



TURBINE GAS METER HANDBOOK



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INTRODUCTION

In this document the operation, the performance, the installation and the output facilities of Instromet Turbine meters are summarised.

Comparisons are made between turbine meters and other meter types, such as orifice plate meters and rotary piston meters.



Instromet turbine meter SM-RI X4X

1. OPERATION

1.1 Operating principle

A schematic drawing of a typical turbine meter is given in figure 1. The gas enters the turbine meter through a specially designed flow straightener which imposes an evenly distributed pattern on the flow, impinging on the turbine wheel. The contraction of the flow in the annular slot increases gas velocity in order to exert a higher torque on the turbine wheel. The blades of the rotor are positioned under an angle of 30 to 45°. The gas flow drives the turbine wheel with a speed proportional to the velocity of the gas. The total volume of the gas passing through the meter per unit of time is equal to the velocity of the gas multiplied by the area of the annular slot, and every revolution of the turbine wheel is equivalent to a certain fixed volume passing through.

The turbine wheel in turn drives a counter. The counter is geared to indicate the volume passed through the meter in the appropriate units (m^3 or ft^3). Proximity sensors provide electrical outputs, either from the blades of the turbine wheel or from a special disc. In this way a frequency signal is generated that is proportional to flow rate.

A theoretical analysis of the turbine meter operation is given in appendix 1.

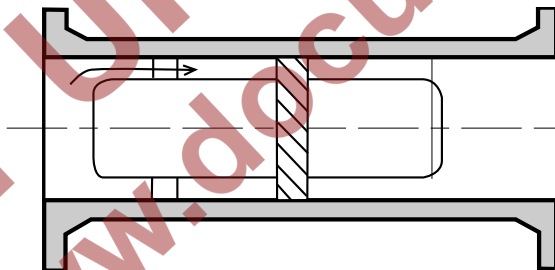


Figure 1. Schematic diagram of turbine flow meter

1.2 Conversion of volume to quantity (mass, standard volume)

The turbine meter is one link in the chain to determine quantity. Quantity can be expressed in terms of standard, normal, or base volume, or in terms of mass. The volume measured by the meter under operating pressure and temperature can be converted to volume at standard or base pressure and temperature in several ways.

The most common method is the PTZ method. The pressure of the gas is determined at a representative point in the meter and the temperature is measured immediately downstream. The base temperature and base pressure have fixed values. Base pressure is mostly 1.01325 bar, but base temperature values of 0°C,

15 °C and 60 °F are used. The compressibility Z can be calculated from the gas composition. The compressibility is not a constant, but varies with temperature and pressure. Several correlations exist to calculate compressibility from the composition and pressure and temperature.

The equation to calculate the base volume is:
$$V_b = V_m \cdot \frac{P_m}{P_b} \cdot \frac{Z_b}{Z_m} \cdot \frac{T_b}{T_m}$$

In this equation the subscript "m" indicates measured values at operating conditions or, in case of Z_m , the compressibility at operating conditions determined from the composition and operating temperature and pressure. The subscript "b" is used for the values at base conditions. For low pressures, the value of Z_b/Z_m is very close to 1 and under those conditions the gas is usually considered to be incompressible ($Z_b = Z_m = Z$).

An alternative method uses the density at operating conditions, measured by a densitometer, and the density at base conditions. The latter can either be measured directly or can be determined from the composition. The equation in this case is:

$$V_b = V_m \cdot \frac{\rho_m}{\rho_b}$$

In this equation ρ_m and ρ_b are the densities at operating and at base pressure and temperature respectively.

Instromet manufactures a range of high quality automatic volume correctors for a variety of applications and with a wide choice of options. In addition the Instromet ENCAL gas chromatographs provide the composition of natural gas on-line. This makes it possible to determine the compressibility and the density at base conditions ρ_b for highest accuracy metering. It also provides the heating value, so that the total amount of energy supplied can be accurately determined.

2. PERFORMANCE

2.1 Standards

Instromet turbine meters are made to satisfy the new ISO 9951* standard "Measurement of gas flow in closed conduits - Turbine meters". They also satisfy OIML** requirements for fiscal metering and all national metrological standards derived from the OIML requirements as well as the requirements of AGA*** report number 7.

* ISO = International Organization for Standardization.

** OIML = Organisation Internationale de Métrologie Légale (International Organization of Legal Metrology)

*** AGA = American Gas Association

2.2 Rangeability

The minimum and maximum flow rates between which a meter operates within specified accuracy limits, is defined as the range. The maximum error for this purpose is specified in ISO 9951 as plus or minus 2 % of the actual value at low flow rates and plus or minus 1 % at high flow rates (See figure 2). The high flow rates are defined as between the maximum flow rate Q_{\max} and 20% of Q_{\max} , and low flow rates are between 20% of Q_{\max} and the specified minimum flow rate Q_{\min} . This is consistent with EEC regulations.

