NEW DESIGN FOR A TRANSFER STANDARD METHOD FLOW STAND

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Abstract

In 2000, Micro Motion, Inc. presented a paper at FLOMEKO introducing a new system for calibrating its flow meters referred to as a Transfer Standard Method (TSM) liquid calibration system. The transfer standards for this system are Coriolis reference meters installed in parallel. The stability of the reference meters is one of the largest contributors to the overall measurement uncertainty in this system. To reduce the measurement uncertainty, reference meters are limited in flow range and two reference meters of each size are used as a quality check with one installed upstream of the unit under test (UUT) and the other installed downstream of the UUT. An updated design of the Transfer Standard Method liquid calibration system incorporating reference meters in series was recently built and put into service at Micro Motion. A discussion of the updated design, the quality check data that is inherently built into the updated design and an analysis of these results are presented in this paper.

Introduction

Since 2000, many continuous improvement efforts have been applied to the Transfer Standard Method (TSM) liquid calibration systems. Improvements to the measurement assurance process, traceability, uncertainty analysis, and the TSM calibration stand design itself have been made. As this paper is an update to the original 2000 FLOMEKO paper, "Traceability and Uncertainty Analysis for Flowmeter Calibration Process with Coriolis Flowmeters as Reference" by R. DeBoom, M. Buttler, A. Kolbeck, A. Pruysen [1]; much of the same format will be utilized in this paper for ease of comparisons.

The purposes of this paper are:

- To present a new design concept for a Transfer Standard Method (TSM) liquid calibration system utilizing Coriolis reference meters in series versus the original design of parallel reference meters.
- To review the current traceability of the TSM calibration stands.
- To update the uncertainty analysis for the TSM calibration stands.

Flow meter calibration stand requirements

Much of the same flow meter calibration stand requirements remain the same from the original paper with the following changes and additions:

- Calibration and Measurement Capability (CMC) < 0.03% mass. (This CMC value is required when calibrating Coriolis flow meters with an optional reference mass flow accuracy of 0.05%)
- Calibration and Measurement Capability (CMC) < 0.08% water density. (This CMC value is required when calibrating Coriolis flow meters with an optional reference density accuracy of 0.2 kg/m^3)
- ISO/IEC 17025 Accredited

TSM operation

Figure 2 is a simplified P&ID (process and instrument diagram) of the parallel reference meter TSM calibration stand. Figure 3 is a simplified P&ID of the reference meter in series TSM design. Some notable improvements over the previous design are:

- Elimination of the second bank of reference meters referred to as the QCM (Quality Check Meters).

- Fewer reference meters to cover the same flow range.
- Less complexity and cost due to the elimination of the second set of valves, piping, etc., required for the QCM.

As with the previous design, the TSM calibration stand with reference meters in series is scalable to accommodate different flow rates. The UUT (unit under test) section remains the same, utilizing an automatic clamping system to facilitate rapid installation and removal of the UUT. UUT refers to the meter, or meters, being calibrated.

The UUT is calibrated and adjusted against a reference meter. One of the key features of the parallel design TSM was the comparison of the reference meter to the QCM during calibration of the UUT. The meter is series design still follows the QCM concept, but with the smaller reference meter checking the larger reference meter only at specific flow rates. The meter in series, TSM reference meters, are specifically chosen to allow the QCM check to happen at standard production flow rates, i.e. a production calibration point at 10% of a 3” meter is 226 kg/min. This flow rate is also 10% of a 3” reference meter and 100% of a 1” reference meter. Using the high end (100%) of the smaller reference meter to check the low end (10%) of the larger reference meter allows the zero stability of the larger reference meter to be monitored and controlled. In the previous design, reference meters were not utilized below approximately 30% of their flow range to allow for zero drift. Monitoring the reference meter zero drift allows the reference meter to be used over a wider flow range and gives more information about the long term stability.

