Development of an Arbitrary Pressure Pulsation Generator for Testing Gas Flow Meters

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Abstract

The purpose of this study is to develop a novel and compact pneumatic pressure pulsation generator that can generate arbitrary pressure pulsations in a pipe system in order to evaluate the characteristics of flow meters and flow sensors. Gas flow meters and sensors (used in industrial processes and in homes) are exposed to unsteady pressure pulsations generated by the operation of other equipment and piping. In this paper, in order to establish a compact (laboratory-size) testing device to characterize gas flow meters and sensors (particularly around their zero point) at various pressure pulsations, a compact arbitrary pressure pulsation generator is developed and tested. First, using ordinary 15 m length piping and a T-tube, pressure pulsations are generated and supplied to two flow meters (a laminar flow sensor and an ultrasonic flow meter). Then, the pulsations are duplicated using the newly developed compact pressure pulsation generator and supplied to the flow meters. The experimental results indicate that the developed pulsation generator can accurately duplicate the pulsations generated by the ordinary piping. These results indicate that our system can potentially be used to reduce the cost of flow meter evaluation.

KEYWORDS: pressure control, flow rate measurement, gas pulsation generator, gas meter testing device

1. Introduction

Gas flow meters and flow sensors are widely used in industrial plants and even residential homes. The gas pressure in the pipe system can be affected by the condition of other connected equipment and the surrounding environment. Currently, the static characteristics of such flow meters and sensors are thoroughly evaluated according to strict international and domestic standards [ISO (International Organization for Standards) and JIS (Japanese Industrial Standards)]. However, gas flow meters and sensors used in industrial processes are exposed to unsteady pressure pulsations (which may contain several superimposed frequencies) that are generated by the operation of other equipment and piping (such as the reflection of pressure waves). In other words, flow meters and sensors may be measuring flow rates that contain unsteady pressure pulsations, and so the signal outputs may be influenced by these pressure pulsations /1/. Currently, in order to assess the performance of flow meters and sensors in the presence of these pressure pulsations, it is necessary to either place a meter (or sensor) at the location where the pulsation occurs or replicate the entire pipe system in the laboratory. Although a method of generating flow containing pressure pulsations using resonance tubes was reported in a previous study, this method has the following limitations:

- This method cannot generate pulsations with superimposed frequencies.
- The length of the tube must be adjusted when changing the frequency of the pulsation (this takes time and labor).
- The resonance tube, which must be installed in a straight line, takes up a great deal of space.

Therefore, a compact pressure pulsation generator that can generate arbitrary unsteady pulsations is needed for testing flow meters and sensors. In the present study, we propose a novel and compact pneumatic pressure pulsation generator that uses a very quick and precise pressure measurement and control technique. The proposed system is composed of a high-precision quick-response (HPQR) pneumatic pressure regulator and bent gas piping that simulates the gas piping in a typical home. Using this system, we assess the performance of a flow meter and a flow sensor, particularly around their zero point. In the experiment, first, pressure pulsations generated using ordinary 25 m length piping and a T-tube are supplied to the flow sensor and flow meter. Then, the pulsation is duplicated using the newly developed compact pressure pulsation generator, and the generated pulsation is supplied to the flow meters. Using the experimental results, the effectiveness of the proposed pressure pulsation generator is evaluated.

2. Development of the arbitrary pressure pulsation generator

2.1. Outline of the proposed arbitrary pressure pulsation generator

The concept of the proposed arbitrary pressure pulsation generator is shown in **Figure 1**. The system represents a gas supply pipe system between a gas company and a typical home. The generator consists of an air supply (a compressor), a pressure controlling device (the developed pressure regulator), the tested flow meter, pressure sensors, and bent gas piping that simulates the gas piping in a typical home. Before performing experiments on the developed pressure pulsation generator, the pressure pulsation in a real pipe system should be measured using the pressure sensor that is installed just upstream of the flow meter. Then, the developed pressure regulator, which can control the arbitrary pressure wave very quickly, duplicates the pressure pulsation. The gas piping downstream of the flow meter simulates the gas piping in a typical home. The effect of the volume and the reflection of pressure waves can be duplicated. In order to evaluate the characteristics around the zero point, the very end of the piping is closed. A schematic of the proposed pressure pulsation generator is shown in **Figure 2**.

