Manual of Petroleum Measurement Standards Chapter 5—Metering

Section 7—Testing Protocol for Differential Pressure Flow Measurement Devices

FIRST EDITION, FEBRUARY 2003

American Petroleum Institute

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1 Introduction

This document defines the testing and reporting protocols for flow measurement devices based on the detection of a pressure differential that is created by the device in a flowing stream. These protocols are designed to supply industry with a comparable description of the capabilities of these devices for the measurement of single-phase fluid flow when they are used under similar operating conditions. The objectives of this Testing Protocol are to:

1. Ensure that the user of any differential pressure flow meter knows the performance characteristics of the meter over a range of Reynolds numbers as applicable or defined by tests,
2. Facilitate both the understanding and the introduction of new technologies,
3. Provide a standardized vehicle for validating manufacturers' performance specifications,
4. Provide information about relative performance characteristics of the primary elements of the Differential Pressure metering devices under standardized testing protocol.

To accomplish these objectives, the testing protocol defines the test limits for operating conditions of the meter, the requirements of the facility or facilities to perform the tests, the fluids to be tested, and the ranges for pressure, differential pressure, temperature, secondary instrumentation and Reynolds number.

Examples of flow meters covered in this standard include, but are not limited to orifice plates, Venturis, nozzles, V-Cones, wedge meters, and averaging Pitot tubes. Reporting and testing protocols for test facilities are included to ensure that the performance characteristics of each meter are compared with identical conditions as set forth in this standard. These protocols require descriptions of the test fluids to be used, the mechanical configuration of piping, effects of fluid flow profile and spatial orientation of the meter. A description of required dimensional measurements and tolerances and the mathematical equations required to convert the differential pressure reading to a flowrate prediction is also necessary. This document primarily addresses testing protocol for differential pressure flow meters that operate under the flowing condition that is in the turbulent flow regime. The differential pressure flow measurement devices that operate on the principle of physical laws of laminar flows require special testing protocol, which is addressed in Section 3.6.

1.1 SCOPE

The protocols are limited to single-phase Newtonian fluid flow, and no consideration is given to pulsation effects. Further revisions of this document may include the testing of such meters in wet gas or multi-phase service and the effects of pulsation. This standard does not address testing protocols of those devices that operate on the principle of critical or choked flow condition of fluids.

The testing protocol covers any flow meter operating on the principle of a local change in flow velocity, caused by the meter geometry, giving a corresponding change of pressure between two set locations. There are several types of differential pressure meters available to industry. It is the purpose of this standard to illustrate the range of applications of each meter and not to endorse any specific meter. The basic principle of operation of the flow measuring devices follows the physical laws relating to the conservation of energy and mass for the fluid flows through the device.

Any existing or later developed API MPMS document addressing a specific type or design of differential pressure flow measuring device will supersede the requirements of this document. Example of one such existing standard is API *Manual Petroleum Measurement Standards* Chapter 14.3—"Concentric, Square-Edged Orifice Meters."

1.2 DIFFERENTIAL PRESSURE OR HEAD-TYPE FLOW METERS

The operating principle of a differential pressure flow meter is based on two physical laws—the conservation of energy and conservation of mass, where changes in flow cross-sectional area and/or flow path produce a differential pressure, which is a function of the flow velocity, fluid path, and fluid properties. The following diagrams are presented as examples of the some of the possible differential pressure devices. Other variations of meter designs are available and possible.

It is the intention of this Testing Protocol that no differential pressure meter should be excluded. Therefore, the examples presented are of eligible meters and the document is not limited to these meter types alone.

