Establishment of a standard supply system for liquid flowmeter development and quality control

Nobuyuki Sugiyama, Toru Yamaguchi

Key words
Calibration service provider registration system, JCSS, calibration facility, liquid flowmeter, high flow rate, micro flow rate

Azbil Corporation manufactures and sells liquid flowmeters, including electromagnetic and thermal models. This article introduces our calibration facility, which is indispensable for the development and production of these products, and describes its features and capabilities for evaluating the performance of the products. In addition, we explain how our utilization of the Japan Calibration Service System (JCSS) helps us to maintain a high level of technology and product traceability.

1. Introduction

This article introduces the calibration facilities of the azbil Group, which are indispensable for maintaining the quality and performance of the liquid flowmeters for water (hereinafter simply "liquid flowmeters") that we manufacture and sell. These facilities are located at Azbil's Fujisawa Technology Center (FTC) and at Azbil Kyoto. They are capable of performing Japan Calibration Service System (JCSS) calibrations in the range from micro flow (1 g/min ≈ 1 mL/min) to high flow (5090 m^3/h). For reference, while it takes about 5 minutes to fill a teaspoon (approx. 5 mL) at a micro flow rate of 1 mL/min, it takes about 7 minutes to fill a regular 25 m swimming pool (approx. 600 m^3) at the high flow rate of 5090 m^3/h.

Here we will discuss micro flow rate liquid flowmeters used for charging and mixing based on the measurement of micro flows and electromagnetic flowmeters used to measure process fluid, slurry fluid, and the like, our two main types of liquid flowmeter product.

The measurement ranges for each of these flow amounts are shown in figure 1. We calibrate the products before shipment to verify that flows from micro to high can be measured correctly. This paper describes the detailed measures (equipment use, procedures, etc.) that are needed for calibration for various amounts of flow.

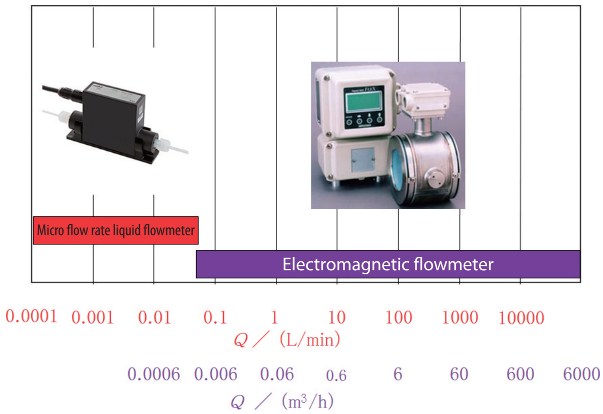

Fig. 1. Flow measurement range of products

2. Introduction of calibration equipment

2.1 Calibration of liquid flowmeters

First, this section describes the general method of calibrating liquid flowmeters. As shown in figure 2, a flowmeter that serves as the standard, known as the standard flowmeter, and the flowmeter to be calibrated are connected to the same system of pipes, and water is sent through the pipes by increasing the upstream pressure. The equipment is left this way for a certain time to stabilize the flow in the pipe, and the flowmeter is calibrated by comparing its output with the output of the standard flowmeter. This method of calibrating is called the comparison method.

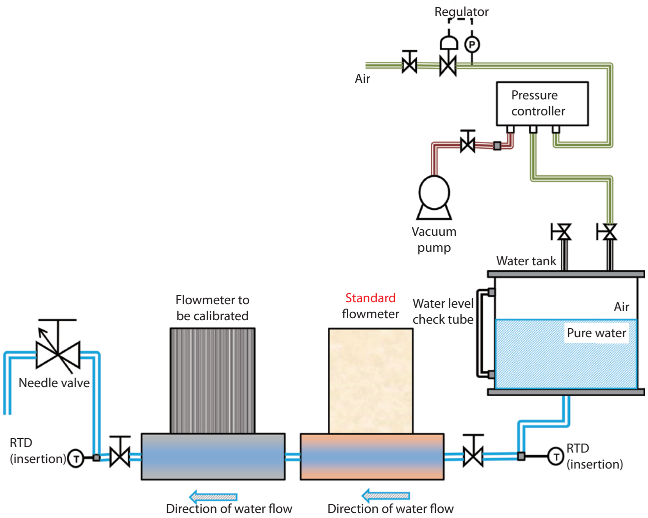

Fig. 2. Comparison calibration of liquid flowmeters

With this method, the accuracy of calibration cannot exceed the accuracy of the standard flowmeter. Therefore the weighing method, which is described below, is used for high-accuracy calibration. In the weighing method, the weight of the water that has passed through the flowmeter and the amount of time are measured to calculate the mass flow rate.