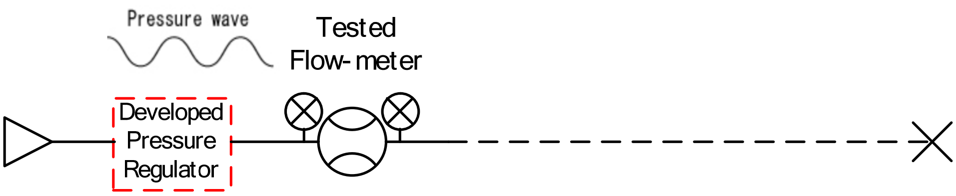


Figure 1: Concept of the Proposed Pressure Pulsation Generator

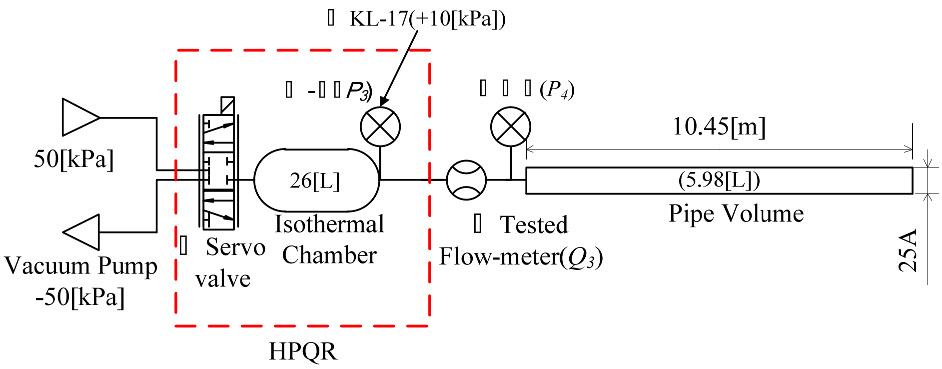


Figure 2: Schematic of the Proposed Pressure Pulsation Generator

2.2. Explanation of the pressure controlling device (pressure regulator)

A picture of the developed pressure regulator is shown in **Figure 3**. It is composed of an SP valve (FESTO MPYE-5-M5-B), an isothermal chamber, a pressure sensor (Nagano Keili KL-17 +10kPa), and a vacuum pump. Although the SP valve has five ports, the valve is used as a three-port servo valve (i.e., supply, control, and exhaust ports), and the unused ports are plugged. The removal of air from the exhaust port is increased using the vacuum pump. The isothermal chamber used herein has a volume V of 0.026 [m^3].

