

FISCAL FLOW MEASUREMENT OF NATURAL GAS

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DESIGN AND ENGINEERING PRACTICE



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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for measuring, with the highest accuracy class, volume flow, mass flow and energy flow of natural gas. The typical field of application of this DEP concerns Custody Transfer and Sales measurements for onshore and offshore applications, requiring uncertainties of not more than 1 %.

The DEP specifies the requirements of flow measurement stations and gives recommendations for their selection, design, installation, validation and maintenance, with the purpose of achieving a consistent and cost-effective approach and realising contractually agreed availability and uncertainty levels.

The word "fiscal" in context of this DEP has been expanded from its original meaning of "pertaining to government finance" to "pertaining to income and revenues of parties concerned, including government taxation". However, as an example wet gas measurements and gas allocation measurements, which both could have fiscal duties, are excluded because they usually fall in different accuracy classes, if only due to their inability to comply with the strict conditions specified in this DEP.

NOTE: Allocation measurement via wet gas or multi-phase flow measurement demands an approach that takes specific account of flow conditions, as discussed in separate documents or standards. For allocation measurement, the Principal shall be contacted.

This DEP covers four types of meter: multi-path ultrasonic, orifice, turbine and Coriolis meters. The legal status of each type is different and this may affect the choice of the meter.

This is a revision of the DEP of the same number dated December 1999; see (1.6) regarding the changes.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them.

This DEP is intended for use in natural gas facilities.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party, which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project, or operation or maintenance of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party, which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party, which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions

- Black and white list** A contract document providing:
- measurement and analysis methods and standards, data transfer, etc. generally agreed by contract parties for use in fiscal flow measurement (white list);
 - measurement and analysis methods and standards, data transfer, etc. to be agreed by contract parties for application in fiscal flow measurement on a case-by-case basis (black list).

1.4 GLOSSARY OF TERMS AND THEIR ABBREVIATIONS

1.4.1 General terms

Automatic Gain Control	AGC	A mechanism in the electronic control unit of an ultrasonic flow meter that automatically adjusts the amplification of the received transducer signals to a specific level.
Autonomy Time		The specified time of a UPS that the battery shall be capable of supplying rated current to the load within the specified voltage limits.
Availability		The relative time that a system performs its assigned duty. Unavailability is complementary to availability.
Coriolis meter		Device consisting of a flow sensor (primary device) and a transmitter (secondary device) which primarily measures the mass flow by means of the interaction between a flowing fluid and the oscillation of a tube or tubes; it may also provide measurements of the density of the fluid (ISO 10790).
Data Acquisition and Control Architecture	DACA	The standard architecture used to enable process control, monitoring and optimisation of assets, through secure and reliable networks, systems and applications
Fiscal		Concerned with income and revenues of parties concerned including government taxation. NOTES: 1. This is an expansion of the DTI definition: "Concerned with government finance" and is inclusive of aspects concerning Custody Transfer and Sales. 2. Analytical and availability performance of the various categories of measurements covered by this DEP are not necessarily identical. Requirements follow from project specifications.
Fiscal (...) measurement		A measurement yielding fiscal data (<i>of specified parameter</i>). E.g.: fiscal <i>flow</i> measurement NOTE: This is an expansion of the DTI definition: "A system, or element of that system, that is used to determine production rates that will ultimately generate revenue for the Government".
Fiscal data		Data relating to income and revenues of parties concerned including government taxation.
Fiscal Measurement Network		A data network that interconnects various components of the fiscal measurement system. (without reference) NOTE: The fiscal measurement network is typically a TCP/ IP Ethernet and is often a vendor proprietary system.
Fiscalisation		The process of producing and accruing fiscal data from fiscal measurement(s).

Flow computer		Element of the flow measurement that performs the flow computation and flow integration. NOTE: A flow computer is a secondary instrument and is usually a fiscal element in the measurement system.
(...) Measurement station		The station or plant that performs measurement (<i>of specified property or properties</i>). (without reference) E.g.: <i>Fiscal flow measurement station</i>
(...) Measurement system		A complete set of measuring instruments and other equipment assembled to carry out a (<i>specified measurement task</i>) (BS 5233). E.g.: <i>Flow measurement system</i>
Metrological tapping		Process connection used for measurement.
Multipath		Method of flow rate measurement in which the average fluid velocity over a number of different paths is determined (ISO/TR 12675).
On-line Process Gas Chromatograph	PGC	Usually a liquid-gas chromatograph that has been designed to operate continuously without human intervention. Its principal task is to split a subjected sample into its constituents and to measure and report them as a fraction of mass or volume. (without reference) NOTE: Human intervention should only be required for maintenance and performance retention of the equipment.
Orifice meter		Method of flow rate measurement based on the pressure difference over an orifice plate, which is generated by the flowing fluid.
Pressure reference tap	Pr point	A metrological tapping on the body of turbine or ultrasonic meters for the measurement of the pressure relevant for the determination of the operating density (also Pm point). (without reference)
Primary device		Device, which generates a signal enabling the determination of the flow-rate. (ISO 4006) NOTE: A primary device is an instrument.
Process Control Network	PCN	A data network system that interconnects various instrumentation systems for the purpose of process control and process automation. (DACA) NOTES: 1. It is also connected to the Process Control Access Domain, which enables communication with the Office Domain. 2. The process control network is an element of the data acquisition and control architecture.
Recording device		A printer or electronic device that logs one or more outputs from the flow computer and / or from the supervisory computer. NOTES: 1. The data typically concerns fiscal amounts but also data that is legally required. 2. A (fiscal) recording device is typically the non-volatile memory of the flow computer including its display or an equivalent electronic device or a conventional (ticket) printer.
Redundancy		Duplication of functionality.

