American School of Gas Measurement Technology
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Ultrasonic Flow Meter Calibration

Considerations and Benefits

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Background

With natural gas playing a central role in modern energy markets, the accuracy of custody-transfer measurements has become paramount. Ultrasonic flow meters are widely adopted because their broad measurement range and minimal pressure loss, making them suitable for large-diameter pipelines. To ensure these meters deliver traceable and reliable data, high-pressure calibration must be carried out under conditions that replicate field operation, correcting inherent biases and establishing a reference baseline for monitoring meter performance once installed.

Pipeline operators therefore look to recognized calibration standards to sustain the credibility of their custody-transfer measurements and ensure that invoiced volumes reflect actual delivered energy. The value derived from rigorous calibration supports fair trade and mitigates financial exposure in an industry where even small measurement errors can translate into significant revenue discrepancies.

In this context, the present paper outlines the principal factors to consider when calibrating ultrasonic meters and describes a representative high-pressure calibration workflow. While individual laboratories may adjust specific procedures, the fundamental steps and diagnostics described herein form a common foundation across most calibration services.

1. INTRODUCTION

Although calibration is an important step for enhancing the accuracy of all measurement technologies, in ultrasonic metering, this activity plays an even more prominent role. The extended flow ranges capability of ultrasonic technology, although capacity adventitious can magnify measurement error if not corrected through proper calibration.

For ultrasonic metering, high-pressure calibration not only provides immediate performance value through measurement correction, removing the meter's intrinsic uncertainty and offering traceable accurate readings at the laboratory; it also provides on-going operational field value through the definition of a meter specific performance baseline for continual qualification of meter health once operational in the field.

2. PRECALIBRATION CONSIDERATIONS

Typically, several questions come to mind prior to the actual calibration taking place. Common questions are:

1) What components of my measurement system should I send?

2) How is the test performed and what flow points should I consider?
3) Which output signals and adjustment method should the lab use?
4) Do I want the meter's configuration write protected after calibration?
5) Should the metering package remain assembled after calibration for shipping back to the field?
6) What documentation does the laboratory need from me?

These questions will be answer in this and following sections.

In addition to the meter itself, the end user will typically send the immediate upstream piping, downstream piping, flow conditioner and thermo-wells. The downstream meter tube in generally accepted as being optional for the calibration providing the calibration laboratory can supply a meter spool with similar pipe length to replicate the temperature-sensor position as close to the final installation as possible. However, a large percentage of calibrations performed do include installation of the immediate up and down stream piping. Some operators go even further, supplying all the pieces in the exact order and orientation they will be in the field, to make the calibration as realistic as possible



Figure 1. Customer special meter pipe configuration

End user's typically do not supply pressure and temperature transmitters with the metering package as the laboratory utilizes devices maintained in house for the calibration, to maintain the validity of the facility uncertainty statement. However, installation of the customer's thermo-wells for the calibration process is generally recommended.

All the laboratories in North America provide some forms of pre-calibration checklist that is used to provide the laboratory with information about the metering package as well as specific customer requests. In the checklist example shown below, the customer can define the calibration points desired. AGA Report No. 9, requires calibrations at Qmax, 70% Qmax, 40% Qmax, 25% Qmax, 10% Qmax and 5% Qmax as a minimum. Users will often define additional calibration points within the typical operating range of the meter. Also, a minimum of one post adjustment verification point is performed. We will discuss this topic in more detail later in this paper.

TRANSCANADA CALIBRATIONS

Box 880, 1048 Arnould Road
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tel (204) 878-4373
fax (204) 878-4531

ULTRASONIC PRE-CALIBRATION CHECKLIST

This form must be completed and returned via fax or email at least 10 business days prior to the calibration date.

Customer Information

Will customer witness Calibration? please select from list
Onsite:
Remotely:

Company Name: | Contact Name:
Address: | Telephone:
City, State, Country: | Fax:
Zip/Postal Code: | e-mail:
Inservice Location: | Calibration Date:

Paper Certificate Required Cost $125 **Yes / No** PDF will be emailed no charge
If YES, please provide delivery address and contact information in the Special Instructions section below if different than above.

Meter / Meter Run Information

Serial Number: | Size: **NPS**
Type of meter: | ANSI:
Manufacturer: | Piping Schedule/I.D.:
Model: | Overall Dimension: **mm or inches**
Flow Conditioner:

Calibration Specifications

Prefered Certificate Units : please select from list

** Meters will be calibrated to manufacturers Qmax unless specified below*

	Calibration Points (or fixed)	Select Scale (%Qmax or Pipe Velocity) please select from list	Verification Points (after adjustment)
1st Point			
2nd Point			
3rd Point			
4th Point			
5th Point			
6th Point			
7th Point			
8th Point			
9th Point			
10th Point			

Please provide the preferred adjustment method.

please select from list
Adjustment Method:

If meter is for use in Canada: please select from list
1) Does the meter require Measurement Canada Sealing? (Custody Transfer)
2) Please provide your Company Measurement Canada Registration #
3) Please provide the meter inspection # (SAP, Entity, etc.)

Special Instructions

Figure 2. TCC Pre-calibration check list

In addition to this checklist, the laboratory will normally require certain QC test documentations relating to the fabrication of the meter run spools and meter. This documentation includes meter run drawings, hydro-test and NDT reports. Regulations may vary with geographical location of the laboratory so be sure to consult with the appropriate person within the calibration laboratories' organization.

