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DEVELOPMENT OF INDUSTRIAL ULTRASONIC METER FOR CUSTODY TRANSFER

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ABSTRACT

Tokyo Gas Co., Ltd., Tokico Technology Ltd. and Sonic Corp. have jointly developed a new ultrasonic gas flow meter for a medium-pressure gas range (0.04-0.99 MPa) to strengthen energy management and to respond to the increase in industrial gas transactions.

Through the introduction of unique features, namely a rectangular measuring conduit and balanced pressure chambers, this gas meter enables the flow rate to be stably measured free from the impact of the uneven gas velocity distribution caused by the upstream pipe, and of the internal pressure of the pipe. This gas meter also has the following characteristics:

- Is not prone to failure and is highly durable thanks to having no moving parts or components susceptible to degradation over time in contact with the gas.
- Is less susceptible to dust and mist in the gas.
- Is explosion-proof, and thus can be installed in explosion-proof areas including the basement and gas governor box.
- Has a wide flow velocity measurement range of 1:40.
- Has a function for calculating the total volume of gas used per time slot.
- Has a communication function, which can be used to gather various information through automatic meter reading, self-diagnosis, remote monitoring and load survey.

Based on the stability of performance observed through various tests including a metering performance test, disturbance test and long-term reliability test, as well as through a year-long field test at actual sites, this gas meter will be installed at various sites for pilot introduction starting from this year.

TABLE OF CONTENTS

1. INTRODUCTION

Tokyo Gas Co., Ltd., Tokico Technology Ltd. and Sonic Corp. have jointly developed a new ultrasonic gas flow meter for a medium-pressure gas range (0.04-0.99MPa) to strengthen energy management and to respond to the increase in industrial gas transactions. The developed ultrasonic gas meter has rectangular measuring conduits sandwiched with balanced pressure chambers. These unique inventions have resulted in a wide measuring range, no moving parts, and compact size. Various performance tests proved the high reliability of this product as a flow meter for retail gas.

2. MEASUREMENT PRINCIPLE

Figure 1 shows the measurement principle of the ultrasonic gas meter. Based on the difference between t_1, which is the time taken for an ultrasonic wave to travel from an upstream sensor to a downstream sensor, and t_2, which is the time taken for an ultrasonic wave to travel from a downstream sensor to an upstream sensor, the flow rate V is obtained.

As shown in equation (3), since the difference between the inverse values of t_1 and t_2 is proportional to the flow rate, high linearity is ensured. Further, measurement can be made irrespective of the type or temperature of gas, as variable C, which is the sound velocity in the gas, can be removed.

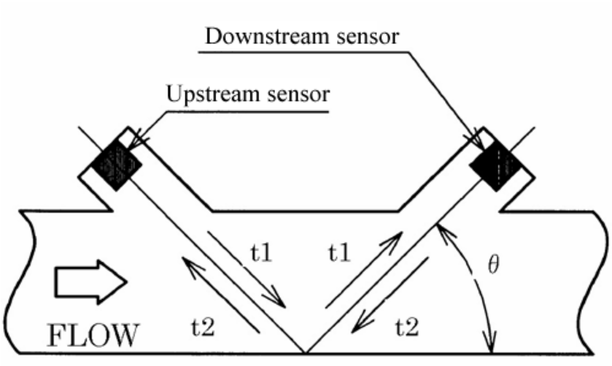


Figure 1: Measurement Principle

$$t_1 = \frac{L}{C + V\cos\theta} \quad (1) \qquad t_2 = \frac{L}{C - V\cos\theta} \quad (2)$$

Based on equation (1), (2),

$$V = \frac{L}{2\cos\theta}\left(\frac{1}{t_1} - \frac{1}{t_2}\right) \quad (3)$$

V : Flow velocity [m/s]

L : Distance between sensors [m]

θ : Angle between the propagation axis of the ultrasonic wave and the central axis of the pipe

C : Sound velocity in the gas [m/s]

3. SPECIFICATIONS AND CHARACTERISTICS

Figure 2 shows an external view of the gas meter, and Table 1 shows the development specifications. This gas meter has the following characteristics.