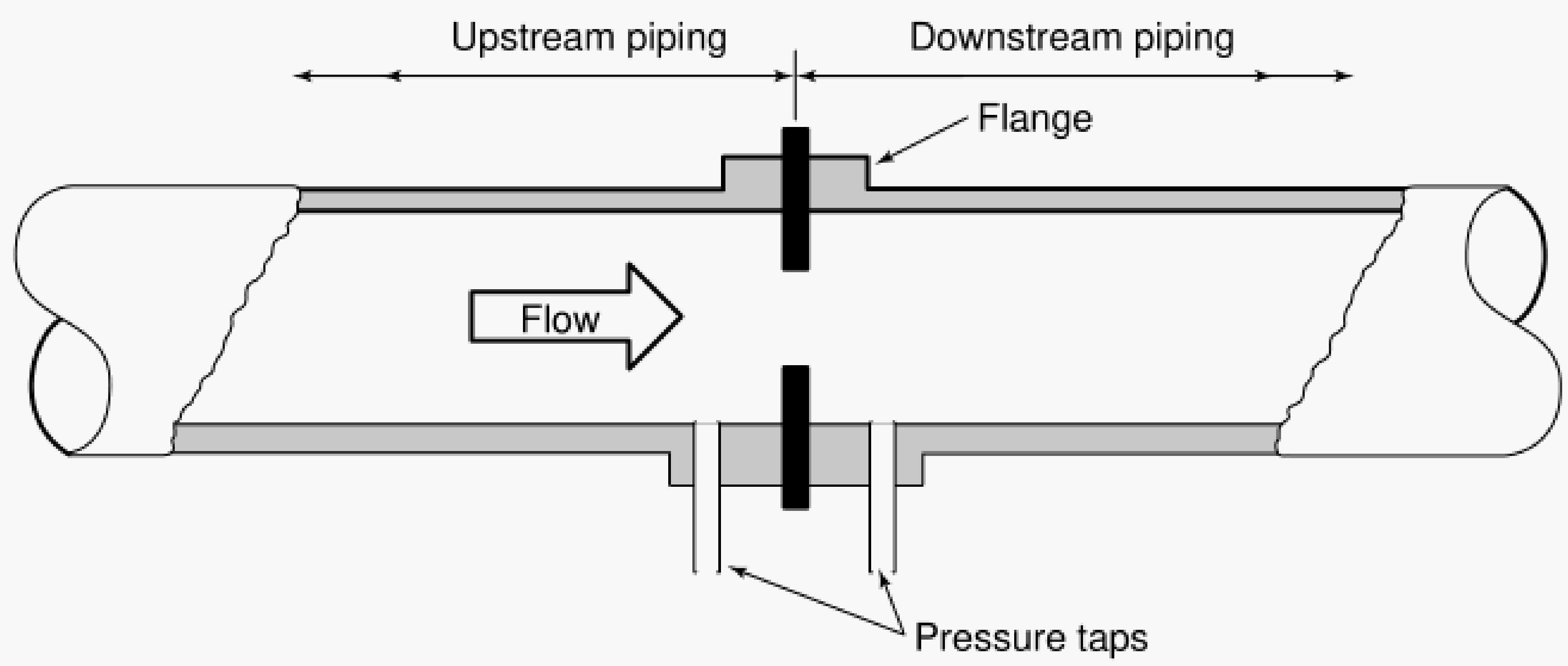


Figure 1—Concentric Orifice Flow Meter

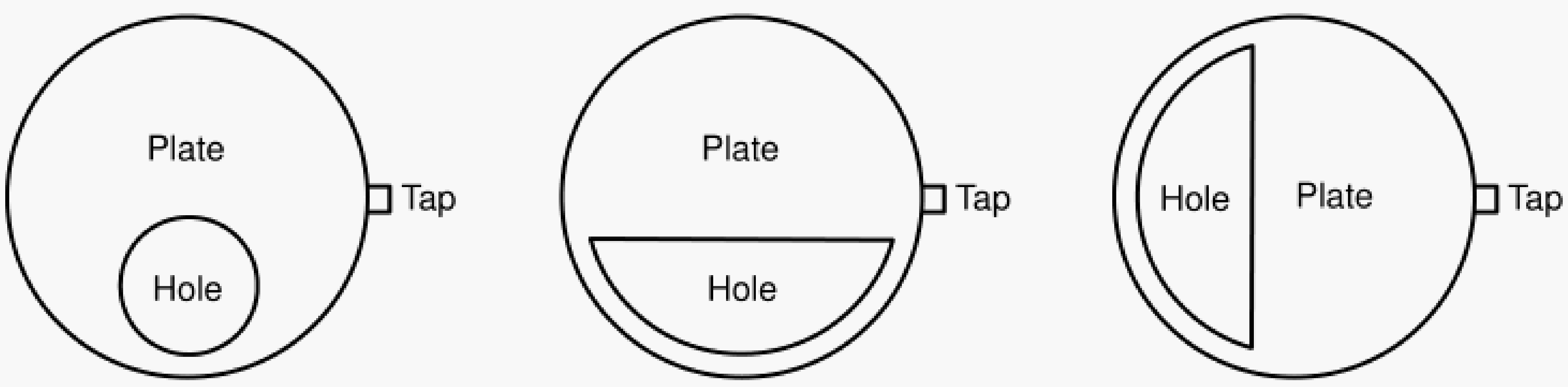


Figure 2—Eccentric and Segmental Orifice Flow Meters

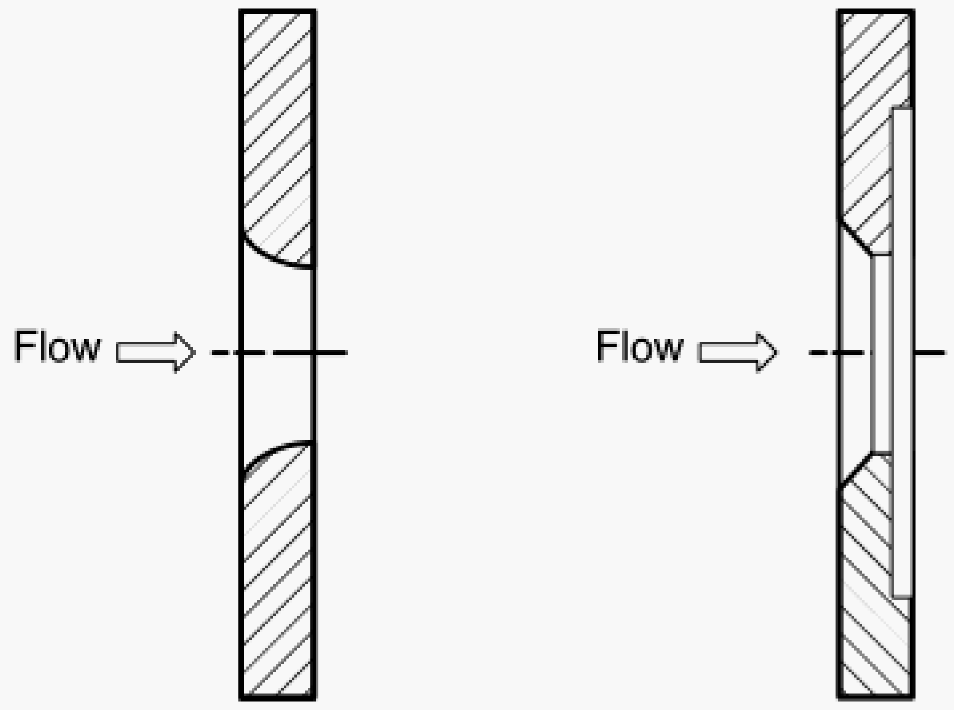


Figure 3—Quadrant-Edge and Conical Orifice Plates

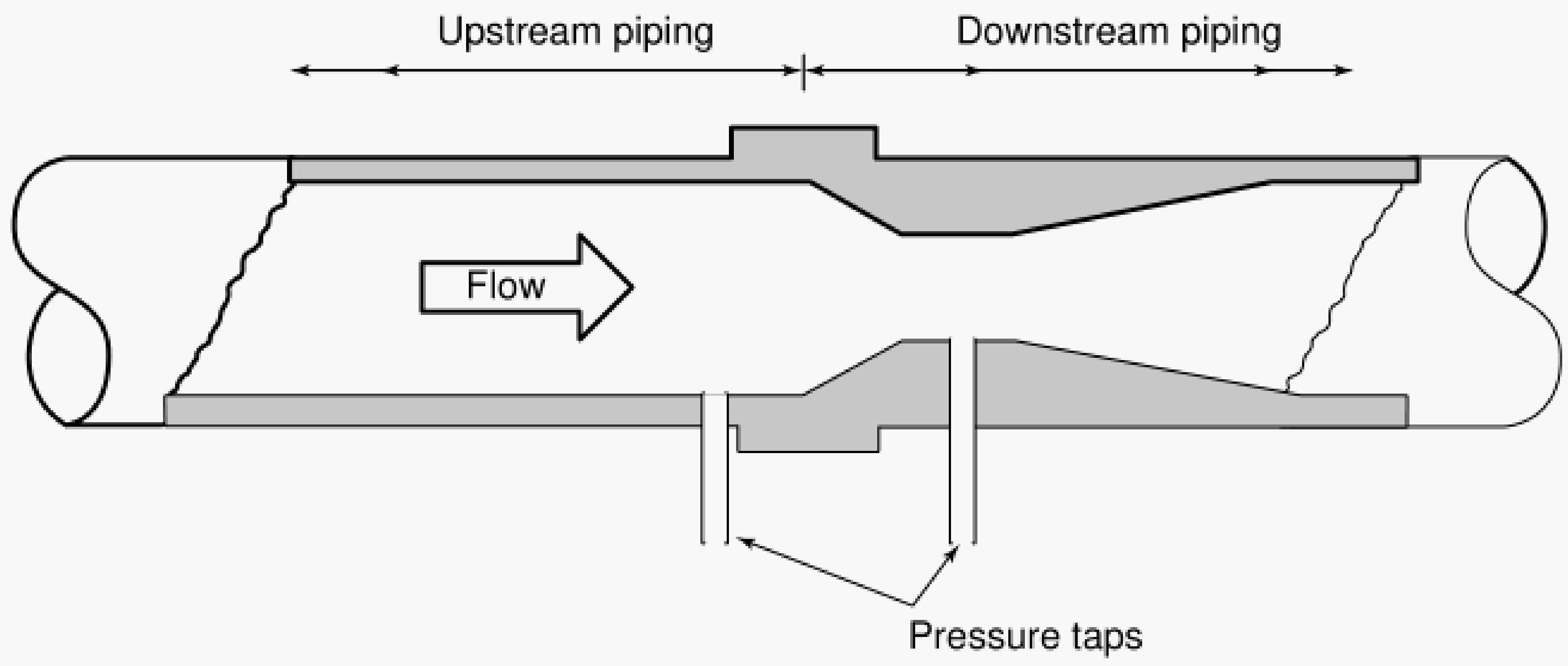


Figure 4—Venturi Flow Meter

