

BS 7965:2013



BSI Standards Publication

Guide to the selection, installation, operation and calibration of diagonal path transit time ultrasonic flowmeters for industrial gas applications

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Contents

Foreword *ii*

1	Scope	1
2	Normative references	1
3	Symbols and abbreviations	2
4	Selection	3
5	Installation recommendations	14
6	Operational considerations	22
7	Ultrasonic flowmeter verification and calibration	35
8	Condition-based maintenance (CBM)	53

Annexes

Annex A (informative)	Application of flow calibration results	56
Annex B (informative)	Methods for correcting a USM's flow measurement error at flow calibration	59
Annex C (informative)	Thermowell installations in bi-directional flow installations incorporating flow-conditioners	66
Bibliography		67

List of figures

Figure 1	General ray geometry for transit time velocity measurement	4
Figure 2	Transducer designs	7
Figure 3	Variations in path configuration	8
Figure 4	Some typical cross-sectional acoustic path configurations	11
Figure 5	Performance specification summary for Class 1 meters	23
Figure 6	Performance specification summary for Class 2 meters	24
Figure 7	Performance specification summary for Class 3 meters	25
Figure 8	Performance specification summary for Class 4 meters	26
Figure B.1	Un-corrected and FWME-corrected flow calibration	62
Figure C.1	Bi-directional flow installation employing two USMs	66
Figure C.2	Bi-directional flow installation employing one USM	66

List of tables

Table 1	Symbols and abbreviations	2
Table 2	Class performance criteria – Meter requirements	12
Table 3	System uncertainties and applications – System requirements	13
Table 4	Common thermal expansion coefficients in the 0 to 100 °C range	27
Table 5	Calibration options and applications	36
Table 6	Internal diameter tolerance	36
Table 7	Tolerance for beam path length	37
Table 8	Minimum nominal test flow rates	43
Table 9	Spread or repeatability (max. error minus min. error) versus number of test points for a specified uncertainty in the mean	45
Table 10	Effects of number of readings	45
Table A.1	Sequential flow calibration results	58
Table B.1	Example flow calibration data table for 200 mm diameter USM	60
Table B.2	Flow weighted mean error calculation	61
Table B.3	FWME-corrected flow calibration data summary	61
Table B.4	Example results from a typical flow calibration	63
Table B.5	Example calibration results	64
Table B.6	Calculation of percentage flowrate	65

Summary of pages

This document comprises a front cover, an inside front cover, pages i to ii, pages 1 to 68, an inside back cover and a back cover.



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Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 October 2013. It was prepared by Subcommittee CPI/30/5, *Velocity based methods*, under the authority of Technical Committee CPI/30, *Measurement of fluid flow in closed conduits*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

This British Standard supersedes BS 7965:2009, which is withdrawn.

Information about this document

This is a full revision of the standard, and introduces the following principal changes:

- further division of meter sizes into large, medium and small to incorporate meter sizes with a nominal bore <4 inches;
- meters that are not standard in line meters, such as cartridge type meters;
- where appropriate, the standard is aligned with revisions made to other USM documents such as AGA Report No. 9 [1] and BS ISO 17089-1, taking account of results from research and development projects and end-user experience;
- updated in the light of research and user experience since 2009;
- includes a new section covering condition-based maintenance.

Hazard warnings

CAUTION: High gas velocities can cause flow-induced thermowell vibration, which could result in catastrophic metal fatigue failure of the thermowell.

CAUTION: The use of extractor tools to extract ultrasonic transducers without depressurization should only be undertaken by competent personnel.

Use of this document

As a guide, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification or a code of practice and claims of compliance cannot be made to it.

Presentational conventions

The guidance in this standard is presented in roman (i.e. upright) type. Any recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

1 Scope

This British Standard gives recommendations and guidance on the selection, installation, operation and calibration of transit time ultrasonic flowmeters (USMs) for industrial gas applications (including flare gas).

It is applicable only to those devices in which the entire gas stream flows through the body of the USM and the transducers (wetted or invasive type), or a wetted interface, are in contact with the fluid. This includes full-bore/reduced-bore and insertion type meters employing direct or reflective paths. It is also applicable to “dirty gases”, i.e. those contaminated with solids and/or liquids in sufficiently small quantities, depending upon the application.

It is not applicable to clamp-on/externally mounted, domestic or stack/chimney (combustion exhaust) meters.

As an aid to selection, this standard incorporates an uncertainty classification for USMs. This takes into account the components of uncertainty relating to the meter plus those additional uncertainties associated with installation and operation effects. There are four classifications offered. These range from high accuracy applications (Class 1) to process flow indication and control applications (Class 4).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

BS 7834, *Specification for turbine meters used for the measurement of gas flow in closed conduits*

BS EN ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

BS ISO 20765-1:2005, *Natural gas – Calculation of thermodynamic properties – Part 1: Gas phase properties for transmission and distribution applications*

BS ISO/TR 12765:1998, *Measurement of fluid flow in closed circuits – Methods using transit-time ultrasonic flowmeters*

Other publications

[N1] AMERICAN SOCIETY FOR TESTING AND MATERIALS. *ASTM E1002-11, Standard practice for leaks using ultrasonics, Book of Standard Volume 03.03.*¹⁾

¹⁾ Available from <<http://www.astm.org/Standard/index.shtml>> [last viewed 14 October 2013].

3 Symbols and abbreviations

For the purposes of this British Standard, the following symbols and abbreviations apply.

Table 1 Symbols and abbreviations

Symbol	Meaning	Units
A	cross-sectional area of meter body	m^2
C_f	speed of sound in a fluid	m/s
CI	confidence interval	—
d	diameter of meter spool	M
E_i	indicated flow rate error in percent	(%)
F	single calibration factor	—
f_r	frequency	Hz
f_i	variable weighting factor for i th velocity path	—
k_h	theoretical correction factor	—
k_r	uniform equivalent roughness	mm
K	meter factor typically the ratio of reference/meter flows	—
l	acoustic path length between two ultrasonic transducers	M
mA	current in milli-amps	mA
P	absolute static pressure of gas	bar
q_i	flow rate	m^3/s
$q_{\max}$	maximum volumetric flowrate of meter	m^3/s
$q_{\min}$	minimum volumetric flowrate of meter, as specified by the manufacturer, as being the flowrate below which the expanded error limit for the meter class is exceeded.	m^3/s
q_t	transitional volumetric flowrate where the specified performance of the meter changes	m^3/s
q_v	volumetric flow rate	m^3/s
R_a	arithmetic mean deviation of the (roughness) profile	μm
T	temperature of fluid	$^{\circ}\text{C}$
t_{ab}	transit time for ultrasound to travel from transducer a to transducer b	s
t_{ba}	transit time for ultrasound to travel from transducer b to transducer a	s
USM_{tol}	predetermined tolerance	%
Δt	$t_{ba} - t_{ab}$	s
$\bar{t}$	mean of t_{ab} and t_{ba}	s
τt	average transducer/electronic delay time.	s
v_i	averaged axial component of velocity along the path between two transducers	m/s
$\bar{v}$	mean pipe velocity	m/s
V	Voltage	V
w_i	constant weighting factor for i th velocity path	—
Wf_i	flow rate weighting factor	—
X	distance between transducers in the axial plane	m
Z	compressibility of fluid	—
θ	angle between the direction of ultrasound and the axis of the pipe	$^{\circ}$
a.c.	alternating current	A
d.c.	direct current	A