(1) Safety and Reliability

- Is not prone to failure and is highly durable thanks to having no moving parts or components susceptible to degradation over time in contact with the gas.
- Is less susceptible to dust and mist in the gas.
- Has limited pressure loss and does not halt the supply even if it fails, as there are no obstacles in the measuring conduit.
- It is explosion-proof, and thus can be installed in explosion-proof areas including the basement and gas governor box.

(2) Measurement Capability

- This gas meter has a wide flow velocity measurement range of 1:40.
- With the unique features of a rectangular measuring conduit and balanced pressure chambers, it is capable of stable measurement.

(3) Additional Functions

- The gas meter has a function for calculating the total volume of gas used per time slot.
- It has a communication function, which can be used to gather various information through automatic meter reading, self-diagnosis, remote monitoring and load survey.

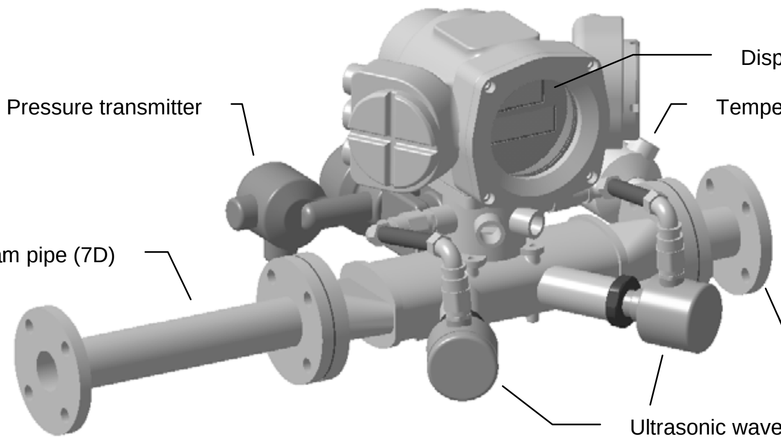


Figure 2: External View

Diameter	50 mm	80 mm	100 mm	150 mm
Range of flow rate (m^3/h) (actual flow rate)	5 - 220	13 - 550	25 - 900	50 - 2100
Number of ultrasonic sensors	1 pair (V path)	2 pairs (V path)	2 pairs (Z path)	2 pairs (Z path)
Piping connection	Flange (JIS 10K FF)			
Upstream and downstream straight pipe lengths	Upstream 7D, downstream 2D			
Accuracy	±1% of reading for the meter ±1.5% of reading after temperature and pressure compensation			
Ambient temperature	-10 to 50 degrees			
Working pressure	0.04 to 0.99 MPa			
Indicator	Flow quantity (multiplication, instantaneous), etc. are displayed digitally. Integrated design of the measurement part and the indication part			
Output	Pulse Analog output (4-20 mA DC) of flow quantity, temperature, and pressure Self-diagnosis function, remote monitoring port, and automatic meter-reading port			
Power supply	AC 100 V, 50/60 Hz			
Structure	Explosion-proof			

Table 1: Specifications

4. STRUCTURE OF THE MEASURING SECTION

The rectangular measuring conduit and balanced pressure chambers that characterize this gas meter are described below. Figure 3 shows the structure of the core part of the developed meter.

