International Gas Union Research Conference 2014

Development of a new ultrasonic smart gas meter for domestic customers

Takashi Oowaku, Mitsunori Komaki
Tokyo Gas Co., Ltd.

Akiharu Asada, Yasuhiro Fujii, Yudai Masuda
Osaka Gas Co. Ltd.

Kazuhiro Nishiguchi, Takao Ichikawa
Toho Gas Co. Ltd.

JAPAN

ABSTRACT

Smart meters and advanced metering infrastructure have attracted much attention and provide practical benefits such as the ability to visualize energy consumption and reduction of carbon dioxide emissions. The smart gas metering system has been developed, and is composed of three main components: a WAN device (Pu-NCU); ad-hoc mesh networks (U-Bus Air); and ultrasonic smart gas meters with the new communication port (U-Bus). This paper describes the smart ultrasonic gas meter, which employs the "Repetitive Inverse Transit Time Difference Method."

The smart ultrasonic gas meter has four main characteristics: a wide measurement range; a simple design; low energy consumption; and a safety function. Specifically:

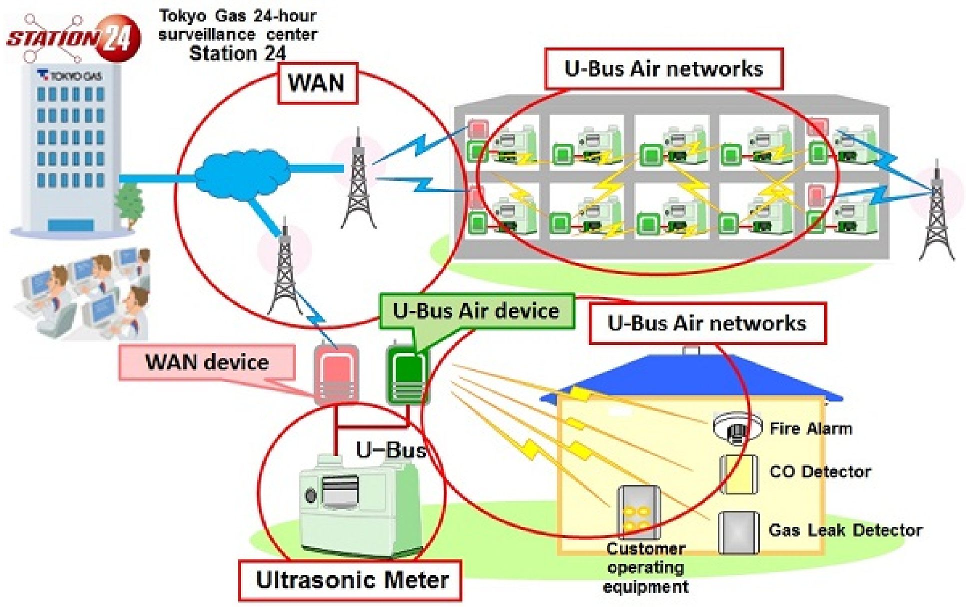
(1) It can measure flow rates from 3 to 12,000 L/h, which covers a very wide range with a single ultrasonic sensor.

(2) The number of the parts is significantly less than the conventional diaphragm-type gas meter; therefore, it is compact, has reduced weight, and is highly reliable. This enables a simple design with reduced transportation and storage cost.

(3) It is equipped with the new communication port (U-Bus), which enables 30 times the data transmission speed of the conventional communication interface (300 bps A-line) and reduced energy consumption that extends battery life to 10 years. Also, because packet communication is employed, it allows diverse configuration of WANs and PANs with wireless WAN devices, ad-hoc mesh network devices, and so on. This potentially enables new services such as the control of appliances.

(4) It has a microcomputer, a seismic sensor, a pressure sensor, and a valve driven by a stepping motor. This especially improves monitoring of flow, and it enables several safety functions that include the shutdown of gas supply upon the detection of earthquakes, low or high pressure, or abnormal gas flow possibly caused by dangerous gas leaks.

The ultrasonic smart gas meter has been used by more than 300,000 customers since 2005. In the next version, the number of the electronic parts (by which high durability and reliability are achieved) will be reduced by the electronic components module, which will lead to cost reduction. Furthermore, the newly equipped acceleration sensor will improve flexibility of installation compared to the conventional diaphragm type.



