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NATIONAL MEASUREMENT INFRASTRUCTURE FOR HIGH-PRESSURE NATURAL GAS AND TRACEABILITY PRACTICES

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ABSTRACT

Based to the policies of efficient energy utilization, environmental protection, particularly in reduction in CO_2 emission; and stable economical growth, Taiwan government adopted natural gas as a source of clean energy since 1980s. Each year, over 3 million tons of Liquefied Natural Gas is imported from Indonesia and Qatar for electrical power generation from national-owned and private industrial-own companies. It is estimated by the year 2020, the appropriation of natural gas consists of 25% of national energy sources.

Evidently, to safeguard fair trade of energy transactions and validation of gas emission on global warming effect, accurate measurement of natural gas consumption and traceability to national primary standards is essential. Roughly, a 1% error in measurement causes 40 million USD un-accounted losses per year for NG supplier. Thus, a project to construct a national measurement infrastructure to serve this purpose was initiated since 1990s.

This paper describes the use of three different flow design principles to construct an unbroken chain of traceability hierarchy and demonstrates calibration with well-proven uncertainties. For each standard facility, ultrasonic meters are used in parallel to cascade up from Dia:150mm, 10bars, 1000 Actual m^3/hr; to Dia:600mm, 55bars pressure, and 16000 Actual m^3/hr. For two years' successive on-site measurement of six meters, relative errors are within ±0.1%, with uncertainty less than 0.35%. The daily difference between custody transfer and check meters remains within ±0.2%.

INTRODUCTION

Traditionally, turbine meters have been used predominately as a reliable working standard for calibration laboratories or in a metering station for trade purposes, besides the orifice plates. However, the characteristic of a turbine meter is Reynolds number dependent. Also, as the meter is operated at different flow pressure (different density), error curve shifts accordingly. For orifice plate, the limited turndown ration, as well as bulky in size, difficult for real flow calibration, and relative large error, makes it less attractive for high-precision transaction measurements of high-valued commodity, such as natural gas.

In recent years, the development of ultrasonic technology with its diagnostics capability has proven its advantage, in some way, over turbine meters and orifice plates. The basic working principles of a transit-time ultrasonic meters shows its less affected to gas properties as well as working conditions, such as pressure or temperature. As described in ISO 17089[1], the pressure correction on relative meter error is 0.06%, for a pressure variation of 6.3MPa, and pipe wall thickness to radius ratio of 0.25. With a temperature change of 23℃, the correction in flow measurement error is less than 0.07%. Minor concerns are only the minimum gas pressure (density) required for acoustic coupling and content of carbon dioxide or hydrogen in the gas mixture for acoustic absorption.

Adding to the advantages of selecting an ultrasonic meter are its diagnostics features such as, footprints of signal to noise ration, speed of sound along each acoustic path, and performance alarm, etc. These allow users to track back possible failure modes of the meter, whether in a calibration process or day-to-day metering situation. It is with such reasons, that Chinese Petroleum Corporation (CPC) adopted ultrasonic meters to replace all orifice plates in the metering stations supplying natural gas to 10 power plants since 2005. The measurement errors and uncertainty of these meters would be safeguarded by the National Measurement Traceability Scheme operated by Center for Measurement Standards/ITRI. In this paper, the scheme and the traceability practices of Da-Tan metering station will be discussed in details.

NOMENCLATURE

V Volume of the gas
P Absolute pressure
T Absolute temperature
Z Compressibility Factor
E Relative Error of Calibration
R Gas constant
t index of the meter under test
i index of the standard flowmeter

NATIONAL PRIMARY FLOW SYSTEM

Under the auspice and authorization of Bureau of Standard, Metrology and Inspection (BSMI), Center for Measurement Standards (CMS) maintains Taiwan's highest high-pressure air-flow national standard. As a joint venture by BSMI, CMS, and CPC, this primary standard was constructed in the 1980s, with an air flow capacity of 18,000 m^3/h and pressure range of 1~60 kg/cm^2[2]. Since its commission, it has provided industries with precise measurement traceability and reached international equivalence through BIPM Key Comparison[3]. The schematic diagram shown in Fig. 1 represents one type of a flow system design, namely the blow-down type facility, which was originated from National Engineering Laboratory (NEL) Scotland. The system utilizes a gyroscopic weighing scale suitable for high precision gravimetric high-pressure flow measurement up to 160 kg with a resolution of 2 grams. The maximum advantage of the blow-down type facility is the ability to endure greater pressure difference due to piping and secondary measurement standards, i.e. sonic nozzle; or meter under test (MUT). The measurement uncertainty of the gyroscopic scale was estimated to be 0.013 % at a collecting weight of 20 kg.