Secondary instrument	Any other instrument than a primary device that is required for obtaining volume flow or mass flow or energy flow under specified conditions. NOTE: ISO 4006 defines a secondary device as: "Device, which receives from the primary device a signal and displays, records, transforms and/or transmits it in order to obtain the value of the flow rate ". This definition is too limited to be of use in this DEP.
Supervisory computer	A digital computer that processes the data from one or more flow computers for producing reports and executing the connection with the process control network. (without reference) NOTE: A supervisory computer is a secondary instrument and is usually not a fiscal element in the measurement system.
Transit time (time-of-flight) difference method (in short: "transit time")	Method of flow rate measurement in which the average fluid velocity along the acoustic path is determined from the transit-time difference of two ultrasonic signals, one travelling upstream and one downstream, over the same distance in the flowing fluid (ISO/TR 12675).
Turbine meter	A fluid measuring device in which the dynamic forces of the flowing fluid cause the turbine wheel to rotate with a speed approximately proportional to the rate of volume flow (ISO 9951).
Turndown ratio (...)	The quotient of the maximum and minimum result (<i>of a specified property</i>) that can be achieved with retention of specified characteristics. NOTE: For example, the turndown ratio in <i>flow</i> should obey the specified uncertainty of the measurement station.
Ultrasonic flow meter	Flow meter which generates ultrasonic signals and receives them again after they have been influenced by the flow in such a way that the observed result can be used as a measure of the flow rate (ISO/TR 12675).
Uninterruptible Power Supply	UPS Secure source of power for vital systems.

1.4.2 Terms concerning accuracy performance

Adjustment	The operation intended to bring a measuring instrument or a measurement system into a state of performance and freedom from bias suitable for its use.
Average Run Length	ARL The average number of times that a process will have been sampled and evaluated before a shift in process level is signalled. (ISO 3534-2) NOTE: The ARL is a Control Chart property and is a function of the significance level of testing and the magnitude of the error.
Calibration	The set of operations which establishes, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, or values represented by a material measure, and the corresponding known values of a measured quantity (measurand) (BS 5233). NOTE: In various Shell DEPs the term validation is often used with the same meaning as the above definition whilst calibration is often used with the same meaning as Adjustment as defined above. This DEP will use the terms Calibration and Adjustment in strict compliance with the definitions herein, i.e. in compliance with BS 5233.

Chance Causes	The causes of variability, which are common to the natural variations of the process ("Fundamentals of Quality Control and Improvement", A. Mitra).
Control Chart	A chart, with upper and/or lower control limits, on which values of some statistical measure for a series of samples or sub-groups are plotted, usually in time or sample number order. The chart frequently shows a central line to assist detection of a trend of plotted values toward either control limit (ISO 3534-2). NOTE: A control chart is used to investigate if a process can be considered to be under control.
Control Limit CL	The error limit which, if exceeded, justifies immediate action in order to regain Statistical Control. NOTES: 1. The limit relates usually to the 99.7 % confidence level. 2. At the control limits or beyond, i.e. outside the interval between the upper and lower control limits, immediate corrective action is required in order to recover from out-of-control conditions and to limit their effects.
Error	The result of a measurement minus the (conventional) true value of the measurand (BS 5233).
Measurand	A quantity subjected to measurement (BS 5233).
Measurement result	The value of a measured quantity (BS 5233).
Measurement Standard	A material measure, measuring instrument, reference material or measuring system intended to define, realize, conserve or reproduce a unit or one or more values of a quantity in order to transmit them to other measuring instruments by comparison (to serve as a reference) (BS 5233). NOTE: In the context of this DEP, Measurement Standards refer to calibration equipment and reference material.
Overall uncertainty (of a measurement)	The combined uncertainty of measurement when that result is obtained from the values of a number of other quantities. NOTE: This definition is a modified version of that in ISO 5168: "The combined standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities". Standard uncertainty in ISO 5168 is the "Uncertainty of the result of a measurement expressed as a standard deviation". Standard deviation in the context of this DEP has been taken as the experimental standard deviation as applied in BS 5233.
Permissible error	The extreme values of an error permitted by specifications, regulations etc. for a given measuring instrument (BS 5233). NOTES: 1. In the context of this DEP, it should include: An error which relevant parties have agreed to be without consequences for any of the parties concerned. 2. The permissible error shall not exceed the specified uncertainty of measurement or, in the case of an entire measurement system, the specified overall uncertainty of measurement.
Primary standard (reference material)	A standard that is designated or widely acknowledged as having the highest metrological qualities and whose value is accepted without reference to other standards of the same quantity (ISO 14111).

