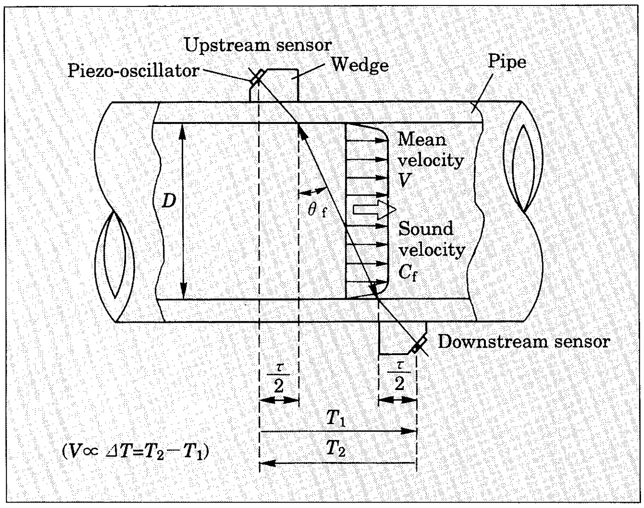
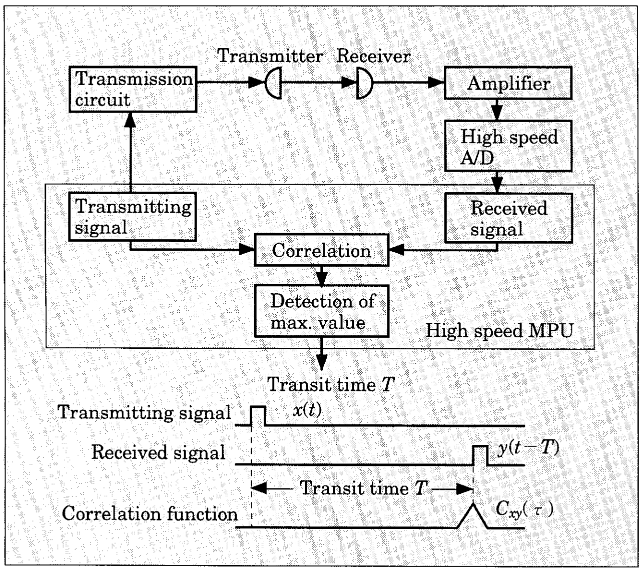


Fig. 2 Transit time measuring system



Now, if C_f is assumed to be the sound velocity of the measured fluid, the above mentioned equation is reformed as follows:

$$Q = \frac{\pi D^2}{4} \cdot \frac{1}{K} \cdot \frac{C_f}{2\sin\theta_f} \cdot \frac{\Delta T}{T_0 - \tau} \qquad \cdots\cdots\cdots(2)$$

The sound velocity C_f changes when the temperature or the pressure of the fluid changes. As a result, τ and θ_f change respectively. But in actually, we can get τ, θ_f and C_f from the transit times T_1 and T_2 analytically. K is the ratio of the mean velocities of the inside of pipe cross section and the propagation path. This ratio K is a function of the Reynolds number which shows the phenomena of the flow.

The PORTAFLOW-X performs these calculations with a 32 bit microprocessor in real time and can even be used for a fluid with an unknown sound velocity. Therefore, measurement of the flow rate by the PORTAFLOW-X is influenced by neither the temperature nor the pressure of the fluid.