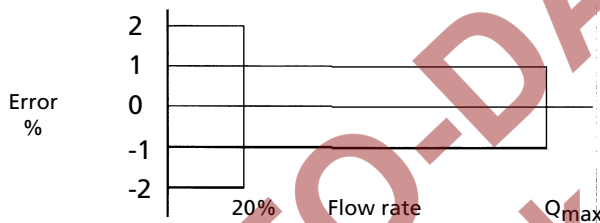


Figure 2. Maximum allowable error according to ISO 9951

For air at atmospheric pressure, the rangeability of Instramet SM-RI turbine meters is specified as in table 1 (See page 7). The range is normally 1:20 except for the very small flow meters. The range of a turbine meter is also dependent on the density of the gas it handles: the higher the density, the greater the range. At the lower end, the range is limited by the mechanical friction of bearings and register. A denser gas can deliver more torque to overcome the friction. The lower limit decreases in inverse proportion to the square root of the density of the gas. In terms of specific gravity or relative density (d), the minimum flow rate under operating conditions $Q_{\min \text{ operating}}$ can be determined from the minimum flow rate with air under atmospheric conditions $Q_{\min \text{ air}}$ by the following relation:

$$Q_{\min \text{ operating}} = Q_{\min \text{ air}} \sqrt{\frac{P_{\text{atm}}}{P_m} \cdot \frac{1}{d}}$$

where P_{atm} is the atmospheric pressure (1.01325 bar or 14.7 psi) and P_m the absolute operating pressure of the meter in the same units. For natural gas d is normally 0.6 to 0.7.

Example:

Size	: G160
Maximum flow rate	: 250 m ³ /h
Minimum flow rate air, atmospheric pressure	: $\frac{250}{20} = 12.5 \text{ m}^3/\text{h}$

For gas at specific gravity of 0.6, atmospheric pressure:

$$\text{Minimum flow rate} \frac{12.5}{\sqrt{0.6}} = \frac{12.5}{0.775} = 16.1 \text{ m}^3/\text{h}$$

For gas at atmospheric pressure, as the gas density is lower than that of air, the minimum flow rate increases and therefore the range decreases.

Next consider the same gas at 6 bar gauge:

Density is approximately $0.6 \cdot (6+1) = 4.2$ times the density of air.

$$\text{Therefore minimum flow rate is } 12.5 \cdot \sqrt{\frac{1}{7} \cdot \frac{1}{0.6}} = \frac{12.5}{2.05} = 6.1 \text{ m}^3/\text{h}$$

For gas of 0.6 s.g. at an absolute pressure of 7 bar, the minimum flow rate decreases and therefore the range is increases with respect to atmospheric air.

On the high end, the range is limited by overspeeding of the turbine wheel. The maximum flow rate is therefore fixed, independent of pressure or density.

There may be a maximum limit given for the density to restrict the mechanical load on the rotor

Turbine meters have rangeabilities of normally 1:20. In contrast, orifice plate installations with a single pressure differential transmitter rarely have a rangeability of more than 1 in 3. Higher ranges are covered by complicated arrangements such as automatic switching of additional metering runs, additional pressure differential transmitters with higher differential and automatic change-over etc.

Positive displacement meters have higher rangeabilities. The Instromet IRM Infinity has an exceptionally high rangeability of 1:150 and more. Their range extends to lower flow rates than achievable with turbine meters. Vortex meters and other hydrodynamic oscillators have rangeabilities similar to turbine meters.

2.3 Reynolds number dependence

It is explained under Rangeability that the lower end of the range is determined by mechanical friction and is extended by increasing density and therefore by increasing pressure.

MEASUREMENT RANGES SM-RI

Size mm	G- rating	Q _{max} m³/h	Q _{min} m³/h	tr** m³	Overall length	Pressure rating	Body material	Wgt. kg	Pressure rating	Body material	Wgt. kg
50 2"	40 65	65 100	13 10	0,1 0,1	150	ND 10/16 ANSI 125	GGG 40	10 10	ND 100	St	26
						ND 10/16 ND 2540 ND 64	St	20 20 23	ANSI 150 ANSI 300 ANSI 400 ANSI 600	St	18 20 20 20
						ND 10/16 ANSI 125	GGG 40	15 15	ND 100	St	34
						ND 10/16 ND 2540 ND 64	St	26 26 30	ANSI 150 ANSI 300 ANSI 400 ANSI 600	St	24 28 28 28
100 4"	160 250 *400	250 400 650	13 20 32	1 1 1	300	ND 10/16 ANSI 125	GGG 40	28 28	ND 100	St	46
						ND 10/16 ND 2540 ND 64	St	30 38 40	ANSI 150 ANSI 300 ANSI 400 ANSI 600	St	35 42 42 50
						ND 10/16 ANSI 125	GGG 40	44 44	ND 100	St	87
						ND 10/16 ND 2540 ND 64	St	42 50 72	ANSI 150 ANSI 300 ANSI 400 ANSI 600	St	48 66 77 98
200 8"	650 1000 *1600	1000 1600 2500	50 80 130	10 10 10	600	ND 10 ND 16 ANSI 125	GGG 40	70 70 70	ND 40 ND 64 ND 100	St	98 125 161 91
						ND 10 ND 16 ND 25	St	77 77 89	ANSI 150 ANSI 300 ANSI 400 ANSI 600	St	117 135 135 155
						ND 10 ND 16 ND 25	St	90 95 108	ANSI 150 ANSI 300 ANSI 400 ANSI 600	St	108 148 170 236
						ND 40 ND 64 ND 100	St	128 156 220	ANSI 300 ANSI 400 ANSI 600	St	236 236 236
300 12"	1600 2500 *4000	2500 4000 6500	130 200 320	10 10 10	900	ND 10 ND 16 ND 25	St	120 150 180	ANSI 150 ANSI 300 ANSI 400 ANSI 600	St	160 210 240 290
						ND 40 ND 64 ND 100	St	240 340	ANSI 300 ANSI 400 ANSI 600	St	290 290 290
						ND 10 ND 16 ND 25	St	350 380 410	ANSI 150 ANSI 300 ANSI 400 ANSI 600	St	400 460 460 580
						ND 40 ND 64 ND 100	St	480 510	ANSI 300 ANSI 400 ANSI 600	St	580 580 580
500 20"	4000 6500 *10000	6500 10000 16000	320 500 800	10 10 10	1500	ND 10 ND 16 ND 25	St	550 600 640	ANSI 150 ANSI 300 ANSI 400 ANSI 600	St	650 800 830 980
						ND 40 ND 64 ND 100	St	680	ANSI 300 ANSI 400 ANSI 600	St	980 980 980
						ND 10 ND 16 ND 25	St	900 950	ANSI 150 ANSI 300 ANSI 400 ANSI 600	St	1050 1300 1350 1500
						ND 40 ND 64 ND 100	St	1000	ANSI 300 ANSI 400 ANSI 600	St	1500 1500 1500