Reference material	A material or substance one or more of whose property values are sufficiently homogeneous and well established to be used for the calibration of an apparatus, the assessment of a measurement method or for assigning values to materials (ISO 14111).
Secondary standard (reference material)	A standard whose value is assigned by comparison with a primary standard of the same quantity (ISO 14111).
Statistical Process Control	The condition of stable chance causes under which the process operates ("Fundamentals of Quality Control and Improvement", A. Mitra).
Traceability	The property of a result of a measurement whereby it can be related to appropriate standards, generally international or national standards, through an unbroken chain of comparisons (BS 5233).
True value	The value which characterizes a quantity perfectly defined, in the conditions that exist when that quantity is considered. The true value of a quantity is an ideal concept and, in general, cannot be known exactly (BS 5233). NOTE: True value is estimated by repeated or single measurements.
Uncertainty (of measurement)	An estimate characterizing the range of values within which the true value of a measurand lies (BS 5233). NOTE: In the context of this DEP, the uncertainty of a measurement shall be estimated on basis of two times the experimental standard deviation as permitted by BS 5233.
Validation	The process that ensures the trueness of the measurement. NOTE: During normal operation, validation is conducted to ensure that the equipment item continues to operate according to its performance specification.
Verification	A demonstration that an equipment item operates as expected. NOTE: It is usually assumed that no calibration or corrective action is required in case the subject has passed verification.
Warning Limit WL	The error limit which, if exceeded, justifies immediate action in order to secure Statistical Control. NOTES: 1. The limit relates usually to the confidence level of 95 %. 2. At the warning limits or beyond, i.e. outside the interval between the upper and lower warning limits but without either the upper or lower control limit being exceeded, attention is called to the possibility of out-of-control conditions. It is good practice to check immediately any overshooting of the warning limit. Confirmation indicates that the process is not under control and that intervention is therefore justified.

1.4.3 Terms concerning fluid properties

Compression factor	Z	The quotient of the actual (real) volume of an arbitrary mass of gas, at a specified pressure and temperature, and the volume of the same gas, under the same conditions, as calculated from the ideal gas law.
Compression factor	Z₀	The compression factor at specified conditions.
Density		The mass of a gas sample divided by its volume at specified conditions of pressure and temperature (ISO 6976).

Gross Heating Value (industry) or Superior Calorific Value (ISO 6976)	GHV	The amount of heat which would be released by the complete combustion in air of a specified quantity of gas (<i>on a molar, mass or volume basis</i>), in such a way that the pressure at which the reaction takes place remains constant, and all the products of combustion are returned to the same specified temperature as that of the reactants, all of these products being in the gaseous state except for the water formed by combustion, which is condensed to the liquid state at the same specified temperature (ISO 6976) . NOTE: Superior Calorific Value is based on the real gas conditions and can be expressed per unit volume under specified conditions or per unit mass. Specified conditions are by default as defined in ISO 13443 and should therefore be taken as 288.15 K for the temperature and 101.325 kPa for the pressure, which values also hold for the enthalpic correction of the superior calorific value as mentioned in the above definition.
Limit properties		The constraints of composition or properties of the gas as stipulated in the gas supply contract.
Relative density	RD	The density of a gas divided by the density of dry air of standard composition (both) at the same specified conditions of the density (ISO 6976). NOTE: Specified conditions are by default as defined in ISO 13443 and should therefore be taken as 288.15 K for the temperature and 101.325 kPa for the pressure.
Wobbe Index	WI	The superior calorific value on a volumetric basis divided by the square root of the relative density (ISO 6976).

1.5 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in curly brackets {}. Other documents referenced in this DEP are listed in {8} and {9}.

1.6 SUMMARY OF MAIN CHANGES

This DEP is a revision of the DEP of the same number dated December 1999. This has been a major revision and it is impractical to list the changes herein.

1.7 COMMENTS ON THIS DEP

Comments on this DEP may be sent to the DEP Administrator at standards@shell.com. Shell staff may also post comments on this DEP on the Surface Global Network (SGN) under the Standards folder.

2. GAS SALES CONTRACTS AND APPROVAL AUTHORITIES

2.1 PHILOSOPHY

The fiscal flow measurement system shall be fair and impartial to all parties concerned.

The design of new installations or revision of existing installations shall be subject to agreement between contract parties and legal/metrology authorities concerned.

There should be a single party responsible for design, construction and commissioning.

Relevant parties shall retain the right to duly witness commissioning and validation and to audit the measurement station on compliance with the contract.

2.2 CONTRACT CONDITIONS

The contract should refer to the main commercial and fiscal issues.

Measurement details should be covered as an addendum to the contract thus avoiding undue revision of the contract if only technical details change. Any deviations or changes concerning the addenda should be justified and agreed at working level {7.1}.

The overall uncertainty and availability data of the metering station should initially be estimated from operational experience with other facilities of similar design and purpose, and may be quoted as target values in the contract.

The "Black and White List" in Appendix A should be considered when designing the contract.

3. FLOW MEASUREMENT METHODS

3.1 COMMON REQUIREMENTS

Fiscal flow measurement shall be performed using generally accepted and field-proven methods and international standards.

The total life cycle costs of ownership of the measurement station shall be optimised against the requirements stated below. Due attention shall be given to safety, environment and legal aspects.