3. MECHANICAL INSTALLATION

All metering components are thoroughly inspected upon receipt at the calibration laboratory. Meter run piping is inspected for both internal and external damage that may have occurred during shipping. Meters are normally

shipped within a protective crate typically equipped with a shock-watch device. The status of this device is noted.

Utilizing the customer supplied engineering details, the installation of the meter run piping begins with the installation of the most upstream pipe following with the next meter run component (typically the flow conditioner) then continuing with the next sequential component downstream. This step installation from upstream to downstream allows for the continual internal inspection of the piping assembly from the most critical upstream location to downstream of the meter prior to installing the final component. Meter run piping is typically marked with unique serial numbers or identifiers as outlined on the meter run schematic.

The installation of the flow conditioner should be completed in accordance with the flow conditioner manufacturer's instructions and the orientation of the device marked (if not done by the manufacturer) and documented. Serial numbers are also documented. A reputable flow conditioner manufacturer should provide a unique identifier on all flow conditioners that can be documented on the final calibration certificate. This eliminates the possibility of mixing up components in the case of multiple calibrations of devices of the same size.

Internal alignment of flanges is very important especially at the inlet flange of the ultrasonic meter as misalignment can cause flow profile distortions that may affect the meter's output. Alignment dowel pins are sometimes supplied to ensure correct assembly at this location. The utilization of dowel pins, however, does not always provide a perfect bore alignment but does provide an avenue for a repeatable installation regardless of the assembler. Mated flanges are also used at the inlet and outlet of the meter for some installations.

Before completing the installation, photographic records of the internal piping conditions are taken and filed for future reference.

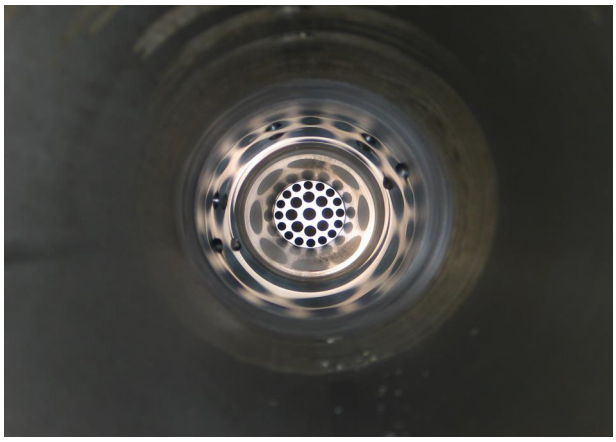


Figure 3. Inspection of installed Flow Conditioner

All flange bolts are now torqued in accordance with the facility's operation procedures or sometimes customer supplied specifications. Some customers will have the metering run shipped to the final installation after flow calibration as a complete unit. In those cases, customer supplied gaskets and bolts would be used, and the torque procedure would be in compliance with the end user's quality assurance program. In cases where the meter run will be disassembled upon completion of the calibration, the facility bolting and gaskets are typically used.



Figure 4. Calibrated torque tools for mechanical assembly

4. METER CONNECTIONS AND INSTALLATION OF ANCILLERY INSTRUMENTATION

Once the mechanical installation has been completed, pressure and temperature device can be installed. AGA Report No. 9 stipulates the temperature sensing element should be installed between 2 and 5 pipe diameters downstream of the ultrasonic device for a uni-directional

application. Following the customer supplied drawing, the temperature sensing element is installed in the indicated thread-o-let. Often, laboratories will use a second temperature element for quality control purposes. Next the pressure sensing device can be connected. Again, the AGA report No. 9 document clearly states that the pressure measurement must be taken from the meter manufacturer supplied port on the meter body. There are many considerations that are taken into account for the placement of temperature sensing elements. For this paper, we will assume an AGA report No. 9 compliant installation.

Connections to the ultrasonic meter can now be made. Typical connections are power, frequency output and data output signals. Power is typically 24 Vdc. The frequency outputs usually can be configured TTL or open collector. The data output is typically RS-232 or RS-485 utilizing either a Modbus protocol or a proprietary protocol. In addition to the above connections, an Ethernet connection is becoming more common.

Now that all connections have been completed and the mechanical installation has been verified, the meter run can be pressurized and leak checked.

5. Calibration Process

The first step in the calibration process is the configuration of the facility data acquisition system. Utilizing the meter manufacturer's software and one of the data signal lines, communication is established with the meter. The meter configuration is read from the meter and collected as part of the calibration documentation. This configuration file contains information that is required for programming into the facility system. Critical information includes, k-factors, meter I.D., communication parameters, etc. Once the acquisition system is programmed, the received signals are verified. For example, if the customer has selected the frequency output as the custody transfer signal, a frequency is forced from the meter using the meter software or hardware and the receive signal is verified and documented.

Now that the meter run has been pressurized and the facility acquisition system has been programmed, the instrumentation is checked for agreement. All piping is equalized, and the pressure measurement is verified. This is performed with zero flow though the test run. Agreement of temperature measurement is normally checked with a low flow through the facility reference bank and test run. This low flow condition also allows for the temperature stabilization of the facility piping.

The facility valves are positioned to allow a low flow condition though the reference and test run piping. During the low flow stabilization period, the meter performance is verified. The ultrasonic meter's corrected VOS, per path VOS, corrected gas velocity, raw gas velocities (profile), gain levels, and signal to noise ratios are all verified. This ensures the meter is functioning correctly prior to calibration and prevents time and resources being wasted calibrating faulty equipment.