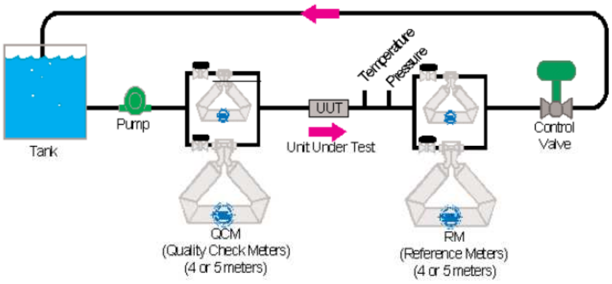


Figure 2. Simplified P&ID for a parallel TSM flow meter calibration stand

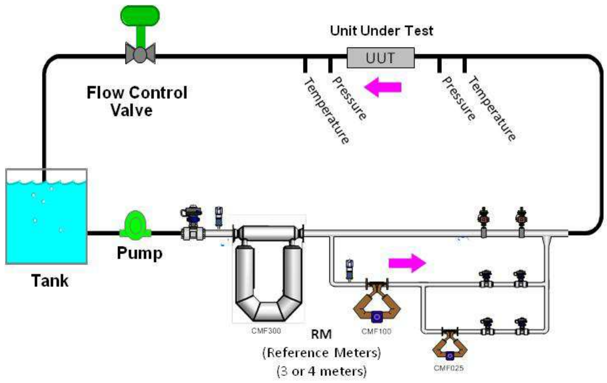


Figure 3. Simplified P&ID for a series TSM flow meter calibration stand

Mass traceability for TSM stands

The uncertainty in mass of the TSM calibration process is traceable through an unbroken chain of successive measurements to the SI (system of international units) as shown in Figure 4. The boxes labelled U1, U2, u3, and U4 represent the successive uncertainty calculations for the Micro Motion controlled steps in the traceability chain. Micro Motion owns a set of NIST (National Institute of Standards and Technology) traceable reference mass standards used to calibrate the scales on the gravimetric Primary flow stands which become part of U1. Travelling Measurement Standards, known as a GRM’s (Global Reference Meters), are calibrated on a Primary flow stand with an uncertainty calculated as U2. Each TSM reference meter is initially calibrated on a gravimetric Primary flow stand. When the TSM reference meter is installed in the TSM calibration stand, it is verified and then calibrated annually using a GRM which is installed in the UUT section. By utilizing a GRM installed in the UUT section to calibrate the TSM reference meter, the TSM reference meter is calibrated in place which leads to improved long term stability and a better representation of how the reference meter is used during the calibration of customer’s flow meters. The calibration uncertainty of the TSM reference meter (u3) is one component that is combined when determining the overall TSM CMC (calibration and measurement capability) U4.

The Primary flow stands located at Boulder, Colorado USA are accredited to the international standard ISO/IEC 17025. The CMC for mass is 0.014% as listed within the NVLAP (National Voluntary Laboratory Accreditation Program) scope of accreditation (NVLAP Lab code: 900218). The CMC value is verified traceable to international standards through the results of annual inter-laboratory comparisons with national metrology institutes such as: NIST-USA, VSL-The Netherlands, NIM – China.

Currently, TSM stands located at Boulder, Colorado USA and Nanjing, China are accredited to ISO/IEC 17025. (Boulder, NVLAP Lab code: 900218; Nanjing, SAC-Singlas Cert No: LA-2010-0469-C) These CMC values are verified traceable to international standards following the same inter-laboratory comparisons for the Primary flow stands described earlier.

