Manual on Installation of Refinery Instruments and Control Systems

Part I—Process Instrumentation and Control
Section 1—Flow

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SECTION 1—FLOW

1.1 Scope

This section presents recommended practices for installing differential pressure instruments and area flowmeters. These meters are commonly used to indicate, record, transmit, and control fluid flow.

Flow measurement falls into two broad classifications: refinery process flow measurement and custody transfer. This section is primarily concerned with process flow measurement. Liquid custody transfer is normally done with positive displacement meters or turbine meters, usually combined with meter proving equipment. Custody transfer flow measurement [1, 2, and 3] is covered in Chapters 4, 5, and 6 of the API *Manual of Petroleum Measurement Standards*.[1]

1.2 General

1.2.1 DIFFERENTIAL PRESSURE INSTRUMENTS

The differential-head type of instrument measures flow inferentially from the differential pressure caused by flow through a primary element. This differential pressure is sensed by diaphragms, bellows, or manometers. Transmitters of the force or motion type are either pneumatic or electronic. Electronic transmitters use strain gages, capacitance detectors, or other solid state detectors to provide output with minimal sensing element displacement.

Primary elements are generally one of the types described in 1.2.1.1 through 1.2.1.6.

1.2.1.1 Orifice

Orifices are usually thin concentric plates, but they may be eccentric, segmental, quadrant edge, or some other special form, depending upon their application.

1.2.1.2 Flow Nozzle

Flow nozzles are used in installations where higher velocity and moderately better pressure recovery are required than are obtainable with an orifice plate.

1.2.1.3 Venturi Tube

Venturi tubes are used in installations where high capacity and good pressure recovery are required or where the measured stream contains some solids.

1.2.1.4 Flow Tube

Flow tubes are used in installations where low pressure loss is a major consideration or where piping configurations are restrictive.

1.2.1.5 Pitot Tube

Generally, pitot tubes are used in installations where no appreciable pressure drop can be tolerated on high-volume flows, such as on cooling water. The accuracy of the measurement depends upon the determination of the average velocity from the velocity profile. An averaging pitot tube is also available.

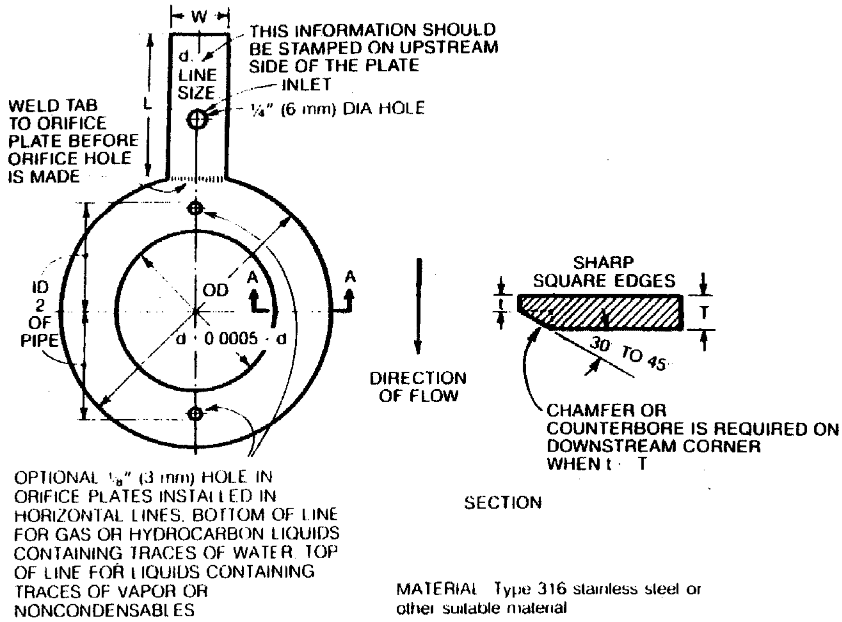
1.2.1.6 Elbow Taps

Elbow taps are used in installations where the velocity is sufficient and where high accuracy is not required [4]. Although they are less accurate than other differential pressure instruments, elbow taps possess good repeatability. A water velocity of 17 feet per second (5 meters per second) will produce a water differential of approximately 100 inches (2500 millimeters). Some test data are available [5, 6].

1.2.2 VARIABLE AREA FLOWMETERS

For refinery service, rotameters are the most commonly used meters in the area class.

[1]Bracketed numbers indicate references to be found on pages 27 and 28.



Orifice Plate Outside Diameters to Fit ANSI Service Rated Flange Unions

Nominal Pipe Size	T	t	CLASS 300	600	900	1500	2500	TAB L	W
2	⅛	1/32	4⅜	4⅜	5⅝	5⅝	5¾	4	¾
3	⅛	1/32	5⅞	5⅞	6⅝	6⅞	7¾	4	¾
4	⅛	1/16	7⅛	7⅝	8⅛	8¼	9¼	6	1
6	⅛	3/32	9⅞	10½	11⅜	11⅛	12½	6	1
8	⅛	⅛	12⅛	12⅝	14⅛	13⅞	15¼	6	1
10	¼	3/16	14¼	15¾	17⅛	17⅛	18¾	6	1
12	¼	7/32	16⅝	18	19⅝	20½	21⅝	6	1
14	¼	7/32	19⅛	19⅜	20½	22¾		6	1
16	⅜	9/32	21¼	22¼	22⅝	25¼		6	1
18	⅜	9/32	23½	24⅛	25⅛	27¾		6	1
20	⅜	⅜	25¾	26⅞	27½	29¾		7	1
24	⅜	⅜	30½	31⅛	33	35½		7	1

NOTES:

