

Inter-Laboratory Tests In Air Flow Standard

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Abstract: A set of two laminar flow meters was used in 1998 as transfer standard for inter-laboratory tests in the range of 100sccm~1slm on Brooks piston prover. Results were used for in-depth scrutinizing on the alignment of the vertical trigger mechanism and measuring volume, for possible leak checking and for improvements on secondary instruments of the piston prover at CMS. Further calibration, after such adjustment on the prover, shows an agreement of both sets of data within 0.2 %

In 1999, an inter-laboratory test between CMS and KRISS was conducted with the same set of laminar flow meters. Test results indicated a mean deviation no greater than 0.2 %, within the claimed measurement uncertainty. With the use of an Excel laser interferometer for piston stroke length measurement, repeatability of the piston traversing length is improved to 0.015mm. Temperature measurements between inlet and outlet ports have agreement within 0.15° with a temperature balancing helical tube installed upstream of the flow path. The pressure variation during the course of a piston stroke is maintained within 16pa after adjustment on the tapping location. Overall, an expanded measurement uncertainty of 0.15 % of reading can be achieved.

Subsequently, internal tests of flow rates from 200sccm to 12slm were carried out among five different tubes with several mass flow meters. Comparison of test data in terms of mean error showed an agreement within 0.05%~0.1 % is achieved.

Keywords: Inter-laboratory tests, Laser Interferometer, Mass flow meter, Piston prover.

1 INTRODUCTION

In fluid flow measurements, the piston prover is a commonly used primary standard for flow rate below about 24slm in low-pressure application. Its flow rate is determined by collecting, under conditions of steady flow and fluid properties, a measured volume of the flowing fluid over a measured time interval, with all measured quantities (i.e., temperature and pressure) referenced to established standards. Manufacturers employ different sensing mechanism design to determine the position of the piston in flight, such as ultrasonic sensors or mercury sealed piston with photo sensors.

Due to the design of the measurement system, unavoidable measurement errors are frequently encountered caused by such effects as mercury generation of electric charge on the surface of the glass tube, or unsteady motion of the piston that reduces stability of the trigger mechanism [1]. The alignment of the length scale mechanism and glass tube may cause additional errors as well. Thus, original design of a piston prover can only provide expanded uncertainty down to 0.3%.

It is essential, then, to frequently checking the mechanical traversing scale and make proper adjustments, not to mention the routine traceability of the temperature and pressure probes to safeguard the measurement accuracy. Perhaps most difficult is task of establishing traceability of the volume of the glass tube. For dimensional traceability, an LVDT can be used to measure the tube internal diameter section by section. The process not only is tedious, but it does not truly reflect the measurement system in a dynamic calibration process. Up to now, there has been no widely used verification system, such as the Basic Verification System in NMI for the bell prover [2], that provides a dynamical traceability chain, either volumetrically or gravimetrically.

In addition to estimating the measurement uncertainty by static traceability to basic units, a measurement assurance program (MAP), including inter-comparisons of flow systems through

measurement capability of a laboratory, and second to identify measurement problems and initiate correction actions.

Among flow communities, round-robin measurements using two test samples in tandem position and applying Youden analysis for test data have been generally accepted, as advocated by Mattingly [3][4] and supported by many past comparison activities [5][6]. The tandem meter and Youden analysis approach allows quantification of random and systematic differences in an inter-laboratory comparison. On the other hand, a proficiency test program could be simplified, in order to down scale the magnitude of the test artifact or reduce turn around time. Often, a single test sample is adopted and test data are used to determine necessary adjustments and compare the test results between laboratories with comparable test capability.

Following such a concept, between 1998 to 1999, CMS used a set of mass flow sensors as transfer standards, and conducted two series of comparison tests. The objective of this paper is to describe how the accuracy of our piston prover was improved based on the results of intercomparison to meet the requirements of calibration. As a result of correction actions, an expanded uncertainty of 0.15% can be achieved for individual piston prover flow measurements.

2 EXPERIMENTAL FACILITY & ARTIFACT

In the Center for Measurement Standards, a five-tube Brooks piston prover (shown in Fig. 1) with flow range from 20sccm to 24slm is used as the primary standard. The five tubes have effective collection volumes of approximately 150 cm³, 400cm³, 1000cm³, 3000cm³, and 12000cm³ respectively. The five tubes are mounted together in a console and connected by a manifold to a single air source and inflow line. This arrangement allows more than one tube to be used for calibration of a flowmeter if its range so requires, and facilitates comparisons between different tubes. A similar three-tube prover is used at NIST with measurement uncertainty less than 0.17%. At KRISS, the same Brooks five-tube prover is used with uncertainty level of 0.25%.