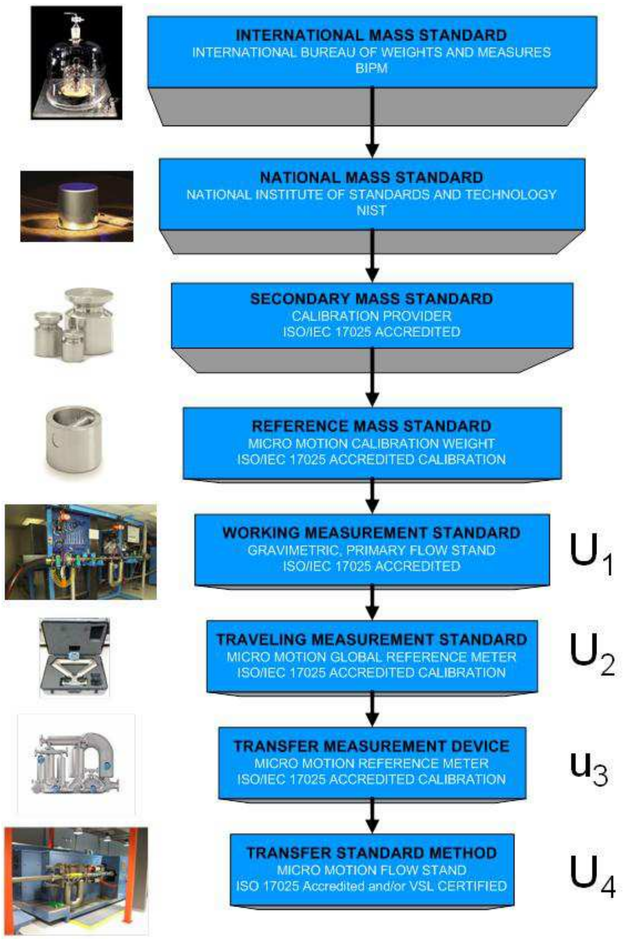


Figure 4. Calibration traceability for TSM stands

Measurement assurance

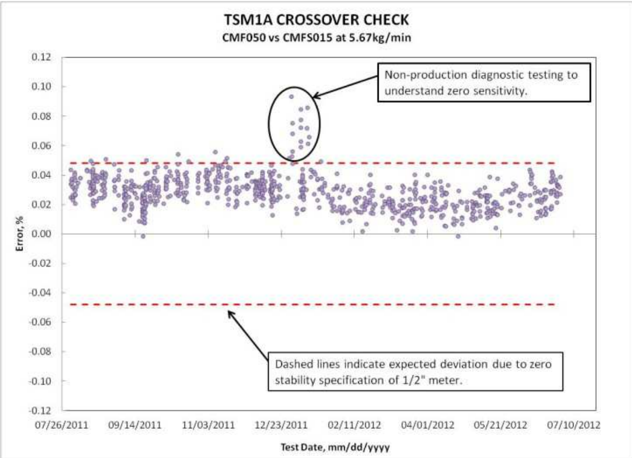
As described earlier, the first level of measurement assurance provided is having the TSM reference meters installed in series where the larger reference meter is checked for stability against the smaller reference meter.

The second level of measurement assurance continues through the use of “Gold” meters. Gold meters are standard Micro Motion Elite meters which are utilized to check the TSM calibration stand on a regular basis. A Gold meter is installed in the UUT section and calibrated regularly without any meter factor adjustments to monitor the stability of each TSM reference meter.

Another benefit of the meter in series design is that the number of Gold meter tests required checking the TSM reference meters could potentially be limited to only check the smallest reference meter. After the condition of the smallest reference meter is verified, the automated QCM checks will continually verify the stability of each larger meter. Checking the 10% flow rate of the reference meters and the inherent stability of the Coriolis technology at the 100% flow rate gives good confidence that the system is working properly.

Figure 5 shows QCM results from the initial meter in series TSM design during the first year of operation, showing the stability of the 10% flow rate of a ½” meter as compared to the 100% rate of the smaller reference meter (5.67kg/min). The data shows the random variation between the two meters is approximately +/- 0.02%. This is less than half the amount of variation due to the zero stability specification of the ½” meter. This QCM data allows real time monitoring of the zero drift value of the larger reference meter allowing it to be used over a wider turndown. Ultimately this data, along with the Gold meter check, could be used for real time adjustments to the TSM stand to maintain an optimized performance level.

Figure 5. QCM Results for Meter in Series TSM stand



Uncertainty analysis

Uncertainty analysis: general

Definitions

- The word 'uncertainty' in this paper means 'expanded uncertainty' (k=2 approximately 95% confidence)
- CMC (Calibration and Measurement Capability) refers to the lowest uncertainty of measurement that can be obtained by a flow stand when calibrating the best existing device. In this case, the standard uncertainty from the UUT is included in the final expanded uncertainty.

This analysis if guided by:

- JCGM 100:2008 (Guide to the expression of uncertainty in measurement, GUM 1995 with minor corrections). [2]
- ISO/IEC 17025:2005. [3]
- Micro Motion global work instruction GWI-116 (Guide to the Uncertainty of Measurement). [4]
- Consultant's Report on the Uncertainty of Mass-UUT Delivered by the MMI-PFS7K. [5]

As referenced earlier in the traceability diagram (Figure 4), the uncertainty analysis and CMC value (mass) for the Micro Motion TSM flow calibration stand, consists of four parts:

a) U_1, uncertainty analysis of the Primary flow calibration stand (CMC value (mass) as reported on scope of accreditation)
b) U_2, uncertainty analysis of the Global Reference Meter (GRM)
c) u_3, calibration uncertainty of the GRM while on the TSM stand
d) U_4, uncertainty analysis of the TSM flow calibration stand (CMC value (mass) as reported on scope of accreditation)

Uncertainty analysis: gravimetric Primary flow stands

The Primary flow stands at Micro Motion are gravimetric calibration stands that utilize the static-start/stop method as outlined in ISO 10790:1999, [6], to make mass flow measurements. The test fluid is water and is collected in a tank which is located on a scale so that the total amount of mass is determined by weighing. Ambient pressure, temperature, and humidity are collected during each collection to make an accurate weighing. Additionally, pressure and temperature are measured both upstream and downstream of the UUT. In this manner, the mass total from the UUT is directly compared to the mass of the reference scale.