1. All measurements in inches.
2. The outside diameter (OD) of the orifice plate is that required to fit inside the bolts of standard ANSI flanges. The outside diameter is equal to the diameter of bolt circle minus the nominal diameter of bolt, within a manufacturing tolerance of +0 inches, −1/32 inch (+0 millimeters, −.8 millimeters).
3. For orifice plate outside diameters in flange sizes and ratings not listed above, refer to gasket OD dimensions given under Figure 3, Table 1, Appendix E in ANSI B 16.5—1981, *Steel Pipe Flanges and Flanged Fittings*, available from the American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017.
4. The upstream face of the orifice plate shall be as flat as can be obtained commercially; any plate departing from flatness along any diameter more than 0.010 per inch (.25 millimeters) of dam height, $(D\text{-}d)/2$, shall be unacceptable. Surface roughness shall not exceed 50 microinches in a band at least 0.25 diameter wide around the orifice bore.
5. All seating surfaces for spiral-wound gaskets should be clean and free of rust, burrs, nicks, and so forth. Any surface not meeting the following tolerances should be relapped:
(a) Roughness: Should not exceed 80 root mean square with 63 root mean square or better as optimum.
(b) Flatness: Out-of-plane tolerances must not exceed 0.0025 inch (0.06 millimeter). The cumulative out-of-flatness for two mating surfaces shall not exceed 0.0040 inch (0.1 millimeter).

Figure 1-1—Concentric Orifice Plate

1.2.3 FORCE OR TARGET FLOWMETERS

Force or target flowmeters measure flow inferentially by measuring the force developed at a disk-shaped target suspended in the flow path.

1.2.4 TURBINE FLOWMETERS

Turbine meters measure flow from the rotation produced by the flow past a turbine or propeller.

1.2.5 ELECTROMAGNETIC FLOWMETERS

If a fluid has some degree of electrical conductivity, an electromagnetic flowmeter can measure its average flow velocity inferentially from the voltage generated by the fluid as it moves through a magnetic field.

1.2.6 POSITIVE DISPLACEMENT METERS

This meter measures flow by isolating, counting, and totaling segments of known volume as they are displaced through its body [1].

1.2.7 VORTEX SHEDDING FLOWMETERS

Vortex meters are oscillatory flowmeters that utilize the vortex train generated by an obstruction placed in a fluid stream. They measure flow by counting the vortices.

1.2.8 SONIC FLOWMETERS

There are two main classes of sonic flowmeters. Contrapropagating meters measure the difference in the transit times of sounds transmitted upstream and downstream. Doppler or reflection meters measure the frequency shift of sound reflected back from particles or bubbles in the flow stream.

1.3 Differential Primary Elements

1.3.1 THIN-PLATE ORIFICES

1.3.1.1 Concentric Orifice Plates

The sharp-edge, concentric orifice plate is the most frequently used primary element because of its low cost, adaptability, and the availability of accurate coefficients.

For most services, orifice plates are made of corrosion-resistant materials, usually Type 304 or 316 stainless steel. Other materials are used for special services.

The upstream face of the orifice plate should be as flat as can be obtained commercially. It must be smooth, and its finish should be at least equivalent to that given in Figure 1-1.

The thickness of the orifice plate at the orifice edge should not exceed (minimum requirements governing in all cases):

$D/50$ (one-fiftieth of pipe diameter)

$d/8$ (one-eighth of orifice diameter)

$(D-d)/8$ (one-fourth of dam height)

In some cases, including large pipe diameter and high pressure and temperature, the thickness of the orifice plate will be greater than is permitted by the limitations for the thickness of the orifice edge. In such a case, the downstream edge shall be counterbored or beveled at an angle of 45 degrees or less to the required thickness at the orifice edge. The word "upstream" or "inlet" should be stamped on the orifice tab on the square-edge side of the plate. Dimensions for orifice plates are shown in Figure 1-1.

Bores must be round and concentric. Practical tolerances for orifice diameters, as given in ANSI/API 2530 [7], are shown in Table 1-1.

The upstream edge of an orifice should be square and sharp. It is usually considered sharp if the reflection of a beam of light from its edge cannot be seen without magnification. The edge radius should not exceed 0.0004 times the bore diameter. It should be maintained in this condition at all times. For two-way flow, both edges must be square. Orifice plate details and schedule of thicknesses are shown in Figure 1-1. Detailed tolerances are discussed in ANSI/API 2530 and American Society of Mechanical Engineers publications [8, 9].

In wet-gas or wet-steam services, where the volume of condensate is small, a weep hole flush with the bottom of the orifice run may be used to prevent a buildup of condensate in horizontal lines. The weep hole serves as a drain to prevent freeze-up during shutdown periods. A weep hole flush with the top of the pipe can also be used to pass small quantities of gas in liquid streams. If the diameter of the hole is less than one-tenth of the orifice bore diameter, the maximum flow through the drain hole is less than 1 percent of the total flow.

Table 1-1—Practical Tolerances for Orifice Diameters (Dimensions in Inches)

Orifice size, d	Tolerance plus or minus (per inch of diameter)
0.250	0.0003
0.375	0.0004
0.500	0.0005
0.625	0.0005
0.750	0.0005
0.875	0.0005
1.000	0.0005
Over 1.000	0.0005

Because more test information is available for thin-plate orifices than for other primary devices, it is possible to design orifice installations to acceptable accuracies. Sometimes the layout of equipment precludes the use of the most accurate design. A lower order of accuracy is often acceptable in installations used only for control purposes than in installations used for accounting, material balance, or custody transfer.

1.3.1.2 *d/D* (β) Ratio

Orifice diameters should be selected so that the ratio of orifice diameter to actual internal pipe diameter, *d/D*, does not exceed the limits as shown on ANSI/API 2530, as follows:

1. With meters using flange taps, β shall be between 0.15 and 0.70.
2. With meters using pipe taps, β shall be between 0.20 and 0.67.

With either type of pressure taps, diameter ratios as low as 0.10 may be used while ratios as high as 0.75 may be used with flange taps and as high as 0.70 may be used with pipe taps. The flow constants, F_b, for these extreme values of β are subject to higher tolerances, and it is recommended that the use of these extreme ratios be avoided (see ANSI/API 2530).

When using small bores, care should be exercised to prevent plugging by pipe scale or other foreign material.

1.3.1.3 Other Orifice Plates

Eccentric or segmental orifices may be used in horizontal runs for special services where concentric orifices cannot be used. In some installations, the fluid stream possesses a large quantity of undissolved gas or a gas containing condensables, which may be carried along the pipe. This type of plate can produce full venting or full drainage, whichever is required, if the orifice opening is properly located.

