Terasen
Gas

Turbine Meter Training

Presented by Kevin Ehman

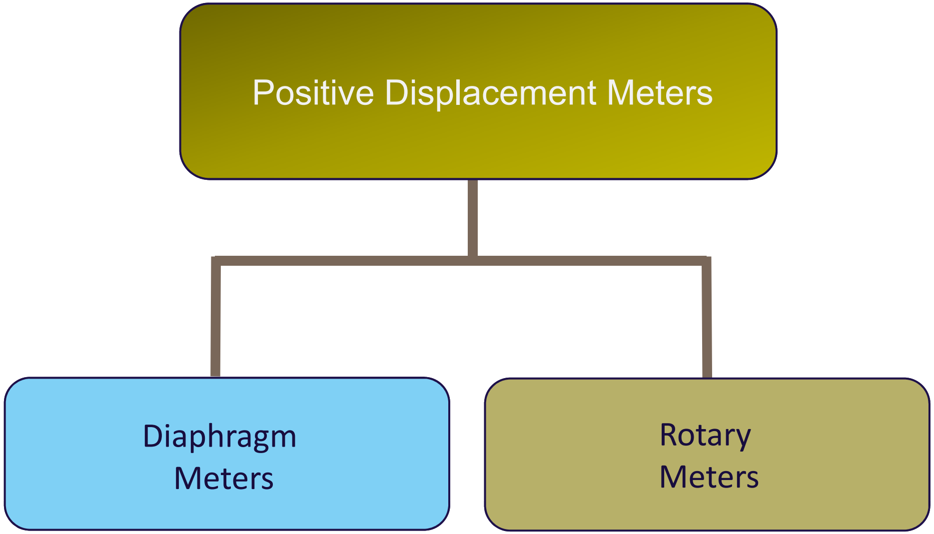
2008.10.08

Common Types of Gas Meters

- Types of Gas Meters
  - Positive Displacement Meters
  - Inferential Meters

Material quoted in part from Sensus publication

Common Positive Displacement Meters

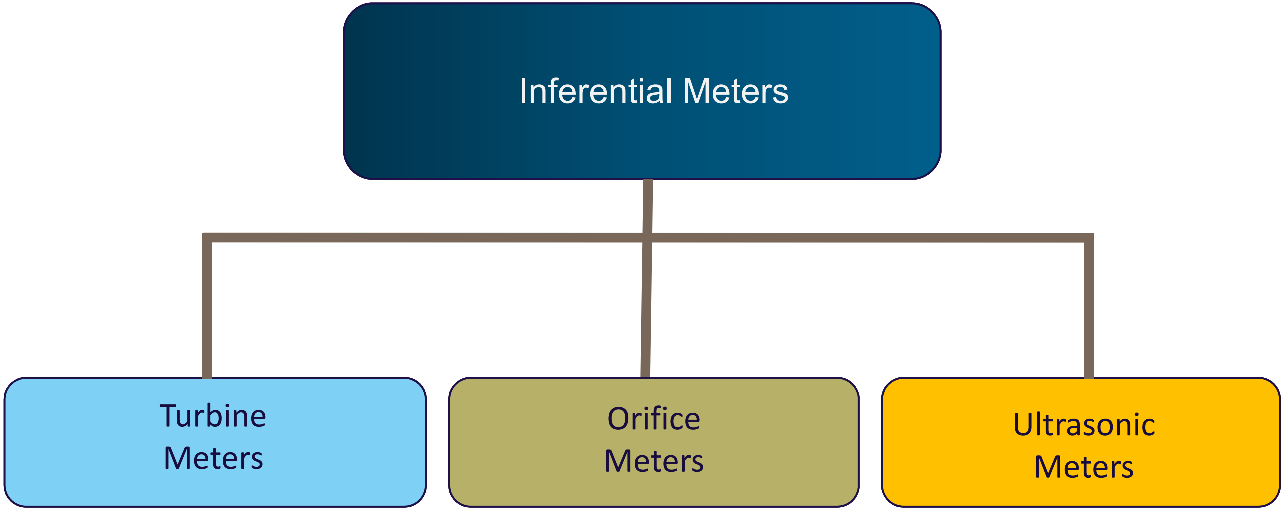


Positive Displacement Meters

Diaphragm Meters

Rotary Meters

Common Inferential Meters



Inferential Meters

Turbine Meters

Orifice Meters

Ultrasonic Meters

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Calculating Flow Rate Measured by an Inferential Meter

$$Q = V \times A$$

Where: Q = Flow Rate in CFH
V = Gas Velocity
A = Flow Area

Inferred Flow Rate = A flow rate derived indirectly from evidence (e.g. velocity through a known area)

Advantages and Disadvantages of Turbine Meter

Turbine Meters

Advantages

- Good Rangeability
- Compact, Easy to Install
- Direct Volume Readout
- No Pressure Pulsations
- Wide Variety of Readouts
- Will not shut off gas flow

Disadvantages

- Limited Low Flow
- Susceptible to mechanical wear
- Affected by pulsating flow

Material quoted in part from Sensus publication

Let’s Start with Explaining a Few Key Definitions

Error	The different between a measurement and its true value.
K-factor	A number by which the meter's output pulses are multiplied to determine the flow volume through the meter.
Meter factor	A number by which the result of a measurement is multiplied to compensate for systematic error.
MAOP	Maximum allowable operating pressure
Pressure drop	The permanent loss of pressure across the meter
Qmax	The maximum gas flow rate through the meter that can be measured within the specified performance requirement.
Qmin	The minimum gas flow rate through the meter that can be measured within the specified performance requirement.
Rangeability	The ratio of the maximum to minimum flow rates over which the meter meets specified performance requirement. Rangeability is also known as the turndown ratio.

Material quoted in part from AGA publication

Conversion to Base Conditions

Base conditions is a set of given temperature and pressure which describes the physical state of gas in flow measurement.

Base conditions are defined jurisdictionally:

In Canada	P_b = 101.325 kPa, T_b = 15°C
In USA	P_b = 14.73 psi, T_b = 60°F

The Ideal Gas Law

The Ideal Gas Law

Conversion of the measured line volume to base volume relies on the equation of state for the particular gas.

$$PV = nRT \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

In this equation

P is the absolute pressure

V is the volume

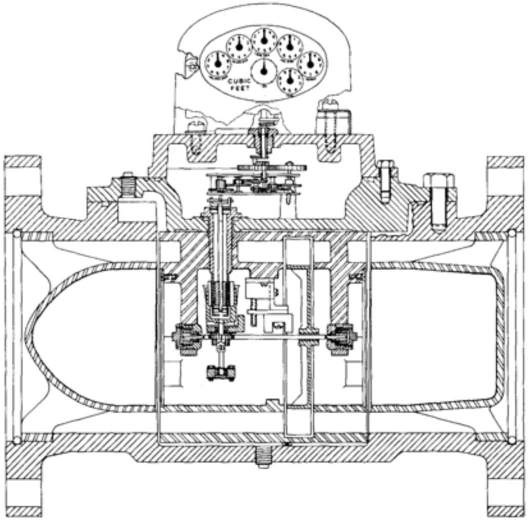
n is the number of moles of the gas

R is the universal gas constant and equals 8.31451 J/mol K.

T is the thermodynamic (or absolute) temperature

This equation is valid for n moles of gas and describes the relation between the volume V, the (absolute) pressure P and the (absolute) temperature T.

Gas Turbine Meter - a Well Established Technology



Sectional view of a turbine meter

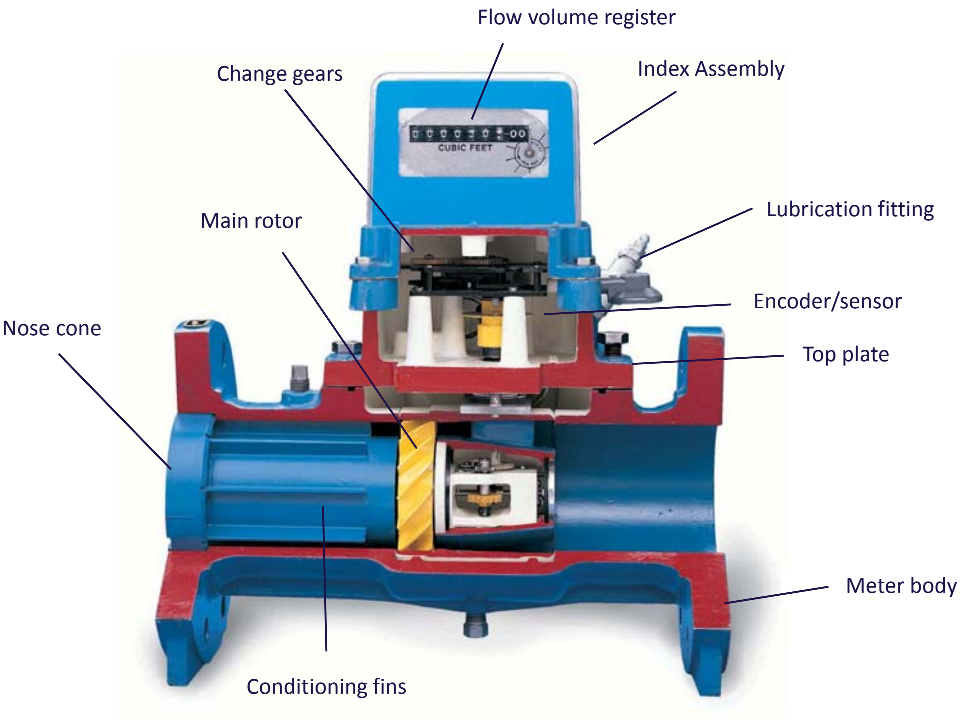
Reinhard Woltman was generally credited to be the inventor of the turbine meter in 1790 for measuring water flow.

Modern gas turbine meters are very accurate and repeatable over a wide flow range.

These meters have a very extensive installed base in the natural gas industry worldwide.

Material quoted in part from Sensus publication

Cut-out View of a Turbine Meter



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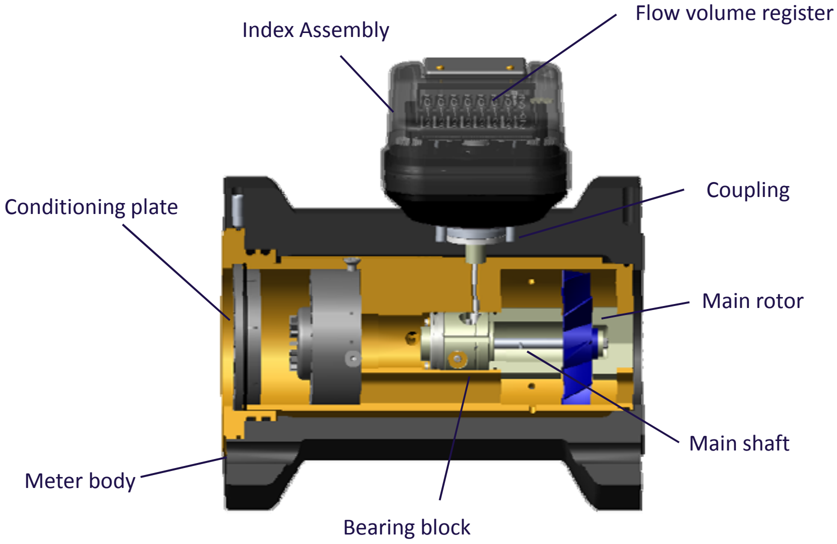
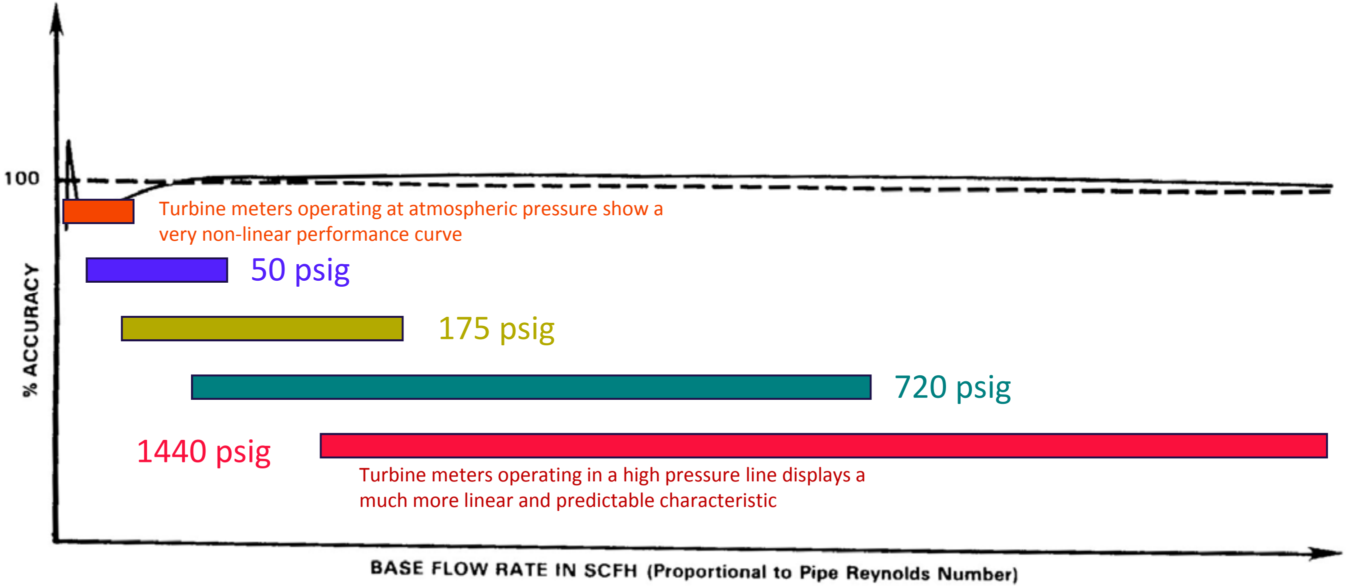
Cut-out View of another Turbine Meter



Material quoted in part from iMeter publication

Turbine Meter Operating at Various Pressure Ranges



Turbine meters operating at atmospheric pressure show a very non-linear performance curve

Turbine meters operating in a high pressure line displays a much more linear and predictable characteristic

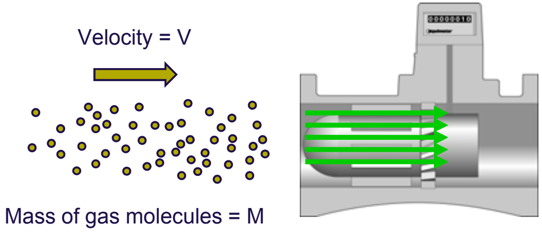
ACCURACY CURVE OF A GAS TURBINE METER PLOTTED AGAINST BASE FLOW RATE AT VARIOUS PRESSURES

Material quoted in part from Sensus publication

Principle of Turbine Meters

The Law of Conservation of Energy

Kinetic Energy = Dynamic Energy of Mass in Motion



$$KE = {}^{1}/_{2}\, M\, V^{2}$$

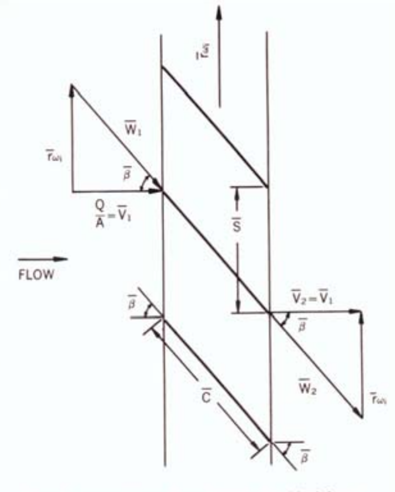
Where:

KE = Kinetic energy of the moving gas molecules
M = Mass of gas molecules
V = Velocity of gas molecules

In an turbine meter, a portion of the linear kinetic energy of the moving gas molecules is converted into rotational energy of the rotor

Principle of Turbine Meters

Analysis of an Ideal Rotor



Velocity Diagram For Rotor Radius ($\bar{r}$)—Ideal Case.