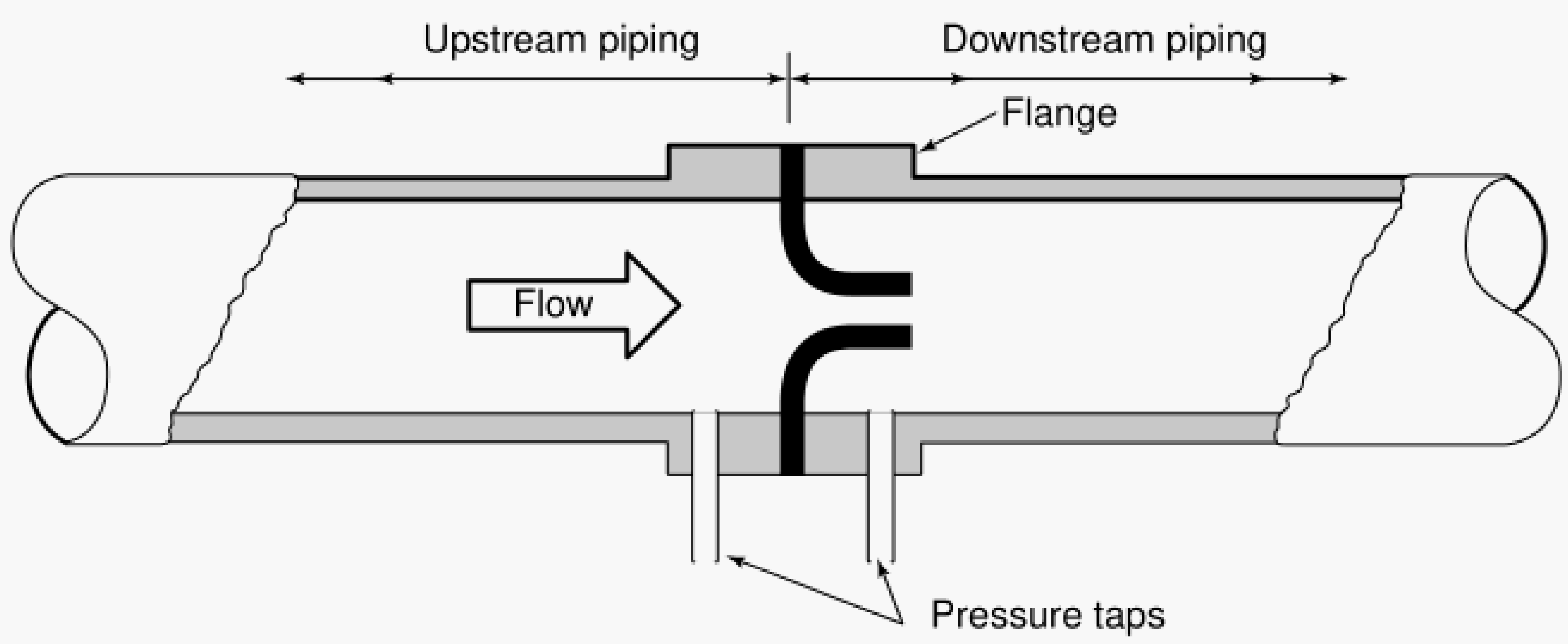


Figure 5—Flow Nozzle

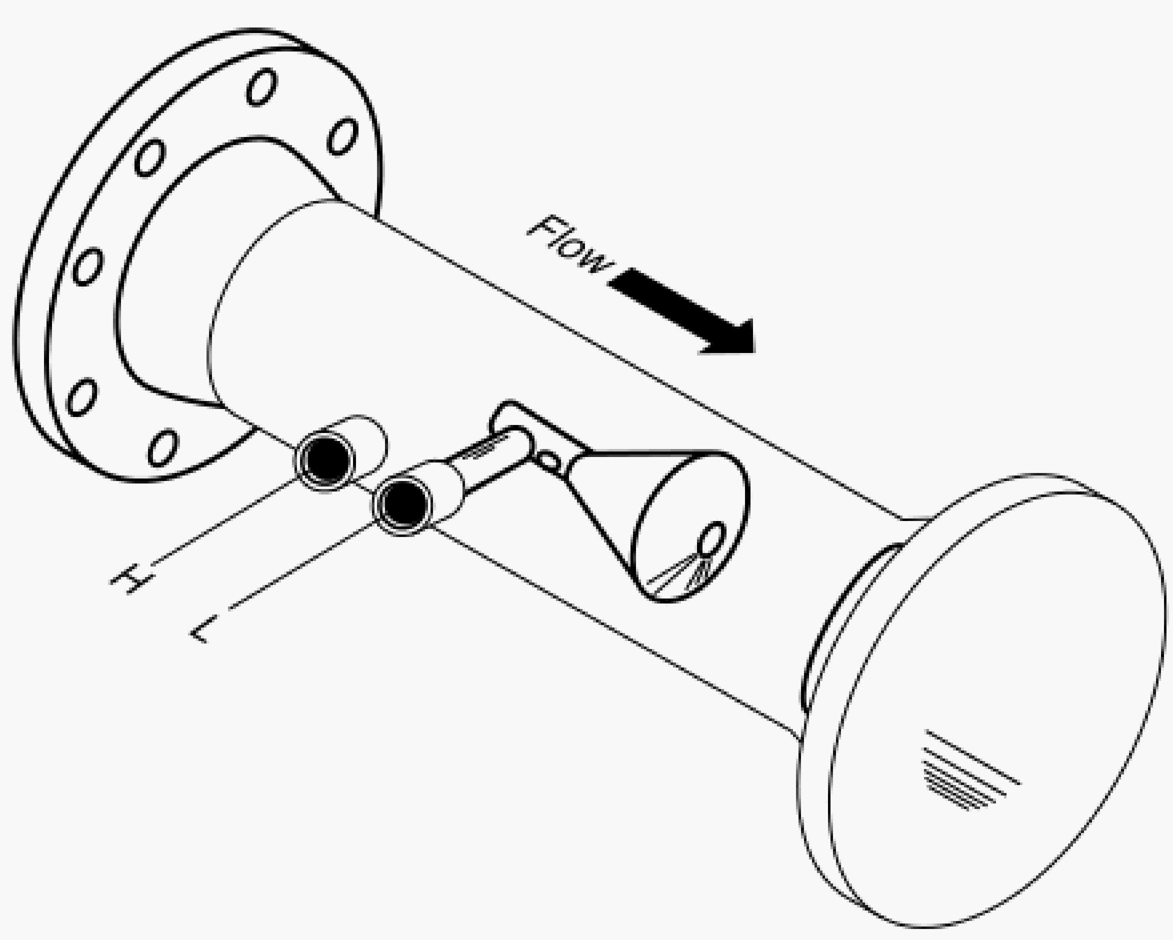


Figure 6—V-Cone Flow Meter

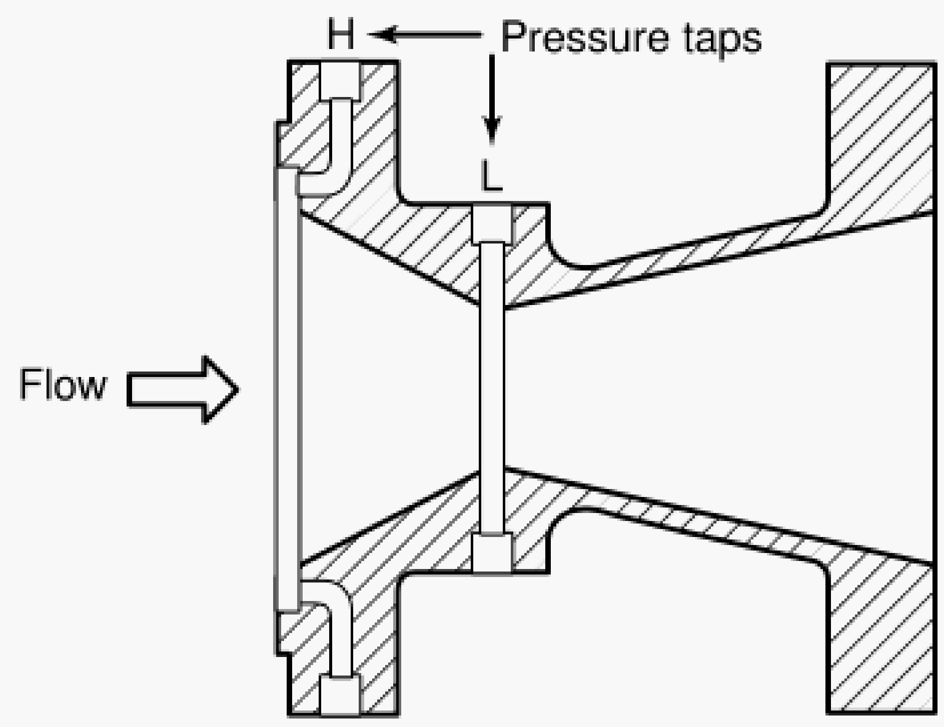


Figure 7—DALL Tube Flow Meter

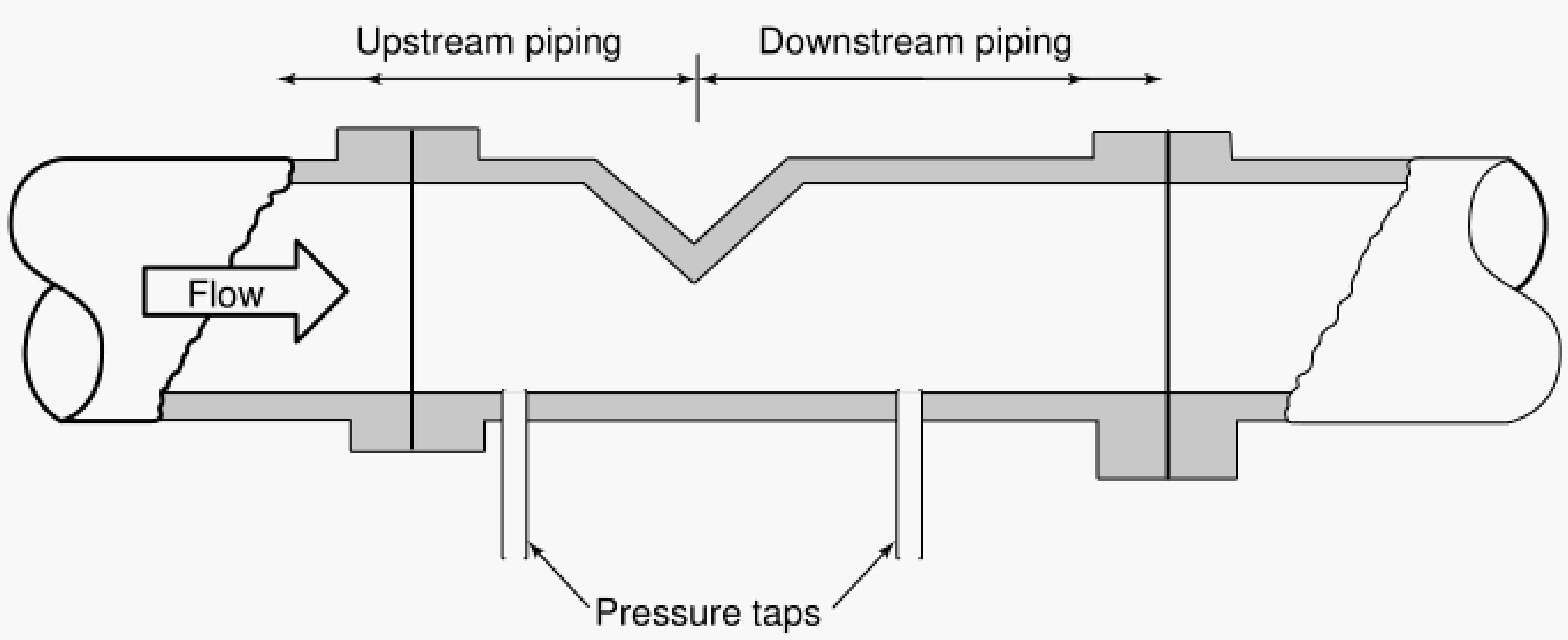


Figure 8—Wedge Flow Meter

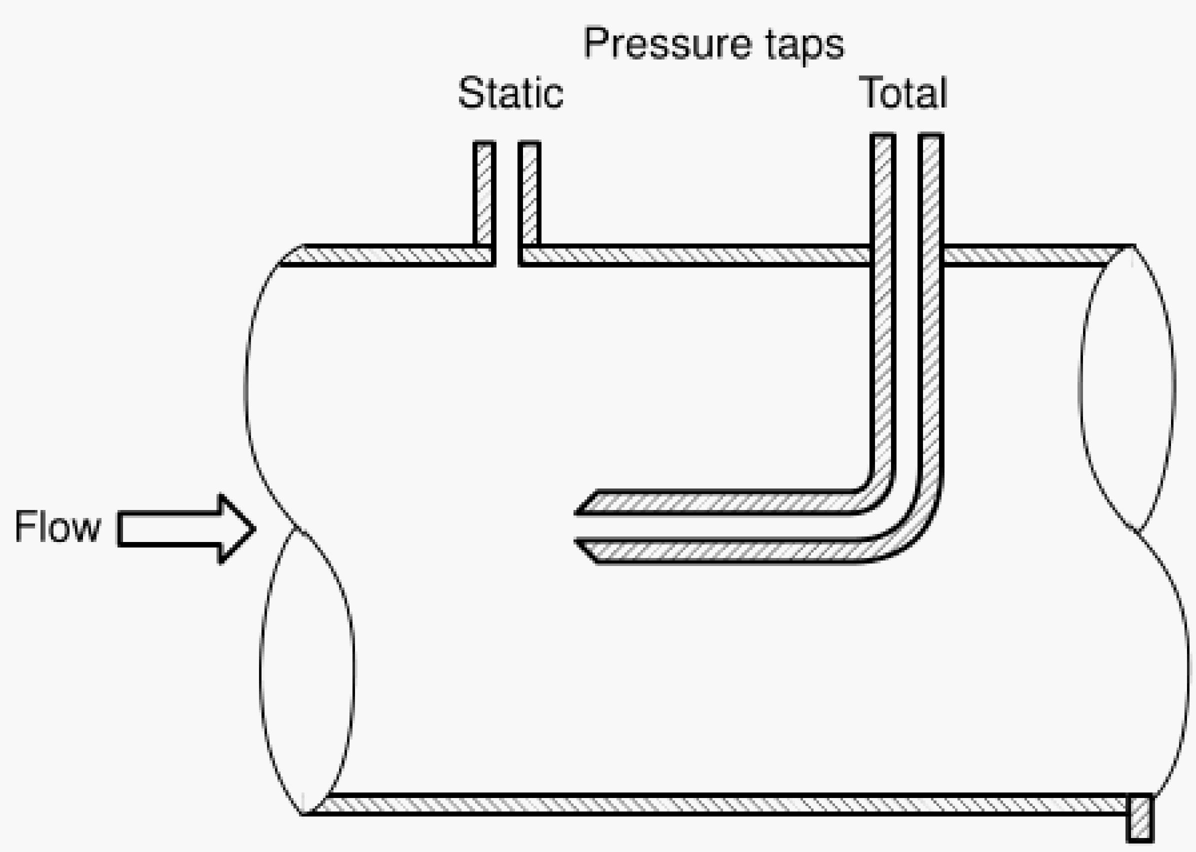


Figure 9—Pitot-Static Tube Flow Meter