Composition of Smart Gas Metering System

1. INTRODUCTION

In order to reduce the risk of gas-related accidents, Japan's gas utilities started deploying microcomputer-controlled gas meters called "Micom Meters" for residential customers in 1983. In addition to a measurement function, the Micom Meter has various safety functions such as a shutoff function, which is activated in the event of a major earthquake or abnormal gas flow. In view of these capabilities, the installation of safety functions for residential customers was made compulsory by law in 1997, and now almost 100% of residential gas meters are Micom Meters. More recently, Japanese gas utilities have started to offer value-added services and automatic meter reading (AMR) using Micom Meters with a communication function. These Micom Meters have a 10-year lifespan, as Japanese regulations require that the measurement accuracy of residential gas meters be certified every decade.

It is difficult to make the conventional diaphragm-type gas meter compact, since it has adopted a mechanical metric form that needs capacity in the gas meter itself. For this reason, we demand that the electronic gas meter be compact, in overall design and physical size for installation. Moreover, we expect to effectively reduce cost with future mass production by using the electronic gas meter. We also want a gas meter that can measure a variety of information and work well with the communications network; this is because we believe that services such as automatic meter reading implemented by city gas utilities will spread with the rapid development of communications technology.

For these reasons, we have been developing an intelligent residential ultrasonic smart gas meter with multiple functions. The ultrasonic smart gas meter is characterized by a simple structure with no mechanical moving parts, and compared with the conventional diaphragm-type microcomputer-controlled gas meter currently dominant in Japan, it is expected to offer the advantages of being more compact and light.

City gas utilities in Japan have used ultrasonic gas meters since 2005, and installed about 350,000 ultrasonic gas meters as of the end of March 2014. The ultrasonic gas meter has also been used by LPG utilities in Japan since 2009, and the total number of installation reached about 330,000 as of the end of March 2014.

2. FEATURES OF THE NEW ULTRASONIC SMART GAS METER

Since the ultrasonic smart gas meter has a simple structure with no moving mechanical parts, it is small, lightweight, and able to be installed freely in many locations. The meter's volume is about one-third that of the conventional diaphragm-type meter, with a weight about half that of the conventional diaphragm-type meter. Figure 1 shows the ultrasonic gas meter and the diaphragm-type gas meter found widely in Japan. The ultrasonic gas meter has achieved durability and reliability with its electronic components, and is expected to reduce cost with mass production of its electronic components module.

Figure 1: Ultrasonic gas meter (left) and diaphragm-type meter (right)

Major components, including the ultrasonic sensors, pressure sensor, shutoff valve, and metering circuit, are shared between city gas and LP gas to reduce the cost through scale merits. The ultrasonic sensors, which are optimized for gas metering, are highly sensitive and designed to run on a low voltage level. The long battery life of 10 years is achieved by combining these sensors with a low-power controller (microcomputer and metering circuit). The sensors can measure flow rates from 3 to 12,000 L/h, which covers a very wide range with a single ultrasonic sensor. Figure 2 illustrates the configuration of the ultrasonic gas meter.