Table 1 Symbols and abbreviations

AGC	automatic gain control	—
CBM	Condition-based maintenance	—
CFD	Computational fluid dynamics	—
EU-ETS	European Union Emissions Trading Scheme	—
FWME	flow weighted mean error	—
LDA	Laser-Doppler Anemometry	—
MSOS	measured speed of sound	—
PTZ	pressure, temperature and compressibility	—
SOS	speed of sound	m/s
SNR	signal-to-noise ratio	—
SPU	signal processing unit	—
TSOS	theoretical speed of sound	—
USM	ultrasonic flowmeter	—
USMP	USM package, including meter, meter tubes, flow conditioner and thermowell	—
WME	weighted mean error	—

4 Selection

COMMENTARY ON CLAUSE 4

There are a number of USMs currently in service and under development. This clause aims to present a generic overview of the meters available and offer guidance as to their selection for specific applications.

4.1 Principles of measurement

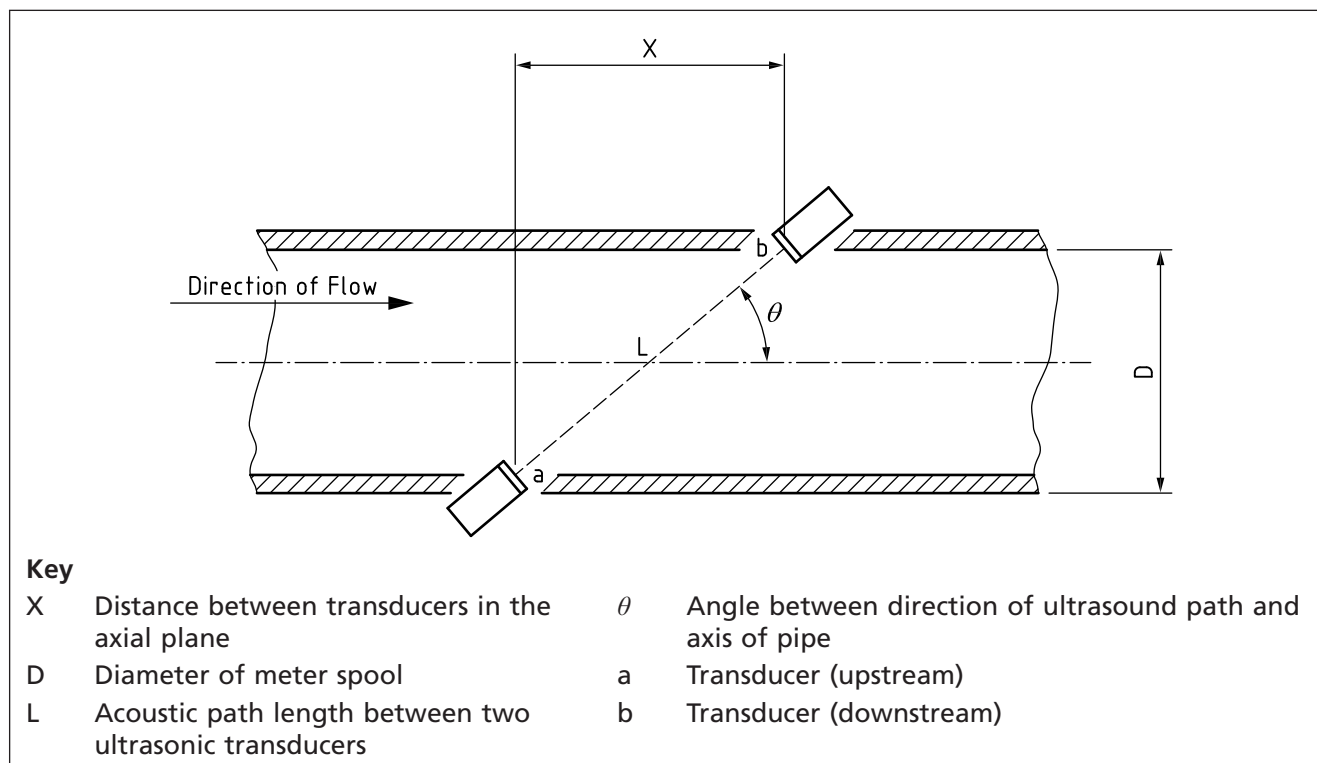
4.1.1 Gas velocity

USMs are based on the measurement of the propagation time of acoustic waves in a flowing medium. Generally, the assertion that the apparent velocity along a path is given by the speed of sound in the fluid at rest, C_f , plus the averaged axial component of fluid velocity along the path between the transducers, v_i , is applied. To eliminate the speed of sound from the subsequent derivation, transit times are determined both in the direction of flow and against it. Considering the general ray geometry shown in Figure 1, the upstream and downstream transit times are given by the following equations:

$$t_{ab} = \frac{L}{(C_f + v_i \cos \theta)} \quad (1)$$

$$t_{ba} = \frac{L}{(C_f - v_i \cos \theta)} \quad (2)$$

Figure 1 General ray geometry for transit time velocity measurement



There are four basic methods by which transit time velocity measurement can be performed: direct time differential, phase differential, phase control, and frequency differential as defined in BS ISO/TR 12765:1998, Clause 3 and Clause 5. In modern ultrasonic flowmeters the direct time differential method is most common. Short pulses are propagated upstream and downstream and the time interval for each excitation/detection is measured against an accurate high-frequency clock. In this case, the expressions for the upstream and downstream transit times are then solved for v_i as follows:

$$\frac{1}{t_{ab}} - \frac{1}{t_{ba}} = \frac{(C_f + v_i \cos \theta) - (C_f - v_i \cos \theta)}{L} \quad (3)$$

$$v_i = \frac{L}{2 \cos \theta} \times \left(\frac{1}{t_{ab}} - \frac{1}{t_{ba}} \right) = \frac{L}{2 \cos \theta} \times \frac{\Delta t}{t_{ab} t_{ba}} = \frac{L^2}{2X} \times \frac{\Delta t}{t_{ab} t_{ba}} \quad (4)$$

Where:

$$\cos \theta = X/L$$

To obtain the volumetric flow rate, q_v , individual velocity measurements are combined by a mathematical function to yield an estimate of the mean pipe velocity and multiplied by the cross-sectional area of the measurement section, A , as follows:

$$q_v = A \bar{v} \quad (5)$$

Where:

$$\bar{v} = f(v_1, \dots, v_n) \quad (6)$$

Where:

n is the total number of paths.

Even for a given number of paths, the exact form of

$$\bar{v} = f(v_1, \dots, v_n)$$

differs due to variations in path configuration and different proprietary approaches to solving Equation 6 (see 4.3).