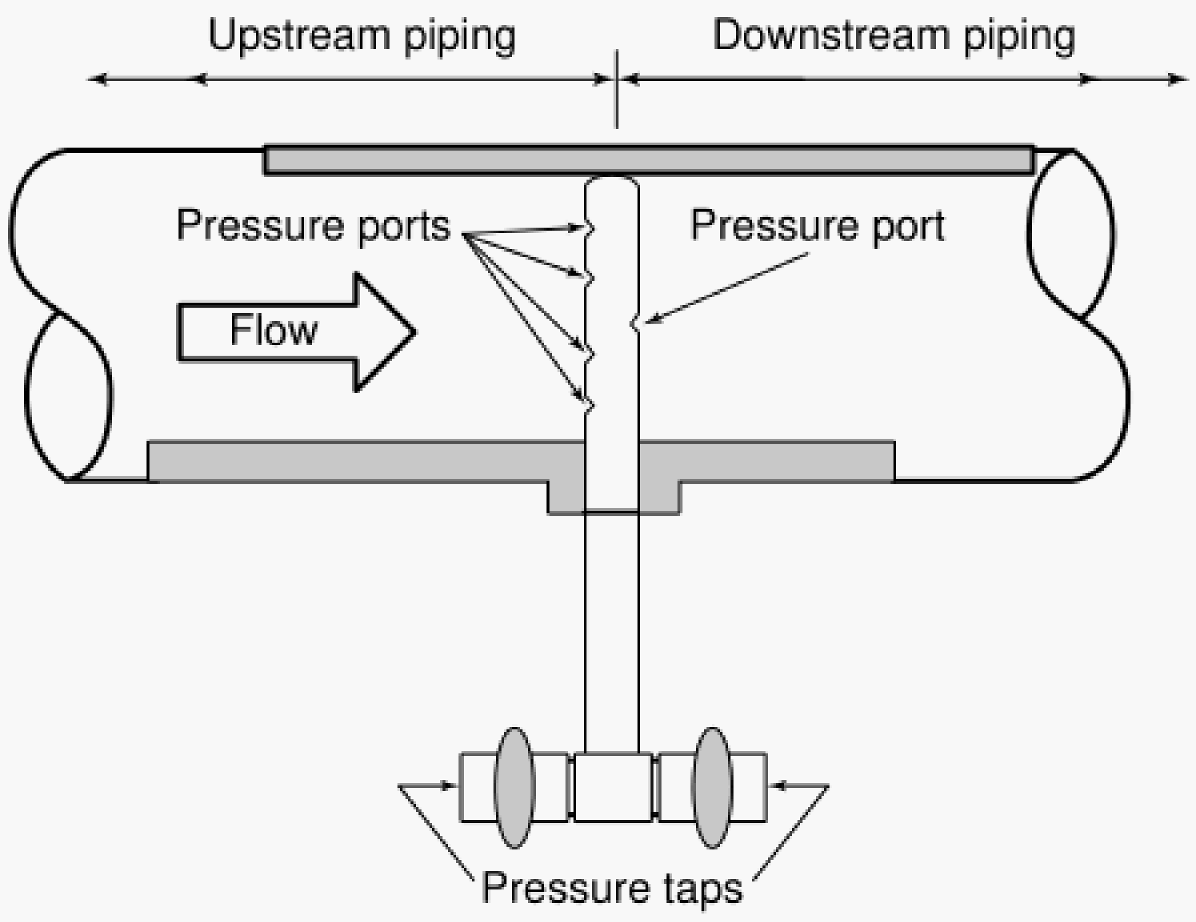


Figure 10—Multi-Port Averaging Pitot

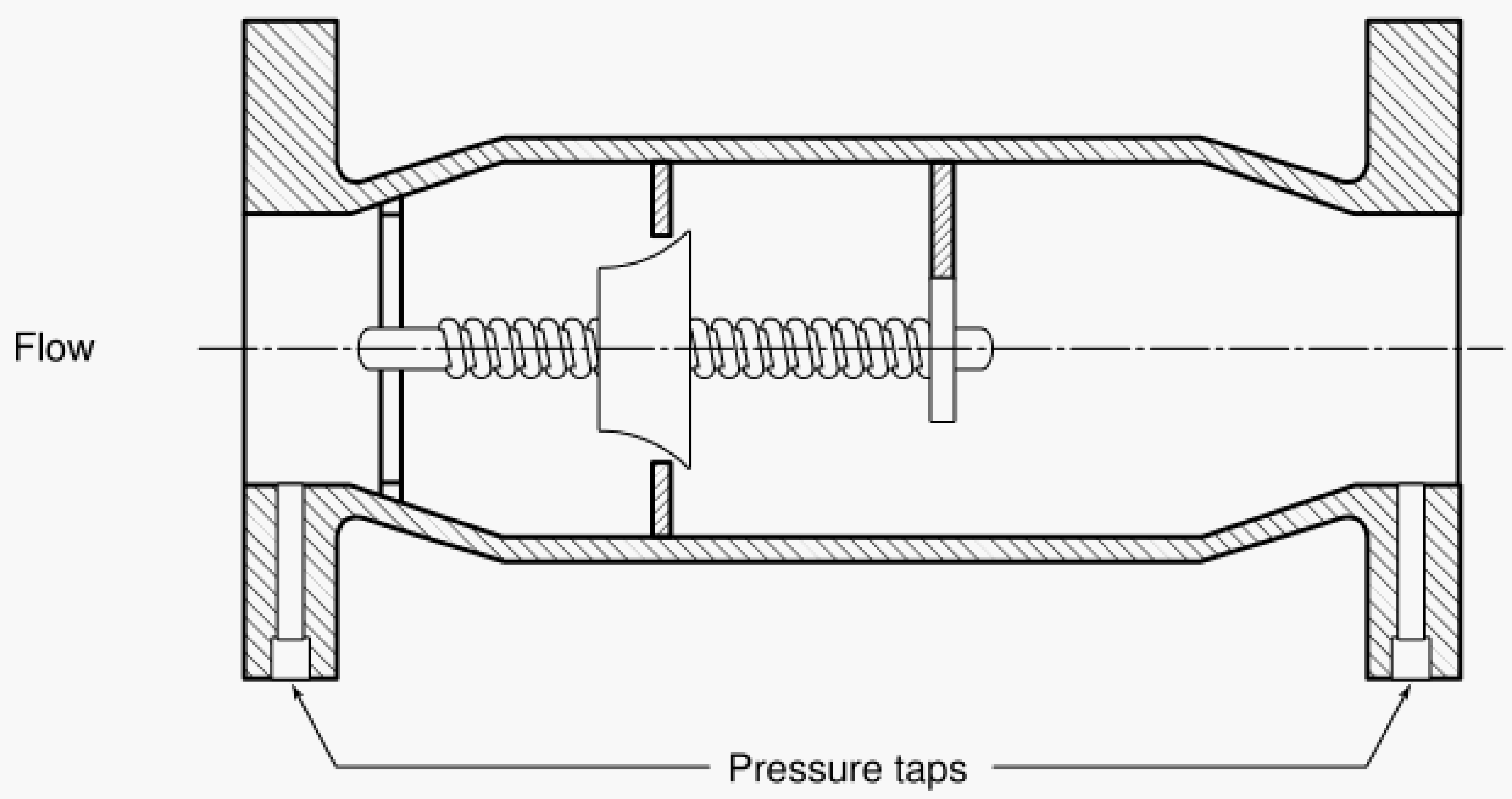


Figure 11—Variable Area Flow Meter

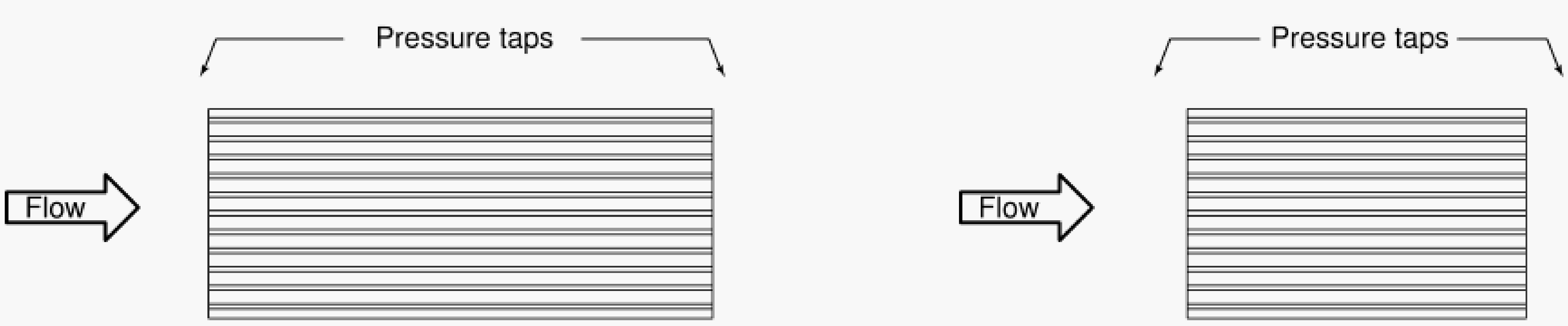


Figure 12—Laminar Flow Element

2 Terminology and Definitions

The definitions are given to emphasize and clarify the particular meaning of terms as used in this document.