2.2 Micro flow calibration equipment

2.2.1 JCSS registration

Our calibration equipment for micro-flow flowmeters is at FTC, where the Technology Standardization Department's Measurement Standard Section, along with its equipment is registered as a JCSS service provider, as shown in table 1.

Table 1. JCSS registration (for micro flow)

Registration number	0155
Calibration method category	Liquid flowmeter
Type	Micro flow meters
Calibration range	1 g/min to 30 g/min
Expanded uncertainty Confidence level: approx. 95%	0.15 %

1 g/min ≈ 0.001 L/min

2.2.2 Equipment overview

An overview of the calibration equipment for micro flow meters is shown in figure 3. The equipment can be installed in a 1.5 m × 1.5 m space. Water flows from the tank on the right to the scale on the left through a pipe. The pressure in the tank, and therefore the water supply, is controlled by the pressure controller at the upper right of the figure (set to an absolute pressure in the 250–400 kPa range).

In order to control the flow rate at a certain level, the water pressure must be maintained at a certain level. However, if we controlled the water pressure with water, pulsation would result because the force would be transmitted too fast. Therefore the equipment is designed to use the viscosity of air to reduce pulsation through pipe resistance and the volume of the tank.

Water pushed out of the tank runs through the flowmeter and is discharged and collected in a container that is on a scale. After a certain amount of time has passed, the flow rate can be determined by dividing the mass of the water in the container by the elapsed time. However, the smallest flow rate that can be measured in this way is 1 mL/min, and measuring with high accuracy requires that various phenomena be taken into account. The following section describes these phenomena and the measures taken in detail.

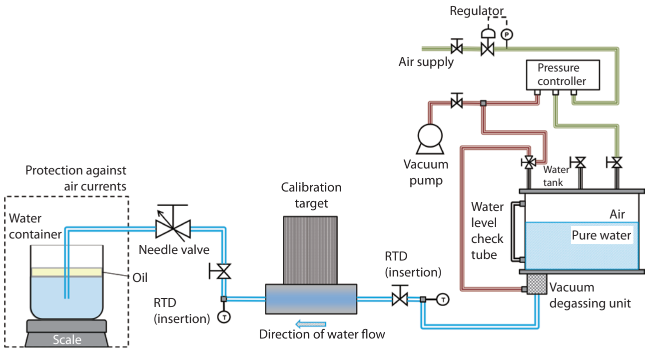

Fig. 3. Diagram of the micro-flow calibration equipment

2.2.3 Equipment overview

Accurate measurement of flow rates requires an understanding of error factors and the corresponding countermeasures. Since some of these countermeasures involve troublesome trade-offs, it is necessary to ascertain the coefficient of uncertainty and the transient physical phenomena and then to adjust the construction of the calibration equipment, or add some steps to the procedure, etc., taking into account the balance among various factors. Below we describe the features of our equipment that reduce the impact of the four error factors listed below.

(1) Countermeasures for evaporation of water

First, we describe how we prevent the evaporation of water (refer to fig. 3). When calibrating a flowmeter using the weighing method, water that runs through the flowmeter is collected in the container on the scale. Since this is a very small amount of water, even a slight amount of evaporation during measurement affects the results. To prevent evaporation, we must use a little ingenuity to keep the water from coming into direct contact with the air in the measurement environment. We keep the water from evaporating by using a layer of vegetable oil as a floating lid over the water in the container. Part of the reason we chose this substance is that it is a liquid that puts a minimal force on the scale.