$\bar{r}$	is the average of the rotor radius
Q	is the volume flow rate
A	is the annular flow area
$\overline{\beta}$	is the blade angle
V_1, V_2	are the gas velocities at point (1) and (2)
ω_1, ω_2	is the fluid velocity relative to the rotor blades
ω_i	is the ideal angular velocity

$$\frac{\omega_i}{Q}=\frac{\tan\overline{\beta}}{\bar{r}A} \qquad \text{———— (1)}$$

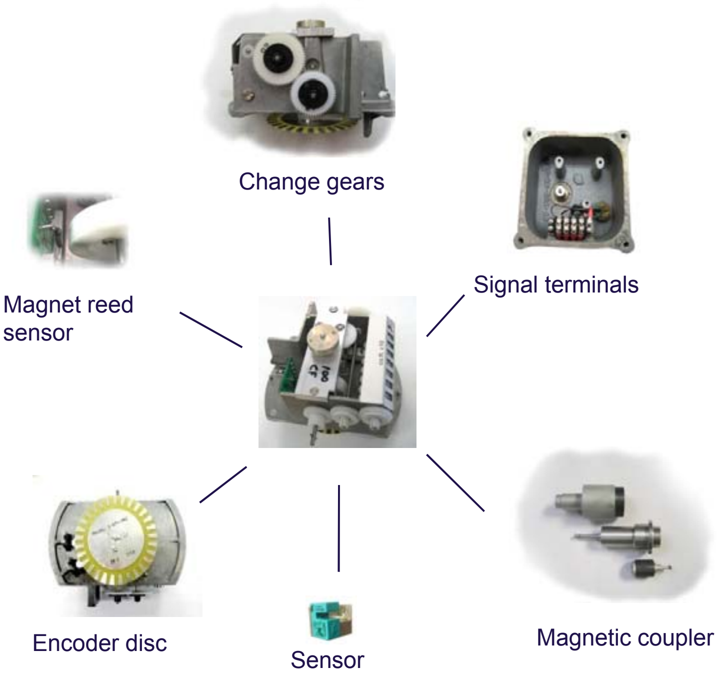
$$Q=\frac{\bar{r}A\omega_i}{\tan\overline{\beta}} \qquad \text{———— (2)}$$

The angular velocity of the rotor is proportional to the volume flow rate

$$\boxed{Q \propto \omega_i} \qquad \text{———— (3)}$$

Material quoted in part from Sensus publication

Turbine Meter Index Assembly



Change gears

Magnet reed sensor

Signal terminals

Encoder disc

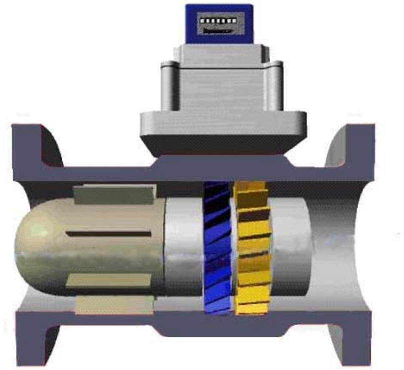
Sensor

Magnetic coupler

Index Assembly

The index assembly typically houses a readout register of flow volume and one or more sets of encoder disc and sensor for generating flow output pulses for electronic measurement systems.

Dual-Rotor Turbine Meter



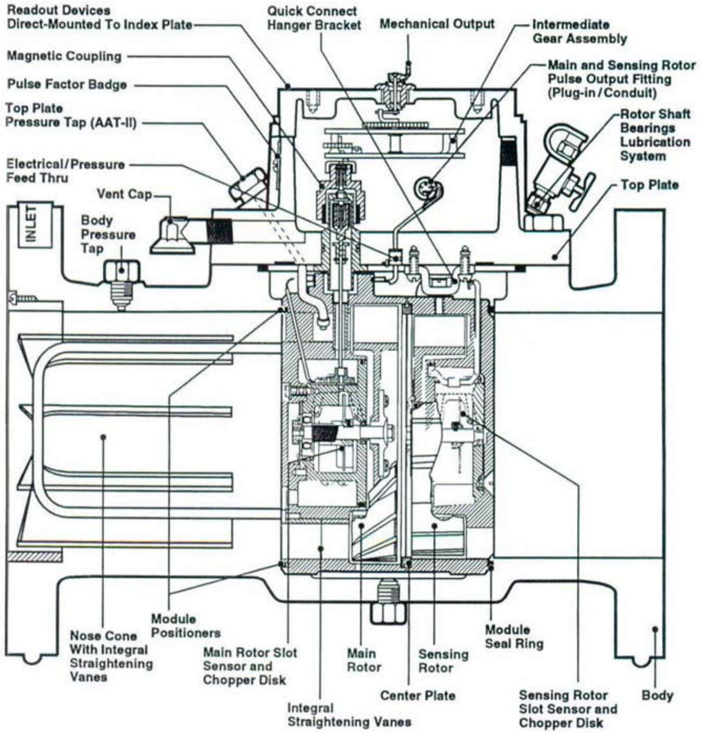
Cut-out view of an Auto-Adjust meter

The primary rotor of a dual-rotor turbine meter is basically the same as that of a single-rotor design. A second rotor is added for checking and/or improving the measurement integrity of the primary rotor under various flow conditions.

- Adjusted Volume at Initial Calibration
- Basic Adjustment Principle
- Operating Changes in Retarding Torque
- Self-Checking Feature

Material quoted in part from Sensus publication

Construction of a Turbine Meters



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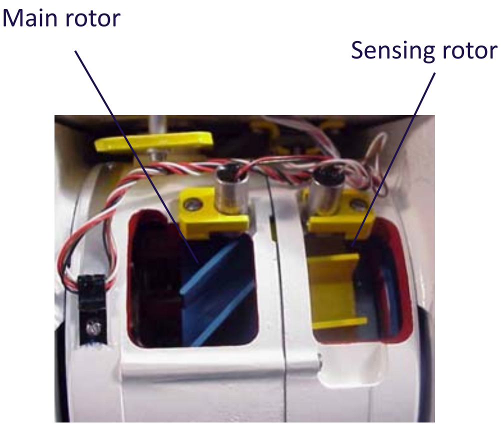
Dual-Rotor Turbine Meter



Cut-out details of an Auto-Adjust dual rotor housing

The main rotor is calibrated to register 110% of the actual flow passing through the meter. The sensing rotor is calibrated to register 10% of the actual flow. By design of the two rotors and their placement in the meter body, the flow error experienced by the sensing rotor matches that of the main rotor. The "Adjusted Volume" therefore provides a very accurate account of the true flow.

$$V_{adjusted} = V_{main} - V_{sensing}$$

The sensing rotor correction factor Ā is provided by factory calibration.

Material quoted in part from Sensus publication

Dual-Rotor Turbine Meter

The Auto-Adjust Turbine Meter Equations:

$$\overline{A} = \left[\frac{V_{sensing}}{V_{adjusted}} \times 100\right] = \left[\frac{V_{sensing}}{V_{main} - V_{sensing}} \times 100\right] \qquad (1)$$

$$\Delta A = \left[\frac{V_{sensing}}{V_{main} - V_{sensing}} \times 100\right] - \overline{A} \qquad (2)$$

Where:

V_{main} = volume by main rotor
$V_{sensing}$ = volume by sensing rotor
$V_{adjusted}$ = adjusted volume
$\bar{A}$ = average value of the factory sensing rotor % adjustment
ΔA = % deviation in field operation from factory calibration

Material quoted in part from Sensus publication

Dual-Rotor Turbine Meter

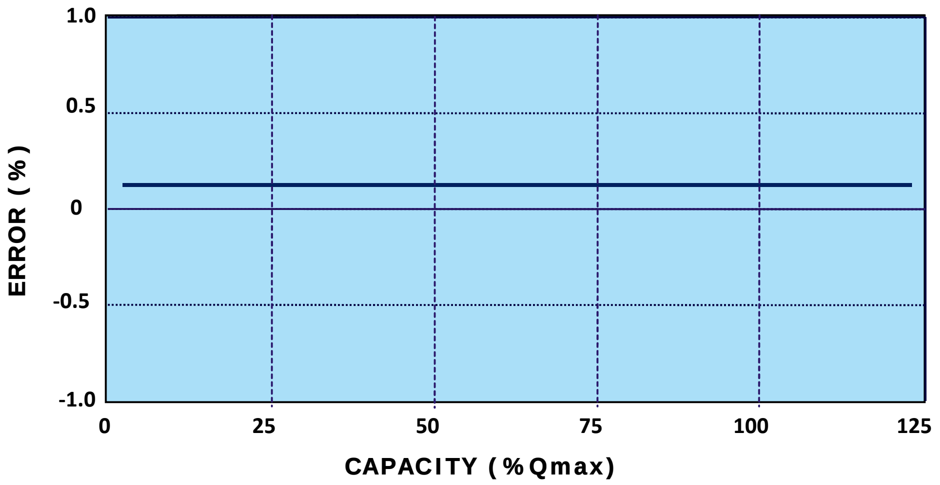
The Auto-Adjust self-checking Indicator:

$$\Delta A = \left[\frac{V_{\text{sensing}}}{V_{\text{main}} - V_{\text{sensing}}} \times 100 \right] - \overline{A}$$

The parameter ΔA (delta A) is a self-checking indicator of the performance of an auto-adjust turbine meter. It shows the amount of adjustment the meter is making, thereby warning the user of meter or flow conditioning problems.

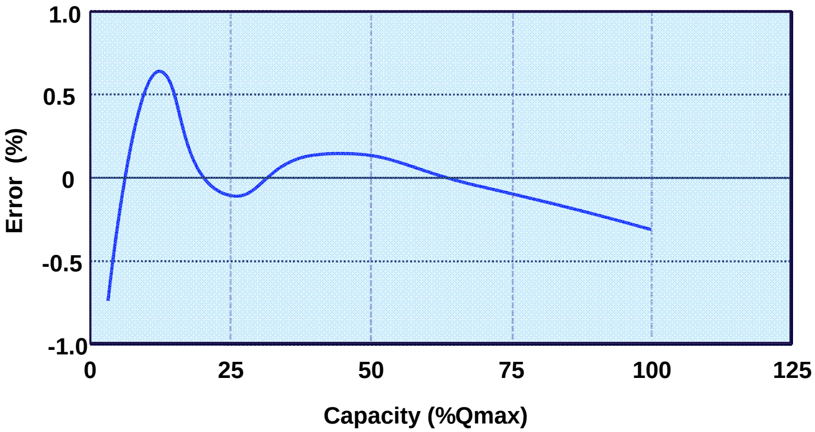
Material quoted in part from Sensus publication

Performance Curve of an “Ideal” Gas Turbine Meter



An ideal turbine meter has a flat error curve extending from Q_{min} to Q_{max}

Performance curve of a "Real" Gas Turbine Meter



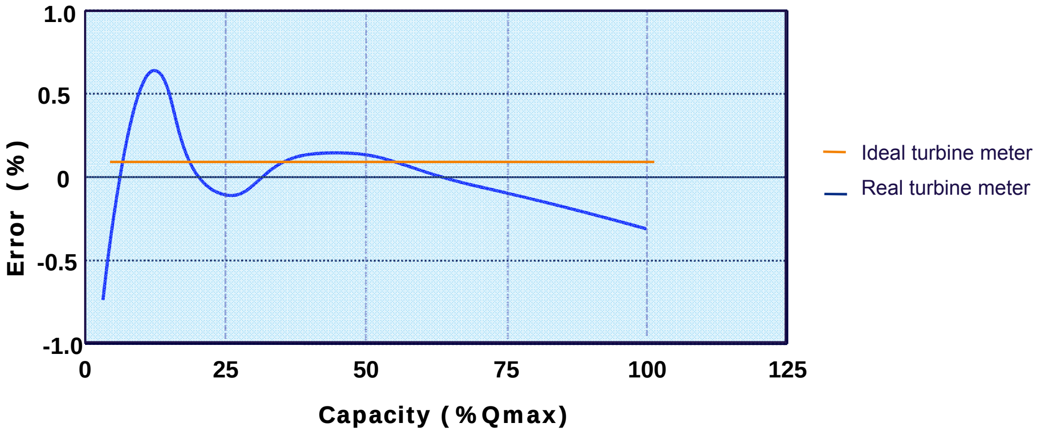
Typical performance curve of a turbine meter

Causes for "non-ideal" turbine meter behaviours:

- Dirty gas
- Mechanical friction
- Pertubations
- Density effect
- Reynolds effect

Material quoted in part from iMeter publication

Of course Nothing is Perfect……



Performance curve of a “real” gas turbine meter

Material quoted in part from iMeter publication

Of course Nothing is Perfect

Gas turbine meter

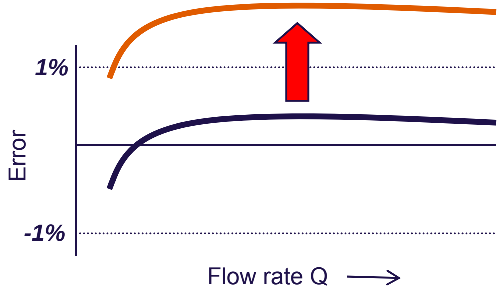
The accuracy of a gas turbine meter is influenced by mechanical friction at low flow rate and Reynolds number at high flow rate.

Recent research has shown that relatively large measurement errors can occur if a turbine meter was not calibrated at or near its operating pressure.

Impact of Dirt on Turbine Meter

Dirt accumulated on the rotor blades has a tendency to speed up a turbine meter, thus resulting in overestimated flow volume.

Dirt on the rotor blades



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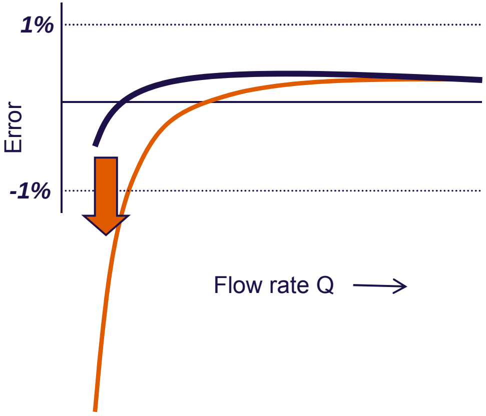
Impact of Dirt on Turbine Meter

Dirt accumulated in bearings slows down a turbine meter, therefore results in underestimated flow volume.