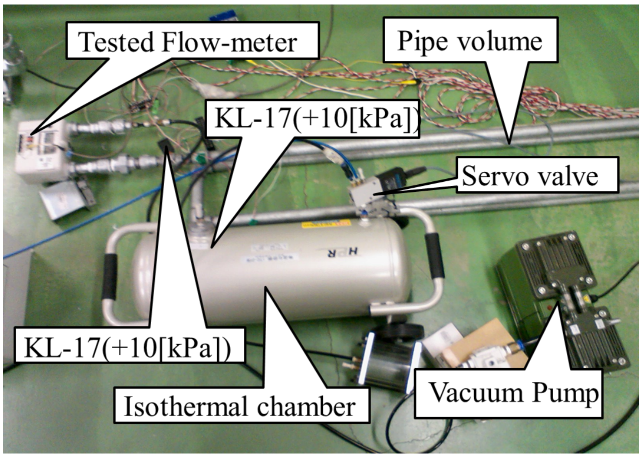


Figure 3: Picture of the Developed Pressure Regulator

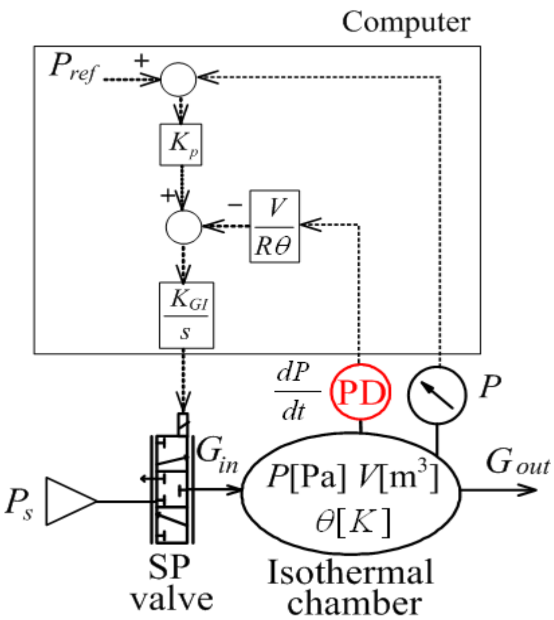
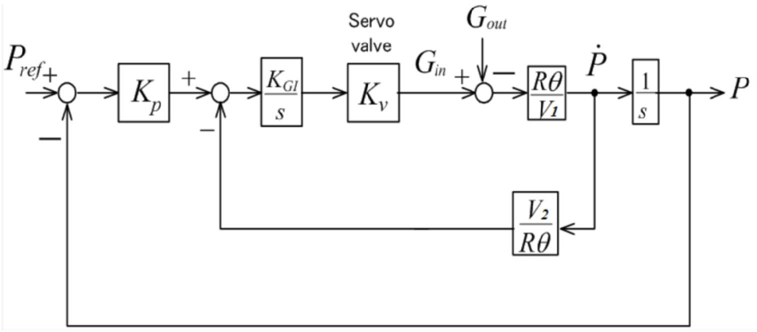


Figure 4: Schematic of the Developed Pressure Regulator



$K_P = 3.09\times10^{-6}$[(kg/s)/Pa], $K_{GI} = 3.6\times10^{5}$[V/kg]

Figure 5: Block Diagram of the Developed Pressure Regulator

A schematic and a block diagram of the proposed pressure regulator are shown in **Figures 4** and **5**, respectively. The SP valve characteristics are approximated to a linear constant K_v. The main loop is a pressure feedback loop. The minor loop is a differentiated value feedback loop, which compensates for the nonlinear characteristics of the SP valve and can also reduce the effects of supply pressure variation and the output flow rate G_{out}. Since the controller gains are set as shown in Figure 5, the time constant of the pressure control loop is about 0.1 [s]. The control is performed using a digital signal processor (MTT s-box) with a sampling time of *st* = 0.001 [s].

3. Experiments

3.1. Flow sensor and flow meter

The experiments are performed using a laminar flow sensor and an ultrasonic flow meter as the testing targets. **Figure 6** and **Table 1** show the laminar flow sensor and its specifications, respectively. The sensor is called a "quick response laminar flow

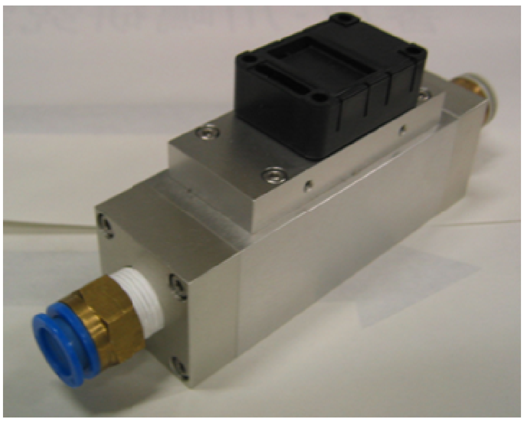


Figure 6: Picture of Quick Response Laminar Flow Sensor (QFS)

Type	QFS-03-50-10 (Tokyo Meter Co., Ltd.)
Inner diameter of inlet	R_c3/8
Output signal range [V]	0.5-4.5
Dynamic response rate [Hz]	Not less than 50
Size (W×H×D) [mm]	115×70×35
Differential pressure sensor	Nagano-Keiki KL-17 ±500[Pa]

Table 1: Specifications of QFS

Figure 7: Picture of Ultrasonic Flow Meter (USM)

sensor" (QFS), and our previous research confirms its dynamic response rate to be no less than 50 [Hz] /2/. In the experiment, the signal from the QFS is measured every 0.001 [s]. **Figure 7** shows an ultrasonic flow meter (USM) that is used for measuring the city gas (13A); these USMs are already used by thousands of Tokyo Gas customers. The signal from the USM is measured every 2 [s].