(2) Countermeasures for air bubbles and dissolved air

A method is also needed to prevent the generation of air bubbles in the pipes. The micro flow meter calibration equipment includes some fittings and valves, resulting in uneven inner diameters in the pipe. The difference in diameters causes a pressure difference in the water as it flows through the pipe, creating an environment where air bubbles are readily generated. Air bubbles in the pipes during liquid flowmeter calibration would cause error due to differences in physical properties like the volume of the liquid and its thermal conductivity. Therefore, air bubbles and dissolved air in the water are removed by vacuum degassing of the water inside the tank before the start of calibration. Afterward, when calibration begins and the air inside the tank is pressurized to supply water, air gradually dissolves into the water. To remove the air that is dissolved into the water during calibration, the vacuum degassing unit is located at the exit of the tank. The flow path through the degassing unit is composed of a porous Teflon membrane surrounded by a container on the outside. With this structure, a vacuum is maintained in the container and air bubbles pass through the membrane and out of the flow path. Due to the principles involved in degassing, part of the water turns into steam at the same time, and the heat of vaporization causes the water temperature to decrease. For that reason the pipe is covered with a heater to restore the lost heat and accurately control the water temperature. At the same time, the steam is also degassed and the water pressure inside the pipe decreases. A design that anticipates this pressure loss is necessary.

(3) Countermeasures for temperature changes

The following describes what impact changes in temperature have on flow rate calibration. No matter how accurately the temperature of the measurement environment is controlled, it is virtually impossible to eliminate variation due to the entry and exit of people and the heat generated from the calibration equipment. In addition, when water flows through the pipe, the water's temperature rises due to heat generated by the electronic circuits, etc., as the water passes through the flowmeter. Therefore, eliminating changes in the water temperature is also very difficult. The phenomenon that needs to be considered here is that any change in temperature due to varying thermal conductivity and coefficient of thermal expansion between the pipe and water have an impact on flow rate calibration. This is because the water is forced out or sucked in by expansion and contraction. An approach that minimizes the volume of piping between the flowmeter and the container on the scale is effective. If the pipe is too small (narrow and short), however, the pressure loss is greater, restricting the flow of water. Accordingly, we originally designed the line size and length on the assumption of a flowmeter with a large pressure loss. However, for micro flow rates we were not able to obtain the results expected on the basis of theory, and we had to find an appropriate pipe volume through trial and error.

(4) Countermeasures for droplets

In micro flow rate calibration, due to the small amount of water being measured, if the pipe outlet is above the surface of the water, droplets fall from the pipe into the container on the scale intermittently, which prevents the acquisition of continuous data. As a result, the change in mass per hour is not consistent. To deal with this, the pipe's outlet is immersed in vegetable oil while water is being supplied, making it possible to acquire continuous data. Figure 4 shows part of the results from before and after implementation of this countermeasure. Even though the flow rate is only approximately 0.05 g/min, continuous data can be acquired using this method.

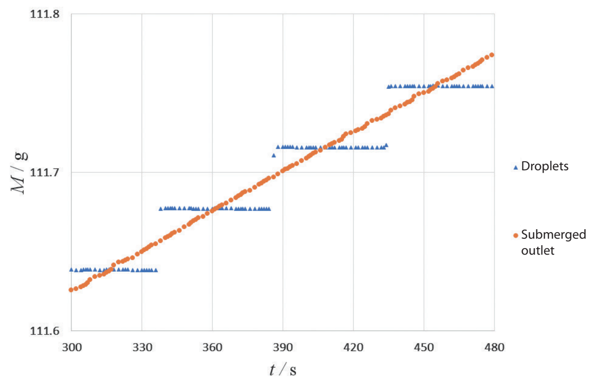

Fig. 4. Impact of droplets and effect of immersing the pipe outlet

As shown in figure 4, the problem of droplets has been solved. However, the amount of water in the container increases during measurement, so that the pipe gradually becomes deeper under the water. As a result, as the amount of the pipe in the water increases, the buoyancy for that volume is a source of error. For that reason the submerged pipe is designed to be as narrow as possible, allowing the impact of this error to be ignored.

2.3 High-flow calibration facility

2.3.1 JCSS registration

Our calibration facility for high-flow flowmeters is at Azbil Kyoto, where the Calibration Group with its facility is registered as a JCSS service provider, as shown in table 2.