Once the facility piping has stabilized, the isolation valves to the test section are again closed. A zero-flow verification test is performed again to verify the meter's operation. Using the meter manufacturer's software, a log file is recorded and stored as a record of the meter's health prior to the calibration process commencing. AGA Report No. 9 states that all raw gas velocities must be within +/- 0.04 ft/sec at zero flow conditions. This criterion is checked at this time. Generally, this criterion is applicable to the dry calibration process in which a true zero condition can be achieved but depending on the valve and piping configuration of the facility, comparable zero flow conditions can be simulated.

Results have shown a very good correlation between the facility findings and those documented during the dry calibration for the same device. This procedure is not intended to replace the dry calibration procedure but is only intended as verification. We have found that many meters, especially meters that have been in service for several years, will exhibit zero flow bias on one or more paths while showing very good performance under flowing conditions. This zero bias can skew calibration results, especially at lower flow rate. Now that the meter's health has been verified, the calibration process can commence.

Facilities within North America are all quality system certified and traceable to recognized standards. For this paper TCC uses standards maintained in accordance with the ISO-17025 standard.

The calibration process involves flowing gas through one or more reference devices and through the customer metering package. Flows are achieved at rates provided by the customer on the pre-calibration checklist. The following picture shows TCC's pipe configuration corresponding to an open loop calibration system.

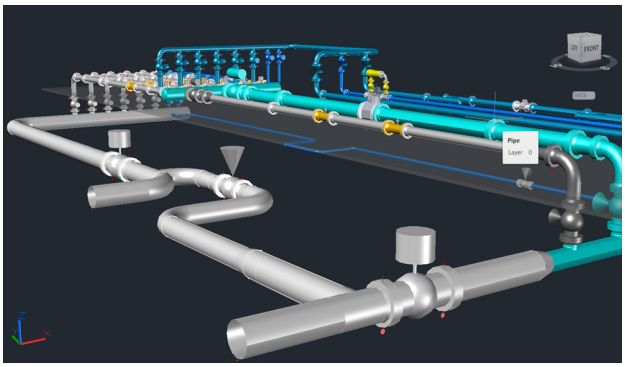


Figure 5. TCC Open loop calibration system

The calibration process begins with the highest indicated flow rate. The flow of the facility is slowly increased until the high flow rate is established. The stability of the systems is allowed to equilibrate before any data is sampled. The facilities acquisition system provides stability indicators for all input parameters during the calibration process and the stabilization period. This information can be reviewed both graphically and in a tabular format.

In an open loop system, the facility has no direct control over the loop pressure and temperature so to ensure that the stability of these inputs is not influencing the error calculations, it must be checked against control limits and documented for reference. Operators of closed loop systems may also perform stability checks but have direct control over the pressure and temperature set-points. The following figures show both the graphical and tabular format of the input data stability.

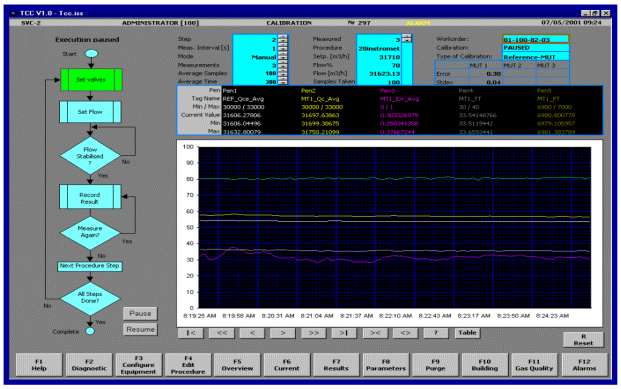


Figure 6. Q, P and T and meter error stability checks during meter calibration at TCC

TCC Calibration Report

Date of tes			Samples	100	Calibration Step		4		
Time			Tests	3					
	(End of 300 sec sample)								
Serial Number									
Imp/m3		1130.67		635.664				1000	1647.76
Snapshot		MUT1		MUT2		MUT3		Ref USM	Ref Turbine
Q Raw	m3/h	1223.98		1213.83				1215.78	1217.14
Frequency	Hz	384.4205		214.3308					557.0987
Q	m3/h	1220.00		1219.97				1220.21	1219.03
StDev		5.04		5.93				3.50	6.84
Re		5.18		5.14				7.75	7.73
Error	%	0.3259		-0.4361				0.0863	-0.01
StDev		0.00		0.00					
P	kPa	6217.75		6221.77				6247.82	6228.05
StDev		0.08		0.09				0.11	0.14
dP	kPa			4.02				30.07	10.31
StDev				0.09				0.17	0.08
T	oC	29.13		29.14				29.30	29.22
StDev		0.02		0.00				0.00	0.01
Z		0.89847		0.89842				0.89827	0.89845
Density	kg/m3	46.731		46.762				46.941	46.795
Corr 1		-						1.0045	1.0014
Corr 2		-						69.3259	68.4743
Corr 3		-						-2.9123E-07	-1.1610E-06
FCF		-						1.0045	1.0015
Viscosity	Pa.s	1.3E-05		1.3E-05				1.30258E-05	1.30217E-05

Samples/A	100							
Averages	MUT1		MUT2		MUT3		IRPP	Ref
Err_Ref_i_MUT_I Avg	**-0.01**		**0.03**		**0.00**			
Err_Ref_i_MUT_I StDev	0.17		0.15		0.00			
Err_Ref_i_MUT_I StDev/N	0.02		0.01		0.00			
Qce Avg	**1222.04**		1222.56					1222.43
Qce StDev	2.51		2.32					2.05
Qce StDev/NrOfTests	0.26		0.24					0.21
Err_RR_MUT_I Avg	**-0.03**		**0.01**					
Err_RR_MUT_I StDev	0.16		0.15					
Err_RR_MUT_I StDev/NrC	**0.02**		0.02					0.00
RR_TbQceAvg	**1222.43**							
RR_TbQceStDev	2.73							
RR_UsQceAvg	1222.18							
RR_UsQceStDev	2.05							
RR_QceAvg	1222.43							
RR_QceStDev	2.73							

Figure 7. TCC test flow rate snapshot report

Sampling times may vary depending on the calibration facility but the total sample time per flow point is always over 300 seconds. TransCanada Calibrations takes 100 samples over 300 seconds and repeats this sampling at least two times.