Table 1 Main specifications

Measured fluid	Uniform liquid turbidity 1,000 mg/l or less, liquid with unknown sound velocity measurable		
Flow condition	Axis-symmetric flow in liquid filled pipe		
Fluid temperature	−40 to +200 ℃ (see Fig.5)		
Flow velocity range	0 to ±0.3 …… ±32 m/s		
Piping materials	Steel, stainless steel, cast iron, PVC, FRP, asbestos, copper, aluminum, etc.		
Pipe diameter	13 to 6,000 mm (see Fig.5)		
Lining materials	No liner, tar epoxy, mortar, rubber, etc.		
Sensor mounting	V, Z or W method		
Straight pipe length	Upstream: 10*D*, downstream: 5*D* (*D*: inner diameter of pipe)		
Accuracy	Pipe diameter	Flow velocity	Accuracy
	13 to 50mm or less	2 to 32m/s	1.5% of rate
		0 to 2 m/s	0.03 m/s
	50 to 300mm or less	2 to 32 m/s	1.0% of rate
		0 to 2 m/s	0.02 m/s
	300 to 6,000mm	1 to 32 m/s	1.0% of rate
		0 to 1 m/s	0.01 m/s
Built-in battery	Special NiCd battery, continuous operation time: 5 hours recharging time: 2 hours		
Power supply adapter	90 to 264 V AC (47 to 63 Hz), or 10 to 30 V DC		
Display	5 inch graphic LCD with LED back light		
Operation panel	10 keys (ON, OFF, Light, Print, ESC, etc.)		
Response time	1 second or less		
Input/output signal	4 to 20 mA DC, output: 1 point (max.load 1kΩ) input : 1 point		
Serial communication	RS-232C, transmission speed: max. 9,600 BPS		
Printer	Thermal serial dot printing (optional)		
Ambient temperature	Converter: −10 to +55 ℃ Detector: −20 to +60℃		
Mass	Converter: 1.5 kg Small sensor: 0.8 kg		
Dimensions	Converter: H240×W127×D70 (mm) Small sensor: H540×W53×D90 (mm)		
Functions	Language: Japanese / English, unit: metric/inch, time indication, damping, low cut, output setting, data logger, waveform display, trend graph display, printout, etc.		

We at Fuji Electric call this new method of calculation which measures flow rate the "new sound velocity measurement system".

3.2 Measurement of transit time

The PORTAFLOW-X adopt digital signal processing technology to measure the transit times T_1 and T_2 and the transit time difference ΔT. The conceptual diagram is shown in Fig. 2.

After reception and amplification of the signals, the processor carries out high speed A/D conversion. Then, the processor calculates the convolution of the transmitted and received signals, as well as the transit time T from the maximum value of the correlation function.

Fig. 3 External view of the PORTAFLOW-X

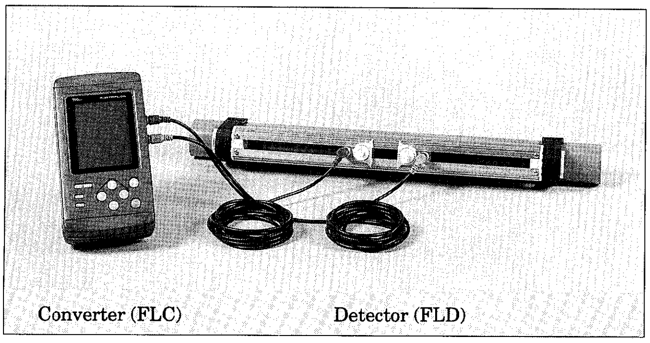
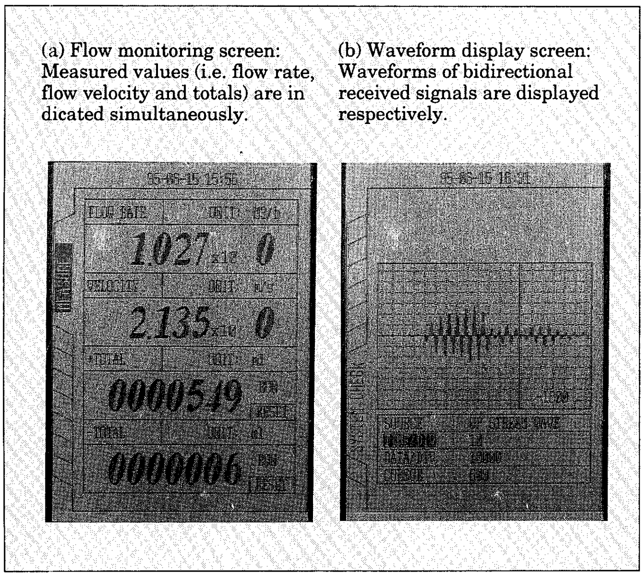