3.2. Gas pulsation generating experiment using an ordinary pipe system

We fabricated a gas pipe system as shown in **Figure 8**. In the system, the air pressure is controlled using a commercially available precision pressure regulator (① Konan RV6-03-G3267). The volume of the buffer tank (②) is 30 [L]. The pipe labeled (40A, 15 [m]) is assumed to be an underground gas main from the gas company. The pipe labeled (25A, 10 [m]) is installed downstream of the tested flow meter (or sensor) (⑦) as it would be in a typical home. The very end of the piping is closed. In the experiments, the pressure pulsation is generated using a T-tube (⑤ divergence pipe) and a spool-type servo valve (④ FESTO MPYE-5-1/8-LF-010B). The disturbance flow rate is measured using a flow sensor (⑥ Tokyo Meter QFS-800). Since the end of the pipe is closed, no matter how much disturbance (pressure pulsation) is generated and supplied to the tested flow meter (or sensor), the total flow rate should be zero. The pressure values upstream and downstream of the tested flow meter (or sensor) are also measured.

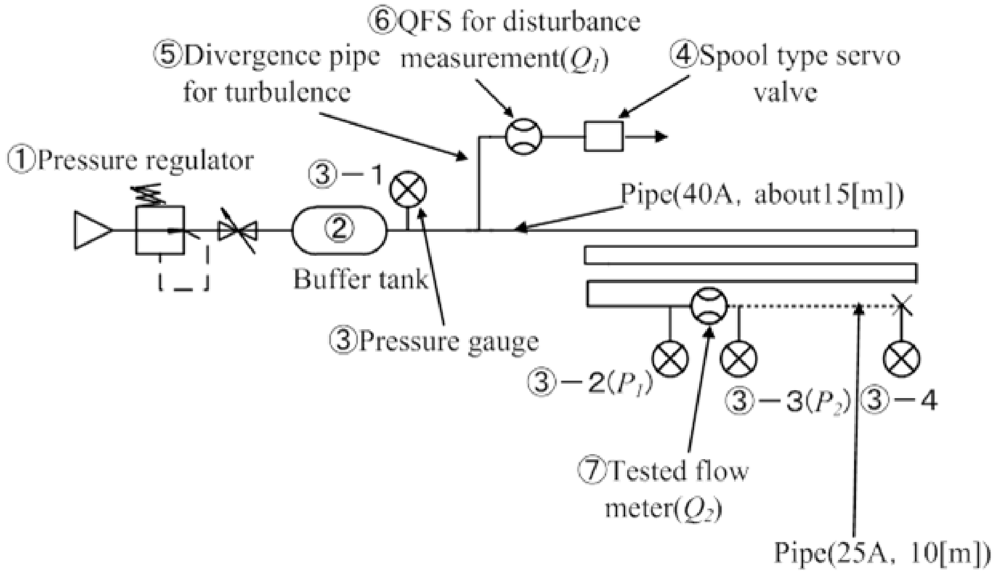


Figure 8: Schematic of Gas Piping

3.2.1. Experimental conditions and procedures

In the experiment, the supply pressure is first set to about 6[kPa gauge] using the precision pressure regulator (①). After the pressure sufficiently stabilizes, each experiment is started. Then, the control signal is sent to the servo valve (④) according to Equation (1).

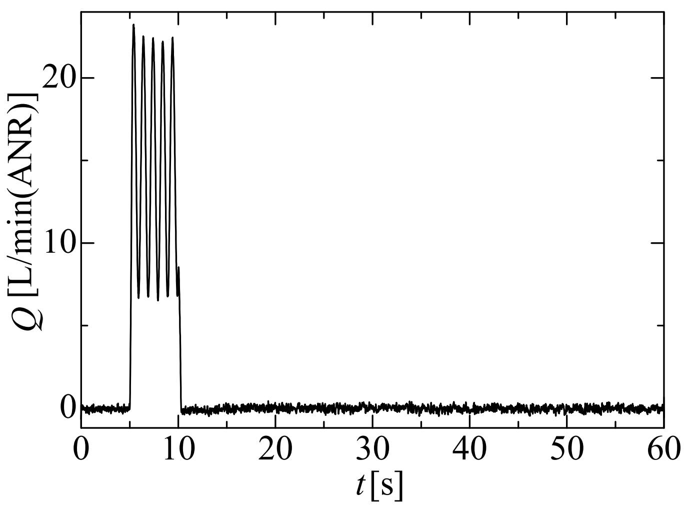


Figure 9: Measured Flow Rate (Q1)

$$E_i[\mathrm{V}] = \begin{cases} 0(t < 5) \\ 7 + \sin 2\pi ft(5 \le t \le 10) \\ 0(10 > t) \end{cases} \quad (1)$$

The disturbance flow rate measured by the QFS (⑥, Q1) is shown in **Figure 9**. The flow rates are measured by the QFS and USM when they experience a disturbance (pressure pulsation). The pressures upstream and downstream of the flow sensor/meter are also measured using pressure sensors.