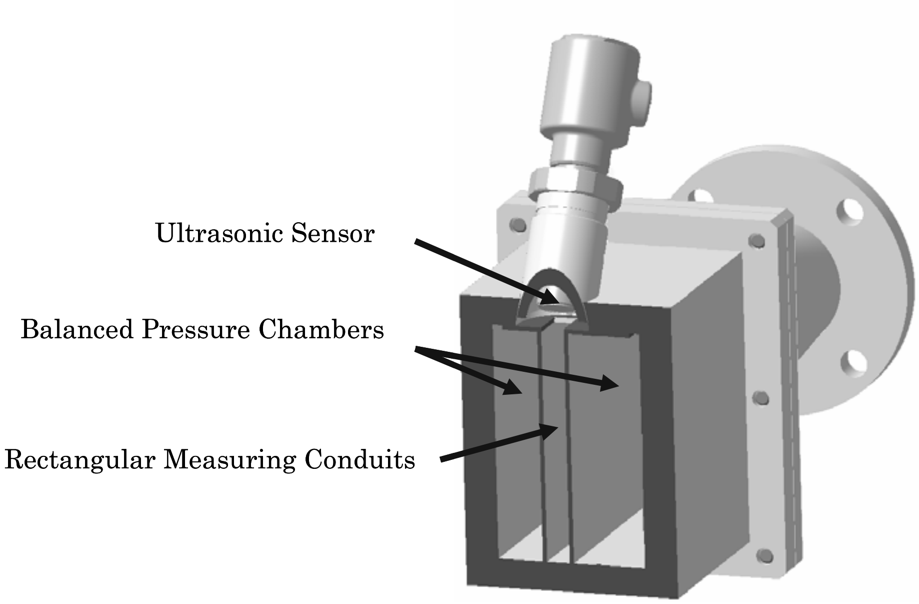


Figure 3: Cross-sectional View of the Measuring Section

4.1 Rectangular Measuring Conduit

A rectangular cross-section conduit is one of the features of this unique shaped meter; the conventional ultrasonic gas meter has a circular cross-section conduit. The rectangular conduit enables the average flow velocity to be measured, because the sound beam passes the whole area of the rectangular conduit, so only one pair of sensors can measure each section. [1] On the contrary, with a circular cross-section conduit, the ultrasonic wave passes only a specific part of the circular section, even though the distribution of gas velocity is uneven in the circular conduit. Therefore, a circular cross-section conduit generally requires at least two pairs of sensors for accurate measurement.

With rectangular conduits, a flow conditioner that rectifies the flow is not needed, and the length of the straight part of the upstream pipe can be shortened to 7D with sufficient robustness and accuracy.

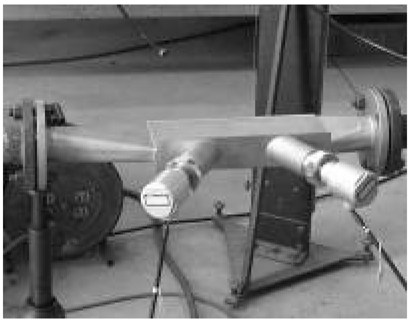
4.2 Results of Tests Using a Prototype Conduit

To verify the effect of the rectangular measuring conduit, a test was conducted to check the impact of the uneven distribution of gas velocity caused by the upstream pipe. Rectangular and circular prototype conduits were each connected to three types of upstream pipes as shown in Table 2, and the instrument error was measured. The prototype gas meter had a diameter of 50 mm, and air at atmospheric pressure was used as the test fluid.

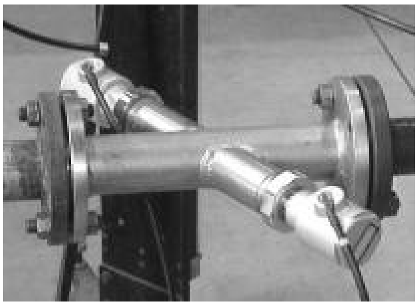
Case 1	a 10D straight pipe
Case 2	a 5D straight pipe with horizontal elbow
Case 3	a 5D straight pipe with vertical elbow

Table 2: Upstream Pipe Patterns for the Test

Figure 6 shows the results of the instrument error test. In this graph, using the result for Case 1 (10D straight pipe) as the reference, the deviation of instrument error of each test case is plotted. The figure shows that the measurement error caused by the upstream elbow is smaller for the rectangular conduit than for the circular one. This is assumed to be because the distribution of gas velocity is less uneven in a rectangular conduit than in a circular one, and because the sound beam passes through the whole area of the rectangular conduit cross-section, thus measuring the average flow velocity of the conduit.

