Traceability and Field Measurement Results of Large Capacity Gas Ultrasonic Meters

J.-H. Shaw[1], C.-Y. Kuo[2],
F.-R. Yang[3], I.-C. Chen[4]

[1~4]Cneter for Measurement Standards/ITRI, #30 Ta-Shueh Road, Hsinchu, Taiwan, ROC
E-mail (corresponding author): jiunn-haur.shaw@itri.org.tw

Abstract

This paper presents years of field measurement results for large capacity ultrasonic flow meters, through a well-maintained, from NMi to the field, measurement infrastructure. From 2008-2013, Center for Measurement Standards (CMS) maintained an un-broken chain of traceability for the on-site calibration of six 600 mm USM at 55 bars, located at Da-Tan power plant. A total of eight USM, 150 and 300 mm respectively, were used as transfer standards. In addition, 17 high-pressure custody meters, 250 and 300 mm, from gas distribution stations were calibrated at Chinese Petroleum Corporation (CPC) using the same traceability chain. Due to limitation of flow rate and pressure range at CMS, the four 150mm Instromet meters could be calibrated up to 1000 m^3/h around 10-12 bars only. The rational is based on the design principle that USM measured only transient time and should not be affected by pressure effect, or gas properties. Manufacturer specification also claims a four times pressure difference should not affects its measurement accuracy for industrial applications. Meanwhile, ISO 17089 standards stated an ±0.7% unadjusted meter error band for large capacity class I meters, ±1% for smaller ones.

Data accumulated in that period indicated these 600 mm USM and 17 meters calibrated meet the custody transfer regulation set forth by CPC and Tai-Power Company. However, the low-pressure traceability scheme is not without its risk. Therefore, starting 2014-2015, a set of five 50 mm *Itron* gas meters are used, in parallel, to calibrate an in-house 150 mm SICK USM at 55, 38, and 16 bars, up to 550 m^3/h at the re-circulation system in CMS. The SICK meter is then used at CPC as transfer standards, for calibration of four 150 mm Instromet meters and compared with a 150 mm Q-Sonic Plus meter, which was calibrated at *pigsar.*

In addition, to verify the pressure effect, the SICK meter was tested with CMS blow-down facility at 10 bars, and also at re-circulation system at 55 bars. In 2016, to further verify the effect, the Sick meter was also calibrated at PTB, *pigsar*, at 1, 18, and 50 bars. Test results relating to some years of traceability and field calibration, pressure effect, and from 17 meters calibrated in past years will be presented.

1. Introduction

In recent years, the development of ultrasonic technology with its diagnostics capability has proven its advantage, in some applications, 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[1], the pressure correction on relative meter error is 0.06 %, for a pressure variation of 6.3 MPa, and pipe wall thickness to radius ratio of 0.25. With a temperature change of 23 degree Celsius, 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.

A typical ultrasonic flow meter working principle and its transit time calculation model is given in Figure 1.

The diagram shows only a schematic arrangement of one transducer port. Usually, a multipath ultrasonic transit time gas meter employs several (4-6 pairs) transducers. The transducers are mounted in transducer ports and in direct contact with the gas stream. Gas flow rate is measured, electronically, with the transit times of high frequency sound pulses. Transit times are measured at an angle with respect to the pipe axis, downstream with the gas flow and upstream against the gas flow. For each pair of transducers, time difference between the upstream and downstream propagating transit time is proportional to the average gas flow velocity along the acoustic path. Through integration technique, gas volume flow rate can be calculated.

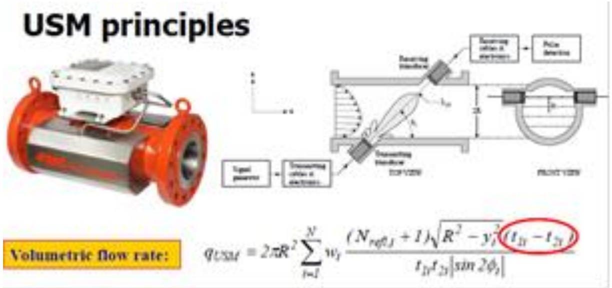

Figure 1: Principle of transit time USM

Adding to the advantages of selecting an ultrasonic meter are its diagnostics features such as, footprints of signal to noise ratio, speed of sound along each acoustic path, and performance alarm, etc. [2]. 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.