2.1 METER

A meter is the assembly of a *primary element*, a *differential producer holder* with the upstream and downstream *meter tubes* that will generate a *differential pressure* when placed in a flow stream. The differential pressure is monitored by *secondary device*(s) to derive the flow rate.

2.2 PRIMARY ELEMENT OR DIFFERENTIAL PRODUCER

The primary element is defined as the *differential producer* when placed in a flowing stream.

2.3 DIFFERENTIAL PRODUCER HOLDER

The differential producer holder is defined as a pressure-containing piping element used to contain and position the differential producer and its associated differential pressure sensing taps in the piping system. An orifice fitting would be an example of such a device.

2.4 METER TUBE

The meter tube is defined as the straight sections of pipe, including all segments that are integral to the differential producer holder, upstream and downstream of the differential producer and the flow conditioner, if required.

2.5 METER TUBE INTERNAL DIAMETER, D, D_i, D_m, or D_r

In this document it has been assumed that the meter tube is circular. If the meter is used in a non-circular cross-sectional flow line or a non-circular device is installed in a circular flow line, the manufacturer of the device must explain how the critical dimensions of the primary element would be defined and calculated. In addition, other necessary or critical upstream and downstream flow conduit geometry and dimensions for the non-circular differential pressure producing flow measuring device must be defined by the manufacturer.

The published meter tube internal diameter (D_i) is the inside diameter as published in standard piping handbooks. This internal diameter is used for determining the required meter run length (e.g., for orifice meters as stated in Tables 2-7 and 2-8 of API *MPMS* Chapter 14.3 Part 2, "Specification and Installation Requirements").

The measured meter tube diameter (D_m) is the average inside diameter of the upstream section of the meter tube measured at a distance from the primary element as defined by either a published standard or by the meter's design and at the temperature of the meter tube (T_m) at the time of the internal diameter measurements. For example, an orifice diameter is measured at one in. upstream of the orifice plate. The meter manufacturer must define how D_m is obtained and utilized to calculate the flow rate for that meter.

The calculated meter tube internal diameter (D), if used, is the inside diameter of the upstream section of the meter tube computed at flowing fluid temperature (T_f). The calculated meter tube internal diameter (D) is used to determine the diameter ratio or β, if applicable, and in the Reynolds Number calculations.

The reference meter tube internal diameter (D_r) is the inside diameter of the upstream section of the meter tube calculated at the reference temperature (T_r). The reference diameter (D_r) is the certified meter tube internal diameter (as described in the orifice meter document API *MPMS* Chapter 14.3.2, Section 2.5.1.2).

2.5.1 Area or Diameter Ratio

The area ratio is the minimum unrestricted area at the primary element divided by the cross-sectional area of the meter tube.

The diameter ratio is the bore diameter of the primary element divided by the meter tube internal diameter.

2.6 SECONDARY DEVICES

Instrumentation required for determining the flow through the primary element, which typically includes monitoring differential pressure and the sensors defining the flowing conditions and fluid properties (pressure, temperature, density, etc.).

2.6.1 Pressure Measurement

The static pressure and differential pressure are measured using either a digital or an analog transmitter. Static pressure transmitters measure either the absolute or gage pressure of the fluid. Differential pressure transmitters measure the differential pressure developed between two points of measurement, caused by the primary element. A multivariable transmitter measures both static and differential pressure and may also accept a temperature sensor input. Analog transmitters provide an analog output proportional to the measured variable. The output of digital transmitters can be either analog and/or digital.

2.6.2 Static and Differential Pressure Measurement, P_1, P_2, and ΔP

The static pressure of the process is usually measured upstream of the differential producer by a tap normal to the flow velocity. The static pressure can be used (in conjunction with the temperature and composition) to determine the density of the flowing fluid.

In all differential producing flow meter designs there are high and low pressure taps. Subscripts 1 and 2 refer to two pressures where 1 is the high pressure and 2 is the low pressure. In many designs these pressures are the static pressures upstream and downstream of the differential producer. In other designs the high pressure may be as high as the upstream *total pressure* and the low pressure is a function of the design of the differential producer and the location and orientation of the pressure tap.

To minimize the effects of the static pressure on the differential pressure reading, an isolation manifold should be used to apply the operating line pressure to both sides of the differential pressure transmitter. The transmitter should then be zeroed at the elevated static pressure.

The differential pressure (ΔP) is the difference between the high and the low pressures (P_1, P_2). Other definitions of differential pressure are permitted provided a definition is given with the meter. The instantaneous differential pressure (ΔP_t) is a single measurement of ΔP at any instant.

The average differential pressure (ΔP_{avg}) is a time mean of the particular meter's individual differential pressure measurements.

The root mean square fluctuating component of the differential pressure (ΔP_{rms}) is the square root of the mean of the squares of the difference between the instantaneous differential pressure ΔP_t and time mean differential ΔP_{avg}.

$$\Delta P_{rms} = \sqrt{\frac{\sum_{i=1}^{n} (\Delta P_{t_i} - \Delta P_{avg})^2}{n}}$$

where

n = is the number of samples,

i = is the i-th data of n-number of sample points,

ΔP_t = is the instantaneous differential pressure, and

ΔP_{avg} = is the average of n samples of ΔP_t values.

2.6.3 Temperature Measurement, T_f, T_m, or T_r

The fluid temperature (T_f) is the temperature of the flowing fluid measured at the manufacturer's designated location. If the flow Mach number (ratio of the average flow velocity of the fluid to the speed of propagation of sound in that fluid under those local conditions) is greater than 0.25, dynamic effects on the temperature measurement should be taken into account. Care must be taken to ensure that the temperature sensing elements are coupled to the flowing fluid and not to the material of the meter tube. The sensed temperature with any necessary corrections is assumed to be the static temperature of the flowing fluid.

The temperature (T_m) is the measured temperature of the meter tube at the time of the measurement of the critical dimensions.

The temperature (T_r) is the reference temperature used when determining the reference critical dimensions or when presenting the results to reference conditions.

2.6.4 Density Determination

The density of the fluids used may be determined by direct measurements, by measurement and calculations based on an equation of state, or by appropriate and generally recognized industry standards.

2.7 ROUGHNESS AVERAGE, R_a

The roughness average (R_a) used in this standard is that given in ANSI B46.1 and is "the arithmetic average of the absolute values of the measured profile height deviation taken within the sampling length and measured from the graphical centerline" of the surface.

2.8 DISCHARGE COEFFICIENT, C_d

The discharge coefficient is the ratio of the actual flow rate to the theoretical flow rate. The theoretical flow rate corresponds to the flow rate without any loss of energy (assume expansibility factor is 1).

2.9 EXPANSIBILITY FACTOR, Δ OR *Y*

The expansibility factor is the ratio of the flow rate for a compressible fluid to its flow rate as an incompressible fluid, for the same Reynolds number and geometry.

2.10 FLOW CONDITIONER

A device installed upstream of the primary element, designed to minimize the effect of flow profile distortions on the discharge coefficient.

2.11 REYNOLDS NUMBER, *Re*

The Reynolds number is the ratio of the inertial forces to the viscous forces of the fluid flow. This non-dimensional parameter is defined as, $Re = \frac{V \cdot \rho \cdot D}{\mu}$, where V is the average axial velocity, ρ is the density of the fluid, μ is the absolute viscosity of the fluid, and D is a characteristic length, which in most applications is the meter tube diameter for Re_D or bore diameter for Re_d.

2.12 SWIRL

Swirl is a condition in which the flow has a rotational (tangential) component in addition to the axial velocity component.

2.12.1 Swirl Angle

The swirl angle, in degrees, is obtained from the ratio of the tangential to the axial velocity components at any point in the flow field.

3 Required Tests

3.1 STANDARD AND NON-STANDARD TESTS

Two types of tests are required for this protocol, namely Standard and Non-standard Tests. The purpose of the Standard Test is to test the flow meter in flow conditions that has fully developed symmetrical velocity profile, which has no appreciable swirl (swirl angle less than 2°). The purpose of non-standard flow conditions is to test the meter in common industrial metering situations with asymmetrical velocity profiles and significant swirl.

It is the responsibility of the manufacturer to specify the allowable range of differential pressures to be used with specific fluids, based on the thermodynamic properties of fluids as well as mechanical and fluid mechanical constraints. In no case shall the differential pressures in these tests exceed the limits imposed by mechanical and fluid mechanical constraints. The effect of static pressure on differential pressure transmitters is a separate technical issue and is addressed in 2.6.2.

In typical industrial flow rates, the maximum liquid velocity is ≅ 30 ft/s (10 m/s) and gas velocity is ≅ 90 ft/s (30 m/s). For some meters the associated differential pressure may be excessively high at these stated velocities. In such a case, the maximum fluid velocities shall be lower than those given above and shall not produce a differential pressure which exceeds the manufacturer's maximum allowable limit. The test report must state the maximum velocities and differential pressures observed during the tests. For compressible fluid flows and the low-pressure test, if the manufacturer specifies a limit on the maximum value of $\Delta P/P_1$, the maximum velocity for the test must be limited to account for the allowable limit of $\Delta P/P_1$ for the meter. Significant temperature changes may influence the performance of differential pressure flow meters through the change of critical geometrical parameters and fluid properties. Meter manufacturers have to specify corrections to be used in data processing. For flow velocities in piping in excess of Mach 0.25, a correction has to be made to the static temperature reading (see 2.6.3). It is generally impractical to change the fluid temperature in a flow laboratory; consequently, the flowing fluid temperature should simply be recorded.