Table 2. JCSS registration (for high flow)

Registration number	0274
Calibration method category	Liquid flowmeter
Type	Water flowmeter
Calibration range	0.002 m^3/h to 5090 m^3/h
Expanded uncertainty Confidence level: approx. 95%	0.10 %

2.3.2 Facility overview

The high-flow calibration facilities at Azbil Kyoto store a large amount of water in an underground tank and then circulate the necessary amount of water for calibration. Below we describe the flow calibration facility and the water flow, which starts from the underground tank, as illustrated by the cross-sectional diagram in figure 5. First, a pump moves water up from the underground tank to the elevated tank. From there, gravity sends the water into various pipes (the calibration lines shown in table 3). The opening of the flow control valve is adjusted to reach the target flow rate based on the output of the control flowmeter as it measures the flow. When the flow rate stabilizes after the water discarding process, the flow path is switched by the diverter so that water is stored in the weighing tank. When the specified amount of water has accumulated, the diverter switches the flow path again and the mass (weight) of the accumulated water is measured with the scale. The diverter is a device used to switch the water flow in a short period of time, and the time in which water accumulates in the weighing tank can be measured accurately based on a switching signal from the diverter. By dividing the mass of the accumulated water by this time, the flow rate during the time interval (mass/time) can be calculated.

Table 3. Diameters for calibration and flow rate range of the calibration lines at Azbil Kyoto

Calibration line	Diameter for calibration	Flow rate range
S1	2.5mm to 25mm	0.005 m^3/h to 14.1 m^3/h
S2	2.5mm to 25mm	0.002 m^3/h to 14.1 m^3/h
M1	40mm to 50mm	4.34 m^3/h to 42.4 m^3/h
M2	50mm to 65mm	14.8 m^3/h to 71.7 m^3/h
M3	80mm to 100mm	39.8 m^3/h to 226 m^3/h
L1	125mm to 200mm	102 m^3/h to 905 m^3/h
L2	250mm to 1200mm	442 m^3/h to 5090 m^3/h
T	15mm to 200mm	0.090 m^3/h to 905 m^3/h

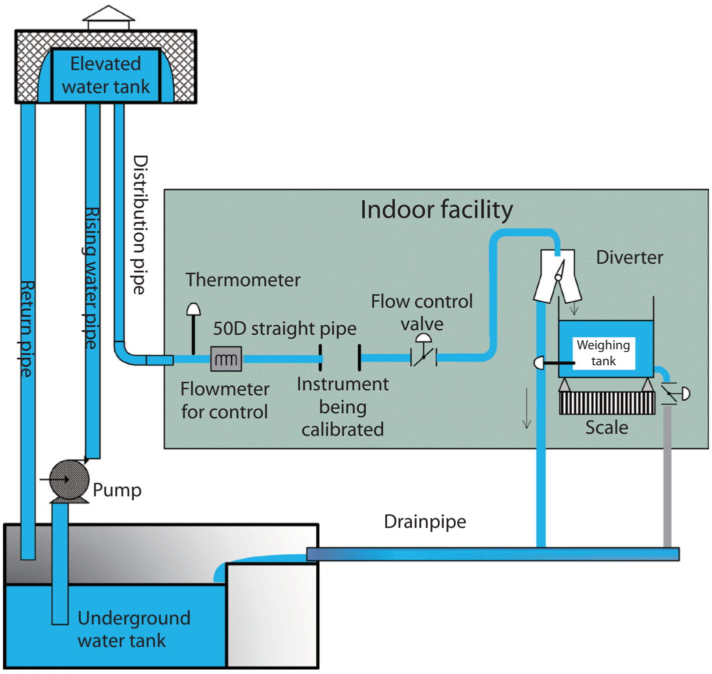

Fig. 5. Cross-sectional diagram of the flow calibration facility

2.3.3 Features of the facility

The following introduces the four main features of our high flow calibration facility.

(1) Elevated water tank

First, we discuss the role and function of the elevated water tank in relation to the stabilization of high rates of flow. Generally, when water is sent through pipes at a high rate, a source of hydraulic pressure such as a pump is used to circulate it. However, such sources of hydraulic pressure naturally cause pulsation and swirl flow. In addition, heat generated from the pump increases the temperature of the water. Consequently, it is difficult to create the stable flows necessary for calibration.