Segmental orifices are recommended for slurry services because of their insensitivity to changes in the liquid-solid ratio and their relatively satisfactory accuracy (approximately 2.2 percent for plate calculations) [10].

The eccentric orifice usually is placed with its edge tangent to a circle having a diameter 0.98 of that of the pipe. The point of tangency is at the top, vertical centerline for liquids containing some vapor, and at the bottom, vertical centerline for vapors containing some liquids. Coefficients are also available for differential pressure taps at 90 or 180 degrees from the point of tangency. Eccentric and segmental orifice plates are shown in Figure 1-2. Segmental orifices are usually constructed with a circle diameter (*D*) between 0.97 and 0.98

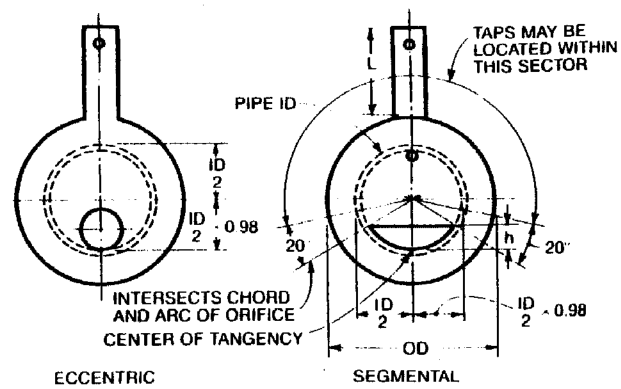


Figure 1-2—Eccentric and Segmental Orifice Plates

percent of the inside pipe diameter (*ID*). They are generally used in services that require that the orifice be placed at the bottom of the line. For best accuracy, the tap location should be 180 degrees from the center of tangency. However, to avoid gas bubbles in the taps, the location may be anywhere within the sector shown in Figure 1-2.

The quadrant-edge, or quarter-circle, orifice is a device in which the upstream edge is rounded to form a quarter circle. The thickness of the plate near the orifice is equal to the radius of the quarter circle.

The quadrant-edge orifice is used for the flow measurement of viscous streams because of its relatively constant coefficient over a wide range of low Reynolds numbers. It is especially valuable where the viscosity is high and variable. In contrast, the square-edge orifice coefficients show increasing dependence on orifice Reynolds number,[2] R_d, below 100,000. Square-edge orifice coefficient correction factors are available for R_d down to approximately 25,000.

The quadrant-edge orifice may be used when the line Reynolds numbers (R_D) range from 100,000 down to 3000 to 5000, depending upon the β ratio. It has a standard deviation of ±1 percent for β from 0.3 to 0.6 and ±1.25 percent for β from 0.25 to 0.3. It is recommended for measurement of flows when the Reynolds number, based on pipe diameter, is less than 10,000. When R_D is below the 3000 to 5000 range, the coefficient curve shows a hump, which is proportionally higher for longer upstream runs. The hump may be suppressed, even at values of R_D below 1000, by taking the flow straight out of a vessel nozzle through a meter run of only a few pipe diameters ahead of the orifice. The hump may also be suppressed by using a screen, such as a multiplate flow straightener, a few diameters upstream [11-14].

[2] In some data, R_D (the Reynolds number for the pipe) is given; in other data, R_d, (the Reynolds number for the restriction) is given. The difference between these two numbers is shown in the following equation:

$$R_D = \beta R_d$$

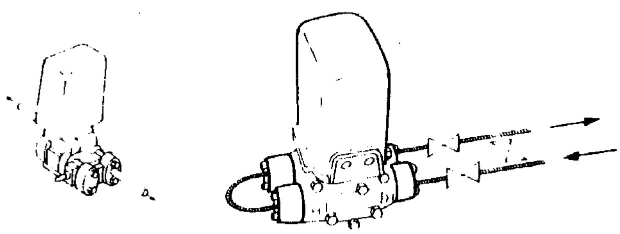
Readings for flows exceeding the maximum Reynolds number limits may be very inaccurate. High-quality machining of quadrant orifice plates is important because the dimensions, shape, and smoothness of the edges can affect the accuracy of its readings.

A very small orifice plate or capillary that is an integral part of a diaphragm pressure transmitter is sometimes used for the measurement of very small flows. Flows as low as 0.04 cubic centimeters per minute of water equivalent or 0.027 standard cubic feet per minute of air may be measured using this method (see Figure 1-3).

1.3.1.4 Sizing Orifices

It is common to size the orifice for a 100-inch (2500-millimeter) water column (dry calibration) at maximum flow. This permits either an increase or a decrease in maximum flow, without changing the orifice bore, by an adjustment of the differential transmitter range. Smaller differentials, 50 inches (1250 millimeters) or 20 inches (500 millimeters), are now commonly used to save energy. For gas or steam flow, a good rule of thumb is that the meter range, in inches of water, should not exceed the flowing pressure, in pounds per square inch absolute.

The procedures for computing orifice sizes and flow through orifices are given in various publications [4, 7, 9, 15, 16]. Special slide rules are especially valuable for checking longhand or computer computations and for preliminary orifice sizing. Programs to size orifices are also available for various programmable calculators. Orifice calculations can be purchased from the manufacturers of orifice plates or flowmeters. Occasionally, only approximate physical properties of the flowing fluid are known before startup; in such cases, a flow slide rule may be used to determine orifice size. Computations can be made later using actual flow conditions, or corrections can be applied to preliminary computations made with the approximate values.



NOTES
1. Upstream strainers or filters are optional, but highly desirable.
2. For continuous services, provide block and bypass valves to allow meter calibration.
3. Provide breakout unions where piping cannot be spread to remove meter body.