The design should aim for a single measurement station.

The gas to be measured shall be homogeneous and single-phase fluid and be free of solids and liquid contaminants in the measuring section. The gas flow shall therefore not reach its water or hydrocarbon dew point anywhere in the measuring section.

NOTE: In the EP environment, gas is not always dry and clean. The measurement location should be chosen with caution, e.g. avoiding outlets of separators where liquid carry over can occur whilst gas composition varies with operating conditions of the separator. Under such conditions additional measures are likely needed such as periodic or even continuous automatic sampling for verifying composition and inferring fluid properties from composition. Even in treated gas, liquid contamination remains a risk, e.g. due to carry over of glycol (or by-products thereof) from glycol treatment plants or seal oil originating from compressor systems. Such contamination, together with the remains of solids like iron oxides, will inevitably collect at the bottom of the piping system.

The gas flow in the meter inlet of primary elements other than Coriolis meters shall show a fully developed, turbulent velocity profile without pulsations and be consistent with the requirements of the measurement standard applicable to the device selected.

The number of meter runs shall be based on the design capacity, the allowable maximum and minimum gas velocity, the required minimum flow rate and the designated flow range of the primary device and the availability requirements of the flow measuring station.

NOTE: A large size of meter (apart from a Coriolis meter) will inevitably result in longer meter runs, which may be a reason for reducing the meter size and installing additional meters instead. Such a configuration will result in better turndown of the metering station and may reduce uncertainty (provided the error relative to the maximum flow remains constant over the range of alternative meter sizes).

The design capacity of the flow measuring station is the maximum, continuous flow rate that can be measured within the specified uncertainty. In a station with multiple meter runs, the design capacity is the sum of the flow rates of the non-spare meter runs with no single meter run exceeding its maximum continuous flow rate at which its uncertainty is just within design specifications.

The minimum flow of the measurement station is the minimum, continuous flow rate of the smallest meter run at which its uncertainty is just within design specifications and beyond which flow integration should be stopped. An alarm shall be initiated if an individual flow meter indicates a flow rate below its minimum flow rate at which its uncertainty is just within design specification.

The minimum flow shall be set for positive and, if present, negative flows and shall be determined for each individual meter run. Non-equal distribution of flow between parallel meter runs shall be taken into account. This is particularly critical with low differential pressure across the meter runs.

Redundancy shall meet the requirements of {5}. Any unavailability of the flow measuring station shall only make a small contribution towards the specified unavailability of the production facility, as defined in the field development plan. The policy with respect to spare meter runs or redundant equipment shall be in line with the plant design.

Depending on the availability requirements of the measurement station, a spare primary device may be considered as either "not installed" (and properly stored) or as "installed" in a spare meter run. Spare meters shall not be operated during normal operation and shall only be brought into service in case of failure of other meter run(s).

Meter runs other than those using Coriolis meters shall be thermally insulated in order to eliminate heat transfer from the piping or instrument well attachments and to meet any limiting value for the accuracy of the flow measurement concerned. The length of the insulated section shall at least satisfy the straight length requirements and shall include the temperature element and the primary device.

The contractual availability of gas flow may require a station by-pass, which shall be normally closed and controlled by permits or locks.

The energy flow shall be determined from real time integration of the volume or mass flow and the Gross Heating Value, all expressed in consistent units and, if applicable, referenced to the same reference conditions. Meter runs shall not be located at a low point in the piping location. The configuration shall be such that the primary device shall be in a self-draining position. Refer to Appendix F.

Each meter run shall be equipped with isolation valves of the cylindrical full-bore type conveniently located in order to allow any leakage to be detected.

Layout of the meter run shall provide adequate access for maintenance and for the replacement or removal of the meter and adjacent upstream and downstream piping.

NOTE: Factory recalibration of ultrasonic meter may require the inclusion of upstream and downstream piping, i.e. the complete meter run.

The internal diameter of the pipework shall be selected so that gas velocities do not exceed 25 m/s, thus avoiding vibration-induced fatigue of components such as thermowells and sample probes.

NOTE: Coriolis meters are capable of handling velocities up to 0.4 times the critical gas velocity. In this case the dynamic pressure drop across the meter is usually the limiting factor for the gas velocity.

Structural and pipe vibrations and pulsating flow can cause systematic errors and should be avoided.

NOTE: Pulsations (e.g. from compressor stations) could be reduced by pulsation dampeners or by providing buffer capacity in the system.

3.2 SELECTION, DESIGN AND INSTALLATION OF PRIMARY FLOW ELEMENTS

The selection of the primary flow element shall be subject to approval by the contract parties and/or authorities for each individual application.

The selection of the primary element depends on the fluid properties, performance requirements, (life cycle) costs, and legal and safety requirements.