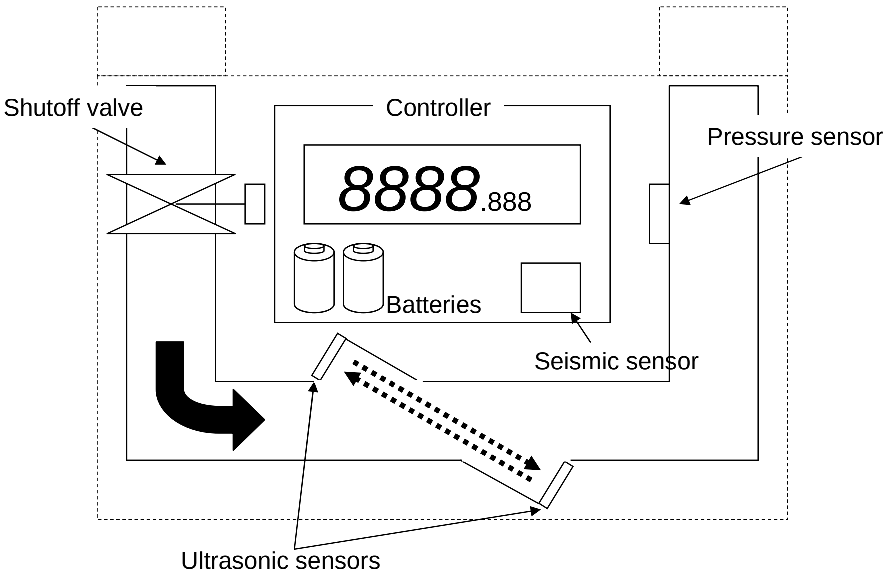


Figure 2: Structure of an ultrasonic gas meter

3. MEASUREMENT PRINCIPLE

To design the ultrasonic gas meter, we employed the established ultrasonic meter principle, "Repetitive Inverse Transit Time Difference Method." Two ultrasonic sensors face each other across the gas flow passage as shown in Figure 3.

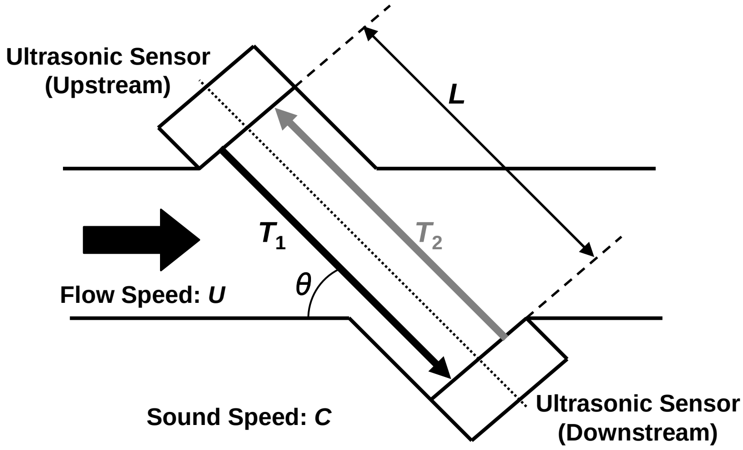


Figure 3: Measurement principle

Ultrasonic waves are initially sent from the upstream sensor to the downstream sensor, and the time taken to arrive (T_1) is measured. Ultrasonic waves are sent in the opposite direction, from downstream to upstream, and the time taken to arrive (T_2) is measured. If there is no flow, there should be no time difference. With a flow speed of *U,* however, these two times will differ: T_1 will be smaller and T_2 will be larger than when there is no flow.

The speed of the gas flow (*U*) can be calculated from the difference between the two times taken for the ultrasonic waves to arrive, using the three principal equations:

$$T_1 = \frac{L}{C + U\cos\theta} \qquad (1)$$

$$T_2 = \frac{L}{C - U\cos\theta} \qquad (2)$$

$$\therefore U = \frac{L}{2\cos\theta}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \qquad (3)$$

Since the flow speed *U* determined in the equation (3) is an average flow speed on the transmission path of the ultrasonic wave, simply multiplying the cross section *S* by the flow speed *U* will not allow us to obtain the flow rate *Q*, our ultimate objective. For this reason, it is necessary to convert the flow speed *U* into the average flow speed of the passage cross-section. Given this flow coefficient *k*, the flow rate *Q* can ultimately be expressed in equation (4).

$$Q = U \times k \times S \qquad (4)$$

The flow coefficient *k* of the ultrasonic gas meters becomes less dependent on flow speed by devising the right passage, and it is very flat. In addition, the difference between the flow coefficient of air and city gas is extremely small. For this reason, calibration of the ultrasonic gas meter may be performed using the air at only one or two flow rate points, and the verification tolerance in city gas can be satisfied using the determined flow coefficient. We may therefore expect only a very few calibration processes to be necessary in mass production of the ultrasonic gas meters. エラー**!** 参照元が見つかりません。 shows an example of the flow coefficient.