Center for Measurement Standards (CMS), acting as National Measurement Laboratory (NML), is responsible for control and monitor measurement errors and uncertainty of these custody transfer meters through a National Measurement Infrastructure [3-4]. For a five years' period, a total of 23 large-capacity USMs have been calibrated periodically and showed good metrological control. However, the original traceability chain relied on calibration of four 150 mm USM up to 10 bars only. Although transient-time USM should not be affected of its calibration curve under higher pressure, the practice was not without its risk. In this paper, a revised traceability scheme will be presented and review of some test results will be discussed in details.

2. Primary standards and recirculation loop

A primary high pressure air flow measurement standard was constructed in Taiwan with a capacity of 18,000 Normal m^3/h and pressure range of 1 to 60 bars. It is a blow down type facility with a gyroscopic weighing scale suitable for high precision gravimetric measurements. The facility has an expanded uncertainty (k = 2) of 0.18 %. The critical flow sonic nozzle array (CSNA) installed upstream of the meter under test (MUT), composed of seven sonic nozzles with different throat diameters in a large plenum, is used as the reference standard meter and provides flexibility in the mass flow control. Another CSNA downstream of the MUT consisting of 13 sonic nozzles, each with nominal flowrate of 40 m^3/h, and a single sonic nozzle with nominal flowrate of 500 m^3/h, were installed downstream of the MUT for back pressure adjustment.

Early 2013, CMS retrofitted a re-circulating loop with five *Itron* high-pressure rotary meters installed. These five meters are served as new working standard and the certified capacity of this system is 550 m^3/h actual flowrate with maximum operating pressure of 55 bars. A schematic of the re-circulating loop is shown in Figure 2.

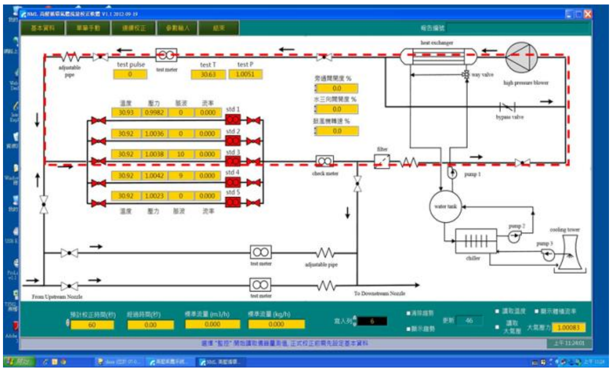

Figure 2: Schematic diagram of re-circulation loop.

Two branches of the pipeline at the upstream and downstream of those rotary meters, are connected with the blow-down type high pressure air flow facility for calibration of the working standards. One meter was calibrated with the sonic nozzles at the blow-down facility with pressures of 16, 38 and 55bars, and flowrates ranging from 10 ~ 150 m^3/h. Other four rotary meters are then calibrated with this golden one to the same pressure rating and flow rates. Combining the four rotary meters, the system has the flow capacity from 10 ~ 550 m^3/h at 55 bars operation pressure. It is estimated with an expanded uncertainty (k = 2) of 0.21%. For control purpose, a 150 mm SICK USM was installed upstream of rotary meters as a check standard. Final calibration results for the SICK USM against the set of five rotary metes are shown in Figure 3, with expanded uncertainty of 0.24%

Based on International Vocabulary of Metrology VIM [5], error in Figure 3 is defined as a measurement unit calibrated against a higher standard, and a complete traceability should include uncertainty sources from Flow meter, Temperature, Pressure, and each level of standard. Error of calibration is defined as in Equation. (1), and typical measurement uncertainty evaluation is given in Equation (2).