Data recorded during the calibration sampling period includes, pressures, temperatures, flow rates (pulse counts or flows polled using serial communication), and gas composition. Flow, density, compressibility, error, and stability (Standard deviation) calculations are performed on each data set and stored in an archival data base. This data acquisition and storage is typically redundant for quality assurance purposes.

At the same time the calibration acquisition system is sampling data, a second system is used to acquire meter performance data (log or maintenance file) via the meter manufacturer's software. At least 2 minutes of logged data is desired. This diagnostic information is used as a base line against which historical and future operational data can be compared. It is also useful during the commissioning process. The data can be used to qualify the meters output and performance in the field where a reference standard is not accessible. This will be discussed later in the paper.

In addition to the calibration data and log file collection, a SOS comparison is performed at all flow rates. This involves calculating a theoretical SOS as defined by AGA report No. 10 and comparing it against the meter corrected SOS. It should be noted that the theoretical SOS can not be compared against the individual SOS (per path or chord) at high velocities for some manufacturers because there is a correction performed on the raw individual SOS before the final corrected SOS is reported. A SOS comparison spread sheet is produced as part of the final document set.

6. Calibration Adjustment and Verification

Once this process has been completed for all requested flow points, an as-found calibration error curve can be produced, and adjustment factors can be determined.

AGA Report No. 9 provides three acceptable methods of adjustment for an ultrasonic device. They are

1) FWME adjustment method
2) Polynomial adjustment
3) Piece-wise linearization

In this first example, we will calculate an adjustment using the FWME method.

Qmax			
280,000			
Meter Flow Rate	Error	Full Scale	Weighted Error
(ACFH)	(%)	Normalized	(%)
279354	-0.56	0.998	-0.5587
195825	-0.53	0.699	-0.3707
140223	-0.53	0.501	-0.2654
69554	-0.5	0.248	-0.1242
27963	-0.42	0.100	-0.0419
13992	-0.36	0.050	-0.0180
	Sum =	2.596	-1.379

Figure 8. FWME adjustment method

The data in the flow rate and error columns are determined during the flow calibration. The full-scale values are calculated by taking the indicated flow rate of the meter for each calibration point and dividing by the full-scale value (Qmax). The weighted error is then calculated by taking the indicated error and multiplying it by the full-scale value for each flow rate.

Full Scale = Indicated Meter Flow Rate/ Qmax
Weighted Error = Indicated Error * Full Scale value

The FWME can be calculated as follows:

FWME = Sum of the Weighted Errors/ Sum Full Scale Weighting

FWME = -1.379/2.596 = -.5312%

Now that the FWME has been calculated, an adjustment factor can be calculated.

Adjustment Factor = 100/100+FWME

= 100/100+ (-.5312)
= 1.0053

Most meter manufactures allow for a number up to four decimal places in resolution to be entered into the adjustment factor field in the meter configuration.

How does this factor work?

1) The meter calculates multiple delta times and calculates multiple RGVs
2) Using proprietary algorithms, the meter calculates a single corrected gas velocity.
3) The meter then multiplies this corrected gas velocity by the programmed adjustment factor to derive an adjusted corrected gas velocity.
4) With the programmed meter bore (area) and the adjusted corrected gas velocity, the meter then calculates a volumetric flow rate.
5) Utilizing the programmed k-factor, the meter then outputs a frequency proportional to this corrected flow rate.

Often, end users confuse the term Adjustment Factor with K–factor. K factors are used for the scaling of frequency outputs and the adjustment of turbine meters. Adjustment factors are used for the calibration adjustment of ultrasonic meters. One can see from the example above, that even if the meter adjustment factor changes, the meter K factor does not. The meter K factor is used for scaling the frequency output that is outputted proportional to the corrected flow rate. Because the calibration adjustment factor is applied before the frequency scaling, even when the adjustment factor is changed at the time of calibration, the K-factor will remain the same.

This contrasts with how turbines are adjusted. Every time a turbine is calibrated and adjusted, a new K-factor is calculated. When you receive the newly calibrated turbine meter with the new K-factor, the factor programmed in the flow computer must be changed to match the factor determined at the turbine meter calibration so the flow computer can properly convert the frequency input back to flow. This need not be done for USMs. The K-factor in the flow computer of a USM will remain the same even after calibration.

The results of the FWME adjustment method is shown below in figure 9.

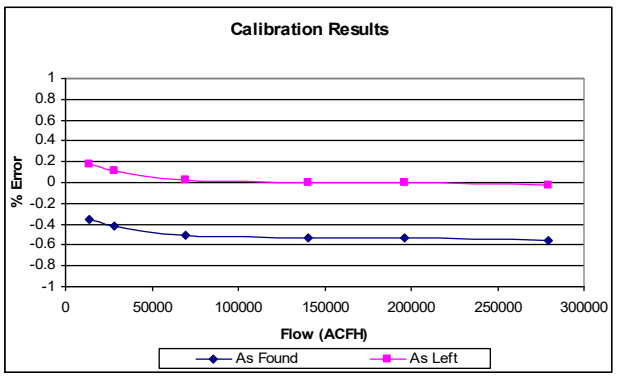


Figure 9. Meter adjusted using FWME method

In our second example we will calculate and apply a polynomial adjustment to the same meter. Different manufactures use different methods of calculating and applying a polynomial. In the example below the following formula is applied to the gas velocity as follows.

