THE UPGRADED CONTROL SYSTEM OF PRIMARY LIQUID FLOW MEASUREMENT STANDARD AT NIMT

T. Chinarak[1], K. Leetang[2] and T. Changpan[3]
[1,2,3]National Institute of Metrology (Thailand), NIMT
[1,2,3]3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120, Thailand
[1] theerarak@nimt.or.th, [2] khanistha@nimt.or.th, [3] tawat@nimt.or.th

Abstract

The liquid piston provers have been widely used as the primary standard for liquid flow measurement. There are many flowmeters which can be used with the prover such as turbine flowmeters, variable area flowmeters, electromagnetic flowmeters, etc. The flowrates from the prover are measured by volumetric method. Thus, the displaced volume of water and the moving distance of the piston during measurement are the key factors. In order to receive the accurate volume, the efficient system for gaining pulses from the linear encoder is needed. Also, temperature and pressure of liquid inside the piston cylinder and the environmental conditions are involved with the measurement.

Recently, the piston prover at NIMT had been upgraded by replacing the out-of-date control system and modifying the key equipments; linear encoder, PT-100 and digital manometer. Moreover, the well-known method called 'water draw' has been brought to verify the new system and provides the piston prover constant value. The uncertainty of the system is evaluated and reported as 0.07% (k=2).

Introduction

The flow calibrator, Piston Prover MT-50 made by 'Flow Technology Company', has been used for calibrating the liquid flow meters at NIMT since 2003. The software and the computer are operated on Windows®95 system which is out of date and some problems have occurred while calibration such as temperature reading error, miss-counted of encoder pulses. Moreover, the maintenance and calibration of elements in the system have not been done correctly according to the national standard.

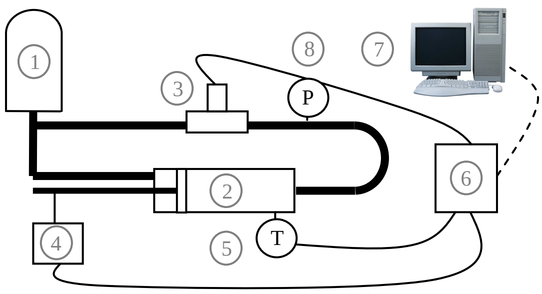
Therefore, the old computer is replaced by a new computer system and software. The new control system has been designed and performance improvements are expected in calibration and measurement. Also, equipments are traceable to SI units and can be done at NIMT.

As a result, the flow calibrator is improved to provide the volumetric flow rate measurement uncertainty from ± 0.10% to ± 0.07%. In calibration of meter under test, the uncertainty of turbine flow meters are ±0.20% and ± 2.0% for variable area flow meters (k=2). Finally, the bilateral comparison result reveals that the new system is sufficient and effective to be the primary standard of liquid calibration system.

Measurement system

Fig. 1 shows the original system of the liquid piston prover. The surge tank acts as a liquid reservoir and catch tank for the system. Flow tube is made of stainless steel with thickness, inner diameter and displacement; 4.7625 mm (0.1875 inch), 152.4 mm (6 inches), 11.355 litres (3 gallons) [1]. When the piston moves along the cylinder, the liquid is swept and flowing through the meter under test, MUT. Simultaneously, the translator converts linear movements to electronics signal and sends the pulses train to the service connection box. Then, liquid volume is calculated accordance to the displaced volume determined by linear movement.

Other parameters involved in calibration are water temperature, water pressure, measuring time and room conditions. The water pressure is measured by the digital pressure manometer which is used only when water draw mode is needed. The room conditions; temperature, humidity and pressure are monitored by electronic thermo-hygrometer. In case of turbine flow meter calibration, the meter frequency is connected to the system. Then, the meter frequency is another parameter which is connected to the interface box (no. 6 in fig.1) as same as the temperature signal from RTD transmitter and translator pulses. Additionally, the measured time also comes from the time base in the computer.