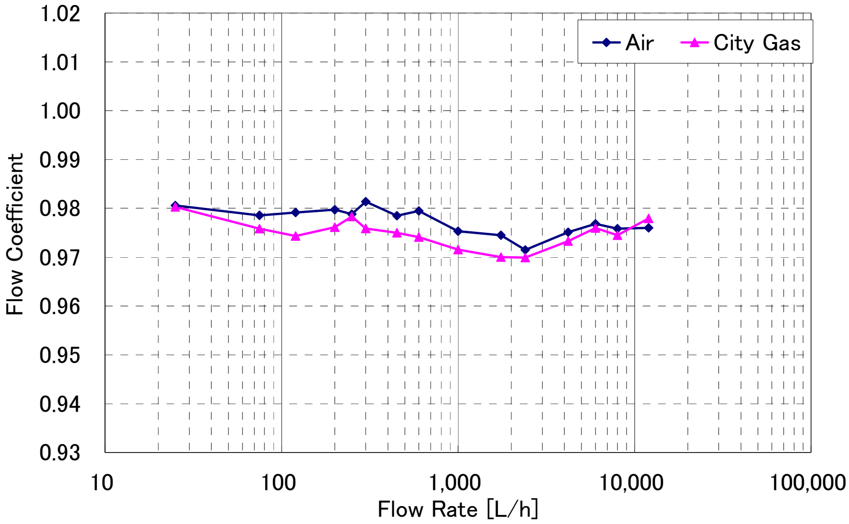


Figure 4: Example of flow coefficient of the ultrasonic gas meter

The instrumental error of the ultrasonic gas meter is shown in Figure 5. Even though the meters have only one flow coefficient calibrated by air at one flow rate point, the difference in characteristics between air and city gas is very small. This means that the composition of the gas has only a minor influence on the measurement functions of the meter.

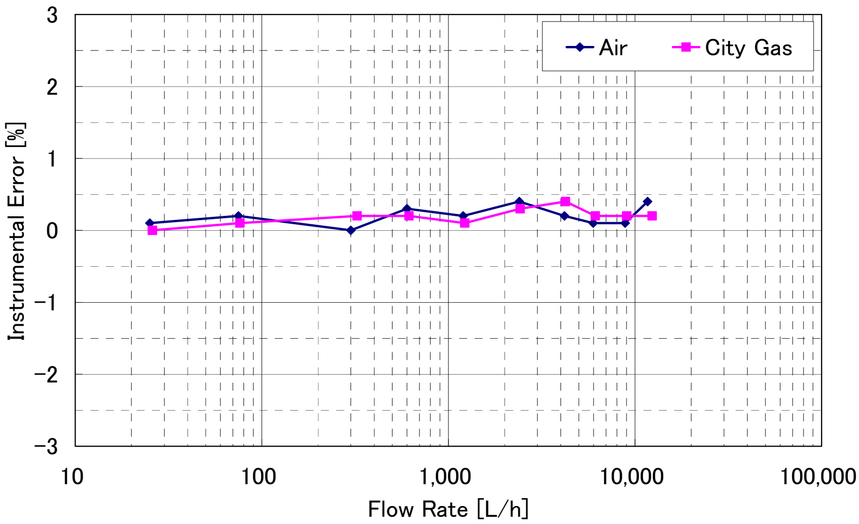


Figure 5: Example of instrumental error of the ultrasonic gas meter

4. SPECIFICATIONS

The specifications of the ultrasonic gas meter are shown in Table 1. Along with several safety functions already installed in the conventional diaphragm meters, our ultrasonic smart gas meter has been designed with self-diagnostic functions that are a unique characteristic of smart gas meters. One example of these functions is the detection of an ultrasonic sensor failure and the detection of the decrease in battery voltage in order to replace the meter while it is still safe.

Table 1: Specifications

<table>
<tr><td>Maximum flow rate</td><td colspan="2">6 m^3/h</td></tr>
<tr><td>Minimum flow rate</td><td colspan="2">80 L/h</td></tr>
<tr><td>Detectable minimum leak</td><td colspan="2">3 L/h</td></tr>
<tr><td>Operating temperature</td><td colspan="2">-25º to 60ºC</td></tr>
<tr><td>Operating pressure</td><td colspan="2">0 to 3.5 kPa</td></tr>
<tr><td>Size</td><td colspan="2">170 mm (width) x 100 mm (depth) x 140 mm (height)</td></tr>
<tr><td>Weight</td><td colspan="2">Approx. 2 kg</td></tr>
<tr><td>Pressure loss (air)</td><td colspan="2">< 190 Pa at 6m^3/h</td></tr>
<tr><td>Power supply</td><td colspan="2">Lithium batteries</td></tr>
<tr><td>Battery life</td><td colspan="2">10 years or more</td></tr>
<tr><td>Stepping motor valve</td><td colspan="2">Open/close 2-way valve</td></tr>
<tr><td rowspan="3">Communication port</td><td>U-Bus (9,600 bps)</td><td>U-Bus Air device, WAN device, etc. are connected</td></tr>
<tr><td>300 bps port</td><td>Devices for current AMR system are connected</td></tr>
<tr><td>Contact input port</td><td>Alert system is connected</td></tr>
<tr><td>Liquid crystal display</td><td colspan="2">

