ASME MFC-1–2014

[Revision of ASME MFC-1M–2003 (R2008)]

Glossary of Terms Used in the Measurement of Fluid Flow in Pipes

AN AMERICAN NATIONAL STANDARD

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The American Society of Mechanical Engineers
Two Park Avenue • New York, NY • 10016 USA

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FOREWORD

The greatest aid to communication, whether verbal or written, is a common vocabulary. Even within a single technical discipline, the same word can have different meanings to different people. In order to help overcome this obstacle in the field of fluid flow measurement, this Standard consists of a collection of terms and their definitions so that a common base of reference is available, so we can speak a common language.

To this end, we need to understand that language is fluid and the definitions given here provide a snapshot of usage at the time of publication. In the preparation of this Standard, an attempt has been made to standardize suitable terms and not to perpetuate unsuitable ones, merely because they have been used in the past. Recognition of terms in common parlance is acknowledged and less ambiguous ones are suggested. Self evident and irrelevant terms have been excluded, as have those terms that are unique to methods of measurement not widely used.

The international standard vocabulary and symbols concerning the measurement of fluid flow in closed conduits prepared by ISO/TC30 has been considered, as well as many other reference sources, both national and international, have been used in order to make this glossary as useful as possible to a broad segment of the measurement community. This Standard varies from earlier revisions in that all terms are listed alphabetically.

The first edition of this Standard was approved by the American National Standards Institute on October 15, 1979. It was subsequently reaffirmed, without change, on August 7, 1986. The previous edition of this Standard was approved by the American National Standards Institute (ANSI) on September 10, 2003. It was subsequently reaffirmed, without change, in 2008.

Suggestions for improvement of this Standard are welcome. They should be sent to Secretary, ASME MFC Standards Committee, Two Park Avenue, New York, NY 10016-5990.

This revision was approved by the American National Standards Institute on August 1, 2014.

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Measurement of Fluid Flow in Closed Conduits

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The Committee welcomes proposals for revisions to this Standard. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

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The request for interpretation should be clear and unambiguous. It is further recommended that the inquirer submit his/her request in the following format:

Subject:	Cite the applicable paragraph number(s) and the topic of the inquiry.
Edition:	Cite the applicable edition of the Standard for which the interpretation is being requested.
Question:	Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. The inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.

Request that are not in this format may be rewritten in the appropriate format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME Committee or Subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

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GLOSSARY OF TERMS USED IN THE MEASUREMENT OF FLUID FLOW IN PIPES

1 GENERAL

1.1 Scope

This Standard consists of a collection of definitions of those terms that pertain to the measurement of fluid flow in pipes. The definitions provided also give guidance for recommended usage in the application of flow measurement devices.

1.2 Organization

This Standard is organized alphabeticlly. Symbols normally applied to various quantities are tabulated in section 3.

1.3 References

This Standard was compiled from many sources, including various reports and standards from The American Society of Mechanical Engineers (ASME), the American Gas Association (AGA), the American Petroleum Institute (API), the International Society of Automation (ISA), the British Standards Institute (BSI), the International Organization for Standardization (ISO), the National Institute for Standards and Technology (NIST), and the International Organization of Legal Metrology (OIML).

2 GLOSSARY OF TERMS

absolute pressure: algebraic sum of the atmospheric pressure and gauge pressure.

absolute static pressure of a fluid: static pressure of a fluid measured with reference to a perfect vacuum.

acceptance test: the evaluating action(s) to determine if an instrument satisfactorily meets its performance criteria, permitting the owner/purchaser to formally accept it from the supplier.

accuracy of measurement: the extent to which a given measurement agrees with a reference for that measurement; often used by manufacturers to express the performance characteristics of a device.

NOTE: "Accuracy" is not the same as "uncertainty" (see "uncertainty of measurement").

acoustic matching layer: material comprising one or more layers, selected to maximize the acoustic coupling coefficient between two media.

acoustic path: the path that the acoustic signals follow as they propagate through the measurement section between the transducer elements.

acoustic ratio: the differential pressure ratio divided by the isentropic exponent (compressible fluid).

air: mixture of gases and associated water vapor surrounding the earth; dry air plus its associated water vapor. The term is used synonymously with atmosphere.

air, dry: mixture of dry gases present in the atmosphere.

ambient temperature: temperature of the atmosphere measured in the immediate vicinity of the point of measurement and unaffected by wind or other atmospheric phenomena.

annular chamber: piezometer ring integral with the pipe or the primary device that simplifies the construction of annular pressure taps.

annular space: area between the tapered tube and the float that normally increases as the float rises.

area meters: flowmeter in which a variation in the cross section of the fluid stream under constant head is used as an indication of the rate of flow, e.g., a float is suspended in a vertical tapered tube and as the fluid flow rate changes, the position of the float in the tube changes.

arithmetic mean: the sum of values divided by the number of values, also called "average."

NOTES:
(1) The term "mean" is used generally when referring to a population parameter, and the term, "average," when referring to the result of a calculation on the data obtained in a sample.
(2) The average of a simple random sample taken from a population is an unbiased estimator of the mean of this population. Other estimators, such as the geometric or harmonic mean, the median, or the mode are sometimes used.

atmospheric pressure: force per unit area exerted by the atmosphere.

NOTE: Standard atmospheric pressure is 760 mm of mercury at 0°C. This is equivalent to 101.325 kPa and 14.696 psia.

average value: arithmetic mean of n readings of the quantity x. The average value $\bar{x}$ is calculated using the following formula

$$\overline{X}_w = \frac{1}{n}\sum_{i=1}^{n} x_i$$

average, weighted: sum of the products of each value and its weight (which can be positive or zero) of measurement divided by the sum of the weights of measurement. It is given by the formula

$$\overline{X}_w = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

averaging pitot tube: common abbreviation for multiport averaging pitot primary element.

base conditions: specified conditions to which a collected volume or volumetric flow rate is converted to produce values of collected volume or volumetric flow rate at specific base conditions.

base flow rate: flow rate converted from flowing conditions to base conditions of pressure and temperature, generally expressed in units of base volume per unit time.

base pressure (fluid): a specified reference pressure to which a fluid volume at flowing conditions is reduced, often for the purpose of billing and transfer accounting.

NOTE: In the United States, the base pressure is often taken as 14.696 psia (101.325 kPa), 14.7 psia (101.353 kPa), or 14.73 psia (101.560 kPa); however other base values are sometimes used.

base pressure (gas): a specified reference pressure to which a gas volume at flowing conditions is reduced for the purpose of billing and transfer accounting. It is generally taken as 14.73 psia (101.560 kPa) by the gas industry in the U.S.

base reference conditions: the values of all the external parameters, i.e., parameters outside the test boundary to which the test results are corrected.

base temperature: a specified reference temperature to which a fluid volume at flowing conditions is reduced, often for the purpose of billing and transfer accounting.

NOTE: In the United States, the base temperature is often taken as 59°F (15°C) or 60°F (15.56°C); however other base values are sometimes used.

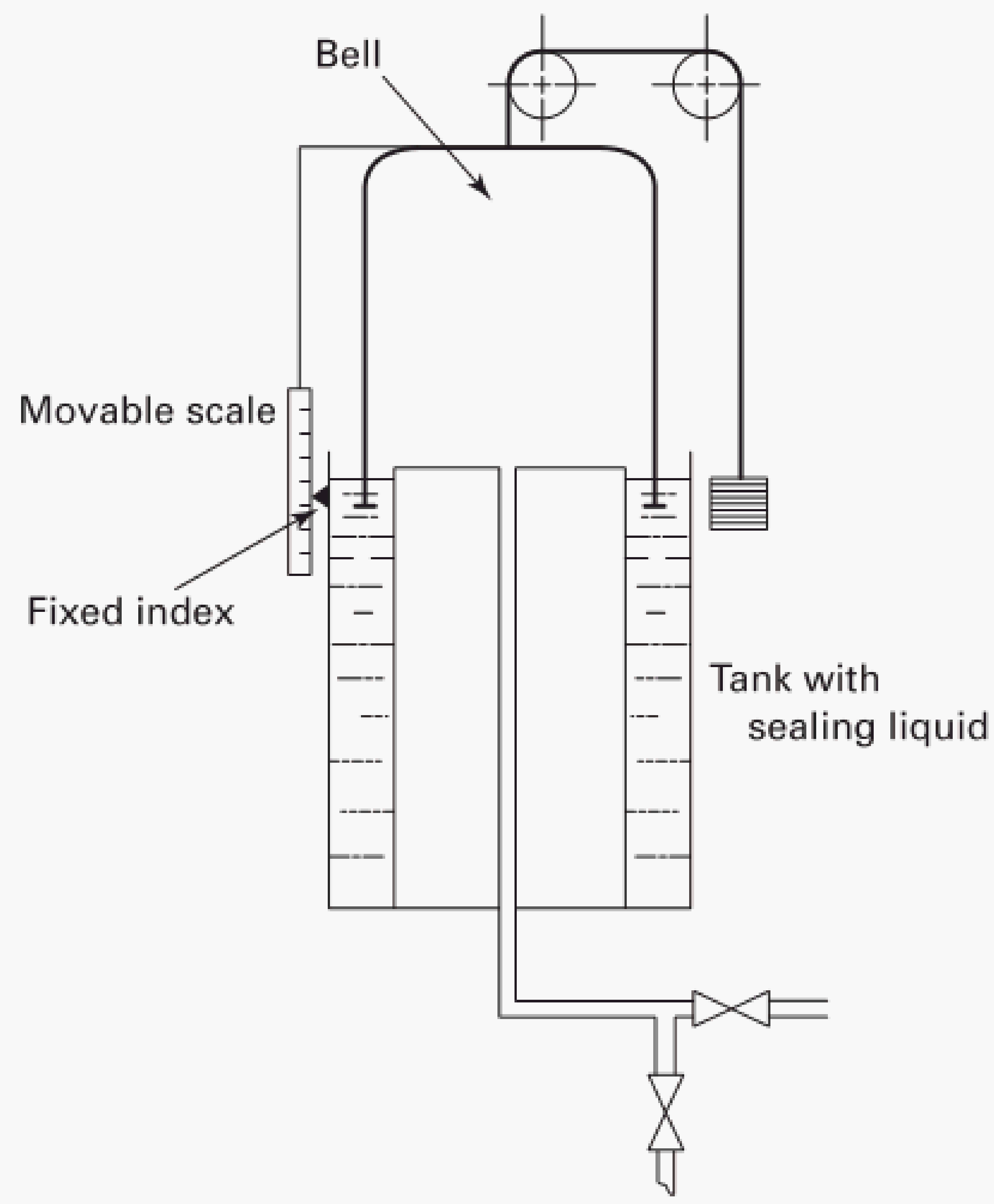
base unit: measurement unit that is adopted by convention for a base quantity.

NOTES:
(1) In each coherent system of units, there is only one base unit for each base quantity, e.g., in the SI system, the meter is the base unit of length.
(2) A base unit may also serve for a derived quantity of the same quantity dimension.

base volume: volume of the fluid at base pressure and temperature.

beam-deflection meter: flowmeter in which an acoustic beam emitted in a direction normal to the flow is deflected by an amount that is approximately proportional to the flow rate.

Fig. 1 Bell Prover



bell prover: volumetric gauging device used for gases that consists of a stationary tank containing a sealing liquid into which is inserted a coaxial movable tank (the bell), the position of which may be determined. The volume of the gastight cavity produced between the movable tank and the sealing liquid may be deduced from the position of the movable tank; see Fig. 1.

bias: the difference between the average of all possible measured values and the true value; the systematic error or fixed error that characterizes every member of a set of measurements; sometimes called "bias error" or "systematic error," see Fig. 2.

NOTE: The bias cannot be reduced by increasing the number of measurements taken under fixed flow conditions.

bias limit: the estimate of the upper limit of the true bias error.

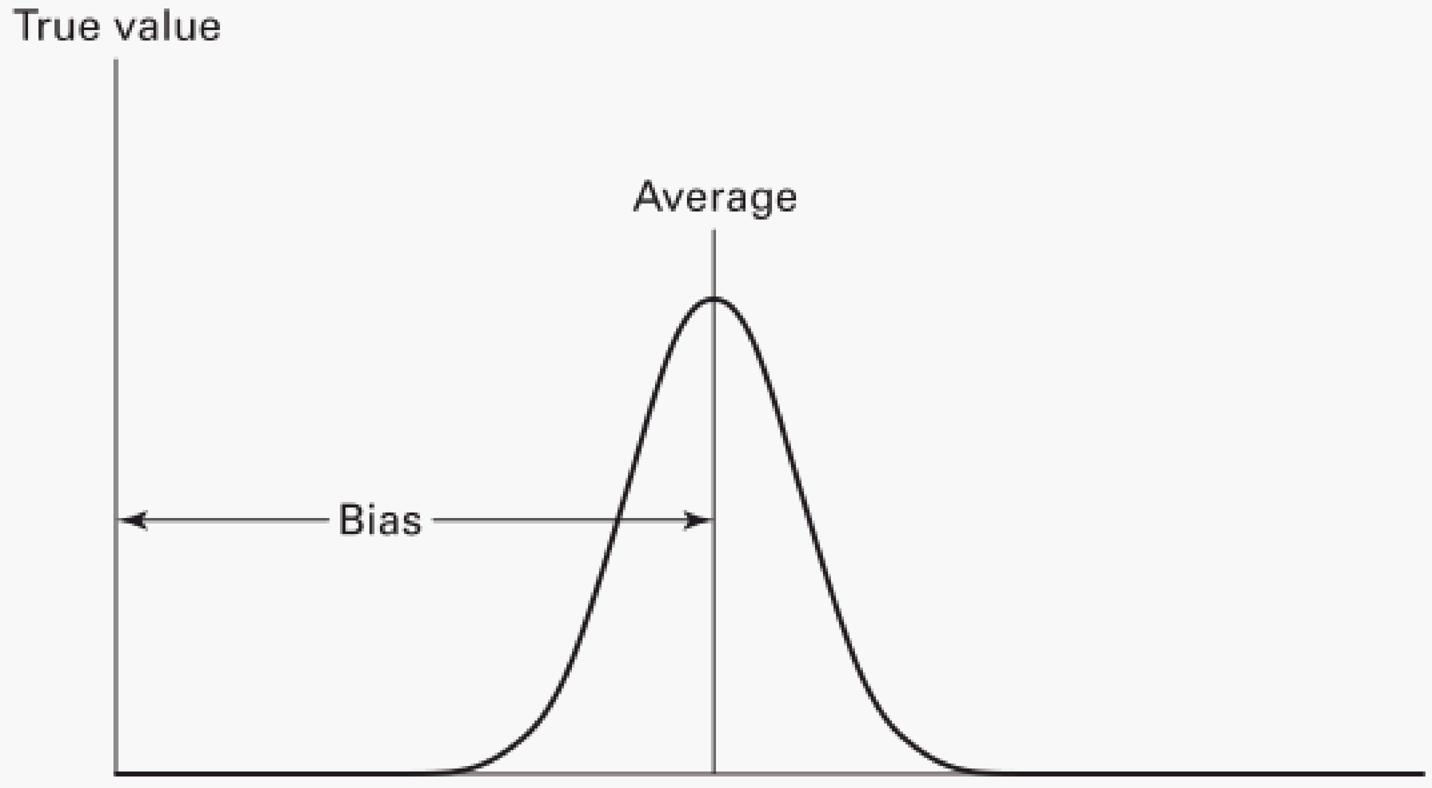
bias of estimator: the deviation of the expectation of an estimator of a parameter from the true value of this parameter. This expression may also be used in a wider sense to designate the lack of coincidence between the expectation of an estimator and the true value of the parameter.

bivariate correction: a correction that is a function of two independent parameters.

bluff body: nonstreamlined body used in vortex flowmeters to produce and shed vortices.

bore area: the minimum cross-sectional flow area of an orifice, nozzle, or venturi; sometimes called the throat area.

Fig. 2 Bias in a Random Process



bore diameter: the minimum diameter of an orifice, nozzle, or venturi; sometimes called the throat diameter.

buoyancy correction: correction made to the readings of a weighing device to compensate for the upward thrust exerted by the atmosphere on the liquid being weighed and on the reference masses used during the calibration of the weighing machine.

bypass: system of pipes and valves whereby the fluid may be led around instead of passing through a meter.

calibration: the experimental determination of the relationship between the quantity being measured and the device that measures it, usually by comparison with a standard, then (typically) adjusting the output of that device to bring it to the desired value, within a specified tolerance, for a particular value of the input.

NOTES:
(1) A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.
(2) Calibration should not be confused with adjustment of a measuring system, often mistakenly called "self-calibration," or with verification of output.
(3) Often, the first step alone in the above definition is perceived as being calibration.

calibration, end-to-end: data relating to the system response (including data acquisition and data reduction) to the application of a known input.

calibration curve: expression of the one-to-one relation between meter indication and corresponding measured quantity value.

calibration factor: a number that enables the flow signal to be related to the flow rate under defined reference conditions for a given value of the reference signal.

calibration hierarchy: sequence of calibrations from a recognized national, international, or reference standard to the final measuring system, and where the outcome of each calibration depends on the outcome of the previous calibration in the sequence.

NOTES:
(1) Measurement uncertainty necessarily increases along the sequence of calibrations.
(2) The elements of a calibration hierarchy are one or more measurement standards and systems executed according to established measurement procedures.
(3) A comparison between two measurement standards may be viewed as a calibration if the comparison is used to check and, if necessary, correct the quantity value and measurement uncertainty attributed to one of the measurement standards.

carrier ring: a single ring or a pair of rings into or between which an orifice plate or nozzle may be mounted. The complete assembly is installed between pipe flanges and is concentric with the conduit axis. Carrier rings incorporate pressure taps or annular chambers, the pressure taps usually being corner taps or, occasionally, flange taps.

cavitation: the implosion of vapor bubbles formed when the local pressure rises above the vapor pressure of the liquid (see flashing).

central moment (of order q): in a distribution of a single characteristic (univariate distribution), the arithmetic mean of the q^{th} power of the difference between the observed values and their average $\overline{x}$

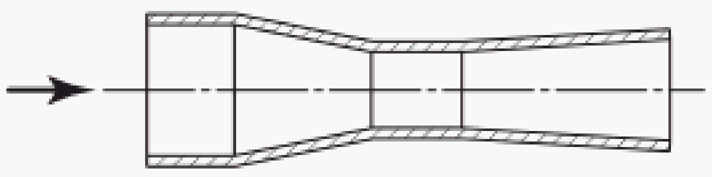
$$\frac{1}{N}\sum_i (x_i - \overline{x})^q$$

where N is the number of observations.

NOTES:
(1) The central moment of order 1 is equal to zero; the central moment of order 2 is the variance of the random variable X.
(2) If the quantities X, $X - a$, Y, $Y - b$, etc., are replaced by their absolute values, other moments called "absolute moments" are defined.

certified reference material: material, accompanied by documentation issued by an authoritative body, providing one or more specified property values with associated uncertainties and traceabilities, using valid procedures.

Fig. 3 Classical Venturi Tube



NOTES:
(1) Documentation is typically given in the form of a "certificate."
(2) In this definition, "uncertainty" covers both measurement uncertainty and the uncertainty associated with the value of the nominal property referenced. "Traceability" covers both metrological traceability of a quantity value and traceability of a nominal property value.

characteristic: a property that helps to identify or differentiate between items of a given population.

NOTE: The characteristic may be either quantitative (by variables) or qualitative (by attributes).

choking pressure ratio: the ratio of the absolute nozzle exit static pressure to the absolute nozzle upstream pressure at which the flow becomes critical.

clamp-on-meter: flowmeter (typically ultrasonic) in which the transducers are fixed on the outside of the pipe in which the flow rate is to be measured.

classical venturi tube: a venturi tube having a conical convergence which is preceded by a cylindrical inlet, or entrance, section. The pressure taps are located in the entrance cylinder and in the cylindrical throat; see Fig. 3.

Coanda effect: effect that occurs when a jet of fluid adheres to a nearby solid surface.

codes: any set of standards set forth and enforced by a government or supervisory agency, generally for the protection of public safety and health.

NOTE: The pipe or tubing installed between the primary and secondary devices must comply with applicable requirements such as national, local and owner codes, standards, and guidelines. The process piping specification determines the specifications for the block or the valve closest to the primary element. The specifications for the piping between this valve and the secondary device, and any valves in this piping, may differ. The small size, limited flow, and often the more limited temperatures involved, justifies these differences.

coefficient of discharge: dimensionless coefficient given by the formula

$$C = \frac{\text{Actual flow rate}}{\text{Theoretical flow rate}}$$

where actual and theoretical flow rates are those for an ideal fluid without any energy loss ($C = 1, \epsilon = Y = 1$).

combined standard uncertainty: standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariances of these other quantities weighted according to how the measurement result varies with changes in these quantities.

common mode voltage: the electric potential that exists equally between each electrode and the earth or other reference potential (electromagnetic flowmeters).

compressibility factor: correction factor expressing numerically the deviation from the ideal gas law of the behavior of a real gas at given pressure and temperature conditions. It is defined by the formula

$$Z = \frac{pM}{QRT}$$

where R, the molar gas constant, equals 8.314 3 J/(mol·K).

concentration: mass of tracer per unit volume or mass of fluid.

concentric orifice plate: thin orifice plate the orifice of which is circular and coaxial with the conduit.

cone-and-disc meter: variation of the orifice-and-plug meter in which the plug is replaced by a disc that is mounted in a conical tube.

NOTE: This configuration reduces the effect of changes in fluid viscosity.

cone-and-float meter: flowmeter in which a float of circular cross section can move freely up and down in a vertical tapered tube under the action of the fluid's dynamic forces and gravity; the variable area consists of the annular space between the float and the tube.

NOTE: Flow is always in a vertical direction and the readout is in terms of the vertical displacement of the float.

confidence coefficient: the value of the probability associated with a confidence interval or a statistical coverage interval, often expressed as a percentage, often referred to as "confidence level."

confidence level: the probability that the true value will lie between the specified confidence limits, assuming negligible systematic error and is generally expressed as a percentage, e.g., 95%, 99%.

confidence limits: the lower and upper limits within which the true value is expected to lie with a specified probability, assuming negligible systematic error.

conical inlet orifice plate: orifice plate for which the junction of the upstream face and the orifice bore has the shape of a straight circular truncated cone.

constant-head meter: flowmeter where the differential pressure is kept constant and the area of the annular space is allowed to vary.

constant level tank: a tank in which the level of liquid is controlled by a weir of sufficient length to ensure a stable total pressure in the circuit being supplied with liquid.

constant rate injection method: method of measuring flow rate in which a tracer solution of known concentration is injected at a constant and known flow rate at one cross section of a pipe. This injection must be sustained for a period long enough to establish a steady concentration with respect to time at a second cross section downstream from the first and distant enough to produce adequate mixing. The flow rate is determined by comparing the concentration of the tracer in the second cross section with that of the injected solution.

containment: construction or fabrication designed to prevent the release of line fluid into the environment in the event of a primary pressure containment failure.

NOTE: Safe containment of the line fluid requires conformance to the applicable standards and codes. It also requires the selection of the proper materials of construction, fabrication methods and practices, fittings, and any required gaskets or sealing materials.

control chart: a chart on which limits are drawn and on which are plotted values of any statistic computed from successive samples of a production. The statistics that are used (mean, range, percent defective, etc.) define the different kinds of control charts.

control device: element of the indicating device that displays the digits of the lowest scale; its smallest scale interval is called the "verification scale interval."

conventional value: quantity value attributed by agreement to a quantity for a given purpose, e.g., standard acceleration of free fall, $gn = 9.80665 \text{ m/s}^{-2}$, often referred to as "conventional quantity value" or "conventional value of a quantity."

NOTES:
(1) The term "conventional true quantity value" is sometimes used for this concept, but its use is discouraged.
(2) Sometimes a conventional quantity value is an estimate of a true quantity value.
(3) A conventional quantity value is generally accepted as being associated with a suitably small measurement uncertainty, which might be zero.

conversion factor between units: ratio of two measurement units for quantities of the same kind, e.g., km/m = 1 000 and thus 1 km = 1 000 m.

coriolis flowmeters: a device consisting of a flow sensor (primary device) and a transmitter (secondary device) that measures the mass flow by utilizing the coriolis force generated by flowing fluid through an oscillating tube or tubes; it may also provide measurements of density and temperature.

corner taps: wall pressure taps drilled on either side of an orifice plate or nozzle, with the spacing between the axes if the pressure taps and the respective faces of the plate or nozzle equal to half the diameter of the taps themselves, so that the holes break through the pipe wall flush with the faces of the plate or nozzle.

corrected result: result of a measurement after correction for systematic error.

correction: value added algebraically to the uncorrected result of a measurement to compensate for systematic error.