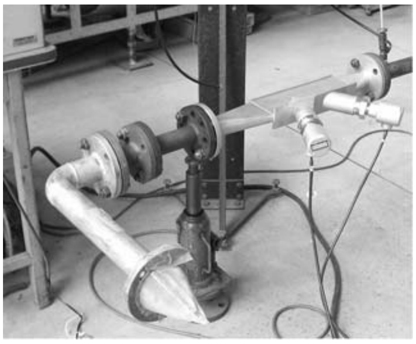


Rectangular Conduit

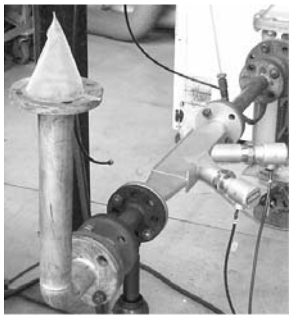


Circular Conduit

Figure 4: Prototype Conduits (Diameter: 50 mm)

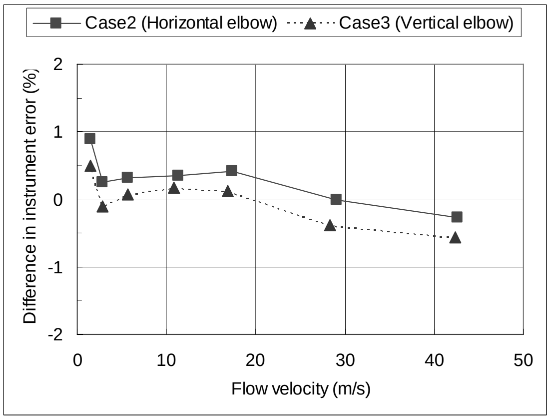


Case 2 (5D straight pipe + horizontal elbow)

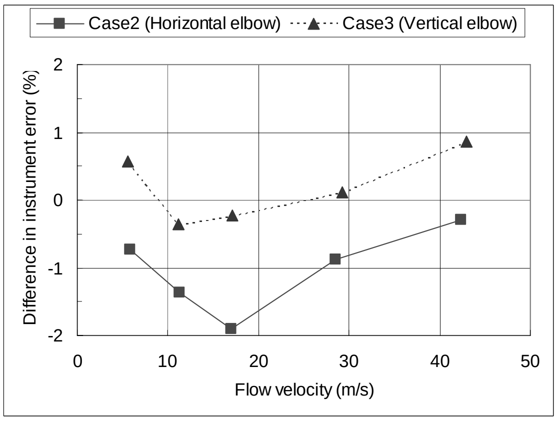


Case 3 (5D straight pipe + vertical elbow)

Figure 5: Upstream Pipes



Rectangular Conduit



Circular Conduit

Figure 6: Impact of Upstream Pipes

4.3 Balanced Pressure Chambers

This section describes the balanced pressure chambers, which is the other characteristic of this gas meter. As previously mentioned, the rectangular conduit makes the gas meter less susceptible to the impact of the upstream pipe, and is capable of stable measurement. However, when the pressure of the gas supply reaches the medium-pressure gas range (0.04-0.99 MPa), which is the working pressure range of this meter, the conduit becomes deformed due to an increase in internal pressure. This changes the cross-sectional area of the conduit, causing a measurement error.

To deal with this problem, a reinforcement rib was secured to the outside of the conduit to prevent the deformation of the conduit due to internal pressure.