• Cumulative flow: 4 digits for m^3, 3 digits for liter
• Valve status: Open/Close
• Alert Indication: 5 x 5 dot matrix</td></tr>
<tr><td>Calendar & clock</td><td colspan="2">YYMMDD hh:mm:ss</td></tr>
<tr><td>Self-diagnostics functions</td><td colspan="2">• Low battery
• Ultrasonic sensor error
• Valve leakage</td></tr>
<tr><td>Safety functions</td><td colspan="2">• Seismic shutoff and self-reopen after automatic safety verification
• High/low pressure shutoff
• Abnormal huge flow shutoff
• Low leakage alert
• Abnormal long gas usage alert and shutoff</td></tr>
<tr><td>Daily profile</td><td colspan="2">Hourly gas consumption or gas pressure profile</td></tr>
</table>

The meter has an excellent ability to measure accurately under extreme temperature conditions without temperature compensation. Figure 6 shows the temperature dependence between -25° and +60° Celsius in city gas.

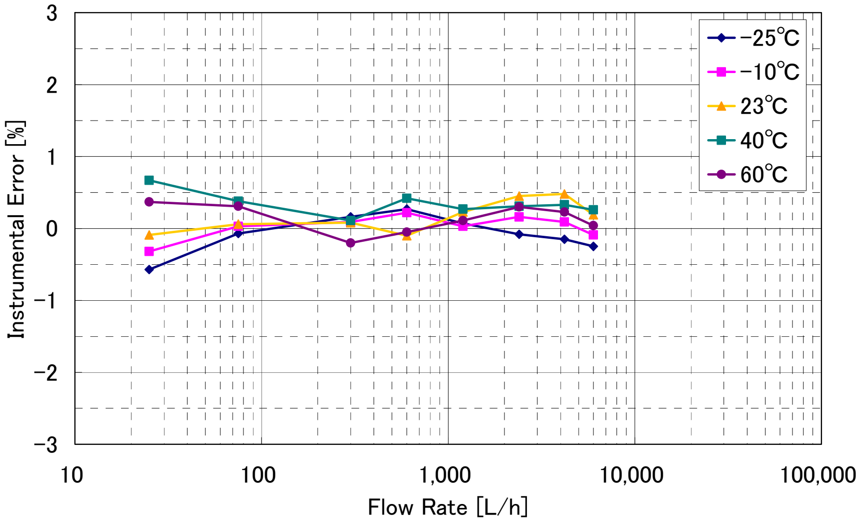


Figure 6: Example of temperature dependence of ultrasonic gas meter

Stability of zero points and low flow rate detection performance is shown in Figure 7. The figure plots the instant flow rate output in intervals of two seconds for the ultrasonic gas meter in city gas, with an extremely low flow rate of 3 L/h (assuming a gas leak after the meter had been left for a certain time with a 0 L/h flow rate). The measurement results for the respective flow rates fall within a certain range. Since there is also an obvious difference in the average value, we can see that the presence or absence of a leak can be determined.