NOTES:
(1) The correction is equal to the negative of the estimated systematic error.
(2) Since the systematic error cannot be known perfectly, the compensation cannot be complete.

correction factor: numerical factor by which the uncorrected result of a measurement is multiplied to compensate for systematic error.

NOTE: Since the systematic error cannot be known perfectly, the compensation cannot be complete.

correlation: the relationship between two or several random variables within a distribution of two or more random variables.

NOTE: Most statistical measures of correlation measure only the degree of linear relationship.

correlation coefficient: a measure of the relative mutual dependence of two variables, equal to the ratio of their covariances to the positive square root of the product of their variances. It varies between −1 and +1, with the intermediate value of zero indicating the absence of correlation. The limiting values indicate perfect negative (inverse) or positive correlation. Thus

$$\rho(y, z) = \rho(z, y) = \frac{\nu(y, z)}{\sqrt{\nu(y, y)\nu(z, z)}} = \frac{\nu(y, z)}{\sigma(y)\sigma(z)}$$

with estimates

$$r(y_i, z_i) = r(z_i, y_i) = \frac{s(y_i, z_i)}{\sqrt{s(y_i, y_i)s(z_i, z_i)}} = \frac{s(y_i, z_i)}{s(y_i)s(z_i)}$$

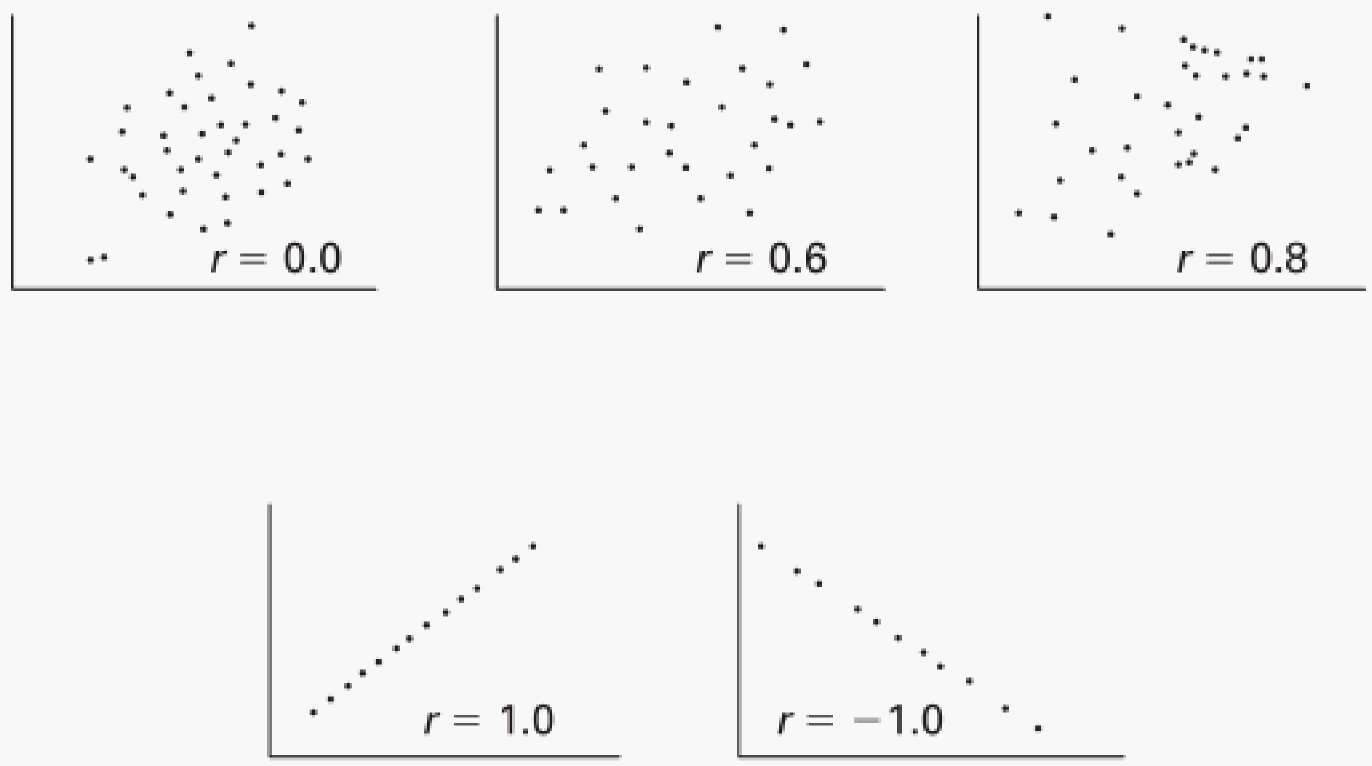
NOTES:
(1) Correlation coefficients are generally more useful than covariances because r and r are pure numbers in the range −1 to +1 inclusive, while covariances are usually quantities with inconvenient physical dimensions and magnitudes.
(2) For multivariate probability distributions, the correlation coefficient matrix is usually given in place of the covariance matrix. Since $r(y, y) = 1$ and $r(y_i, y_i) = 1$, the diagonal elements of this matrix are unity.
(3) If the input estimates x_i and x_j are correlated and if a change d_i in x_i produces a change d_j in x_j, then the correlation coefficient associated with x_i and x_j is estimated approximately by $r(x_i, x_j) \approx u(x_i)d_j/u(x_j)d_i$. This relation can serve as a basis for estimating correlation coefficients experimentally. It can also be used to calculate the approximate change in one input estimate due to a change in another if their correlation coefficient is known; see Fig. 4.

counting rate: for a radioactive tracer, the number of impulses per unit time.

covariance: the covariance of two random variables is a measure of their mutual dependence. The covariance of random variables y and z is defined by

$$\text{cov}(y,z) = \text{cov}(z,y) = E\{[y - E(y)][z - E(z)]\}$$

Fig. 4 Correlation Coefficients



which leads to

$$\begin{aligned} \text{cov}(y,z) &= \text{cov}(z,y) \\ &= \iint (y - \mu_y)(z - \mu_z)p(y,z)dy\, dz \\ &= \iint y\, z\, p(y,z)dy\, dz - \mu_y\, \mu_z \end{aligned}$$

where $p(y, z)$ is the joint probability density function of the two variables y and z. The covariance cov(y, z) - also denoted by $v(y, z)$ - may be estimated by $s(y_i, z_i)$ obtained from n independent pairs of simultaneous observations y_i and z_i of y and z,

$$s(y_i,z_i) = \frac{1}{n-1}\sum_{i=1}^{n}(y_i - \overline{y})(z_i - \overline{z})$$

where

$$\overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \text{ and } \overline{z} = \frac{1}{n}\sum_{i=1}^{n} z_i$$

NOTE: The estimated covariance of the two means $\overline{y}$ and $\overline{z}$ is given by $s(\overline{y},\overline{z}) = s(y_i, z_i)/n$.

covariance matrix: in a multivariate probability distribution, the matrix V with elements equal to the variances and covariances of the variables is termed the covariance matrix. The diagonal elements, $v(z, z) \equiv \sigma^2(z)$ or $\sigma(z_i, z_i) \equiv \sigma^2(z_i)$, are the variances, while the off-diagonal elements, $v(y, z)$ or $\sigma(y_i, z_i)$, are the covariances.

coverage: the percentage frequency that an interval estimate of a parameter contains the true value.

NOTE: A 95% confidence interval will provide 95% coverage of the true value.

coverage factor: number larger than one by which a combined standard measurement uncertainty is multiplied to obtain an expanded measurement uncertainty.

NOTE: Coverage factors are typically in the range of 2 to 3.

critical flow condition: a flow through a differential pressure device such that the ratio of the downstream to upstream absolute pressures is less than a critical value, below which the mass flow rate remains constant when the upstream fluid conditions (density, temperature, and velocity distribution) are unchanged.

critical flow devices: a flowmeter in which a critical flow is created through a primary differential pressure device (fluid at sonic velocity in the throat). A knowledge of the fluid conditions upstream of the primary device and of the geometric characteristics of the device and the pipe suffice for the calculation of the flow rate.

critical flow function: dimensionless function that characterizes the thermodynamic flow properties along an isentropic and one-dimensional path between the inlet and the throat of a device (it is a function of the nature of the gas and of stagnation conditions).

critical flow measurement: a method whereby critical flow is created using a suitable differential pressure device (with sonic velocity in the throat).

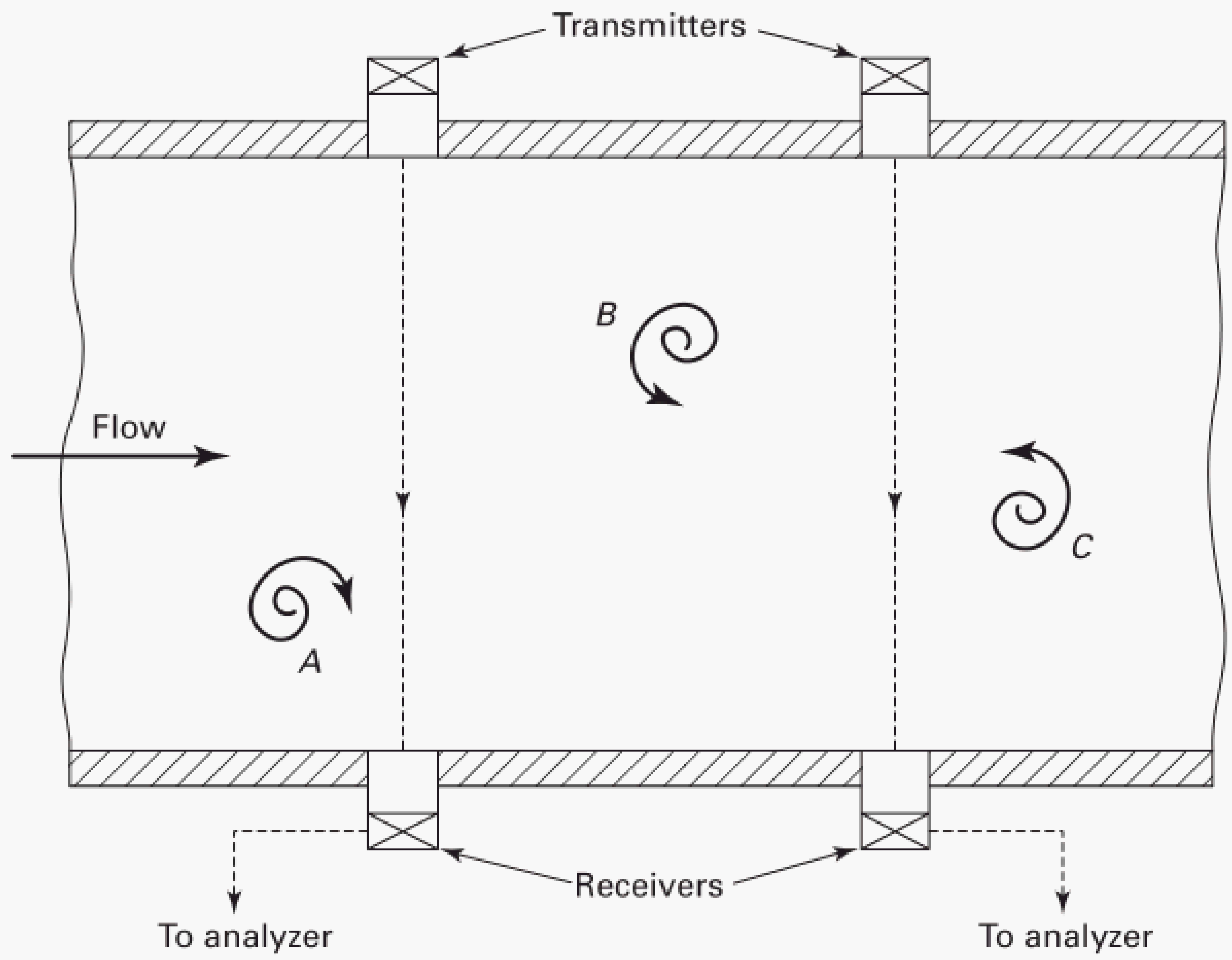
critical flow rate: the maximum flow rate for a particular venturi nozzle that can exist for the given upstream conditions. When critical flow exists, the throat velocity is equal to the local value of the speed of sound (acoustic velocity), the velocity at which small pressure disturbances propagate.

critical pressure ratio: the ratio of the absolute static pressure at the nozzle throat to the absolute stagnation pressure for which gas mass flow through the nozzle is a maximum.

critical venturi nozzle: a venturi nozzle for which the nozzle geometrical configuration and conditions of use are such that the flow rate is critical.

cross-correlation meter: a flowmeter that operates on the principle that two signals, a known distance apart, are modulated by eddies in the fluid flow. These signals are compared by a correlator, the time taken for an eddy to travel between the two receivers is identified, and hence the flow velocity and the flow rate are calculated. The principle of cross-correlation can be applied to many types of injected or existing signals (e.g., ultrasonic, thermal, and radioactive signals); see Fig. 5.

Fig. 5 Principle of Operation of the Cross-Correlation Ultrasonic Meter



cross flow velocity: the component of liquid flow velocity at a point in the measurement section that is perpendicular to the measurement section's axis.

cross-talk: interference through mechanical coupling that may occur when two or more coriolis flowmeters are mounted in close proximity to one another.

current-meter: device fitted with a rotor, the size of which is small in comparison with the size of the conduit, and the rotational frequency of which is a function of the local velocity of the surrounding fluid.

cylindrical throat venturi nozzle: also known as a LMEF venturi nozzle; device consisting of a circular profile convergence, a cylindrical throat, and a conical divergence.

D and D/2 pressure taps: wall pressure taps drilled on either side of an orifice plate, located at a distance of one pipe inside diameter upstream and one-half the pipe inside diameter downstream from the upstream face of the plate.

deadband: for a given measurement device, the band between two measured values, inside of which a variation of the measured variable does not cause any change in indication or output.

degrees of freedom: generally, the number of terms in a sum minus the number of constraints on the terms of the sum. In statistics, sample of N values is said to have N degrees of freedom, and a statistic calculated from it is also said to have N degrees of freedom. If k functions of the sample values are held constant, however, the number of degrees of freedom is reduced by k. For example, the statistic

$$\sum_{i=1}^{N} (X_i - \overline{X})^2$$

where $\bar{X}$ is the sample mean, is said to have $N - 1$ degrees of freedom. The justification for this is that either the sample mean is regarded as fixed, or in normal variation, the N quantities $(X_i - X)$ are distributed independently of X and therefore may be regarded as $N - 1$ independent variates or as N variates connected by the linear relation $\Sigma\ (X_i - X) = 0$.

density calibration factor(s): calibration factor(s) associated with density measurement.

derived quantity: quantity, in a system of quantities, defined in terms of the base quantities of that system.

EXAMPLE: In a system of quantities having the base quantities length and mass, mass density is a derived quantity defined as the quotient of mass and volume (length raised to the third power).

derived unit: measurement unit for a derived quantity.

EXAMPLES: The meter per second, symbol m/s, and the centimeter per second, symbol cm/s, are derived units of speed in the SI. The kilometer per hour, symbol km/h, is a measurement unit of speed outside the SI but accepted for use with the SI. The knot, equal to one nautical mile per hour, is a measurement unit of speed outside the SI.

detection limit: measured quantity value, obtained by a given measurement procedure, for which the probability of incorrectly claiming the presence of a component in a material is α and a probability β of incorrectly claiming its absence.

NOTES:
(1) IUPAC recommends default values for α and β equal to 0.05 (5%).

(2) The abbreviation LOD ("limit of detection") is sometimes used.
(3) The term "sensitivity" is discouraged for "detection limit."

deviation: difference between the value of a quantity and a standard or reference value.

NOTE: The reference value is frequently the arithmetic mean of a series of measurements.

diagonal beam: path followed by an ultrasonic beam when an ultrasonic transmitter and receiver are so placed that the ultrasonic signal is transmitted diagonally across the conduit.

diameter ratio: the diameter of the orifice (or throat) of a primary device divided by the inside diameter of the pipe in which the high pressure, or upstream tap, is located.

NOTE: Often referred to as the "beta" or "beta-ratio" of the device, having the symbol, β.

diaphragm meter: flowmeter having three or four measuring compartments separated by two or more movable partitions ("diaphragms"), attached to the case by an impervious flexible material so that each partition has a reciprocating motion, which may operate the valves that control the flow of gas into and out of the meter.

differential pressure: difference between the pressures measured at the high pressure and low pressure taps in a differential pressure meter or device, assuming no difference in elevation between the pressure taps.

NOTES
(1) The high pressure and low pressure taps are sometimes respectively referred to as the "upstream" and "downstream" pressure taps with orifice meters.
(2) The high pressure and low pressure taps are sometimes respectively referred to as the "upstream" or "inlet" and "throat" pressure taps with venturi meters and flow nozzles.
(3) The high pressure and low pressure taps are sometimes respectively referred to as the "total pressure" and "static pressure" taps with pitot meters.

differential pressure device: device inserted in a pipe to create a pressure difference whose measurement, together with knowledge of the fluid conditions and of the geometry of the device and the pipe, enables the flow rate to be calculated.

differential pressure meter: inferential flowmeter assembly comprising a primary differential pressure device such as an orifice plate, a flow nozzle, or a venturi tube installed in a pipe or conduit.

NOTE: Often, the secondary device necessary for the determination of the flow rate or the volume flow is included.

differential pressure ratio: the static differential pressure divided by the absolute pressure at the upstream tap.

dilution method: method in which the flow rate is deduced from the determination of the ratio of the dilution of the tracer injected to that of the tracer at the sampling cross section.

dilution ratio: the ratio of the concentration of tracer fluid in the injected solution to that at the sampling cross section, sometimes referred to as "dilution rate."

discharge coefficient: dimensionless coefficient given by the formula.

$$C = \frac{\text{Actual flow rate}}{\text{Theoretical flow rate}}$$

where actual and theoretical flow rates are those for an ideal fluid without any energy loss ($C = 1$, $\epsilon = Y = 1$).

discharge velocity: the ratio of the volume rate of flow to the area of the pipe cross section.

distribution function: a function giving, for every value x, the probability that the random variable X be less than or equal to x: $F(x) = Pr(X \leq x)$.

diverter: a device that diverts the flow either to a collection tank (weighing or volumetric) or to its bypass, without disturbing the flow rate in the circuit or through the meter or device being calibrated.

NOTE: The diverter motion should be very rapid, or if not rapid, it should conform to a known law.

diverter time: the time interval required to change the total flow from its by-pass conduit to the collection tank, or vice versa.

doppler effect: apparent change in the frequency of radiation due to relative motion between a primary or secondary source and the observer.

doppler meter: a flowmeter that operates on the principle of the Doppler effect. A signal (generally acoustic) is emitted into a pipe; the signal is then deflected by discontinuities in the fluid and is picked up by a receiver. By comparing the frequency of the deflected signal with that of the original signal, it is possible to calculate the velocity.

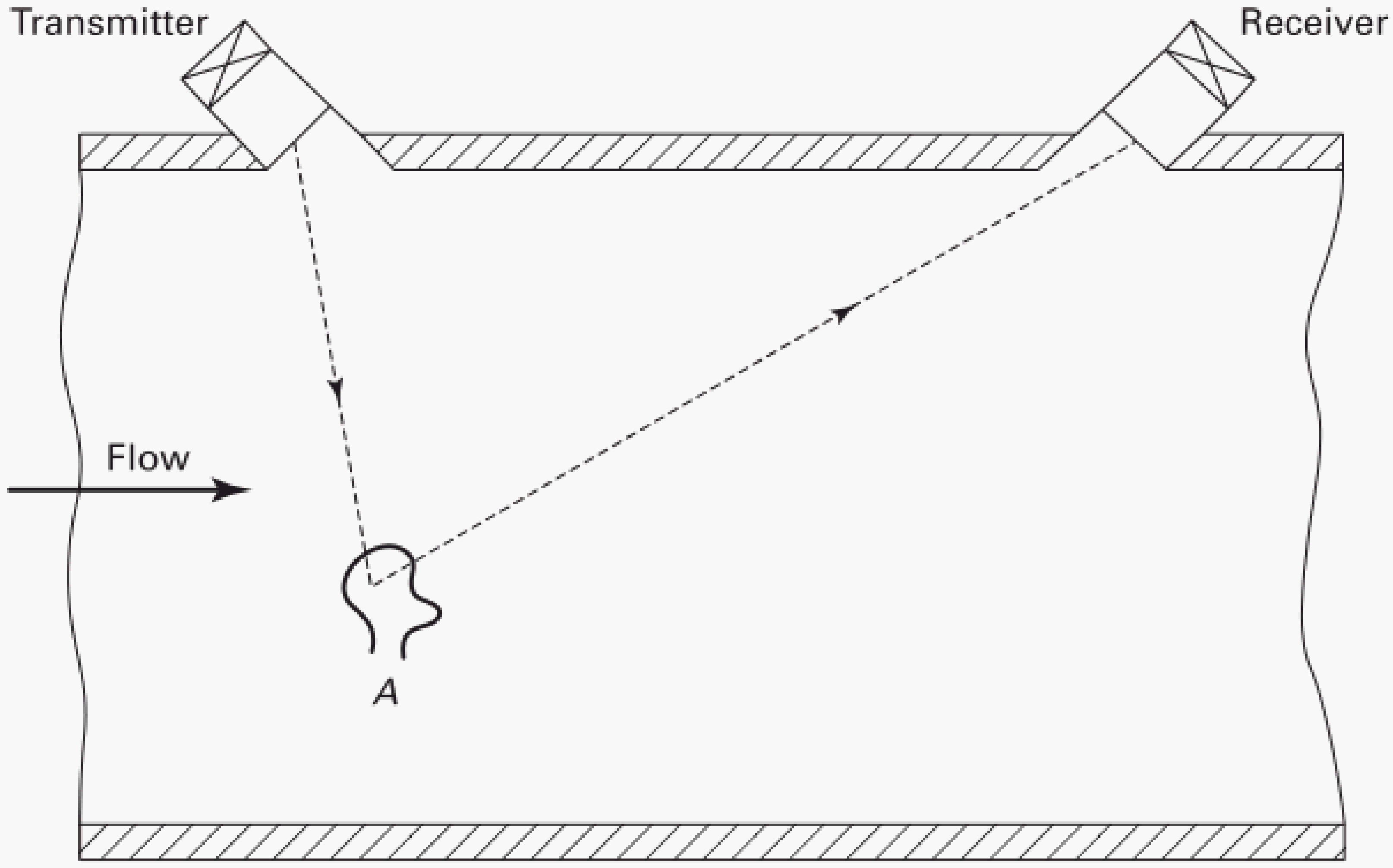
NOTE: The Doppler principle can be applied to various types of injected signals (e.g., ultrasonic, optical, and radar); see Fig. 6.

drain holes: holes drilled through the pipe wall to facilitate the removal from the metered fluid of undesirable solid particles or fluids with densities greater than that of the metered fluid.

drive system: in a coriolis meter, it is the means for inducing the oscillation of the tube(s).

droop: droop is characteristic that defines the relationship between two controlled variables. It is the ratio of relative change of one variable and the resulting relative change of the second variable.

Fig. 6 Principle of Operation of the Doppler Ultrasonic Meter



dry gas meter: displacement meter that measures the volume of gas by the successive filling and emptying of bellows.

NOTE: The most frequently used dry gas meter is the diaphragm meter.

dynamic gauging: technique in which the net volume of fluid collected is deduced from gaugings made while the fluid flow is being delivered into the calibrated measuring tank.

NOTE: A diverter is not required with this method.

dynamic pressure: the increase in pressure above the static pressure that results from the complete isentropic transformation of the kinetic energy of the fluid into potential energy. If the fluid is incompressible, it is equal to the product $\frac{1}{2}\rho U^2$, where ρ is the fluid density and U is the fluid velocity.

dynamic weighing: method in which the net mass of liquid collected is deduced from successive weight measurements done while flow is directed into the weighing tank.

NOTE: A diverter is not required with this method.

eccentric orifice plate: thin orifice plate, the orifice of which conforms to that of a square-edged orifice plate, except that it is eccentric to the conduit axis.