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

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

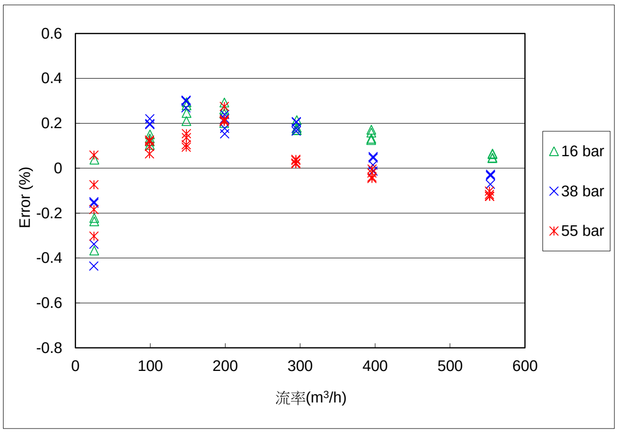

Figure 3: Calibration results of a 150 mm SICK ultrasonic meter.

3. CPC flow standard and on-site through-flow metering system

Built in CPC is a large capacity re-circulating loop capable of calibrating meters up to 60 bars and with flow rate to 4,000 Am^3/h. In early practice, measurement standard is disseminated to CPC through a set of four Instromet 150mm USM calibrated at CMS. Using the CPC facility, four 300 mm USM are calibrated and served as transfer standards between CPC and the through-flow calibration system located in Da-Tan power plant. Through this chain of measurement infrastructure, CMS was able to conduct yearly on-site calibration of six 600 mm USM, at 55 bars, with flow rate up to 16,000 m^3/h, and safeguarding fairness of commodity transaction. The estimated uncertainty of this practice, including uncertainty sources from pressure, temperature, gas compositions, and traceability, is 0.35 %. Photos of the system in CPC and one typical calibration result of 300mm USM are given in Figure 4 and 5.

Figure 4: CPC large capacity re-circulation flow system.

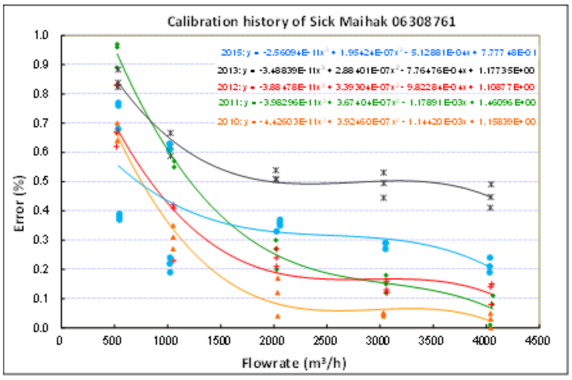

Figure 5: Five years' calibration results of a 300 mm USM standard.

4. Revised traceability practice and comparison results

Based on the new set of five rotary meters installed in the CMS re-circulation loop as working standards, the SICK check meter was calibrated and now serve as a new transfer standard to CPC large capacity flow system. The meter is installed in series with a set of (turbine + 150 mm Instromet USM) at the upstream side, another Q-sonic Plus USM as a check meter in the middle. As shown in Figure 4, four lines of (turbine + USM) were arranged in CPC and each set is calibrated against the SICK four-paths USM. As stated before, the four Instromet USMs were previously sent to CMC for traceability calibration, at 10 bars pressure rating only. For the revised traceability approach, all metes were now calibrated to 55 bars. Possible pressure effect is anticipated to be reduced on the USM calibration, and thus minimizing measurement error. Calibration results of the four Instromet USM at 55 bars were put together with those accumulated in past four years. Due to different pressure ratings, it is expressed in percentile measurement errors against Re number in Figure 6. Judging from the results, all variations are within ± 0.2 % with good overlapping. Thus, consistent traceability of the 150 mm Instromet USM would be expected.

For the two Q-sonic Plus check meters (6020, 6021), those were calibrated by Germany high pressure national standard, *pigsar*, at 20 and 50 bars. During the measurement practice, data of meter 6020 were gathered and compared simultaneously against the SICK transfer meter for each of those four test lines. The results are shown in Figure 7. It can be seen that error trends between those two calibration data are similar, indicating consistent between two traceability systems.