* maximum density 53 kg/m³ at Q_{max}

tr** = m³/revolution of output shaft

GGG 40 = Ductile iron GGG 40

St = Steel

At the higher flow rates, where friction forces are small compared with available hydrodynamic forces, the error is determined by the Reynolds number.

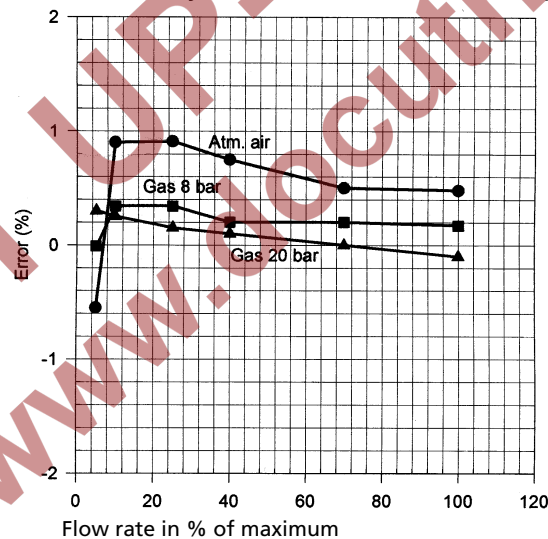
The Reynolds number is dependent on the flow rate, the density, and the dynamic viscosity of the gas:

$$Re = K \cdot Q \cdot \frac{\rho}{\eta}$$

where K is a constant depending on the geometry of the meter, Q is the flow rate, ρ the density under operating conditions and η the dynamic viscosity of the gas under operating conditions.

As the dynamic viscosity for gases is roughly constant, the main variables are flow rate and density and therefore pressure. For similar Reynolds numbers, similar errors are found.

In figure 3, the error is plotted for a meter at different pressures as a function of flow rate and showing different curves. The same data plotted as a function of the Reynolds number shows a continuous curve for the higher flow rates (See figure 4). For the lower flow rates, friction affects the error curve at different Reynolds numbers. This is shown in the curves dropping off at different values of the Reynolds number for different pressures.



- P1 = atmospheric air
- P2 = 8 bar gas
- ▲ P3 = 20 bar gas (rel. density 0.64)

Figure 3. Error of SM-R1 turbine meter, 150 mm, 1000 m³/h max, as a function of flow rate at three different pressures.

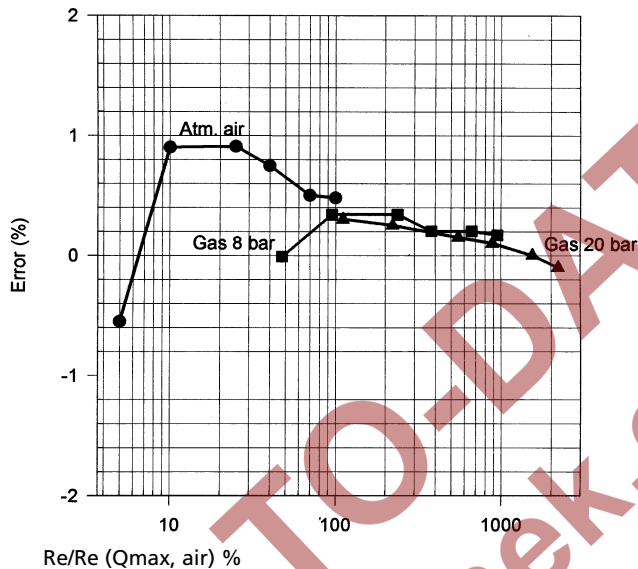


Figure 4. The error curves from figure 3 plotted as a function of Reynolds number

For a well designed meter, the error curve for higher flow rates when plotted as a function of the Reynolds number, is one smooth continuous and roughly horizontal line, even when measured at different pressures.