NOTE: The circle of the orifice is normally tangential to the top or the bottom of a horizontal conduit.

elbow meter: a differential pressure device consisting of a common pipe elbow with pressure taps located in the inner and outer surfaces in the plane determined by the curved centerline of the elbow.

electrode signal: the total potential difference between the electrodes of an electromagnetic flowmeter, consisting of the flow signal and signals not related to flow such as in-phase, quadrature, and common mode.

electromagnetic flowmeter: a flowmeter that creates a magnetic field perpendicular to the pipe axis, enabling the flow rate to be deduced from the induced electromotive force (emf) produced by the motion of a conducting fluid in the magnetic field.

elemental error: bias and/or precision error associated with a single source or process in a chain of sources or processes.

empirical formulation: a representative equation used to estimate the discharge coefficient for a flowmeter developed via theory and experience without application of meter-specific calibration data.

error (of measurement): result of a measurement quantity value minus the "true," or reference quantity value of the measurand.

NOTES:

(1) Since a true value cannot be determined, in practice a conventional true value is used.

(2) When it is necessary to distinguish "error" from "relative error," the former is sometimes called absolute error of measurement. This should not be confused with absolute value of error, which is the modulus of the error.

(3) Measurement error should not be confused with production error or mistake.

estimate: a value calculated from a sample of data as a substitute for an unknown population constant, for example, the sample standard deviation, S, is the estimate that describes the population standard deviation, σ.

estimation: the operation of assigning, from the observations in a sample, numerical values to the parameters of a distribution chosen as the statistical model of the population from which this sample is taken.

NOTE: A result of this operation may be expressed as a single value (point estimate) or as an interval estimate.

estimator: a statistic intended to estimate a population parameter.

expanded (measurement) uncertainty: product of a combined standard measurement uncertainty and a factor larger than one that defines an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand.

NOTES:

(1) The factor depends on the type of probability distribution of the measurement output quantity and on the selected coverage probability.

(2) The term "factor" in this definition refers to a coverage factor.

(3) To associate a confidence level with the interval defined by the expanded uncertainty requires certain assumptions with respect to the probability distribution characterized by the measurement result and its combined standard uncertainty. The level of confidence attributable to this interval can be known only to the extent that such assumptions may be justified.

(4) "Expanded measurement uncertainty" is the recommended term, however, "overall uncertainty" or simply "uncertainty" are often used.

expansibility factor: coefficient used to take into account the compressibility of the fluid given by the formula

(SI Units)

$$\epsilon = \frac{q_m \sqrt{1 - \beta^4}}{\frac{\pi}{4} d^2 C \sqrt{2\Delta p \rho_1}}$$

(U.S. Customary Units)

$$Y = \frac{q_m}{0.09970190\, d^2 C \sqrt{\frac{h_w \rho_1}{1 - \beta^4}}}$$

NOTES:

(1) The expansibility factor is equal to unity when the fluid is incompressible and is less than unity when the fluid is compressible. This method is possible because experiments show that $\epsilon(Y)$ is practically independent of the Reynolds number and, for a given diameter ratio of a given primary device, $\epsilon(Y)$ only depends on the differential pressure, static pressure and the isentropic exponent.

(2) The numerical values of $\epsilon(Y)$ for orifice plates given in this Standard are based on data determined experimentally. For nozzles and Venturi tubes, they are based on isentropic expansion properties.

experimental standard deviation: for a series of n measurements of the same measurand, the quantity $s(q_k)$ characterizing the dispersion of the results and given by the formula

$$s(q_k) = \sqrt{\frac{\sum_{k=1}^{n} \left(q_k - \bar{q}\right)^2}{n - 1}}$$

q_k being the result of the k^{th} measurement and $\bar{q}$ being the arithmetic mean of the n results considered.

NOTES:

(1) Considering the series of n values as a sample of a distribution, $\bar{q}$ is an unbiased estimate of the mean μ_q, and $s^2(q_k)$ is an unbiased estimate of the variance σ, of that distribution.

(2) The experimental standard deviation should not be confused with the population standard deviation s of a population of size N and of mean m, given by the formula

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (x_i - m)^2}{N}}$$

(3) If the series of n measurements is considered to be a sample of a population, s is an estimate of the population standard deviation.

(4) The expression $s(q_k)/\sqrt{n}$ is an estimate of the standard deviation of the distribution of $\bar{q}$ and is called the experimental standard deviation of the mean.

(5) "Experimental standard deviation of the mean" is sometimes incorrectly called standard error of the mean.

experimental standard deviation of the mean: estimate of the standard deviation of the arithmetic mean $\bar{x}$ with respect to the mean of the overall population given by the formula:

$$s(\bar{x}) = \frac{s(x)}{\sqrt{n}}$$

experimental variance: a measure of the scatter or spread of a distribution. It is estimated by calculating the sum of the squares of deviations of measurements about the mean, divided by the number of degrees of freedom.

$$S^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}$$

fade: the failure to shed or to detect vortices by a dropout of one or more pulses (vortex meters).

flange (pressure) taps: wall pressure taps drilled on either side of an orifice plate with their axes being 25.4 mm (1.00 in.) from the upstream or downstream faces of the plate, respectively.

flashing: the formation of vapor bubbles in a liquid when the local pressure falls to or below the vapor pressure of the liquid, often due to local lowering of pressure because of an increase in the liquid velocity. See also cavitation.

float: freely moving element of a variable area meter that is made of a material denser than the fluid being measured and which rises or falls with changes in flow rate (sometimes called "sinker").

flow calibration factor(s): any of a number of factors associated with flow primary and/or secondary; numerical factor(s), unique to each primary device and determined by flow calibration, which, when programmed into a secondary, enables the meter to perform to its stated specification.

flow coefficient: dimensionless coefficient given in the case of a flow of fluid considered as not compressible by the formula

$$\frac{q_m\sqrt{1-\beta^4}}{\frac{\pi}{4}d^2\sqrt{2\Delta p\rho_1}}$$

where
- d = diameter of the orifice or throat of the primary device
- q_m = mass flow rate of the flow
- Δp = differential pressure
- ρ_1 = mass density of the fluid upstream of the device

flow conditioner: general term used to describe any one of a variety of devices intended to reduce swirl and/or to regulate the velocity profile.

flowing pressure: static pressure of the fluid at the measurement section of the meter during operation and at the flowing condition.

flowing temperature: temperature of the fluid at the measurement section of the meter during operation and at the flowing condition.

flowmeter: a device for measuring the quantity or rate of flow of a moving fluid in a pipe; it consists of a primary device (e.g., orifice, electromagnetic flow tube, etc.) and a secondary device.

NOTE: The term "flowmeter" is also used for a device that indicates the total amount of fluid passed during a selected time interval.

flow metering run: the entire section of piping consisting of the primary element, flow conditioner (if applicable), and upstream and downstream piping that conforms to the installation requirements of that design.

flow profile: graphic representation of the velocity distribution.

flow rate: quantity of fluid flowing through a cross section of a pipe per unit of time.

flow rate range: range of flow rates bounded by the minimum and maximum flow rates.

flow signal: that part of the primary element output signal that can be related to flow rate.

EXAMPLES:
(1) For an orifice meter, flow nozzle, and venturi, the flow signal would be the differential pressure produced between the high and low pressure, or upstream and downstream, taps.
(2) For an electromagnetic flowmeter, the flow signal would be that part of the electrode signal proportional to flow rate, magnetic field strength, and distance (usually assumed as constant) between electrodes.

flow stabilizer: device or structure, forming part of the piping system, designed to ensure a stable flow rate in the pipe; for example, in a constant level head tank, the level of liquid may be controlled by a weir of sufficient capacity.

flow straightener: flow conditioner inserted in a pipe to reduce or eliminate swirl and to provide an acceptable velocity profile.

gate-type meter: flowmeter in which a gate is moved in response to changing flow rate so as to maintain a constant pressure drop across the device.

gauge pressure: difference between the absolute static pressure of a fluid and the atmospheric pressure at the place and time of the measurement (sometimes referred to as "gage pressure").

Gaussian quadrature: method of defining the optimum positions for the measuring paths and then calculating the flow rate from the individual path velocities in a multipath ultrasonic flowmeter.

hertz: unit of frequency equal to one cycle per second.

housing: environmental protection for the flow sensor and/or secondary electronics.

hydraulic diameter: the ratio of four times the cross sectional area of the flow to the wetted perimeter.

NOTE: For a filled circular pipe, the hydraulic diameter is equal to the inside diameter of the pipe.

identical: differing by less than the uncertainty interval for the measurements. It is assumed that every reasonable effort is made to eliminate significant bias and precision errors.

independence: two random variables are statistically independent if their joint probability distribution is the product of their individual probability distributions.

NOTE: If two random variables are independent, their covariance and correlation coefficient are zero, but the converse is not necessarily true.

index of asymmetry: dimensionless number used to characterize the lack of axial symmetry of the velocity distribution in a circular or annular cross section, the value of which is given by the formula

$$Y = \frac{1}{U}\left[\frac{\sum_{i=1}^{n}(U_i - U)^2}{n-1}\right]^{1/2}$$

where U_i is the mean velocity along the i^{th} radius, calculated from the local velocity measurements on this radius; and n is the number of measurement radii.

indicating device: device displaying the mass or volume flow rate, or the totalized mass or volume flow.

indication: quantity value provided by a measuring instrument or a measuring system.

inferential flowmeter: device that measures the volume of fluid passing through it by integrating over a given time period.

influence coefficient: the ratio of the change in a result to a unit change in a parameter.

influence quantity: quantity that is not the measurand but that affects the result of the measurement, e.g., temperature of a micrometer used to measure length.

NOTE: An indirect measurement involves a combination of direct measurements, each of which may be affected by influence quantities.

injection cross section: the pipe cross section in which the tracer is injected for purpose of the measurement, sometimes referred to as "injection station."

inlet area: the cross-sectional flow area at the inlet opening of a meter or flow measurement device.

inlet pressure: gauge pressure measured at the inlet of a meter or flow measurement device.

input quantity in a measurement model, input quantity: quantity(s) that must be determined in order to calculate the quantity value of a given measurand.

EXAMPLE: When the length of a steel rod at a specified temperature is the measurand, the actual temperature, the length at that actual temperature, and the linear thermal expansion coefficient of the rod are input quantities in a measurement model.

NOTES:
(1) An input quantity in a measurement model is often an output quantity of a measuring system.
(2) Indications, corrections and influence quantities can be input quantities in a measurement model.

in situ: installed in the actual piping configuration and under actual flowing conditions in the conduit where a specified flow element is to be used.

inspection (of installation): a visual examination of an installation for conformance to prescribed flow measurement requirements, pertinent building codes, and safety regulations.

NOTE: It is recommended that each installation be inspected before putting a flowmeter into service.

installation conditions: general physical circumstances in which a flow measuring device may be used.

NOTE: The circumstances include the ambient conditions, the fluid state and the range of values of its physical properties, and the geometrical arrangement of the conduit and of its associated fittings.

installation effect: any difference in performance of a component or the measuring system arising between the calibration under ideal conditions and actual conditions of use. This difference may be caused by different flow conditions due to velocity profile, perturbations, or by different working regimes (pulsation, intermittent flow, alternating flow, vibrations, etc.).

instrument: a tool or device used to measure physical quantities, such as flow rate, length, thickness, width, weight or any other value of a variable.

instrument bias: average of replicate indications of a measuring device minus a reference quantity value.

instrument drift: continuous or incremental change over time in indication, due to changes in metrological properties of a measuring device.

integration method : technique of measuring the flow rate in which a known quantity of a tracer is injected over a short time period at one cross section of a conduit, and its dilution is measured at another cross section sufficiently far downstream so that a specified level of mixing has occurred.

NOTE: The measuring period is long enough to allow all the tracer fluid to pass that measuring cross section so that the mean concentration of tracer during the sampling time can be determined.

international measurement standard: measurement standard recognized by signatories to an international agreement and intended to serve worldwide, e.g., the international prototype of the kilogram.

International System of Quantities: system of quantities based on the seven base quantities: length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity (often referred to by its abbreviation, ISQ).

NOTE: The International System of Units (SI) is based on the ISQ.

International System of Units, SI: system of units, based on the International System of Quantities, their names and symbols, including a series of prefixes and their names and symbols, together with rules for their use, adopted by the General Conference on Weights and Measures (CGPM).

NOTES

(1) The SI is founded on the seven base quantities of the ISQ and the names and symbols of the corresponding base units that are contained in the following table:

Base Quantity	Base Unit	
Name	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

(2) The base units and the coherent derived units of the SI form a coherent set, designated the "set of coherent SI units."

(3) For a full description and explanation of the International System of Units, see the current edition of the SI brochure published by the Bureau International des Poids et Mesures (BIPM) and available on the BIPM website.

(4) In quantity calculus, the quantity "number of entities" is often considered to be a base quantity, with the base unit one, symbol 1.

(5) The SI prefixes for multiples of units and submultiples of units are as follows:

	Prefix			Prefix	
Factor	Name	Symbol	Factor	Name	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	μ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atta	a
10^{2}	hecto	h	10^{-21}	zepto	z
10^{1}	deca	da	10^{-24}	yocto	y

irregularity (of a pipe): any fitting, element, or configuration that differentiates a pipe from a straight length.

NOTE: Any condition that produces a considerable change in the wall roughness may also be considered an irregularity.

ISA 1932 nozzle: a nozzle that consists of an upstream face that is perpendicular to the throat axis, a convergent section defined by two arcs, a cylindrical throat, and a recess; these nozzles measure flow using corner pressure taps.

NOTE: ISA refers to the former International Standards Association, now the International Organization for Standardization (ISO).

isentropic critical flow function (for a perfect gas): a dimensionless function that characterizes the thermodynamic flow properties along an isentropic and one-dimensional path between inlet and throat. It is a function of the nature of the gas and of stagnation conditions.

$$C_{*i} = \sqrt{\gamma\left(\frac{2}{\gamma + 1}\right)^{(\gamma+1)/(\gamma-1)}}$$

isentropic critical flow function (for a real gas): a dimensionless function that characterizes the thermodynamic flow properties of a real gas along an isentropic one-dimensional path between the nozzle inlet and throat. It is a function of the nature of the real gas and of the stagnation conditions. The function is the isentropic perfect gas critical flow function divided by the square root of the compressibility factor for the real gas.

$$C_{Ri} = C_{*i}/\sqrt{Z}$$

The real gas critical flow coefficient is often estimated by the isentropic real gas critical flow function.

isentropic exponent: ratio of the relative variation in pressure to the corresponding relative variation in density under elementary reversible adiabatic (isentropic) transformation conditions.

$$\kappa = \frac{\rho}{p}\left(\frac{\partial p}{\partial \rho}\right)_s$$

NOTES:

(1) For ideal gases, the isentropic exponent is equal to the ratio of specific heat capacities and is equal to $5/3$ for monatomic gases, $7/5$ for diatomic gases, $9/7$ for triatomic gases, etc.

(2) In real gases, the forces exerted between molecules, as well as the volume occupied by the molecules, have a significant effect on gas behavior. In a perfect gas, intermolecular forces and the volume occupied by the molecules are neglected.

(3) Often, this ratio is assumed constant over the chosen integration interval.

joint distribution function: a function describing the simultaneous distribution of two variables.

K-factor: in pulses per unit volume, is the ratio of the meter output in number of pulses to the corresponding total volume of fluid passing through the meter during a measured period. Variations in the K-factor may be presented as a function of either the Reynolds number or of the flow rate of a specific fluid at a specific set of thermodynamic conditions. In practice, the K-factor that is commonly used is the mean K-factor, which is defined by

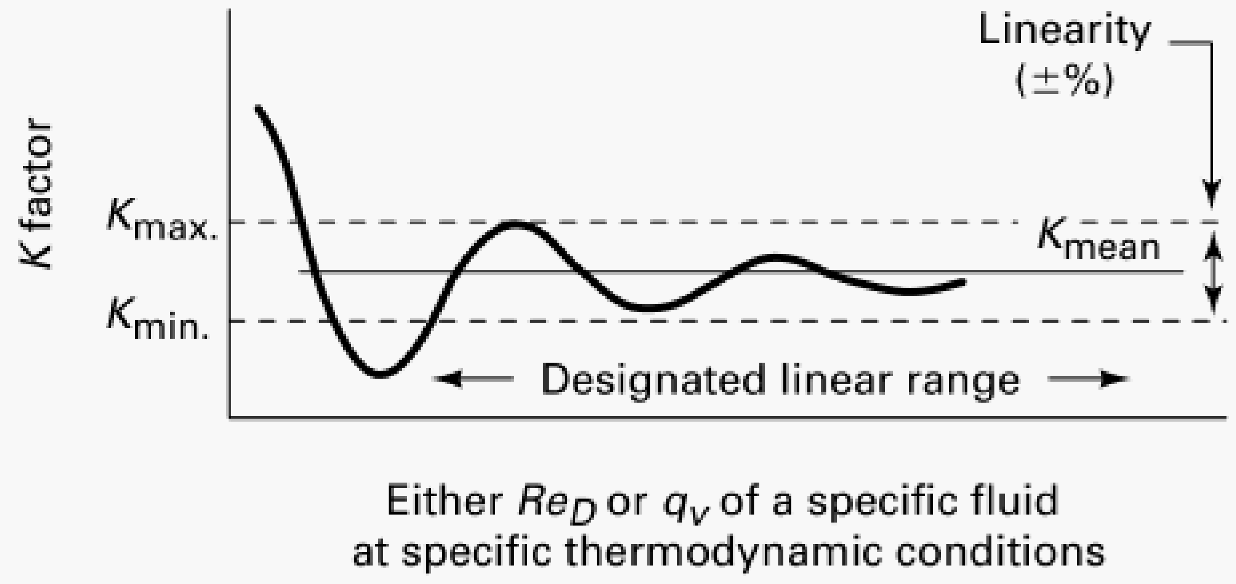
$$K_{mean} = \frac{K_{max} + K_{min}}{2}$$

where

K_{max} = maximum K-factor over a designated range

K_{min} = minimum K-factor over the same range; see Fig. 7

Fig. 7 Example of a *K* Factor Curve



kinetic energy coefficient: Coefficient defined by the formula

$$\alpha = \frac{1}{A}\iint_A \left(\frac{v}{U}\right)^3 dA$$

where A is the cross-sectional area of the flow; and dA is an element of the cross-sectional area.

laboratory standard: an instrument that is traceable to a national or international reference standard.

laminar flow: flow under conditions where forces due to viscosity are more significant than forces due to inertia; flow conditions where adjacent fluid particles move in essentially parallel paths.

NOTES:
(1) Laminar flow may be unsteady but is completely free from turbulent mixing.
(2) Laminar flow in a pipe follows the Poiseuille law.

leading edge: in ultrasonic flow metering, it is the first edge of a pulse of ultrasound. It is also a flow measurement method based on the travel of ultrasonic pulses emitted in two directions along one or more diagonal paths across the pipe and the direct measurement of their times of flight.

lead line: tube or pipe connecting the pressure taps of a metering device to the secondary device, sometimes referred to as "secondary piping."

linearity: linearity refers to the constancy of a calibration factor over a specified range, usually defined by pipe Reynolds number, velocity, or flow rate. This linear range is often specified by a band defined by maximum and minimum K factors, within which the K factor is assumed K_{mean}. The upper and lower limits of this range can be specified by the manufacturer as a maximum and minimum Reynolds number range, a flow rate range of a specified fluid, or other meter design limitations such as pressure, temperature, or installation effects.

liquid displacement system: volumetric gauging device, used for gases, in which a volume of gas is displaced by an equal volume of liquid in a calibrated tank; see Fig. 8.

liquid-sealed drum: a flowmeter consisting of rigid measuring compartments mounted on a shaft such that successive compartments are filled and emptied when the drum is rotated within an exterior casing that is filled with a sealing fluid.

long-radius nozzle: a nozzle that consists of an upstream face that is perpendicular to the throat axis, a convergent section whose shape is a quarter ellipse, a cylindrical throat, and a recess or a bevel.

lowest local pressure: the lowest pressure found in a meter or metering section.

NOTE: This is the pressure of concern regarding flashing and cavitation.

Mach number: ratio of the mean axial fluid velocity to the velocity of sound in the fluid at the considered temperature and pressure. It is given by the formula

$$Ma = \frac{U}{c}$$

magnetic field: the magnetic flux generated by the electromagnet in the primary device and which passes through the meter tube and flowing fluid.

manifold: system of valves installed to permit calibrating the secondary device without removing it.

NOTE: Manifolds used to block the impulse pressure lines from the primary device and to open a path between the high and low secondary device pressure taps (3-valve). Often, two additional valves are installed to allow draining or venting of the impulse piping to the atmosphere or drain (5-valve). The secondary device zero, or no flow signal, can be adjusted at operating pressure with one block valve closed and the bypass valve open. Manufactured valve manifolds may reduce cost and save space. Manifolds integrate the required valves and connections into one assembly and have connection spacing compatible with orifice flanges and the standard secondary devices. Install manifolds in the orientation specified by the manufacturer to avoid possible errors caused by pockets of trapped gas or liquid in the body; see Fig. 9.

mass flow rate: mass of fluid per unit time flowing through a cross section of a pipe.

mass methods: technique that enables the mass flow rate to be determined from the inferred measurements.

master flowmeter: a flowmeter calibrated with a primary flow reference and used as a secondary or transfer reference to calibrate other flowmeters.

mathematical model: a mathematical description of a system. It may be a formula, a computer program, or a statistical model.

maximum flow rate: the highest value of the flow rate for which the device is required to operate satisfactorily and for which is not subject to an error greater than the maximum permissible error.