Figure 1-3—Integral Orifice Flowmeter—Liquid and Gas

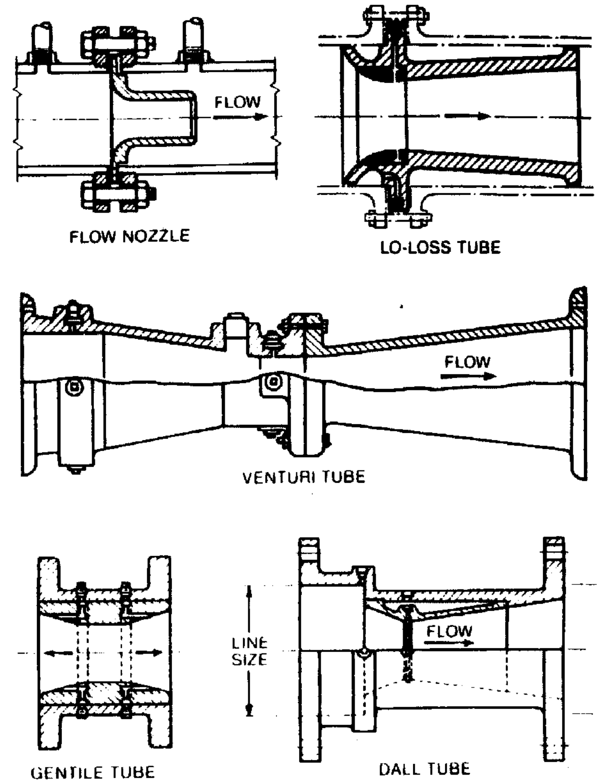


Figure 1-4—Flow Nozzle, Venturi Tube, and Flow Tubes

1.3.2 FLOW NOZZLES

Flow nozzles are used less frequently than orifice plates. Their principal advantages are better pressure recovery and approximately 65 percent higher flow capacity for a given diameter than can be obtained under the same conditions with orifice plates. Flow nozzles may be used in light slurry service; however, accuracy is poor below certain Reynolds numbers [1, 5, 6]. Meter run requirements, flange ratings, and tap requirements are generally the same as for orifice installations. However, because the d/D ratio for the same flow and line size is smaller, a shorter meter run may be used where the run length is based on the minimum run for the actual d/D ratio.

A typical flow nozzle is shown in Figure 1-4. There are several forms of flow nozzles, one of the most common being the American Society of Mechanical Engineers' long-radius form [4, 9]. Properly installed and calibrated, flow nozzles are nearly equal in accuracy to sharp-edge orifices. Calculation procedures and coefficients for flow nozzles have been published [4, 7, 8].

1.3.3 VENTURI TUBES AND FLOW TUBES

1.3.3.1 General

Venturi tubes and flow tubes are frequently used in refinery operations. Permanent head loss for these devices is lower than for other constricting primary elements. Venturi and flow tubes should be considered for all applications where minimizing head loss is an important factor. These primary devices are more costly than orifice or flow nozzle installations, and the long-form venturi is the most expensive. The venturi tube and flow tubes are shown in Figure 1-4.

1.3.3.2 Venturi Tubes

Venturi tubes (see Figure 1-4) give a much lower permanent head loss than orifices or flow nozzles. For a long-form venturi tube, the approximate head loss will be between 10 and 14 percent of the measured differential, dependent upon the *d/D* ratio. Minimum runs are usually shorter for these tubes than for orifice plates or flow nozzles. As a rule, the manufacturer of the venturi tube can supply the minimum length meter run data.

Although coefficients are available for the calculation of flow through venturi tubes [4, 8, 9], the manufacturer may specify the flow for a given differential. Venturi tubes usually give an accuracy nearly equal to that of a thin-plate orifice. Venturi tube flow coefficients are relatively stable over a wider range of Reynolds numbers than are the coefficients of sharp-edge orifices.

When properly purged, venturi tubes are suitable for metering streams that contain solids. An increase in the solid-liquid ratio will cause a higher reading.

1.3.3.3 Dall Tubes

The Dall tube [17] is available as a fabricated line insert, approximately 2 diameters long. The static pressure tap is in a line-size section followed by a sharp shoulder and a steep, conical entrance to a short, cylindrical section, which has an annular slot, followed by a 15-degree conical diffuser, terminating with a shoulder (see Figure 1-4).

Upon examination, the Dall tube gives the impression that a fluid flowing through it would be subject to a very high permanent head loss. Actually, the Dall tube head loss is only about 2½ to 6 percent of the measured differential as compared to 10 to 14 percent for the same flow in a long-form venturi. The coefficient may vary for line Reynolds numbers below 500,000. Rounding of the sharp edges will cause slight variations in the coefficients.

Unless it is purged, the Dall tube should not be used for slurries or fluids that contain suspended solids because the annular throat slot is subject to plugging. Dall tubes require longer minimum meter runs than venturi tubes.

1.3.3.4 Gentile Tubes

The Gentile tube has impact- and suction-type piezometer openings to increase the measured differential. The Gentile tube is short and gives a good differential with a relatively small amount of constriction (approximately 1½ diameters) (see Figure 1-4). Its coefficients are the same for flow in either direction, and it is less expensive than a venturi tube. However, Gentile tubes are very susceptible to line roughness. Until sufficient data has been accumulated on the effect of manufacturing tolerances and upstream piping configurations on its accuracy, a Gentile tube should be calibrated for any application where accuracy is important [18].