It is essential that the calibration at different pressures is carried out against a set of consistent references with only small systematic differences. Instromet operates its own high and low pressure testing installations that are all run under auspices of the official Dutch Legal Metrology Service NMI* that regularly checks accuracy and consistency.

At low Reynolds numbers the error curve has a tendency to lift up, i.e. the meter has a tendency to run fast at low Reynolds numbers. The reason for this can be understood easily when considering figure 5. In the absence of friction forces, the rotor will have a speed such that the bulk of the flow will pass straight through the meter. In the figure, the flow profile for a high and low Reynolds number is indicated for the same rotational speed of the turbine wheel. For the low Reynolds number the average speed is clearly less for the same turbine wheel speed, resulting in the meter reading high. For small meters this tends to compensate for the influence of mechanical friction.

* NMI = Nederlands Meetinstituut

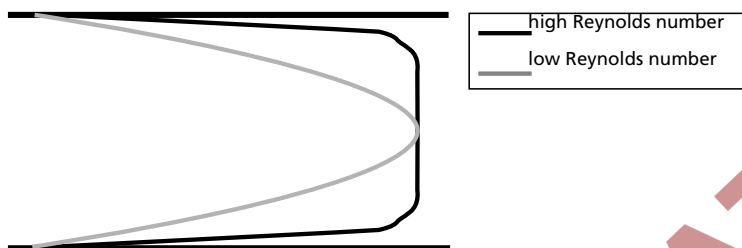


Figure 5. Velocity profile for low and high Reynolds numbers in flow channel of turbine wheel.

Instromet uses its high pressure testing station in Utrecht to test all meters supplied for this purpose at a pressure of approximately 8 bar. Many meters are tested at even higher pressures at one of the Official Dutch calibration stations. All these data are collected and serve as the basis for improvement of the Instromet product. The ever increasing volume of data enables Instromet to continue developing its products.

The continuous availability of a dedicated test facility and the experience that has been built up, distinguishes Instromet from its main competitors. It is a dominating factor in achieving and maintaining excellence in quality of the Instromet design.

As a result of this, Instromet can now accurately predict the error curve of a turbine meter, solely on the basis of design and dimensions.

2.4 Accuracy/Uncertainty

One has to clearly distinguish the uncertainty of the volumetric flow measurement as performed by the turbine meter and the uncertainty in the resulting quantity measurement. In the latter, the uncertainty in the measurement of pressure, temperature, the accuracy with which the gas composition is known and the uncertainty in the knowledge of the gas properties plays a role.

Another property is the repeatability of the measurement. For Instromet SM-RI meters, the repeatability is in the order of 0.1% or better, which is the best that can be achieved in gas flow metering. It means that if a measurement is repeated at the same Reynolds number, the meter will have the same error within 0.1%. This value may have a systematic bias, given by the value of the error curve at that Reynolds number. Normally this systematic error is not compensated for and regarded as part of the uncertainty.

The uncertainty in the volumetric flow measurement is thus given by the maximum error in the range over which the meter will be used. For most flow rates this is plus or minus 1%.

For special applications the maximum error can be reduced to a narrower bracket at extra cost. This is presently possible for meters of a diameter of 250 mm and larger, and for operating pressures of 10 bar and higher.

The volumetric flow rate is measured at the turbine wheel. In close vicinity of the wheel, a special reference pressure point P_r is provided. An error will be introduced if the pressure (or density), used to calculate quantity, is not equal to that at the reference point.

The total uncertainty for high pressure volume metering can presently be as low as 0.5 %. This includes an uncertainty of 0.3 % in the reference standard for the turbine meter calibration. Repeatability can be close to 0,1 % for turbine meter measurement.

In contrast, for orifice plates the uncertainty in the orifice plate coefficient alone, already amounts to 0.6 %. Repeatability over a period of several hours has been reported to be not much better.

Positive displacement meters can achieve similar uncertainties as turbine meters.

2.5 Linearity

Linearity shows itself in the calibration curve (error curve) being more or less flat. A meter with an absolutely flat calibration curve is absolutely linear. It is another way of expressing the uncertainty as explained above.

Orifice meters have a square root character and can only be linearised through root extraction devices.

Positive displacement meters are also highly linear.

2.6 Calibration

All Instromet turbine meters are calibrated with air of atmospheric pressure. The Instromet test installation is recognised by NMI, the official Dutch Legal Metrology Service. Individual calibrations can be witnessed and certified by the representative of NMI to satisfy for example EEC requirements.

Meters destined for high pressure operation are also calibrated at the Instromet High Pressure Test Installation in Utrecht operating at 8 bar. This

installation too is recognised by the NMI and standards are traceable to fundamental units. Calibrations can be witnessed and certified by the NMI representative.

For higher pressure and very high accuracy applications, meters can be calibrated at one of the other high pressure calibration installations in the Netherlands such as the NMI facility in Bergum (up to 50 bar) or Gasunie's Bernoulli laboratory in Westerbork, or any other reputable test facility.