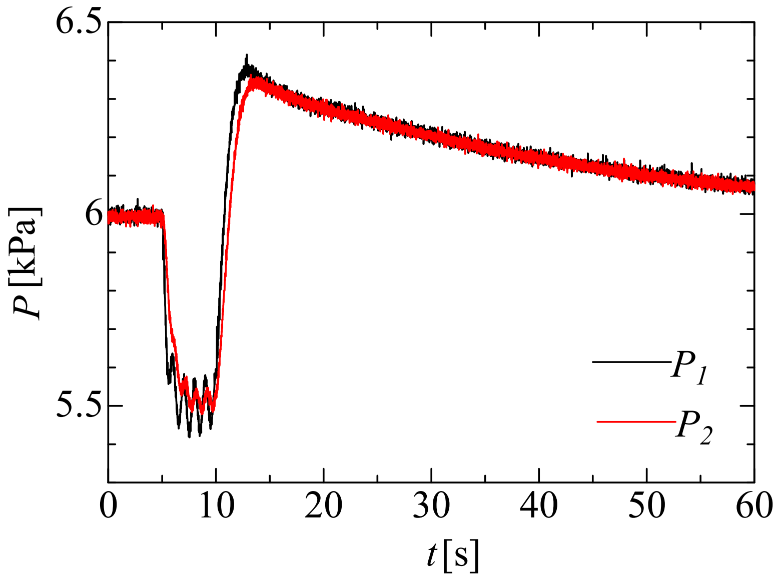


Figure 10: Measured Values of Pressure (P_1, P_2) (Target: QFS)

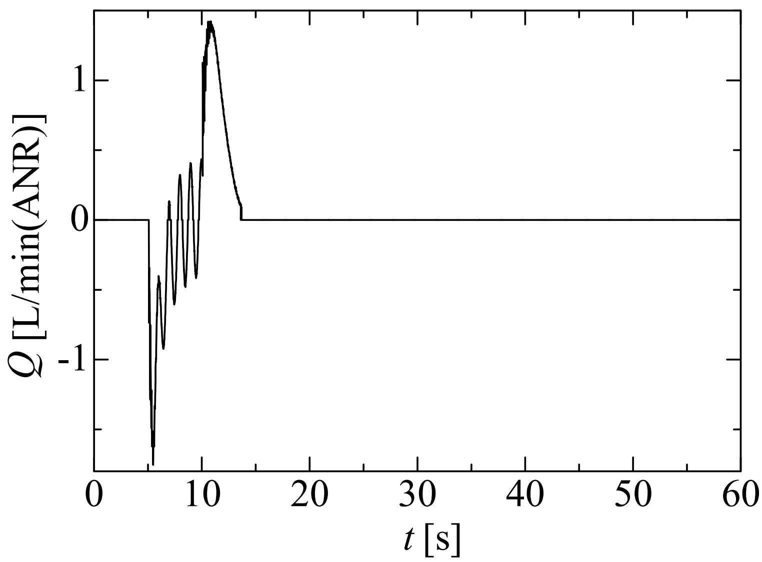


Figure 11: Measured Flow Rate (Q_2) (Target: QFS)

3.2.2. Experimental results

The experimental results for the QFS are shown below. The pressure values (P1, P2) and measured flow rate from the QFS (Q2) are shown in **Figures 10** and **11**, respectively. The difference between P1 and P2 is due to the inner impedance of the laminar flow element in the QFS. As a disturbance occurs upstream, pressure pulsations occur, and the flow rate measured by the QFS (Q2) also fluctuates. The measured flow rate in Figure 11 is integrated, and the total mass of flow is calculated. The integrated value is +0.018 [L].