Besides the gyroscopic weighing scale, a fast acting diverter and a sliding-joint connect-disconnect mechanism, a hydraulic power driving unit; and a set of seven sonic nozzles designed as a binary set such that the throat diameters progress by a factor of 2, comprised the core of the flow system to perform a primary mass flow calibration. As the flow-rate and pressure reached a stable condition, the high-pressure air was diverted into the weighing tank. Two 90 degrees out-of-phase ball valves were designed to have a switching over time of less than 60 ms via the control of the hydraulic actuator. Through a series of test following concept of ISO 4185[4], the triggering time position was carefully adjusted to ensure minimum timing error during valves switching. Such that when performing a meter calibration under the maximum flow-rate condition, the discharge coefficient of the working standard, will not be over- or under-estimated, due to the limited collecting time imposed by the choke condition of the sonic nozzle. From a basic fluid mechanics principle, as the flow is choked by the nozzle, it also reached a stable mass flow condition, and thus suitable to work as a reference standard. However, it is also due to the large pressure ratio of sonic nozzle that a blow-down type system is literally limited in flow rate and produces high flow noise that is inherently difficult to operate when calibrating ultrasonic type flow meters. The measurement uncertainty of the working standards was estimated as 0.18% at 95% confidence level with a coverage factor of two

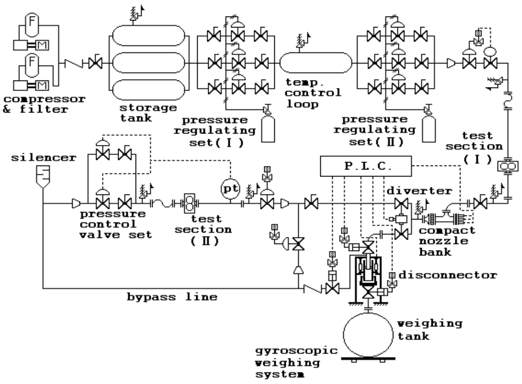

FIGURE 1. PRIMARY HIGH PRESSURE AIR FLOW MEASUREMENT STANDARD

SECONDARY STANDARD AND ON-SITE METERING SYSTEM

To compensate for limited flow range and operation down time for recharging high-pressure storage bottles in the primary system, a consultancy agreement was reached between CMS and CPC in the early 2000s to construct a re-circulating loop flow calibration system. The system is in the form of a closed loop charged and held to a required pressure (up to 60 kg/cm^2) with air as working medium. Flow is induced through the loop by a set of three encapsulated blowers and a bypass line used in conjunction with regulators for flow rate control between 80~4000 Actual m^3/h. The system is designed to overcome 4 kg/cm^2 flow pressure loss at maximum flow rate and sets of ultrasonic meters and turbine meters are used as working standards and check standards. With a heat exchanger system implemented for temperature stabilization to 0.15 degree Celsius and the case with which extremely stable pressure can be altered at will, it demonstrates the advantage and ability of fast throughput and versatility of meter calibration services. A set of four ultrasonic meters, with 150mm in diameter, are traceable to national system at 10 kg/cm^2 with expanded measurement uncertainty of 0.27%. With the four meters operate in parallel, flow capacity and operation pressure are cascaded up to 60 kg/cm^2 and 4000 Actual m^3/hr, with measurement uncertainty of 0.30% at 95 confidence level. The system was commissioned in 2007 in conformance with ISO 17025 quality system and certification from Taiwan Accreditation Foundation (TAF). Figure 2 shows the overlook of the system.

FIGURE 2. CPC SECONDARY HIGH-PRESSURE AIR FLOW MEASUREMENT SYSTEM

At the same time of constructing the secondary system, a through-flow type, natural gas calibration system was constructed in Da-Tan power plant to serve as a transfer standard for custody transfer and check meters between CPC and Taiwan Power Company (TPC). Through-flow system is a simple and straightforward calibration method in which gas is fed to and withdrawn from the system continually during operation. There are, clearly, various ways in which the gas removed from a through-flow system can be handled including recompression, buffer storage volume and liquefaction. At high flow rates, significant volumes of gas would require extra cost for handling it. This is the disadvantage of the through-flow system. However, in this Da-Tan scenario, natural gas is directly used by the power plant and the only disadvantage is calibration practice needs highly coordinated efforts among metering station and power plant operators.

As depicted in Fig. 3, high-pressure natural gas over 50 kg/cm^2 is diverted to a set of, in this case, four 300mm ultrasonic meters calibrated at CPC secondary system; after passing though four 600mm ultrasonic custody transfer meters. And then, the natural gas is re-directed back through two 600mm check meters, before going to the power plant gas turbines. This flow-through type design allows the custody and check meters to be calibrated simultaneously by the transfer standards. The estimated uncertainty of the MUT, including uncertainty sources from pressure, temperature, gas compositions, and traceability, is 0.35%.