Good bearings

Damaged bearings



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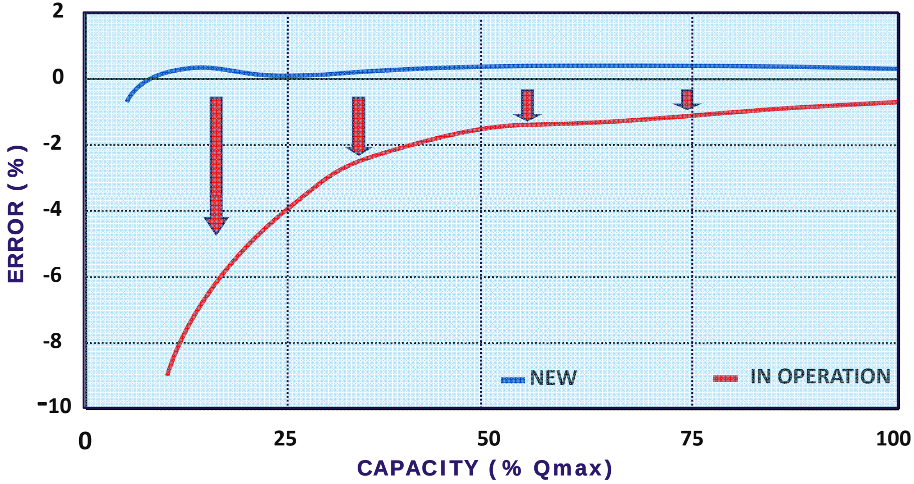
Impact of Damaged Bearings

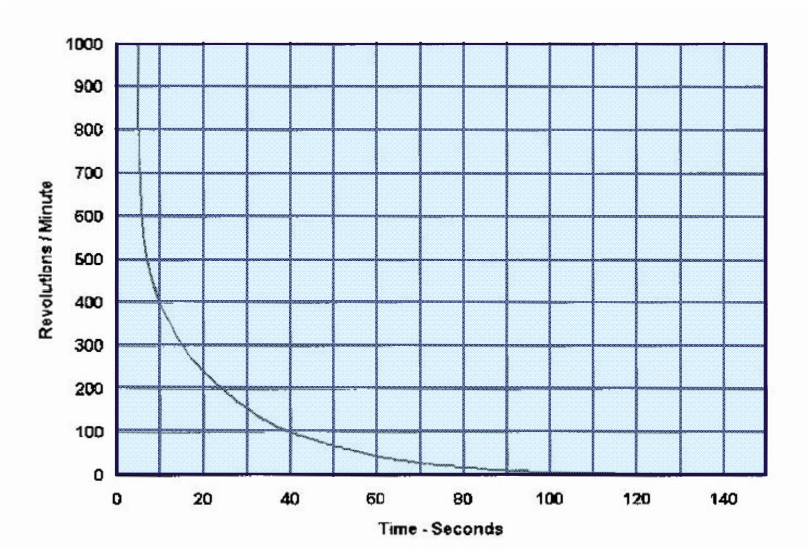


At a constant inlet pressure, increase in mechanical friction due to bearing wear has more significant effect on **LOW FLOW** accuracy.

Damaged bearings slow down a turbine meter considerably

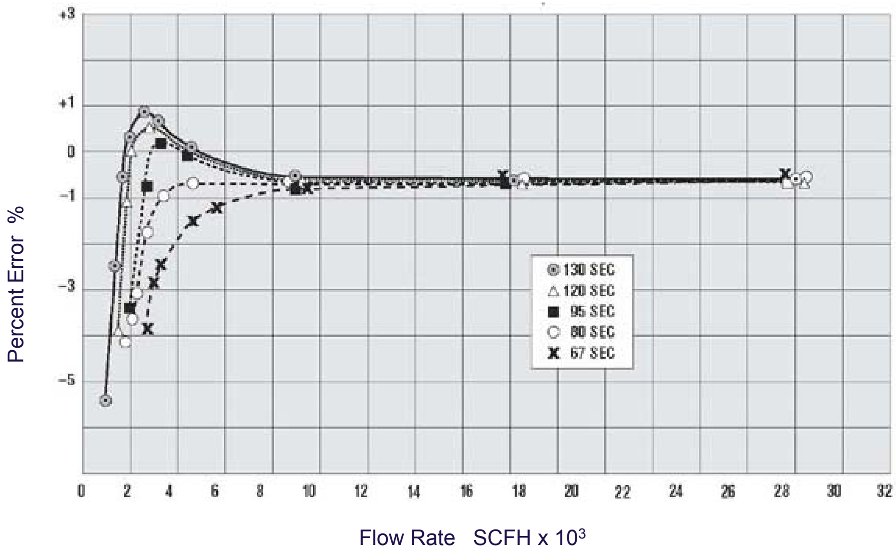
Material quoted in part from iMeter publication

Typical Turbine Meter Spin Time Decay Curve



The spin time of a turbine meter is a very good indicator of its condition

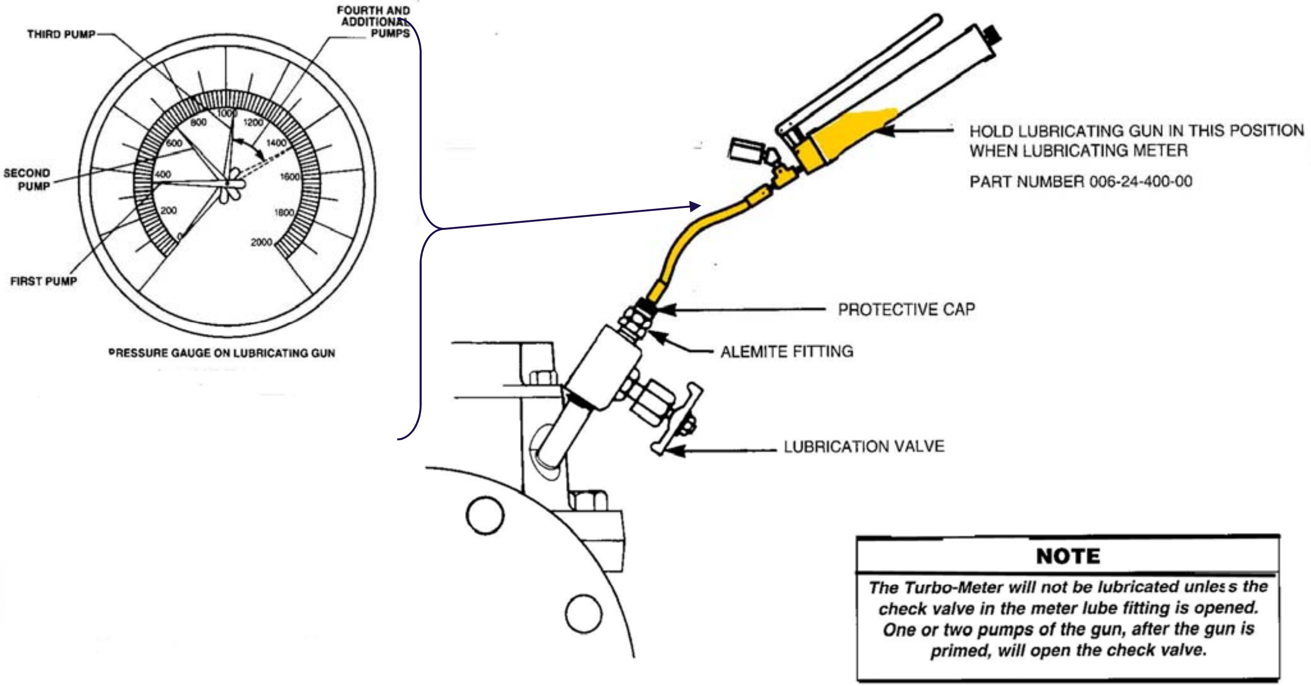
Spin Time Effect on Proof



Effect of spin time on the proof of a T-35 Mark-II turbine meter

Quote from Sensus Turbo-Meter Installation & Maintenance Manual MM-1070 R9

Lubricating a Turbine Meter

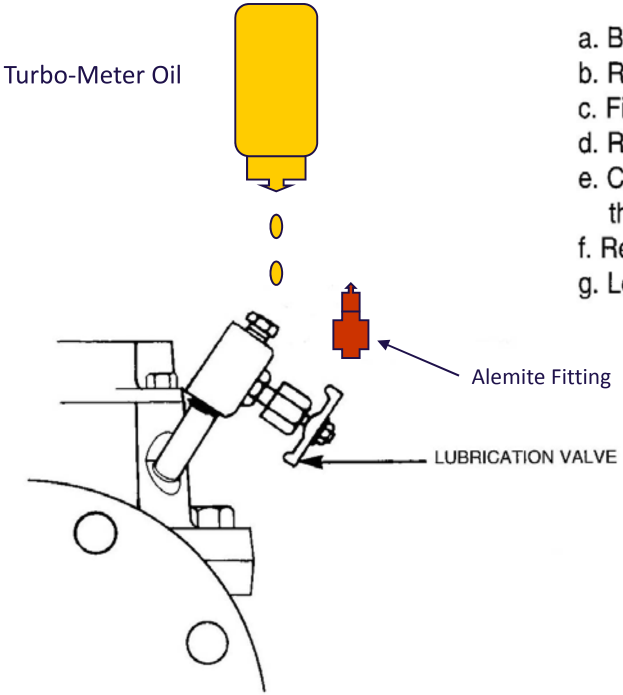


NOTE

The Turbo-Meter will not be lubricated unless the check valve in the meter lube fitting is opened. One or two pumps of the gun, after the gun is primed, will open the check valve.

Material quoted in part from iMeter publication

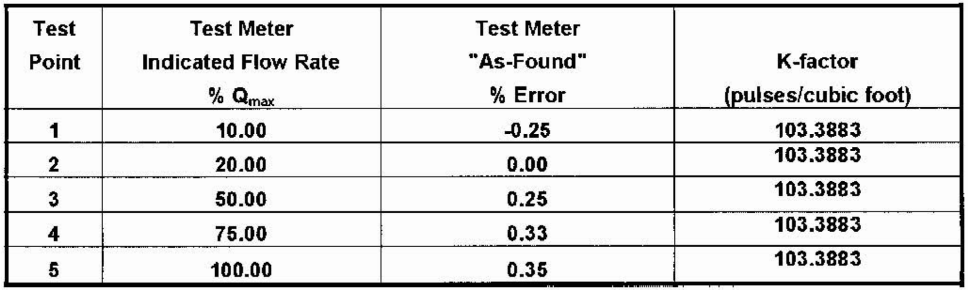
Lubricating a Turbine Meter



a. Be sure lubrication system valve is securely closed.
b. Remove Alemite fitting.
c. Fill inlet of valve with recommended Turbo-Meter oil.
d. Re-install Alemite fitting securely.
e. Cycle lubrication system valve full open to full closed three times.
f. Repeat steps “a” through “e” above.
g. Leave lubrication system valve closed.

Material quoted in part from iMeter publication

Single K-factor Representation

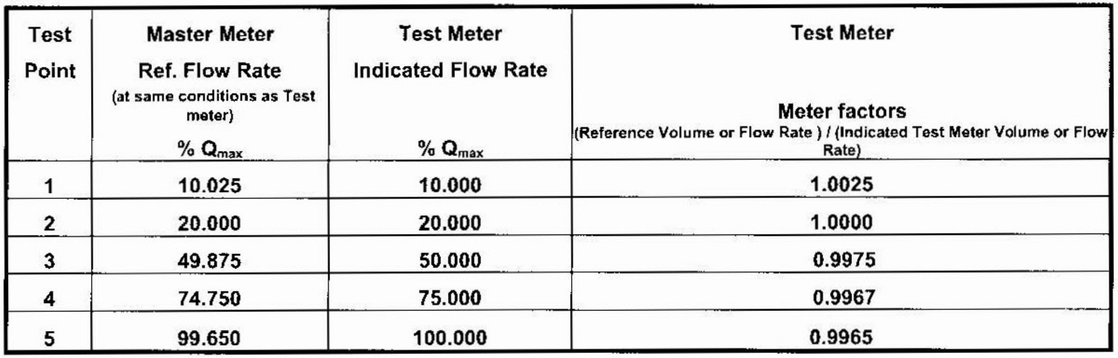


Test Point	Test Meter Indicated Flow Rate % Q_{max}	Test Meter "As-Found" % Error	K-factor (pulses/cubic foot)
1	10.00	-0.25	103.3883
2	20.00	0.00	103.3883
3	50.00	0.25	103.3883
4	75.00	0.33	103.3883
5	100.00	0.35	103.3883

A single K-factor is often used to express the calibration of a turbine meter. It is simple but does not represent the operating characteristics of the meter throughout the entire flow range.

Material quoted in part from AGA publication

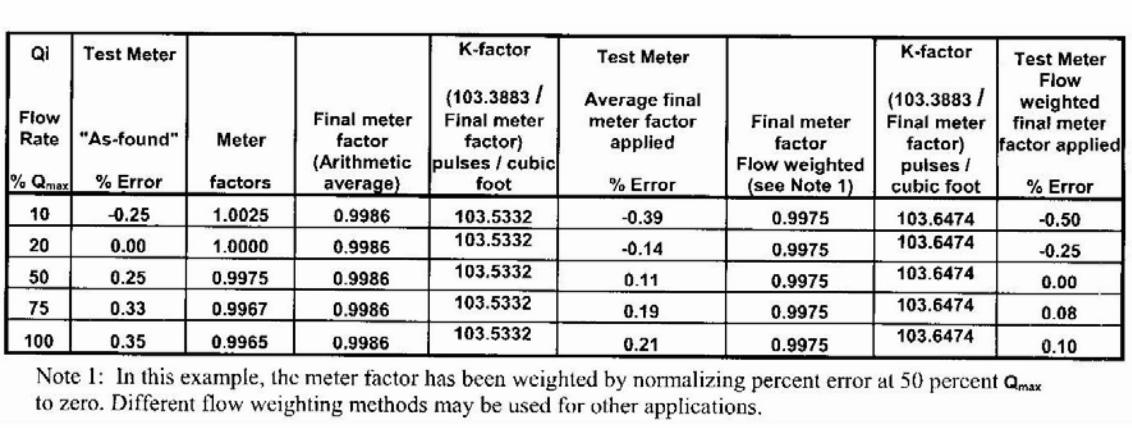
Meter Factors



Test Point	Master Meter Ref. Flow Rate (at same conditions as Test meter) % Q_{max}	Test Meter Indicated Flow Rate % Q_{max}	Test Meter Meter factors (Reference Volume or Flow Rate) / (Indicated Test Meter Volume or Flow Rate)
1	10.025	10.000	1.0025
2	20.000	20.000	1.0000
3	49.875	50.000	0.9975
4	74.750	75.000	0.9967
5	99.650	100.000	0.9965

Material quoted in part from AGA publication

Flow Weighted K-factor and Meter Factor

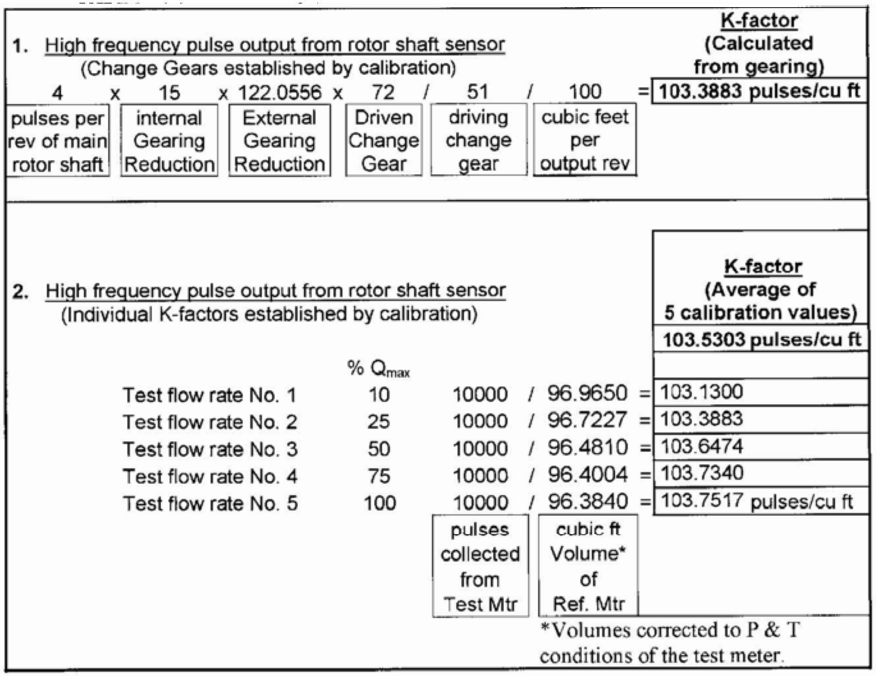


Qi Flow Rate % Q_{max}	Test Meter "As-found" % Error	Meter factors	Final meter factor (Arithmetic average)	K-factor (103.3883 / Final meter factor) pulses / cubic foot	Test Meter Average final meter factor applied % Error	Final meter factor Flow weighted (see Note 1)	K-factor (103.3883 / Final meter factor) pulses / cubic foot	Test Meter Flow weighted final meter factor applied % Error
10	-0.25	1.0025	0.9986	103.5332	-0.39	0.9975	103.6474	-0.50
20	0.00	1.0000	0.9986	103.5332	-0.14	0.9975	103.6474	-0.25
50	0.25	0.9975	0.9986	103.5332	0.11	0.9975	103.6474	0.00
75	0.33	0.9967	0.9986	103.5332	0.19	0.9975	103.6474	0.08
100	0.35	0.9965	0.9986	103.5332	0.21	0.9975	103.6474	0.10

Note 1: In this example, the meter factor has been weighted by normalizing percent error at 50 percent Q_{max} to zero. Different flow weighting methods may be used for other applications.