Fig. 8 Liquid Displacement System

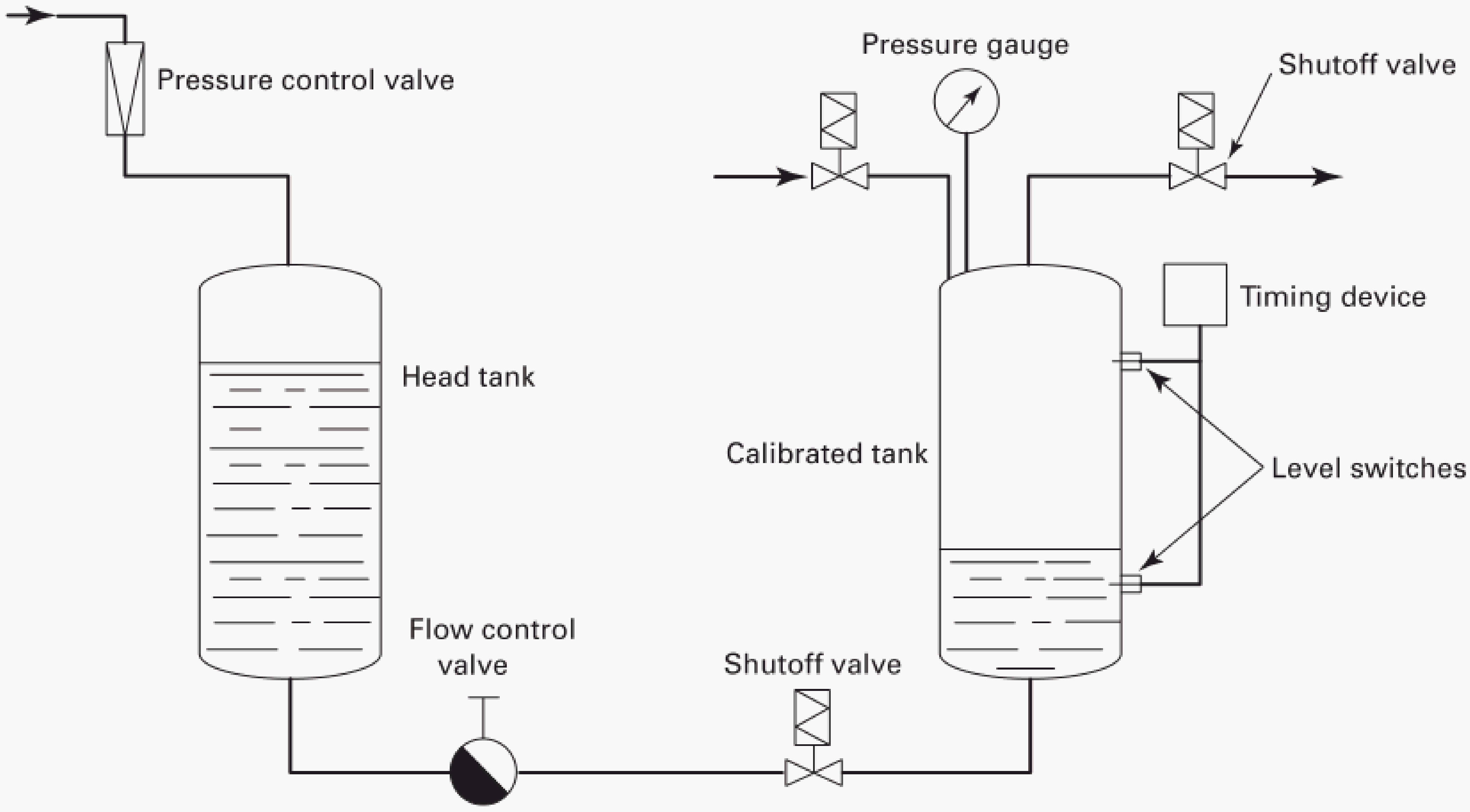
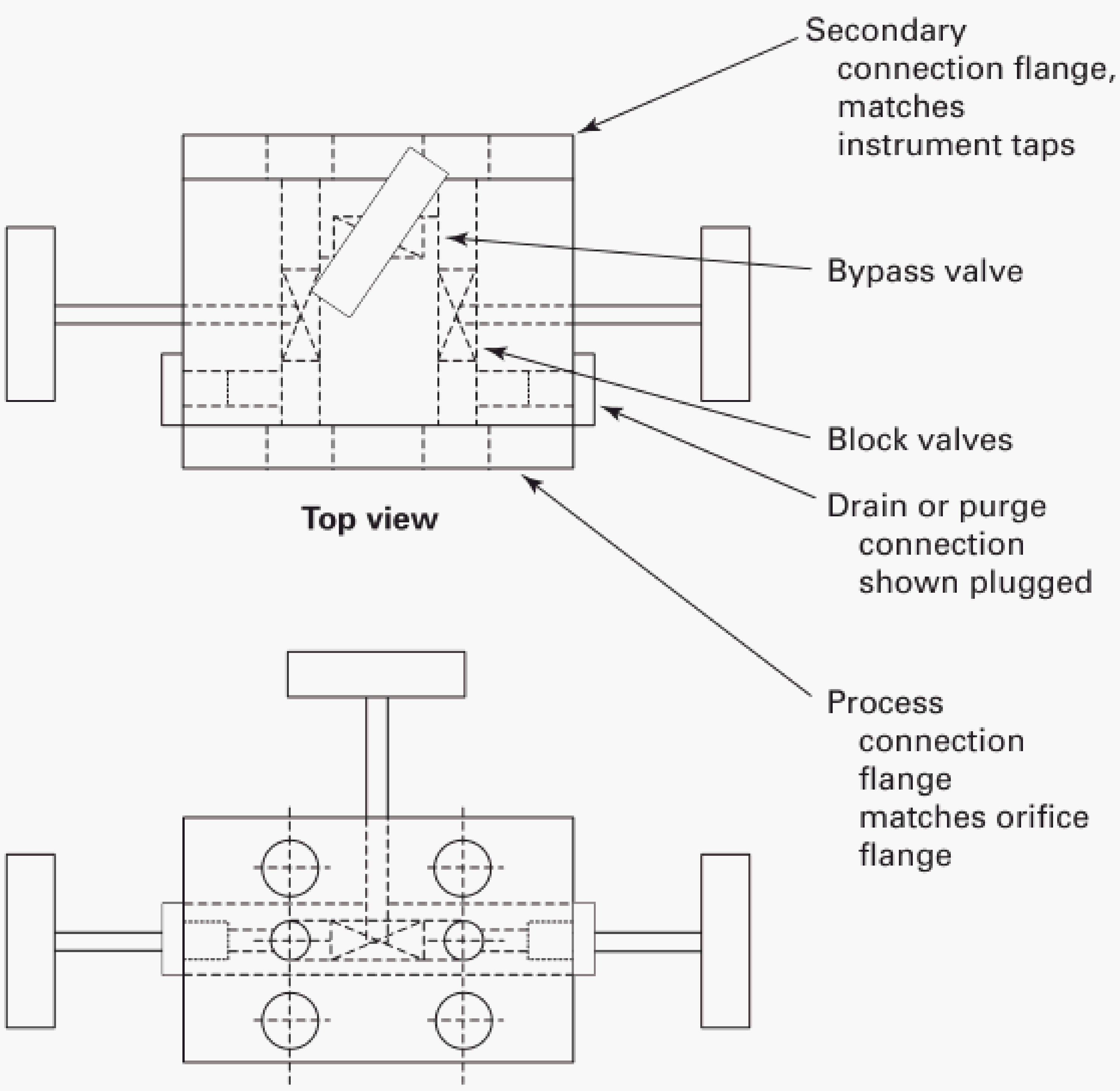


Fig. 9 Three Valve Manifold, Schematic



maximum permissible (measurement) error: extreme value of measurement error, with respect to a known reference quantity value, permitted by specifications or regulations for a given measurement, measuring instrument, or measuring system (often referred to as "maximum permissible error" or "limit of error").

NOTES:
(1) Usually, the term "maximum permissible errors" or "limits of error" is used where there are two extreme values.
(2) The term "tolerance" should not be used to designate "maximum permissible error."

mean, arithmetic, weighted: sum of the products of each value and its weight (which can be positive or zero) of measurement divided by the sum of the weights of measurement. It is given by the formula

$$\overline{X}_w = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

mean axial fluid velocity: ratio of the volumetric flow rate (the integral over a cross section of the conduit of the axial components of the local fluid velocity) to the area of the measurement cross section.

mean dynamic pressure (at a given cross section): ratio of the power of the fluid flowing through the cross section in the form of kinetic energy to the volume flow rate.

mean flow rate : mean value of the mass or volumetric flow rate over a specified period of time.

measurand: particular quantity subject to measurement.

EXAMPLE: Vapor pressure of a given sample of water at 20°C.

NOTE: The specification of a measurand may require statements about quantities such as time, temperature, and pressure.

measured (quantity) value: quantity value representing a measurement result.

NOTES:
(1) For a measurement involving replicate indications, each indication can be used to provide a corresponding measured quantity value. This set of individual measured quantity values can be used to calculate a resulting measured quantity value, such as an average or median, usually with a decreased associated measurement uncertainty.
(2) When the range of the true quantity values believed to represent the measurand is small compared with the measurement uncertainty, a measured quantity value can be considered to be an estimate of an essentially unique true quantity value and is often an average or median of individual measured quantity values obtained through replicate measurements.
(3) In the case where the range of the true quantity values believed to represent the measurand is not small compared with the measurement uncertainty, a measured value is often an estimate of an average or median of the set of true quantity values.
(4) In the GUM, the terms "result of measurement" and "estimate of the value of the measurand" or just "estimate of the measurand" are used for "measured quantity value."

measurement: set of operations having the object of determining a value of a quantity.

NOTES:
(1) Measurement does not apply to nominal properties.
(2) Measurement implies comparison of quantities and includes counting of entities.
(3) Measurement presupposes a description of the quantity commensurate with the intended use of a measurement result, a measurement procedure, and a calibrated measuring system operating according to the specified measurement procedure, including the measurement conditions.

measurement accuracy: closeness of agreement between a measured quantity value and a true quantity value of a measurand.

NOTES:
(1) The concept "measurement accuracy" is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.
(2) The term "measurement accuracy" should not be used to mean "measurement trueness" and/or "measurement precision."
(3) "Measurement accuracy" is sometimes understood as closeness of agreement between measured quantity values that are being attributed to the measurand.

measurement bias: estimate of the effect of systematic measurement errors, i.e., those that cannot be reduced by increasing the number of measurements taken under fixed conditions.

measurement error: result of a measurement minus a true value of the measurand.

NOTES:
(1) Since a true value cannot be determined, in practice a conventional true, or reference, value is used.
(2) When it is necessary to distinguish "error" from "relative error," the former is sometimes called absolute error of measurement. This should not be confused with absolute value of the error.
(3) If the result of a measurement depends on the values of quantities other than the measurand, the errors of the measured values of these quantities contribute to the error of the result of the measurement.

measurement function: function of quantities, the value of which, when calculated using known quantity values for the input quantities in a measurement model, is a measured quantity value of the output quantity in the measurement model.

NOTES:
(1) If a measurement model $h(Y, X_1...X_n) = 0$ can explicitly be written as $Y = f(X_1...X_n)$, where Y is the output quantity in the measurement model, the function f is the measurement function. More generally, f may symbolize an algorithm, yielding for input quantity values $x_1,...,x_n$ a corresponding unique output quantity value $y = f(x_1,...,x_n)$.
(2) A measurement function is also used to calculate the measurement uncertainty associated with the measured quantity value of Y.

measurement model: mathematical relation among all quantities known to be involved in a measurement.

NOTES:
(1) A general form of a measurement model is the equation $h(Y, (X_1..., X_n) = 0$, where Y, the output quantity in the measurement model, is the measurand, the quantity value of which is to be inferred from information about input quantities in the measurement model $X_1..., X_n$.
(2) In more complex cases where there are two or more output quantities in a measurement model, the measurement model consists of more than one equation.

measurement precision: closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions.

NOTES:
(1) Measurement precision is usually expressed numerically by measures of imprecision, such as standard deviation, variance, or coefficient of variation under the specified conditions of measurement.
(2) The "specified conditions" can be, for example, repeatability conditions of measurement, intermediate precision conditions of measurement, or reproducibility conditions of measurement (see ISO 5725-3:1994).
(3) Measurement precision is used to define measurement repeatability, intermediate measurement precision, and measurement reproducibility.
(4) Sometimes "measurement precision" is erroneously used to mean measurement accuracy.

measurement procedure: set of operations, described in detail, used in the performance of particular measurements according to a given method, including any calculation to obtain a measurement result.

NOTE: A measurement procedure should be documented in sufficient detail to enable an operator to perform a measurement and may include a statement concerning a target measurement uncertainty.

measurement repeatability: measurement precision under a set of repeatability conditions of measurement (set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions, and same location, and replicate measurements on the same or similar objects over a short period of time).

measurement reproducibility: measurement precision under reproducibility conditions of measurement (a set of conditions that includes different locations, operators, measuring systems, and replicate measurements on the same or similar objects).

measurement result: set of quantity values being attributed to a measurand, together with any other relevant information.

NOTES:
(1) A measurement result is generally expressed as a single measured quantity value and its uncertainty. If the measurement uncertainty is considered to be negligible for a specific purpose, the measurement result may be expressed as a single measured quantity value.
(2) A measurement result may contain "relevant information" about the set of quantity values, such that some may be more representative of the measurand than others. This may be expressed in the form of a probability density function.

measurement section: length of conduit between two measurement cross sections, two sampling cross sections, or between an injection and a sampling cross section. For ultrasonic flowmeters: The section of conduit in which the volumetric flow rate is sensed by the acoustic signals and is bounded at both ends by planes perpendicular to the axis of the section and located at the extreme upstream and downstream transducer positions.

measurement sensor, coriolis: sensor to detect the Coriolis effect and to measure the frequency of the tube oscillations.

measurement standard: realization of the definition of a given quantity, with stated quantity value and associated measurement uncertainty, used as a reference, e.g., 1 kg mass measurement standard with an associated standard measurement uncertainty band of 3 μg; or a 100 Ω measurement standard resistor with an associated standard measurement uncertainty of 1 μΩ .

NOTES:
(1) A "measurement standard" can be provided by a measuring system, a material measure, or a reference material.
(2) A measurement standard is frequently used as a reference in establishing measured quantity values and associated measurement uncertainties for other quantities of the same kind, thereby establishing metrological traceability through calibration of other measurement standards, measuring instruments, or measuring systems.
(3) The term "realization" used denotes three procedures of "realization:"

(a) the physical realization of the measurement unit from its definition and is a realization in the strictest sense

(b) termed "reproduction", consisting of setting up a highly reproducible measurement standard based on a physical phenomenon, as it happens

(c) consisting in adopting a material measure as a measurement standard, e.g., the measurement standard of 1 kg

(4) A standard measurement uncertainty associated with a measurement standard is always a component of the combined standard measurement uncertainty in a measurement result obtained using the measurement standard. Frequently, this component is small compared with other components of the combined standard measurement uncertainty.
(5) Quantity value and measurement uncertainty must be determined at the time when the measurement standard is used.
(6) Several quantities of the same kind or of different kinds may be realized in one device which is commonly also called a measurement standard.

measurement trueness: closeness of agreement between the average of an infinite number of replicate measured quantity values and a reference quantity value.

NOTES:
(1) Measurement trueness is not a quantity and thus cannot be expressed numerically, but measures for closeness of agreement are given in ISO 5725.
(2) Measurement trueness is inversely related to systematic measurement error, but is not related to random measurement error.
(3) Measurement accuracy should not be used for "measurement trueness" and vice versa.

measurement uncertainty: non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used.

NOTES:
(1) Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the definitional uncertainty.
(2) The parameter may be, for example, a standard deviation called a "standard measurement uncertainty" (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.
(3) Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterized by standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.
(4) In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

measurement unit: real scalar quantity, defined and adopted by convention, with which any other quantity of the same kind can be compared to express the ratio of the two quantities as a number.

NOTES:
(1) Measurement units are designated by conventionally assigned names and symbols.
(2) Measurement units of quantities of the same quantity dimension may be designated by the same name and symbol even when the quantities are not of the same kind. For example, "joule per kelvin" and "J/K" are, respectively, the name and symbol of both a measurement unit of heat capacity and a measurement unit of entropy, which are generally not considered to be quantities of the same kind. In some cases, however, special measurement unit names are restricted to be used with quantities of a specific kind only. For example, the measurement unit "second to the power of negative one" (1/s) is called hertz (Hz) when used for frequencies and becquerel (Bq) when used for activities of radionuclides.
(3) Measurement units of quantities of dimension one are numbers. In some cases these measurement units are given special names, e.g., radian, steradian, and decibel, or are expressed by quotients such as millimole per mole equal to 10^3 and microgram per kilogram equal to 10^9.
(4) For a given quantity, the short term "unit" is often combined with the quantity name, such as "mass unit" or "unit of mass."

measuring point: any point where the local velocity (or process measurement) of the flow is measured.

measuring system: one or more measuring instruments assembled to provide measured quantity values within specified intervals for quantities of specified kinds.

measuring transducer: device, used in measurement, that provides an output quantity having a specified relation to the input quantity, e.g., a thermocouple, strain gauge, etc.

meter bore Reynolds number: a dimensionless parameter expressing the ratio between inertia and viscous forces and referenced to the bore diameter of an orifice meter (primarily), but often to the throat diameter of a venturi or nozzle; the meter bore Reynolds number is determined by velocity, density, and viscosity of the flowing fluid at the meter bore cross section of the device. It can be determined from

$$Re_d = \frac{4q_m}{\pi d \mu_0}$$

meter electrodes: in an electromagnetic flowmeter, one or more pairs of contacts by means of which the induced voltage is detected.

meter factor: the number, determined by liquid calibration, that enables the output flow signal to be related to the volumetric flow rate under defined reference conditions; often expressed as the reciprocal of mean K-factor.

meter flow rate: quotient of the mass or volume of fluid passing through the meter and the time taken for this volume to pass through the meter.

meter tube: section of conduit fabricated specifically for the placement of or incorporation of a flow measuring device or mechanism.

EXAMPLES:
(1) With an electromagnetic flowmeter, the meter tube is the section through which the fluid to be measured flows, it contains the meter electrodes, and its inner surface is usually electrically insulated.
(2) In the case of an orifice flowmeter, the meter tube is some specified length of upstream and downstream piping (conforming to the appropriate flow measurement standard) that incorporates the orifice flanges and taps, or a mounting or carrier mechanism that allows for the removal of the orifice plate from the conduit.

method of least squares: technique used to compute the coefficients of the equation when a particular form of equation is chosen for fitting a curve to data. The principle of the method of least squares is the minimization of the sum of squares of deviations of the data from the curve.

method of measurement: logical organization of operations, described generically, used in the performance of measurements.

NOTE: Methods of measurement may be qualified in various ways such as the substitution, the differential, and/or the null methods.

metrological comparability of measurement results: comparability of measurement results, for quantities of a given kind, that are metrologically traceable to the same reference, sometimes referred to simply as "metrological comparability."

EXAMPLE: Measurement results, for the distances between the earth and the moon, and between Paris, France and Greenwich, United Kingdom, are metrologically comparable when they are both metrologically traceable to the same measurement unit, for instance the meter.

metrological compatibility of measurement results: property of a set of measurement results for a specified measurand, such that the absolute value of the difference of any pair of measured quantity values from two different measurement results is smaller than some chosen multiple of the standard measurement uncertainty of that difference, sometimes referred to simply as "metrological compatibility."

NOTES:
(1) Metrological compatibility of measurement results replaces the traditional concept of "staying within the error," as it represents the criterion for deciding whether two measurement results refer to the same measurand or not. If in a set of measurements of a measurand, thought to be constant, a measurement result is not compatible with the others, either the measurement was not correct (e.g. its measurement uncertainty was assessed as being too small) or the measured quantity changed between measurements.
(2) Correlation between the measurements influences metrological compatibility of measurement results. If the measurements are completely uncorrelated, the standard measurement uncertainty of their difference is equal to the root mean square sum of their standard measurement uncertainties, while it is lower for positive covariance or higher for negative covariance.

metrological traceability: property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.

NOTES:
(1) For this definition, a "reference" can be a definition of a measurement unit through its practical realization, or a measurement procedure including the measurement unit for a non-ordinal quantity, or a measurement standard.
(2) Metrological traceability requires an established calibration hierarchy.
(3) For measurements with more than one input quantity in the measurement model, each of the input quantity values should itself be metrologically traceable and the calibration hierarchy involved may form a branched structure or a network. The effort involved in establishing metrological traceability for each input quantity value should be commensurate with its relative contribution to the measurement result.
(4) Metrological traceability of a measurement result does not ensure that the measurement uncertainty is adequate for a given purpose or that there is an absence of mistakes.
(5) A comparison between two measurement standards may be viewed as a calibration if the comparison is used to verify and, if necessary, correct the quantity value and measurement uncertainty attributed to one of the measurement standards.
(6) Full metrological traceability shall include an unbroken metrological traceability chain to an international measurement standard or a national measurement standard, a documented measurement uncertainty, a documented measurement procedure, accredited technical competence, metrological traceability to the SI, and calibration intervals.
(7) The abbreviated term "traceability" is sometimes used to mean "metrological traceability" as well as other concepts, such as "sample traceability" or "document traceability" or "instrument traceability" or "material traceability," where the history of an item is meant.
(8) The full term of "metrological traceability," therefore, is preferred if there is any risk of confusion.

metrological traceability chain: sequence of measurement standards and calibrations that is used to relate a measurement result to a reference, sometimes referred to simply as the "traceability chain."

NOTES:
(1) A metrological traceability chain is used to establish metrological traceability of a measurement result and is defined through a calibration hierarchy.
(2) A comparison between two measurement standards may be viewed as a calibration if the comparison is used to verify and, if necessary, correct the quantity value and measurement uncertainty attributed to one of the measurement standards.

metrological traceability to a measurement unit: metrological traceability where the reference is the definition of a measurement unit through its practical realization.

minimum flow rate: the lowest flow rate at which the meter will operate within the maximum error limits specified by the manufacturer.

mixing length: the minimum distance downstream of the injection cross section beyond which the injected solution is sufficiently distributed over a cross section to enable the flow rate to be measured to the accuracy required.

multipath diagonal-beam meter: ultrasonic flowmeter which works on the same principle as a single-path diagonal-beam meter but which emits several beams to compensate for fluctuations in the velocity distribution.

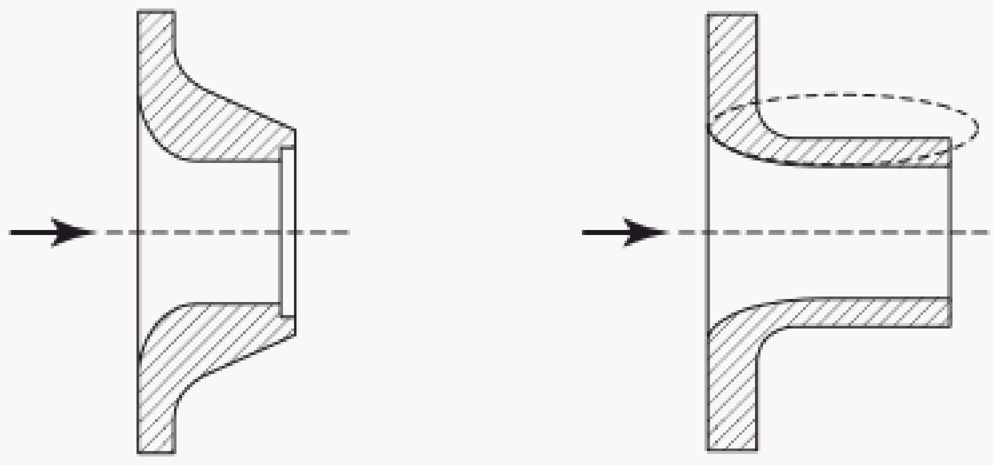
multiple measurement: more than a single concurrent measurement of the same parameter.

nominal property: property of a phenomenon, body, or substance, where the property has no magnitude.

EXAMPLES:
(1) Sex of a human being.
(2) ISO two-letter country code.

NOTES:
(1) A nominal property has a value that can be expressed in words, by alphanumerical codes, or by other means.

Fig. 10 Nozzles



(2) "Nominal property value" is not to be confused with nominal quantity value.

nominal quantity value: rounded or approximate value of a characterizing quantity of a measuring instrument or system that provides guidance for its appropriate use.

EXAMPLES:
(1) 100 Ω as the nominal quantity value marked on a standard resistor.
(2) 0.1 mol/l as the nominal quantity value for amount-of-substance concentration of a solution of hydrogen chloride, HCl.
(3) −20°C as a maximum Celsius temperature for storage.

NOTE: "Nominal quantity value" and "nominal value" are not to be confused with "nominal property value."

nondimensional (relative) velocity: ratio of the flow velocity at a given point to a reference velocity measured at the same time, which may be the velocity at a particular point (for example, the centerline velocity) or the mean axial fluid velocity.

nonrefractive system: an ultrasonic flowmeter in which the acoustic path crosses the solid/process liquid interfaces at a right angle.

normal distribution: the probability distribution of a continuous random variable x, the probability density function of which is

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]$$

for $-\infty < x < +\infty$

NOTE: μ is the expectation, typically the arithmetic mean, and σ is the standard deviation of the normal distribution (also known as the Laplace-Gauss distribution).

nozzle: a primary device consisting of a convergent inlet having a curved profile with no discontinuities leading to a cylindrical throat; see Fig. 10.

nozzle venturi tube: a venturi tube with the convergent section formed by a nozzle.

number of degrees of freedom: in general, the number of observations minus the number of parameters.

NOTE: For example, the standard deviation is said to have $(n - 1)$ degrees of freedom because for the estimation of the mean it is necessary to use one degree of freedom.

numerical value: number in the expression of a quantity value, other than any number serving as the reference (also known as "numerical quantity value" or "numerical value of a quantity."

NOTES:
(1) For quantities of dimension one (a.k.a. "dimensionless"), the reference is a measurement unit is not considered as a part of the numerical quantity value.

EXAMPLE: In an amount-of-substance fraction equal to 3 mmol/mol, the numerical quantity value is 3 and the unit is mmol/mol. The unit mmol/mol is numerically equal to 0.001, but this number 0.001 is not part of the numerical quantity value, which remains 3.

(2) For quantities that have a measurement unit (i.e., those other than ordinal quantities), the numerical value $\{Q\}$ of a quantity Q is frequently denoted $\{Q\} = Q/[Q]$, where $[Q]$ denotes the measurement unit.

EXAMPLE: For a quantity value of 5.7 kg, the numerical quantity value is {m} = (5.7 kg)/kg = 5.7. The same quantity value can be expressed as 5 700 g in which case the numerical quantity value {m} = (5 700 g)/g = 5 700.

numerical value equation: mathematical relation between numerical quantity values, based on a given quantity equation and specified measurement units.

EXAMPLES:
(1) $\{Q_1\} = \zeta\{Q_2\}\,\{Q_3\}$ where $\{Q_1\}$, $\{Q_2\}$, and $\{Q_3\}$ denote the numerical values of Q_1, Q_2, and Q_3, respectively, provided that they are expressed in either base units or coherent derived units or both.
(2) In the quantity equation for kinetic energy of a particle, $T = (\frac{1}{2})\, mv_2$, if $m = 2$ kg and $v = 3$ m/s, then $\{T\} = (\frac{1}{2}) \times 2 \times 32$ is a numerical value equation giving the numerical value 9 of T in joules.