Turbine meters have presently the best proven long term and short term repeatability of all gas flow meters. As a result, turbine meters are excellently suited to be individually calibrated. The data gathered when calibrating will reproduce exactly when retested and when used in the field. To calibrate gas meters which do not repeat so well to the same accuracy would take a very long time to average out the variations. Alternatively, when the calibration is limited in time, the uncertainty of the calibration increases.

2.7 Legal metrology aspects

Instromet meters can be supplied to satisfy any known National or International legal requirement. A complete range of meters satisfying EEC legal requirements is available. Where appropriate, special National Requirements can be met.

Calibration by Instromet is traceable to the International Standards of length and time, and is carried out under supervision of the Official Dutch Metrological Service NMI.

Instromet has representatives of NMI permanently on site at each of its calibration sites. Type approval of meters is obtained after extensive tests by NMI both on accuracy and performance, and conducted at Instromet facilities and at the facilities of NMI. Where applicable, tests are carried out to check on electromagnetic interference at the special facilities of NMI in Delft.

2.8 Stability

Stability of the Instromet turbine meters has been demonstrated clearly in a recalibration exercise carried out by Gasunie, the Dutch gas transmission company (Ref 1). These data show that over a period of up to 15 years, the weighted mean error of 128 meters did not shift by more than plus or minus 0.6% apart from one exception at 0.9%.

The continuing development of the turbine meters at Instromet means that present meters will exhibit a performance superior to this excellent record. For high density fluids (Ethylene) and high pressure natural gas, Instromet

has developed meters with heavier bearings, thus increasing the stability even further. This can only be done if performance at low pressures is not of interest.

The meter body is normally constructed of ductile iron, steel or stainless steel and the internals from aluminium with Viton O-ring seals. This is fully compatible with commercially distributed fuel gas and can be handled without any problems. Industrial gases have to be judged on their compatibility with the above materials.

It is not possible to guarantee that the temperature of any part of the meter will not exceed a certain value during normal operation. This should be made clear to anyone considering the use of the meters for oxygen.

2.9 Short term stability

Short term stability of the measurement is governed by dependence on varying temperature and pressure or variations in gas quality.

As described under Rangeability and under Reynolds number dependence, the density of the gas affects the performance of the meter. Pressure, temperature and gas composition determine the density and affect therefore meter performance. Direct influence of these parameters on meter performance is as follows:

Temperature

Materials, tolerances and lubrication are chosen in such a way that the operating temperature can safely be varied between -10 and +65°C for standard meter designs. Within this range, the direct influence of temperature on the accuracy is negligible.

Pressure

The materials of the meter bodies can be supplied to satisfy any recognised safety standard such as ASTM, API, DIN, and similarly the construction can be according to ASME, ANSI, BS, AD-M or Stoomwezen. There is no direct influence of pressure on meter accuracy.

Gas composition

Gas composition does not affect the indication of the meter other than through the density and viscosity. In normal applications the gas composition variations are limited and the influence of gas composition on meter behaviour is negligible.

2.10 Influence of flow variations

Turbine meters have normally a fast response to flow variation. They follow increasing flow variations faster than decreasing flow variations. At high flow rates, the meter response is very fast, even for decreasing flow. When the flow reduces to very low values, the meter becomes very slow to follow. Turbine meters should therefore not be used on installations that are controlled in on-off mode with short "on" periods, as they may seriously overregister under those conditions.

The effect of flow variations of a sinusoidal nature is negligible for very low frequencies of pulsation. The rotor speed follows the flow variations accurately. For higher frequencies the rotor will not be able to follow the flow variations and the meter will overregister. For very high frequencies of pulsation the rotor will turn at a constant rate and the error under these conditions can be calculated for a sinusoidal pulsation of the flow rate.

If the amplitude of the pulsations is ΔQ and the average flow rate is Q , a pulsation factor I can be defined as

$$I = \frac{\Delta Q}{Q}$$

For very high frequencies of pulsation the error in the reading will be

$$E = 1/2 I^2.$$

For lower frequencies the error will be smaller. In many cases an estimate of the maximum likely effect of pulsations can be made on this basis.

In appendix 2 the equation of motion for a turbine meter is given.

3. INSTALLATION

3.1 Installation length

The error curve of a meter is checked by calibration in an installation with an axisymmetric non-swirling flow. The inlet of the meter acts as a straightener to eliminate swirl and non-uniform profile effects. Instromet has systematically researched the efficiency of straighteners at high and low pressures in its test facilities. This extensive research has resulted in the optionally available,

unique built-in X4X straightener (patents pending) which satisfies the requirements of ISO 9951, both for the low and high level perturbations defined in that Standard, without requiring any additional straightener.

ISO 9951 requires the manufacturer to state the installation conditions that do not give a shift of more than 0.33 % from the undisturbed situation. Instromet high pressure turbine meters equipped with a X4X straightener do not normally need an external straightener nor any additional straight length to stay within 0.15 % for all high and low perturbations specified in ISO 9951!

The high level disturbance as defined in ISO 9951 consists of two bends, in perpendicular planes, with a segmental orifice blocking half the pipe area located between the two bends. The size of the bends is one size smaller than the size of the meter. There is only two diameters straight length between the disturbance and the meter. The objective is to model the disturbance created by a regulator, creating a well defined, vigorously swirling, non-uniform flow. As was stated earlier, Instromet high pressure SM-RI meters equipped with an X4X internal flow conditioner, do not need any straighteners or extra length for this condition and will not exhibit an error shift of more than 0.15 %.