Velocity (adj) = bo + b1* Velocity (corr) + b2*Velocity *(vel/30)^2
Please note that in this equation, the meter uses the velocity in metric units to apply the correction.

Factors determined are b0 = -0.0024, b1 = 1.0051 and b2 = 0.0181

Using the highest flow rate as an example:
Velocity (corr) = 50.08 ft/sec = 15.264 m/s

Velocity(adj)=-0.0024+(1.0051*15.264)+
0.0182*sin(15.264)*(15.264/30)^2
= 15.340 m/s
= 50.334 ft/sec

Results of the polynomial adjustment method are shown in Figure 10.

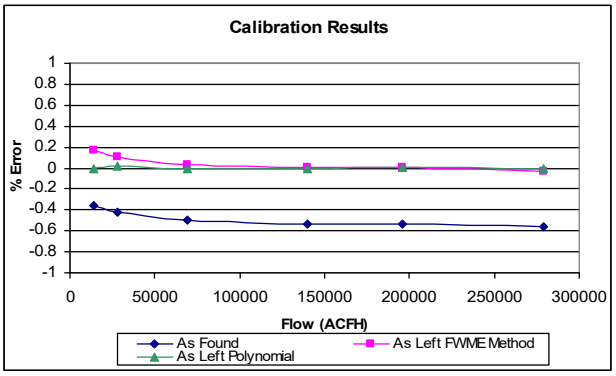


Figure 10. Polynomial meter adjustment method

Finally, using our third adjustment method, an adjustment factor is calculated using the same formula as in example #1, only in this example, a factor is calculated and entered into the meter configuration for every flow rate tested and the individual errors are used in the formula in place of the FWME. Keep in mind that the meter's firmware must allow for this type of adjustment method. Please consult with your meter manufacturer about the methods of adjustment available within your devices.

The following table shows the adjustment factors calculated for each flow rate.

Qmax				
280,000				
Meter Flow Rate	Error	Full Scale	Weighted Error	Adjustment
(ACFH)	(%)	Normalized	(%)	Factor
279354	-0.56	0.9977	-0.558708	1.0056
195825	-0.53	0.6994	-0.37066875	1.0053
140223	-0.53	0.5008	-0.265422107	1.0053
69554	-0.5	0.2484	-0.124203571	1.0050
27963	-0.42	0.0999	-0.0419445	1.0042
13992	-0.36	0.0500	-0.017989714	1.0036
	Sum =	2.596	-1.379	

Figure 11. Piece wise Linearization method

The result of using the Piece-wise linearization method is shown in Figure 12.

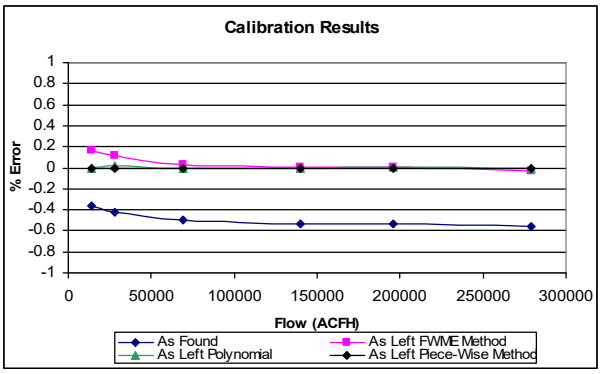


Figure 12. Piece-wise correction error

Numerical results of the individual adjustments methods are shown in Figure 13.

Qmax			After Adjustment	
280,000			Errors	
Meter Flow Rate	As Found Error	FWME	Polynomial	Piece-Wise
(ACFH)	(%)	(%)	(%)	(%)
279354	-0.56	-0.03	0.00	0.00
195825	-0.53	0.00	0.01	0.00
140223	-0.53	0.00	-0.01	0.00
69554	-0.5	0.03	-0.01	0.00
27963	-0.42	0.11	0.01	0.00
13992	-0.36	0.17	-0.01	0.00

Figure 13. Adjustment methodology comparison

Once the adjustment method is selected, the factors are entered into the meter's configuration and the verification is performed. During the verification process, the meter is tested as in the original process of calibration at predetermined flow rates. AGA Report No 9 requires a minimum of one verification point but often more points are selected depending on the method of adjustment. Particularly when a polynomial adjustment is performed, verification of the meter output will occur at a high and low flow rate to verify the application of all factors. The results of the verification will be shown on the calibration document along with the as found data.

7. CALIBRATION DOCUMENTATION

The calibration document set typically includes:

1) Calibration Certificate
2) Final Meter Configuration File
3) SOS Comparison Spreadsheet
4) Soft copy of meter log files (flow and zero)
5) Log file analysis, if requested

Figures 14 through 18 show examples of a typical document set.