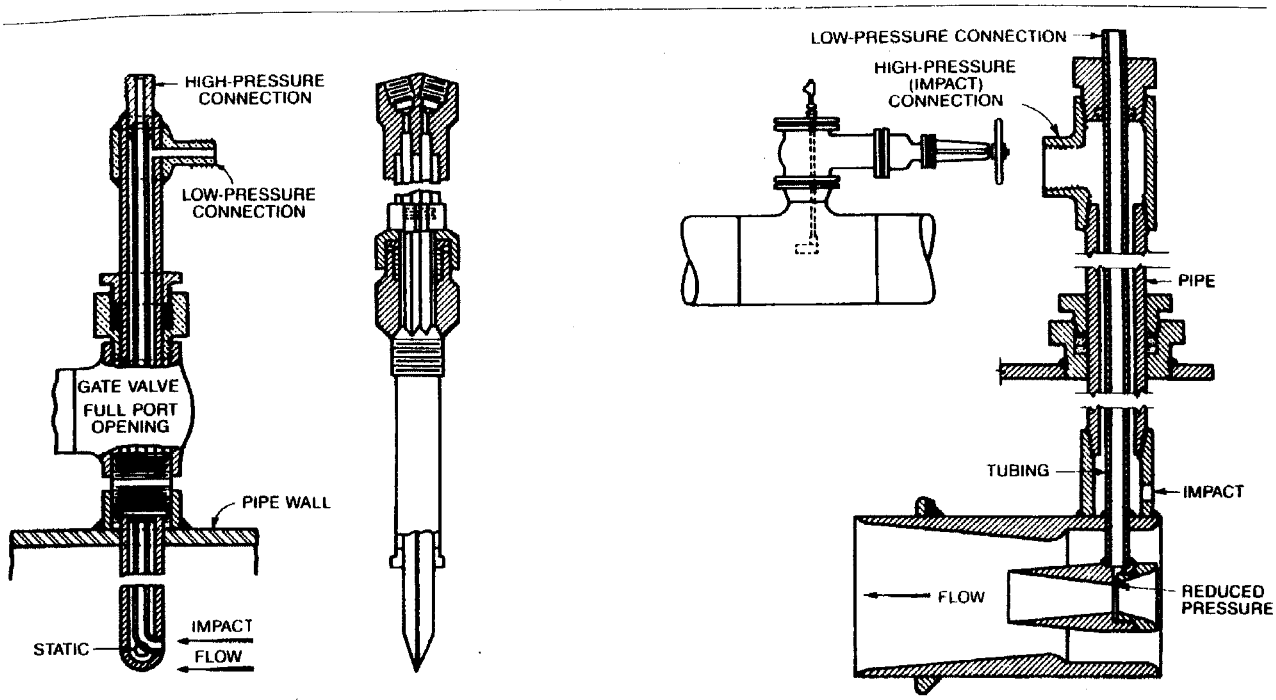
1.3.3.5 Lo-Loss Tubes

The Lo-Loss tube [19] is another type of differential producer designed for very high-pressure recovery. Its installation requires much less length than the venturi tube, but its use should be restricted to relatively clean services (see Figure 1-4).

1.3.4 PITOT TUBES AND PITOT VENTURIS

Pitot tubes and pitot venturis are used where the pressure drop or power loss through other devices cannot be tolerated and where accuracy is not of prime concern (see Figure 1-5). Frequently, these devices are used to measure high air and water flow rates. Pitot venturis are useful in applications where an ordinary pitot tube does not give satisfactory differential. However, they require a larger tap size. Pitot venturis should not be used in a liquid service of greater than 9 feet per second if dissolved gases are present. Higher velocities cause cavitation, and gas bubbles collect in the meter connecting lines. A traverse is required for good measurement unless there is sufficient straight upstream run to obtain a uniform velocity profile, except in cases where an averaging type of pitot tube is used.

Proper design will permit the installation or removal of pitot tubes and pitot venturis from lines that are in service. Care should be exercised when considering their use in hot oil or other hazardous service except in fixed installations designed to be leakproof. As the line size increases, the cost of pitot tubes and pitot venturis decreases in relation to other primary elements. A typical pitot tube installation is shown in Figure 1-6.



PITOT TUBES

TYPICAL PITOT VENTURI

Figure 1-5—Pitot Tubes and Pitot Venturi

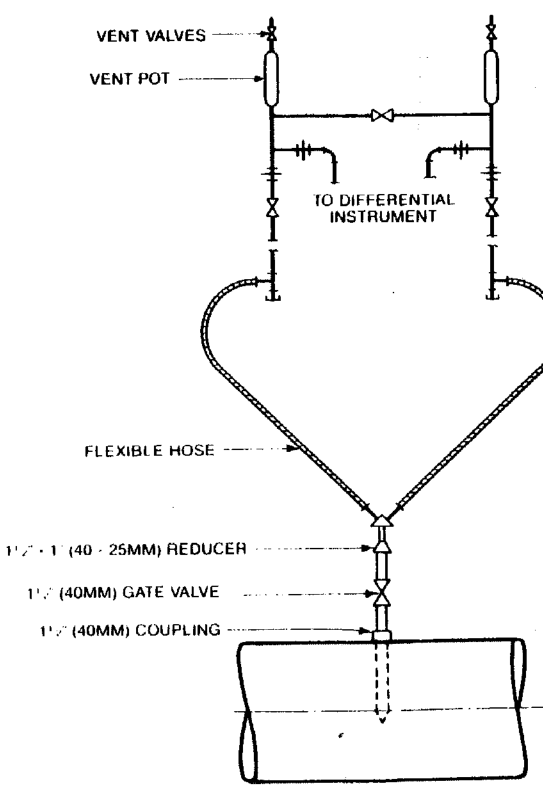


Figure 1-6—Pitot Tube Installation

1.3.5 METERING RUNS

1.3.5.1 Orifice Taps

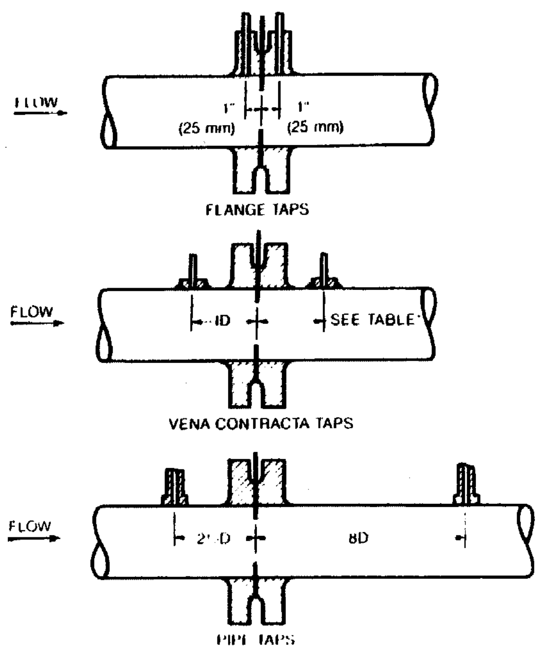
Orifice taps may be of several types, as shown in Figure 1-7. Flange taps usually are preferred for refinery use. Vena contracta taps and pipe taps sometimes are used in refineries. However, vena contracta taps cannot be used with some sizes and pressure ratings of welding-neck flanges because one or both taps may fall in an undesirable location in the flange hub or weld. Also, when changing orifice bore, the downstream tap must be changed.