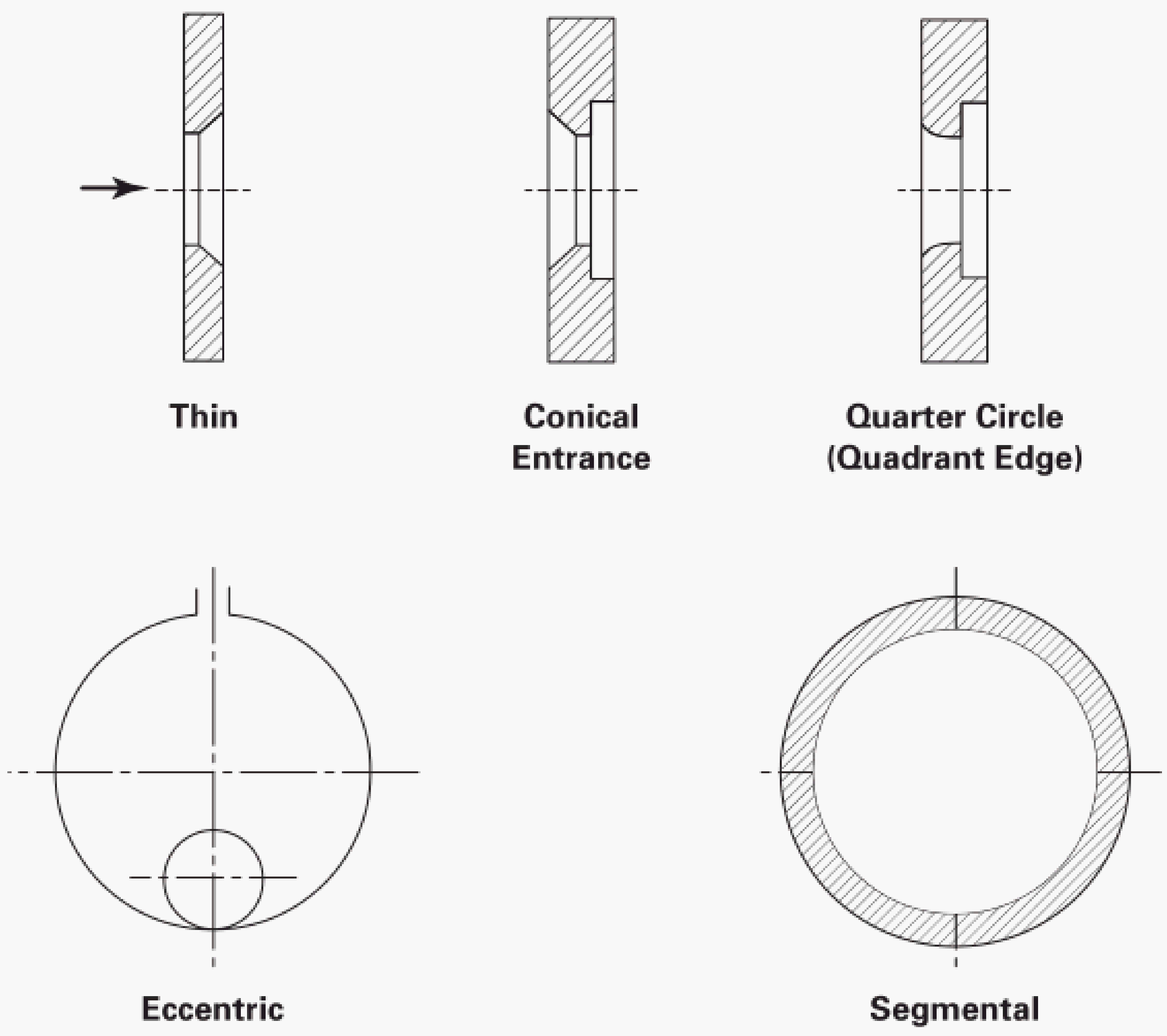
nutating disk meter: a flowmeter consisting of a disk mounted in a circular chamber with a conical roof and either a flat or conical floor. The motion of the disk, which is called nutating, is such that the shaft on which it is mounted generates a cone with the apex down. Rotation of the disk on its own axis is prevented by a radial slot that fits about a radial partition extending in from the chamber sidewall nearly to the center. The inlet and outlet openings are in the sidewall of the chamber on either side of the partition. Sometimes called a "fluidic flowmeter."

observed value: the value of a characteristic determined as the result of an observation or test.

octave band: the segment of a frequency spectrum where the highest frequency is twice the lowest frequency.

one-sided confidence interval: When T is a function of the observed values such that, θ being a population parameter to be estimated, the probability $Pr(T \leq \theta)$ or the

Fig. 11 Orifice Plates



probability $Pr(T \geq \theta)$ is equal to $1 - \alpha$ (where $1 - \alpha$ is a fixed number, positive, and less than 1), the interval from the smallest possible value of θ up to T, or the interval between T and the greatest possible value of θ, is a one-sided $(1 - \alpha)$ confidence interval for θ.

NOTE: The limit T of the confidence interval is a random variable and as such will assume different values in every sample. In a long series of samples, the relative frequency of cases where the interval includes θ would be approximately equal to $1 - \alpha$.

orifice, throat or bore: opening of minimum cross-sectional area of a primary device.

NOTE: Standard primary device orifices are circular and coaxial with the pipeline.

orifice-and-plug meter: flowmeter in which a tapered plug fits into a circular orifice in such a way that the area of the annular space is proportional to the lift of the plug.

orifice fitting: the combination of an orifice plate and the conduit in which the orifice plate is mounted, including its pressure taps.

orifice plate: thin plate in which a circular, concentric aperture has been machined, the leading edge of which is sharp and square.

NOTE: Standard orifice plates are described as "thin plate" because the thickness of the plate is small compared with the diameter of the measuring section. Standard orifice plates are also described as "with sharp square edge" because the upstream edge of the orifice is sharp and square; see Fig. 11.

oscillating tube: a tube through which the fluid to be measured flows in a coriolis meter.

outlier: an observed value that appears to be inconsistent with the remainder of the set of data.

output signal: output from the secondary device that is a known function of the flow rate (e.g., linear, square, etc.) and in the form of a standardized transmission signal (4 – 20 mADC, 3 – 15 PSIG, known digital protocol, etc.).

parameter: The following are two separate descriptions for the term parameter:

(a) a quantity that may vary over a certain set of values and is used in describing the probability distribution of a random variable.

(b) a physical quantity at a given location which is sensed by direct measurement of a one or more like instruments.

NOTE: In statistics, it occurs in expressions defining frequency distributions (population parameters).

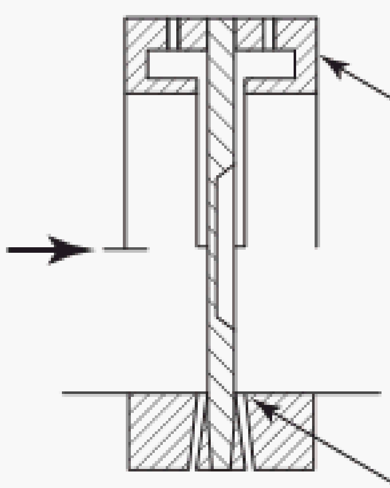
EXAMPLES:
(1) The mean of a normal distribution.
(2) The expected value of a Poisson variable.

parties to a test: those persons and companies interested in the results of a test.

peripheral flow : the volume flow rate of fluid in the area between the pipe wall and the contour defined by the velocity measurement points that are the closest to the wall; also called "annular flow."

phase-shift meter: flowmeter that works on the principle that a phase shift occurs when sound travels in a moving medium; also called a Doppler meter.

Fig. 12 Piezometer Ring



PID (proportional, integral, derivative): a controller strategy comprising the summation of proportional, integral, and derivative gain terms processing a composite error input to produce an output command for control purposes, e.g., valve position, pump speed, etc.

piezometer ring: a pressure equalization enclosure linking together two or more pressure taps installed at a given cross section, and to which a secondary device can be connected; also called a "pressure averaging ring."

NOTE: It can be integral with the pipe or the primary device or a separate structure connected to the pipe or the primary device; see Fig. 12.

pig: a mechanical device, forced axially through a pipe section for the purpose of cleaning the inside pipe walls and/or the removal construction debris.

NOTE: "Smart" pigs can identify, record, and transmit the condition of the internal surface of the pipe and location of any defect.

pipe: a tube or hollow cylindrical body, usually circular in cross section, used for the conveyance of a fluid; a closed conduit.

pipe Reynolds number: a dimensionless parameter expressing the ratio between inertia and viscous forces and referenced to the pipe inside diameter; the pipe Reynolds number is determined by velocity, density, and viscosity of the flowing fluid in the pipe. It can be determined from:

$$Re_D = \frac{4q_m}{\pi D \mu_0}$$

pipe roughness: the internal surface finish of the pipe characterized by the height of surface irregularities.

piston prover: volumetric gauging device consisting of a section of pipe with a constant cross section and of known volume. The flow rate is determined from the time taken by a piston, with free or forced displacement, to travel through this section.

NOTE: When free piston is spherical shaped, the prover is also known as a "ball prover," see Fig. 13.

pitot-static tube: a pitot tube provided with static pressure tap holes drilled at specific positions on the circumference of the cylinder that is oriented parallel to the flow direction; these holes can be located at one or more cross sections (the total pressure tap faces the flow direction at the tip of the axisymmetric nose or head of the cylinder).

NOTE: When there is no possibility of confusion, the expression "Pitot tube" without further explanation may be used to designate a Pitot-static tube.

pitot tube: tubular device consisting of a cylindrical head attached perpendicularly to a stem. It is provided with one or more pressure tap holes and it is inserted into a flowing fluid, thus giving the stagnation or static pressure.

points of mean axial fluid velocity: points in a cross section of the conduit where the local velocity of the flow is equal to the mean axial fluid velocity.

population: the totality of items under consideration.

NOTES:
(1) In the case of a random variable, the probability distribution is considered to define the population of that variable.
(2) Every clearly defined part of a population is called a subpopulation.

population parameter: s quantity used to describe the distribution of a characteristic in the population.

precision error: the random error observed in a set of replicated measurements that can be the result of a large number of different effects.

precision index: Also known as "sample standard deviation;" the computed standard deviation of the measurements.

$$S = \sqrt{\frac{\sum_{i=1}^{N}\left(X_i - \overline{X}\right)^2}{N-1}}$$

When combining multiple elemental precision indices:

$$S = \sqrt{\sum_i S_i^2}$$

pressure loss (caused by a primary device): the difference between the upstream pressure and the pressure downstream of a primary device after recovery.

pressure ratio: the ratio of the absolute static pressure at the low pressure metering tap to the absolute static pressure at the high pressure metering tap.

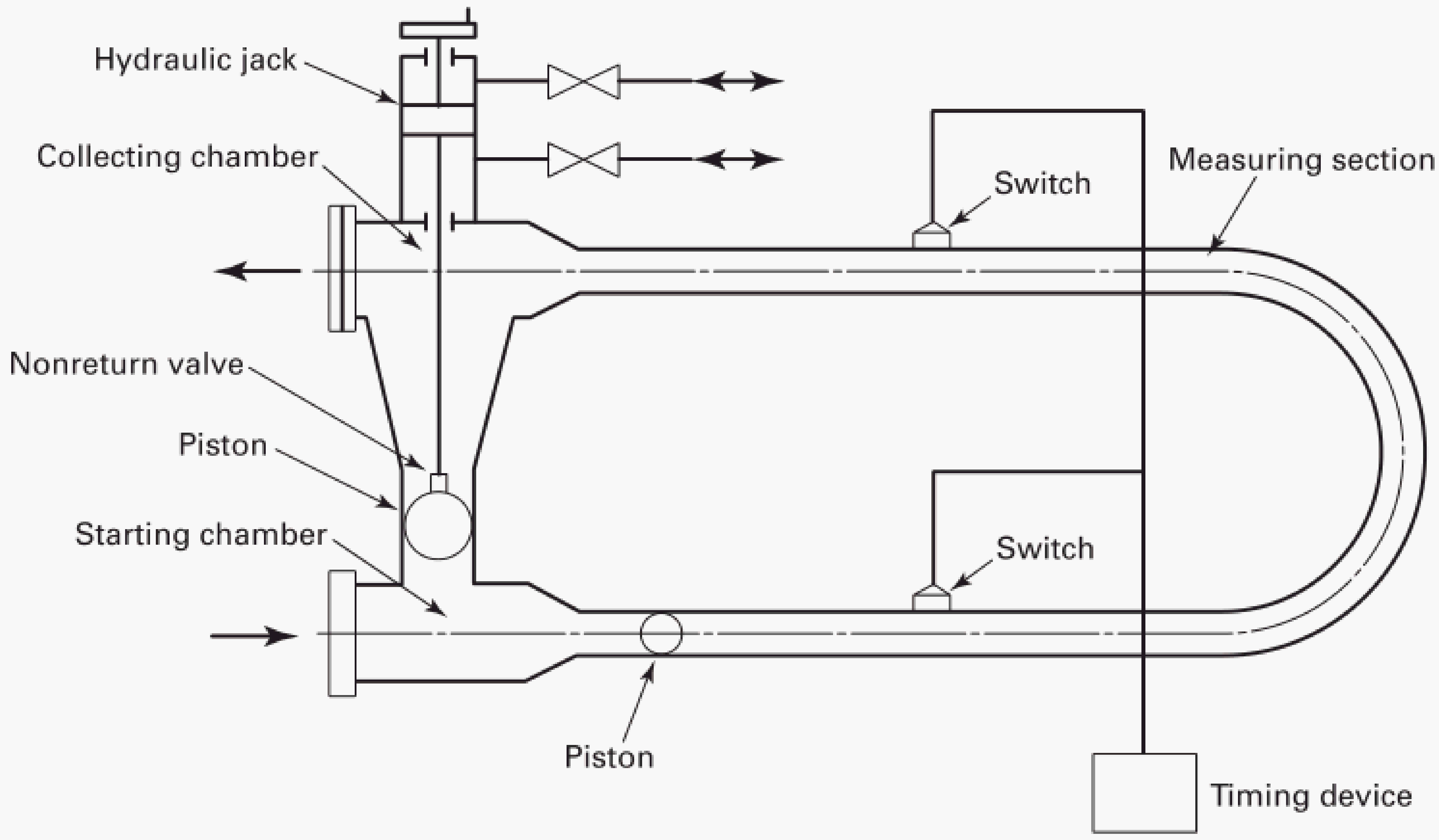
pressure tap connection: secondary instrumentation connection to pressure taps; see Fig. 14.

pressure taps (piezometer taps): hole or annular slot in a flange, fitting or the wall of a pipe, or throat of a primary device that is flush with the inside surface.

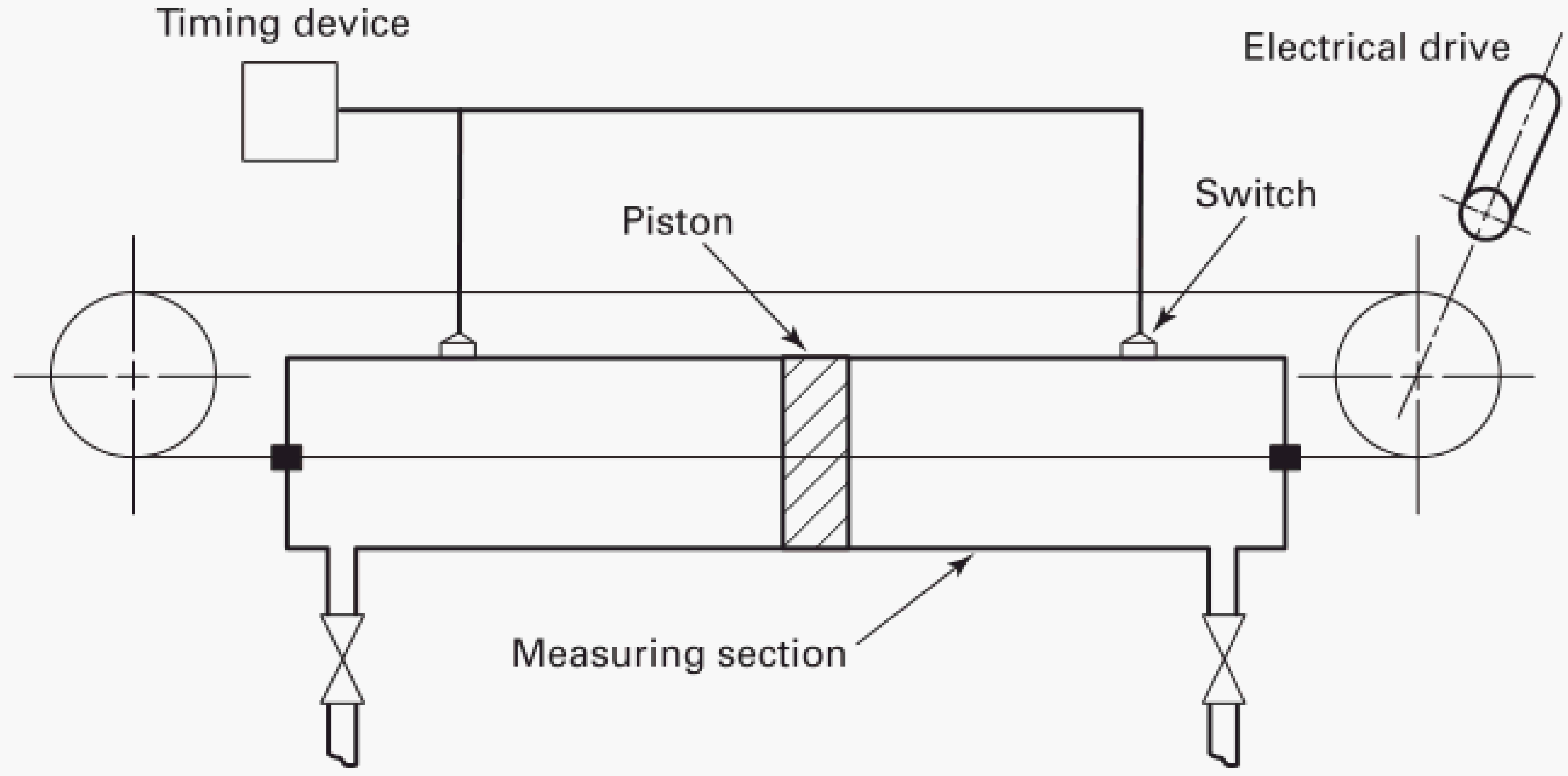
pressure test: typically, a hydrostatic pressure test that may be required for piping systems to prove the integrity of the pressure-containing parts of the piping system.

primary device: device which generates a signal enabling the determination of the flow rate.

Fig. 13 Piston Provers

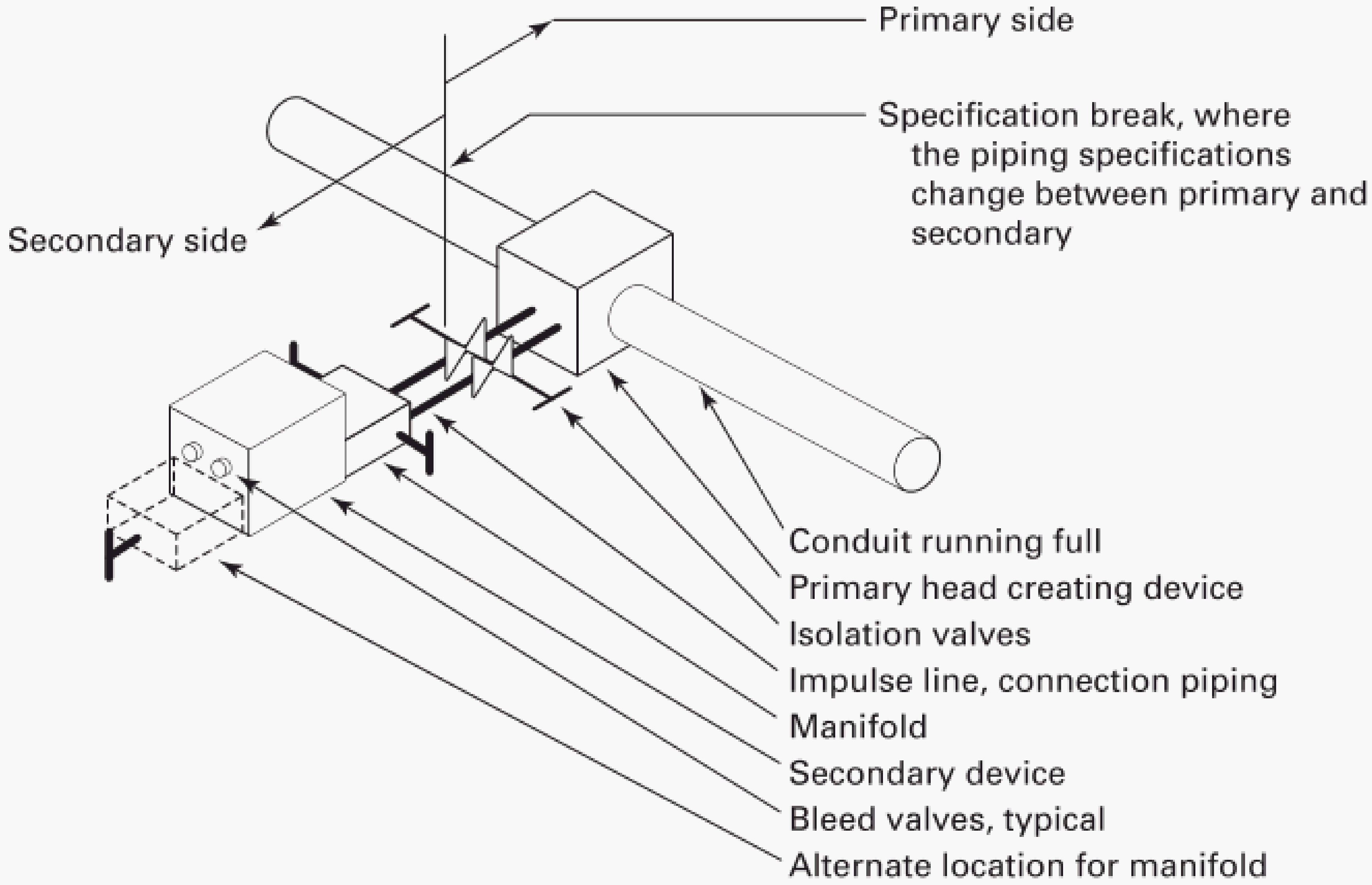


(a) Free Piston Prover



(b) Forced Piston Prover

Fig. 14 Primary and Secondary at Same Elevation, Preferred Installation



primary device (of a differential pressure meter): differential pressure producing device, inclusive of its pressure taps.

EXAMPLES: Orifice, venturi, flow nozzle, averaging pitot tube.

primary device (of an electromagnetic flowmeter): an electromagnet that produces a magnetic field (constant or time-varying) in the meter tube; the primary device develops the signal that is sensed by the electrodes.

primary device (of an ultrasonic flowmeter): device consisting of a meter tube through which the fluid to be measured flows, and a set of ultrasonic transducers used to measure the flow rate.

primary element: differential pressure producing device, inclusive of its pressure taps.

primary measurement standard: measurement standard established using a primary reference measurement procedure, or created as an artifact, chosen by convention.

EXAMPLES:

(1) Primary measurement standard for pressure based on separate measurements of force and area.

(2) The international prototype of the kilogram as an artifact, chosen by convention.

primary reference procedure: reference measurement procedure used to obtain a measurement result without relation to a measurement standard for a quantity of the same kind.

primary variables: those used in calculations of test results. They are further classified as the following:

(a) Class 1 primary variables that have a relative sensitivity coefficient of 0.2 or greater

(b) Class 2 primary variables that have a relative sensitivity coefficient of less than 0.2

primary velocity measuring device: any device that changes a local flow velocity into a physical quantity suitable for measurement (e.g., differential pressure, frequency of an electric signal).

principle of measurement: phenomenon serving as the basis of a measurement, for example, the Doppler effect applied to the measurement of velocity.

probability: a real number attached to the likelihood of a random event; expressed on a scale of 0 to 1.

probability density function (for a continuous random variable): the derivative (when it exists) of the distribution function: $f(x) = dF(x)/dx$.