As regulators vary considerably in construction and also in operating conditions, real regulators may generate conditions still worse than the ISO 9951 high level disturbances. Also, it may be desirable to reduce extra installation errors even further. A tee with one of the straight ends blocked has proven to be very effective to break up the initial jet issuing from a regulator (see figure 6). When mounted in this way, any regulator can be regarded as not worse than the ISO defined high level perturbation.

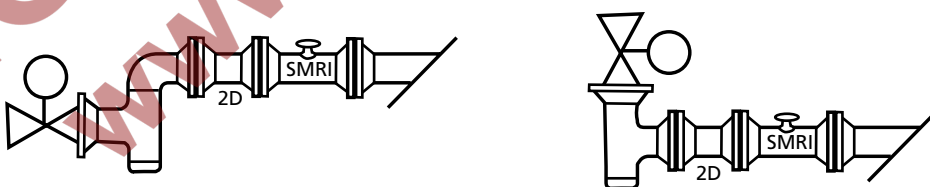


Figure 6. Recommended ways of connecting a turbine meter downstream of a regulator.

Alternatively the Instromet straightener FC 20 will eliminate any influence, even after a regulator. A space of at least one diameter has to be left

between the straightener and the meter flange. Two diameters or more should separate the regulator from the straightener. The straightener does introduce an extra pressure drop and can only be used up to a limited pressure (16 bar). For configurations or pressures where neither the FC 20, nor the "tee" is suitable, Instromet can provide similarly effective, custom designed straighteners.

The sensitivity to upstream disturbances has thus been reduced by Instromet to a level traditionally only reserved for positive displacement meters.

In comparison, for the installation of orifice plates, straight lengths of up to eighty times the nominal pipe diameter D are required according to ISO 5167 to achieve a claimed best accuracy of 0.6%. Instromet high pressure SM-RI meters only need five diameters for conditions that are worse, beyond the disturbances ISO 5167 specifies!

3.2 Overspeeding

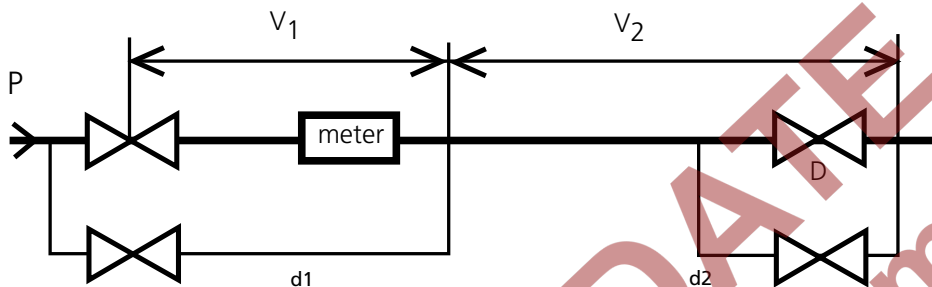
Instromet turbine meters are designed to be subjected to a 20% higher flow rate than the maximum rating for short periods. They should not be run at higher speeds, as bearing damage and ultimately turbine wheel damage will occur.

Overspeeding is generally caused by filling up or pressurizing a section of pipe through the meter in an uncontrolled way. The design of the installation should be such that pressurizing can be done through a small diameter tube, preferably connected such that the meter is located in the smallest volume.

By choosing the internal diameter of the pipe, by-passing the main valve as indicated in the table, the flow rate will be limited to the listed value (for natural gas).

If a meter is mounted in an installation that is separately pressurized, particular care has to be taken when subsequently pressurizing the pipework downstream of the metering installation. Preferably the downstream piping should be pressurized through a pipe sized according to the table.

It is often advocated to pressurize downstream pipework through a valve, by-passing the downstream valve of the metering installation, and with a diameter d_2 one fourth of the diameter of the downstream valve. This valve still has to be very carefully operated in order to prevent overspeeding of the meter.



d1 and d2 to be chosen according to table 1

Figure 7. Recommended way to pressurize installation

Table 1.

Maximum flow rate for by-pass of internal diameter d (P in bar)

d mm	m ³ /h
10	60.P
12	90.P
15	140.P
20	250.P
25	400.P

3.3 Pressure drop

The pressure drop over the meter is proportional to the gas density and the square of the flow rate.

Instromet specifies for each meter type the pressure drop for a gas with 0.6 relative density at atmospheric pressure and maximum flow rate.

For gases with different relative densities and at different pressures the pressure drop can be calculated from the following equation:

$$\Delta P_m = \Delta P_{\text{spec}} \cdot \left(\frac{d}{0.6} \right) \cdot \left(\frac{P_m}{P_{\text{atm}}} \right) \cdot \left(\frac{Q_m}{Q_{\text{max}}} \right)^2$$

In this equation the subscript "m" relates to the actual measuring conditions, ΔP is the pressure difference and Q the volumetric flow rate under operating conditions. Q_{max} is the maximum flow rate as given in the table and d is the relative density.