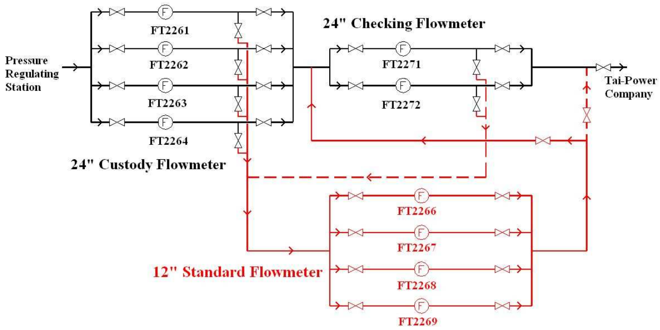

FIGURE 3. SCHEMATIC DIAGRAM OF DA-TAN METERING STATION

DISSEMINATION OF MEASUREMENT STANDARD

Based on International Vocabulary of Metrology VIM[5], a calibration practice represents determination of indicated difference of a measurand against that of a higher standard with stated uncertainty and the process should be traceable to SI units through an un-broken chain of calibration. The general idea is clearly demonstrated in Taiwan as described in aforementioned national high-pressure natural gas traceability hierarchy. A complete traceability diagram showing Flow meter, Temperature, Pressure, and each level of standard is given in Fig. 4. Error of calibration is defined as in Eq. 1 and typical measurement uncertainty evaluation is given in Eq. 2. In the following sections, calibration practices and pertinent data will be presented.

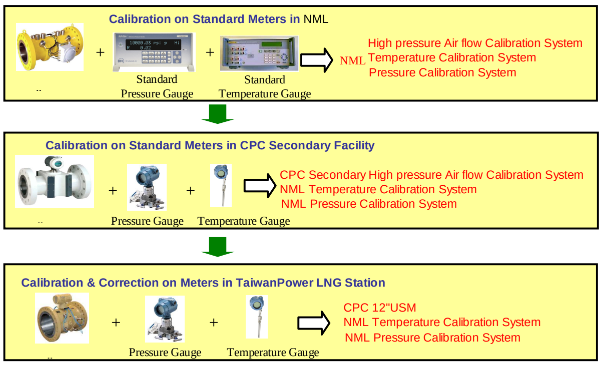

FIGURE 4. NATIONAL TRACEABILITY SCHEME

$$E\% = \frac{V_t - V_i}{V_i} \times 100\% \qquad (1)$$

$$\left(\frac{u(V_t)}{V_t}\right)^2 = \left(1 - \frac{P_i}{Z_i}\frac{\partial Z_i}{\partial P_i}\right)^2 \left(\frac{u_2(P_i - P_t)}{P_i}\right)^2 + \left(1 + \frac{T_i}{Z_i}\frac{\partial Z_i}{\partial T_i}\right)^2 \left(\frac{u_2(T_i - T_t)}{T_i}\right)^2 + \left(\frac{u(V_i)}{V_i}\right)^2 \qquad (2)$$

Transfer Standard Calibration at NML

A set of four ultrasonic transfer standards from CPC were calibrated at the National Primary flow facility. The pipe arrangement is shown in Fig. 5. Each ultrasonic meter is installed between upstream standard compact nozzle array, and a package of 13 flow control nozzles, each with same throat diameter. To attenuate flow noise induced by the nozzle array, two 90-degrees T-sections and a flow acoustic filter were installed before the MUT. Over 20D pipe length and a Zanker flow conditioner were placed before the USM. This arrangement proved to be effective to keep the USM at 100% performance and good signal to noise ratio, judging from the diagnostics software of the meter.

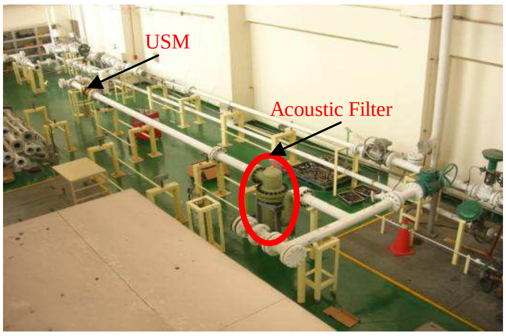

FIGURE 5. PIPE ARRANGEMENT OF USM CALIBRATION

Meter calibrated errors against flowrate of these four USM are shown in Fig. 6. For flowrate below 200m^3/h, also 12.5% of meter maximum flow range, the meter registered higher deviation. However, calibration errors are all within the range of 0.0~0.8%. Comparing to a measurement assurance program of over 1000 USM check meter data points provided by CEESI[6], these four meters perform well and suitable to be the working standards of secondary flow system at CPC.