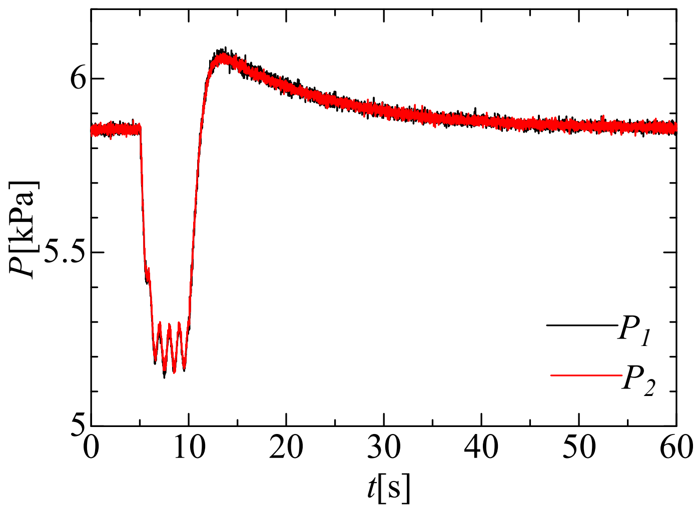


Figure 12: Measured Values of Pressure (P_1, P_2) (Target: USM)

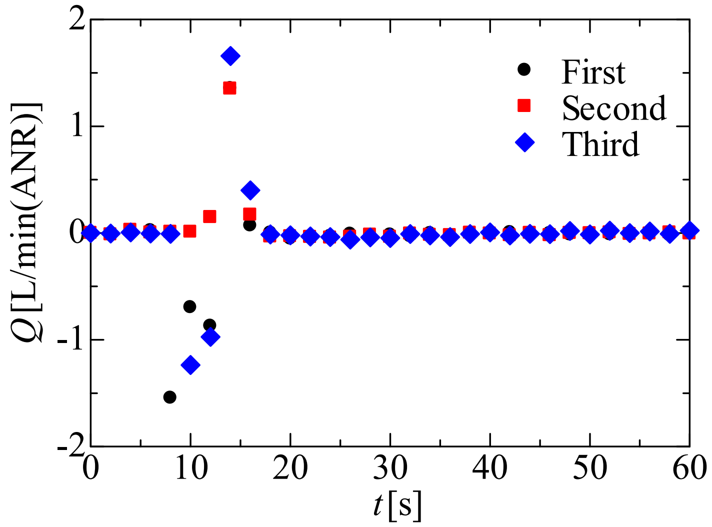


Figure 13: Measured Flow Rates (Target: USM)

Type of flow meter	Integrated value [L]			
QFS	+0.018			
USM	1st	2nd	3rd	Average
	-0.066	+0.046	-0.017	-0.012

Table 2: Integrated Values of the Flow Rates

The experimental results for the USM are shown in **Figure 12** (pressure values) and **Figure 13** (flow rates). Since the USM has a small inner impedance, the difference between P1 and P2 is quite small. The experiment was performed a total of three times, so there are three sets of results shown in Figure 13. The experimental result varied each time, and the average of the integrated values is -0.012 [L] (**Table 2**).

3.3. Gas pulsation generating experiment using the developed arbitrary pressure pulsation generator

In this section, instead of using the gas pipe system shown in Figure 8, the proposed pressure pulsation generator (Figure 2) is used. In this experiment, the measured pressure value P1 (Figure 10) is used as the set pressure value (P_{ref}) of the developed pressure regulator (Figure 4). The experimental results comparing P_{ref} and P_3 are shown in **Figure 14**; the measured pressure pulsation from the last section was duplicated very well. The measured flow rates for the QFS are shown in **Figure 15** alongside the measured flow rate from the last section (Figure 11). The two flow rate curves correlate very well. The integrated value of the flow rate is +0.018 [L], which matches the value from the experiment in the last section.

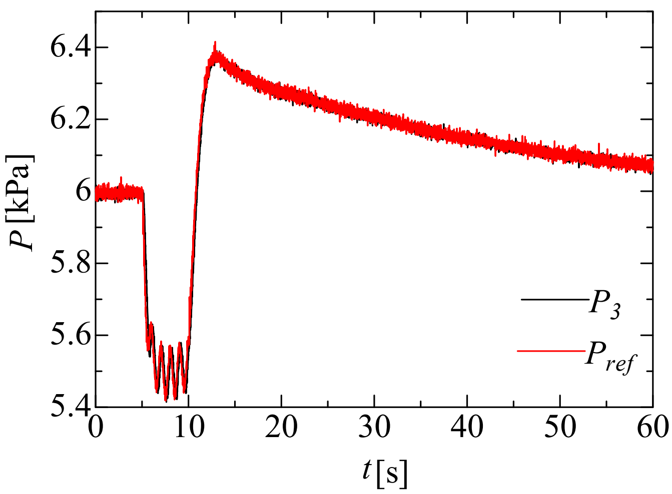


Figure 14: Comparison of Pressures (P_3, P_{ref})