3.1.1 Required Flow Conditions for Standard Tests and Non-Standard Tests

3.1.1.1 Standard Tests

The standard tests are designed to establish a meter's performance under fully developed ideal flowing conditions. If the test facility requires that a flow conditioner be used, the flow conditioner must be installed upstream of the meter tube.

The inlet of the meter being tested should be located at the position of the inlet of the reference orifice meter that was used to establish the replication of the Reader-Harris & Gallagher (R-G) equation (see 4.1). The meter tube, including a flow conditioner, if required by the meter manufacturer, will be tested for the Standard Condition.

As described in 3.2 and 3.3, this protocol requires the Standard Tests at two significantly different pressures. The two test pressures are mandatory for gas testing but optional for liquid testing. For gas flows, the high pressure must be at least five times the low pressure. If the meter is offered for ANSI 600 # flange rating or more, the high pressure test should be at least 800 psi (5.5 MPa).

3.1.1.2 Non-Standard Tests

The following three non-standard tests are required to evaluate a meter's performance in common industrial non-ideal flow conditions. These tests highlight the worst-case scenario encountered in practical applications, without introducing artificially extreme conditions.

If a flow conditioner is used with the meter, it must be explicitly stated in the published results. Tests will be carried out for the manufacturer's meter installed directly downstream of the following three non-standard conditions. In each case, flow entering the disturbance must have a symmetrical flow pattern and no swirl, as in 3.1.1.1. The manufacturer must define the distance of the following disturbances to the primary element being tested and record these distances in the test report (see 6.3).

a) **Two adjoining (close coupled) out-of-plane 90° elbows (long radius):**

   Installing these piping elements immediately upstream of the meter will generate a moderate swirl and flow profile asymmetry.

   The spacing between the end of the curved portion of the first elbow and the beginning of the curved portion of the second elbow shall not exceed two pipe diameters ($2D_i$).

b) **A half-moon orifice plate (asymmetric flow profile):**

   Installing this device immediately upstream of the meter will generate a strong asymmetric axial velocity profile.

c) **Swirl generator:**

   Installing this device immediately upstream of the meter will generate high swirl. A high swirl test is required to generate typical flow conditions as found downstream of industrial installations like headers. The swirl generator device (e.g., vanes) should produce a maximum swirl angle across the pipe of at least 24° at a distance of $18D$ downstream of this device. The angle of swirl must be confirmed on the test apparatus by use of a generally recognized technique (e.g., multi-hole Pitot tube). The setting of the vane angle on the swirl generator is not considered to be a measure of the swirl angle at the location of the meter. One direction of swirl being tested is regarded as sufficient to allow understanding of the meter's performance with swirl.

3.2 LIQUID FLOW TESTS

Two nominal line sizes are required for these tests. The smaller line size should be equal to 4-in. (100 mm) and the larger line size should be equal to or greater than 8-in. (200 mm). It may be appropriate to test meters smaller than 4-in. (100 mm) diameters. The minimum 2:1 ratio between the sizes tested must be maintained.

For meters that have geometries designed to produce area ratios (e.g., β^2 for orifice), tests shall be performed with two area ratios on either of the line sizes. The larger of the two required line sizes shall have the largest area ratio applicable for the meter to achieve a relatively low differential pressure. The smaller line size shall have the smallest area ratio applicable for the meter to achieve a relatively high differential pressure.

Meters that do not have varying area ratio for a given line size will be tested in two line sizes as defined above.

Each of the above tests shall include at least five different Reynolds number values spread evenly from the minimum value (±5%) to the maximum value (±5%). The maximum recommended velocity is typically 30 ft/s (10 m/s), but may be alternatively defined by the manufacturer. The manufacturer will define the minimum practical flow rate for the meter. The ratio of the maximum to the minimum flowrate should be 3:1 or greater as per specification claimed by the manufacturer. A further 3 intermediate flow rates will be selected to produce evenly spaced rates for the test. Each Reynolds number tested must have at least five data points to assure ±0.5% repeatability is being achieved. The test results are valid within this Reynolds number range but not beyond. The test meter's performance shall be compared with the primary standard or reference meter in the approved test facility (see Section 4.1). Only if the primary elements are geometrically similar may the range of conditions be extrapolated; i.e., Reynolds number, pipe size and area ratio, if applicable. Acceptance of meter uncertainty for custody transfer is left to the terms and condition of the contract between the parties involved.

3.3 GAS FLOW TESTS

Two nominal line sizes are required for these tests. The smaller line size should be equal to 4-in. (100 mm) and the larger line size should be equal to or greater than 8-in. (200 mm). It may be appropriate to test meters smaller than 4-in. (100 mm) diameters. The minimum 2:1 ratio between the sizes tested must be maintained. The gas flow test matrix must include at least two line pressures and the ratio of the absolute pressures must be at least 5:1 on either line size. For meters that have geometries designed to produce area ratios (e.g., β^2 for orifice), tests at multiple line pressures may be performed with only one area ratio for a given line size.

For meters that have geometries designed to produce area ratios (e.g., β^2 for orifice), tests shall be performed with two area ratios on either of the line sizes. The larger of the two required line sizes shall have the largest area ratio applicable for the meter to achieve a relatively low differential pressure. The smaller line size shall have the smallest area ratio applicable for the meter to achieve a relatively high differential pressure.

For meters that have geometries designed to produce area ratios (e.g., β^2 for orifice), additional tests shall be performed with a third area ratio on the line size that was tested with two area ratios to verify the expansibility equation across the stated range of the meter. The verification of the expansibility equation is to be performed at the lower of the two test pressures.

Meters that do not have a varying area ratio for a given line will be tested in two line sizes as defined above.

Each of the above tests shall include at least five different Reynolds number values spread evenly from the minimum value (±5%) to the maximum value (±5%). The maximum velocity should be 90 ft/s (30 m/s) or as defined by the manufacturer. The manufacturer will define the minimum practical flow rate. The ratio of the maximum to the minimum flowrate should be 3:1 or greater or as per specification claimed by the manufacturer if less than 3:1. A further 3 intermediate flow rates will be selected to produce evenly spaced rates for the test. Each Reynolds number tested must have at least five data points taken to assure ±0.5% repeatability is being achieved. If the Reynolds number reaches beyond 3,000,000 then the results can be extrapolated to a higher Reynolds number, with added uncertainty. The predicted uncertainty may be based on the difference between the calibration factor at the maximum Reynolds number tested and the extrapolated limit of the calibration curve. If the test matrix has a maximum Reynolds number less than 3,000,000 then that is the maximum Reynolds number covered by the Primary Element. The minimum Reynolds number is to be chosen by the manufacturer. The tests results are valid within this Reynolds number range.

The test meter's performance shall be compared with the primary standard or reference meter in the approved test facility (see Section 4.1). These test results will verify whether the meter conforms to the uncertainty tolerance specified by the manufacturer. Only if the primary elements are geometrically similar may the range of conditions be extrapolated; i.e., Reynolds number, relative wall roughness, tap locations, meter geometry, and area ratio. Acceptance of meter uncertainty for custody transfer is left to the terms and conditions of the contract between the parties involved.

3.4 GENERAL GUIDELINES FOR BOTH LIQUID AND GAS FLOWRATE TESTS

If a meter is to be tested in both liquid and gas flows then as long as the fluid type conforms to the Standard (4.2) a combination of liquid and gas flow tests from different approved test centers are acceptable in order to achieve the required Reynolds number range.

3.5 ACOUSTIC NOISE TEST

Audiometric testing is accomplished in accordance with 29 *CFR* 1910.95 (h) of Occupational Safety and Health Administration's (OSHA) Occupational Noise Exposure Standard. These tests are required to ensure that the meter does not emit an unacceptable level of noise to the surrounding atmosphere. The test to ascertain the noise level must be done at the noisiest condition, which must be noted. The noisiest condition is not necessarily the highest Reynolds Number. Care must be taken to make sure that the measured noise is from the Primary Element alone and not from neighboring components. The maximum noise level must be recorded on the test certificate.

3.6 LAMINAR FLOW METER TESTS

Special testing is required for differential flow meters that measure fluid flows in the laminar flow regime by measuring the differential pressure between two defined pressure tap locations on the meter. The laminar pipe flow regime is defined here when the fluid flow velocity profile is fully developed at Reynolds Number less than 2,300. In many references, a conservative Reynolds number of 2,000 in pipe flow is defined as the upper limit of the laminar flow regime. The experimentally defined upper limit of Reynolds number for the laminar flow regime is 2,300 in pipe flow. Laminar flow meters operate on the principle of the physical law expressed in the Hagen-Poiseuille Equation, which defines the differential pressure between two locations on a straight length of pipe with a uniform and constant cross-sectional area. For a fluid of known density or specific gravity, the differential pressure,

$$\Delta P = \rho \cdot g \cdot h_l = \frac{64}{Re} \cdot \frac{L}{D_i} \cdot \frac{\rho \cdot V^2}{2} \tag{1}$$

where

V = average velocity through the pipe cross-section,

h_l = differential head of liquid between the two locations on the straight pipe,

Re = flow Reynolds number,

D_i = internal diameter of the pipe,

L = distance between the pressure taps,

g = local acceleration due to gravity, and

ρ = fluid density.