Primary elements should be selected from the following options and shall be suitable for the intended purpose:

a) Multi-path transit-time ultrasonic flow meter {3.2.1}

- 1) Design should be full line-size and multi-path time-of-flight.
- 2) Ultrasonic flow meters may not be approved as fiscal elements in some countries, unless exempted by local authorities (e.g. Weights and Measures).

b) Orifice flow meter {3.2.2}

- 1) Where trouble-free operation of ultrasonic flow meters cannot be ensured, square-edge flange-tapped orifice flow meters should be considered. Orifice flow meters are widely accepted as fiscal elements.

c) Turbine flow meter {3.2.3}

- 1) In view of their vulnerability to wear and tear, the permanent operational use of turbine flow meters should be avoided.

d) Coriolis meter {3.2.4}

Coriolis meters are primarily mass flow meters, which means they are practically independent from flow distribution patterns no flow conditioning is required. They yield excellent calibration stability and require minimum secondary instrumentation as compared to other meters discussed in this DEP.

3.2.1 Multi-path transit-time ultrasonic flow meter

3.2.1.1 General considerations

Fiscal gas flow measurements by means of ultrasonic flow meters shall be in accordance with ISO/TR 12765 and AGA 9 and with field-proven installation practices.

The ultrasonic flow meter shall have a locally approved certificate of calibration in accordance with the Manufacturer's procedures. A certificate of the calibration of the ultrasonic flow meter at operating pressure shall only be produced if required by the parties involved. The calibration data provided in the certificate shall include the error of the meter for at least 6 points over the whole range of the meter according to ISO 9951. The monitoring facilities available in modern ultrasonic meters shall be used for health checking (transducer performance/malfunctioning, meter pollution), to enable early detection of imminent malfunction of the meter.

Ultrasonic flow meters can be susceptible to ultrasonic noise (control valves) and distortions of the flow profile, which shall be fully considered during the design stage.

3.2.1.2 Design

Depending on the availability requirements {5} and in order to provide maintenance access to the transducers without the need to shut down the metering run, the metrological tappings holding the transducers may be equipped with double-block-and-bleed valves.

At least one set (2 pcs) of spare transducers of each transducer type (if applicable) shall be procured and properly stored.

3.2.1.3 Installation

Multi-path transit-time ultrasonic flow meters shall be installed and operated in accordance with ISO/TR 12765, AGA 9 and the Manufacturer's recommended installation practices and applicable regulations.

The ultrasonic flow meter shall be operated within the specified operating envelope to satisfy its uncertainty constraints. Swirl and non-uniform velocity profile effects should be reduced to an insignificant level by piping design. Swirl-free conditions can be taken to exist when the swirl angle at all points across the pipe cross-section is less than 2°. Straight length requirements, inlet and outlet connections and/or the type and location of a low pressure-loss flow conditioner should be in accordance with Manufacturer's specifications. The upstream and downstream straight length piping should be included in the scope of delivery of the metering station, thereby allowing for calibration of the meter including the associated straight pipe lengths.

The straight length downstream of a concentric piping reducer shall be at least 40 pipe diameters. The straight length downstream for all other all cases shall be 3 pipe diameters. If no concentric reducer is installed, the straight length upstream for one-directional flow measurement shall be at least 25 pipe diameters. For bi-directional measurement the upstream and downstream straight length shall be at least 25 pipe diameters in each direction and 40 pipe diameters between the meter and a concentric reducer, if installed.

It shall be verified that the ultrasonic meter is not influenced by the layout of the upstream or downstream piping in such a way that overall uncertainty specifications are exceeded. If necessary, flow straighteners of standardised design (ISO 5167) or of agreed proven design might be installed. The flow straightener may form part of the 10-pipe diameters upstream length.

NOTE: Mechanical strain on the meter, provided it remains below the values set by the Manufacturer, should not affect the meter's accuracy.

The centre line of the ultrasonic flow meter shall be aligned with the pipe centre line within 1 % of the internal pipe diameter

The upstream and downstream straight lengths shall be straight and their cross-section circular over their entire length.

The root pass of any circumferential weld in the upstream pipe section shall be ground flush with the inside pipe wall. Inspection of the inside of the pipe shall be possible. Seam-welded pipe may be used provided that the internal weld bead is parallel to the pipe axis throughout the entire required straight length. The seam shall not be within any sector of $\pm 30^\circ$ centred on any pressure tapping used in conjunction with the primary element. Any weld bead shall be restricted in height to the permitted step in diameter.

Gaskets shall not protrude at any point inside the meter tube assembly.

The bores of the upstream straight length section and the downstream straight length section shall equal the inlet and outlet bores of the meter, respectively.

The operating pressure shall be measured at the location of the pressure tapping, which shall be within an angle of 30° from top orientation of the pipe (often the Pr point on the body of the meter).

The operating temperature shall be measured at the following point. The temperature sensor(s) for uni-directional flow measurement shall be located between 3 pipe diameters and 5 pipe diameters downstream of the meter. For bi-directional flow measurement this location shall be between 3 pipe diameters and 5 pipe diameters upstream or downstream of the meter.

The densitometer pocket should be located between 2 pipe diameters and 5 pipe diameters downstream of the meter.

The meter shall not be installed in the immediate vicinity of devices that may affect the ultrasonic signals; e.g. pressure reduction valves. Tees or short-radius bends could accomplish some in-line noise reduction.

3.2.1.4 On-line computation of the flow rate

The flow rate (both negative and positive) shall be calculated according to ISO/TR 12765.