Furthermore, the four Instromet USMs were calibrated by SICK transfer standard with Q-sonic Plus meter 6021 as check meter at 20 and 50 bars, for flow rate close to 1,200 m^3/h. It was necessary to employ a boot-strapping approach between SICK transfer standard and four sets of USM under calibration. The results were then put together for comparison. As shown in Figure 8, except at flow rate lower than 200 m^3/h, both sets of data are comparable and consistent in meter factor (MF) distributed across flow rate up to 1,200 m^3/h.

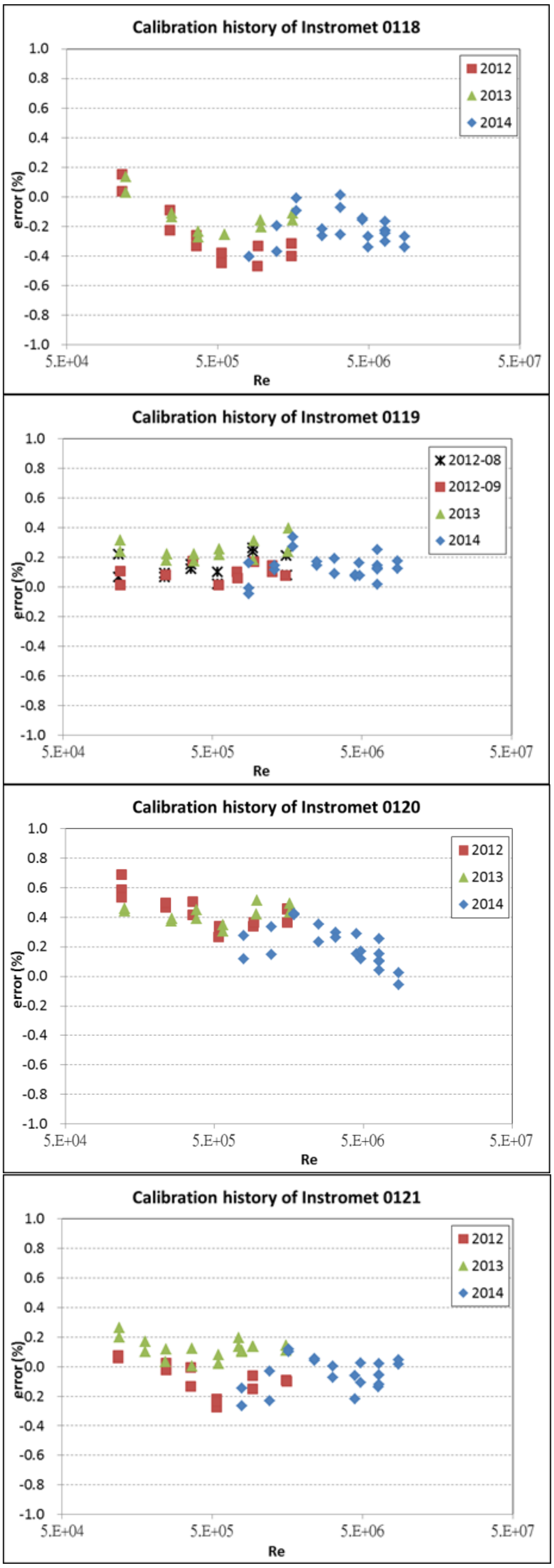

Figure 6: Calibration results of four 150mm Instromet USM; at 10 and 55 bars.