NOTE: $f(x)dx$ is the "probability element," $f(x)dx = Pr(x < X < x + dx)$.

probability distribution (of a random variable): a function giving the probability that a random variable takes any given value or belongs to a given set of values.

NOTE: The probability on the whole set of values of the random variable equals 1.

probability mass function: a function giving, for each value x_i of a discrete random variable X,the probability p_i that the random variable equals x_i: $p_i = Pr(X = x_i)$.

profile regulator: flow conditioner inserted in a pipe to reduce the straight length required to achieve fully developed velocity distribution.

propeller-type current meter: current meter, the rotor of which is a propeller rotating around an axis approximately parallel to the flow.

protective device: device used to protect the integrity of a meter, including the indicating device, after calibration.

proving: the determination of meter performance by the determination of the relationship between the volume actually passed through the meter and the volume indicated by the meter.

pulsating flow of mean constant flow rate: flow in which the flow rate varies with time, but for which the mean flow rate is constant when it is averaged over a sufficiently long period of time.

NOTE: Two types of pulsating flow are found: Periodic pulsating flow and fluctuating (random) pulsating flow.

quadrant-edge orifice plate; quarter-circle orifice plate: Thin plate in which a circular, concentric aperture has been machined, the profile of which between the upstream face to the cylindrical bore is a quarter of a circle.

quadrature voltage: in electromagnetic flowmeters, that part of the electrode signal that is 90 deg out of phase with the flow signal does not vary with the flow rate.

NOTE: This definition concerns only alternating current-type (AC) electromagnetic flowmeters.

quality control: set of operations intended to maintain or to improve quality, prevent defective products and services from being released or performed, and to operate at the most economical level that allows for customer satisfaction.

quantity: property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a value and a reference (number and dimensional unit).

NOTES:
(1) The generic concept "quantity" can be divided into several levels of specific concepts, as shown in the following table. The left hand side of the table shows specific concepts under "quantity." These are generic concepts for the individual quantities in the right hand column.

Length, l	Radius, r	Radius of circle A, rA, or $r(A)$
	Wavelength, λ	Wavelength of sodium D radiation, λ_D or λ(D:Na)
Energy, E	Kinetic energy, T	Kinetic energy of particle i in a given system, Ti
	Heat, Q	Heat of vaporization of sample i in water, Qi
Electric charge, Q		Electric charge of the proton, e
Electric resistance, R		Electric resistance of the resistor i in a given circuit, Ri
Amount-of-substance concentration of entity B, cB		Amount-of-substance concentration of ethanol in wine sample i, $ci(C_2H_5OH)$
Number concentration B, CB		Number concentration of erythrocytes in blood sample i, C(Erys; Bi)
Rockwell C hardness (150 kg) HRC (150 kg)		Rockwell C hardness of steel sample i, HRCi (150 kg)

(2) A reference can be a measurement unit, a measurement procedure, a reference material, or a combination of such.
(3) A quantity as defined here is a scalar; a vector, the components of which are quantities, is also considered to be a quantity.
(4) The concept "quantity" may be generically divided into, e.g. "physical quantity," "chemical quantity," and "biological quantity," or base quantity and derived quantity.

quantity, measurable: attribute of a phenomenon, body, or substance that can be distinguished qualitatively and determined quantitatively.

NOTE: "Quantity" may be applied in a general sense (length, time, mass, temperature, etc.) or to a specific quantity (laying length of a given meter, flow rate in a given hydraulic loop, etc.).

quantity dimension: expression of the dependence of a quantity on the base quantities of a system of quantities as a product of powers of factors corresponding to the base quantities, omitting any numerical factor. For example, the quantity dimension of force is denoted by dim F = MLT^{-2}.

NOTES:
(1) In deriving the dimension of a quantity, no account is taken of its scalar, vector, or tensor character.
(2) Symbols representing the dimensions of the base quantities in the ISQ are:

Base Quantity	Symbol for Dimension
Length	L
Mass	M
Time	T
Electric current	I
Thermodynamic temperature	Ω
Amount of substance	N
Luminous intensity	J

Thus, the dimension of a quantity Q is denoted by dim $Q = L^{\alpha} M^{\beta} T^{\gamma} I^{\delta} \Omega^{\epsilon} J^{\eta}$, where the exponents, named dimensional exponents, are positive, negative, or zero.

quantity of dimension one: quantity for which all the exponents of the factors corresponding to the base quantities in its quantity dimension are zero.

NOTES:
(1) The term "dimensionless quantity" is commonly used and is kept here for historical reasons. It stems from the fact that all exponents are zero in the symbolic representation of the dimension for such quantities. The term "quantity of dimension one" reflects the convention in which the symbolic representation of the dimension for such quantities is the symbol 1 (see ISO 31-0:1992, 2.2.6).
(2) The measurement units and values of quantities of dimension one are numbers, but such quantities convey more information than a number.
(3) Some quantities of dimension one are defined as the ratios of two quantities of the same kind, such as plane angle, refractive index, specific gravity, mass fraction, friction factor, Mach number, etc.
(4) Numbers of entities are quantities of dimension one, such as the number of turns in a coil.

quantity value: value and reference (number and dimensional unit) that together express the magnitude of a quantity, i.e., 54 cm, 6 lbs, 2.72 kg, Refractive Index = 1.35, 42.2 HRC, etc.

NOTES:
(1) According to the type of reference, a quantity value can have dimensions (inches, °C, etc.), be dimensionless (a ratio), or cite a reference procedure (Rockwell C Hardness Test).
(2) The number can be complex [Electric impedance of a given circuit element at a given frequency, where j is the imaginary unit: $(7 + 3j)\ W$].
(3) In the case of vector or tensor quantities, each component will have a quantity value.

ramping rate for setpoint adjustment: the rate of change of a controlled variable expressed in setpoint units per second.

random error: result of a measurement minus the mean that would result from an infinite number of measurements of the same measurand carried out under repeatability conditions; the component of the error of measurement that, in the course of an infinite number of measurements of the same measurand carried out under repeatability conditions, varies in an unpredictable way; component of measurement error that in replicate measurements varies in an unpredictable manner.

NOTES:
(1) A reference quantity value for a random measurement error is the average that would ensue from an infinite number of replicate measurements of the same measurand.
(2) Random measurement errors of a set of replicate measurements form a distribution that can be summarized by its expectation, which is generally assumed to be zero, and its variance.
(3) Random measurement error equals measurement error minus systematic measurement error.
(4) Because only a finite number of measurements can be made it is possible to determine only an estimate of random error. It is not possible to correct for random error.

random uncertainty: the component of uncertainty associated with a random error. Its effect on mean values can be reduced by taking many measurements.

NOTE: Often, the random uncertainty is referred to as a "Type A uncertainty," but it is not entirely synonymous.

random variable: a variable that may take any of the values of a specified set of values and with which is associated a probability distribution, sometimes called "variate."

NOTES:
(1) A random variable that can take only isolated values is said to be "discrete;" that which can take any value within a finite or infinite interval is said to be "continuous."
(2) The probability of an event A is denoted by Pr (A).

rangeability: the rangeability of a flowmeter is the ratio of the maximum to minimum flow rates (Reynolds numbers, velocities, etc.) in the range over which the meter meets a specified and acceptable uncertainty, also called "turndown."

rate of flow passing through a primary device: mass or volume of fluid passing through the orifice (or throat) per unit time.

NOTE: It is necessary to state explicitly whether mass flow rate units (q_m) or volumetric flow rate units (q_v) are being used.

rated conditions: conditions of pressure, temperature, and fluid composition as specified by the manufacturer that rates the meter.

ratio of the specific heat capacities: ratio of the specific heat capacity at constant pressure (isobaric) to the specific heat capacity at constant volume (isochoric)

$$\gamma = \frac{c_p}{c_V}$$

It varies in general whenever the gas temperature and/or pressure vary.

real gas critical flow coefficient: a flow coefficient defined by the equation shown below

$$C_R = \frac{q_m\sqrt{(R/M)T_0}}{A^*P_0}$$

The real gas critical flow coefficient is often estimated by the isentropic real gas critical flow function.

reciprocating piston meter: a flowmeter consisting of one or more pistons reciprocating in one or more fixed chambers or cylinders in which the volumetric flow rate is calculated by considering the piston bore, piston stroke, and the frequency or number of piston strokes.

reference: a test facility traceable to a recognized national or international measurement standard.

reference conditions: those conditions of a test medium that are specified by either an applicable standard or an agreement between the parties to the test, which may be used for uniform reporting of measured flow test results.

reference data: data related to a property of a phenomenon, body, or substance, or to a system of components of known composition or structure, obtained from an identified source, critically evaluated, and verified for accuracy.

NOTE: In this definition, "accuracy" covers, for example, measurement accuracy and "accuracy of a nominal property value."

reference material: material, sufficiently homogeneous and stable with reference to specified properties, that has been established to be fit for its intended use in measurement or in examination of nominal properties.

NOTES:
(1) Examination of a nominal property provides a nominal property value and associated uncertainty: This uncertainty is not a measurement uncertainty.
(2) Reference materials with or without assigned quantity values can be used for measurement precision control whereas only

reference materials with assigned quantity values can be used for calibration or measurement trueness control.
(3) "Reference material" comprises materials embodying quantities as well as nominal properties.

EXAMPLES:
(1) Water of stated purity, the dynamic viscosity of which is used to calibrate viscometers, is an example of a reference material embodying quantities.
(2) Steel with a stated minimum yield strength is an example of a reference material embodying nominal properties.
(4) A reference material is sometimes incorporated into a specially fabricated device.
(5) In a given measurement, a given reference material can only be used for either calibration or quality assurance.
(6) The specifications of a reference material should include its material traceability, indicating its origin and processing.

reference measurement procedure: measurement procedure accepted as providing measurement results fit for their intended use in assessing measurement trueness of measured quantity values obtained from other measurement procedures for quantities of the same kind, in calibration, or in characterizing reference materials.

reference measurement standard: measurement standard designated for the calibration of other measurement standards for quantities of a given kind, in a given organization, or at a given location, sometimes referred to as "reference standard."

reference operating condition: operating condition prescribed for evaluating the performance of a measuring instrument or measuring system, or for comparison of measurement results, sometimes referred to as "reference condition."

NOTE: Reference operating conditions specify intervals of values of the measurand and of the influence quantities.

reference quantity value: quantity value used as a basis for comparison with values of quantities of the same kind, sometimes referred to as "reference value."

NOTES:
(1) A reference quantity value can be a true quantity value of a measurand (in which case it is unknown), or a conventional quantity value (in which case it is defined and known).
(2) A reference quantity value with associated measurement uncertainty is usually provided with reference to: a material, a device, a reference measurement procedure, and/or a comparison of measurement standards.

reference signal: in an electromagnetic flowmeter, the signal proportional to the magnetic flux of the primary device that is compared in the secondary device with the flow signal.

reflecting surface: in an ultrasonic meter, an acoustically nonabsorptive (acoustically hard) surface.

refractive system: an ultrasonic flowmeter in which the acoustic path crosses the solid/process fluid interfaces at other than a right angle.

regression: process of quantifying the dependence of one variable on one or more other variables. Regression is a procedure for determining the unknown constants of a proposed model in such a manner that predictions from the model are as close as possible to the data in some way. Often, "as close as possible" is taken to mean that the sum of squares of the deviations is a minimum. Many of the available computer programs suitable for curve fitting have the word regression in the title. For the purpose of this Standard, regression and least squares may be regarded as synonymous.

regular velocity distribution: distribution of velocities which sufficiently approaches a fully developed velocity distribution to permit an accurate measurement of the flow rate to be made.

relative error: error of measurement divided by a true value of the measurand.

NOTES:
(1) Since a true value cannot be determined, a conventional true value or reference is used in practice.
(2) Often expressed as a percentage.

relative standard measurement uncertainty: standard measurement uncertainty divided by the absolute value of the measured quantity value.

relative velocity: the ratio of a flow velocity at a given point to a reference velocity measured at the same time. The reference velocity may be measured at a particular point (e.g., the centerline velocity) or may be the discharge velocity.

repeatability, qualitative: closeness of agreement among a series of results obtained with the same method on identical test material, under the same conditions (same operator, same apparatus, same laboratory, and short intervals of time).

NOTE: The representative parameters of the dispersion of the population that may be associated with the results are qualified by the term repeatability.

EXAMPLES:
(1) Standard deviation of repeatability.
(2) Variance of repeatability.

repeatability, quantitative: closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement.

NOTES:
(1) These conditions are called repeatability conditions.
(2) Repeatability conditions include the same measurement procedure, using the same measuring instrument under the same conditions with the same observer in the same location, repeated over a short period of time.
(3) Repeatability may be expressed quantitatively in terms of the dispersion characteristics of the results.

reproducibility, qualitative: closeness of agreement between results obtained when the conditions of measurement differ; for example, with respect to different test apparatus, operators, facilities, time intervals, etc.

A complete statement of reproducibility should include a description of the conditions of measurement.

reproducibility, quantitative: closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions of measurement.

NOTES:
(1) A valid statement of reproducibility requires specification of the conditions that have changed.
(2) The changed conditions may include the principle or method of measurement, the observer, the measuring instrument(s), the reference standard(s), the time and location, and/or the conditions of use.
(3) Reproducibility may be expressed quantitatively in terms of the dispersion characteristics of the results.
(4) Results are here usually understood to be corrected results.

reproducibility condition (qualitative): condition of measurement, out of a set of conditions that includes different locations, operators, measuring systems, and replicate measurements on the same or similar objects.

NOTES:
(1) The different measuring systems may use different measurement procedures.
(2) A specification should give the conditions changed and unchanged, to the extent practical.

residual standard deviation: also known as the *standard error of the estimate*; the measure of dispersion of the dependent variable (output) about the least-squares line obtained by curve fitting or regression analysis, it is the precision index of the output for any fixed level of the independent variable input. For a curve based on n data points and for which the equation has a number k of coefficients, the standard error of estimate is calculated as follows:

$$S_R = \sqrt{\frac{\sum_{i=1}^{N}(y_i - \hat{y})^2}{n-k}}$$

NOTE: This equation is similar to the expression for standard deviation except that the curve-fit value $\hat{y}$ replaces the mean value $\bar{y}$ and k replaces 1.

residual variance: The square of the residual standard deviation.

$$S_R{}^2 = \frac{\sum_{i=1}^{N}(y_i - \hat{y})^2}{n-k}$$

resolution: smallest change in a quantity being measured that causes a perceptible change in the corresponding indication.

NOTE: Resolution may depend on, for example, noise (internal or external). It may also depend on the magnitude of a quantity being measured.

response time: The time interval between specified process change and the instant when the response of the instrumentation reaches and remains within specified limits around its final steady value.

EXAMPLE: 0.5 s to reach and remain within 1% of the steady value following an abrupt change from 90% of full scale to 10% of full scale.

NOTE: The "time constant" is a special case of response time that indicates the dynamic behavior is completely described by a first order differential equation in time.

result of a measurement: value attributed to a measurand, obtained by measurement.

NOTES:
(1) When a result is given, it should be made clear whether it refers to the indication, the uncorrected result, or the corrected result, and whether multiple values have been averaged.
(2) A complete statement of the result of a measurement includes information about the uncertainty of measurement.

reversible Cole pitometer: a special type of pitot tube in which the low pressure tap and total pressure tap are identical holes facing in opposite directions.

reversible meter: a meter that may be operated in a direction contrary to the normal direction of flow with the accuracy staying within the maximum permissible error limits, also called a bidirectional meter.

Reynolds number: a dimensionless parameter expressing the ratio between inertia and viscous forces and referenced to some pertinent characteristic dimension, e.g., diameter of the pipe, diameter of the bore of a differential pressure device, diameter of the Pitot tube shaft, etc.; the Reynolds number is determined by velocity, density, and viscosity of the flowing fluid at the characteristic dimension of the device and is given by the general formula

$$Re = \frac{U\ell}{v}$$

where

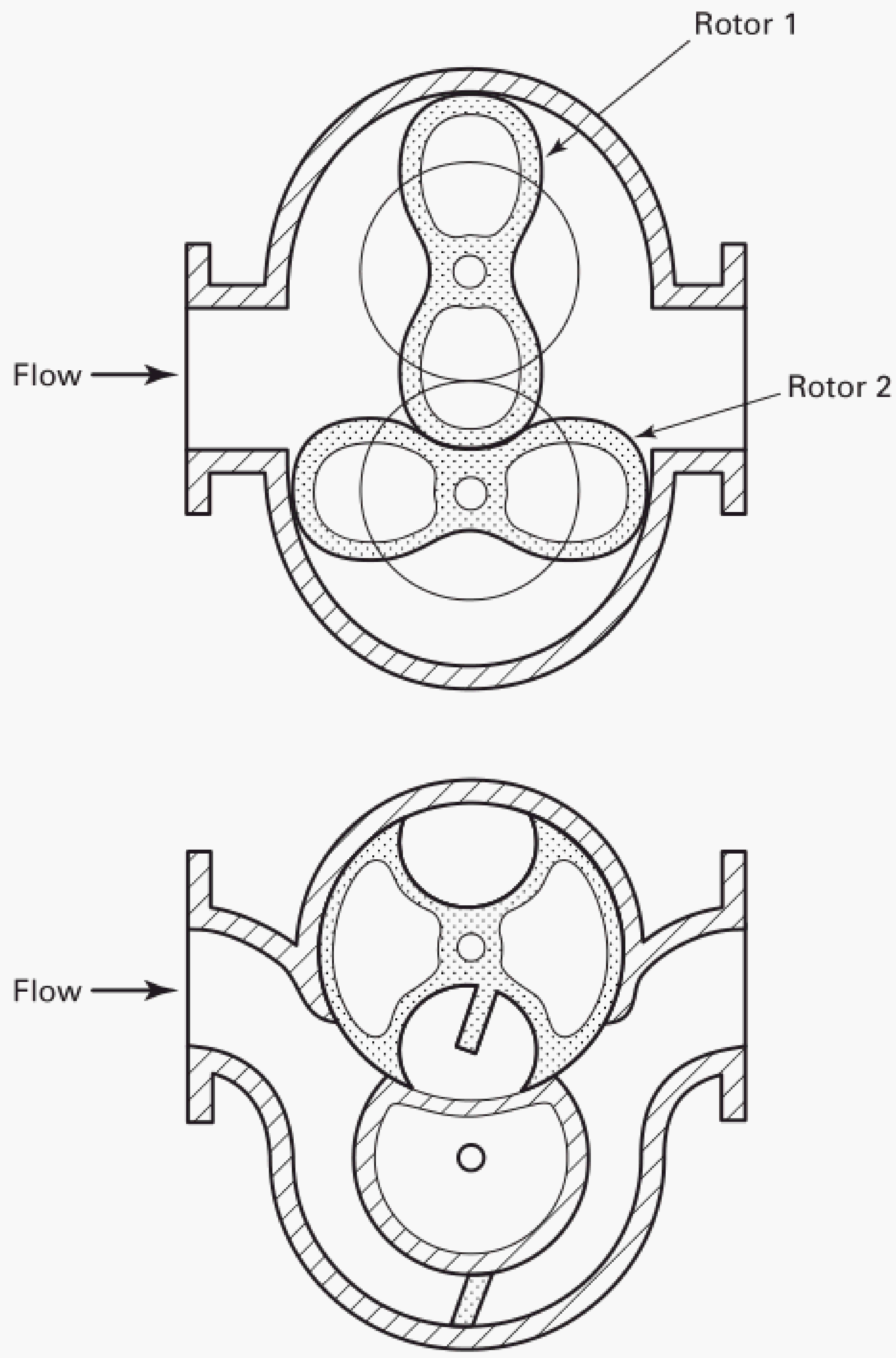
ℓ = characteristic dimension of the system in which the flow occurs
U = average spatial fluid velocity
v = kinematic viscosity of the fluid

NOTE: The above formula is in a generalized form; other formulae, specific to a given application, device, flow units, etc., given in various standards are (or should be) derived from this one.

ring balance: volumetric gauging device, used for small gas flow rates, in which a known volume of gas is displaced by a sealing liquid that partly fills an annular chamber, causing the ring to rotate by a counterweight.

rod out: the use of a rod or other physical device to remove materials blocking the free flow of fluid from a pressure or sampling tap into impulse or sampling lines,

Fig. 15 Examples of Rotary Displacement Meters



alternately referred to as a "tap cleaner" or "bayonet cleaner."

NOTE: Some installations require provision for rodding out of the process connections. Observe the applicable safety precautions.

rotary displacement meter: meter in which the measuring chamber is formed between the walls of a stationary chamber and an element or elements that are rotated by the fluid flow. The leakage between the rotating element(s) and the walls is negligible compared with the flows within the preferred working range. The rotation of the element(s) is transmitted mechanically or otherwise to an indicating device which registers the volume flow; see Fig. 15.

rotary meter: inferential flowmeter comprising a vane-type anemometer that is placed in the fluid stream.

rotary positive displacement meter, lobed-type: a flowmeter consisting of two rotors or impellers, each with two or more lobes mounted so as to rotate with almost rolling contact, in a manner similar to gears. The inner surface of the case and the impeller tips have minimal clearance.

rotary positive displacement meter, piston- or vane-type: a flowmeter having one or more vanes that serve as rotary or movable partitions for separating the fluid segments. The vanes must make almost wiping contact with the walls of the measuring chamber, and the axis of rotation may or may not coincide with that of the chamber. The portion of the chamber in which the fluid is measured usually includes about 270 deg. In the remaining 90 deg, the vanes are returned to the starting position by the use of an idle rotor, gear, or cam, or a radial partition.

roughness profile: arithmetical mean deviation from the mean line of the profile being measured; the mean line is such that the sum of the squares of the distances between the effective surface and the mean line is minimized. In practice, R_a can be measured with standard equipment for machined surfaces but can only be estimated for rougher surfaces of pipes.

NOTE: For pipes, the uniform equivalent roughness may also be used. This value can be determined experimentally or taken from tables.

sample: one or more items taken from a population and intended to provide information regarding the population; a sample typically serves as a basis for a decision about the population or the process which produced it.

sample size: the number of observations that are to be included in the sample.

sampling cross section: a cross section of the pipe, located downstream of the injection cross section, at which samples are taken or in which concentration is directly measured, also called "station."

sampling error: part of the total estimation error of a parameter due to the random nature of the sample.

seal pot: chambers containing a liquid that separates the metered fluid from a fluid (typically thermally and chemically inert) in the secondary device.

secondary containment: housing designed to provide protection to the environment if the sensor tube(s) of a coriolis meter fails.

secondary device: a device that receives a signal from the primary device and displays, records, and/or transmits it as a measure of the flow rate.

NOTE: In an electromagnetic flowmeter, the secondary device extracts the flow signal from the electrode signal and converts it to a standardized output signal proportional to flow rate.

secondary measurement standard: measurement standard established through calibration with respect to a primary measurement standard for a quantity of the same kind.

NOTES:
(1) Calibration may be obtained directly between a primary measurement standard and a secondary measurement standard, or involve an intermediate measuring system calibrated by the primary measurement standard and assigning a measurement result to the secondary measurement standard.

(2) A measurement standard having its quantity value assigned by a ratio primary reference measurement procedure is a secondary measurement standard.

secondary variables: variables that may be measured but do not enter into the calculation.

segmental orifice plate: thin orifice plate, the orifice of which has the shape of a segment of a circle, typically tangent to the inside surface of the bottom or top of the pipe.

selectivity of a measuring system: property of a measuring system, used with a specified measurement procedure, whereby it provides measured quantity values for one or more measurands such that the values of each measurand are independent of other measurands; sometimes simply called "selectivity."

EXAMPLE: Capability of a receiver to discriminate between a wanted signal and unwanted signals, often having frequencies slightly different from the frequency of the wanted signal.

self-compensating propeller: propeller of a current meter designed in such a way that its speed of rotation is proportional to the component of the fluid velocity coaxial with the current meter throughout a wide range of approach angles of the velocity vector relative to the current meter axis.

sensitivity (influence) coefficient: ratio of the change in a result R to the change in an input parameter x

$$\theta_x = \frac{\Delta R}{\Delta x}$$

which, in relative terms this becomes

$$\theta_x' = \frac{(\Delta R/R)}{(\Delta x/x)}$$

sensitivity of a measuring system: the change in an indication of a measuring system relative to the corresponding change in a value of a quantity being measured; may be expressed as a percentage or in flow units; sometimes simply called "sensitivity."