3.2.1.5 Health monitoring

Health monitoring facilities based on the built-in diagnostic features of path comparison (velocity of sound and path differences), AGC levels, pulse rejection check, noise etc. should be applied to their full extent.

3.2.2 Orifice flow meter

3.2.2.1 General considerations

Fiscal gas flow measurements by means of orifice meter runs shall be in accordance with ISO 5167-2. Square edge/flange taps orifice meter types should be used.

3.2.2.1 Design

In view of the constraints described below and of the general uncertainty requirements for fiscal gas measurements based on orifice flow meters, which could typically be 1 % overall uncertainty, the turndown ratio of a single orifice meter run should not exceed 5 : 1.

The maximum flow reading taken from a differential pressure device (dP-cell) shall not be clipped by the maximum output of the transmitter. Hence, the maximum flow maximum flow rate shall be reached when reading 90 % to 95 % of the calibrated range.

The diameter ratio ($\beta = d/D$) should not exceed 0.6 in order to achieve minimum uncertainty according to ISO 5167-2. The overall uncertainty in the volume flow rate measurement shall be calculated according to ISO 5168 and the "ISO Guide to the expression of uncertainty in measurement".

The differential pressure at maximum flow across the highest range differential pressure transmitter should not exceed 700 mbar and shall not exceed 1000 mbar. In the latter case the bending of the orifice plate shall be verified to ensure that it does not exceed the minimum requirements as stated in ISO 5167-2 and ISO/TR 9464.

The minimum permissible calibrated range for a differential pressure transmitter is 60 mbar.

The number of differential pressure transmitters per meter run and their ranges are determined by the required rangeability of the measurement station under operating conditions and by the uncertainty specifications of the installed differential pressure transmitters, which should be not more than three, defined as "High", "Medium" and "Low".

Smart transmitters should be used on account of their built-in temperature compensation and diagnostic features, and because they enable an all-digital circuit to be created using the Hart protocol thus further reducing uncertainty. Multi-variable smart transmitters shall not be used unless they are used for single-variable measurement and are legally accepted (e.g. Weight and Measures approved).

Fieldbus concepts do not necessarily improve performance as compared to analogue devices with Hart capability.

3.2.2.3 Installation

The operating pressure shall be measured at the plane of the upstream pressure tapping of the differential pressure transmitters. Though the static pressure of the gas shall in general be measured by means of an individual pipe wall pressure tapping, it is preferable to use the same upstream tapping as the differential pressure transmitter(s).

The operating temperature of the gas shall be measured downstream of the primary element, to avoid flow profile distortion. The thermowell shall be situated between 5 and 15 pipe diameters downstream of the primary element or in accordance with the values given in ISO 5167-2 if it is located upstream.

The thermowell well shall be positioned in close proximity with the densitometer, if the latter is installed.

It may generally be assumed that the downstream and upstream temperatures of the fluid at the differential pressure tapings are the same within the limits of application of ISO 5167-2. However, if the highest accuracy is required and there is a large pressure loss between the upstream pressure tapping and the temperature location downstream of the primary device, then it is necessary to calculate the upstream temperature from the downstream temperature (measured at the above distance from the primary device), assuming an isenthalpic expansion between the two points.

3.2.2.4 On-line computation of the flow rate

The flow rate shall be calculated according to ISO 5167-2, using equipment approved by all contractual, operational and legal/regulatory (e.g. Weights and Measures) parties concerned.

For the on-line computation of the flow rate, fixed values may be used for the kinematic viscosity (ν) and the isentropic exponent (κ), based on the average operating conditions.

The calculation of the Reynolds number (Re) shall be based on the actual flow rate.

3.2.3 Turbine flow meter

3.2.3.1 General considerations

Fiscal gas flow measurement by means of turbine meters shall be in accordance with ISO 9951. Turbine meters should not be used where frequently interrupted and/or strongly fluctuating flow or pressure pulsations are present. The turbine meter shall be in accordance with contractual and/or legal obligations (e.g. Weights and Measures authorisation).

For each turbine meter a (Weights and Measures) certificate of calibration at a high (line) pressure shall be available. The calibration data stated in the certificate shall include the error of the meter for at least 6 points over the whole range of the meter according to ISO 9951.

The risk of incurring damage from extreme operating conditions shall be minimised by carefully selecting the location of the measurement station and by providing adequate,

additional protection if required. Typical risks are: dirt or liquid pollution during start-up, shock waves when opening valves.

3.2.3.2 Design

Depending on the availability requirements {5} of the flow measuring station one spare turbine meter shall be available either as a 'not installed' (and properly stored) or as an 'installed' (in a spare meter run) spare meter. The policy with respect to spare meter runs or redundant equipment shall be in line with the plant design.

3.2.3.3 Installation

The turbine meter shall operate within the specified operating conditions. Swirl and non-uniform velocity profile effects shall be reduced to an insignificant level by proper installation of the meter. Straight length requirements and/or the type and location of a flow conditioner shall be in accordance with ISO 9951 and Manufacturer's specifications.

The turbine meter centre line shall be within $\pm 1\%$ of the pipe centre line.