Consequently, in order to achieve a stable high-rate water flow, Azbil Kyoto installed elevated tanks with 35 m and 20 m drops and constant water overflow from the tanks to keep the water's surface at a constant level and thereby stabilize the water pressure. This is called the overflow method, and using it gives the facility a system in which stable flows are created by gravity, eliminating the effects from a source of hydraulic pressure such as a pump. As of 2021, the elevated water tanks at Azbil Kyoto have the largest capacities and the greatest heights of any in Japan.

Each calibration line shown in table 3 is individually connected by pipes to the elevated water tanks, and so its flow stabilizes as the water pressure stabilizes without any effect (water pressure fluctuation) from water flowing through the other calibration lines. In addition, as shown in figure 6, the elevated water tanks have a two-stage structure, with the bottom stage supplying water to large calibration lines and the top stage to smaller lines.

The water used for the calibration lines flows into the underground water tank below the pump room. The underground tank is always ready with at least 800 m^3 of water, which is plenty even at the maximum flow rate. Since the water is reused by circulating it from the underground tank to the elevated tanks, the system is designed with consideration of the environment.

(2) Piping

An important element of flow rate measurement, in addition to stable water pressure as explained in (1) above, is the state of the water flow. As shown in figure 6, the piping includes converging pipes, branching pipes, valves, and elbows. In such places drift flows (drift) and rotating flows in the pipe (swirl flow) occur. Since some of the flowmeters to be calibrated may be affected by these factors, it is necessary to create a well-ordered (axisymmetric) flow without drift or swirl components. In piping design, a fluid simulation is performed to achieve a pipe layout in which swirl flow is minimized. In addition, straight pipes with lengths 50 times the diameter (50D) are installed immediately in front of the flowmeter being calibrated on all calibration lines to achieve a stable flow.

(3) Countermeasures for air bubbles and dissolved air

Bubbles are a cause of error even for high flow rates. Since the elevated water tanks are exposed to the atmosphere, it is not possible to prevent bubbles from forming by using vacuum degassing of the water, but if conditions in which the bubbles dissolved in the water are small can be maintained, a significant impact from them is unlikely in a large flow. However, if air bubbles coalesce in the pipe and are discharged into the weighing tank during calibration, they will be a major cause of error. To prevent this, a place where air bubbles readily gather is created by taking advantage of the difference in elevation of the pipes, and the air is vented immediately before starting calibration. This venting is performed on all eight calibration lines shown in table 3, and air bubble detectors are also installed. If air bubbles are detected, the system automatically stops the calibration process.

(4) Prevention of temperature changes

The effects of changes in the temperature of the environment, as well as the temperature of the water and pipes, on the calibration results is the same as for micro flows, so some details are omitted. However, the calibration facility at Azbil Kyoto is extremely large in size and cannot be installed in a thermostatic chamber. Accordingly, the temperature of the water and pipes changes significantly depending on the season due to the outside air temperature. We therefore take the time to do a warm-up run of the facility by circulating a large amount of water and thereby stabilizing the water and pipe temperature to minimize temperature fluctuations during calibration.