Fig. 4 Examples of display screens



Let the transmitting signal be $x(t)$, and the received signal be $y\,(t-T)$, then the correlation function is

$$c_{xy}(\tau)=\int_{-\infty}^{+\infty} x\,(t)\;y\,(t+\tau-T)\;dt \qquad \cdots\cdots\cdots(3)$$

The following equation is satisfied

$$\max\,[c_{xy}\;(\tau)]=c_{xy}\;(T)$$
$$=\int_{-\infty}^{+\infty} x\,(t)\;y\,(t)\;dt \qquad \cdots\cdots\cdots(4)$$

To increase the S/N ratio, a synchronized summation of the received signals is carried out. This new method differs from the old method in that the analogical trigger on an individually received signal resists disturbances such as electrical noise, bubbles and debris in the fluid.

We call this method "Advanced ABM (Anti-Bubble Measurement)".

4. Main Specifications and an External View of the PORTAFLOW-X

The main specifications of the PORTAFLOW-X are shown in Table 1, and an external view of the converter without a printer and a small sensor are shown in Fig. 3.

Fig. 5 Types of sensors

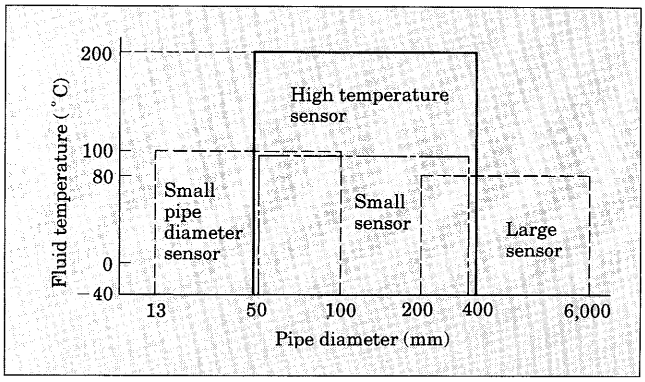


Fig. 6 Measurement error

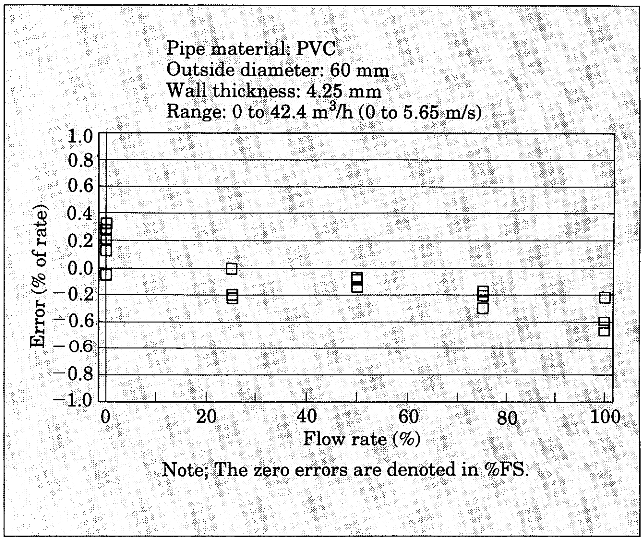
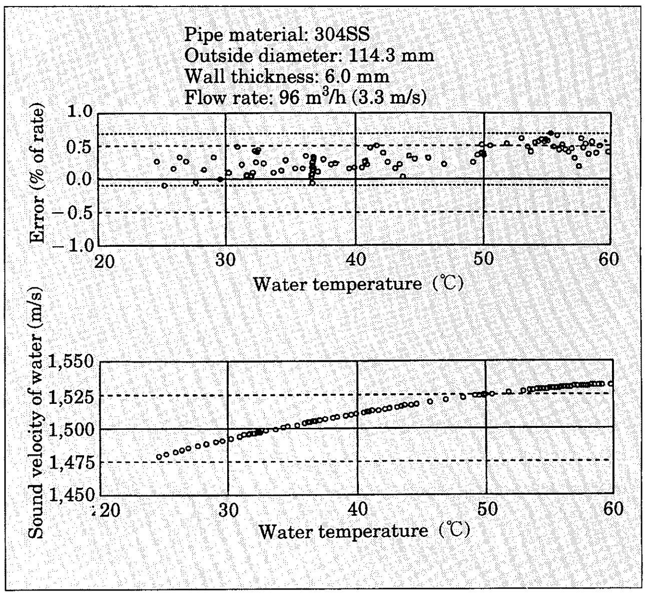
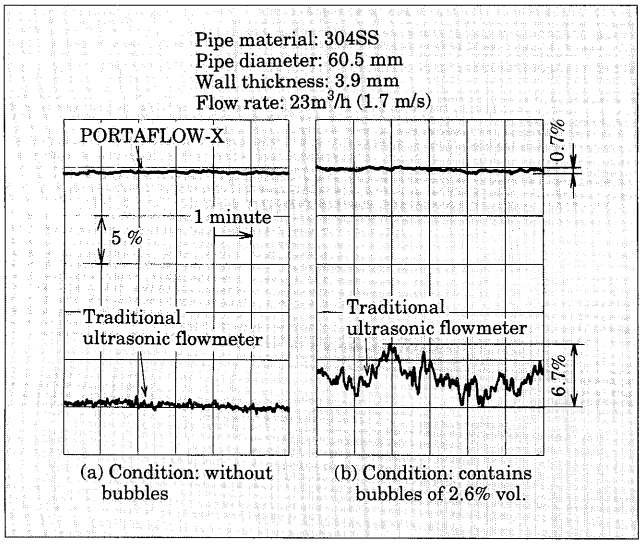