Example:

Natural gas of 0.64 relative density is measured at a pressure of 20 bar with a G1000 meter with specified maximum pressure drop of 2.5 mbar. The maximum flow rate is expected to be 1300 m³/h. The pressure drop under those conditions will be:

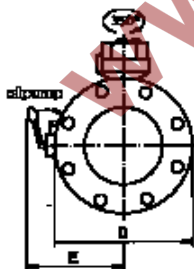
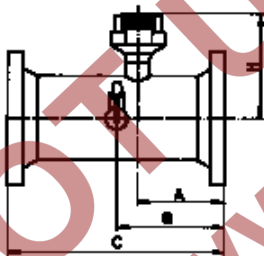
$$\Delta P_m = 2.5 \left(\frac{0.64}{0.6} \right) \cdot \left(\frac{20+1}{1} \right) \cdot \left(\frac{1300}{1600} \right)^2 = 3741$$

3.4 Physical size

Turbine meters are the most compact accurate gas meters presently available. The installation length also compares very favourable with other types of meters. The special built-in Instromet X4X straightener reduces required space to an absolute minimum. Dimensions for the Instromet SM-RI range are given in table 2.

Table 2.

Dimensions SM-RI



Size mm	G Rating	Dimensions in mm					
		A	B	C	D	E	H
50 (2")	40 65	60	-	150	AS PER FLANGE CLASS DIMENSION	-	235
80 (3")	100 160 250	96	-	240		-	205
100 (4")	160 250 400	120	130	300		210	218
150 (6")	400 650 1000	180	180	450		247	273
200 (8")	650 1000 1600	240	240	600		273	298
250 (10")	1000 1600 2500	300	360	750		327	314
300 (12")	1600 2500 4000	360	390	900		352	338
400 (16")	2500 4000 6500	480	510	1200		395	380
500 (20")	4000 6500 10000	600	630	1500		445	431
600 (24")	6500 10000 16000	720	750	1800		495	482

4. OUTPUTS

4.1 Mechanical outputs

Meters are normally provided with a mechanical index. Several models are available. All have in-line registers with clearly readable figures. Great attention has been paid to ensure reliability for exterior mounting. Special tropicalised versions are available. A special version is available for meters handling very cold gas (down to - 30 °C). This allows metering downstream of pressure regulating stations that do not have preheating, without the index icing up.

4.2 Electrical outputs

High frequency signals can be obtained from proximity sensors (Reprox probes) that sense either the passage of the blades or of a follower disc mounted on the shaft. These primary data are captured by specially developed high reliability probes that are accessible from the outside with the meter installed.

Table 3. Pulse data

Size in mm	G- rating	Q _{max} m ³ /h	m ³ /h	HF Index Hz at Q _{max}	Blades Turbine Rotor	HF Proximity Switch Hz at Q _{max}	Low frequency Pulses per m ³			
							1 pulse per rev.	2 pulses per rev.	5 pulses per rev.	10 pulses per rev.
50	40	65	0,1	140	12	1700**	10	20	50	100
2"	65	100	0,1	210	12	2600**	10	20	50	100
80	100	160	1	110	12	1300**	1	2	5	10
3"	160	250	1	160	12	2000**	1	2	5	10
	250	400	1	150	12	1800**	1	2	5	10
100	160	250	1	100	16	1100**	1	2	5	10
4"	250	400	1	160	16	1800**	1	2	5	10
	400	650	1	140	16	1600**	1	2	5	10
150	400	650	1	150	20	1200**	1	2	5	10
6"	650	1000	1	230	20	1800**+	1	2	5	10
	1000	1600	1	210	20	1700**	1	2	5	10
200	650	1000	10	50	20	770	0,1	0,2	0,5	1
8"	1000	1600	10	90	20	1200	0,1	0,2	0,5	1
	1600	2500	10	80	20	1100	0,1	0,2	0,5	1
250	1000	1600	10	90	24	825	0,1	0,2	0,5	1
10"	1600	2500	10	140	24	1300	0,1	0,2	0,5	1
	2500	4000	10	130	24	1200	0,1	0,2	0,5	1
300	1600	2500	10	50	24	810	0,1	0,2	0,5	1
12"	2500	4000	10	80	24	1300	0,1	0,2	0,5	1
	4000	6500	10	70	24	1200	0,1	0,2	0,5	1
400	2500	4000	10	160	24	680	0,1	0,2	0,5	1
16"	4000	6500	10	260	24	1100	0,1	0,2	0,5	1
	6500	10000	10	220	24	900	0,1	0,2	0,5	1
500	4000	6500	10	130	24	530	0,1	0,2	0,5	1
20"	6500	10000	10	210	24	900	0,1	0,2	0,5	1
	10000	16000	10	190	24	800	0,1	0,2	0,5	1
600	6500	10000	100	50	24	470	0,01	0,02	0,05	0,1
24"	10000	16000	100	80	24	700	0,01	0,02	0,05	0,1
	16000	25000	100	70	24	600	0,01	0,02	0,05	0,1

Frequency to current convertors, amplifiers and other equipment, matching the sensors can be supplied. Cenelec approved intrinsically safe electronic equipment and/or approved barriers can be provided.

APPENDIX 1

THE IDEAL TURBINE METER

The ideal turbine meter would have no retarding forces, infinitely thin rotor blades, total driving force concentrated at the mean blade radius and a uniform fluid velocity distribution entering the blades in an axial direction.