Material quoted in part from AGA publication

Typical Turbine Meter K-factors by Calibration



1. High frequency pulse output from rotor shaft sensor
(Change Gears established by calibration)

K-factor
(Calculated from gearing)

4 x 15 x 122.0556 x 72 / 51 / 100 = **103.3883 pulses/cu ft**

4	15	122.0556	72	51	100
pulses per rev of main rotor shaft	internal Gearing Reduction	External Gearing Reduction	Driven Change Gear	driving change gear	cubic feet per output rev

2. High frequency pulse output from rotor shaft sensor
(Individual K-factors established by calibration)

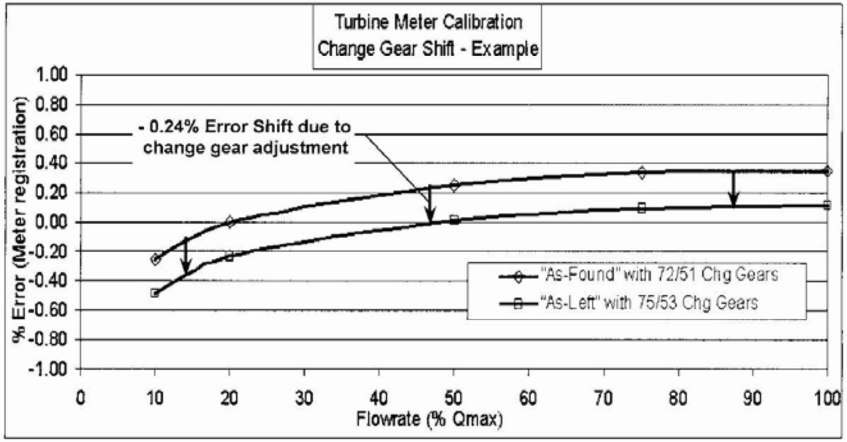
K-factor
(Average of 5 calibration values)
103.5303 pulses/cu ft

	$\% Q_{max}$	pulses collected from Test Mtr		cubic ft Volume* of Ref. Mtr		
Test flow rate No. 1	10	10000	/	96.9650	=	103.1300
Test flow rate No. 2	25	10000	/	96.7227	=	103.3883
Test flow rate No. 3	50	10000	/	96.4810	=	103.6474
Test flow rate No. 4	75	10000	/	96.4004	=	103.7340
Test flow rate No. 5	100	10000	/	96.3840	=	103.7517 pulses/cu ft

*Volumes corrected to P & T conditions of the test meter.

Material quoted in part from AGA publication

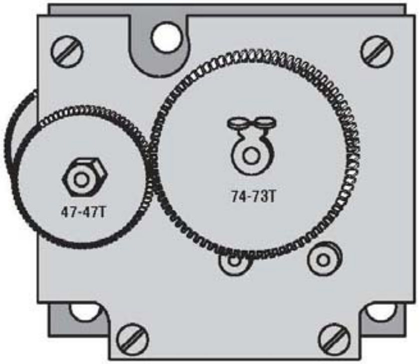
Shifting Error Curve by Change Gear



Test Point	Master Meter Ref. Flow Rate (at same conditions as Test meter) % of Q_{max}	Test Meter Indicated Flow Rate % of Q_{max}	Test Meter "As-Found" with 72/51 Change Gears % Error	Test Meter "As-Left" with 75/53 Change Gears (% Error – 0.24% Shift)
1	10.025	10.00	-0.25	-0.49
2	20.000	20.00	0.00	-0.24
3	49.875	50.00	0.25	0.01
4	74.750	75.00	0.33	0.09
5	99.650	100.00	0.35	0.11

Material quoted in part from AGA publication

Fine Tuning K-Factor with Change Gear



Change Gear = 73/47

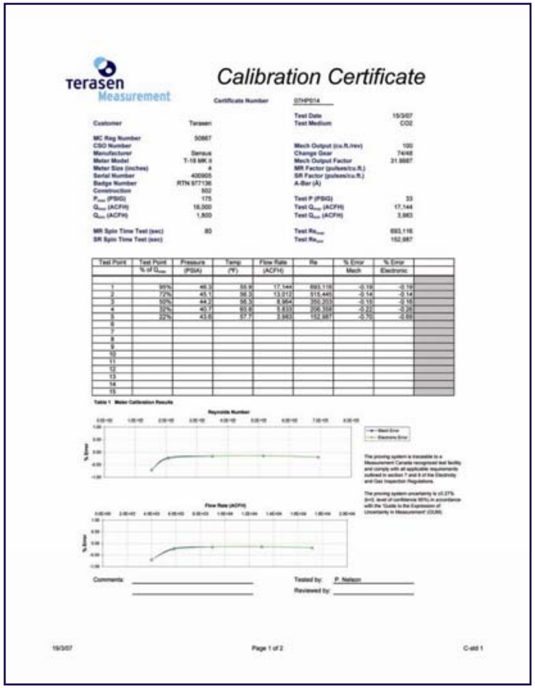
Calibration adjustment of the mechanical output of a turbine meter is typically accomplished by choosing an appropriate set of change gears.

Linearization

Linearization of flow meter

If the error of a flow meter is known, it can be corrected for. Some flow computers have the ability to carry out this correction. First the correction data resulting from calibration are fed into the instrument. Next, the appropriate correction factor at the particular flow rate is determined and applied. The result will be perfectly linear.

Typical Turbine Meter Calibration Certificate



Calibration Certificate

Certificate Number 07HP014

		Test Date	15/3/07
Customer	Terasen	Test Medium	CO2
MC Reg Number	50867		
CSO Number		Mech Output (cu.ft./rev)	100
Manufacturer	Sensus	Change Gear	74/48
Meter Model	T-18 MK II	Mech Output Factor	31.8667
Meter Size (inches)	4	MR Factor (pulses/cu.ft.)	
Serial Number	400905	SR Factor (pulses/cu.ft.)	
Badge Number	RTN 977136	A-Bar (Ā)	
Construction	502		
P_{max} (PSIG)	175	Test P (PSIG)	33
Q_{max} (ACFH)	18,000	Test Q_{max} (ACFH)	17,144
Q_{min} (ACFH)	1,800	Test Q_{min} (ACFH)	3,983
MR Spin Time Test (sec)	80	Test Re_{max}	693,116
SR Spin Time Test (sec)		Test Re_{min}	152,987

Test Point	Test Point % of Q_{max}	Pressure (PSIA)	Temp (°F)	Flow Rate (ACFH)	Re	% Error Mech	% Error Electronic	
1	95%	46.3	55.9	17,144	693,116	-0.19	-0.19	
2	72%	45.1	56.3	13,012	515,446	-0.14	-0.14	
3	50%	44.2	58.3	8,964	350,203	-0.15	-0.16	
4	32%	40.7	60.6	5,833	206,358	-0.22	-0.26	
5	22%	43.6	57.7	3,983	152,987	-0.70	-0.69	
6								
7								
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15								

Table 1 Meter Calibration Results

The proving system is traceable to a Measurement Canada recognized test facility and comply with all applicable requirements outlined in section 7 and 8 of the Electricity and Gas Inspection Regulations.

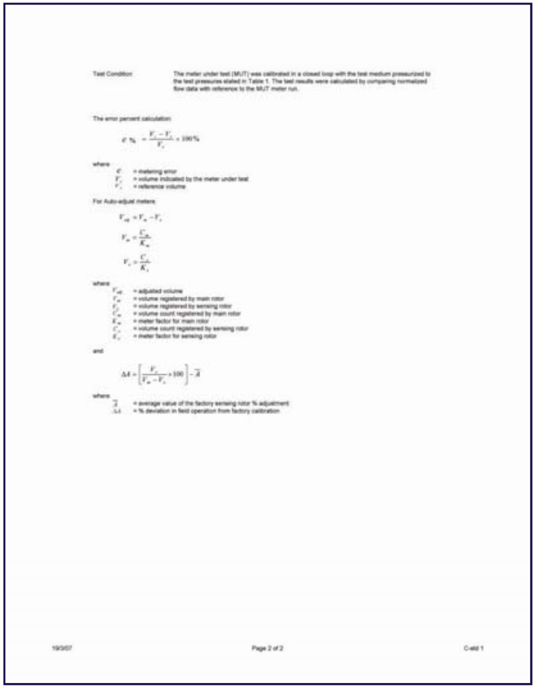
The proving system uncertainty is ±0.27% (k=2, level of confidence 95%) in accordance with the "Guide to the Expression of Uncertainty in Measurement" (GUM).

Comments:

Tested by: P. Nelson

Reviewed by:

19/3/07 Page 1 of 2 C-std 1



Test Condition: The meter under test (MUT) was calibrated in a closed loop with the test medium pressurized to the test pressures stated in Table 1. The test results were calculated by comparing normalized flow data with reference to the MUT meter run.

The error percent calculation:

$$e\ \% = \frac{V_i - V_r}{V_r} \times 100\%$$

where

e = metering error
V_i = volume indicated by the meter under test
V_r = reference volume

For Auto-adjust meters:

$$V_{adj} = V_m - V_s$$

$$V_m = \frac{C_m}{K_m}$$

$$V_s = \frac{C_s}{K_s}$$

where

V_{adj} = adjusted volume
V_m = volume registered by main rotor
V_s = volume registered by sensing rotor
C_m = volume count registered by main rotor
K_m = meter factor for main rotor
C_s = volume count registered by sensing rotor
K_s = meter factor for sensing rotor

and

$$\Delta A = \left[\frac{V_s}{V_m - V_s} \times 100\right] - \bar{A}$$

where

$\bar{A}$ = average value of the factory sensing rotor % adjustment
ΔA = % deviation in field operation from factory calibration

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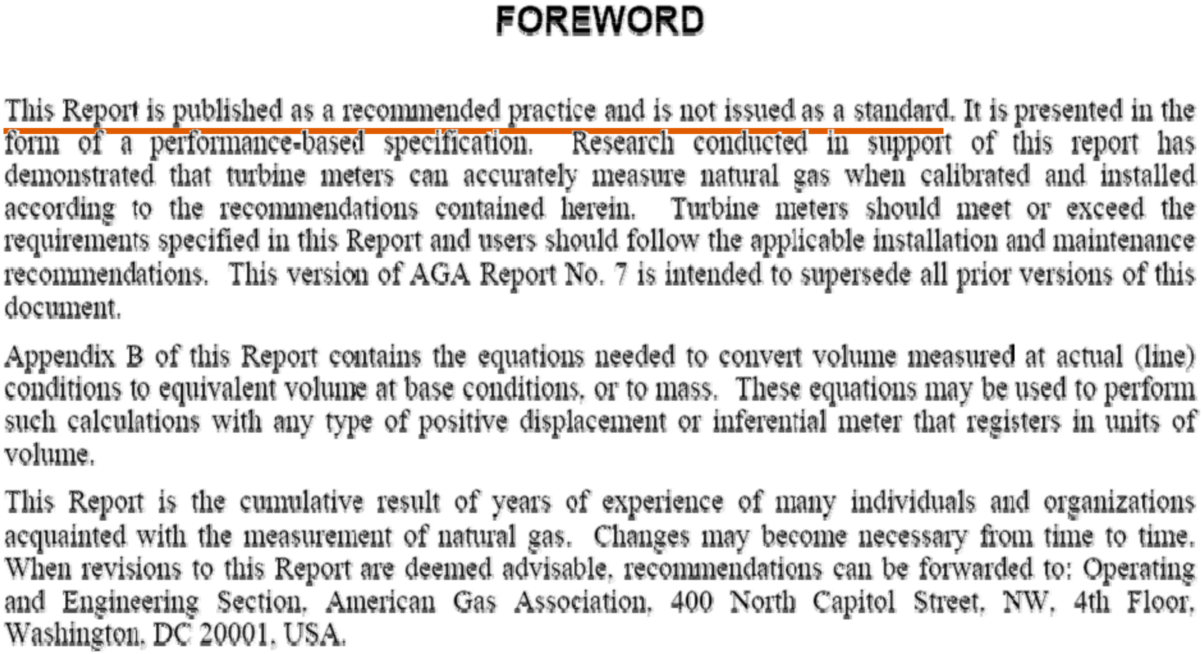
AGA-7



FOREWORD

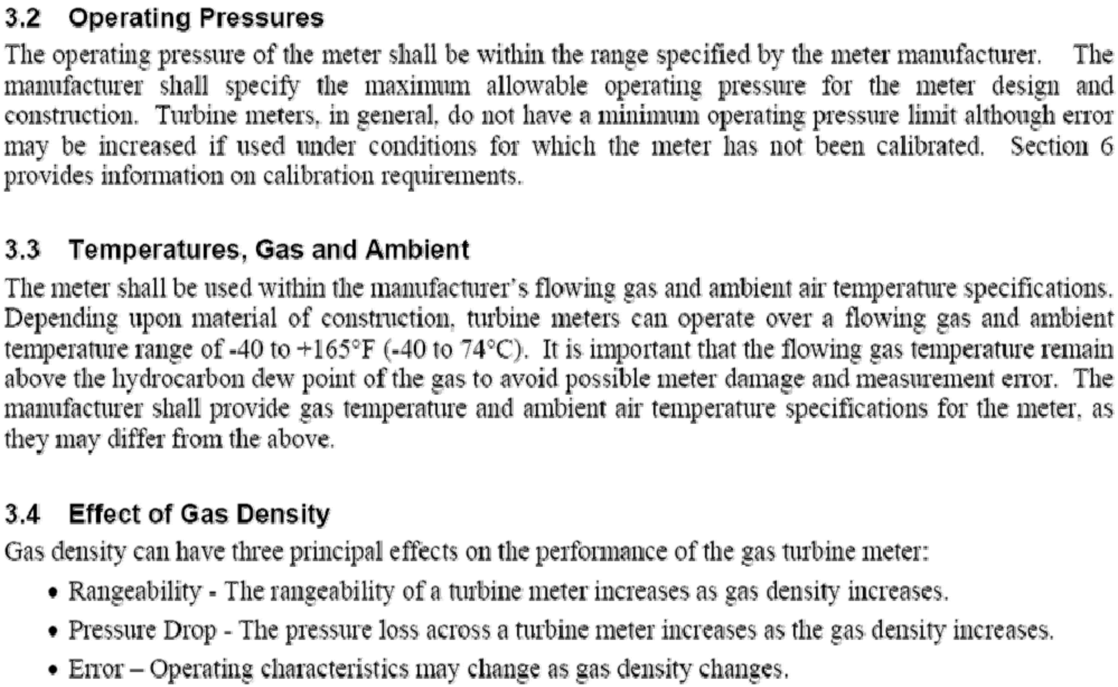
This Report is published as a recommended practice and is not issued as a standard. It is presented in the form of a performance-based specification. Research conducted in support of this report has demonstrated that turbine meters can accurately measure natural gas when calibrated and installed according to the recommendations contained herein. Turbine meters should meet or exceed the requirements specified in this Report and users should follow the applicable installation and maintenance recommendations. This version of AGA Report No. 7 is intended to supersede all prior versions of this document.