Radius or throat taps (those located 1 pipe inside diameter upstream and ½ pipe inside diameter downstream) can be used for refinery service. The downstream tap for the radius or throat tap sometimes falls either fully or partially into the flange hub.

Corner taps [20] are used by some refiners, particularly on small lines where flange taps may be at the wrong location in the pressure profile. One type of corner tap orifice flange arrangement is shown in Figure 1-8.

Pipe taps or full-flow taps, located 2½ diameters upstream and 8 diameters downstream, measure the permanent pressure loss. These can measure higher flow rates for a given meter differential than can flange, vena contracta, radius, or corner taps.

Orifice flanges with flange taps, as shown in Figure 1-8, are generally used. These flanges have a minimum thickness of 1½ inches (40 millimeters). In the smaller sizes, they are



d/D (β)	0.25	0.3	0.4	0.5	0.6	0.7
Distance from orifice plate (in IDs)	0.84	0.80	0.74	0.65	0.56	0.45

Tolerance is approximately ± 0.1 D.

Figure 1-7—Flange Taps, Vena Contracta Taps, and Pipe Taps

thicker than the standard class 300 flange. Each tap should be positioned 1 inch (25 millimeters) from the nearest face of the orifice plate. It is important to allow for compressed gasket thickness.

Curves on allowable variations in pressure tap hole location versus β ratio can be found in ANSI/API 2530. It is recommended that the tolerances for β ratio of 0.70 minimum be used.

For pipes smaller than 4 inches (100 millimeters), the tolerance is 0.025 inches (0.6 millimeters). This tolerance increases to 0.065 inches (2 millimeters) at a β of 0.40 or smaller.

For pipes 4 inches or larger, the tolerance is 0.05 inch (1 millimeter). This tolerance increases to 0.125 inch (0.1 millimeter) at a β of 0.40 or smaller.

If ¾-inch (20-millimeter) taps are used, minimum flange thickness should be 1⅝ inches (40 millimeters). Where piping specifications exclude threaded joints in primary piping, socket or fillet-weld taps may be used with socket-weld block valves. If secondary piping may be screwed, the block valves may be socket-weld on one end and threaded on the other. Screwed taps may be seal-welded to minimize leakage. It is recommended that nipples to the first block valves be at least Schedule 160. Between adjacent lines sufficient space should be provided for orifice taps, block valves, and connecting piping. Consideration should be given to room requirements for rodding or drilling out taps.

Special orifice plate holding fittings are available that make it easier to change orifice plates. With some of these devices, changing orifice plates is possible while the line is under pressure. These types are considerably larger, more costly, and require regular lubrication and maintenance.

1.3.5.2 Minimum Length of Meter Runs

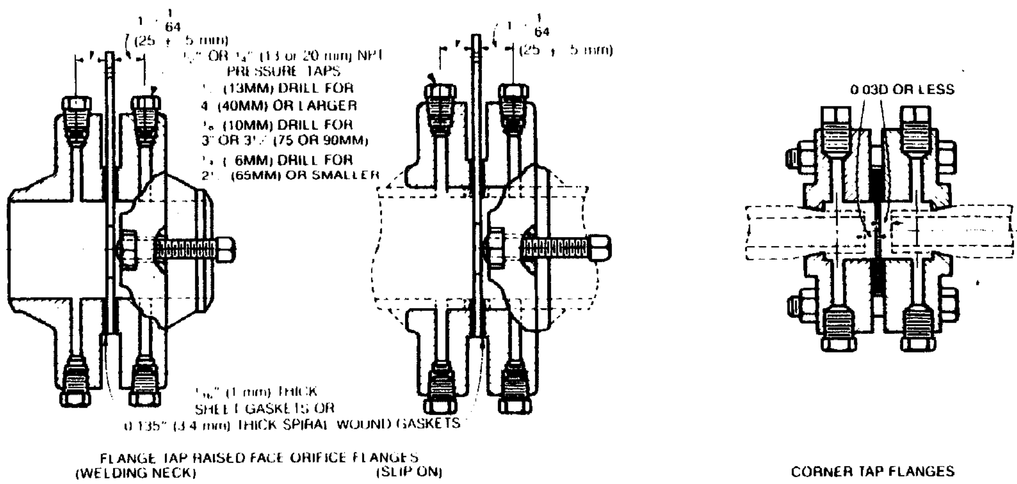
Meter runs [21, 22] should be designed with not less than a minimum length (usually given in nominal pipe diameters) of straight pipe preceding and following the orifice (see details 1 through 13 in Figure 1-9 and Table 1-2). It should be noted that these show minimum lengths of run; these runs should be increased if practicable [4, 7, 9, 15, 21]. If straightening vanes are used, refer to ANSI/API 2530 for run requirements. Where pipe taps are used, the upstream run should be increased by 2 pipe diameters and the downstream run increased by 8 pipe diameters. The meter run length shown in Table 1-2, based on a minimum d/D ratio of 0.70, is recommended wherever practical, even if the actual d/D ratio is smaller. If other reasons make it necessary to use runs designed for less than 0.70 d/D, a future increase in d/D requirements should be considered. Straightening vanes should be avoided because of the possibility of their fouling or loosening and working downstream.

1.3.5.3 Orientation of Meter Runs

Vertical orifice runs, in liquid service and with widely separated pressure taps, may have a head error due to temperature differences. Although horizontal orifice runs avoid this head error, vertical orifice runs are often preferable for gas or steam flows containing appreciable amounts of condensate and for liquids containing vapor. Vertical flows should be upward for liquids; downward for wet gases and steam. The potential for error in vertical lines can be minimized by proper manifolding, as shown in Figures 1-10 to 1-13, or by using seals or purges. For steam, the condensate pots must be at the same level as shown in Figures 1-11 and 1-13.