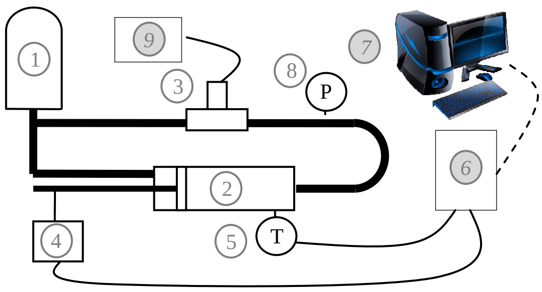
LEGEND: 1 Surge tank, 2 Flow tube, 3 Meter under test, 4 Service connection box (Linear encoder), 5 RTD, 6 Interface box, 7 Computer, 8 Pressure manometer

Figure 1 Old data acquisition system

Apparently, timing, linear encoder signal calibration, meter frequency reading and temperature measuring are dependent on the old data acquisition system. The upgrading of such a system improves overall uncertainty evaluation, intermediate check and maintenance.

Therefore, the upgraded data control system as shown in fig. 2, has been designed and developed. The computer and interface box are replaced. The new computer operates on Windows® XP system (Intel Core 2 Duo CPU). The interface box was replaced by PCIe6321 (NI DAQ) which is important in executing input and output signal.

The sinusoidal wave form which is output from the encoder is transformed to squared wave by the service connection box attached next to the encoder. Then the squared wave is sent out to the DAQ box and ready to be executed by the programme (LABVIEW). The advantage from the improved method is that the displacement calibration of the linear encoder is done easily by using the laser interferometer.



LEGEND: 1 Surge tank, 2 Flow tube, 3 Meter under test, 4 Service connection box (Linear encoder), 5 RTD, 6 PCIe6321 (NI DAQ), 7 Computer, 8 Pressure manometer, 9 Frequency counter

Figure 2 Upgraded data acquisition system

The wiring between RTD and DAQ is one of the advantages of temperature measurement by using DAQ. The complicated connection and large size of wires have been replaced by smaller ones and connected to the DAQ sockets which are designed to be friendly for users. Moreover, the temperature measuring result in the new programme is calculated directly from the compensation equation presented on its calibration certificate. Consequently, the temperature measurement in the new system is very accurate.

As mentioned above, the frequency counter is needed when the turbine meter is calibrated. The counter with the high accuracy of frequency reading while calibrating the turbine flow meters is introduced into the system. Thus, the new frequency counter with uncertainty 4.7 x 10^{-7} Hz calibrated at NIMT is installed.

Finally, DAQ provides the good accuracy of clock generator which is 10 MHz. That means the measuring time while calibrating flow rate comes from the DAQ with high accuracy. Since all data (time, frequency, temperature and encoder pulses) are sent out to DAQ, the volumetric flowrate measurement can be executed and the system is completed for flow calibration.

To verify the system and a new programme, we use the water draw mode and calibration mode. The water draw method is recommended by the calibrator manufacturer [1] and also this method is commonly used for determining the prover constant and uncertainty. The water draw mode and calibration mode will be discussed in topic no. 4 and 5. Then, the bilateral comparison is applied to confirm that the calibrator performances have reached the international standards.

Traceability

The traceability is very important for the primary system that verifies reliability of uncertainty evaluations in flow applications. With new data acquisition system, it allows equipments to be calibrated and kept monitored periodically. Furthermore, the out of date equipment can be changed to improve the system appropriately.

Tables 1 to 4 present the details of each component which has been changed for the improvement purposes.