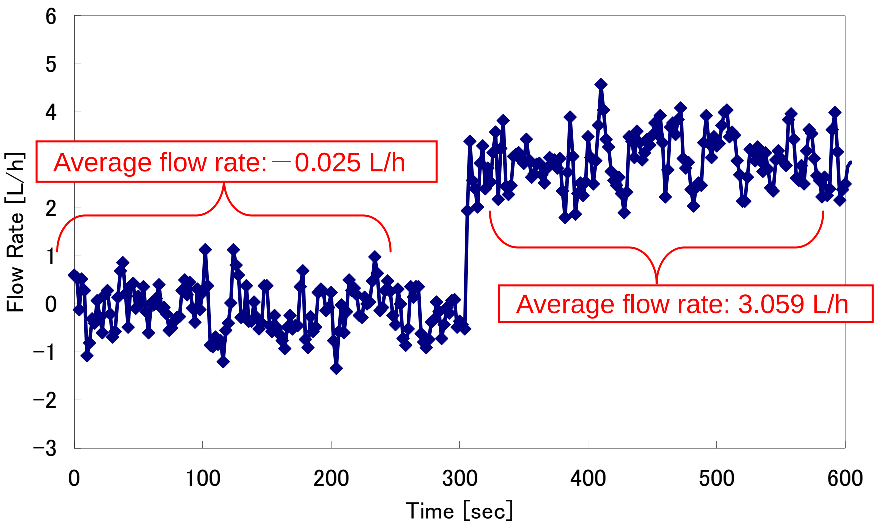


Figure 7: Example of stability of zero points and low flow rate detection performance with city gas

5. SMART FUNCTIONS

5.1 Communication Functions

Our ultrasonic smart gas meter is equipped with U-Bus, a next-generation communications port. The specifications and advantages of U-Bus are listed in Table 2. It supports packet communication and 30 times faster transmission of data than the standard communication interface specifications of conventional city gas metering devices in Japan. This means that the new meter uses less energy for communication, and it is possible to increase the frequency of communication and reduce the number of batteries used. Versatile specifications support diverse configurations of WANs and PANs with wireless WAN devices, ad-hoc mesh network devices, and so on. Since devices with the same communication interface can communicate over the bus, U-Bus will enable new services to be developed such as the control of appliances.

Table 2: Specifications and advantages of U-Bus

Layer	Specification	Description
Physical layer	Bus connection	• Allows shared use of various devices.
	High transmission speed (9600bps)	• Wider application and higher service level as a result of high-speed transmission • Approx. 30 times faster than the current port
Data link layer	Packet communication	• Improved bi-directional communication between terminals with different transmission speeds • More efficient use of communication links • Improved fault resistance
	Fixed packet length (104 characters per packet)	• Improved efficiency of data processing by terminals • Faster response (0.12 sec with each packet)
Network layer	Gateway function added to the meter	• Supports addressing in wide area networks and relayed wireless networks
	Simplified addressing	• Simplified terminal installation
Security	Encryption as a standard	• Improved access control and security protection

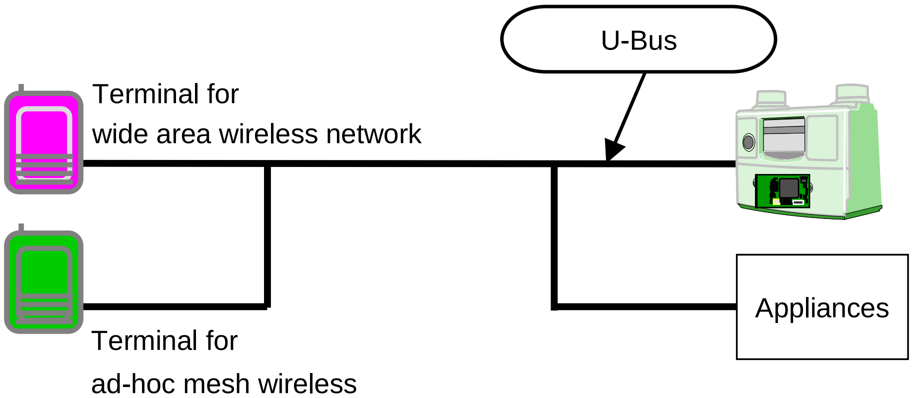


Figure 8: Example of connecting terminals using U Bus

5.2 Safety Functions

The ultrasonic gas meter comes with many unique safety functions developed in Japan. It can detect various situations such as leaks of more than 3 L/h, unexpectedly large flows, continuous use for a long period, major earthquakes, and pressure drops in the gas supply. In accordance with the detected situation, the shutoff valve in the meter closes to cut off the flow of gas and an alarm is activated. To provide these safety functions, the meter has a shutoff valve, pressure sensor, and seismic sensor as shown in Figure 9. Each part has the following features.