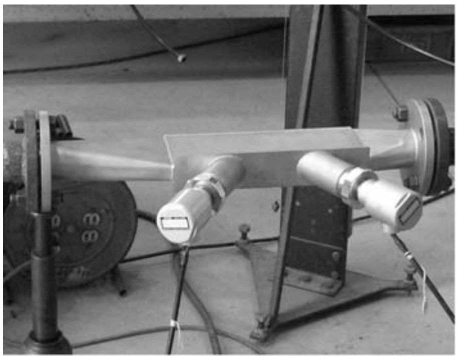


Figure 7: Rectangular conduit (without reinforcement rib)

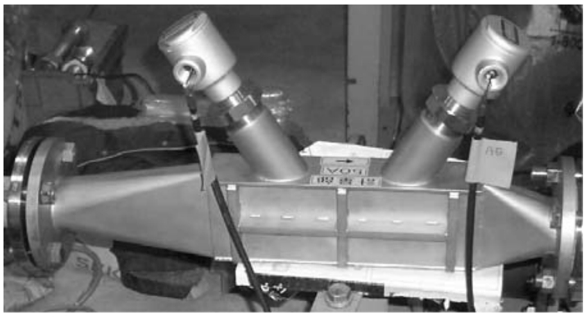
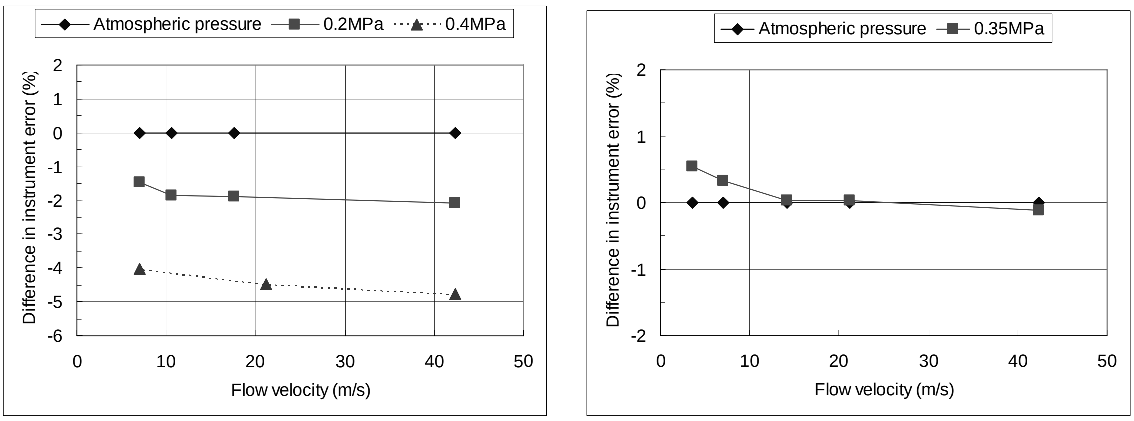


Figure 8: Rectangular conduit (with reinforcement rib)



Without reinforcement rib With reinforcement rib

Figure 9: Result of Instrument Error Test

Figure 9 shows the results of the instrument error test using a 50-mm diameter conduit. In this graph, at atmospheric pressure as the reference, the deviation of instrument error at each pressure is plotted. While the instrument error deviates further from the result at atmospheric pressure as the internal pressure rises for a conduit without a reinforcement rib, for a conduit with a reinforcement rib, the deviation of instrument error is limited due to the absence of pressure-induced conduit deformation.

However, the reinforcement rib causes many design issues such as the unacceptable increase in the weight of the flow meter and the need for a strain analysis for each pipe diameter. To solve these issues, balanced pressure chambers were adopted. The balanced pressure chambers are "spaces with equal pressure", which is equal to the internal pipe pressure, placed on both sides of the measurement conduit to prevent any difference in pressure on the wall of the conduit. This structure prevents deformation of the measurement conduit caused by internal pressure, keeps the strain within the pressure capacity of the outer wall of the flow meter, and allows the strength design to be done by a simple wall thickness calculation.

A pressure test using a prototype conduit with 80 mm diameter having balanced pressure chambers produced similar results as a conduit with a reinforcement rib. Thus, the developed meter can be designed in a compact size at reasonable cost.