4.1.2 Density/molecular weight

The dynamically measured average speed of sound, after correcting for pressure and temperature, or possibly some other disruptive variables, suffices to determine the molecular weight and density of the flowing medium.

An alternative indirect mass method is to enter a fixed static density into an ultrasonic flow meter that assumes a well defined and constant gas composition.

The dynamic function is often employed in flare gas mass flow measurement. The accuracy of density determination is generally stated by manufacturers as better than 2.0%; a value that can be improved upon if the composition of the flare gas is well defined and relatively constant. An example of a disruptive variable for a flare gas measurement is that of nitrogen as a non-hydrocarbon.

The determination of density from speed of sound measurement, in an ultrasonic flow meter, has been demonstrated as capable of matching traditional vibrating tube densitometers when employed on single component, ultra-pure fluids such as Ethylene.

Determination of molecular weight of flare gas may be employed in identifying specific flare gas sources in common flare gas headers such as in an oil refinery or petro-chemical complex. Specific molecular weights or changes from the average molecular weight can signal and help identify leakages into the flare gas stream from passing relief valve systems.

4.2 Factors affecting performance

The performance of a USM is dependent on a number of intrinsic and extrinsic factors.

Intrinsic factors (i.e. those related to the meter and its calibration, as applicable to the class of meter, prior to delivery) include the:

- geometry of the meter body and ultrasonic transducer locations and the uncertainty with which these are known;
- accuracy and quality of the transducers and electronic components used in the transit time measurement circuitry (e.g. the electronic clock stability);
- techniques used for transit time detection and computation of mean velocity (the latter of which determines the sensitivity of the meter to variations in the flow velocity distribution);
- calibration applicable to the class of meter (for static calibrations this includes proper compensation for signal delays in electronic components and transducers);
- thermal expansion coefficient of the meter body;
- pressure coefficient of the meter body.

Extrinsic factors (i.e. those related to the flow and environmental conditions of the application) include the:

- flow velocity profile;
- temperature distribution;
- flow pulsation;
- gas composition;

- noise (acoustic and electromagnetic);
- solid and liquid contamination;
- impurities in the gas.

4.3 Description of generic types

4.3.1 General

This subclause is a generic description of USMs for gases. It recognizes the scope for variation within commercial designs and the potential for new developments. For the purpose of description, ultrasonic meters are considered to consist of several components, namely:

- transducers, see 4.3.2;
- meter spool (and acoustic path configuration), see 4.3.3;
- electronics, data processing and presentation unit(s), see 6.5.

4.3.2 Transducers

Transducers can be supplied in various forms. Typically, they comprise a piezoelectric element with electrode connections and a supporting mechanical structure with which the process connection is made. The process connection can be welded, flanged or threaded, or can be more mechanically complex, for example, to allow removal of transducers from a pressurized line. When inserted in the line, the active element transmits ultrasonic waves at an angle to the meter spool axis in the direction of a second transducer or reflection point in the meter spool interior. The active element is usually isolated from the fluid by a mechanical barrier.

For specific applications, special transducers might be needed to cope with the conditions detailed below. These special transducers can differ from the norm in terms of frequency, construction materials and mechanical arrangement. Transducer specification and mounting should be given careful consideration for extreme or difficult application conditions, such as:

- high gas flow velocities;
- high, low and/or rapid cyclic temperature;
- high, low and/or rapid cyclic pressure;
- corrosion/erosion;
- wet or “dirty” gas;
- close proximity to high ultrasonic noise sources;
- the gas composition.

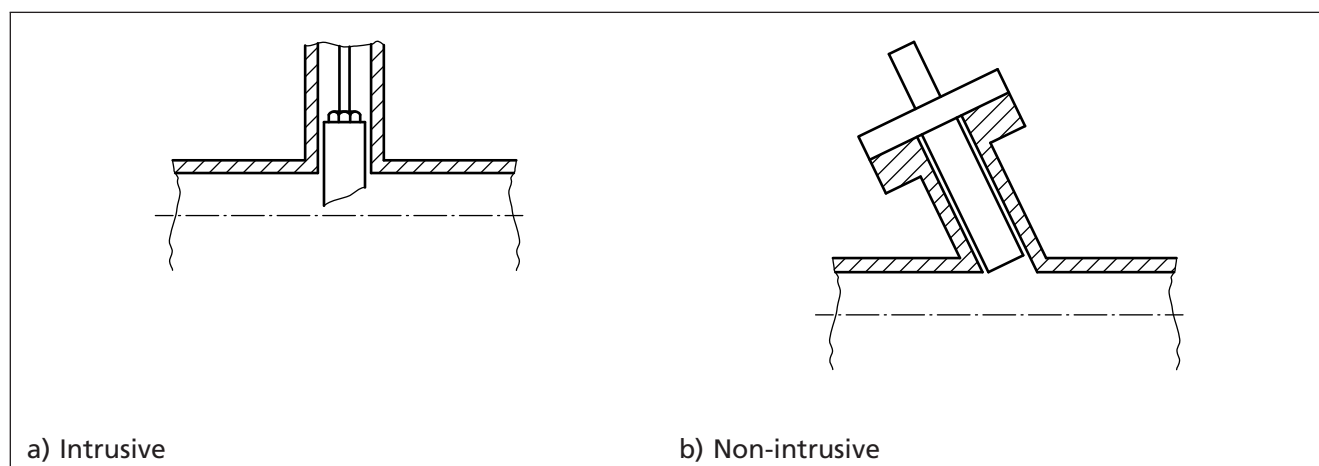
Two general examples of transducer design are depicted in Figure 2.

4.3.3 Meter spool and acoustic path configurations

4.3.3.1 General

The meter spool is a conduit comprising one or more pairs of ultrasonic transducers. An acoustic path is the transmission link between two transducers through the flowing fluid. USMs are available in a variety of path configurations. A particular configuration is generally chosen based on a requirement with respect to variations in velocity distribution and/or built in redundancy requirements.

Figure 2 Transducer designs



As well as variations in the location of the measurement paths in the cross-section, the path configuration can be varied in orientation to the pipe axis. By using reflection of the ultrasonic wave from the interior of the meter spool or from a fabricated reflector, the path can traverse the cross-section several times.

4.3.3.2 Elementary acoustic paths

Elementary acoustic paths are illustrated in Figure 3. The number of traverses and three-dimensional geometry of each traverse describe an arbitrary path.

Certain path configurations might offer reduced susceptibility to disturbed flow profiles. Claims for any such reduced susceptibility will need to have been demonstrated by the manufacturer with appropriate supporting test data.

In some specific applications the path length may be reduced, e.g. flare gas meters.