The upstream pipe section adjacent to the turbine meter shall be cylindrical over a length of at least 2 pipe diameters according to ISO 5167. The root pass of any circumferential weld in the upstream pipe section shall be ground flush with the inside pipe wall. Inspection of the inside of the pipe shall be possible. Seam-welded pipe may be used provided that the internal weld bead is parallel to the pipe axis throughout the entire required straight length. The seam shall not be within any sector of $\pm 30^\circ$ centred on any pressure tapping used in conjunction with the primary element. Any weld bead shall be restricted in height to the permitted step in diameter.

Upstream filters shall be installed. The filter elements shall be of such a type that 98 % of particles measuring $1\ \mu\text{m}$ or larger will be intercepted, or the turbine Manufacturer's requirements shall be followed if more stringent.

The pressure tapping marked 'Pm' (or old mark: 'Pr') on the meter body shall be used as the pressure sensing point for the operating pressure measurement.

The operating temperature shall be measured at the following point. The recommended location of the thermowell is as close as possible downstream of the turbine wheel but within 5 pipe diameters from the wheel.

Turbine meters shall be provided with vane failure detection.

3.2.3.4 On-line computation of the flow rate

The flow rate shall be calculated according to ISO 9951 using equipment approved by the contract parties and by the local authorities (e.g. Weights and Measures).

Refer to {5} for the relationship between availability and flow computation.

3.2.4 Coriolis meter

3.2.4.1 General considerations

Fiscal gas flow measurements by means of Coriolis meters shall be in accordance with ISO 10790 and AGA 11 and with field-proven installation practices.

The Coriolis meter shall be in accordance with contractual and/or legal obligations (e.g. Weights and Measures authorisation).

The Coriolis meter shall have a locally approved certificate of calibration in accordance with the Manufacturer's procedures. The calibration data stated in the certificate shall include the error of the meter for at least 6 points over the whole range of the meter.

3.2.4.2 Design

Due to economics, Coriolis meters larger than typically DN 150, which could be typically installed in a DN 200 manifold, should not be selected.

The design should take into consideration the lower density limit, which is constrained by the accuracy limitation of the meter. The lower density limit should be typically set to 4 kg/m^3 .

NOTE: The following is a type specific case.
Maximum meter capacity in kg/h of a DN 100 meter is limited to the numerical value of $3150 \times \text{density}$ in kg/m^3 and a lower capacity limit of 9000 kg/h, which typically results in a rangeability of 1:25 for a 100 bar gas application.

Coriolis meters are primarily mass flow meters. The density signal from a Coriolis meter shall not be used for fiscal purposes due to the wide ranging uncertainty of typically 0.5 kg/m^3 absolute, in relation to the actual range of densities that apply to gas measurements. If required, the volumetric flow under specified conditions shall be calculated from the prime mass flow signal and either of the following options:

- On-line measurement of relative density {4.5.3.2}
- Relative density inferred from composition {4.4.c, 4.5.3.3}

The density signal from the Coriolis meter may be used as an indicative measurement, e.g. for the detection of entrained liquid, which may show up as a transient.

Mass flow accuracy is not affected by meter pollution e.g. by coating. However, since this type of pollution will change the added mass to the vibrating tubes it will consequently cause offset of the density calibration. Facilities should be made available to allow cleaning, e.g. by rinsing if the density output is used and in cases where such conditions could be expected.

Materials shall be selected so as to minimise erosion and corrosion and thereby limit the risk of calibration shifts.

Depending on its design characteristics, the meter may be immune to swirling fluid or non-uniform velocity profiles. However, the Manufacturer shall be consulted regarding upstream and downstream piping requirements and the use of flow conditioners.

Monitoring facilities available in modern design Coriolis meters shall be used for health checking enabling early detection of imminent malfunction of the meter.

NOTE: Modern design includes on-line validation whereby a forced response of the meter is validated against a known value. Such a test is usually operator induced and can be performed on-line under flowing conditions or during a limited period of instrument outage or under no-flow conditions.

In view of their inherent geometry, Coriolis meters are likely to cause a noticeable pressure drop, which should be taken into account when designing the measurement system.

The meter shall be checked for noise conditions in accordance with the Manufacturer's recommendation. Harmonics of the exciting frequency and other frequencies that have a simple relation to the exciting frequency of the vibrating tubes will interfere with the meter operation. These harmonics may also be flow induced; e.g. due to pulsation. High gas velocities, valves, choked flows, shock waves, critical nozzles, liquid and solid particles present in the fluid, etc., may generate noise.

If a Coriolis master meter is used for validation {6.9}, care should be taken to avoid cross talk, which could be achieved by separating the sensors over a distance of three times the lay-length of the meter (so as to achieve sufficient signal attenuation). Cross talk can also be avoided when applying meters that operate at different vibrating frequencies.

The design shall take into account the effects of varying operating pressure on the calibration of the meter. The Manufacturer should advise on the dynamic pressure compensation that may be required depending on the variability of the operating pressure and the targeted uncertainty of the meter.

3.2.4.3 Installation

The meter orientation shall be highest point up.

The flow sensor will be subjected to axial, bending and torsional forces during operation. Changes in these forces, resulting from variations in process temperature and/or pressure,

can affect the performance of the Coriolis meter. Care should be taken to ensure that no forces are exerted on the meter from clamping arrangements.