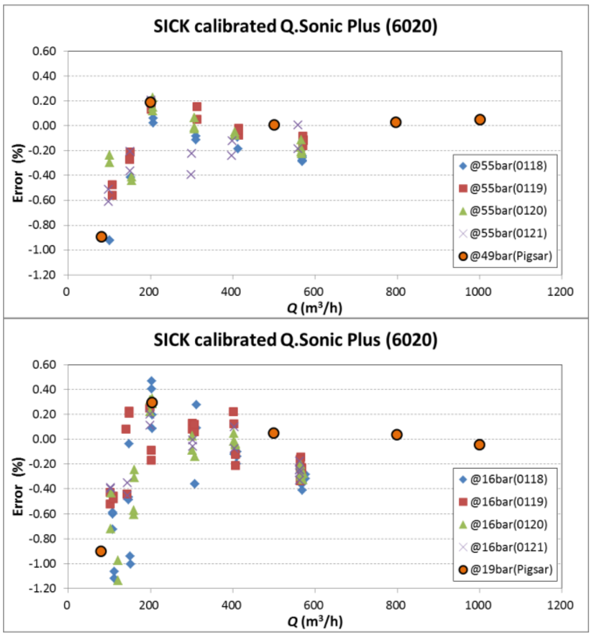

Figure 7: Comparison results bet. *Pigsar* & CMS at 55, 16bars

5. Periodical check results

As for other 17 high-pressure custody transfer meters, besides yearly re-calibration for as-found and as-left data, two particular 300 mm meters were selected for three months' periodic check at CPC, over a span of more than three years. Those two meters were calibrated only for as-found results, without making adjustment on the meter Adjust Factor and Linearity for as-left data. In total of 9 periodic checks were conducted and first 8 data were based on original 10 bars traceability scheme, while the final one is based on *pigsar* traceability. Results are given in Figure 9.

It can be seen that, for meter one, only calibration number 3 and 4 were out of a control band of ±0.3%. For meter two, the final calibration 9 was way out of band. Reason for such meter deviation is uncommon and further study is necessary to have better explanation. However, for regular yearly calibrations of other 15 meters, with CMS or *pigsar* traceability, after adjusting linearity for as-left data, meter deviations are all within ±0.3% control band and thus, satisfying CPC and customer transaction requirement.

For the four 600 mm custody transfer USMs, through six years field calibration at the power plants' operation pressure of 55 bars and over 10,000 Am3/h, meter corrections level are shown in Figure 10. Except in 2014, where no adjustment was mad, all shows different level of correction; while meter 430910 has bigger variation then others.

For the SICK 150 mm USM, starting 2016, it is now intended to serve as transfer standard to CPC. The meter was calibrated with CMS blow-down facility at 10 bars, we well as 55 bars at re-circulating system. In addition, the same meter was calibrated at PTB at ambient test pressure, and at *pigsar* at 18 and 50 bars, for further assuring the meter pressure effect. A down shift deviation of 0.25% was found between the two test pressures, indicating pressure effect in such large pressure difference. However, through the assistance of PTB and SICK, with dedicated parameter settings on velocity profile and Reynolds number corrections, a generic fitted curve for the 150 mm SICK transfer standard was found and shown in Figure 11[6]. This particular curve will serve as baseline data for future traceability calibrations of CMS and CPC transfer standards.