Figure 3 Variations in path configuration

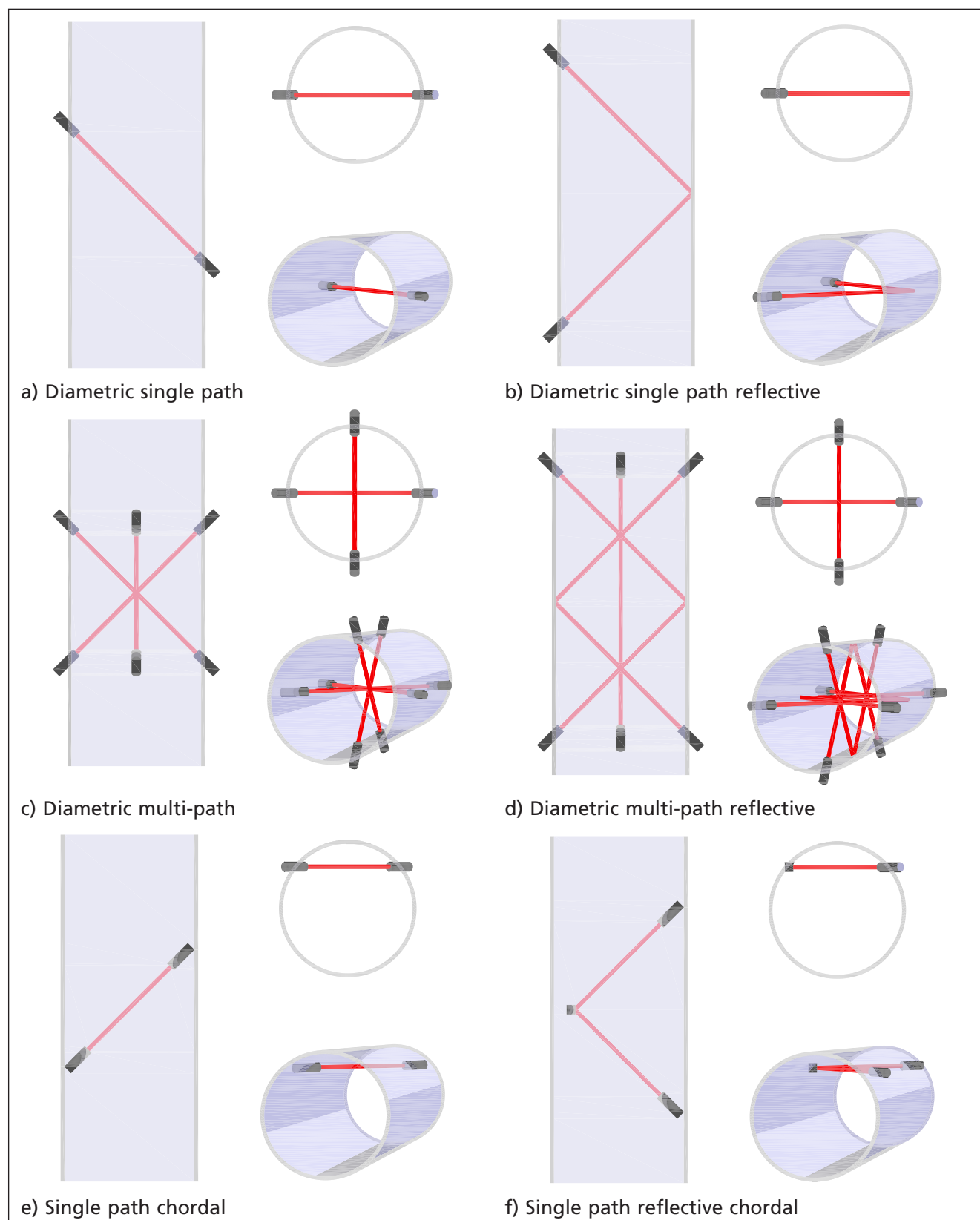


Figure 3 Variations in path configuration

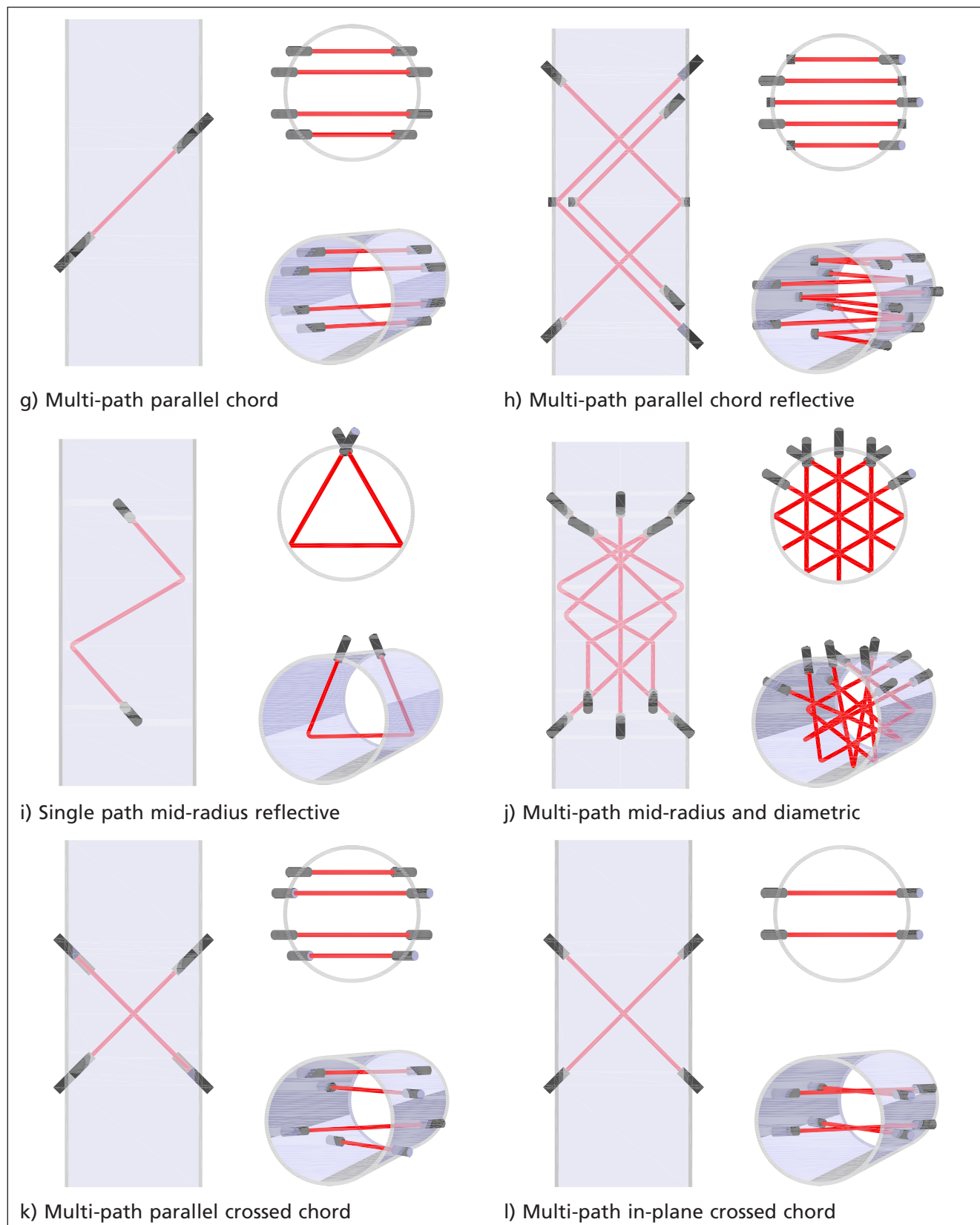
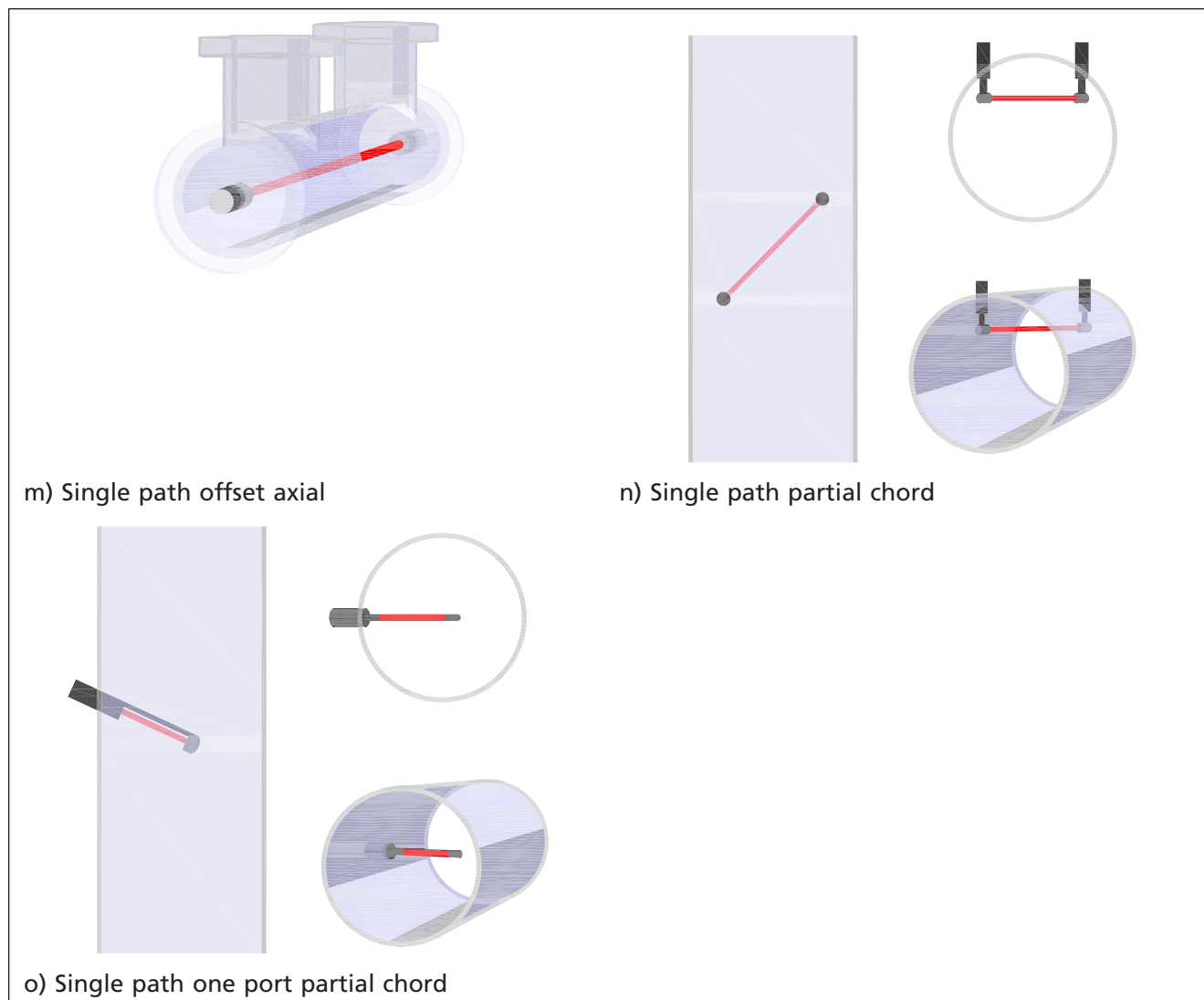


Figure 3 Variations in path configuration



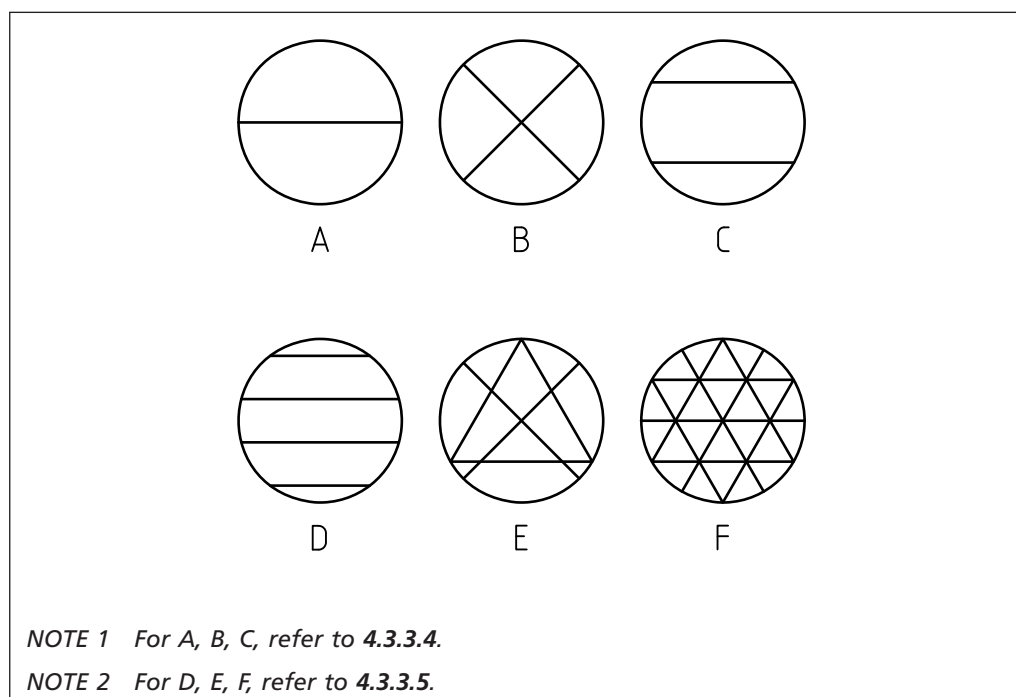
4.3.3.3 Common cross-sectional path configurations

The cross-sectional configuration is important as this dictates what information about the axial velocity distribution is available for computation of the mean axial velocity. A selection of commonly encountered cross-sectional configurations is shown in Figure 4. The actual configuration selected by the manufacturer for a specific meter type can incorporate paths of equal radial displacement, paths at multiple radial displacements or a combination of both.

4.3.3.4 Meters with paths of equal radial displacement

Meters with paths of equal radial displacement (e.g. configurations A, B, C in Figure 4) essentially make the same measurement with respect to velocity distribution if the flow is axisymmetric, regardless of the number of paths employed. For this reason, the mean velocity is usually determined by simple average. In fully developed flow a theoretical correction factor, k_h , can be introduced to account for the known variation in velocity profile.