The volumetric flow rate equation can be found by the extension of this physical law for known pipe geometry, fluid viscosity, and pressure drop. The volumetric flow rate is

$$Q = \frac{\pi \cdot \Delta P \cdot D_i^4}{128 \cdot \mu \cdot L} \tag{2}$$

where

ΔP = differential pressure across the defined length,

L = defined length with a uniform and constant cross-sectional area,

D_i = pipe diameter of the flow cross-sectional area, and

μ = absolute viscosity of the fluid.

A laminar flow meter predicts a volumetric flow rate directly from the friction pressure loss across the meter, the meter geometry, and the viscosity of the fluid. The stated theory is for straight pipe laminar flow meters. However, in reality laminar flow meter designs vary and Equation 2 can be reduced to a generic form to define the volume flow rate as,

$$Q = k \frac{\Delta P}{\mu} \tag{3}$$

where

k = constant that relates to the particular meter geometry.

This Test Protocol requires that laminar flow meters be tested over the flow rates and fluid viscosity range defined by the manufacturer. Some laminar flow meters are so designed that although the flow through the main flow line may not be laminar, the meter cross-section and meter internals are such that the flow through the meter is laminar.

The meter manufacturer must state the value of "*k*" to be used prior to performing the test. The laminar flow meter is to be tested at minimum of three flow rates, using a single phase Newtonian fluid and a fluid viscosity range defined by the manufacturer. The high flow rate for the test must be at, or higher than, 95% of the maximum flow rate of the meter for the test fluid at the flowing condition, but not to exceed the maximum flow rate specified by the manufacturer. The high and low flow rates for the test must be at least 3:1 or more. At each flow rate, at least five data points must be acquired.

3.6.1 Laminar Meter Test for Compressible Flows

For meters used in compressible flows, if correction for the expansibility of the gas is necessary for the flow rate calculation, the meter manufacturer must state the expansibility correction equation prior to the test and the meter must be tested with a compressible fluid at two different operating pressures. The high test pressure will be at least 80% of the test meter's highest pressure rating or at least 800 psi (5.5 MPa); the lower of the two pressures will apply for the high pressure test. The low pressure test must be at less than 50 psi (3.4 MPa) or at the lowest operating pressure specified by the manufacturer. The higher of the two pressures will apply for the low pressure test.

3.6.2 Laminar Meter Test for Turbulent Flows in the Main Pipe Line

Laminar meters having non-laminar flow regime in the main flow line should be tested with fluids of two different viscosities. This test is to establish the viscosity effects. The ratio of the two test fluid viscosities should be at least 5:1.

4 Installation and Test Facility Requirements

4.1 ACCEPTABLE TEST FACILITIES

Test facility measurement systems for mass, length, time, temperature, and pressure must be traceable to the NIST Primary Standards or an equivalent National or International Standard.

In addition, an independent facility verification shall be performed once at the beginning of this testing protocol. The test facility must be able to determine values of the orifice Discharge Coefficient for orifice metering systems that meet the requirements of API *MPMS* Chapter 14.3, within the 95% confidence interval of the R-G equation. Having established the veracity of the Test Facility, the orifice meter run shall be removed and replaced by the primary element under test. The orifice metering system will be tested over at least 3:1 flow range. The upper and lower limits of the orifice test will be within the range of flow rates of the primary element to be tested. For flow meters with rangeability of less than 3:1, the flow rate range of the orifice meter test must cover the entire flow rate range of the meter being tested.

4.2 ACCEPTABLE TEST FLUIDS

Testing of differential pressure flow meters can be conducted with various fluids provided that during the test the following conditions are met:

- The fluid is and will remain homogenous and in single phase during the test; i.e., gas shall not undergo condensation and liquid shall not cavitate. Liquid flows shall have no gas present (e.g., entrained air) in the test meter or any part of the test facility.
- Only Newtonian fluids are permitted.
- All physical properties of the fluid used shall be determined by direct measurements, by measurement and calculations based on an equation of state, or by appropriate and generally recognized industry standard. Fluids shall be characterized by the following properties: density, viscosity (dynamic or kinematic), temperature, isentropic exponent of compressible fluid, and composition.

Meter manufacturers that wish to test meters for liquid or gas applications only, may do so by choosing to use either an incompressible fluid (liquid) or a compressible fluid (gas) only. In such cases, this restriction shall be explicitly stated in the results.

The set of tests required by this protocol can be performed on different accepted facilities with different relevant fluids in order to achieve the required ranges of Reynolds number. It is preferable that meters to be used for compressible fluids are tested in a gas flow facility and meters to use for incompressible flows are calibrated in a liquid flow facility.

4.3 REQUIRED METER DIMENSIONS

Differential pressure meters must be manufactured to certain dimensional tolerances to enable a flow uncertainty to be determined. The internal dimensions/geometry of the meter must be known to establish the cross-sectional area to determine a volume flow rate. It is not necessary to know the dimension of the primary element, because the combination of the cross-sectional area and the meter discharge coefficient may be established by flow testing.

For orifice meters the dimensional tolerances are specified in API *MPMS* Chapter 14.3. The ISO 5167 standard provides the tolerances for orifice, venturi and nozzle meters.

The differential pressure devices not covered by these standards should have the tolerances specified by the manufacturer.

4.4 REQUIRED PIPING CONSIDERATIONS UPSTREAM OF THE METER

It is known that some differential pressure meters are sensitive to the shape of the fully developed velocity profile. As the roughness of pipe wall, R_a, is known to affect the shape of the fully developed velocity profile, it is a requirement that all test facilities should have a similar pipe roughness in the minimum required straight length pipe section, specified by the manufacturer, upstream of the meter. The test facility upstream pipe shall conform to the following:

For pipe diameter 12-in. (300 mm) or smaller:

$$R_a = 40\ \mu\text{-in. } (1\ \mu\text{m}) \text{ to } 250\ \mu\text{-in. } (6\ \mu\text{m})$$

For pipe diameter greater than 12-in. (300 mm):

R_a =40 μ-in. (1 μm) to 500 μ-in. (12 μm)

Application of the meter with pipe wall roughness outside these limits should be demonstrated by actual tests.

In this test protocol upstream and downstream lengths are defined as straight lengths of pipe with no tees, branches, drain holes or any obstructions. Spirally welded pipes are not permissible as upstream and downstream meter tube for the performance verification tests.

4.5 INSTALLATION REQUIREMENTS SPECIFIC FOR THE METER BEING TESTED

The meter manufacturer must specify the installation requirements for the meter and stipulate the upstream and downstream lengths of pipe required to meet the claimed uncertainty of the device. This can include the use of a flow conditioner installed at a specific location in relation to the primary element. The precise position must be recorded in the test documentation.

4.6 EFFECT OF FLOW CONDITIONERS (IF SPECIFIED BY THE MANUFACTURER OF THE METER BEING TESTED)

If the manufacturer specifies that a particular flow conditioner is required, then this flow conditioner and the associated piping configuration must be used during the tests. Manufacturer's required upstream and downstream piping and actual installed lengths must be recorded in the test report.

4.7 METER AND SECONDARY INSTRUMENT ORIENTATION

Meters are normally tested in the horizontal orientation. In general, testing meters in the vertical orientation may be difficult. However, the meter should be tested in the orientation in which it is to be used. For meters installed vertically, differential pressure readings may need to be corrected as defined by the manufacturer for the relative elevation of the pressure taps.

Differential pressure transmitters are sensitive to mounting position orientation. To minimize the effects of orientation the transmitter must be zeroed after installation.

5 Flow Rate Equation

The flow rate equation used to calculate the volume or mass flow rate from the measured differential pressure must be clearly stated with all the dimensional units (e.g., inch, mm, psi, in.in. of water, etc.). Any non-dimensional parameter used in the flow rate equation must be defined with applicable engineering units for each of the variable defining the non-dimensional parameter. If any term is a function of fluid properties, (density, viscosity, etc.) or is dependent on any non-dimensional parameter (e.g., Reynolds number), the range or limits must be defined by the manufacturer. If the flow rate equation is limited by certain geometrical dimensions, those limits must also be stated by the manufacturer. The flow rate equation specified by the manufacturer and applicable limits, if any, must be documented when reporting the test results. For compressible fluids, the expansibility equation of the meter must be stated in the test results. The expansibility equation must be verified during the required tests (see 3.3). In reporting the flow rates for the tests, results must be corrected by using the expansibility equation defined by the manufacturer.

6 Procedure for Reporting Meter Performance Results

6.1 REQUIRED TABLES, GRAPHS, AND OTHER INFORMATION

All tests must be reported in the set format of this document as described here to facilitate comparison between meters. Proof of the test facility's compliance with 4.1 needs to be presented in the report. The result of the tests should be reported in tabular and graphical form, including results of the standard tests, the non-standard tests and the difference between these two tests.

A sample of the Test Data Report form is shown in 6.3. The Test Report shall contain the following information elements:

- Name of the meter manufacturer
- Type/Name/Description of the meter
- Meter serial number and model number
- Manufacturer, model number, and uncertainty of transmitters used to measure pressure, differential pressure, and temperature
- Nominal size of meter and piping
- Meter and piping schedule with pressure rating
- Meter geometry and critical dimensions (drawing of the meter)
- Name and location of the test facility
- Date and time of test
- Fluid(s) used
- Meter orientation (i.e., horizontal or vertical)
- Pressure tap location with respect to orientation of the upstream disturbance
- Clear indication of test type (e.g., "standard" or "non-standard: high swirl" etc.)

- Manufacturer's required upstream and downstream piping and actual installed lengths, if different from that specified by the manufacturer
- Position and type of any required flow conditioner.
- Description of the full test matrix
- Table of results, including estimates of uncertainty in measurement parameters
- Deviations between the tested and reference meters (normalized over the reference meter)
- All equations required to predict the flow rate for the test meter should be clearly stated in the test report, especially those that are specifically used for that type of meter design. Equations should include the expansibility equation, the discharge coefficient equations and the flowrate equation, when applicable.