Appendix B of this Report contains the equations needed to convert volume measured at actual (line) conditions to equivalent volume at base conditions, or to mass. These equations may be used to perform such calculations with any type of positive displacement or inferential meter that registers in units of volume.

This Report is the cumulative result of years of experience of many individuals and organizations acquainted with the measurement of natural gas. Changes may become necessary from time to time. When revisions to this Report are deemed advisable, recommendations can be forwarded to: Operating and Engineering Section, American Gas Association, 400 North Capitol Street, NW, 4th Floor, Washington, DC 20001, USA.

Material quoted in part from AGA publication

AGA-7



3.2 Operating Pressures

The operating pressure of the meter shall be within the range specified by the meter manufacturer. The manufacturer shall specify the maximum allowable operating pressure for the meter design and construction. Turbine meters, in general, do not have a minimum operating pressure limit although error may be increased if used under conditions for which the meter has not been calibrated. Section 6 provides information on calibration requirements.

3.3 Temperatures, Gas and Ambient

The meter shall be used within the manufacturer's flowing gas and ambient air temperature specifications. Depending upon material of construction, turbine meters can operate over a flowing gas and ambient temperature range of -40 to +165°F (-40 to 74°C). It is important that the flowing gas temperature remain above the hydrocarbon dew point of the gas to avoid possible meter damage and measurement error. The manufacturer shall provide gas temperature and ambient air temperature specifications for the meter, as they may differ from the above.

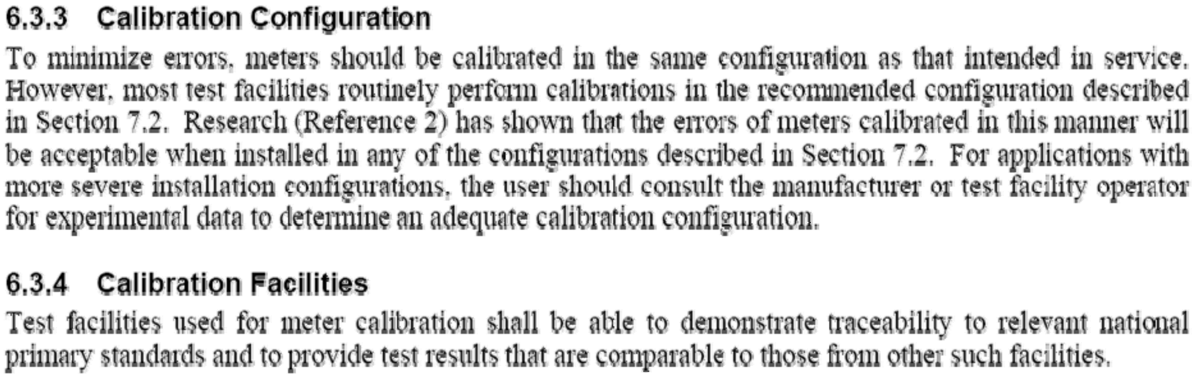
3.4 Effect of Gas Density

Gas density can have three principal effects on the performance of the gas turbine meter:

- Rangeability - The rangeability of a turbine meter increases as gas density increases.
- Pressure Drop - The pressure loss across a turbine meter increases as the gas density increases.
- Error – Operating characteristics may change as gas density changes.

Material quoted in part from AGA publication

AGA-7



6.3.3 Calibration Configuration

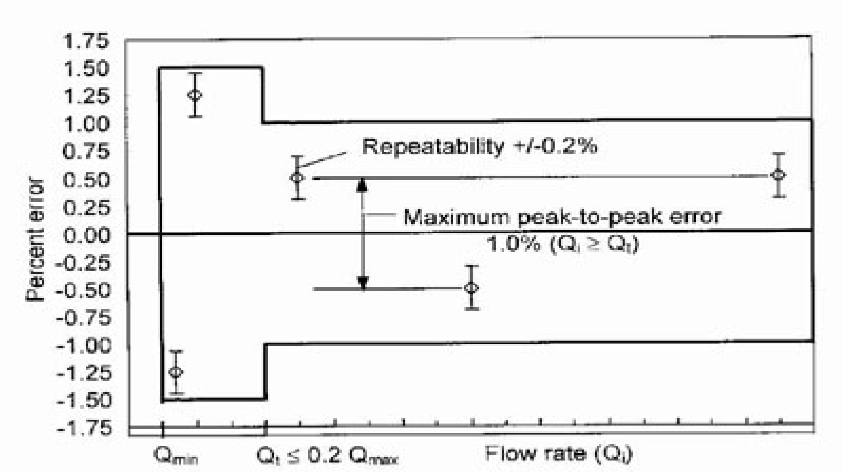
To minimize errors, meters should be calibrated in the same configuration as that intended in service. However, most test facilities routinely perform calibrations in the recommended configuration described in Section 7.2. Research (Reference 2) has shown that the errors of meters calibrated in this manner will be acceptable when installed in any of the configurations described in Section 7.2. For applications with more severe installation configurations, the user should consult the manufacturer or test facility operator for experimental data to determine an adequate calibration configuration.

6.3.4 Calibration Facilities

Test facilities used for meter calibration shall be able to demonstrate traceability to relevant national primary standards and to provide test results that are comparable to those from other such facilities.

Material quoted in part from AGA publication

AGA -7 General Performance Tolerances

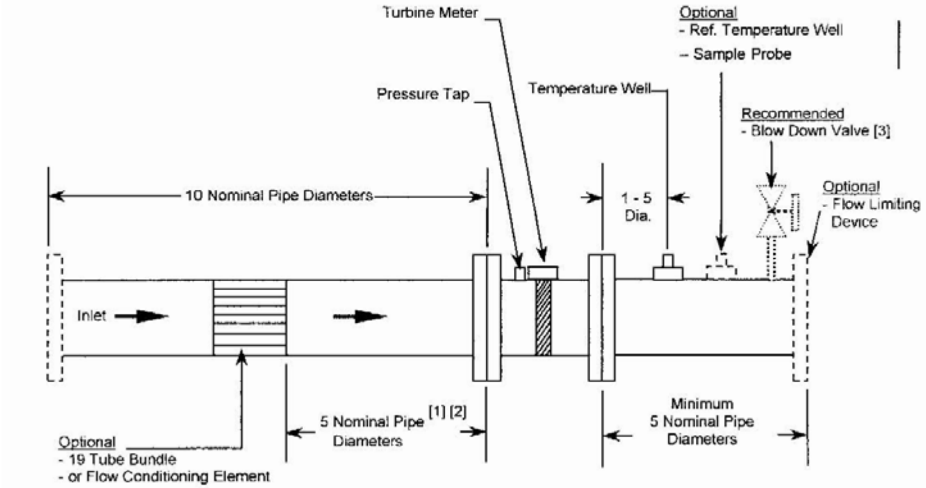


Repeatability:	±0.2% from Q_{min} to $_{Qmax}$
Max peak-to-peak Error:	1.0% above Q_t
Maximum error:	±1.0% from Q_t to Q_{max} ±1.5% from Q_{min} to Q_t
Transition flow rate:	Q_t not greater than 0.2 Q_{max}

Material quoted in part from AGA publication

AGA 7 - Installation for In-line Meter

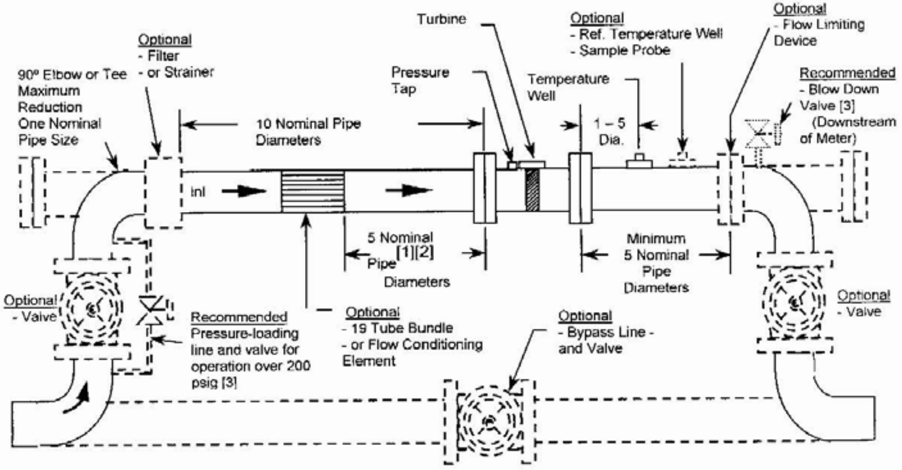
Terasen Gas



NOTES:
[1] Recommended spacing, unless otherwise supported by published test data for the flow conditioning element.
[2] No pipe connections or protrusions allowed within this upstream section.
[3] For recommended size of blow down valve, see Table 1. Locate downstream of meter.

Material quoted in part from AGA publication

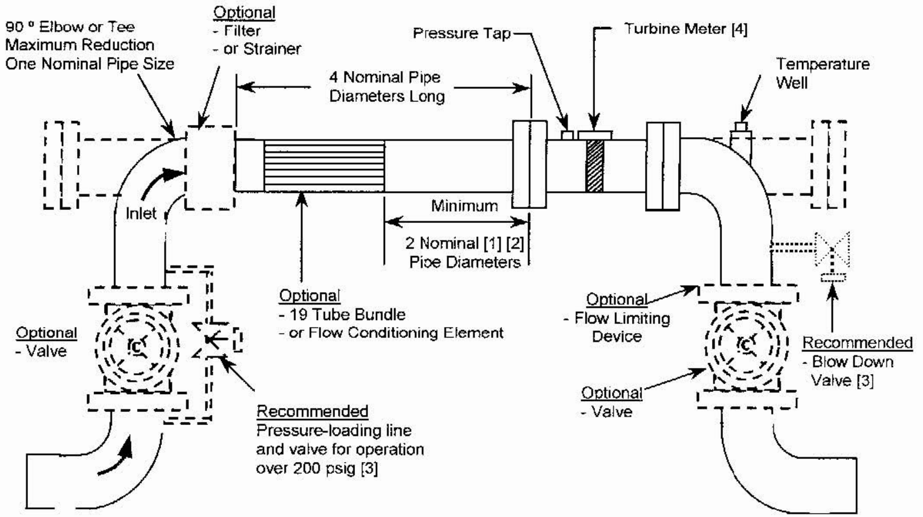
AGA 7 - Typical Meter Set Assembly



NOTES: [1] Recommended spacing, unless otherwise supported by published test data for the flow conditioning element.
[2] No pipe connections or protrusions allowed within this upstream section.
[3] Size of pressure loading line and valve to be the same as recommended blow down valve sizing, (see Table 1).

Material quoted in part from AGA publication

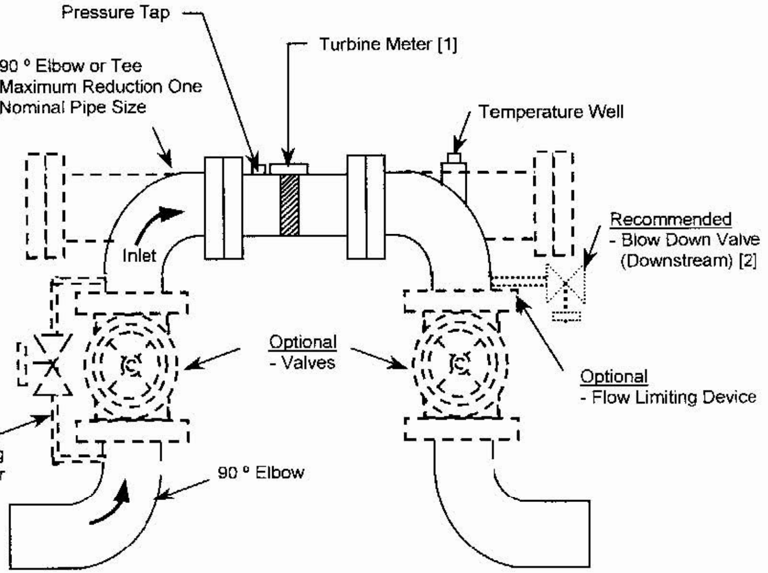
AGA 7 - Short-Coupled Installation



NOTES:
[1] Recommended spacing, unless otherwise supported by published test data for the flow conditioning element.
[2] No pipe connections or protrusions allowed within this upstream section.
[3] Size of pressure loading line and valve to be the same as recommended blow down valve sizing, (Table 1).
[4] Turbine meter must have integral flow conditioner.

Material quoted in part from AGA publication

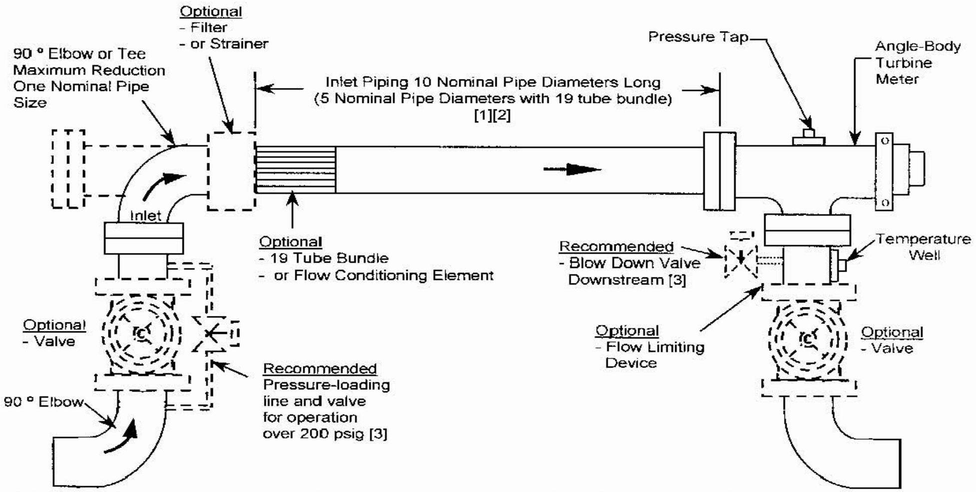
AGA 7 - Close-Coupled Installation



NOTES: [1] Turbine meter must have integral flow conditioning element.
[2] Size of pressure-loading line and valve to be the same as recommended blow down valve sizing, (Table 1).