A set of two mass flow sensors made by DHI was chosen as the transfer standard. Both have measurement capacity of 1slm maximum with manufacturer claimed error of 0.2% and 0.1% linearity. During test measurements, information from only one sensor was gathered although both sensors were calibrated for cross checking purposes. The installation arrangement of the meter under test is shown in Fig. 2. Test flow rates range from 100 to 1000sccm, with interval of 250sccm. CMS performed two separate calibrations, one before and one after, for each of the NIST and KRISS calibrations.

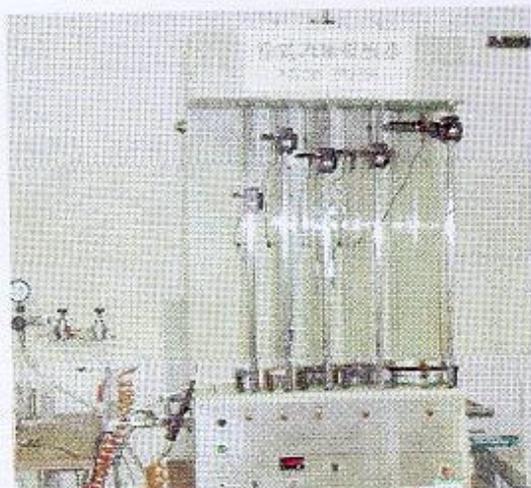


Fig.1 Five-tube BROOKS piston prover in CMS



Fig.2 The transfer standard

3 RESULTS OF INTER-COMPARISON

Fig. 3a and 3b show results of comparison tests between CMS and NIST. The first set of calibration data, designated by CMS#1 & NIST, shows calibration corrections of 0.3% to 0.5% at flows below 200sccm. However, the error curves for both calibrations are quite similar, indicating possible system deviation.

Following the first stage of the comparison test, some adjustments were applied to the piston prover at CMS. These include firstly, precision alignment of the mechanical trigger mechanism and fixing the movable scale at its maximum measurement volume, so that errors of timer triggering due to the refractive index of glass tube bending the light can be reduced. A laser interferometer was then

used to carefully examine the piston traversing process so that the traversed distance is accurately measured as well as identifying any unsteadiness of the piston motion. The measurement uncertainty of the piston traversing length was thus reduced to 0.015mm with resolution down to 1 μ m, a ten fold improvement from the original design.

This incorporation of a laser interferometer for traversing length monitoring has the following advantages:

- (a) It is fast and accurate readings not affected by piston rocking or sticking.
- (b) It can verify the position of detector assembly relative to the actual trigger point of the moving mercury seal.

Secondly, a helical tube before the inlet of the system was installed so that airflow temperature has ample time to stabilize. The glass tube thermometer was replaced with a precision, resolution 0.01°C, Pt-100 sensor. This reduces the measurement uncertainty of temperature to 0.11°C. Furthermore, a Ruska absolute pressure gauge was installed for airflow pressure measurement in lieu of the original U-shape water column pressure sensing device. The measurement uncertainty of pressure was thus improved to 16Pa. During the process, small-scale leakage was found and corrected. Proper corrections on temperature readings, timer error, and compressibility factor were also considered.