The governing equation for the determination of mass then becomes:

$$M(Reference) = M(scale) * buoyancy\ factor\ (BF) * connecting\ volume\ (CVt)$$

Utilizing relative uncertainties in percentages where the sensitivity coefficients are the exponents of the respective factors, which are all 1, the uncertainty equation becomes:

$$u_r[M(UUT)] = u_r[M(scale)] + u_r[BF] + u_r[CVt]$$

Continuing according to the GUM and the propagation of uncertainties, the expanded uncertainty becomes:

$$U = k(u_r[M(UUT)]) = k\sqrt{u_r[M(scale)]^2 + u_r[BF]^2 + u_r[CVt]^2}$$

Where k=2 for approximately 95% confidence.

Figure 6 is an example of a CMC table for one of the Primary flow stands. The CMC table consists of three main sections that represent the categories identified in the uncertainty equations for mass. Micro Motion currently calculates, and reports, only the worst case CMC value for each flow stand. For the Primary flow stands, this value (U_1, Figure 4) is 0.014% @ k=2, approximately 95% confidence.

Tabulation of Relative Uncertainties (32 kg Scale PFS7K)

Minimum Batch Size 2.500 kg

Minimum Flow Rate 0.400 kg/min

1	2	3	4	5	6	7	8	9	10	11	12	13
Quantity / Symbol	**Source of Uncertainty**	**Units**	**Absolute Value**	**Relative u(Spec) (%)**	**Type Uncrt**	**Prob Distrb**	**Divisor**	**Relative Sensitivity Coefficient**	**Multiplier**	**u(Symbl) (%)**	**Degrees of Freedom**	**% of Combined**
Scale Mass Reading / M_{scale}												
a	Resolution (SCALE)	kg	0.0001	0.0040	B	R	1.732	1	1	0.0023	∞	11.1
b	Repeatability (SCALE)	kg	0.0001	0.0023	B	R	1.732	1	1	0.0013	∞	3.7
c	Long term stability (SCALE)	%	0.0013	0.0013	B	R	1.732	1	1	0.0007	∞	1.1
d	Weights	%	0.0016	0.0016	B	R	1.732	1	1	0.0009	∞	1.8
e	Water Substitution	kg	0.0001	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A
f	Transfer point	g	0.0626	0.0025	A	N	1.000	1	1	0.0025	9	13.0
g	Pulse Resolution (DAQ)	N	60000	0.0017	B	R	1.732	1	1	0.0010	∞	1.9
h	Pulse Resolution (UUT)	N	60000	0.0017	B	R	1.732	1	1	0.0010	∞	1.9
i	Software (DAQ)	%	0.0014	0.0014	B	R	1.732	1	1	0.0008	∞	1.4
j	Best Repeatability (UUT)	%	0.0028	0.0028	A	N	1.000	1	1	0.0028	9	16.4
									Sub Total	0.0050	91	52.3
Buoyancy Factor / **BF**												
a	Air-Cal Density	kg/m^3	1.2012	0.3	B	R	1.732	1	0.0002	0.0000	∞	0.0
b	Weights Density	kg/m^3	8000	5.0	B	R	1.732	1	0.0003	0.0009	∞	1.6
c	Air Density	kg/m^3	0.9962	0.3	B	R	1.732	1	0.0010	0.0002	∞	0.1
d	Liquid Density	kg/m^3	995.64	0.007	B	R	1.732	1	0.0010	0.0000	∞	0.0
									Sub Total	0.0009	∞	1.6
Connecting Volume term / **CVt**												
a	CV Water Mass @ Ref T	kg	48.17	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A
b	Water Thrm Vol Expn Coef	C^{-1}	2.12E-04	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A
c	Minimum Batch Size	kg	2.50	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A
d	Spatial Avg CV Temp	°C	20	0.05	B	R	1.732	1	0.1631	0.0047	∞	46.0
									Sub Total	0.0047	∞	46.0
Uncertainty Characteristics					**Processing Uncertainties**					**Uncertainty Results**		
				Combined uncertainty @ approximately 68% confidence					u_c : k=1	0.007	335	100.0
				Expanded uncertainty @ approximately 95% confidence					U_e : k=2	0.014	335	

Figure 6. CMC Table for Primary flow stand, PFS7K

Uncertainty analysis: global reference meters

Global Reference Meters (GRMs) are the travelling measurement standards (U_2 Figure 4) used for performing in situ calibrations of the TSM reference meters. These are Micro Motion Elite model flow meters that are calibrated annually on one of the Primary flow stands. The uncertainty value for the GRM is a combination of the Primary flow stand CMC (U_1), the worst case type A uncertainty in the mean of repeated measurements from the annual calibration, zero drift, and the long term stability of the GRM based on the variation of historical calibrations. Figure 7 is an example uncertainty table for one GRM. The typical value for the expanded uncertainty of a GRM is 0.020% @ k=2, approximately 95% confidence (U_2).