Table 1 Data Acquisition (DAQ)

Measurand	Time
Manufacturer	National Instruments
Range	0 – 25 MHz
Measurement Accuracy	50 ppm
Traceability	Frequency Counter (see Table 4)

Table 2 Linear encoder

Measurand	Length
Manufacturer	Mitutoyo
Range	0 – 500 mm
Measurement Uncertainty	80 µm
Traceability	Dimension Lab (NIMT)

Table 3 RTD

Measurand	Temperature
Manufacturer	Kinetic Co.
Range	21 – 25 °C
Measurement Uncertainty	0.1 °C
Traceability	Temperature Lab (NIMT)

Table 4 Frequency Counter

Measurand	Frequency
Manufacturer	Agilent
Range	10 MHz
Measurement Uncertainty	4.7 x 10^{-7} Hz
Traceability	Time and Frequency Lab (NIMT)

Water draw method

With a simple method but effectiveness in result, the water draw is an important procedure used for calibrating the prover system. Basically, the involved equipments in this process are weight balance, standard weights and water container. The measuring process is done under control conditions that are room temperature (20 ± 2 °C) and room humidity (55 ± 15 %RH). Additionally, the room pressure, and water pressure and temperature are also measured.

The water in the surge tank has to be left in the room temperature for 24 hours prior to test. There is no MUT installed in the system while doing water draw. The entrapped air in the system has to be released by the air bleeding valve. These are preparation for the water draw mode. Once the piston moves with the constant speed, the water is dispensed into the container. The control conditions are recorded. The water and the container are accurately weighed on the weight balance. The mass of water, m_w, is determined following the mass comparison method [2]. Then, the volume of water, V_w, is achieved as shown in equation (1) which has Z and Y represented for combined factors of the buoyancy correction and conversion from mass to volume and the thermal expansion correction factor of the delivering device respectively [3], [4].

$$V_w = m_w \times Z \times Y \qquad (1)$$

.

The expansion of cylinder according to temperature and pressure changes affects the volume measurement. Then, the effective volume of water, V_{eff}, is the product of V_w considered with coefficients; compressibility of water, C_{cw}, expansion of cylinder due to temperature, C_{et}, expansion of cylinder due to pressure, C_{ep}.

$$V_{eff} = \frac{V_w}{C_{cw} \times C_{et} \times C_{ep}} \qquad (2)$$

Finally, the piston prover constant, K_p, is achieved as shown in equation (3). It comprises of the effective volume of water and the encoder pulse numbers, N_e.

$$K_p = \frac{N_e}{V_{eff}} \qquad (3)$$

In the SI unit, the K_p is typically reported in pulses per litre. After data collection, the result reveals that the relative uncertainty of the primary standard is ±0.07%. The example of uncertainty evaluation of the piston prover constant, K_p is shown in table 5.

Table 5 Uncertainty budget for the piston prover constant, K_p

Source of uncertainty	Relative uncertainty (%)
The combined factor for buoyancy correction and conversion from mass to volume, Z	*0.00698*
The thermal expansion of delivering device, Y	*0.00014*
The compressibility of water, C_{cw}	*0.00085*
The expansion of cylinder due to temperature, C_{et}	*0.00129*
The expansion of cylinder due to pressure, C_{ep}	*0.00052*
The mass of measured water, m_w	*0.01108*
The encoder pulse number, N_e	*0.00225*
Repeatability of the calibration, u_{repeat}	*0.02894*
Combined Uncertainty, $u(K_p)$	0.032
Expanded Uncertainty (k =2), $U(K_p)$	**0.064**

Even the example in table 5 shows the uncertainty of the system at 0.053%, the system is still guaranteed at ±0.07% uncertainty (K=2).

Calibration mode

Turbine flowmeters have been used as transfer standards because of its high accuracy and repeatability. The small turbine flowmeters made by Flow Technology® were used for carrying out the calibration result of the developed data acquisition system for the primary standard. The frequency counter is used as one of the main equipments for measuring the frequency signals which is sent out from the meter pick off. Other measuring parameters are time, t, encoder pulses number, N_e, and the piston prover constant, K_p.