6.2 UNCERTAINTY CALCULATIONS

There should be a measurement uncertainty estimate (e.g., a 95% confidence level) derived from the test data and reported by the test facility for both the lab reference flow meter and the test meter for each test flow rate. For the case of the test meter, where applicable, the uncertainty calculation should conform to relevant ASME, API or ISO uncertainty calculations. The uncertainty calculation procedure must be clearly stated in the report for meter types where no uncertainty calculation procedure is published by a generally accepted authority. Separate uncertainty estimates can be calculated and reported for the average flow rate values, when multiple test points are measured at each test flow condition.

Uncertainty of secondary instrumentation must be considered. The performance of transmitters used as secondary devices is generally stated in terms of percent of span or percent of full scale. For use in flow measurement uncertainty calculations, the instrument uncertainties expressed as a percent of span must be converted to percent of reading by the use of the following equation:

$$U_{rdg} = \pm\left(\frac{\frac{U_{span}}{100}\times Span}{V_{meas}}\right)\times 100$$

where

U_{rdg} = uncertainty in percent of reading,

U_{span} = specified uncertainty in percent of span,

V_{meas} = value in units measured by the instrument,

$Span$ = calibrated span of the instrument.

Changes in the ambient temperature of the secondary instrumentation can affect their performance. Flow tests should be performed with the secondary instruments maintained at an ambient condition that has negligible effect on the secondary device. Alternatively, the increased uncertainty of the secondary device should be included in the system uncertainty.

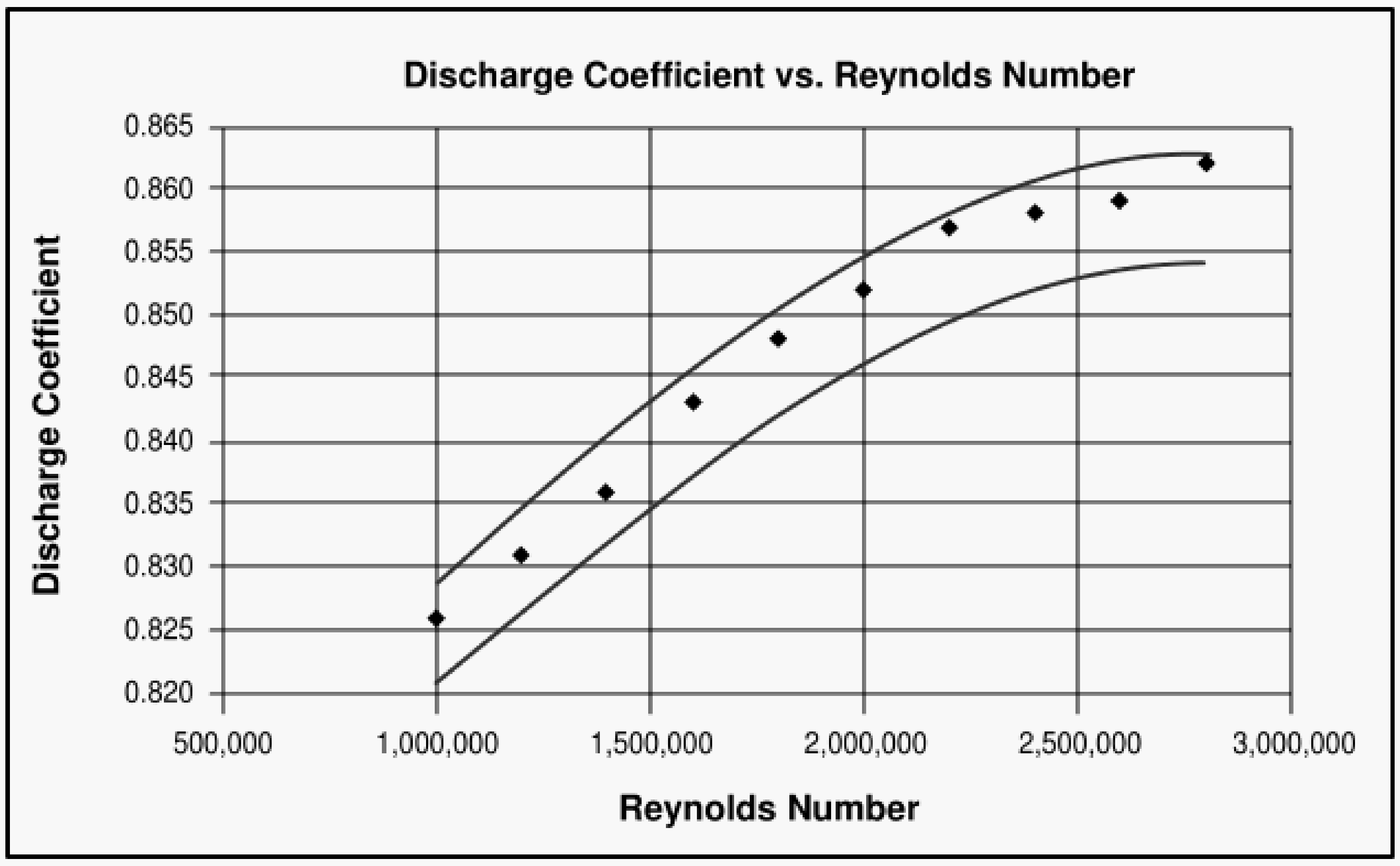
6.3 SAMPLE TEST DATA RECORDING FORM

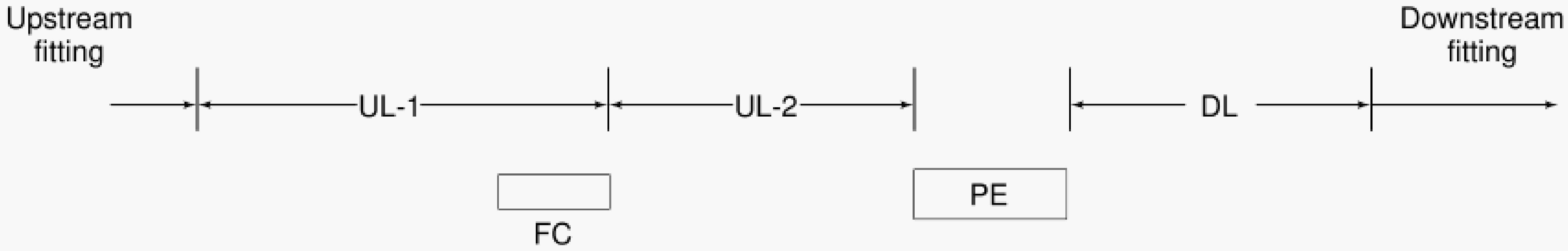
TEST REPORT OF GENERIC DIFFERENTIAL PRESSURE FLOWMETER

Manufacturer:	Generic, Inc.
Meter Description:	DP Flow Widget
Serial Number:	02-000038DD
Model # :	FW-26A
Line Size:	4.026"
ANSI Rating:	600#
Pipe Schedule:	40
Test Date/Time:	1-Mar-03
Test Fluid:	Natural Gas
Viscosity:	0.018 cP
Density:	2.28 lb/ft^3
Static Pressure:	720 psig
Fluid Temperature:	76.2 deg-F
Test Type:	High Swirl

Reynolds Number	Actual Flow Coefficient	Predicted Flow Coefficient
1,000,000	0.823	0.82480
1,200,000	0.831	0.83046
1,400,000	0.836	0.83601
1,600,000	0.843	0.84127
1,800,000	0.848	0.84611
2,000,000	0.852	0.85036
2,200,000	0.857	0.85387
2,400,000	0.858	0.85649
2,600,000	0.859	0.85807
2,800,000	0.862	0.85844

Predicted flow coefficient = function of Reynolds number





Sample Installation Drawing

UL-1 = Straight pipe length from the end of the upstream fitting to the end of the Flow Conditioner
UL-2 = Straight pipe length from the end of the Flow Conditioner to the entrance of the Test Meter
FC = Flow Conditioner
PE = Primary Element and/or Test Meter
DL = Straight pipe length downstream of the Test Meter to the entrance of the downstream fitting

APPENDIX A—TEST MATRIX

Standard Tests (3.1): 2 Line Sizes: 4-in. (100 mm) and ≥ 8-in. (200 mm)

Liquid Standard Tests (3.2): 1 Pressure, 5 Reynolds Values each Test Series

Test Series	Diameter Ratio	Line Size
1	$ß_1$	D_1
2	$ß_2$	D_1
3	$ß_1$	D_2

Gas Standard Tests (3.3): 5 Reynolds Values each Test Series

Test Series	Pressure	Diameter Ratio	Line Size
1	P_1	$ß_1$	D_1
2	P_2	$ß_1$	D_1
3	P_1	$ß_2$	D_1
4	P_1	$ß_3$	D_1
5	P_1	$ß_1$	D_2

Non-Standard Tests (3.1.1.2): 5 Reynolds Values each Test Series with 1 Line Size, 1 Pressure, 1 Diameter Ratio

a) 2 close-coupled elbows out-of-plane

b) Half-moon plate

c) Swirl Generator

Additional Tests

1) Acoustic Noise Test (3.5)

2) Laminar Flow Test (3.6)

Acceptable Test Facilities (4.1)

1) Use an orifice metering system to establish that the facility can reproduce coefficients of discharge for the R-G Equation within a 95% confidence level.

2) Replace the orifice metering system with the metering system to be tested.

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1220 L Street, Northwest
Washington, D.C. 20005-4070
202-682-8000

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