Figure 4 Some typical cross-sectional acoustic path configurations



$$\bar{v} = k_h \frac{\sum_{i=1}^n v_i}{n} \quad (7)$$

Where:

n is the total number of paths.

The k_h factor is a function of Reynolds number, pipe roughness and radial displacement. In practice, it can be input as a single constant or can be calculated on the basis of static parameters and/or measured variables.

4.3.3.5 Meters with paths at multiple radial displacements

In the case of these meters (e.g. configurations D, E and F in Figure 4), the velocity is measured at different radial positions. Several methods can be used when combining the velocities to obtain the mean pipe velocity. These can be classified as follows.

- Summation with constant weighting:

$$\bar{v} = \sum_{i=1}^n w_i v_i \quad (8)$$

where the radial displacements of the paths and the constants w_i to w_n are determined on the basis of documented numerical integration methods.

- Summation with variable weighting:

$$\bar{v} = \sum_{i=1}^n f_i v_i \quad (9)$$

where the radial displacements of the paths are fixed at design and the variables f_i to f_n can be determined from input parameters and/or measured variables (e.g. velocities). To allow analysis of the sensitivity of this meter design to velocity profile, the function used to determine f_i should be obtained from the manufacturer.

In any of the given configurations, a multiplying or meter factor, K , (either constant or variable) can be applied after summation to correct for deviations due to manufacturing tolerances and/or incomplete assumptions (see Equation 10).

$$q_v = K A \bar{v} \quad (10)$$

4.4 Criteria for selection

The aim of this subclause is to look at the selection of a meter based on the overall uncertainty required for the measurement. This divides the meters available into (essentially) four classes of performance as outlined in Table 2.

Table 2 Class performance criteria – Meter requirements

Class	Total USM uncertainty (actual volume flow) %	Repeatability %	Reproducibility %	Resolution mm/s	Error limit (plus or minus) (q_t to q_{max})		
					Large meters	Medium meters	Small meters
					%	%	%
1	<±0.7	<±0.20	<±0.30	<1	0.7	1.0	2.0
2	<±1.5	<±0.25	<±0.60	<2	1.0	1.5	3.0
3	<±3.0	<±0.35	<±0.90	<4	1.5	2.0	4.5
Error limit (plus or minus) (q_{min} to q_{max})							
4	<±7.5	<±1.0	<±1.20	<10	5.0	5.0	7.0

NOTE 1 Large meters are defined as meters with nominal bores equal to or greater than 300 mm (12 inches). Medium meters are defined as meters with a nominal bore below 300 mm (12 inches) but greater than 100 mm (4 inches). Small meters are defined to have a nominal bore equal to or less than 100 mm (4 inches).

NOTE 2 Repeatability is defined as the closeness of agreement between successive flow rate measurements with the same flow meter when obtained under the same conditions (same fluid, same flow meter, same operator, same test facility and a short interval of time) and without disconnecting or dismantling the flow meter.

NOTE 3 Reproducibility is defined as the closeness of agreement between successive flow rate measurements with the same flow meter when obtained under any differing conditions (different fluid, different operator, different test facility) or disconnecting or dismantling and subsequent reinstalling of the flow meter.

Actual meter performance, inclusive of total meter uncertainty, repeatability, resolution and maximum peak-to-peak error, depends upon a number of factors which include:

- pipe internal diameter;
- acoustic path length;
- number of acoustic paths;
- gas composition/speed of sound;

- meter timing repeatability (itself a function of transducer frequency); and
- actual flow velocity.

NOTE 1 See also 4.2 and 4.3.2.

Class 3 and Class 4 meters are often retro-fitted to existing process plant where flow rates are uncertain and sometimes unknown, where piping geometry does not support a fully developed velocity profile, where meter spools are not third-party calibrated or indeed the transducer ports are welded to the parent-pipe section on site and the transducers inserted through hot-tap methods. The user should provide the manufacturer with comprehensive process data and consult with them to assess actual meter performance versus required meter uncertainty for a given application (see Table 3).

Table 3 System uncertainties and applications – System requirements

Class	Typical system uncertainty %	Maximum installation effect %	Typical applications
1	<±1.0	0.3	Custody transfer
2	<±2.0	0.5	Allocation
3	<±4.0	1.0	Utilities/fuel gas
4	<±10	5.0	Process/flare gas

The four classes represent different measurement specifications commonly applied in UK industry. Depending on the importance of measurement with respect to regulatory or fiscal demands, the total uncertainty budget for the system is different, as outlined within Table 3. To aid meter selection, an approximate uncertainty budget for the meter is suggested in order to meet the system uncertainty budget. Typical uncertainty values from recognized gas flow calibration establishments are in the order of ±0.3%. For Class 1 and 2 meters, this is a significant part of the total value for the USM uncertainty.

NOTE 2 These applications are for guidance only, with each application to be considered on its own merits. Attention is drawn to the European Union Emissions Trading Scheme (EU-ETS).

NOTE 3 See Annex A for the application of flow calibration results and Annex B for methods of correcting flow measurement error.

The difference between the uncertainty figures of the meter and the system indicates the uncertainty budget permitted in determining additional uncertainties associated with the metering process, e.g. secondary instrumentation, derivation of density and flow computers. For example, the composition, pressure and temperature of a gas might result in an uncertainty value for the derivation of density that causes the budget available for the system to be exceeded. For these reasons it is important that this aspect is not neglected. For natural gas, BS EN ISO 12213-1 and BS EN ISO 12213-2 should be consulted for guidance on the derivation of density and uncertainty.

When identifying a meter for a particular purpose, it is important to have access to the information in Table 2 and Table 3. In respect of Table 2, this information should be obtained from the meter manufacturer and it is recommended that the actual test data regarding the meter performance is reviewed when purchasing for the first time or from a new supplier or manufacturer.

Other criteria for selection can be determined by regulatory or statutory bodies, such as the Department of Energy and Climate Change (DECC) Energy Group: Energy Development Unit, and also by agreements between companies for custody transfer/allocation metering. The accuracy of measurement in the event of a path failure is important in many custody transfer applications. For most other forms of flowmeter a major failure in the measurement process would lead to a complete shutdown while the meter is replaced. In the event of a path failure with USMs, it is possible for some meters to substitute values in place of the failed path measurements from knowledge of the velocity profile present in the meter prior to the failure. For Class 1 meters, the additional error owing to a path failure under stable flowing conditions is expected to be less than 0.1%.

5 Installation recommendations

5.1 General

The guidance in this clause has been derived from comparable meter standards, good engineering practice and experience gained to date in the testing of these meters. Installation criteria should be considered in conjunction with specific recommendations from outside agencies such as the meter manufacturers, the statutory authorities and other interested parties.

5.2 Environmental considerations

5.2.1 Temperature

Some USMs might be sensitive to differences between ambient and line temperature and adequate insulation, heating and/or cooling should be installed in order to minimize the effects of extreme differences between ambient and line temperature.

The meter should be able to operate within specification within an ambient air temperature range of -25°C to 55°C . This temperature range applies to the meter body with and without gas flow, field mounted electronics, ultrasonic transducers, cabling, etc. The manufacturer should be asked for ambient temperature specifications for the USMs if different from -25°C to 55°C .