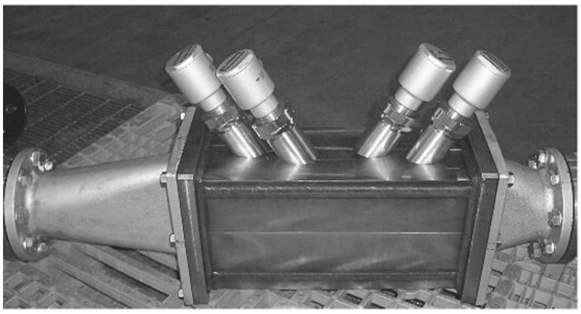


Figure 10: Prototype Conduit with Balanced Pressure Chambers (diameter: 80 mm)

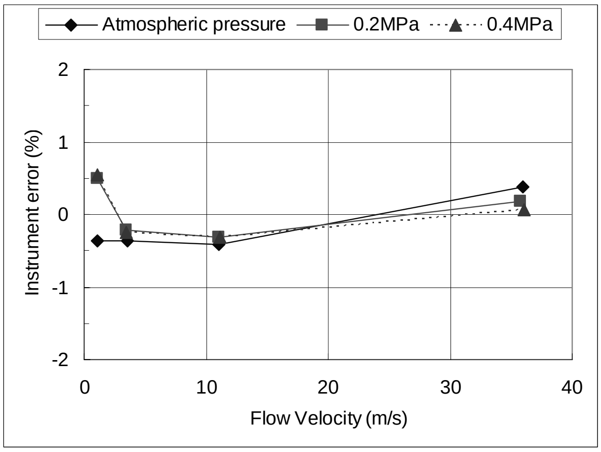


Figure 11: Result of Instrument Error Test Using a Conduit with Balanced Pressure Chambers (diameter: 80 mm)

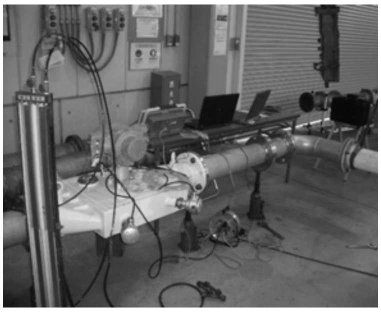
5. EVALUATION RESULTS

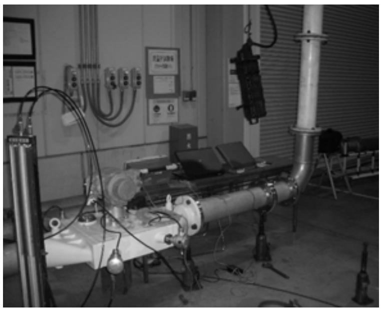
5.1 Impact of Upstream Pipe

In addition to the test using a prototype conduit described in Chapter 4, the impact of the upstream pipe on each conduit diameter was checked as a part of the product evaluation. One such example is shown below, in which the three types of upstream pipes shown in Table 3 were connected to the meter and instrument error was measured. The test gas meter had a diameter of 50 mm, and air at atmospheric pressure was used as the test fluid. The results confirmed that stable measurement can be secured irrespective of the direction of the upstream elbow.

Case 1	a 10D straight pipe
Case 2	a 7D straight pipe with horizontal elbow
Case 3	a 7D straight pipe with vertical elbow

Table 3: Upstream Pipe Patterns for the Test





Horizontal Elbow Vertical Elbow

Figure 12: Test on Impact of Upstream Pipe

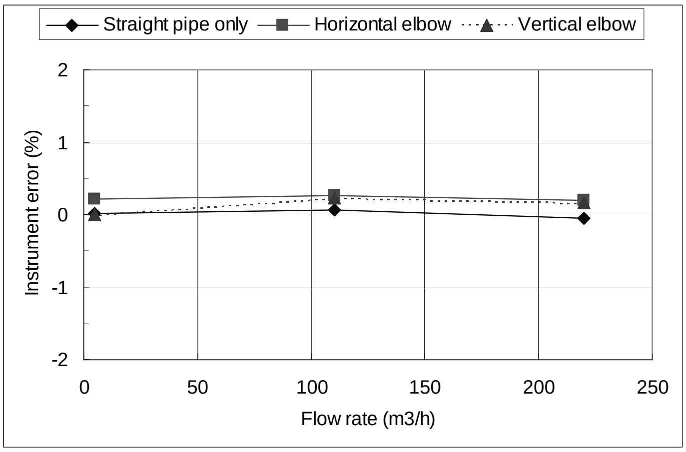


Figure 13: Result of Test on Impact of Upstream Pipe (diameter: 50 mm)