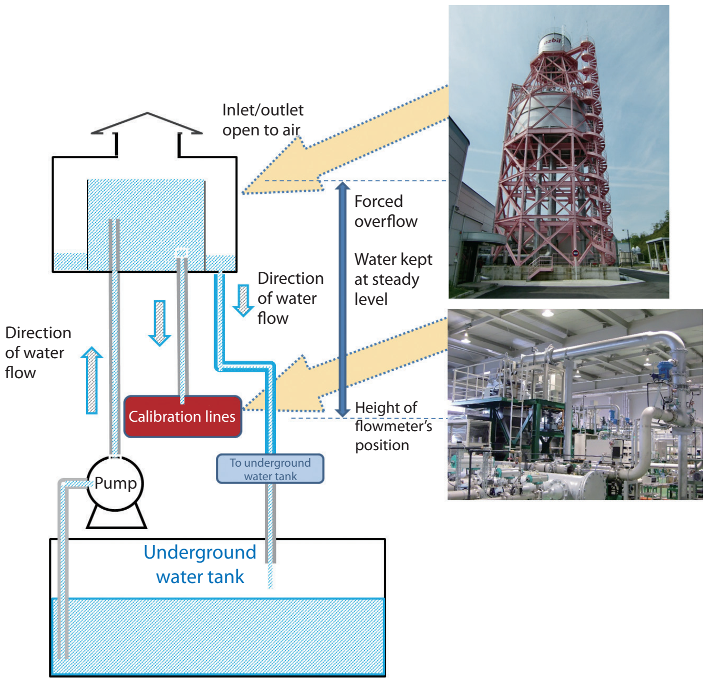

Fig. 6. Flow of water in the high-flow calibration facility

3. Traceability

A flow rate is defined by mass (or volume) and time, and clarifying its traceability requires being able to trace it back to higher standards for these two components. First, a mass-measuring device (balance, etc.) is calibrated onsite at one tenth or less of the uncertainty of the flow measurement using JCSS-calibrated balance weights. Next, for time measurement, the time on a PC is used for the micro flow calibration equipment (section 2.2 above) at FTC. A special frequency board is installed in the PC, and a 10 MHz signal from a standard frequency generator is input to the PC to use its time as the reference time. Therefore, the standard frequency generator (fig. 7) serves as the standard device for time measurement. This standard frequency generator is set to receive signals from GPS satellites and is calibrated remotely in real time by comparing the standard time from the National Institute of Advanced Industrial Science and Technology (AIST) via GPS signals. The Technology Standardization Department's Measurement Standard Section at Azbil, which uses this remote calibration mechanism, is also registered as a JCSS service provider in the frequency category.

Azbil Kyoto's high-flow calibration facility (section 2.3 above) reads the time interval for switching by the diverter from the frequency counter. In the same manner as at our micro flow calibration equipment, a 10 MHz signal from a standard frequency generator is input to the external reference signal input of the frequency counter. Therefore, the standard for time measurement is not the internal time base of the frequency counter but the standard frequency generator, which has higher accuracy. This standard frequency generator is remotely calibrated with the FTC's standard frequency generator as the standard, using the remote calibration mechanism described above. Before the standard frequency generator was introduced at Azbil Kyoto, a total of 16 frequency counters installed in calibration lines (two per line) were sent to FTC for calibration once a year. After the introduction of the remote calibration system (called e-trace), calibration of individual frequency counters is no longer necessary, which eliminated the risk of drift due to removal or transportation of counters, since they are no longer transported.

Using a standard frequency generator as the standard, rather than the internal clock of the PC or a frequency counter as described above, has significantly reduced the uncertainty that is attributable to the time standard. In addition, the synchronization function of the standard frequency generator enables it to be constantly synchronized with the time standard of AIST via the Internet. Therefore, the error in time measurement is negligibly small for the uncertainty in flow measurement.