TransCanada Calibrations

TransCanada Calibrations Ltd.
Box 880
Ile des Chenes, Manitoba, Canada
R0A 0T0

Certificate of Calibration

Applicant:	Company A 1001 34th Street Houston, Texas 78003 E. Kentucky Meter Stn.	**Certificate Number:**	2804
		Work Order:	06-100-462-02
		Date of Calibration:	December 3, 2006
		Units	US

Meter Under Test

Type:	Ultrasonic	**Medium:**		Natural Gas
Manufacturer:	Instromet	**Pressure:**	(PSI)	892.74
Model:	Qsonic-5	**Temperature:**	(°F)	84.17
Serial Number:	05-XXXX-Q512064	**Density:**	(Lbs/ft3)	2.85
Meter ID (In)	11.9290	**Compressibility:**		0.90148
Year of Manufacture:	2005	**Direction:**		Unidirectional

Meter Details

Transducer Type:	L2
Firmware Version:	5.21
Pulses/ft3:	50.00

Pipe Spool S/N:	06-XXXX-PS12064, 06-XXXX-PS12064, 06-XXXX-PS12064
Run Configuration:	UST 120", CPA 50E, UST 120", METER, DST 96.375"
Flow Conditioning:	CPA 50E Type A
Flow Conditioner S/N:	22456293
Witness:	None
Comments:	Meter adjustment factor calculated with 75fps-10fps data.

Test Method: The actual flow of the gas meter is established with the aid of standard gas meters, pressure and

Results: The measurement results are stated on page 2 of 2. The total uncertainty in the measurement is based on 2x the

Traceability: The measurement methods utilized in the calibrations and measurements are traceable to primary standards

Facility Uncertainty: 0.21% for Flow Rates less than 1600 m³/hr; 0.19 for Flow Rates above 1600 m³/hr

Test Date:	December 3, 2006	**Tested By:**	Jeff Dahlin
Date of Issue:	December 3, 2006	**Reviewed:**	

Figure 14, Calibration Certificate, Page 1

Measurement Results

			Certificate Number:	2804	
Qmax =	280000	Acf/h	**Serial Number:**	05-XXXX-Q512064	
Qmin =	7000	Acf/h			
Average Error	-0.33		**Adjust Fact.(found)**	1.0000	
Adjusting	0.33		**Adjust Fact.(left)**	1.0033	

Uncorrected

Nom. Flow (Acf/hr)	Act. Flow (Acf/hr)	Velocity (ft/s)	Deviation (%)	StDev (2σ)	Deviation (%)	StDev (2s)	Check Pt. (%)
280000	272000.18	97.35	-0.35	0.04	-0.02	0.04	
210000	212428.96	76.03	-0.33	0.04	0.00	0.04	
140000	140733.59	50.37	-0.33	0.03	0.00	0.03	
70000	70104.75	25.09	-0.34	0.04	-0.01	0.04	
28000	28715.47	10.28	-0.34	0.08	-0.01	0.08	
14000	14741.02	5.28	-0.38	0.09	-0.05	0.09	
7000	7365.47	2.64	-0.41	0.15	-0.08	0.15	
196000	192632.11	68.94					0.00
28000	28514.89	10.21					-0.01

FWME METHODOLOGY: AGA

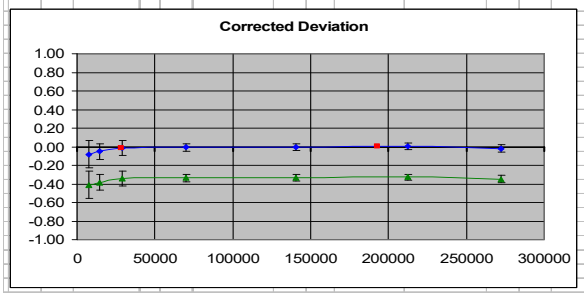


Figure 15, Calibration Certificate, Page 2

TRANSCANADA CALIBRATIONS

Ultrasonic VOS Comparison

Applicant:	Company A			
Meter Details:				
Certificate Number:	2804			
Meter Serial Number	05-XXXX-Q512064			
Manufacturer	Instromet			
Model	Qsonic-5			
Meter I.D.	11.9290	in	0.302997	meters
Meter Capacity	280000	acf/h	7929	acm/h
Flow Conditioner	CPA 50E Type A			
Test Conditions(Avg)				
Medium	Natural Gas			
Pressure	892.74	psia	6155.20	kPa
Temperature	84.17	°F	28.98	°C
Density	2.85	lbs/ft^3	45.58	kg/m^3
Compressibility	0.901481			

VOS Comparison

FlowRate (Acf/hr)	Velocity (ft/s)	Meter Vos (ft/s)	Calc. Vos (ft/s)	Diff. Vos (ft/s)
272000	97.35	1405.53	1405.46	0.07
212429	76.03	1410.10	1410.01	0.09
140734	50.37	1410.61	1410.50	0.11
70105	25.09	1410.87	1410.75	0.12
28715	10.28	1410.03	1409.89	0.14
14741	5.28	1408.18	1408.03	0.15
7365	2.64	1407.93	1407.80	0.13