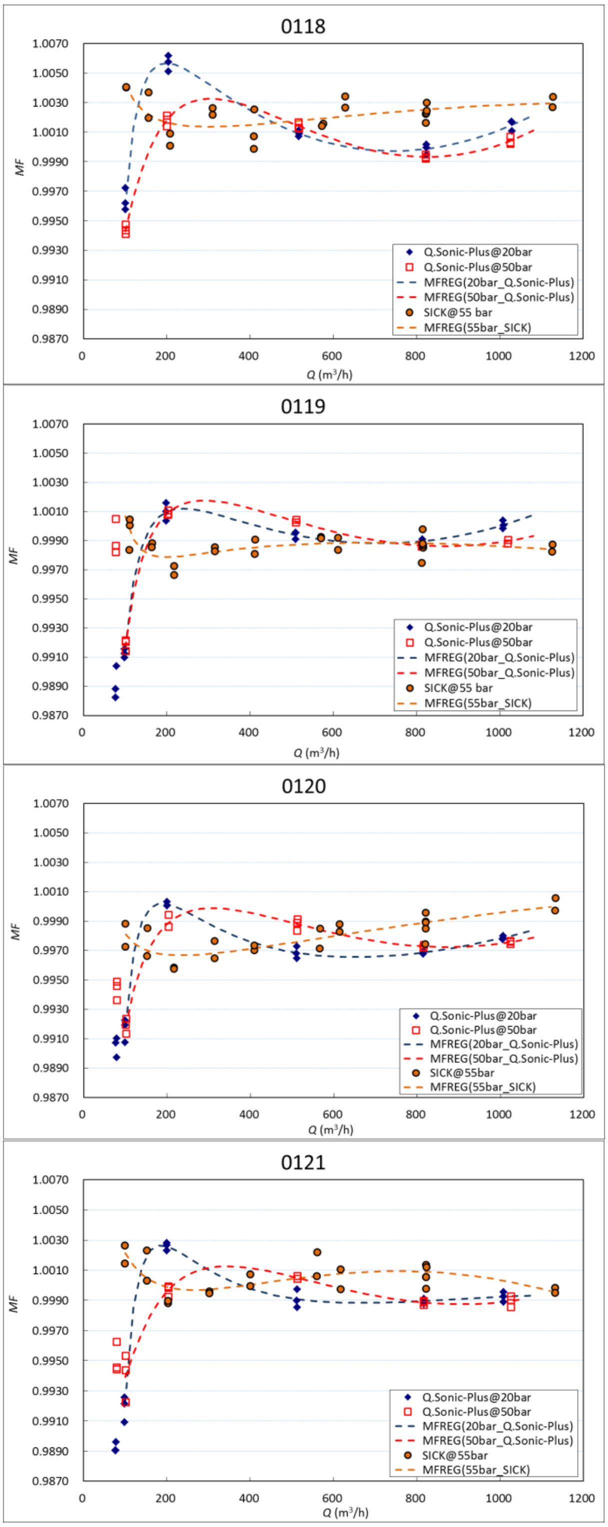

Figure 8: Comparison data for Instromet USM bet. CMS and *pigsar*

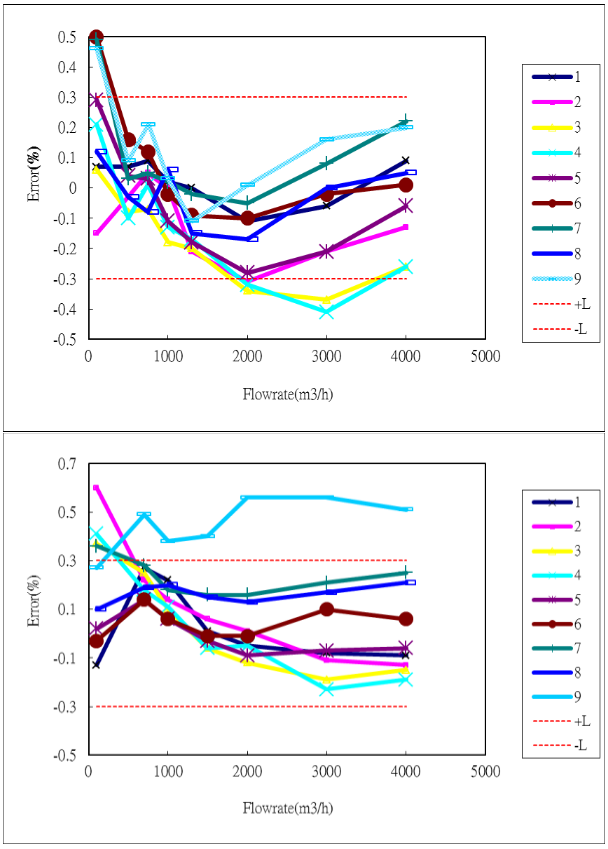

Figure 9: Periodic calibration data of two 300mm USM

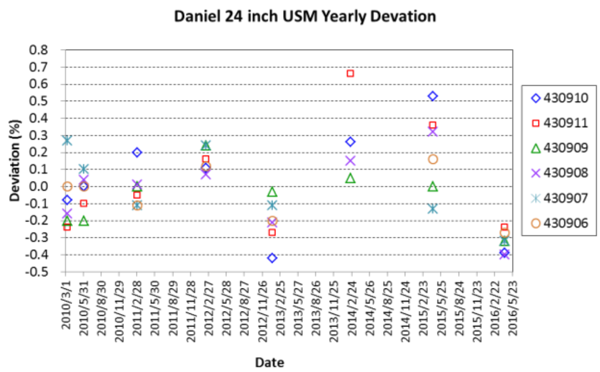

Figure 10: Yearly deviation of 600 mm USMs.