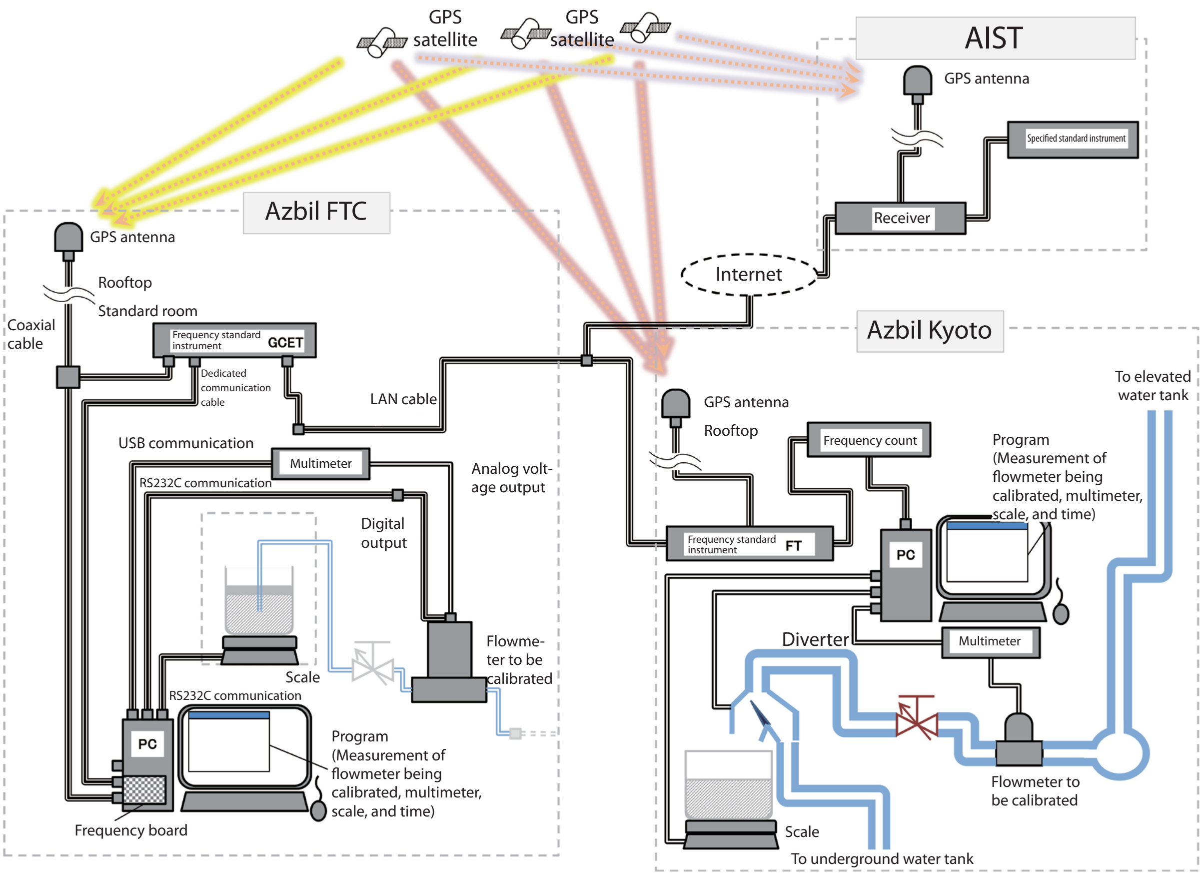

Fig. 7. Traceability diagram

3.1 Ramified traceability

After the establishment of the JCSS system in 1993, ramification was introduced as one of its main improvements, with the aim of spreading JCSS calibration among the more familiar onsite measurement instruments. Ramification refers to a system of calibrating with appropriate and inexpensive methods using measuring instruments calibrated by a registered JCSS service provider with a higher standard of accuracy. For example, flowmeters calibrated at Azbil Kyoto are used as the standards to calibrate other calibration lines, which are also deemed to be JCSS-calibrated facilities (called liquid flowmeter calibration facilities (WS)). This has simplified facility management and reduced calibration costs. Using such calibration lines for JCSS calibration of brand new electromagnetic flowmeters reduces the impact of calibration on product cost.

4. Conclusion

Azbil Kyoto was first registered with JCSS in the liquid flowmeter category in April 2011, and then it expanded the scope of its registration in April 2014 to the current range of 0.002 m^3/h to 5090 m^3/h. Afterward, in October of 2019, Azbil Kyoto was also registered in the micro flow range (1 g/min to 30 g/min). Currently, as one of the registered JCSS service providers for water flowmeters in Japan that supports a wide range of flows, Azbil Kyoto has received a large number of calibration jobs and requests for flow calibration consultation. Because we do nearly 200 calibration jobs per year, including non-JCSS calibration (general calibration), we feel that interest in the calibration and traceability of flowmeters is growing by the year. Going forward, it seems that JCSS calibration will become more common as the need for it increases due to its incorporation into the requirements of various standards, and so it is unlikely that the number of requests for our JCSS calibration will decrease. As both a flowmeter manufacturer and a calibration operator, the azbil Group can contribute to the further familiarization and utilization of the JCSS calibration service provider registration system, while continuing to operate both of these businesses.

Author affiliation

Nobuyuki Sugiyama　Measurement Standard Section
Technology Standardization Department
Azbil Corporation

Toru Yamaguchi　Measurement Standard Section
Technology Standardization Department
Azbil Corporation