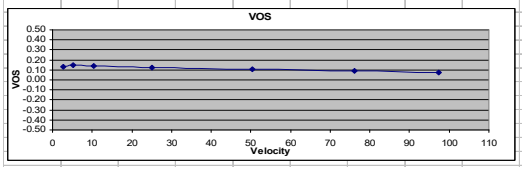


Figure 16, SOS Comparison Spreadsheet

TRANSCANADA CALIBRATIONS

```
************************************
*       Ultrasonic Flowmeter       *
*     Configuration Information    *
*    (Uniform version 3, 0, 1)     *
* ------------------------------- *
* Instromet Ultrasonic Technologies *
************************************

File Name:  05-XXXX3.doc
Customer:  Company A
Meter S/N:  05-XXXX-Q512064
Certificate:  2804

UNIFORM Settings:
=================
  InstrumentType: 24
    > 'Q.Sonic-5 Series-III QL Meter (Stand-alone SPU)'
  COM settings: UNIFORM point-to-point
                4800,N,8,1

Parameter Setup:
================

PROSON II Configuration:
   Instrument Type:24
     > Q.Sonic-5 Series-III QL Meter (Stand-alone SPU)
   Parameter 1: 0xC102
   Parameter 2: 0xA0
   Parameter 3: 0x818A
   Parameter 4: 0x07
   Parameter 5: 0x7104

Module Information:
   Flowmeter Serial Number:  XXXX
   Software Version: V5.21
   Flowmeter Identification: 05-XXXX-Q512064  05F288,

Spool Piece Parameters:
   Diameter: 11.9290 Inch.
   Line 1:
      Path Length: 27.6120 Inch.
      Beam Angle:  60.00 deg
   Line 2:
      Path Length: 35.8400 Inch.
      Beam Angle:  60.00 deg
   Line 3:
      Path Length: 27.6270 Inch.
      Beam Angle:  60.00 deg
   Line 4:
      Path Length: 35.7670 Inch.
      Beam Angle:  60.00 deg
   Line 5:
      Path Length: 27.6420 Inch.
      Beam Angle:   60.00 deg
```

Figure 17, Meter Configuration, page 1

```
V-Module Parameters:
   Application-specific Parameters:
      Velocity of Sound Range:
         Lower Limit:   1000.00 ft/s
         Upper Limit:   1600.00 ft/s
      Gas Velocity  Range:
         Lower Limit:   -130.00 ft/s
         Upper Limit:    130.00 ft/s
   Device-specific Parameters:
      Sample Rate:          15 Hz
      Timing Constant 1:   1140
      Timing Constant 2:      0
      Timing Constant 3:      0
      Pulse Length:         195

Profile Correction Parameters:
   Reynolds Number Computation:
      Density:                2.90 lb/cu.ft
      Dynamic Viscosity: 1.30e-002 cP
   Profile Correction Coefficients:
      Axial Path(s):
         p1:   3792.0000
         p2:     26.0000
         p3:      0.7502
         p4:      0.9711
         p5:      0.0231
         p6:     -3.3190
      Swirl Paths:
         p1:   3401.0000
         p2:     66.0000
         p3:      1.0037
         p4:      1.0093
         p5:      0.0175
         p6:     -3.2090

Calibration Parameters:
  Coefficients:  c1      c2      c3      c4
    s=1         0.1590  0.8410  0.0080  0.0000
    s=2         0.0300  0.0200  0.0500  0.0000
    s=3         0.0500  0.0060  0.0000  0.0000
    s=4         0.0300  0.0000  0.0000  0.0000
    s=5         0.0000  1.0000  0.0000  0.0000
    s=6         1.0000  0.0000  0.0000  0.0000

Adjust Factor:
   Adjust Factor: 1.0033

Low Pass Filter:  Off

Low Flow Cut-off:  Off

Frequency Output: Vol. Flow (Line Cond.)
  Vol. Flow (Line Cond.) Range:
      Lower Limit:     0.00 CFH
      Upper Limit: 360000.00 CFH
   Frequency Range
      Lower Limit:     0.00 Hz
      Upper Limit:  5000.00 Hz
      Error:        6000.00 Hz
   Meter Factor:    50.00 Impulses/acf
```

Figure 18, Meter Configuration, Page 2

AGA Report No 9 Requires the calibration laboratory to maintain a copy of the calibration documentation for a minimum of 10 years.

8. POST CALIBRATION PROCESS

Upon completion of the flow calibration the meter is again subjected to a zero-flow state so that the calibration technician can once again obtain a meter calibration log which is used as a record of the meter's health prior to disassembly and shipping to the destination.

Once the final zero flow verification is complete, the calibration test run is vented and purged until free of gas. All meter run flanges are marked and given an identifier to assist the field personnel in the re-assembly process. The duplication of flange alignment is critical to ensure similar flowing conditions in the field.

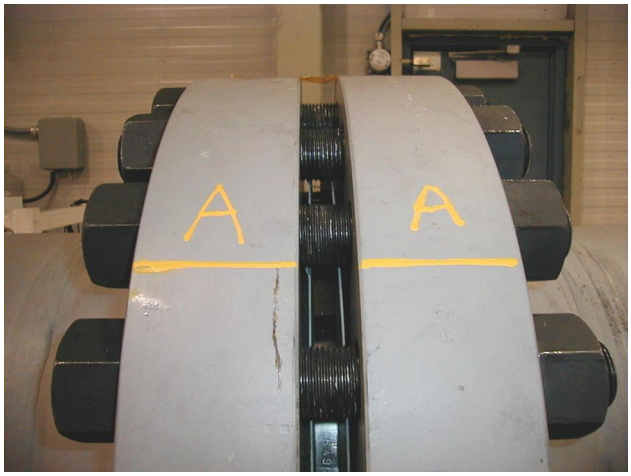


Figure 19, Flange Marking and Alignment

All piping is end capped and wrapped with a vapour barrier to ensure no damage to piping internals occurs during shipment. The meter's write-protect jumper is installed when required and the meter is repackaged in its original shipping container. The meter internal may be coated with a rust preventing oil for the return shipment upon request.

As previously stated, some USM users will supply skids to have the entire metering package shipped as a complete unit to the final installation site.