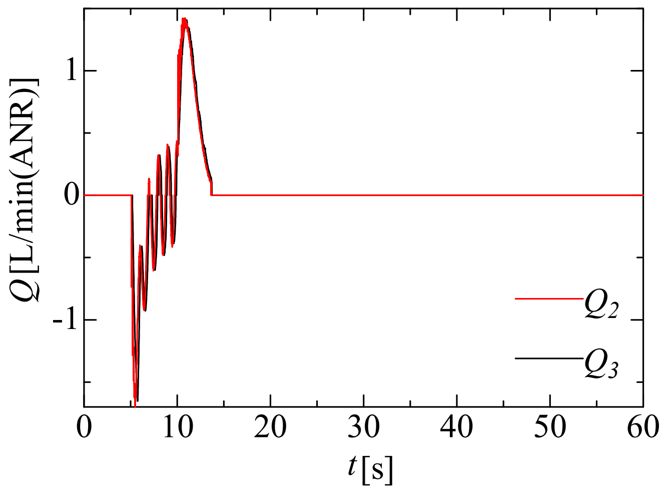


Figure 15: Comparison of Flow Rates (QFS)

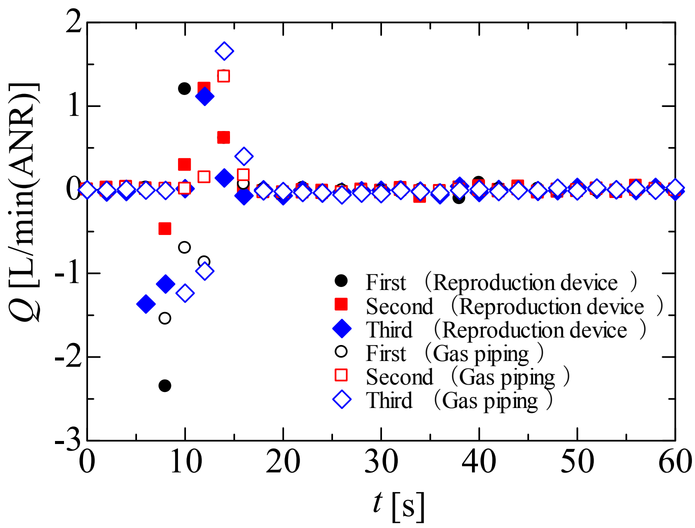


Figure 16: Comparison of Flow Rates (USM)

Type of flow meter	Integrated value [L]				Difference from Table 2 [L]
QFS	+0.018				0
USM	1st	2nd	3rd	Average	+0.019
	+0.019	+0.053	-0.052	+0.007	

Table 3: Integrated Values of the Flow Rates

The USM experiment was performed three times, and the results are shown alongside the results from the previous section (Figure 13) in **Figure 16** (there are a total of six results shown). The experimental result varied each time, and the average of the integrated values is -0.019 [L] (**Table 3**).

4. Conclusions

In order to establish a compact (laboratory-size) characteristics testing device for gas flow meters and sensors (particularly around their zero point) at various pressure pulsations, a compact arbitrary pressure pulsation generator was developed. As a preliminary experiment, before conducting the experiments using the proposed system, real pressure pulsations were generated in an upstream pipe (using 15 [m] of upstream piping and a divergence pipe) and were measured using pressure sensors and a flow meter (and a flow sensor). Then, using the proposed system, those pressure pulsations were duplicated. The experimental results gained by those 2 cases, were in good agreement. These experimental results indicate the effectiveness of the proposed testing method for flow meters and sensors with the presence of pressure pulsations in the piping.

5. Bibliographical References

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6. Symbols

E_i	Control voltage given to servo valve	V
K	Gain	-
P	Pressure	Pa gauge
Q	Flow rate	L/min ANR
R	Gas constant	J/(Kg K)
V	Volume of chamber	m^3
θ	Temperature	K