As indicated in Micro Motion's NVLAP scope of accreditation, Lab Code 200918-0, Micro Motion is accredited to perform on-site calibration of master meters located at Emerson sites in accordance with CP 79 (internal control procedure for calibrating TSM reference meters). Each TSM reference meter is issued an accredited calibration certificate based on the annual calibration with a GRM. The calibration uncertainty (u_3) using the GRM is the starting point for determining the CMC of a TSM calibration stand and is the final uncertainty value in the traceability chain (U_4).

		Global Reference Meter (GRM) K-Factor Uncertainty										
				CMFO5O S/N: 14291035								
			Annual Calibration:			May 29, 2012						
1	2	3	4	5	6	7	8	9	10	11	12	13
Quantity / Symbol	Source of Uncertainty	Units	Absolute Value	Relative u(Spec) (%)	Type Uncrt	Prob Distrb	Divisor	Rel Sens Coef	Multiplier	u(Symbl) (%)	Degrees of Freedom	% of Combined
a	CMC (PFS)	%	0.0070	0.0070	B	N	1.000	1	1	0.0070	∞	54.9
b	Type A GRM (PFS)	%	0.0016	0.0016	A	N	1.000	1	1	0.0016	9	3.0
c	Zero Stability (GRM)	%	0.0012	0.0012	B	N	1.000	1	1	0.0012	∞	1.6
d	Long term stability (GRM)	%	0.0099	0.0099	B	R	1.732	1	1	0.0057	∞	36.6
e	Static Start/Stop (GRM)	%	0.0017	0.0017	B	N	1.000	1	1	0.0017	∞	3.4
f	Pulse Resolution GRM (DAQ)	Hz	100000	0.0010	B	R	1.732	1	1	0.0006	∞	0.4
g	Software (DAQ)	%	0.0001	0.0001	B	R	1.732	1	1	0.0001	∞	0.0
Uncertainty Characteristics					Processing Uncertainties					Uncertainty Results		
					Combined uncertainty @ 68% confidence				u_c : k=1	0.009	9832	100.0
					Expanded uncertainty @ 95% confidence				U_e : k=2	0.019	9832	

Figure 7. Expanded uncertainty of a GRM

Uncertainty Analysis: CMC of TSM calibration stand

The determination of mass for a TSM reference meter is based on the mass from the GRM, corrected for pressure if required, and the connecting volume of the TSM calibration stand.

The governing equation for the determination of mass then becomes:

$$
\begin{aligned}
M(TSM\ reference) &\\
&= M(GRM) \\
&* pressure\ correction(P_c) \\
&* connecting\ volume(CV_t)
\end{aligned}
$$

Utilizing relative uncertainties in percentages where the sensitivity coefficients are the exponents of the respective factors, which are all 1, the uncertainty equation becomes:

$$u_r[M(TSM)] = u_r[M(GRM)] + u_r[P_c] + u_r[CVt]$$

Continuing by following the GUM and the propagation of uncertainties, the expanded uncertainty becomes:

$$
\begin{aligned}
U &= k(u_r[M(TSM)]) \\
&= k\sqrt{u_r[M(GRM)]^2 + u_r[P_c]^2 + u_r[CVt]^2}
\end{aligned}
$$

Where k=2 for approximately 95% confidence.

Figure 8 is an example of a CMC table for one reference meter on a TSM calibration stand. CMC tables are generated for each reference meter within a TSM calibration stand. As with the Primary flow stands, Micro Motion currently calculates and reports only the worst case CMC value for each TSM calibration stand. For the TSM calibration stands, this value (U_4, Figure 4) is targeted to be 0.030% @ k=2, approximately 95% confidence.