5.2 Dust Test

Since the pipes on which the gas meter will actually be installed are likely to contain dust, a test to check the dust resistance of the gas meter was conducted. JIS Type 1 test dust was blown through the test gas meter, and the change in instrument error and the ultrasonic waveform after the dust had passed through were measured. As a result, it was confirmed that the change in instrument error after the dust had passed through is negligible, and the form of the ultrasonic wave remained normal.

Figure 14: Measurement Conduit after Dusting

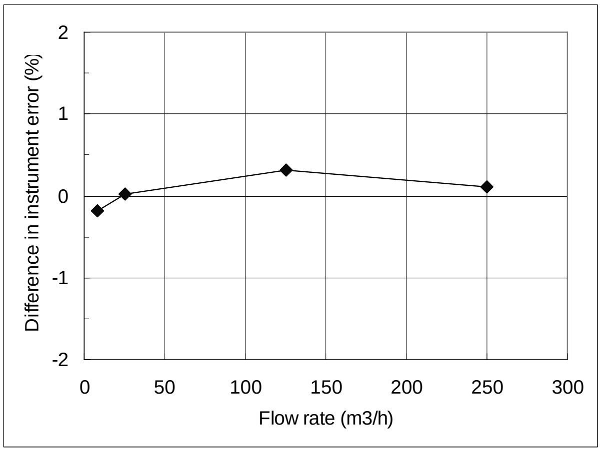
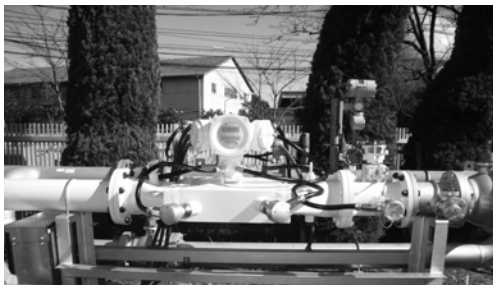


Figure 15: Change in Instrument Error after the Dust Test

5.3 Field Test

For one year starting from 2009, field tests were conducted for pipes with diameters of 50 mm, 80 mm and 150 mm to confirm that there is no problem in the measurement capability and integrity of the different functions, durability and ease of installation of this gas meter. Furthermore, inspections of the gas meters that were removed after the field test showed no change in instrument error from the time of shipment. The figure below shows examples of the gas meters installed for the field tests.

Diameter: 50 mm



Diameter: 150 mm

Diameter 80 mm

Diameter 80 mm (vertical pipe)

Figure 16: Gas Meters Installed for Field Tests

6. CONCLUSION

Tokyo Gas Co., Ltd., Tokico Technology Ltd. and Sonic Corp. have jointly developed a new ultrasonic gas flow meter, which features a rectangular conduit and balanced pressure chambers, for a medium-pressure gas range for custody transfer. Based on the results of various tests including a metering performance test, disturbance test and long-term reliability test, as well as through a year-long field test at actual sites, it was confirmed that this gas meter has sufficient reliability for custody transfer. The gas meter will be installed at various actual sites for pilot introduction.

REFERENCES

[1] H. Ishikawa, M. Takamoto, K. Shimizu, H. Monji, G. Matsui: Effect of Measurement Cross Section on Flow Rate Characteristics in Ultrasonic Flowmeters, Transactions of the Society of Instrument and Control Engineers (Transactions of SICE), Vol. 36, No. 5 (2000)

LIST TABLES

LIST OF FIGURES