For Class 1 and Class 2 applications, where optimum accuracy is required or the gas temperature varies from the ambient temperature, the meter spool and the meter tube assembly, including the upstream and downstream pipework, should be fully insulated. This insulation should extend up to and include the thermowell housing of the temperature element and also any intermediate flanges and fittings.

Sudden large changes in temperature caused, for example, by compressor start-up or close proximity to a flare stack should be avoided. It is also important to insulate the meter spool when there is a deep cavity between the inner pipewall and the transducer fronts.

5.2.2 Vibration

The manufacturer should be consulted regarding the performance of the meter in a vibrating environment as there is a potential for measurement error. It is recommended that measures are taken to isolate sensitive equipment from the vibration source, such as the provision of anti-vibration mountings.

5.2.3 Electrical noise

Good wiring practice should be implemented to minimize the effect of electrical noise.

NOTE Attention is drawn to EMC-RF obligations for equipment used within the EU, some of which might be met by conformity to BS EN 61000-6-3 and BS EN 61000-6-4.

The meter and associated electrical conduits, cables and circuits should be designed and installed in accordance with applicable electrical codes and particular care should be taken with the type of screening and routing of interconnecting cable installed between the transducers and the control unit.

5.2.4 Mechanical noise

COMMENTARY ON 5.2.4

Additional information on gas control valve interference with gas USMs is available in TUV NEL Guidance Note [2].

Some installations, including, for example, pressure reducing control valves, which are specifically designed to reduce audible noise, can produce very high levels of ultrasonic noise under certain flow conditions. The ultrasonic noise from these control valves can interfere with the operation of a nearby ultrasonic flowmeter even when the valve is located downstream of the USM. The manufacturer should be consulted when planning to install a USM in the vicinity of a pressure-reducing component including control valves, reducers, etc.

If acoustic noise is considered to be a potential problem for the USM in service, a means should be provided to monitor its impact on the meter using the signal-to-noise ratio (SNR); an alarm facility might be needed to advise the operator when the ratio exceeds an acceptable level.

In general, it is good practice to locate control valves, compressors, etc. downstream of the USM. If this is not possible, then the maximum distance between the control valve and the USM should be targeted. Blind tees, baffles and other such fittings, which provide high attenuation, should be fitted between any source of noise and the USM. This precaution should be taken for both downstream and upstream sources of noise. These devices should be fitted at the maximum distance from the USM that the pipework allows, given that some of them can and will produce distorted velocity profiles.

USM manufacturers recognize the potential for operating problems, and most USMs have diagnostic capabilities that indicate whether acoustic noise impairs meter performance while operating. Strategies have also been devised by users and manufacturers to estimate and/or limit a USM's susceptibility to noise interference, such as:

- evaluation of the USM's response to acoustic noise prior to station installation;
- enhanced signal processing to improve ultrasonic pulse recognition and detection;
- signal filtering to narrow the bandwidth surveyed for better/faster pulse recognition;
- installation of fittings, such as blind tees or filters, to isolate the noise source from the USM;
- development of specialized silencers that are installed in the piping between the USM and the noise source to isolate the meter from the noise.

In general, noise sources upstream of USMs have a more adverse impact on meter performance than those installed downstream, although downstream installation of pressure reduction or other noise generating equipment does not guarantee interference will not occur. Also, greater separation between a noise source and the USM and the consequent increased number of fittings provides more attenuation than would be the case if the meter and source were installed in close proximity to each other.

When considering installation of a USM, particularly in the vicinity of pressure or flow regulation (the most common noise generators), the factors that should be taken into account during the USM station design phase are:

- the installed position of valves (as potential noise sources) relative to the meter (upstream, downstream, distance between meter and source, number and type of fittings between meter and source);
- the operating frequency of the meter and the range of frequencies generated by the noise source (noise reduction trim valves are of particular concern since the design generates noise exceeding audible frequencies which is often in the ultrasonic range);
- whether additional attenuation between noise source and USM is required, which could include blind tees or other fittings or acoustic filters;
- whether enhanced filtering of digital signal processing has to be applied and, if so, whether it slows signal processing time beyond acceptable limits (limits are given for a linear measuring device in the *API Manual of Petroleum Measurement Standards* (MPMS), Chapter 21.1 [3]);
- the cost/benefit of pursuing one or more strategies to limit USM exposure to offending acoustic noise.

When installation of a USM near a potential noise source is anticipated, the manufacturer should be contacted for recommendations specific to their products and the proposed installation prior to finalizing USM station design. Cooperation between specifiers/users and manufacturers during the design of the facilities can avoid the need for potentially expensive remedial actions at a completed meter installation.

Further guidance can be found in ISO 17089-2:2012, Annex A.

5.2.5 Gas composition restrictions

The presence of certain gases might impact on the performance of a meter (for example, high levels of carbon dioxide and hydrogen in a gas mixture can influence and even inhibit the operation of a USM owing to their acoustic absorption properties). Meter manufacturers should be supplied with the expected constituents of the gases to be measured and the associated pressure and temperature range.

5.3 Installation conditions

5.3.1 Flow direction

Where the flow is in one direction only, this should be clearly marked on the body of the meter. For bi-directional applications, both ends of the USM should be considered upstream and the markings attached to the meter spool should clearly indicate the primary flow direction.

NOTE For example, plates might be affixed to the meter as a means of marking.

5.3.2 Upstream and downstream fittings

COMMENTARY ON 5.3.2

Various combinations of upstream fittings (valves, bends, expanders, tees, reducers, etc.) might produce velocity profile distortions and swirl at the inlet to the USM that could result in measurement errors. The magnitude of error is dependent on the type and severity of the flow distortion and the ability of the USM to compensate for this distortion. To a much lesser extent, downstream fittings could also affect the accuracy of the meter.

The manufacturer should be consulted to evaluate how upstream and/or downstream fittings and piping configurations can affect the performance of the USM. In the absence of performance data for a specific installation, and where a Class 1 or Class 2 meter is involved, it might be necessary to use a flow-conditioner and calibrate the USM and flow conditioner together (see 5.3.3). Alternatively, it might be necessary to model the system by experimental means in order to determine its impact on the USM.

The general configuration of the pipework upstream of the meter tube assembly and the self-compensating features associated with the USM should be taken into account when assessing the potential impact of pipe geometry on the velocity profile of the gas. For Class 1 applications, the meters should only be installed where the impact of fittings and pipework configurations does not have a detectable effect on the performance of the meter. In all circumstances, the pipework should be designed so that swirl or poor velocity profiles that affect the installed uncertainty of the meter reading are not produced, i.e. that these effects are within the manufacturer's stated limits for the meter; this might be verifiable at site by on-board diagnostics in certain multi-path USMs.

The user can either verify the USM in-situ or remove the meter to a flow calibration facility in which the test piping configuration is representative of the planned installation. Alternatively, for Class 1 and Class 2 USMs, the manufacturer should be requested to do one of the following as desired by the user.