Results of Meter Calibration at Secondary Standard and On-Site Real Flow Measurement

As depicted in Fig. 7, four USMs were placed in parallel, for the calibration of four sets of 300 mm USM, one by one. To safeguard the calibration results, each USM has a check turbine meter placed downstream of it. The combined test flow rates were from 500~4000 m^3/h, with two test pressure of 20 and 50 kg/cm^2. The test results are shown in Fig. 8 & 9. These data have the same trend as those of 150 mm USMs and repeatability all less than 0.08%. It is, however, an average deviation of 0.1~0.2% observed for each meter, between data set of 20 and 50 kg/cm^2. This pressure correction needs to be taken care of based on ISO recommendation.

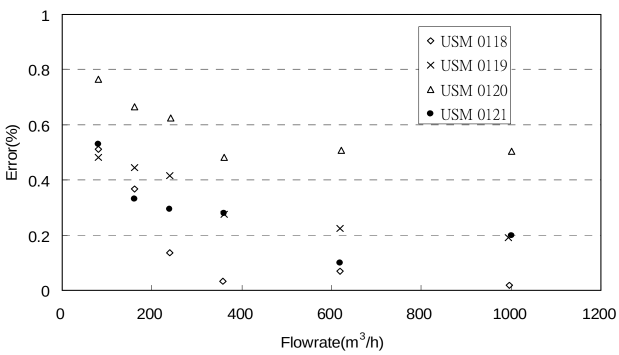

FIGURE 6. CALIBRATION DATA OF FOUR USM METERS AT WORKING PRESSURE: 10 KG/CM^2

FIGURE 7. 300MM USM CALIBRATION

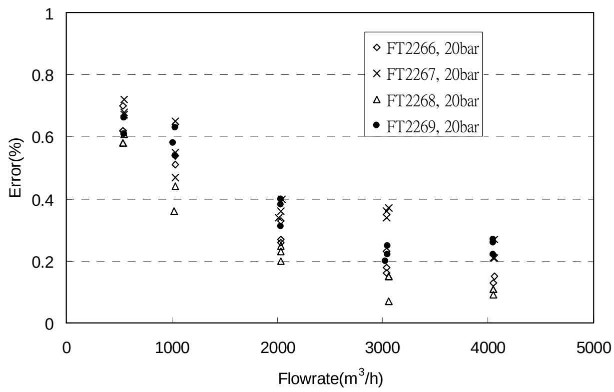

FIGURE 8. DATA OF 300MM USM CALIBRATION AT 20 KG/CM^2

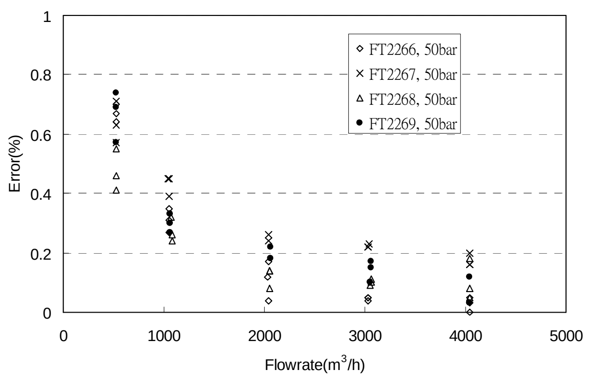

FIGURE 9. DATA OF 300MM USM CALIBRATION AT 50 KG/CM^2

Finally, the results of calibration for 600mm USM at Da-Tan power station is given in table one. As the flow rate and pressure are constrained by the demand of gas turbine for power grid balance, tests were conducted only for working pressure of 55 kg/cm^2 and flow rate from about 17% to 35% of the maximum. Based on the contract, the flowmeter is adjusted of its calibration factor if deviation as found exceeds +/-0.1%. After adjustment, the errors should fall within +/-0.2%. Table one shows the as left data with expanded uncertainty of 0.35%.

TABLE 1. AS LEFT DATA OF 600MM USM CALIBRATION

USM	Flowrate m3/h	Error (%) As Left	Expanded Uncertainty (%)
FT 2261	2850	0.06	0.38
FT 2262	5420	0.14	0.38
FT 2263	4070	0.02	0.38
FT 2264	4880	0.04	0.38
FT 2271	2600	0.08	0.38
FT 2272	5700	-0.07	0.38

CONCLUSION

It took more than 15 years' joint efforts, from BSMI, CPC and TPC, to construct this model case of traceability hierarchy for high pressure natural gas measurement. CMS/ITRI has played a key role in system design and coordination for on-site calibrations. The experience on the usage of USM and data analysis, diagnostics will accumulate in the future, as all metering stations establish such traceability model. From the case of Da-Tan metering station, this calibration practice and actual evaluation of the measurement uncertainty, maintained within 0.38%, has contributed to and given the government agency, a valid proof of the reduction of green house effect.

ACKNOWLEDGMENTS

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