The effective volume of water, V_{eff}, is achieved from the encoder pulses and the piston prover constant as shown in equation (3). Then, the meter frequency, f_m, which is read by the frequency counter, is used for calculating the pulses made by the meter, N_m. Equation (4) shows the relationship between the meter K factor, K_m, and the effective volume of water and the meter pulses number.

$$K_m = \frac{N_m}{V_{eff}} = \frac{f_m \times t}{V_{eff}} \qquad (4)$$

Similarly, the meter K factor, K_m, in equation (4) is reported in the unit of pulses per litre.

Comparison result and discussion

The bilateral comparison between Center of Measurement Standards (CMS) Taiwan and National Institute of Metrology Thailand (NIMT) was performed in order to demonstrate the degree of equivalence of the water flow measurement standards and to provide supporting evidences for the calibration and measurement capabilities (CMCs) claimed by them. The turbine flowmeters were chosen to act as transfer standards.

At CMS, the calibration was tested by the primary standard – gravimetric method. The characteristics of the transfer standard are considered by the meter K factor, flowrates and uncertainty. Fig. 3 shows the result of transfer standards after data collection at CMS and NIMT.

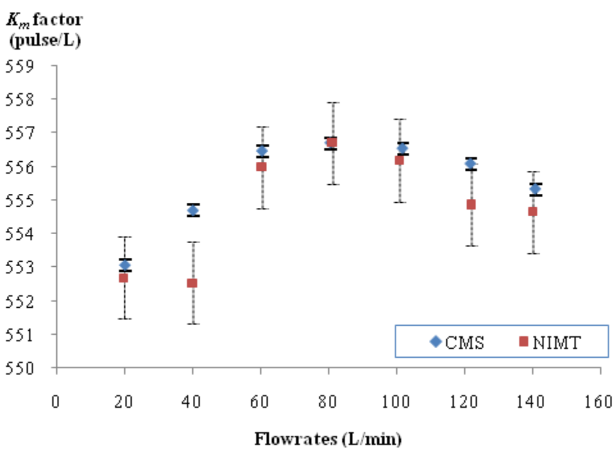


Figure 3 K_m factor - volumetric flowrate (L/min)

Regardless of uncertainty and linearity of the graph in fig. 3, the relationship between flowrates and K_m of both CMS and NIMT is growing in the same trend.

When considering of uncertainty and linearity, however, the discussion of result are listed.

- The uncertainty of CMS primary standard is much smaller than NIMT's that results in large E_n number.
- More data collection is needed in order to predict the characteristics of the standard flow meters.
- Flow meters from different manufacturers shall be calibrated to gain more data.

In conclusion of comparison result, the meters have already show good trend of characteristics which is calibrated under the developed data acquisition at NIMT. All the suggestions made after the comparison will be applied. Also, the improvements according to those suggestions are considerably valuable for the system.

Conclusion

The new data acquisition system in liquid flow measurements at NIMT presented above has provided some advantages as follow:

- The equipments can be periodically replaced by a new and technology applications and also they have higher performances
- Similarly, the software can be updated easily when they have launched the new version
- Element traceability can be done at NIMT providing the international standards
- Uncertainty can be evaluated clearly
- Any improvements of equipment affect on the uncertainty determination and the primary performances
- The new data acquisition system is proved by comparison measurements which is the good sign for any further improvements in the future

References

[1] J. Blasius, *Microtrak/Omnitrak MT-10, MT-50, OT-150, OT-400 Calibrator*. Flow Technology, 2007.

[2] *OIML R 111-1:2004(E).* Weights of classes E_1, E_2, F_1, F_2, M_1, M_{1-2}, M_2, M_{2-3} and M_3 Part 1: Metrological and Technical Requirements.

[3] *Part X Metering Proving Section 3 code of practice for the design, installation and calibration of pipe provers*, The institute of petroleum, London. First edition, August 1988.

[4] *ISO/TR 20461.* Determination of uncertainty for volume measurements made using the gravimetric method