- a) Recommend at least one upstream and downstream piping configuration, without a flow conditioner, and one configuration with a flow conditioner that will not create an additional flow rate measurement error of more than $\pm 0.3\%$ due to the installation configuration. This error limit should apply for any gas flow rate between $q_{\min}$ and $q_{\max}$; this recommendation should be supported by test data.
- b) Specify the maximum allowable flow disturbance (e.g. the limits on swirl angle, velocity profile asymmetry, turbulence intensity) at the meter's upstream flange, or at some specified axial distance upstream of the meter, that avoids creating an additional flow rate measurement error of more than $\pm 0.3\%$ due to the installation configuration. This error limit should apply for any gas flow rate between $q_{\min}$ and $q_{\max}$; this recommendation should be supported by test data.

NOTE Asymmetric velocity profiles can persist for 50 pipe diameters or more downstream from the point of initiation. Swirling velocity profiles can persist for 200 pipe diameters or more. A flow conditioner properly installed upstream of a USM can help shorten the length of straight pipe required to eliminate the effects of an upstream flow disturbance. Some types of USM can compensate for some levels of flow profile disturbance.

USMs are sensitive to flow profile disturbances, for example those created by out-of-plane bends (often causing swirl) and those created by in-plane bends (often causing asymmetry). It is recommended that the upstream straight lengths be as long as possible; multi-path USMs are less sensitive to upstream flow disturbances than those with fewer diagonal path. Also, the use of a flow conditioner, if calibrated with the USM, allows a reduction in the required upstream straight length (see 5.3.3).

5.3.3 Flow conditioners

One of the major benefits of USMs is the lack of pressure drop due to the unrestricted pipe area available with many USM designs and the ability to reduce the system uncertainty by reproducing calibration conditions.

Flow conditioners might or might not be necessary depending on the manufacturer's meter design and the severity of any upstream flow profile disturbance. The manufacturer should be consulted with to determine the selection and location of flow conditioners with attention being given to the upstream piping configuration.

Where flow conditioners are recommended by the manufacturer, conditioners should be selected that do not generate ultrasonic noise, which can be the case with some perforated plate devices. For Class 1 and Class 2 meters, the installation of flow conditioners should be in the same location and orientation as when the USM package (USMP)/USM flow conditioner combination was calibrated; this needs dowels or other means of mechanical location to ensure the conditioner is correctly installed. The formation of hydrates should also be prevented.

NOTE This might be prevented by good process control and/or the use of a hydrate inhibitor.

Provision for inspection of the flow conditioner, for a build-up of debris and/or particulate contamination, should be ensured; this can be in the form of an inspection port. Where only one inspection port is provided, this should be on the upstream side of the flow conditioner.

The inspection port should be sized and positioned to enable a boroscope to be inserted into the line and the whole of the flow conditioner viewed.

5.3.4 Meter orientation

The manufacturer should be asked whether there is a preferred meter orientation for the given upstream piping configurations and operation conditions which are known to produce flow profile distortions. Consultation should also include the preferred orientation to avoid liquid accumulation if this is a potential hazard. For Class 1 and Class 2 meters and any meters requiring flow calibration, the orientation of the meter during calibration should be the same as during site installation.

5.4 USM spool and meter tube assembly

5.4.1 Protrusions and circularity

Changes in the internal diameters and protrusions at the inlet to the USM spool should be avoided as local disturbances to the velocity profile might be created. For Class 1 and Class 2 meters, mechanical means of alignment should be used, especially on smaller meters (<254 mm).

For Class 1 or Class 2 meters, the USM bore, flanges and adjacent upstream pipe section should all have the same internal bore to within 1.0% of the mean over the minimum recommended upstream section of the meter tube assembly.

For meters that are not of an in-line design, and where the step change limit of 1.0% is exceeded, the manufacturer should be asked to demonstrate that the meter meets its required uncertainty criteria.

The internal mean bore, D , should be the arithmetic mean of at least twelve measured diameters, namely four diameters positioned at approximately equal angles to each other, distributed in each of at least three cross-sections evenly distributed over a length corresponding to the measured bore of the USM. This should also be the case for the upstream pipe section to a minimum of $20D$. Where flow conditioners are installed, this should apply to the length downstream of the conditioner and, in addition, a length upstream of the conditioner in accordance with the manufacturer's recommendation. In the event of not using flow conditioners, if the upstream length is less than $20D$, an analysis of the impact of fluid hydraulics should be undertaken.

The USM and meter tube piping should ideally be installed in a region of zero stress in the pipeline, so as to minimize strain on the meter. For meters having a bore diameter different from the meter tube, a maximum transition taper should be 8° outside of the measurement section. The upstream pipework should be carefully aligned to minimize flow disturbances, especially at the upstream flange of the meter. For optimum accuracy the actual step caused by misalignment and/or change in diameter should not exceed 1.0% at any point in the internal circumference of the pipe. Therefore, mating flanges need the bores to be matched and the flanges aligned on installation. All internal welds should be checked to see that they have been machined flush and no part of the upstream flange or gasket protrudes.

If liquids are to be encountered, then the USM should be sloped in the direction of flow to allow draining of the meter. It is also recommended that care should be taken that the meter is not placed in such a position that the transducer ports collect liquid. If the design of the USM is such that the transducer ports could potentially collect liquid, the design of the transducers should be such that any accumulated liquid does not impact upon or adversely affect the USM performance. If possible, areas of the pipework used for ultrasonic path reflection should be kept free of liquid accumulation. There should not be steps at the flange connections that allow liquids to collect.

In respect of the downstream section, the step in adjacent pipe sections up to 3D from the meter should be limited to 1.0% (visual inspection is normally sufficient to determine the circularity of the downstream cross-section). The upstream and downstream flange internal weld bead should be ground smooth to ensure that the diameter is within the piping tolerance.

Experience with Class 1 meters has shown that diameter steps between the upstream pipe and the meter cause metering errors of the order of 0.05% systematic error per 1% diameter step; an error that can be reduced by chamfering as long as the angle of inclination is less than 7°.

Thermowells, located as described in 5.4.5, are excluded from the above protrusion limits.

If gaskets or sealing rings are used, they should be fabricated and installed in such a way that they do not protrude at any point inside the meter tube assembly by more than 1.0% of the mean bore, i.e. over the minimum recommended upstream straight pipe section (20D) of the meter tube assembly and at the downstream meter flanges.

NOTE During the installation of bolted flanges, three or more insulating flange bolt sleeves can be used at the 4, 8 and 12 o'clock positions to keep the gasket centred while tightening the nuts.

5.4.2 Internal surface

The interior of the meter and meter tube assembly should be clean at all times, as even a thin coating of contaminant can be sufficient to alter the surface roughness without significantly altering the internal cross-sectional area of the meter; however, changes in pipe surface roughness, in turn, can cause changes in the velocity profile.

To maintain accuracy, the meter bore should have a surface roughness, R_a , such that:

$$k_r/D \leq 10^{-4} \quad (11)$$

where:

k_r (the pipe wall uniform equivalent roughness) is approximately equal to $R_a \times \pi$, examples of which can be found in BS EN ISO 5167-1:2003, Annex B.