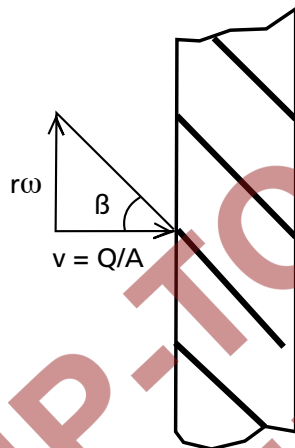


Figure 8. Velocity diagram for rotor radius (r) ideal case

From the blading diagram (Figure 8) it can be seen that for the ideal turbine meter, the rotational speed of the rotor would be:

1)

$$\omega = \frac{\tan \beta \cdot Q}{r \cdot A}, \text{ where:}$$

- r = the mean radius of the rotor
- A = the annular flow area
- β = the blade angle
- Q = the volume flow rate
- ω = the rotational speed of the rotor

Where $V = \frac{Q}{A}$

(V = the velocity of the gas)

for a given meter.

Equation (1) simply states that the rotor speed is directly proportional to the flow rate.

Thus by counting the number of revolutions of the rotor and scaling them for their apparent volume, the volume that has passed through the meter can be totaled. This characteristic is similar to a positive displacement meter.

REAL TURBINE METER

In the real turbine meter there is drag due to the mechanical friction of the bearings and gearing as well as fluid drag on the blades.

The ratio ω / ω_i would indicate the percent registration of the actual meter to the ideal meter. This percent registration can be equated to the ratio of the driving forces to the retarding forces.

$$2) \quad \frac{\omega}{\omega_i} = PR = 1 - \frac{M_r}{M_d}, \text{ where:}$$

PR = Percent registration
 M_r = Total retarding torque
 M_d = Available driving torque

The driving torque M_d is proportional to the kinetic energy of the fluid or:

$$3) \quad M_d \approx \rho \cdot Q^2$$

M_d = driving torque
 ρ = fluid density
 Q = volume flow rate

and the retarding torque M_R :

$$4) \quad M_R = M_f + M_n, \text{ where}$$

M_f = retarding torque due to mechanical forces
 M_n = retarding torque due to fluid forces.

Substituting in equation (2) yields:

5)

$$PR = 1 - \left[\frac{K(M_f + M_n)}{\rho Q^2} \right]$$

K = Constant

This equation simply states that for the meter to achieve its required accuracy, the retarding torques may represent only one or two percent of the available driving torque.

Since the driving torque is directly proportional to the fluid density, and the density of gas is very small at low pressure, the retarding torques in the meter must be kept as small as possible for good low pressure performance. It should be noted that the energy extracted from the fluid is the amount required to overcome the retarding torque, and at higher densities, the available energy is far greater than required. Further, the retarding torque must be small, or proportional to the driving force, to have linear relationship for the accuracy of the meter.

The turbine meter *minimum flow rate* is usually determined by a series of tests with air at low pressure to establish the flow rate at which the meter achieves acceptable registration. The minimum flow rate for any other set of conditions can be determined by equating the new conditions to the minimum conditions determined by test. Since the driving torque must be equal for both conditions, it can be expressed as follows:

6)

$$M_d = [\rho_{\text{air base}} Q_{\text{min air}}^2] = [\rho_m Q_{\text{min operating}}^2]$$

where $\rho_{\text{air base}}$ is the density of air at base conditions at which the minimum flow test was carried out, and ρ_m the density of the measured gas at operating conditions.

If we assume the temperature to be roughly constant, and the gas to behave in first approximation as an ideal gas, then we can write:

7)

$$\rho_m = d \frac{P_m}{P_b} \rho_{\text{air base}}$$

with P_m and P_b the absolute pressures at operating and base conditions respectively and d the relative density with respect to air.

Substitution of this leads to the earlier mentioned expression for the minimum flow rate under operating conditions:

8)

$$Q_{\text{min operating}} = Q_{\text{min air}} \sqrt{\left(\frac{P_{\text{atm}}}{P_m} \right) \cdot \left(\frac{1}{d} \right)}$$

APPENDIX 2

EQUATION OF MOTION FOR TURBINE METERS

The equation of motion for the rotor of a turbine meter can be approximated by:

$$\frac{df}{dt} = AQ (Q - f)$$

where f is the rotational speed of the rotor (normalised), Q the normalised flow rate and A a constant (Ref 2).

This is a first order system with a time constant $T = 1/AQ$, and the solution for a positive step ΔQ in the flow rate is:

$$f = Q - \Delta Q \exp(-tAQ)$$

with Q the value of the flow rate after the step has been applied.

The constant A is inversely proportional to the moment of inertia of the rotor and proportional to the line density of the fluid. For the time constant the inverse conditions hold. For zero flow rate, in vacuum, and in absence of

bearing friction, the time constant would be infinite, and a rotor would keep on spinning indefinitely. As soon as there is a flow rate, there is a finite time constant.

For most purposes, where friction forces can be neglected compared to hydrodynamic forces, the approximation lined out above suffices. Ref. 3, however, gives a more detailed analysis of the dynamics of the rotor.

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