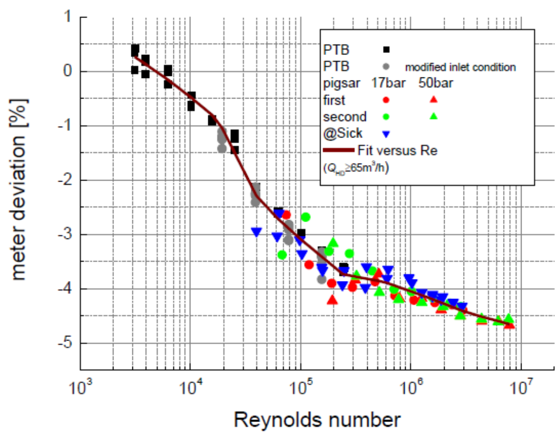

Figure 11: Generic fitted curve for SICK 150 mm transfer meter

6. Conclusion

A re-circulating high-pressure air flow system was retrofitted in CMS and five rotary meters installed as working standard. The system is capable to provide stable calibration services up to 55 bars and flow rate to 550 m^3/h. A SICK USM is serving as checking meter, as well as a transfer meter to CPC high-pressure re-circulating flow system. Although with 10 bars and 55 bars high pressure traceability, results of four Instromet USMs remain consistent with variation less than ±0.2%. Additional comparison, using a Q-sonic plus meter, has shown consistent in high-pressure traceability, in 16 and 50 bars, between *pigsar*/Germany and CMS/Taiwan. Furthermore comparison for four Instromet meters has also shown favorable agreement between the two national flow facilities between 20 and 55 bars.

For custody meters situated across various distribution stations providing natural gas to power plants, periodic check has given satisfactory results, which suggests one-year calibration interval for USM meter should be mandated. Yearly calibration data have shown that through proper third-party metrological control, USM meter could perform within a ±0.3% control band.

Results of calibration of the SICK transfer USM, at CMS PTB, and *pigsar*, at various test pressures, all show good consistent among them. The Sick 150 mm meter is used as transfer standard to CPC's four Instromet meters, and a generic fitted curve was found to serve as a baseline reference data.

7. Acknowledgments

Authors would like to express its gratitude for the project funding supports from Chinese Petroleum Corporation and Taiwan Power Company, as well as facility support from Refinery Manufacturing Research Center. In addition, authors are grateful to Dr. Bodo Mickan/PTB and SICK's assistance in data processing.

References

[1] ISO 17089-1, Measurement of fluid flow in close conduits-Ultrasonic meters for gas –Part 1: Meters for custody transfer and allocation measurements, 2010.

[2] FLOWSIC600 Ultrasonic Gas Flow Meter: Ultrasonic Gas Flow Meter for Custody Transfer and Process Applications, Technical Information 8010125 V2.0 SICK MAIHAK GmbH.

[3] Kuo, C.-Y., Ho, Y.-L., Dietz T., Wang, W.-B., Yang, F.-R., Su, C.-M. and Shaw, J.-H. Calibration of Ultrasonic Flow Meter Using Blow-down Type High Pressure Gas Flow Standard 8th ISFFM (Colorado Spring, CO, USA, June 20-22, 2012).

[4] Yang, F.-R., Ho, Y.-L., Wang, W.-B., Shaw, J.-H., Huang, T.-W., Wu J.-R., Traceable Calibrations from Primary Standard to On-Site Ultrasonic Flowmeter, 15th Flow Measurement Conf. (Taipei, Taiwan, October 13-15, 2010).

[5] International Vocabulary of Metrology – Basic and General Concepts and Associated Terms, VIM, 3rd edition, JCGM 200:2008. Available from the BIPM homepage http://www.bipm.org.

[6] PTB calibration certificate, June, 2016