Measures should also be taken to prevent excessive stresses from being exerted on the Coriolis meter by connecting pipes. Under no circumstances should the Coriolis meter be used to align the pipe work. Alignment of the instrument shall be in accordance with the Manufacturer's specification, i.e. typically within 1 % of the internal pipe diameter.

Common piping practice for the supporting of adjacent piping should be sufficient to suspend the meter and no additional supports are generally required. Arrangements shall be in accordance with the Manufacturer's recommendations.

3.2.4.4 On-line computation of the flow rate

Mass flow is the prime output of the meter, which does not require any further scaling than dynamic pressure compensation if deemed necessary.

3.3 DESIGN AND INSTALLATION OF SECONDARY INSTRUMENTS

Selection of secondary instruments shall be in accordance with:

- DEP 32.31.00.32-Gen.
- Refer to {4.5} for on-line analyser systems.

Redundancy shall be in accordance with {5}.

Refer to {6.3} for calibration ports and testing manifolds.

Metrological tapings shall not be used for other purposes unless specified otherwise in this DEP.

The mounting of the instruments shall facilitate proper readability of their gauges or indicators.

Where applicable, the Hart protocol should be considered for signal transfer so as to reduce the sources of uncertainty in the measurement chain and to improve the diagnosing capabilities of the measurement systems.

3.3.1 Differential transmitters

Selection shall be in accordance with ISO 5167 and DEP 32.31.00.32-Gen.

3.3.2 Pressure

The selection and installation of pressure transmitters shall be in accordance with DEP 32.31.00.32-Gen.

Gauge pressure transmitters are preferred to absolute pressure transmitters because of their better accuracy performance. Operating pressure should be inferred from gauge pressure transmitters in conjunction with the atmospheric pressure measured at the location {4.1.2.1}. Alternatively, the operating pressure should be read as the gauge pressure increased by the average atmospheric pressure of 1.01325 bar.

3.3.3 Temperature

Thermometers for continuous measurement shall be of the platinum resistance insertion type and comply with IEC 60751 tolerance class A. Surface-mounted types should not be used.

The temperature measurement shall accurately present the gas temperature in the line. The effects of heat transfer from the piping or thermowell attachment to ambient shall be limited and the temperature misreading for this reason should be limited to 0.5 K under steady state conditions. Refer to Appendix G for construction details.

The thermowell shall be designed to withstand vortex-induced vibrations in accordance with DEP 32.31.00.32-Gen..

Clustered thermowells should not be installed in a straight line but should have different orientations (straddled fashion) instead in order to prevent vibration-induced fatigue.

Selection of the temperature elements and their installation shall be in accordance with DEP 32.31.00.32-Gen. If redundancy is required {5} both measurement elements may be comprised in a single assembly thus avoiding the need for an additional thermowell.

The temperature elements should be directly connected as 4-wire resistance thermometers to the flow computer.

NOTE: Dual resistance element thermometers as described above are three-wired systems. The fourth wire of each resistance element may be connected under the screw terminal of one of the three wires that are terminated on the termination block of the thermometer (field side).

A separate thermowell for a reference thermometer shall be positioned in the same plane at a position that is off set by at least 30° as compared to the position of thermowell of the continuous instrument. It is good practice to fill the well with thermo-conductive oil when in use during validation {6}.

3.3.4 Fiscal computing systems

3.3.4.1 General requirements

Systems design and architecture and the retention of IT security shall be compatible with DEP 32.01.20.10-Gen. and {3.3.5}

The flow computer(s) and the associated counter(s) and /or ticket printer(s) shall comply with local legal requirements (e.g. Weights & Measures) and/or the requirements of the contract parties.

One flow computer should be dedicated to each meter run.

Any flow computer associated with fiscal gas measurement shall have no functions other than those associated with the flow measurement.

One or more digital computers may be required to perform the required tasks; e.g. a hierarchical system of more than one flow computer supervised by a supervisory system. The locations where the different computational tasks are performed shall be clearly defined and agreed by the contract parties.

Signal transmission from the gas flow meter and from secondary instruments shall be free of interference and cause no systematic errors.

The flow computer(s) shall have a dedicated maintenance mode, which is activated when the gas flow meter is taken off normal operational duty, e.g. during validation or when the flow computer is tested. The test mode shall enable functional testing of all or some of the flow computer hardware and software functionality. The flow computer design shall be such that during meter validation the amounts shall be registered separately and independently of the measured amounts.

All fiscal quantities for each meter run shall be stored on non-volatile memory in the flow computer, i.e. non-resettable flow integrators. The flow computer shall switch its registration of fiscal quantities to 'errant' counters if the measurement system malfunctions. Fiscal and errant quantities of each meter run should be accrued and stored in a database of the supervisory computer.

Flow integrators shall have sufficient digits so that rollover does not occur more frequently than every 2000 hours at maximum flow.

Fiscal flow data shall be automatically accumulated and stored for an agreed period of time.

NOTE: The read-out of the flow computer is generally considered the last fiscal element in the fiscal measurement chain. Data accrued from here is not usually subject to scrutiny by the regulatory authorities.

Manually entered parameters shall be displayed without rounding off or truncation of values.

The resolution of values presented on the visual display shall be sufficient to verify the calculation accuracy.