Fig. 3a Results of CMS-NIST comparison using molbloc-493

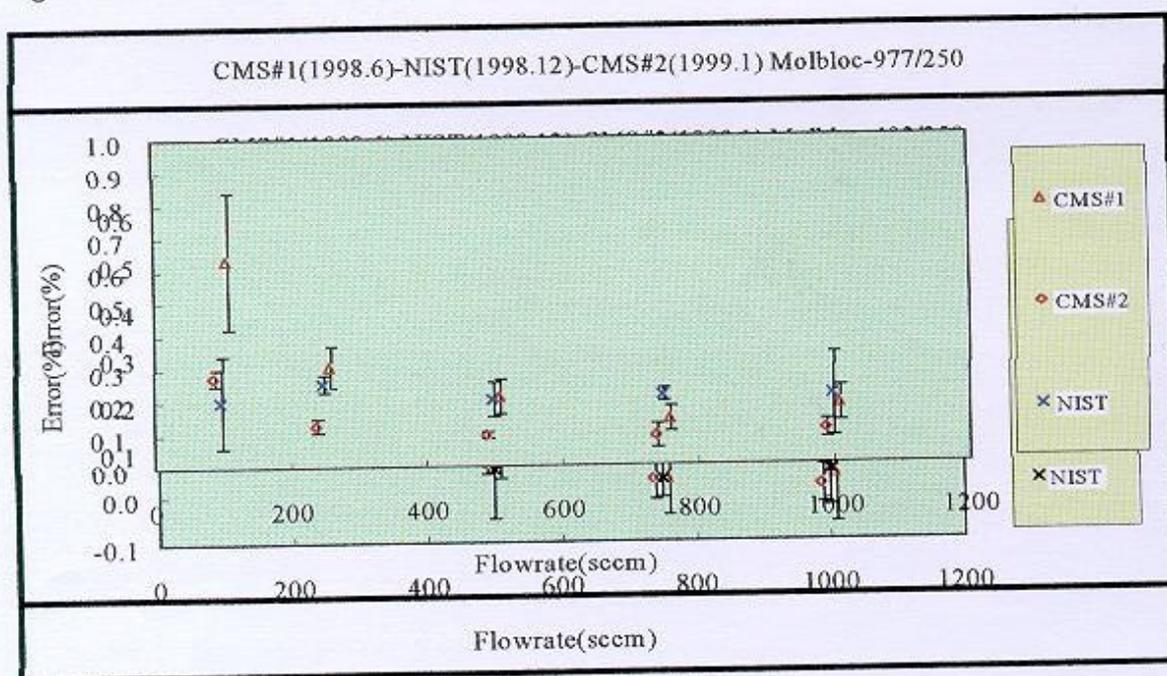


Fig. 3b Results of CMS-NIST comparison using molbloc-977

A second set of measurements was conducted after the above mentioned system re-configuration. The results are indicated by CMS#2 in Fig. 3a,b showing a mean measurement error within 0.2% with the NIST data. Each error bar in the figure represents data scatter for five measurements and its range determined by 2σ of those measurements.

To further verify the outcome of such system adjustment, an inter-laboratory test was carried out between CMS and KRISS. Calibration sequence was arranged such that each tube (tube number 2 to 5) will measure MUT at two different flow rates, from low to high flow and from small to large tube. Test data, as given in Fig. 4a to 4b, indicated a mean deviation no greater than 0.2 %, within the claimed measurement uncertainty. However, individual calibration for flow rates at 250 and 500scm shows deviation up to 0.15% in two groups of data gathered from pair of tubes 2-3 and 3-4, respectively. Similar but less critical deviation was found at other tubes. The reason is unclear but leakage is suspected in one of the measuring volume. Repeatability of each set of measurements is less than 0.1%.

Fig.4a Results of CMS-KRISS comparison using molbloc-493
 Fig.4b Results of CMS-KRISS comparison using molbloc-977