NOTE: The change considered in a value of a quantity being measured must be large compared with the resolution.

sensor: element of a measuring system that is directly affected by a phenomenon, body, or substance carrying a quantity to be measured, e.g., rotor of a turbine flowmeter, Bourdon tube of a pressure gauge, float of a level-measuring instrument.

NOTE: In some fields, the term "detector" is used for this concept.

shunt meter: meter in which the fluid stream is divided into two parts which have a given volumetric ratio to one another. The total volume is deduced from the measurement of the smaller stream.

sing-around: method used in ultrasonic flowmeters whereby two independent streams of pulses are transmitted in opposite directions. Each pulse is emitted immediately after the detection of the preceding pulse in the stream. The difference between the pulse repetition frequency in the two directions is measured and is a function of the fluid velocity.

Fig. 16 Sonic Venturi Nozzle, LMEF Type

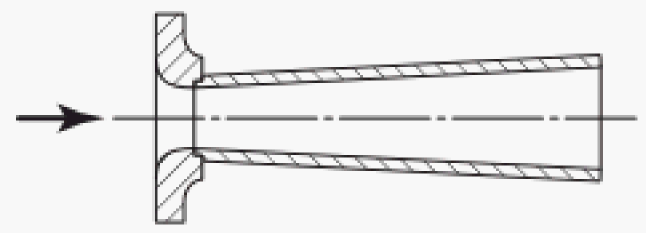
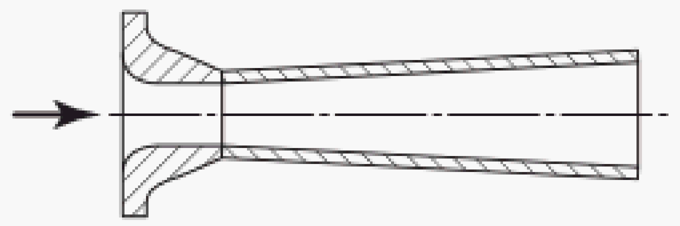


Fig. 17 Sonic Venturi Nozzle, Smith and Matz Type



single-path diagonal-beam meter: ultrasonic flowmeter which sends an ultrasonic signal between two transducers. Either the phase shift or the difference in time of flight between the beams emitted upstream and downstream is measured and used to calculate the flow rate.

sonic nozzle: a nozzle whose geometric profile and conditions of use are such that it produces critical flow.

sonic venturi nozzle: sonic nozzle fitted with a divergent portion so that the pressure loss through the device is reduced.

sonic venturi nozzle, LMEF type: a venturi nozzle consisting of a toroidal convergent section, a cylindrical throat, and a conical divergent section; see Fig. 16.

sonic venturi nozzle, Smith and Matz type: a venturi nozzle consisting of a toroidal convergent section and a conical divergent section; see Fig. 17.

specification break: the change in piping specifications between process (or primary) and the instrument (or secondary) side (typically at the secondary end connection of the process valve).

NOTE: If the process piping specification requires flanged connection, then the process end of this valve is flanged and the mating flange on the secondary side is an instrument connection or may have another approved fitting.

specific fuel consumption: fuel consumption rate per unit of power output; can be expressed in terms of volume or mass per unit of power output.

specific gravity: the ratio of the density of the flowing fluid to the density of some other substance taken as standard (usually water is the standard for liquids and air is the standard for gases); sometimes referred to as *relative density.*

specific volume: the volume of matter per unit mass; the reciprocal of the density.

specified reference conditions: the values of all the conditions to which the test results are corrected.

spin test of a current meter: a test in which the rotor of a current meter is spun either with the fingers or by blowing into its axis to check that it rotates freely and uniformly.

spring-loaded variable-head meter: flowmeter in which the force tending to close the orifice is provided by a spring. In some models the displacement of the plug provides the readout, and in others the readout is the differential pressure.

spurious errors: errors that invalidate a measurement; generally have a single cause such as the incorrect recording of significant digits or instrument malfunction.

square-edged orifice plate: thin plate in which a circular, concentric aperture has been machined, the leading edge of which is sharp and square.

NOTE: Standard orifice plates are described as "thin plate" because the thickness of the plate is small compared with the diameter of the measuring section. Standard orifice plates are also described as "with sharp square edge" because the upstream edge of the orifice is sharp and square.

stability of a measuring instrument: property of a measuring instrument, whereby its metrological properties remain constant in time.

NOTE: Stability may be quantified in terms of the duration of a time interval over which a metrological property changes by a stated amount or in terms of the change of a property over a stated time interval.

stagnation pressure: the pressure corresponding to that obtained when bringing the fluid to a standstill without any increase in entropy, also known as "total pressure."

NOTE: It is equal to the sum of the absolute static pressure and the dynamic pressure; for a fluid at rest, the absolute static pressure and the stagnation pressure have the same numerical value.

stagnation pressure of a gas: pressure that would exist in the gas if the flowing gas stream were brought to rest by an isentropic process; usually expressed in absolute terms (psia, kPa).

stagnation temperature of a gas: the temperature that would exist in the gas if the flowing gas stream were brought to rest by an adiabatic process; usually expressed in absolute terms (°R, K).

standard atmospheric conditions: 14.696 psia (101.325 kPa), 59°F (288.15 K), and relative humidity of 60%.

standard deviation: The positive square root of the variance and the most widely used measure of dispersion of the frequency distribution of a population. It may be shown mathematically that with a Gaussian (normal) distribution, the mean value, plus and minus 1.96 standard deviations, will include 95% of the sample population.

NOTES:
(1) The sample standard deviation is a biased estimator of the population standard deviation.
(2) The precision index, S, calculated from a sample taken from the population, is an estimate of the standard deviation, σ.
(3) Whereas a Type A standard uncertainty is obtained by taking the square root of the statistically evaluated variance, it is often more convenient when determining a Type B standard uncertainty to evaluate a nonstatistical equivalent standard deviation first and then to obtain the equivalent variance by squaring the standard deviation.

standard error: the standard deviation of an estimator; the standard error provides an estimation of the random part of the total estimation error involved in estimating a population parameter from a sample.

standard error of estimate: the measure of dispersion of the dependent variable (output) about the least-squares line obtained by curve fitting or regression analysis, it is the precision index of the output for any fixed level of the independent variable input, also known as the "residual standard deviation." For a curve based on n data points and for which the equation has a number k of coefficients, the standard error of estimate is calculated as follows:

$$S_R = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y})^2}{n-k}}$$

NOTE: This equation is similar to the expression for standard deviation except that the curve-fit value $\hat{y}$ replaces the mean value $\bar{y}$ and k replaces 1.

standard error of the mean: an estimate of the scatter in a set of sample means based on a given sample of size N. The sample standard deviation, S, is estimated as

$$S = \sqrt{\frac{\sum_i \left(X_i - \overline{X}\right)^2}{N-1}}$$

then the standard error of the mean is

$$S_{\overline{X}} = \frac{S}{\sqrt{N}}$$

In the limit, as N becomes large, the estimated standard error of the mean converges to zero, while standard deviation converges to a fixed nonzero value.

standard measurement uncertainty: measurement uncertainty expressed as a single standard deviation, also referred to as "standard uncertainty of measurement" or "standard uncertainty."

standard reference data: source information, values, etc., issued by a recognized authority.

EXAMPLES: Values of the fundamental physical constants, as regularly evaluated and published by ICSU CODATA (International Council for Science, Committee on Data for Science & Technology); relative atomic mass values, also called atomic weight values, of the elements, as published by IUPAC-CIAAW (International Union of Pure and Applied Chemistry — Commission on Isotopic Abundances and Atomic Weights).

standard temperature and pressure (STP): typically defined as 15°C (59°F) and 101.325 kPa (14.696 psia), standard temperature and pressure conditions are often defined by contract and/or application.

standard uncertainty: uncertainty of the result of a measurement expressed as a standard deviation.

static gauging: a method by which the net volume of liquid collected is deduced from measurements of liquid levels, or gaugings, made before and after the liquid has been diverted for a measured time interval into the collection (gauging) tank to determine the volume collected in the tank.

static pressure: pressure of a fluid that is independent of the kinetic energy of the fluid.

static pressure of a fluid (flowing through a differential pressure primary device): pressure measured at a wall pressure tap in the plane of the differential pressure tap.

static pressure tap: pressure passage, typically a circular hole drilled in the wall of a conduit in such a way that the edge of the hole is flush with the internal surface of the conduit and the pressure measured does not include nonaxial velocity effects; a set of holes in a pitot tube positioned so as to measure the static pressure of the surrounding fluid.

NOTE: The pressure passage is usually circular, but in some orifice meter configurations, it may be an annular slot.

static temperature of a gas: the actual temperature of a flowing gas, usually expressed in K or °R.

static weighing: weighing method in which the net mass of the fluid collected is deduced from the tare and gross weights determined respectively before and after the fluid has been diverted for a measured time interval into the weighing tank.

stationary rake: a set of local sensors mounted on one or more fixed stems that simultaneously measure or infer the point velocities at more than one location across the measuring cross section.

statistic: a function of the observed values taken from a sample population; a parameter value based on data, e.g., a sample mean and standard deviation are statistics.

NOTE: The bias limit, a judgment, is not a statistic.

statistical coverage interval: an interval for which it can be stated with a given level of confidence that it contains at least a specified proportion of the population.

NOTES:

(1) When both limits are defined by statistics, the interval is two-sided. When one of the two limits is not finite or consists of the boundary of the variable, the interval is one-sided.

(2) Also called "statistical tolerance interval" or "statistical confidence interval." This term should not be used because it may cause confusion with "tolerance interval" which is defined in ISO 3534-2.

statistical quality control: quality control using statistical methods, such as control charts and sampling plans.

statistical quality control charts: a plot of the results of repeated sampling versus time. The central tendency and upper and lower limits are marked. Points outside the limits and trends and sequences in the points indicate nonrandom conditions.

steady flow: flow in which the flow rate in a measuring section is constant with the measurement uncertainty and over the time period of interest, aside from variations related to natural turbulence generated within the pipe.

NOTE: The steady flows observed in pipes are, in practice, flows in which quantities such as velocity, pressure, mass, density, and temperature vary in time about mean values that are independent of time; these are actually statistically steady flows.

steady-state operating condition: operating condition of a measuring instrument or measuring system in which the relation established by calibration remains valid even for a measurand varying with time.

steam trap: a device which permits the removal of condensate and air and other noncondensable gases, for steam systems at or below saturated steam temperature and prevents or limits the discharge of live steam.

step response time: duration between the instant when an input quantity value of a measuring instrument or measuring system is subjected to an abrupt change between two specified constant quantity values and the instant when a corresponding indication settles within specified limits around its final steady value.

straight (pipe) length: a portion of a pipe whose axis is straight, and in which the cross-sectional area and cross-sectional shape are constant.

Strouhal number: a dimensionless parameter that is relevant to characterizing flowmeters having a cyclic output such as a turbine meter or vortex shedding device For vortex meters, the Strouhal number relates the measured vortex shedding frequency to the velocity and the bluff body characteristic dimension. It is given by

$$St = \frac{f \times L}{U}$$

where

f = frequency
L = characteristic length
U = velocity

NOTE: In practice, a vortex meter's K-factor, which is not dimensionless, replaces the Strouhal number as the significant parameter.

Student's t-distribution: the probability distribution of a continuous random variable t whose probability density function is

$$p(t,\nu) = \frac{1}{\sqrt{\pi\nu}} \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\Gamma\left(\frac{\nu}{2}\right)} \left(1+\frac{t^2}{\nu}\right)^{-(\nu+1)/2}$$

$$-\infty < t < +\infty$$

where Γ is the gamma function and $v > 0$. The expectation of the t-distribution is zero and its variance is $v/(v-2)$ for $v > 2$.

As $v \rightarrow \infty$, the t-distribution approaches a normal distribution with $\mu = 0$ and $s = 1$.

The probability distribution of the variable $(\bar{z} - \mu_z)/s(\bar{z})$ is the t-distribution if the random variable z is normally distributed with expectation μ_z, where $\bar{z}$ is the arithmetic mean of n independent observations z_i of z, $s(z_i)$ is the experimental standard deviation of the n observations, and $s(\bar{z}) = s(z_i)/\sqrt{n}$ is the experimental standard deviation of the mean $\bar{z}$ with $v = n - 1$ degrees of freedom.

supporting structure: support for the oscillating tube(s) of a coriolis flowmeter.

swirl angle: angle between the local velocity vector at a particular point of the cross section and the conduit axis. The swirl angle varies over the cross section.

swirling flow: flow that has axial and circumferential velocity components.

swirl reducer: device inserted in a conduit to eliminate or reduce circumferential velocity components.

systematic measurement error: component of measurement error that in replicate measurements remains constant or varies in a predictable manner, also called "systematic error of measurement" or "systematic error."

NOTES:
(1) A reference quantity value for a systematic measurement error is a true quantity value, or a measured quantity value of a measurement standard of negligible measurement uncertainty, or a conventional quantity value.
(2) Systematic measurement error, and its causes, can be known or unknown. A correction can be applied to compensate for a known systematic measurement error.
(3) Systematic measurement error equals measurement error minus random measurement error.

systematic uncertainty: the error associated with systematic errors, i.e., those that remain constant or vary in a predictable manner and cannot be reduced by increasing the number of measurements under identical conditions (also known as bias).

t-distribution; Student's distribution: see Student's t-distribution.

Taylor series: a power series to calculate the value of a function at a point in the region of some reference point. The series expresses the difference or differential between the new point and the reference point in terms of the successive derivatives of the function. Its form is

$$f(x) - f(a) = \sum_{r=1}^{r=n-1} \frac{(x-a)^r}{r!} f^r(a) + R_n$$

where $f^r(a)$ denotes the value of the r^{th} derivative of $f(x)$ at the reference point $i = a$. Commonly, if the series converges, the remainder R_n is made infinitesimal by selecting an arbitrary number of terms, and usually only the first term is used.

test: an operation made in order to measure or classify a characteristic.

test run: group of readings taken over a specific time period over which operating conditions remain constant or nearly so.

test uncertainty: uncertainty associated with a corrected test result.

thin orifice plate: a plate, the thickness of which is small in comparison to the diameter of the pipe, and which contains a circular orifice concentric with the pipe axis.

NOTE: For measuring flow rate in either direction, a symmetrical orifice plate can be used for which the two edges comply with the characteristics of the upstream edge, and for which the thickness of the plate does not exceed that of the orifice.

throat: the minimum diameter section of a venturi, nozzle, or orifice.

throat area: the minimum cross-sectional flow area of a venturi, nozzle, or orifice, also known as "bore area."

throat diameter: the minimum diameter of a venturi, nozzle, or orifice, also known as "bore diameter."

throat Reynolds number: a dimensionless parameter expressing the ratio between inertia and viscous forces and referenced to the throat diameter of the venturi, nozzle, or orifice; the throat Reynolds number is determined by velocity, density, and viscosity of the flowing fluid at the throat cross section of the device. It can be determined from:

$$Re_d = \frac{4q_m}{\pi d \mu_0}$$

time-of-flight ultrasonic meter: ultrasonic flowmeter where the time difference between an ultrasonic signal traveling upstream and one traveling downstream is used to calculate the fluid velocity and determine the flow rate.

NOTE: Such flowmeters are most commonly of the diagonal-beam type, but can be of the longitudinal-beam type if the piping associated with the flowmeter incorporates a change in direction of flow at each end of the flowmeter.

time of passage of the tracer cloud: the time that elapses between the detection of the first and last particle of a tracer cloud passing through a given cross section.

toroidal throat venturi nozzle: device consisting of a toroidal convergence connected to a conical divergence fit (also known as a Smith and Matz venturi nozzle).

total estimation error: the difference between the calculated value of the estimator and the true value of this parameter used in the estimation of a parameter.

NOTE: Total estimation of error may be due to sampling error, measurement error, rounding errors, a bias or systematic error in the estimator, etc.

total pressure: sum of the static pressure and the dynamic pressure. It characterizes the state of the fluid when its kinetic energy is completely transformed into potential energy, also known as "stagnation pressure."

NOTE: For a fluid at rest, the static (gauge) pressure and the total pressure have the same numerical value.

total pressure pitot tube: a pitot tube with only a total pressure tap hole.

NOTE: A total pressure pitot tube is generally associated with a separate static pressure tap located on the pipe wall.

total pressure tap: A hole in a pitot tube enabling the measurement of the stagnation pressure of the fluid.

traceability: property of a result of measurement whereby it can be related to appropriate standards, generally international or national standards, through an unbroken chain of comparisons. In the United States, the unbroken chain of comparison is generally with standards at the National Institute for Standards and Technology (NIST) or at a state agency for Weights and Measures.

NOTE: Measurements have traceability if and only if scientifically rigorous evidence is produced on a continuing basis to show that the measurement process is producing measurement results (i.e., data) for which the total measurement uncertainty is quantified.

tracer methods: techniques of measuring the flow rate that involve the injection and detection of a tracer (chemical or radioactive substance) in the flow.

transducer: an active component for converting mechanical, thermal, or other stimuli into an electrical signal, and vice versa. It can be used to measure and/or produce quantities such as acoustic stimulation (pressure waves), pressure, heat, and force.

transfer standard: a laboratory instrument that is used to calibrate working standards and that is periodically calibrated against the laboratory standard.

transition flow: flow exhibiting characteristics of both laminar flow and turbulent flow.

NOTE: For a transition flow, the Reynolds number referred to the pipe diameter is generally between a lower limit of 2 000 and an upper limit that varies between 4 000 and 12 000, dependent on the pipe roughness and other factors.

transit time: the time required for an acoustic signal to traverse an acoustic path.

transit time meter: ultrasonic flowmeter where the time difference between an ultrasonic signal traveling upstream and one traveling downstream is used to calculate the fluid velocity and determine the flow rate.

NOTE: Such flowmeters are most commonly of the diagonal-beam type, but can be of the longitudinal-beam type if the piping associated with the flowmeter incorporates a change in direction of flow at each end of the flowmeter.

transit time method: technique in which the flow rate is deduced from the measurement of the time taken by the tracer to flow between two measuring cross sections.

transit time of the tracer cloud: time that elapses between the detection of the first and last particle of a tracer cloud passing through a given cross section.

transmitter: system that transforms the signals from the flow sensor to give an output(s) of measured and inferred parameters, such as flow rate or differential pressure, also referred to as "secondary device."

NOTES:

(1) The secondary system may provide corrections derived from parameters such as temperature and pressure.
(2) The secondary system may provide the drive signal for some flowmeters, such as Coriolis and electromagnetic flowmeters.
(3) The secondary system is typically electronic, but some secondaries for use with differential pressure producing primaries may have a pneumatic pressure output.

traveling measurement standard: measurement standard, sometimes of special construction, intended for transport between different locations.

EXAMPLE: Portable (battery-powered) frequency measurement standard.

true quantity value: quantity value consistent with the definition of a quantity, either by characterizing a quantity perfectly or utilizing an agreed on reference value;

also referred to as "true value of a quantity" or "true value."

NOTES:

(1) In the "Error Approach" to describing measurement, a true quantity value is considered unique and, in practice, unknowable. The "Uncertainty Approach" recognizes that, due to the inherently incomplete amount of detail in the definition of a quantity, there is not a single true quantity value but rather a set of true quantity values consistent with the definition. This set of values is, however, unknowable in principle and in practice. Other approaches dispense altogether with the concept of true quantity value and rely on the concept of metrological compatibility of measurement results for assessing their validity.

(2) In the special case of a fundamental constant, the quantity is considered to have a single true quantity value.

(3) When the definitional uncertainty associated with the measurand is considered to be negligible compared to the other components of the measurement uncertainty, the measurand may be considered to have an "essentially unique" true quantity value (this is the approach taken by the GUM and associated documents, where the word "true" is considered to be redundant).

truncated venturi tube: a venturi tube for which the outlet diameter of the divergent section is less than the inside diameter of the pipe in which it is inserted.

turbine meter: a flow measuring device with a rotor that responds to the velocity of flowing fluid in closed conduit. The flowing fluid causes the rotor to move with a tangential velocity that is linearly proportional to the volumetric flow rate.

turbulent flow: flow under conditions where forces due to inertia are significantly greater than forces due to viscosity; flow conditions where adjacent fluid particles do not move along essentially parallel paths.

NOTE: Turbulent flow is a flow in which irregular (random) velocity fluctuations in time and space are superimposed on the mean flow.

turndown: a numerical indication of the rangeability of a flowmeter relative to the maximum and minimum flow rates for which the meter provides the requisite performance; calculated as q_{max}/q_{min}.

Type A component of uncertainty: a constituent of the measurement uncertainty that can be evaluated using statistical methods.

NOTE: There is not always a direct correspondence between the classification of uncertainty components categorized as "Type A" and "Type B" to the "random" and "systematic" terms that have been used historically. The nature of an uncertainty component depends on how that uncertainty component is employed in the mathematical model that describes the measurement process. If the uncertainty model properly characterizes a given component is to be used in a certain manner, a "random" component may have a "systematic" effect and vice versa. The terms "random uncertainty" and "systematic uncertainty," therefore, can be misleading when used independent of the mathematical model that describes the measurement process.

Type B component of uncertainty: a constituent of the measurement uncertainty that can be evaluated by means other than statistical methods.

NOTE: There is not always a direct correspondence between the classification of uncertainty components categorized as "Type A" and "Type B" to the "random" and "systematic" terms that have been used historically. The nature of an uncertainty component depends on how that uncertainty component is employed in the mathematical model that describes the measurement process. If the uncertainty model properly characterizes a given component is to be used in a certain manner, a "random" component may have a "systematic" effect and vice versa. The terms "random uncertainty" and "systematic uncertainty," therefore, can be misleading when used independent of the mathematical model that describes the measurement process.

ultrasonic flowmeter, transit time: a device that utilizes the travel time of acoustic pulses transmitted between upstream and downstream transducers to derive an average velocity from which the flow rate may be deduced.

ultrasonic methods: methods in which the effect of the fluid flow on an ultrasonic beam (or pulse) is measured and related to the flow rate.

ultrasonic transducer: source or receiver of ultrasonic energy, used in ultrasonic flow measurements.

unbiased estimator: an estimator of a parameter such that its expectation equals the true value of this parameter.

uncertainty budget: statement of a measurement uncertainty, of the components of that measurement uncertainty, and of their calculation and combination.

NOTE: An uncertainty budget should include the measurement model, estimates, and measurement uncertainties associated with the quantities in the measurement model, covariances, type of applied probability density functions, degrees of freedom, type of evaluation of measurement uncertainty, and any coverage factor.

uncertainty interval (U): an estimate of the error band, centered about the measurement, within which the true value must fall with a stated probability. The uncertainty interval is given by

$$U = ku_c = 2\sqrt{u_A^2 + u_B^2}$$

where

k = the coverage factor taken to be 2 for 95% confidence

U_{95} = the expanded uncertainty at 95% confidence (See NIST Technical Note 1297)

u_A = determined with statistical methods

u_B = determined with methods other than statistical

u_c = the combined uncertainty

In the preceding equation, $u_A{}^2$ and $u_B{}^2$ are the root sum square of Type A and Type B uncertainties, respectively.

uncertainty of measurement: parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

NOTES:
(1) The parameter may be, for example, a standard deviation (or a given multiple of it) or the half-width of an interval having a stated level of confidence.
(2) Uncertainty of measurement comprises, in general, any components. Some of these components may be evaluated from the statistical distribution of the results of series of measurements and can be characterized by experimental standard deviations. The other components that can also be characterized by standard deviations are evaluated from assumed probability distributions based on experience or other information.
(3) It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion.

universal head loss coefficient: ratio of the pressure loss (due to flow) along a length of conduit equal to the hydraulic diameter, to the dynamic pressure calculated from the mean axial fluid velocity. It is given by the formula

$$\Delta p = \lambda \frac{l}{D_h} \times \frac{1}{2} \rho U^2$$

unsteady flow: flow that may be laminar or turbulent, in which parameters such as velocity, pressure, density and temperature fluctuate with time; flow in which the flow rate varies (beyond measurement uncertainty) over the time period of interest, not including variations related to natural turbulence generated within the pipe.

NOTE: The time interval being considered has to be sufficiently long that the random components of the turbulent flow itself may be ignored.

validation: verification, where the specified requirements are adequate for an intended use.

EXAMPLE: A measurement procedure, ordinarily used for the measurement of liquid flow, may be validated also for measurement for gas flow.

value: magnitude of a particular quantity, generally expressed as a number multiplied by a unit of measurement.