Fig. 7 Effects of fluid temperature



The PORTAFLOW-X can measure flow rate at a highly accurate 1% of flow rate, and its response time is less than one second.

Fig. 8 Effects of bubbles contained in fluid



The converter's size has been reduced to 1/7 of the previous model, and its mass has been reduced to 1/5.

The PORTAFLOW-X can be operated continuously for five hours with the battery or with the power supply adapter. The battery can be recharged in two hours by the power supply adapter.

Setting of the PORTAFLOW-X can be easily performed by a page selecting system that has a large graphic LCD and only a few keys. Either Japanese or English can be used on the display.

This display is provided with a back light for easy recognition even in the dark. It can also be turned off.

The following functions are provided: display of the waveform, which is required to confirm sensor installation, data logging of up to 40,000 data points and a maximum of 20 places; and display of a trend graph. The logging data, etc. can be read from a serial port. Some of the display screens are shown in Fig. 4.

The detectors are classified in a series, i.e. standard small sensors, large sensors for large diameter pipe, small diameter senors and high temperature sensors. Application in small pipe diameters of 13mm and up to 200℃ of fluid temperature (see Fig. 5) is now possible.

The sensor has become lightweight due to the use of plastic for the sensor housing and flame end. For the wedge material, reliable engineering plastic which resists high temperatures and heat cycles is used.

5. PORTAFLOW-X Performance

Figure 6 shows a diagram of measurement error obtained with use of the small sensor. This example is well within the rated accuracy of ± 1%.

The influence of changes in water temperature of 25℃ to 60℃ on the accuracy, and the sound velocity of water measured at each calibration point in real time are shown in Fig. 7. This example shows the effects of the new sound velocity measurement system.

Measurements of its effect on bubbles contained in the fluid are shown in Fig. 8. This shows that the effect of the advanced ABM and the effect of the bubbles are greatly reduced as compared with that measured by the old flowmeter.

6. Conclusion

This year marks the 20th anniversary of the commercialization of the stationary type of ultrasonic flowmeter by Fuji Electric. We at Fuji Electric have always played the role of pioneer and leader in the field of ultrasonic flow measurement.

With the development of the POLTAFLOW-X, introduced in this paper, the opportunity arose to the new sound velocity measurement system and the digital signal processing adopted in place of past analog processing, which consisted mainly of the TLL (Time Locked Loop).

The new flowmeter is very accurate and easily operated due to these new technologies.

In addition, the sensor menu has been expanded. The rapid advancement of today's microelectronics, low prices and new materials are largely responsible for the development of the new flowmeter. We hope to obtain many more examples of actual applications and to develop even more accurate ultrasonic flow measurement in the future.