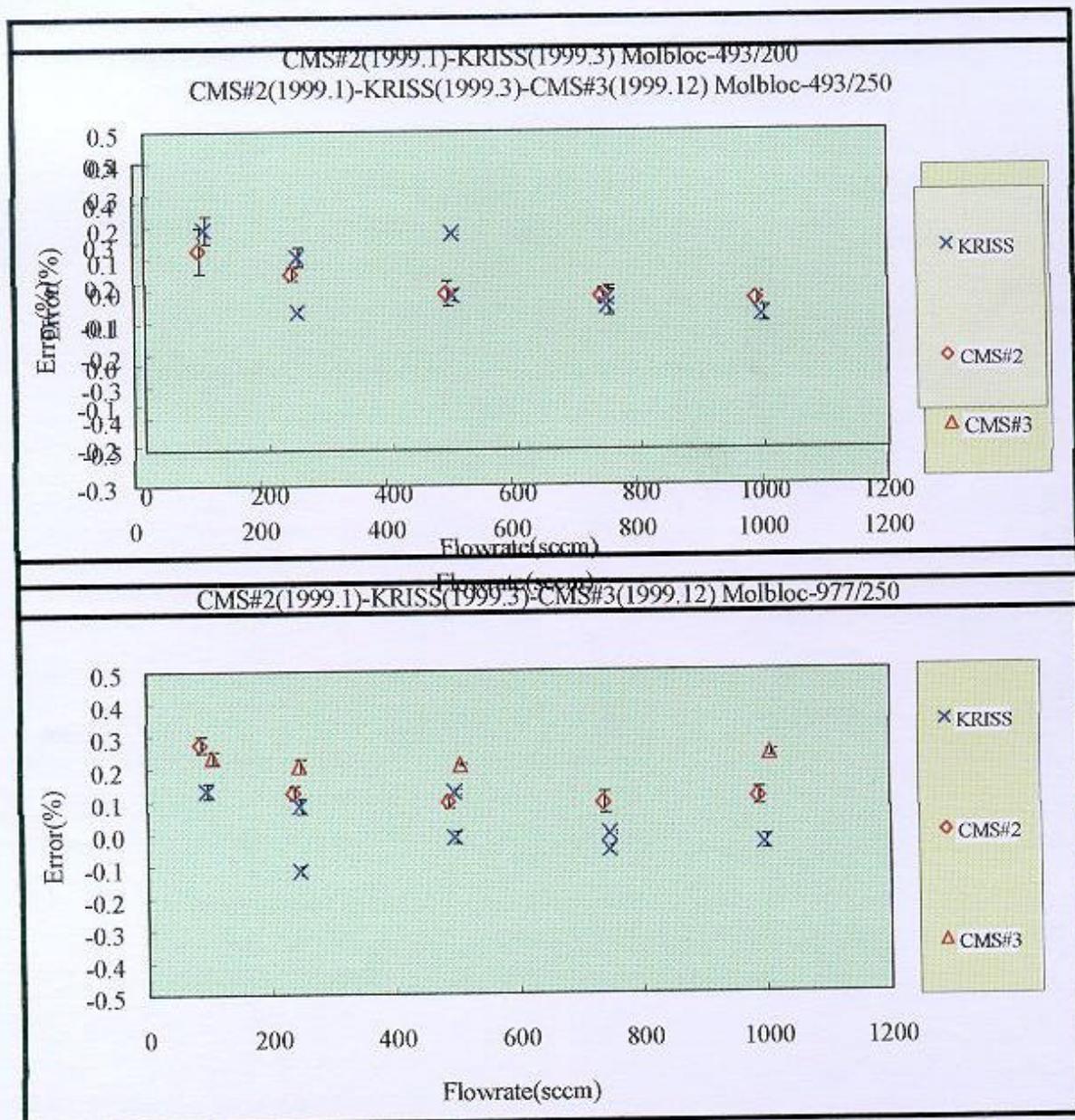


Fig.4c Results of CMS-KRISS comparison using molbloc-493

5 CONCLUSION

This paper describes how an inter-laboratory test program was utilized to assess the performance of an airflow national standard. A set of DHI mass flow meters was used as transfer standards to perform measurement proficiency tests and to determine possible system bias of a piston prover. It also shows that by making the piston stroke length measurement with a laser interferometer, accuracy in length measurement is improved. An expanded uncertainty of 0.15% at 95% confidence level for the system can be achieved after improving secondary instrumentation and detailed estimation of each influencing factor. The mean deviation of less than 0.2%, for the three sets of inter-laboratory comparison result at different flow rates, lies within expectations based on the uncertainty level of each laboratory, and shows good agreement among the three national standards.

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Table 1. Uncertainty budget for the CMS piston prover flow measurements.

Source of Uncertainties	Relative Standard Uncertainty									
	Tube 1		Tube 2		Tube 3		Tube 4		Tube 5	
	Value	%	Value	%	Value	%	Value	%	Value	%
Collection Volume		0.017		0.013		0.010		0.022		0.033
Cylinder Diameter		0.010		0.006		0.008		0.009		0.003
Piston Stroke Length	0.015mm	0.002	0.015mm	0.002	0.015mm	0.002	0.015mm	0.002	0.015mm	0.002
Piston Rocking		0.013		0.011		0.005		0.019		0.032
Thermal Expansion	1.7□	0.003	1.7□	0.003	1.7□	0.003	1.7□	0.003	1.7□	0.003
Air Density		0.046		0.046		0.046		0.046		0.046
Temperature	0.11□	0.041	0.11□	0.041	0.11□	0.041	0.11□	0.041	0.11□	0.041
Pressure	16Pa	0.016	16Pa	0.016	16Pa	0.016	16Pa	0.016	16Pa	0.016
Fitting Function		0.009		0.009		0.009		0.009		0.009
Experimental Data		0.012		0.012		0.012		0.012		0.012
Collection Time		0.018		0.018		0.018		0.018		0.018
Timer Calibration		0.009		0.009		0.009		0.009		0.009
Timer resolution	0.004s	0.014	0.004s	0.014	0.004s	0.014	0.004s	0.014	0.004s	0.014
Timer actuation	0.001s	0.004	0.001s	0.004	0.001s	0.004	0.001s	0.004	0.001s	0.004
Storage Effects		0.040		0.016		0.008		0.005		0.004
Leakage		0.030		0.01		0.01		0.01		0.01
Combined Uncertainty		0.073		0.055		0.052		0.056		0.061

Table 2. Results of cross measurements of different tube

	12slm	3slm	1slm	400sccm	200sccm
Column 5(12L)	0.00%~0.03%	-0.02%~0.00%			
Column 4(3L)		-0.05%~0.01%	0.05%~0.08%		
Column 3(1L)			0.06%~0.08%	0.07%~0.08%	
Column 2(0.4L)				0.10%~0.11%	0.02%~0.06%
Column 1(0.15L)					-0.03%~0.01%

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