NOTES:
(1) The value of a quantity may be positive, negative, or zero and may be expressed in more than one way.
(2) The values of quantities of dimension one are expressed as pure numbers.

variable-area methods: procedures in which flow passes through a space (usually, but not always, an annular space) between two elements so arranged that fluid dynamic forces move one element relative to the other against the action of a restraining force (gravitational, or elastic) in such a manner that the cross-sectional area of the space increases as the flow rate increases.

NOTE: The readout of the instrument is either a measure of the displacement of the movable element from the "no flow" position or a measure of the differential pressure across the variable area.

variable-head meter: flowmeter where both the differential pressure and the area of the annular space are allowed to vary, so giving a wide range of measurement.

variance: statistic that is a measure of data dispersion based on the mean square deviation from the arithmetic mean; specifically, it is the square of the precision index.

variation due to an influence quantity: difference in indication for a given measured quantity value, or in quantity values supplied by a material measure, when an influence quantity assumes successively two different quantity values.

velocity, axial flow: the component of liquid flow velocity at a point in the measurement section that is parallel to the measurement section's axis and in the direction of the flow being measured.

velocity distribution: pattern of the axial vectors of the local fluid velocities over a cross section of a conduit.

velocity meters: device in which the primary device consists of a means of measuring the average velocity within a known cross section.

velocity of approach factor: coefficient given by the formula

$$E = (1 - \beta^4)^{-0.5} = \frac{D^2}{(D^4 - d^4)^{0.5}}$$

where
D = pipe inside diameter
d = diameter of the primary device orifice or throat
β = diameter ratio d/D

velocity profile: the distribution of axial vectors of the local fluid velocities over a cross section of a conduit.

velocity profile correction factor: dimensionless factor based on measured knowledge of the velocity profile used to adjust the meter output.

velocity-area methods: procedures that enable the flow rate to be calculated from the measurement of local fluid velocities at a cross section of the conduit by integration of the velocity distribution over that cross section.

vena contracta taps: wall pressure taps drilled on either side of an orifice plate, the upstream tap being located at a distance of 1D (D being the internal diameter of the pipe) from the upstream face of the plate, and the downstream tap being located at the cross section of minimum static pressure.

NOTE: The location of the downstream tap will vary with the diameter ratio of the orifice plate.

vent holes: holes drilled through the pipe wall to facilitate the removal from the metered liquid of undesirable vapor or fluids with densities less than that of the metered liquid.

venturi nozzle: primary device consisting of a convergent inlet (standardized ISA 1932 nozzle), connected to a cylindrical section called the “throat,” and a conical expanding section called the “divergent” or “recovery cone.”

venturi tube: primary device consisting of a cylindrical entrance section, followed by a conical convergent section, connected to a cylindrical section called the “throat,” and a conical expanding section called the “divergent” or “recovery cone.”

verification: provision of objective evidence that a given item fulfils specified requirements.

EXAMPLE: Use of independent flow calibration to confirm that performance properties and/or legal requirements of a measuring system are met.

NOTES:
(1) When applicable, measurement uncertainty should be taken into consideration.
(2) The item may be a process, measurement procedure, material, compound, or measuring system.
(3) The specified requirements may be that a manufacturer’s specifications are met.
(4) Verification in legal metrology, as defined in VIML, and in conformity assessment in general, pertains to the examination and marking and/or issuing of a verification certificate for a measuring system.
(5) Verification should not be confused with calibration. Not every verification is a validation.

volume flow: volume of water passing through the water meter, independent of the elapsed time.

volume flow rate: fluid rate of flow through a cross section of a pipe, expressed as a volume.

volumetric meter: device fitted into a closed conduit or pipe that consists of chambers of known volume and a mechanism driven by the flow, whereby these chambers are successively filled with fluid and then emptied.

NOTE: By counting the number of these volumes passing through the device, an indicating device can total the volume flow.

volumetric method: technique of measurement in which the flow is directed into or out of a calibrated volumetric tank during a certain period of time.

volumetric prover: a facility to calibrate a flowmeter that is comprised of a calibrated volume tank, a liquid density measurement capability, appropriate temperature and pressure sensors, and, typically, a diverter valve.

NOTE: The pipe system that connects this volumetric prover to the flowmeter being calibrated enters into the uncertainty assessment for the calibration.

volumetric tank: vessel that will not lose its shape and the capacity of which has been determined by a primary method of calibration, used extensively as reference standards for calibration of commercial meters.

volumetric tank, calibrated: tank in which the relationship between the volume at a given temperature and the liquid level is known by an independent calibration method and with a known level of uncertainty.

vortex flowmeter: flowmeter that produces a vortex sheet downstream of an obstacle to enable the flow rate to be determined.

vortex precession meter: flowmeter in which the fluid entering is forced to spin about the centerline by guide vanes.

NOTE: The cross section of the flow channel is contracted to accelerate the flow, and then expanded and its axis is changed, forming vortex precession. The vortex passes a given point with a frequency that is directly proportional to the flow rate.

vortex-shedding meter: flowmeter that comprises a bluff body from which a succession of vortices are shed alternately on each side of the bluff body.

NOTE: For a given range of flow rate, the frequency at which the vortices are shed is directly proportional to the flow rate and can be counted using a wide variety of detectors.

wake oscillator: device placed coaxial with the pipe, consisting of a semi-streamlined body and a disk placed downstream, causing the wake to oscillate alternately at a position between the streamlined body and the disc and a position downstream of the disc.

wall pressure tap: pressure passage, typically a circular hole drilled in the wall of a conduit in such a way that the edge of the hole is flush with the internal surface of the conduit and the pressure measured does not include nonaxial velocity effects; a set of holes in a pitot tube positioned so as to measure the static pressure of the surrounding fluid.

NOTE: The pressure passage is usually circular, but in some orifice meter configurations, it may be an annular slot.

weighing method: technique of measurement, suitable only for liquids, in which the flow is directed either intermittently or continuously into a container the scale of a weighing machine (the flow rate is obtained by measuring the mass of liquid accumulated in a certain time).

weight of measurement: number that expresses the degree of confidence in the result of a measurement of a certain quantity in comparison with the result of another measurement of the same quantity.

wet-bulb temperature: temperature indicated by a properly designed wet-bulb instrument. This closely approximates the thermodynamic wet-bulb temperature (i.e., temperature of adiabatic saturation).

Woltmann meter: device in which the flowmeter houses a propeller, whose axis of rotation coincides with the flow axis.

working conditions: instantaneous values of the physical properties of the fluid flowing through a device, measured in accordance with the specifications of the primary device.

working measurement standard: measurement standard that is used routinely to calibrate or verify measuring instruments or measuring systems; also called "working standard."

NOTES:
(1) A working measurement standard is usually calibrated with respect to a reference measurement standard.
(2) In relation to verification, the terms "check standard" or "control standard" are also sometimes used.

working pressure: static pressure of the fluid flowing through the primary device, measured in accordance with the specifications of the primary device, typically immediately upstream, also called "flowing pressure."

NOTE: For some meters, working temperature is measured downstream of or within the meter.

working standard: an instrument that is calibrated in a laboratory against an interlab or transfer standard and is used as a standard in calibrating measuring instruments.

working temperature: temperature of the fluid flowing through the primary device, measured in accordance with the specifications of the primary device, typically immediately upstream, also called "flowing temperature."

NOTE: For some meters, working temperature is measured downstream of or within the meter.

yaw probe: a sensor fitted with several pressure taps that can be immersed in a flow in order to determine its direction.

NOTE: Under certain conditions, it may be possible to determine the magnitude of the local fluid velocity as well.

zero adjustment: adjustment of a measuring system so that it provides a null indication corresponding to a zero value of a quantity to be measured.

zero offset: flow measurement indicated under zero flow conditions.

zero stability: maximum expected magnitude of the meter output at zero flow after the zero adjustment procedure has been completed, expressed by the manufacturer as an absolute value in mass per unit time.

3 SYMBOLS

While there is a desire that all symbols be unique to a given quantity, conventional, long-established use of certain symbols prevent a comprehensive "single-use" system. As a consequence, there are several instances of certain symbols having multiple applications. The user must be conscious of the context in interpreting a given symbol.

Note that, due to ongoing revisions, all symbols employed in MFC documents may not be listed below. For the latest notations, refer to the specific MFC code in question.

A = cross-sectional area of pipe, conduit, or meter inlet at flowing conditions

a = cross-sectional area of the bore or throat of an orifice, flow nozzle, or venturi

a^* = cross-sectional area of a sonic or venturi nozzle throat at critical or choked conditions

A_2 = cross-sectional area of venturi nozzle exit

A_B = base accuracy (includes linearity, repeatability, and hysteresis)

A_C = cross-sectional area of oscillating tube in a coriolis meter

a_i = manufacturer's specification limits; assumed rectangular probability distribution

a_r = radial acceleration

A_T = total accuracy (includes linearity, repeatability, hysteresis, and zero stability)

a_t = transverse acceleration

B = the estimate of the upper limit of the bias error β'

B_0 = average magnetic field between the electrodes

B_{ij} = an estimate of the upper limit of an elemental bias error. The j subscript indicates the process category of the error, i.e., calibration, data acquisition, or data reduction. The i subscript is the number of the error source within the process

NOTE: If i is more than a single digit, a comma is used between i and j.

$$B = \sqrt{\sum_i \sum_j B_{ij}^2}$$

C = dimensionless parameter that depends on the specific design of the flowmeter

c = speed of sound (acoustic velocity)

C_{*i} = critical flow function for one-dimensional isentropic flow of a perfect gas

C^*_R = real gas critical flow coefficient for one-dimensional real gas flow

C^*_{Ri} = critical flow function for one-dimensional isentropic flow of a real gas

c_1, c_2 = empirical constants used in the calculation of the minimum downstream pressure necessary to avoid flashing or cavitation in a vortex meter

c_p = specific heat of a fluid at constant pressure

c_v = specific heat of a fluid at constant volume

D = diameter of the circular conduit, meter inlet, or meter tube at flowing conditions

d = diameter of the bore or throat of an orifice, flow nozzle, or venturi at flowing conditions
d_{meas} = throat or bore diameter at a specified measured temperature
E = orifice plate thickness
= velocity of approach factor of a differential pressure meter,

$$1/\sqrt{1-\beta^4}$$

emf = electromotive force
emf_c = electrochemical electromotive force
emf_F = electromotive force per Faraday's Law
emf_t = electromotive force related to transformer
emf_v = electromotive force related to velocity
e_r = relative uncertainty
F = isentropic expansion function of a real gas, ratio
f = friction factor coefficient of resistance (Moody Coefficient)
f_0 = friction factor of perfectly smooth conduit
Fa = area thermal expansion factor
F_c = Coriolis force
F_i = isentropic expansion function of an ideal gas

$$\left(\frac{\gamma-1}{\gamma}\right)$$

F_{pb} = pressure base factor
F_{pf} = flowing pressure factor
F_{tb} = temperature base factor
F_{tf} = flowing temperature factor
G = specific gravity
g = gravitational constant or local acceleration of gravity
g_0 = standard acceleration due to gravity, 9.806 650 m/s^2 (32.17405 ft/sec^2)
g_c = proportionality constant in the force-mass-acceleration equation, equivalent to 32.17405. g_c is a dimensional conversion number and is not required when using SI units.
G_f = specfic gravity of float material at flowing conditions
G_{fc} = specfic gravity of float material at calibration conditions
G_I = specfic gravity of fluid, flowing conditions
G_i = ideal specific gravity (gas)

$$G_i = \frac{\text{molecular weight of gas}}{\text{molecular weight of air}}$$

NOTE: Molecular Weight of Air = 28.96247

G_{IC} = specfic gravity of fluid, at calibration conditions
H = enthalpy
h = specific enthalpy
h_w = differential pressure (U.S. Customary System of Measure only; not for use with SI units)

NOTE: In the U.S. customary system, the pressure unit (in. H_2O)$g_{o,T}$ is equal to the difference between the pressure at the bottom of a column of water one inch high, at a temperature of 68°F, at a standard gravity of 32.17405 ft/sec^2, and the standard atmospheric pressure of 14.696 lbf/in.^{2} on top of the water.
1 (in. H_2O)$g_{o,T}$ = 248.64107 Pa.

K = flow coefficient, calibration factor, or meter factor
k = coverage factor, for expanded uncertainty
K_1, K_2 = calibration coefficients for density
K_L = pressure loss coefficient
K_{lm} = linear mass calibration constant
k_s = mechanical stiffness — spring constant
L/D = ratio of the conduit length to the inside diameter (in the same units of measure)
ℓ = pressure tap spacing from orifice plate
M = total mass of line fluid passed through a cross section or meter
m = mass
Ma = Mach number
$m_{liq\text{-}tb}$ = mass of liquid in the oscillating tubes
m_{tb} = mass of oscillating tube(s)
MW = molecular weight of a fluid
N = number of samples or sample size, number of measurements or measurement periods
n = number of moles of gas
= polytropic exponent
N_c = number of cycles
N_p = number of vortex pulses
P = absolute static pressure of the fluid
P^* = absolute static pressure of the gas in the nozzle throat at critical flow conditions
P^*_i = absolute static pressure of the gas in the nozzle throat at critical flow conditions for one-dimensional insentropic flow of a perfect gas
P_0 = absolute stagnation pressure of the gas at the nozzle inlet
P_1 = absolute static pressure of the gas at the nozzle inlet
$(P_1/P_2)_i$ = ratio of nozzle exit static pressure to stagnation pressure for one-dimensional isentropic flow of a perfect gas
P_2 = absolute static pressure of the gas at the nozzle exit
P_{atm} = atmospheric pressure, absolute
P_b = absolute pressure of gas base conditions
P_c = absolute critical pressure of a substance
P_{dmin} = minimum downstream pressure limit
p = line pressure, static gauge

p_{f1} = static pressure of flowing fluid at upstream tap
p_{f2} = static pressure of flowing fluid at downstream tap
p_t = total pressure or stagnation pressure, $p_t = p + \Delta p$
P_v = liquid vapor pressure, in equilibrium, at the flowing temperature
q = flow rate, volume or mass (unspecified)
Q_m = totalized mass flow
q_m = mass flow rate at flowing conditions
$q_{m,A,}$ = net mass flow rate of component A
$q_{m,\,B}$ = net mass flow rate of component B
$q_{m,t}$ = total mass flow rate of the mixture
$q_{\max}$ = maximum flow rate for an acceptable Δp_c
q_{mi} = mass flow rate for one-dimensional insentropic flow
$q_{\min}$ = minimum flow rate for a maximum acceptable measurement error
Q_v = totalized volume flow
q_v = volumetric rate of flow at flowing conditions
q_v, A = net volume flow rate of component A
$q_{v,\,B}$ = net volumetric flow rate of component B
$q_{v,\,t}$ = net total volumetric flow rate
q_{vb} = volumetric flow at base conditions
q_{vb} = volumetric rate of flow at base conditions, $q_{vb} = q_v \rho_f / \rho_b$
$q_{v\text{-}g\text{-}b}$ = gas volumetric flow rate as measured
$q_{v\text{-liq}}$ = liquid volumetric flow rate as measured
$\overline{R}$ = universal gas constant
R = specific gas constant
r = radius
r^* = critical pressure ratio, P^*/P_0
R_a = arithmetic mean deviation from the mean line of the profile; roughness profile
r_c = radius of curvature of nozzle inlet
Re = Reynolds number
Re_D = Reynolds number referred to D, the diameter of the circular conduit, meter inlet, or meter tube
Re_d = Reynolds number referred to d, the diameter of the bore diameter of an orifice, nozzle, or venturi
R_{fm} = flowmeter reading
r_r = radius of rotation for mass Δm
R_{spec} = gas constant specific to given gas or gas mixture
R_Z = compressibility ratio
S = an estimate of the standard deviation σ obtained by taking the square root of S^2, also called the precision index
s = specific entropy of the gas
S^2 = an unbiased estimate of the variance σ^2

$$\frac{\sum_{i=1}^{N}(X_i - \overline{X})}{N - 1}$$

S_{ij} = the estimate of the precision index from one elemental source. The j subscript indicates the process category of the error, i.e., calibration, data acquisition, or data reduction. The i subscript is the number of the error source within the process

NOTE: If i is more than a single digit, a comma is used between i and j.

$$S = \sqrt{\sum_i \sum_j S_{ij}^2}$$

S_{Klm} = sensitivity coefficient for K_{lm}, the linear mass calibration constant
S_{Rfm} = sensitivity coefficient R_fm, the flowmeter reading
St = Strouhal number
S_{xi} = sensitivity coefficient of output y to input x_i
$S_{\rho f}$ = sensitivity coefficient ρ_f, the fluid density
t = time
$\overline{t}$ = average time or time period
T^* = absolute static temperature in the nozzle throat at critical flow conditions
T_0 = absolute stagnation temperature of the gas
t_{95} = two-tailed Student's t = statistical parameter at the 95% confidence level. The number of degrees of freedom ν, of the sample estimate of the standard deviation is needed in order to obtain the t-value from the two-tailed Student's t table.
t_{99} = two-tailed Student's t = statistical parameter at the 99% confidence level. The number of degrees of freedom, ν, of the sample estimate of the standard deviation is needed in order to obtain the t-value from the two-tailed Student's t table.
t_a = averaging time
T_{Abs} = absolute temperature of the flowing fluid, °R or K
T_b = gas base condition temperature
t_f = period of the tube oscillation
T_{meas} = temperature at which dimension of the pipe and plate is measured
T_{ref} = reference temperature
t_w = time window (gate)
U = expanded uncertainty
= mean axial velocity of the fluid in the pipe, conduit, or metering section
$u(x_i)$ = standard uncertainty in x_i
$u(y)$ = standard uncertainty in y

U^* = sonic velocity in the throat or bore of an orifice, nozzle, or venturi
U_{95} = uncertainty at the 95% confidence level
U_{99} = uncertainty at the 99% confidence level
U_{ADD} = uncertainty at the 99% confidence level
U_c = combined uncertainty, as a percentage
u_{qm} = combined standard uncertainty in mass flow rate
u_{qv} = combined standard uncertainty in volume flow rate
U_R = random uncertainty, as a percentage
u_R = random uncertainty, in absolute terms
U_{RSS} = uncertainty at the 95% confidence level
U_S, u_S = systematic uncertainty
u_x = calculated standard uncertainty in x
u_y = calculated standard uncertainty in y
V = volume; volume discharged, totalized, measured, or collected
v = specific volume = $1/\rho$, ft^3/lb or m^3/kg
$\dot{V}$ = volumetric flow rate
V_g = gas volume or gas volume passed
$V_{g\text{-}b}$ = gas volume at base conditions
V_l = liquid volume or liquid volume passed
V_{liq} = liquid volume
$V_{liq\text{-}tb}$ = volume of liquid in the oscillating tube
W = mass fraction
w = width of bluff body normal to the flow
W_A = mass fraction of component A
W_B = mass fraction of component B
wc = inches of water in a water column
x = horizontal axis coordinate in a Cartesian coordinate system; abscissa
X_i = an individual measurement
$\overline{X}$ = sample average of measurements

$$\frac{\sum_{i=1}^{N} X_i}{N}$$

Y = expansion factor for a gas or compressible fluid in a differential pressure meter
y = vertical axis coordinate in a Cartesian coordinate system; ordinate
Y_1 = expansion factor based on upstream pressure
Y_2 = expansion factor based on downstream pressure
Z = gas (vapor) compressibility factor for a real gas
z = level measurement or vertical elevation value
= coordinate axis orthogonal to the x-y plane in a Cartesian coordinate system
Z_0 = compressibility factor at T_0 and P_0
ZS = zero stability
α = coefficient of linear expansion of material
α_D = thermal expansion factor of the pipe, conduit, or meter inlet at flowing conditions
α_d = thermal expansion factor of the bore or throat of an orifice, flow nozzle, or venturi
β = ratio of the throat or bore diameter to that of the inlet or upstream pipe, $\beta = d/D$
Γ = isentropic exponent of a real gas, expressed as a function of p_1, p_2, and T
γ = ratio of specific heat capacities of a gas

NOTE: γ is the ratio of the specific heat capacity at constant pressure to the specific heat capacity at constant volume. For ideal gases, γ and the isentropic exponent (κ) have the same value. These values depend on the nature of the gas.

Δc = variation in concentration of tracer, in percent
Δm = mass
ΔP = pressure loss or pressure drop between two points, typically across a metering section
Δp = differential pressure flow signal
Δx = length
δ = total error, i.e., the difference between the observed measurement and the true value
ϵ = expansibility factor of a compressible fluid
ϵ_1 = expansibility factor based on upstream pressure
ϵ_2 = expansibility factor based on downstream pressure
ϵ_m = accuracy of the mass measurement expressed as a percentage
ϵ_R = uniform equivalent roughness
$\epsilon_{v\text{-}g\text{-}b}$ = accuracy of the standard gas volume measurement percentage
$\epsilon_{v\text{-}liq}$ = accuracy of liquid volume measurement expressed as a percentage
$\epsilon_{\rho\text{-}liq}$ = accuracy of the liquid density measurement expressed percentage
$\epsilon_{\rho\text{-}g\text{-}b}$ = accuracy of reference density with respect to the base percentage
κ = isentropic exponent

NOTE: γ is the ratio of the specific heat capacity at constant pressure to the specific heat capacity at constant volume. For ideal gases, γ and the isentropic exponent (κ) have the same value. These values depend on the nature of the gas.

κ_m = mean isentropic exponent
κ_1 = isentropic exponent based on upstream measurements
κ_2 = isentropic exponent based on downstream measurements

λ = friction factor
ϕ = total angle of the divergent section
ϕ^* = sonic-flow function of a real gas, number
ϕ_i^* = sonic-flow function of an ideal gas, number
φ = volume fraction
φ_A, φ_B = respective volume fractions (expressed as a percentage) of component A and component B in relation to the mixture
μ = absolute viscosity of line fluid (sometimes refered to as "dynamic viscosity")
μ^* = absolute viscosity of the gas in nozzle throat at critical flow conditions
μ_0 = absolute viscosity of the gas at stagnation conditions
μ_{JT} = Joule-Thomson coefficient
ν = kinematic viscosity of line fluid: $\nu = \mu/\rho$
ξ = relative pressure loss
ρ = density of the line fluid
ρ^* = gas density in nozzle throat at critical flow conditions
ρ_0 = gas density at stagnation conditions at nozzle inlet
ρ_a = density of air at 20°C and 1 bar (10^6 Pa)
ρ_A = density of component A in a multicomponent mixture
ρ_B = density of component B in a multicomponent mixture
ρ_b = density of fluid at base conditions
ρ_f = density of flowing fluid
$\rho_{g\text{-}b}$ = gas density at base conditions
ρ_{liq} = density of the liquid
ρ_{meas} = measured density of the mixture
ρ_p = density of standard weights
$\rho_{w,\,68°}$ = density of water at 68°F and 14.696 psia

NOTE: The value quoted in the Standard for density of water at 68°F and 14.696 psia is approximately 62.3208 lbm/ft^3. Refer to the latest ASME steam data for more precision, if necessary.

$\rho_{w,\,\text{ref}}$ = density of water at reference conditions
σ = the true standard deviation of repeated values of the measurement; also, the standard deviation of the error δ. This variation is due to the random error ϵ.
σ^2 = the true variance, i.e., the square of the standard deviation
τ = pressure ratio, $\tau = p_2/p_1$
ω = frequency, rotational speed in turbine meters; or of vortex shedding in vortex meters
= frequency or angular velocity
ω_R = resonant frequency

Subscripts

0 = stagnation property
0,1,…,N = integers denoting specific quantities or indices
1 = refers to the upstream or inlet conditions
2 = refers to the downstream, exit, or outlet conditions
A = type of uncertainty determined using statistical methods
a = upstream static condition
abs = absolute
atm = atmospheric
B = type of uncertainty determined with methods other than statistical
b = base conditions of temperature, pressure, and fluid composition
C = denotes combined uncertainty
d = orifice bore, nozzle or venturi throat
eff = effective degrees of freedom
f = flowing conditions of temperature, pressure, and fluid composition
g = gas
i = isentropic
j = any location
l = liquid
m = mass
meas = measured
0 = initial time
p = inlet pipe
R = random uncertainty
ref = refers to a reference temperature of 20°C (68°F)
r = rated conditions of temperature, pressure, and gas composition as specified by manufacturer
S = systematic uncertainty
v = vapor
= volumetric

Superscripts

* = value at the location of critical flow conditions

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