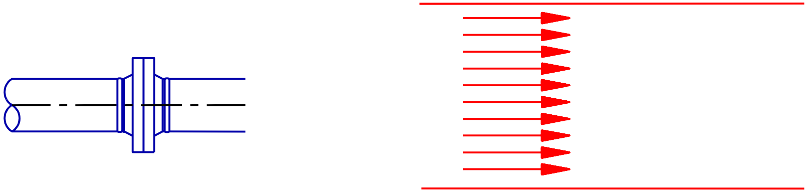
AGA 7 - Angle-Body Meter Installation

Horizontal Installation (Inlet in Horizontal Plane, Outlet Down)

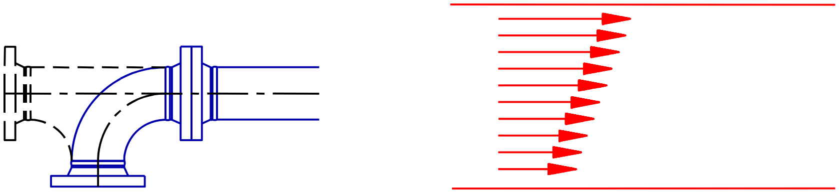


NOTES: [1] Recommended spacing, unless otherwise supported by published test data for the flow conditioning element.
[2] No pipe connections or protrusions allowed within this upstream section.
[3] Size of pressure loading line and valve to be the same as recommended blow down valve sizing, (see Table 1).

Low Level Perturbation



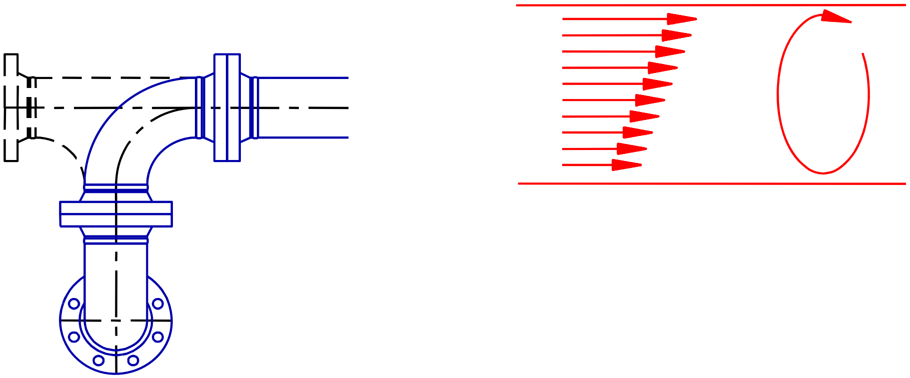
A straight AGA-7 compliant meter run produces an uniform flow profile with the same flow velocity across the cross-section of pipe



An elbow or “tee” introduces a low level perturbation to the flow

Material quoted in part from AGA publication

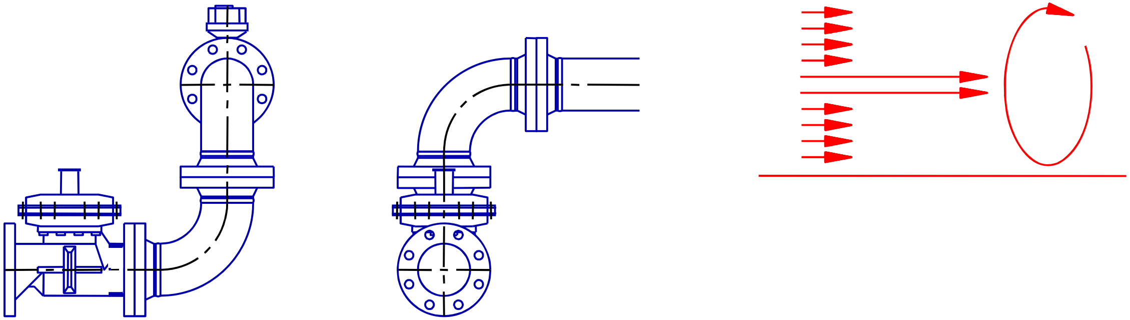
Low Level Perturbation



An additional out-of-plane elbow adds swirl to the already uneven flow profile

Material quoted in part from AGA publication

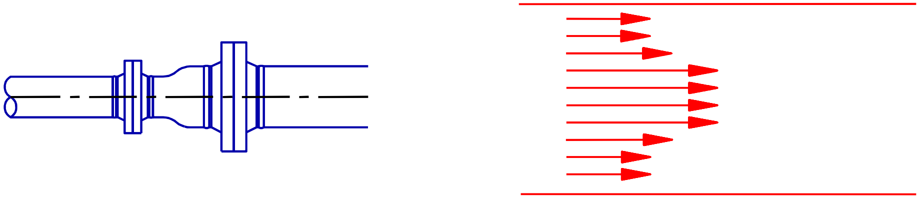
High Level Perturbation



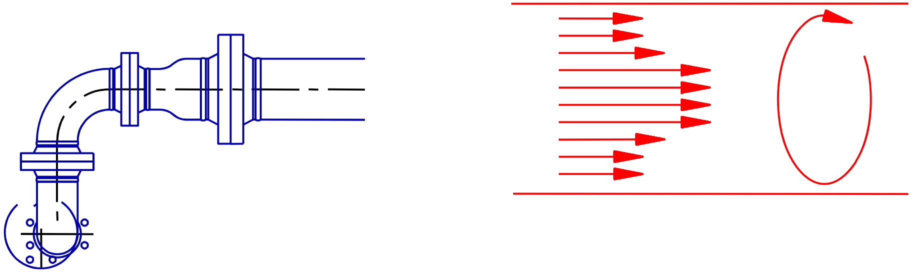
An up-stream regulator and out-of-plane elbow cause a high level of swirl and jetting at the meter run

Material quoted in part from AGA publication

HIGH Level Perturbation



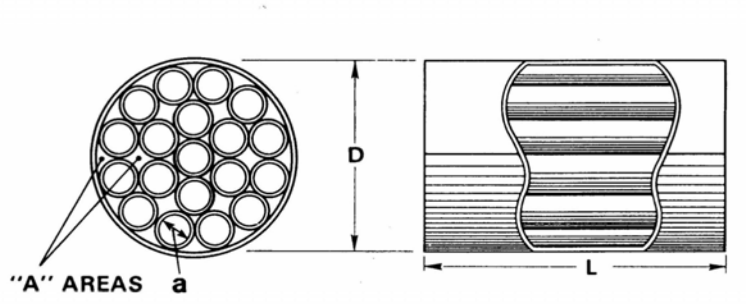
Expanding from a smaller diameter pipe into a larger one introduces jetting which cannot be removed by a tube-bundle flow straightener



Addition of an out-of-plane elbow upstream compounds the problem by adding a swirl component to the flow

Material quoted in part from AGA publication

AGA 7 - Flow Conditioning for Turbine Meter



19-tube bundle straightening vanes

Flow conditioning plate

Material quoted in part from AGA publication

AGA 7 - Meter- Integrated Flow Conditioner

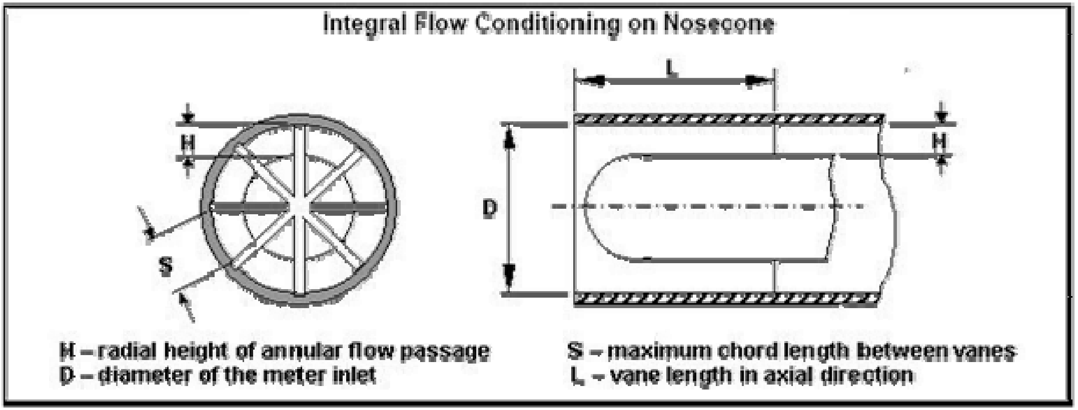


Figure 6: Dimensional Parameters for Integral Flow Conditioning

7.2.2.3 Integral Flow Conditioning

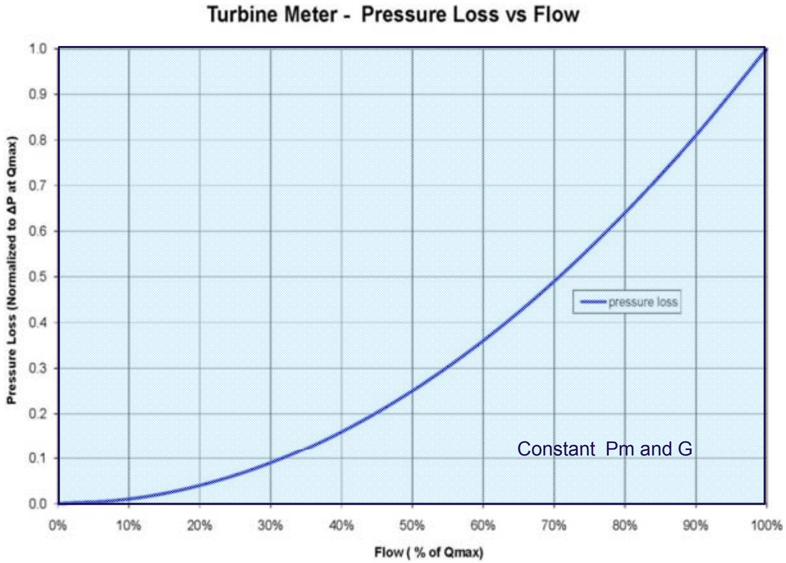
Research (Reference 2) has confirmed that turbine meters with integral flow conditioning in the nosecone flow passages operate satisfactorily in short and close-coupled installations. Those integral flow conditioners tested were similar in design to that shown in Figure 6 and to those evaluated in Reference 8. For this design, the aspect ratios are $H/D \leq 0.15$ and $S/L \leq 0.35$. These parameters are illustrated in Figure 6.

Turbine Meter with Integral Flow Conditioner

Example of a turbine meter with integral conditioning plate

Integral conditioning plate typically allows a turbine meter to be installed in a non-ideal meter run (e.g. short meter run, elbows….) and maintain its accuracy

Pressure Loss Across a Turbine Meter



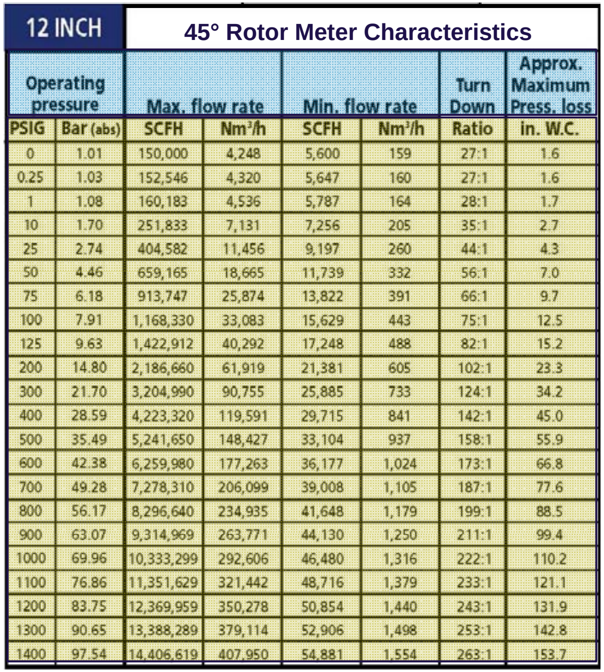
The pressure loss of a turbine meter is directly proportional to the flow pressure and specific gravity and to the square of the flow rate:

$$\Delta P_m \propto P_m \times G \times Q^2$$

Where

ΔP_m = pressure drop across meter
P_m = absolute flow pressure
G = specific gravity of gas
Q = flow rate

Pressure Loss Across a Turbine Meter



12 INCH

45° Rotor Meter Characteristics

Operating pressure		Max. flow rate		Min. flow rate		Turn Down	Approx. Maximum Press. loss
PSIG	Bar (abs)	SCFH	Nm³/h	SCFH	Nm³/h	Ratio	in. W.C.
0	1.01	150,000	4,248	5,600	159	27:1	1.6
0.25	1.03	152,546	4,320	5,647	160	27:1	1.6
1	1.08	160,183	4,536	5,787	164	28:1	1.7
10	1.70	251,833	7,131	7,256	205	35:1	2.7
25	2.74	404,582	11,456	9,197	260	44:1	4.3
50	4.46	659,165	18,665	11,739	332	56:1	7.0
75	6.18	913,747	25,874	13,822	391	66:1	9.7
100	7.91	1,168,330	33,083	15,629	443	75:1	12.5
125	9.63	1,422,912	40,292	17,248	488	82:1	15.2
200	14.80	2,186,660	61,919	21,381	605	102:1	23.3
300	21.70	3,204,990	90,755	25,885	733	124:1	34.2
400	28.59	4,223,320	119,591	29,715	841	142:1	45.0
500	35.49	5,241,650	148,427	33,104	937	158:1	55.9
600	42.38	6,259,980	177,263	36,177	1,024	173:1	66.8
700	49.28	7,278,310	206,099	39,008	1,105	187:1	77.6
800	56.17	8,296,640	234,935	41,648	1,179	199:1	88.5
900	63.07	9,314,969	263,771	44,130	1,250	211:1	99.4
1000	69.96	10,333,299	292,606	46,480	1,316	222:1	110.2
1100	76.86	11,351,629	321,442	48,716	1,379	233:1	121.1
1200	83.75	12,369,959	350,278	50,854	1,440	243:1	131.9
1300	90.65	13,388,289	379,114	52,906	1,498	253:1	142.8
1400	97.54	14,406,619	407,950	54,881	1,554	263:1	153.7

The pressure loss across a turbine meter is directly proportional to the line pressure and specific gravity and to the square of the flow rate:

$$\Delta P_m \propto P_{abs} \times G \times Q^2$$

In which

ΔP_m is the pressure loss across the meter
P_{abs} is the absolute line pressure
G is the specific gravity of the gas
Q is the flow rate

Material quoted in part from iMeter publication

AGA 7 - Recommended Blow Down Valve Size

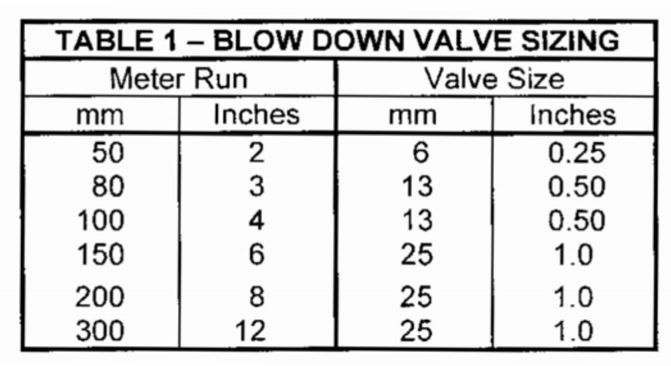


TABLE 1 – BLOW DOWN VALVE SIZING

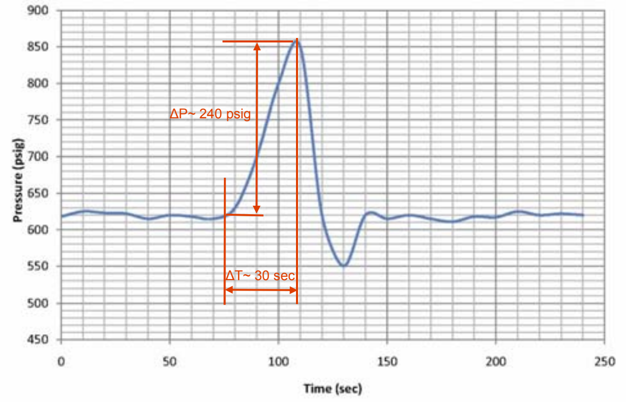
Meter Run		Valve Size	
mm	Inches	mm	Inches
50	2	6	0.25
80	3	13	0.50
100	4	13	0.50
150	6	25	1.0
200	8	25	1.0
300	12	25	1.0

Properly sized blow down valve prevent over-spinning of turbine meter during line purge operation

Material quoted in part from AGA publication

Effect of Rapid Rate of Pressure Change

Pipeline pressure vs Time



$$\text{Rate of pressure change} = \frac{\Delta P}{\Delta t}$$

Where ΔP = maximum pressure change
Δt = time period during which ΔP occurs

Turbine meter manufacturers often specify a maximum rate of pressure change allowed for their products.