Figure 20, Crating of Assembled Meter Package

The calibration documentation is submitted to a final ISO review to ensure documented process compliance. Once the review is completed, the original calibration document set is sent to the user for their records.

9. ULTRASONIC METER CALIBRATION KEY CONSIDERATIONS

Fig 21 from the American Gas Association AGA, Report No 9, highlights the industry minimum requirements for ultrasonic meter performance specification before any adjustment is introduced to correct the output of the meter. Two main components are considered: the maximum meter bias as compared with a traceable facility reference value and the combined effect of facility stability and meter response under installation effects.

9.1. Intrinsic Uncertainty Factors and the Facility Reference Values

The bias reported by the meter under calibration is determined by the intrinsic uncertainty components linked to the meter design and data interpretation for determining a flow rate, weighed against the quality of the components associated with the traceability, reproducibility and integrity of the facility reference values at the calibration laboratory.

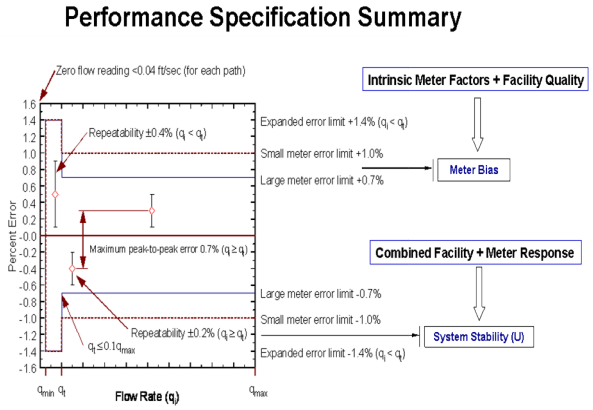


Figure 1 from AGA Report # 9.

Figure 21, AGA 9 USM out of the box Performance Specifications

As an example, a large meter error limit of ±0.7% represents the minimum meter out of the box accepted performance under the impact of the design's remaining uncertainties when that performance is evaluated by a proven reference value.

9.2. Facility Stability and Meter Response Under Installation Effects

The calibrated/adjusted meter output represents a baseline that agrees with the facility reference values to within the combined meter and facility repeatability.

AGA Report No 9 specification states repeatability values of ±0.2% for large meters and ±0.4% for small meters.

During testing, the combined facility and meter repeatability of the error resulting from comparing the ultrasonic meter output with the reference values is affected by following conditions:

- drifting beyond tolerances of the gas flows and process pressure and temperature,
- Unstable flow and process conditions
- Environmental influences
- Data acquisition and processing system

On the data acquisition side, the quality of the sampling and the sampling time to define a calibration point must be sufficient to minimize the Type-A uncertainty contribution [ISO GUM] to the calibration under operational dynamic conditions influence.

Figure 22 depicts the baseline result of a 12" ultrasonic meter after being corrected and validated at the TransCanada Calibration facility.

Repeatability results well within the recommended AGA #9 values are achieved.

Table #1. Verification Results

Qref (Acf/hr)	Velocity (ft/s)	Deviation (%)	Repeat. (2σ)
276950	99.10	-0.02	0.04
209992	75.14	0.00	0.03
139840	50.04	-0.01	0.04
70088	25.08	0.01	0.05
28568	10.22	-0.01	0.08
14889	5.33	-0.01	0.10

Figure 22. Baseline results for calibration of a 12" USM at TCC

10. Meter Diagnostics During Calibration

The calibration and adjustment of the ultrasonic meter (bias removal) is the first step toward a complete ultrasonic meter validation at the laboratory, prior to meter installation in the field.

Each manufacturer has a unique design and data integration technique developed to calculate an average flow velocity. Accordingly, the meter overall performance is an integrated response closely related to the flow conditions developed by the pipe arrangement at the facility.

The log files captured during meter calibration provide the necessary information to diagnostic the flow and operating conditions presented at the facility during meter calibration, at the same time making available a meter specific performance baseline relating the diagnostic data with the corrected meter output.

Together with the calibration certificate, the delivery of meter log files must be a requirement for the following reasons:

- It provides evidence to the customer that the ultrasonic meter was calibrated under acceptable operational conditions.
- It makes available a tool to extrapolate the calibration result to the field attending the laws of similarity between both the laboratory and the field
-

11. RELEVANT METER DIAGNOSTIC PARAMETERS

The validity of the meter calibration once in the field can be traced back using the diagnostic data gathered at the lab and the performance of the meter has a direct link to those diagnostic variables.

Relevant variables include the following:

Raw Gas Velocities (Profile Factor and Ratios)
SOS (Both per path/chord and Avg. corrected)
Gain Control Levels and Limits/SNR
% Performance

12. CONCLUSIONS

The calibration of an ultrasonic meter requires the careful control of the environment and operating conditions at the meter proving facility.

The direct economic impact to the pipeline operator of the correction applied to the meter after calibration emphasizes the importance of the quality of the references values at the calibration facility be properly traced and their calibration status accepted by a recognised quality system

The calibration facility not only corrects a bias in the meter but also collects critical diagnostic information revealing the meter and facility performance during calibration. The user can use that information to assess both the quality of the calibration and to baseline his meter response in the field

A close agreement between diagnostic parameters at the facility and at the meter station is a certain indication of flow conditions similarity and proper meter performance/operation in the field

Tracking of meter performance in the field is a procedure that originates at the calibration laboratory and encompasses the use of critical relevant diagnostic parameters generated both in the laboratory and in the field.