	Tabulation of Relative Uncertainties (Path 2 - RM050 TSM1C)											
	Flowrate = 20 kg/min											
1	2	3	4	5	6	7	8	9	10	11	12	13
Quantity / Symbol	Source of Uncertainty	Units	Absolute Value	Relative u(Spec) (%)	Type Uncrt	Prob Distrb	Divisor	Relative Sensitivity Coefficient	Multiplier	u(Symbl) (%)	Degrees of Freedom	% of Combined
TSM Mass Reading / $\mathbf{M_{TSM\ RM}}$												
a	GRM CMF050 (14291035)	%	0.0094	0.0094	B	N	1.000	1	1	0.0094	∞	59.9
b	Type A GRM (TSM)	%	0.0032	0.0032	A	N	1.000	1	1	0.0032	9	6.7
c	Long Term Stability (TSM)	%	0.0117	0.0117	B	R	1.732	1	1	0.0068	∞	30.8
d	Pulse Resolution GRM (DAQ)	N	60000	0.0017	B	R	1.732	1	1	0.0010	∞	0.6
e	Pulse Resolution TSM (DAQ)	N	60000	0.0017	B	R	1.732	1	1	0.0010	∞	0.6
f	Pulse Resolution UUT (UUT)	N	45000	0.0022	B	R	1.732	1	1	0.0013	∞	1.1
g	Software (DAQ)	%	0.0001	0.0001	B	R	1.732	1	1	0.0000	∞	0.0
h	Best Repeatability (UUT)	%	0.0005	0.0005	A	N	1.000	1	1	0.0005	9	0.2
									Sub Total	0.0122	1983	100.0
Pressure Correction / $\mathbf{P_{c\_TSM\ RM}}$												
a	pressure (cal)	psi	41.0	1.2	B	R	1.732	1	0.0000	0.0000	∞	0.0
b	pressure (use)	psi	6.0	8.3	B	R	1.732	1	0.0000	0.0000	∞	0.0
c	PCF	%/psi	0.0000	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A
									Sub Total	0.0000	∞	0.0
Pressure Correction / $\mathbf{P_{c\_GRM}}$												
a	pressure (cal)	psi	41.0	1.2	B	R	1.732	1	0.0000	0.0000	∞	0.0
b	pressure (use)	psi	6.0	8.3	B	R	1.732	1	0.0000	0.0000	∞	0.0
c	PCF	%/psi	0.0000	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A
									Sub Total	0.0000	∞	0.0
Connecting Volume term / **CVt**												
a	CV Water Mass @ Ref T	kg	14	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A
b	Water Thrm Vol Expn Coef	C^{-1}	2.24E-04	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A
c	Minimum Batch Size	kg	15.0	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A
d	Spatial Avg CV Temp	°C	20	0.05	B	R	1.732	1	0.0086	0.0002	∞	0.0
									Sub Total	0.0002	∞	0.0
Uncertainty Characteristics					**Processing Uncertainties**					**Uncertainty Results**		
			Combined uncertainty @ approximately 68% confidence						u_c : k=1	0.012	1984	100.0
			Expanded uncertainty @ approximately 95% confidence						U_e : k=2	0.025	1984	

Figure 8. CMC of a TSM calibration stand

Conclusion

The Calibration and Measurement Capability (on mass) of the TSM calibration stand meets the target uncertainty of 0.03% for the worst case conditions. The analysis in the previous sections shows the CMC is traceable through a series of calibrations contributing to the final value. The TSM reference meter in series design contributes to a better understanding of the CMC value by providing real time information about the long term stability contribution of the reference meters. Future continuous improvement programs will focus on utilization of the real time information from the reference meters in series to optimize the TSM calibration stand performance.

References

[1] R. DeBoom, M. Buttler, A. Kolbeck, A. Pruysen, "Traceability and Uncertainty Analysis for Flowmeter Calibration Process with Coriolis Flowmeters as Reference", in Proceedings of the Conferences FLOMEKO, 2000.

[2] JCGM 100:2008 GUM 1995 with Minor Corrections, Evaluation of measurement data — Guide to the expression of uncertainty in measurement, JCGM, 2008.

[3] ISO/IEC 17025:2005, General requirements for the competence of testing and calibration laboratories, ISO, 2nd Ed., 2005-05-15.

[4] A. Almazoory and D. Standiford, "FMCC Guide to Uncertainty of Measurement", GWI-116 Rev. H, May 2013.

[5] G. Mattingly, "Consultant's Report on the Uncertainty of the M_{UUT} Delivered by the MMI-PFS7K", September 2010.

[6] ISO 10790:1999, Measurement of fluid flow in closed conduits — Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements), ISO, 2nd Ed., 1999-05-01.