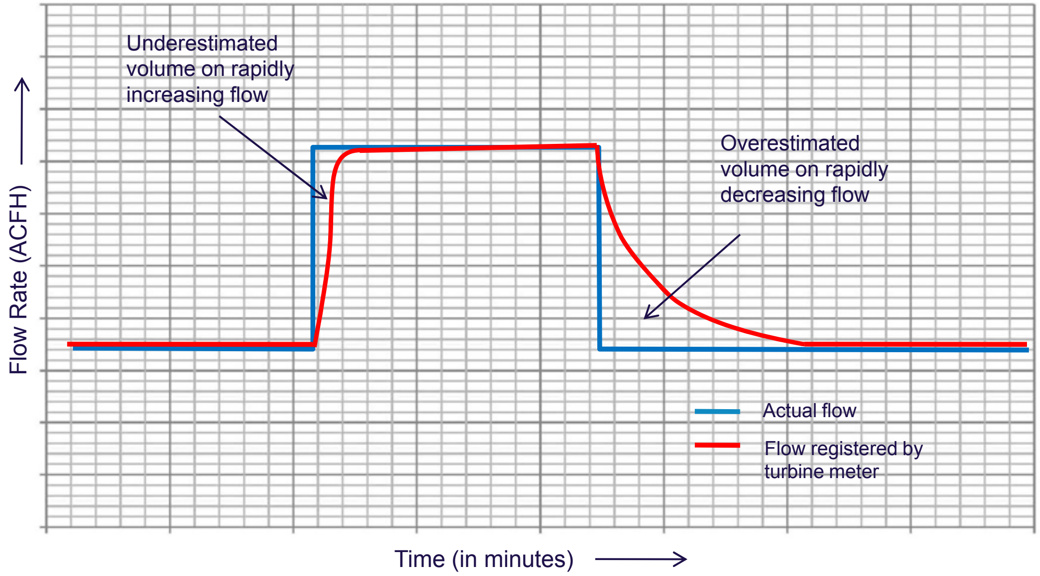
Exposure to rapid pressure change can cause damage to the electronic sensors in a turbine meter.

Typical maximum rate of pressure change rating for turbine meter:

100 psig/minute

Intermittent Flow Characteristic of Turbine Meter

Turbine Meters display different response characteristics while speeding up and slowing down.

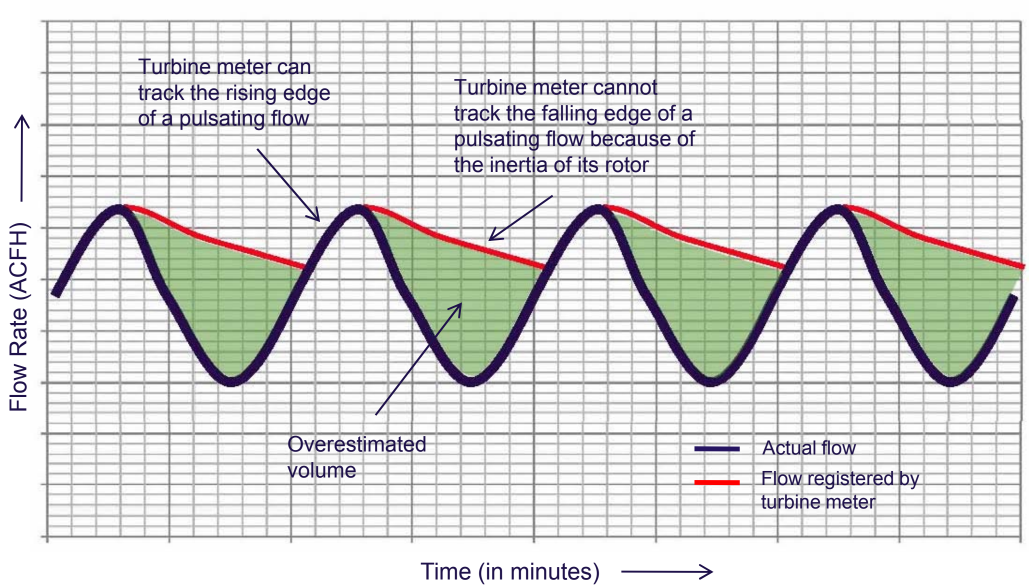


Intermittent Flow Response of Turbine Meter

Material quoted in part from iMeter publication

Intermittent Flow Characteristic of Turbine Meter

Due to the unsymmetrical transient response of turbine meters, they are susceptible to overestimating the flow volume of pulsating devices such as compressors and regulators.



Intermittent Flow Response of Turbine Meter

Material quoted in part from iMeter publication

Reynolds Number

$$\text{Reynolds Number} = \frac{\rho v D}{\eta}$$

ρ = fluid density

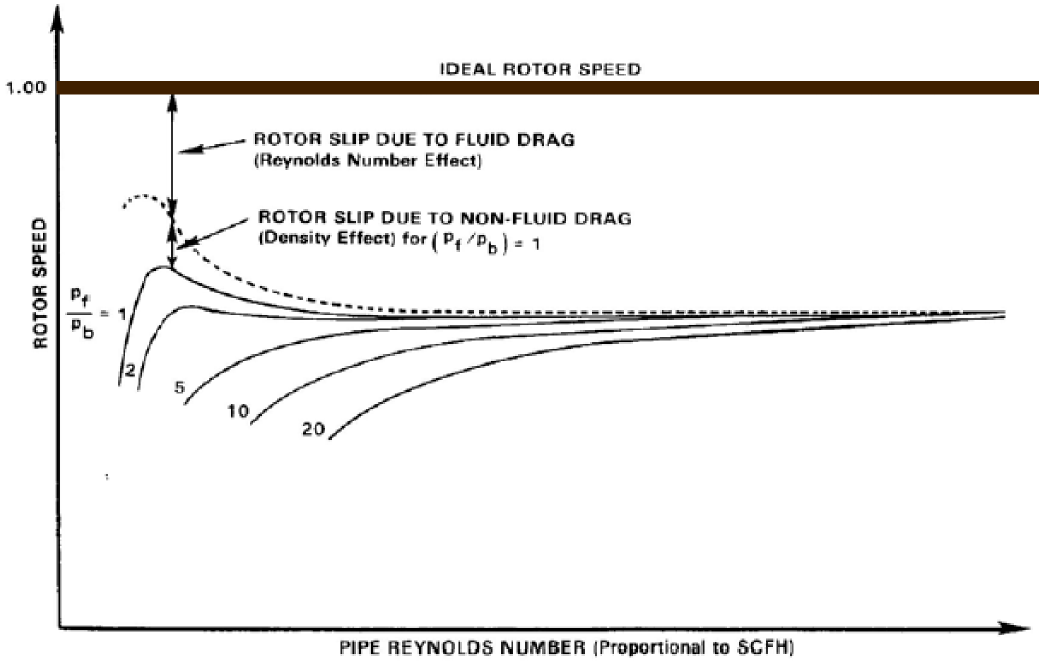
v = flow velocity

D = pipe diameter

η = fluid viscosity

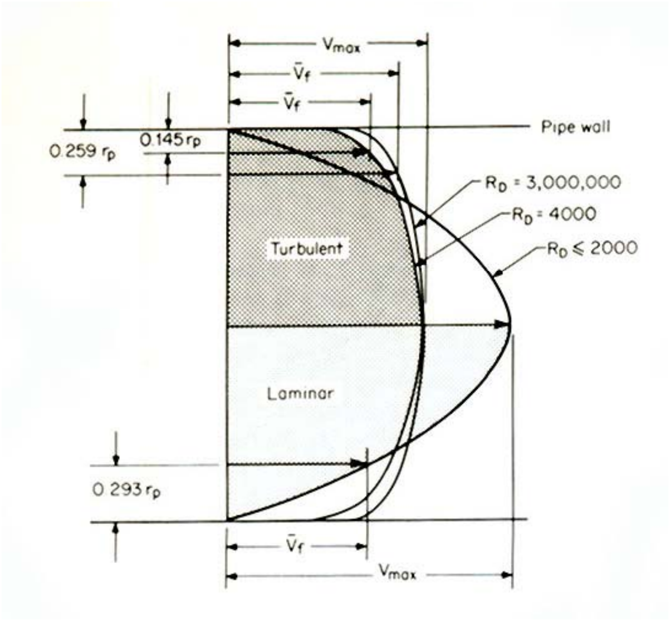
Recent research conducted at CEESI and SwRI on behalf of AGA has demonstrated that commercially available gas turbine meters have markedly different responses to given volumes of natural gas at different Reynolds number.

Turbine Meter Performance vs Reynolds Number



Effect Of Fluid And Non-fluid Retarding Torques On Gas Turbine Meter Performance For Reynolds Number Below 100,000 (Source: Invensys Metering Systems)

Flow Profiles at Various Reynolds Number



Velocity Profiles in Laminar and Turbulent Pipe Flow

Flow Measurement Engineering Handbook – R.W. Miller, McGraw-Hill

Laminar if Re < 2000

Transient if 2000 < Re < 4000

Turbulent if Re > 4000

Reynolds Number examples:

12” Standard Capacity Meter at 350 psia

at 10% of capacity Re = 700,000

at 95% of capacity Re = 6,800,000

Equation of State

The “State” of a gas

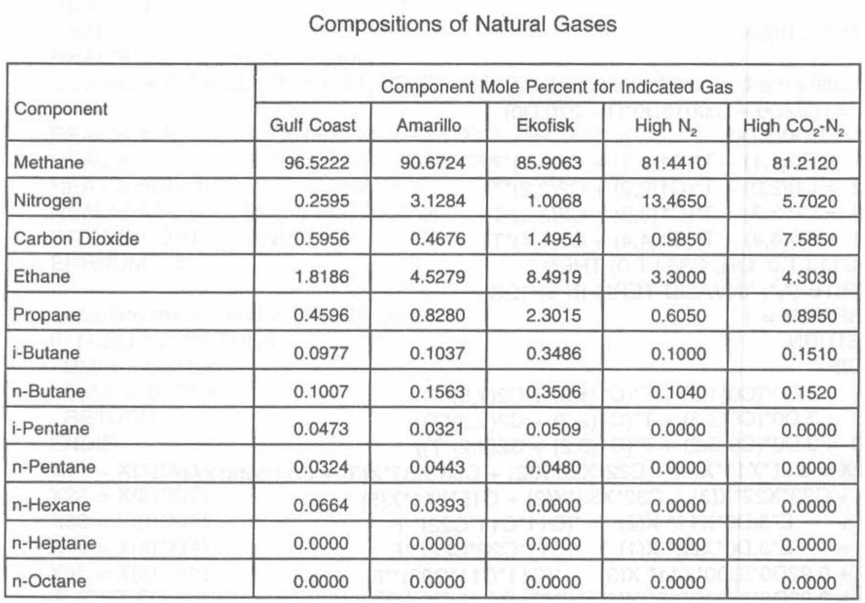
To calculate quantity in terms of base or standard volume one needs to know the quantity of matter, e.g. the number of moles, that occupies the actual volume measured under operating conditions.

This is done by using a suitable “Equation of State” for the type of gas measured and by using measured pressure and temperature.

Equation of State – Composition of Natural Gas

Composition and compressibility

The composition of the gas influences the constants in the Equation of State. This is mostly translated in the “Compressibility factor” or “Z”.

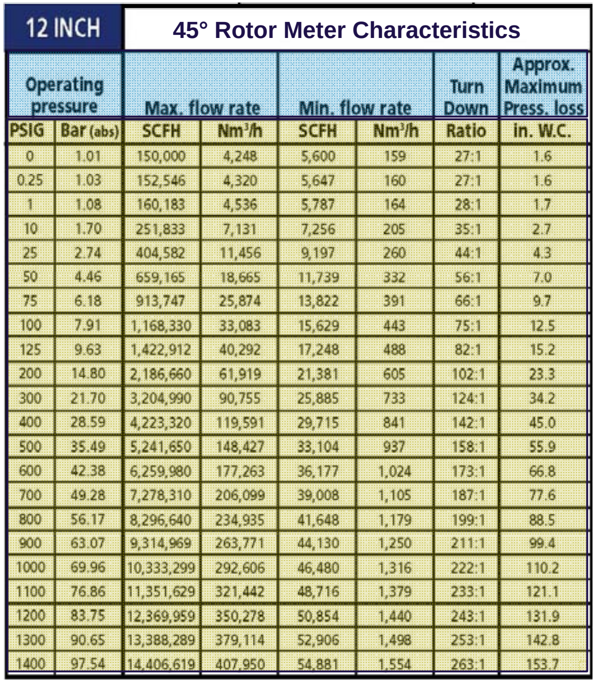


Compositions of Natural Gases

Component	Component Mole Percent for Indicated Gas				
	Gulf Coast	Amarillo	Ekofisk	High N_2	High CO_2-N_2
Methane	96.5222	90.6724	85.9063	81.4410	81.2120
Nitrogen	0.2595	3.1284	1.0068	13.4650	5.7020
Carbon Dioxide	0.5956	0.4676	1.4954	0.9850	7.5850
Ethane	1.8186	4.5279	8.4919	3.3000	4.3030
Propane	0.4596	0.8280	2.3015	0.6050	0.8950
i-Butane	0.0977	0.1037	0.3486	0.1000	0.1510
n-Butane	0.1007	0.1563	0.3506	0.1040	0.1520
i-Pentane	0.0473	0.0321	0.0509	0.0000	0.0000
n-Pentane	0.0324	0.0443	0.0480	0.0000	0.0000
n-Hexane	0.0664	0.0393	0.0000	0.0000	0.0000
n-Heptane	0.0000	0.0000	0.0000	0.0000	0.0000
n-Octane	0.0000	0.0000	0.0000	0.0000	0.0000