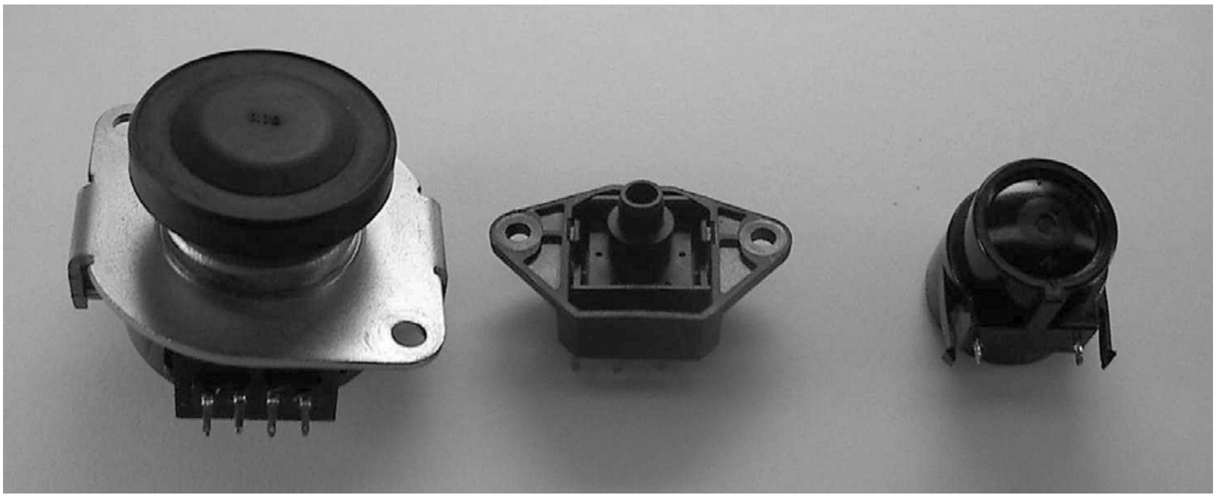


Figure 9: Safety components (from left: shutoff valve, pressure sensor, seismic sensor)

Shutoff Valve

Shutoff valves are installed in the inlets of internal meters, and can electrically open and close. When the safety features of a meter detect an abnormal condition, the microcomputer on the controller generates a signal to close the shutoff valve. The shutoff valve can be opened by triggering it manually, or by remote control using telecommunications.

Pressure Sensor

The pressure sensor monitors the pressure in the measuring passage, and responds to a rise or fall in pressure if the gas supply is obstructed. The measuring range is 0 to 5 kPa, and the resolution is approximately 10 Pa. Since the shutoff valve has been installed in the inlet of the internal meter, when the shutoff valve is closed, the area downstream of the meter becomes a closed space. For this reason, when the closed shutoff valve is opened, we can confirm whether a gas leak has occurred by monitoring the pressure with the pressure sensor.

The beauty of this sensor is that utilities like gas companies can open gas meters remotely without having to dispatch a maintenance engineer to the customer’s site. Closing the valve remotely is no problem; but when opening the gas valve, it is normally necessary to check that there is no leak within the house, which means sending a maintenance engineer to the house. However, this pressure sensor supplies gas to the house briefly by opening the valve and then closing it, detects the pressure drop in the pipe to determine if there was any leakage before opening the valve, and can control the shuttle valve when the pressure is higher or lower than it should be.

Seismic Sensor

When an earthquake of 250 Gal or more is detected, a signal is sent to the microcomputer on the controller. Upon receiving this signal, the microcomputer sends a signal to the shutoff valve to close the valve.

6. FUTURE PLAN

In order to realize a low carbon and energy saving society, an advanced gas meter is required as a tool for visualizing energy consumption. Because of the Great East Japan Earthquake, the role of the smart gas meter has been recognized again in terms of energy security in Japan. Based on this, we expect that a smart gas metering system supporting the energy business is very important. We plan to improve the gas meter to help realize a smart gas metering system. Specifically, we are considering exchange of the seismic sensor with an acceleration sensor, and adding the gas meter to a wireless device. By mounting the acceleration sensor, installation of this meter is an improvement over that of the conventional diaphragm type.

7. ACKNOWLEDGEMENT

The authors thank all those who supported us, including the staff of Toyo Gasmeter, Yazaki Energy Corporation, and Panasonic, who contributed greatly to the development of the ultrasonic gas meter. We also thank the staff at Hokkaido Gas and Nagano Toshi Gas, who helped us carry out field tests.