Material quoted in part from AGA publication

Elevated Pressure Operation of Turbine Meter



12 INCH **45° Rotor Meter Characteristics**

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PSIG	Bar (abs)	SCFH	Nm³/h	SCFH	Nm³/h	Ratio	in. W.C.
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0.25	1.03	152,546	4,320	5,647	160	27:1	1.6
1	1.08	160,183	4,536	5,787	164	28:1	1.7
10	1.70	251,833	7,131	7,256	205	35:1	2.7
25	2.74	404,582	11,456	9,197	260	44:1	4.3
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100	7.91	1,168,330	33,083	15,629	443	75:1	12.5
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1000	69.96	10,333,299	292,606	46,480	1,316	222:1	110.2
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1200	83.75	12,369,959	350,278	50,854	1,440	243:1	131.9
1300	90.65	13,388,289	379,114	52,906	1,498	253:1	142.8
1400	97.54	14,406,619	407,950	54,881	1,554	263:1	153.7

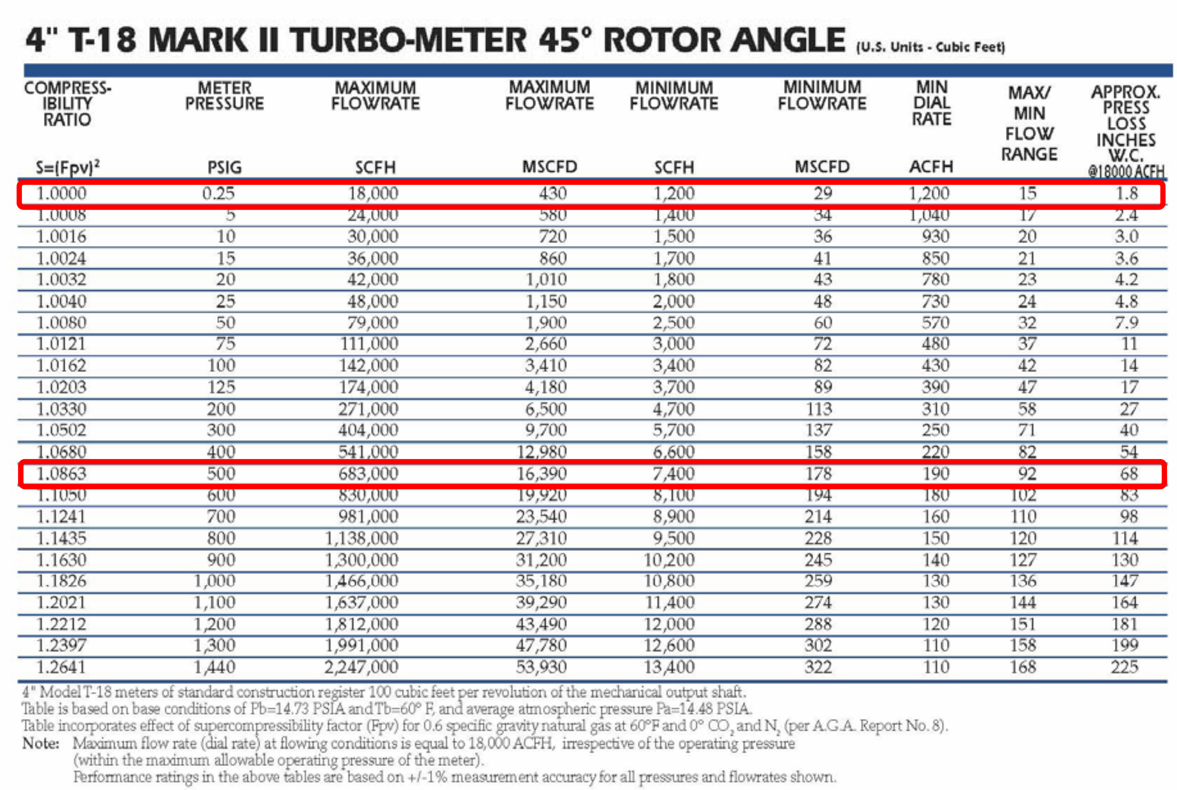
Elevated Pressure Operation

1. Maximum Capacity in SCFH increases directly as does the Boyle’s Law pressure multiplier factor.

2. Minimum (Low Flow) Capabilities increases directly with the square root of the Boyle’s Law pressure multiplier factor.

Material quoted in part from iMeter publication

Calculating Rangeability



4" T-18 MARK II TURBO-METER 45° ROTOR ANGLE (U.S. Units - Cubic Feet)

COMPRESS-IBILITY RATIO S=(Fpv)^2	METER PRESSURE PSIG	MAXIMUM FLOWRATE SCFH	MAXIMUM FLOWRATE MSCFD	MINIMUM FLOWRATE SCFH	MINIMUM FLOWRATE MSCFD	MIN DIAL RATE ACFH	MAX/ MIN FLOW RANGE	APPROX. PRESS LOSS INCHES W.C. @18000 ACFH
1.0000	0.25	18,000	430	1,200	29	1,200	15	1.8
1.0008	5	24,000	580	1,400	34	1,040	17	2.4
1.0016	10	30,000	720	1,500	36	930	20	3.0
1.0024	15	36,000	860	1,700	41	850	21	3.6
1.0032	20	42,000	1,010	1,800	43	780	23	4.2
1.0040	25	48,000	1,150	2,000	48	730	24	4.8
1.0080	50	79,000	1,900	2,500	60	570	32	7.9
1.0121	75	111,000	2,660	3,000	72	480	37	11
1.0162	100	142,000	3,410	3,400	82	430	42	14
1.0203	125	174,000	4,180	3,700	89	390	47	17
1.0330	200	271,000	6,500	4,700	113	310	58	27
1.0502	300	404,000	9,700	5,700	137	250	71	40
1.0680	400	541,000	12,980	6,600	158	220	82	54
1.0863	500	683,000	16,390	7,400	178	190	92	68
1.1050	600	830,000	19,920	8,100	194	180	102	83
1.1241	700	981,000	23,540	8,900	214	160	110	98
1.1435	800	1,138,000	27,310	9,500	228	150	120	114
1.1630	900	1,300,000	31,200	10,200	245	140	127	130
1.1826	1,000	1,466,000	35,180	10,800	259	130	136	147
1.2021	1,100	1,637,000	39,290	11,400	274	130	144	164
1.2212	1,200	1,812,000	43,490	12,000	288	120	151	181
1.2397	1,300	1,991,000	47,780	12,600	302	110	158	199
1.2641	1,440	2,247,000	53,930	13,400	322	110	168	225

4" Model T-18 meters of standard construction register 100 cubic feet per revolution of the mechanical output shaft.
Table is based on base conditions of Pb=14.73 PSIA and Tb=60° F, and average atmospheric pressure Pa=14.48 PSIA.
Table incorporates effect of supercompressibility factor (Fpv) for 0.6 specific gravity natural gas at 60°F and 0° CO_2 and N_2 (per A.G.A. Report No. 8).

Note: Maximum flow rate (dial rate) at flowing conditions is equal to 18,000 ACFH, irrespective of the operating pressure (within the maximum allowable operating pressure of the meter).
Performance ratings in the above tables are based on +/-1% measurement accuracy for all pressures and flowrates shown.

Rangeability calculation example

Material quoted in part from Sensus publication

Calculating Rangeability

Pressure Multiplier = (Line Pressure + Average Atmospheric) / Base Pressure * Compressibility Ratio

= (500psig + 14.48psi) / 14.73 * 1.0863

= 37.942

Maximum Flow Rate = Meter Rating * Pressure Multiplier

= 18,000acfh * 37.942

= 682,956 scfh = 683,000 scfh from table

Minimum Flow Rate = Meter Rating * Square Root of Pressure Multiplier

= 1200acfh * $(37.942)^{0.5}$

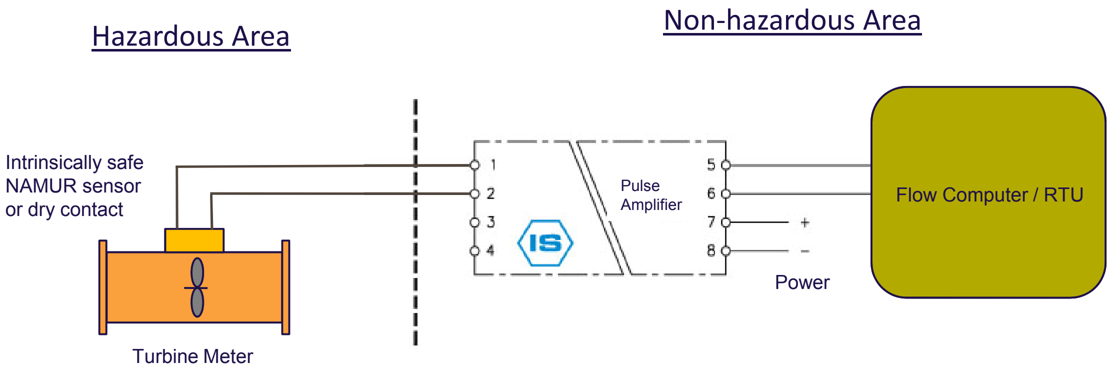
= 7391scfh = 7400 scfh from table

Range = Maximum / Minimum Flow Rater

= 683,000 / 7400 = 92:1

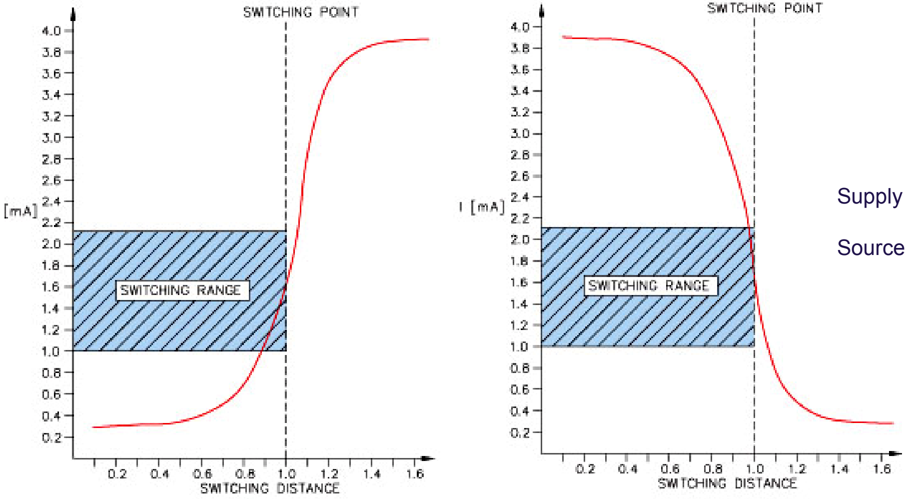
Material quoted in part from Sensus publication

Typical Turbine Meter Installation



Pulse amplifier converting NAMUR signal to a standard 24V digital signal

NAMUR Signal



Inductive Sensor

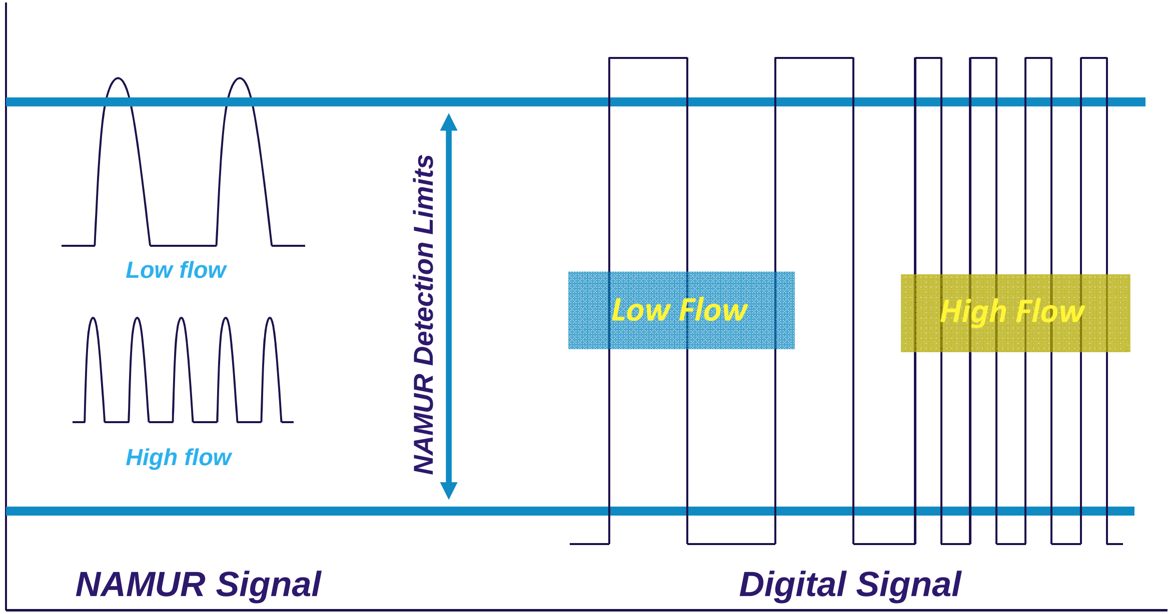
Capacitive Sensor

Supply Voltage = 8.2 VDC

Source impedance ~ 1 kΩ

Typical sensor current versus sensing distance

Turbine Meter Output Signal Format



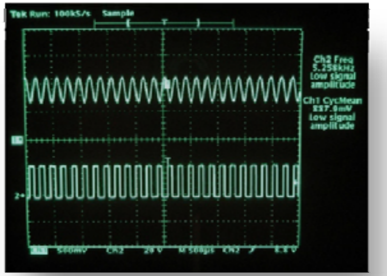
Material quoted in part from iMeter publication

Turbine Meter Pulse Signal Conditioning

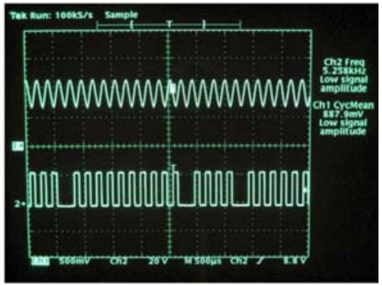
Turbine meter

NAMUR pulse amplifiers

Normal turbine meter signal



Incorrect turbine meter signal



Incorrect supply voltage or source impedance results in missed pulses

Cost of Measurement Error

Turbine Meter Operating at 50 psig

Meter Size	Energy Delivered in a 6 year Calibration Cycle *	Cost of Energy Delivered *	Cost of 0.5% Measurement Error
Inches	MMBtu	US$	US$
4	1,271,208	8,898,458	44,492
6	2,478,052	17,346,361	86,732
8	4,264,180	29,849,258	149,246
8 HC	6,388,224	44,717,567	223,588
12	9,944,389	69,610,722	348,054
12 HC	16,332,613	114,328,289	571,641

Turbine Meter Operating at 500 psig

Meter Size	Energy Delivered in a 6 year Calibration Cycle *	Cost of Energy Delivered *	Cost of 0.5% Measurement Error
Inches	MMBtu	US$	US$
4	10,990,320	76,932,238	384,661
6	21,369,172	149,584,204	747,921
8	36,623,671	256,365,699	1,281,828
8 HC	54,951,598	384,661,188	1,923,306
12	85,476,688	598,336,817	2,991,684
12 HC	140,428,286	982,998,005	4,914,990

Note 1: Turbine meters operating at 30% of Qmax average

2. Energy content of natural gas based on 1.0205 MBtu/cu.ft.
3. Cost of energy calculated based on $7.00 USD per MMBtu (including delivery)

Questions ?

References:	Sensus repair manuals.
	Sensus Turbine Meter hand book.
	iMeter Presentation on Turbine Meter
	Instromet System Handbook
	AGA Report #7
	AGA Report #8