1.3.5.4 Minimum Diameter of Metering Runs

Metering runs for orifices should preferably be 2 inches (50 millimeters) or larger. In lines smaller than 2 inches, it is advisable to swage the line up to the 2-inch size for the metering run or to use rotameters, calibrated meter runs, or other special devices. Errors caused by the roughness of pipe walls become more pronounced in smaller-sized orifice runs.



NOTE: To provide adequate clearance in 1-1/2-inch (40 millimeters) and smaller pipe sizes, the pipe end is often made flush with the face of the raised face flange. In this arrangement, clearance to the plate is the thickness of the compressed gasket.

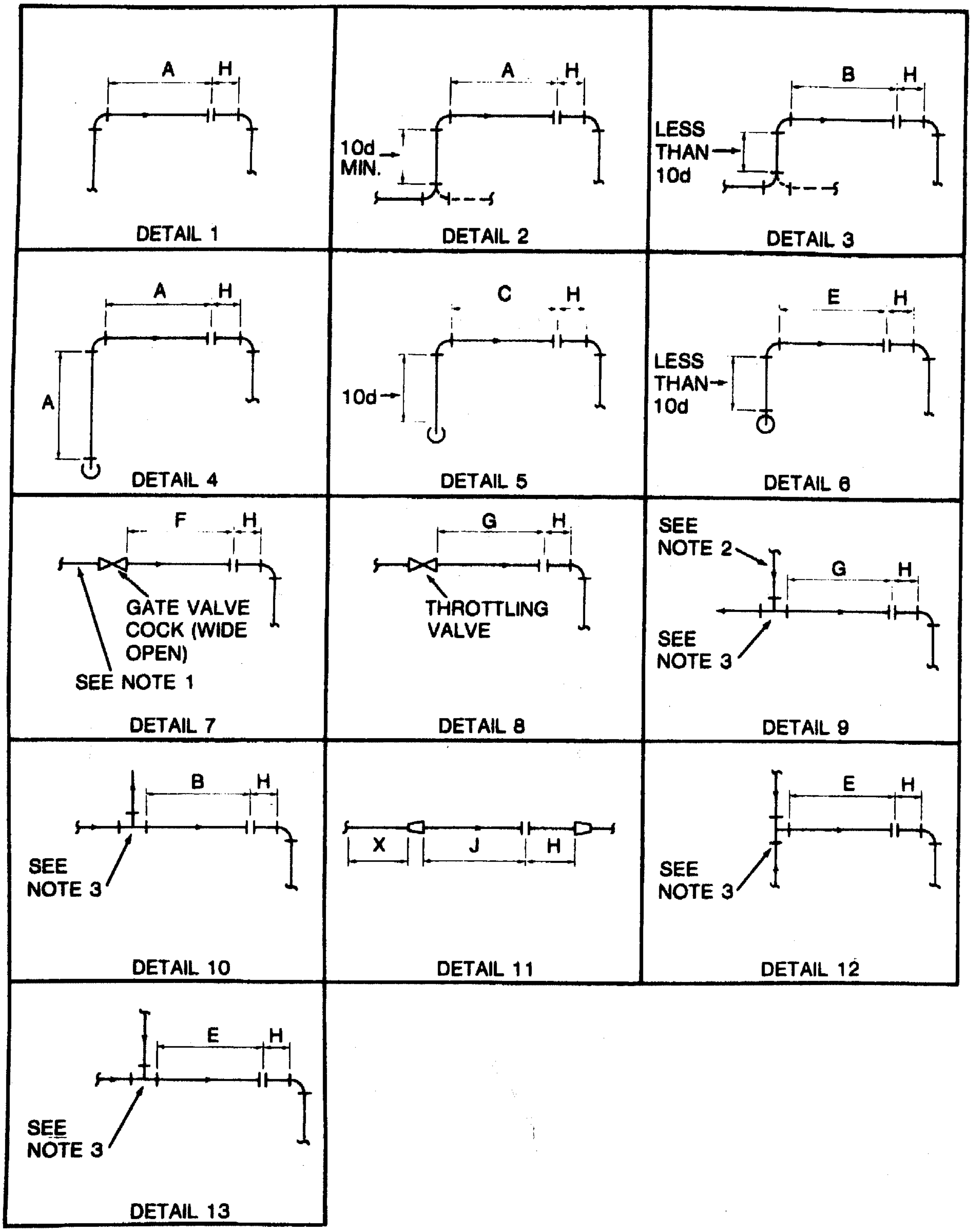
Figure 1-8—Orifice Flanges

Table 1-2—*d/D* Ratio vs. Straight Run Requirements

	Straight Run Requirement (In Nominal Pipe Diameters) See Fig. 1-9							
d/D Ratio	A	B	C	E	F	G	H	J
0.80	20	25	33	40	14	50	5	15
0.75	17	21	27	35	11	44	5	14
0.70	14	19	23	31	9	39	5	13
0.65	12	15	21	28	8	34	5	11
0.60	10	14	19	25	8	31	5	10
0.55	9	12	18	22	7	28	5	9
0.50	8	10	17	21	7	25	5	8
0.45	7	9	16	20	5	24	5	7
0.40	7	9	15	18	5	22	5	7
0.35	6	9	14	17	5	21	5	6
0.30	6	9	14	16	5	20	5	6
0.25	6	9	14	16	5	19	5	6

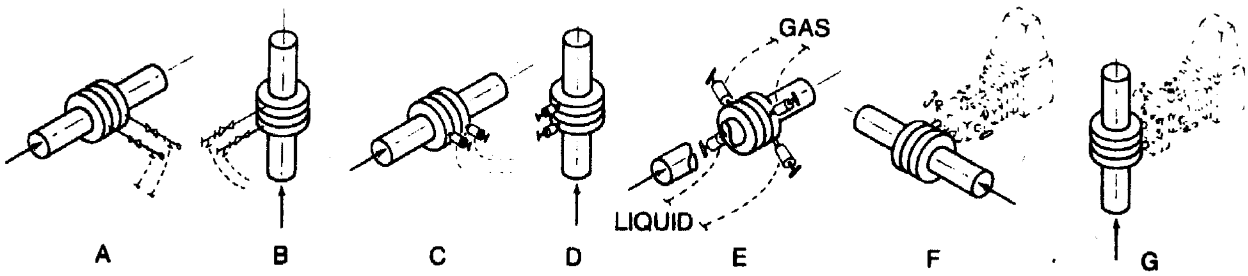
NOTES:

1. When the valve is preceded by fittings, the straight run must be sufficient to cover their requirements.
2. If this line contains fittings in another plane, use Dimension C or E as required by Detail 5 or 6 in Figure 1-9.
3. Double entry fittings may be considered as single bends when the line is normally blocked off, such as at spare pumps.
4. In Figure 1-9 Detail 11, X + J must be equal to the number of diameters required by previous fittings.



NOTE: See Table 1-2 for *d/D* values, run requirements, and detail notes.

Figure 1-9—Straight Run Required



GATE VALVES AND PIPE FITTINGS — SPECIAL ORIFICE ANGLE VALVES — 45 DEGREE TAPS LIQUID AND VAPOR — DIRECT-CONNECTED ORIFICE MANIFOLD

NOTES:
1. A and B—Standard gate valves with Schedule 160 nipples and fittings provide convenient tap cleanout connections. Gate valves must be staggered for installation clearance, which requires extra space.
2. C and D—Special orifice tap valves with dual side taps, one flush-plugged, can be used for a purge connection. The male inlet threads directly to the orifice tap. Pipe fittings are not required. This type of valve can be installed without spreading flanges.
3. E—Alternate 45-degree taps (off the top for gas; off the bottom for liquid) may also be used.
4. F and G—Special direct-connected orifice manifolds permit closest possible coupling of meter to orifice and completely supports meter in various vertical positions. Rod-out connections are available after removing transmitter. Considerably more space is required between adjacent piping. Adjustable inlets accommodate 1/8-inch to 1/4-inch (3 to 6 millimeter) orifice plates. Direct connected orifice manifolds require simplified field adaption to transmitters and are available in various configurations.
5. Vents and drains are not shown.

Figure 1-10—Orifice Flange Connections

Small-size orifices are subject to plugging in all but the cleanest service.

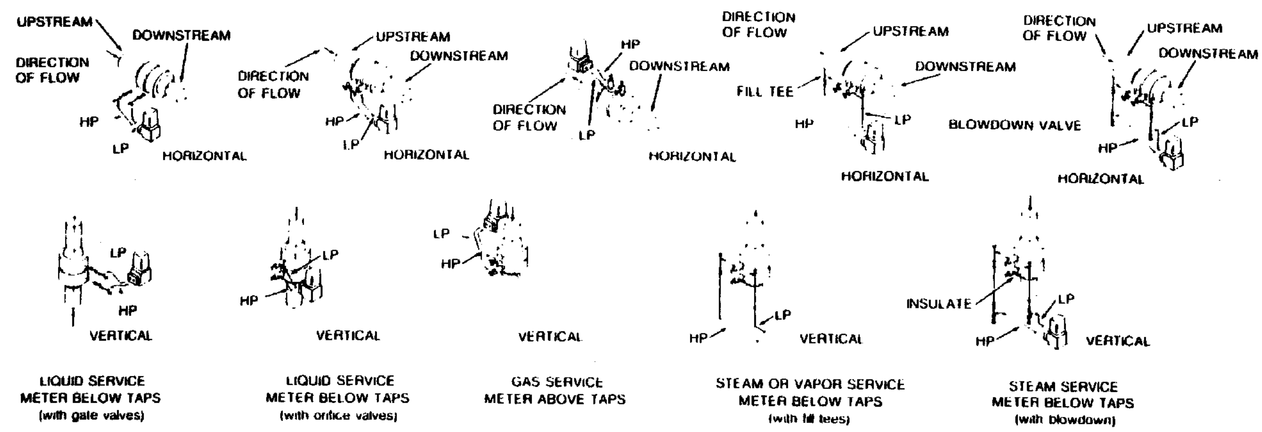
1.3.5.5 Static Pressure and Temperature Measurement Locations

When metering gases, a static pressure tap should be installed in the main line near the primary measuring device. Either an upstream or a downstream pressure tap can be used, but the appropriate expansion factor must be employed for the type of tap selected. Pressure measurement from the downstream tap is recommended. This method is more commonly used because a given change in differential pressure causes less variation, based on downstream pressure, in the value of the expansion factor. However, the upstream tap may be used if variations in the expansion factor are to be neglected. The tap location is sometimes specified in some custody transfer installations by contractual requirements. A common practice is to use the downstream differential tap instead of a separate tap. Neither the upstream nor the downstream tap of flange taps gives a true measurement of line pressure, nor does the downstream tap of vena contracta taps. However, the error in flow rate is both small and predictable. Measurement of the static pressure is required to correct the apparent reading to a measurement of the actual flow.

It may also be desirable to measure the temperature of the flowing fluid, especially if the fluid is a gas, in order to make required corrections in the apparent flow value. Thermowells, if used, should be inserted in the line a sufficient distance from the primary element so that flow disturbances are prevented from affecting the measurement. On the upstream side, thermowells should precede the orifice by at least 20 pipe diameters. If straightening vanes are used, thermowells should be placed not less than 12 inches (300 millimeters) nor more than 36 inches (900 millimeters) upstream from the inlet edge of the vanes. Downstream thermowells should not be located closer than 5 pipe diameters.

1.3.5.6 Installation and Inspection of Metering Runs

Meter run pipe or tubing should be carefully selected for a uniform, but unpolished, internal surface free of striations and grooves. It should also be selected for roundness, for concentricity of inside and outside diameters, and for conformance with published diameters. Some refiners prefer to buy specially selected pipe or tubing for meter runs. Others prefer to buy preassembled meter runs of select, calipered pipe, complete with orifice flanges for installations where accuracy is important. Fifteen diameters of the special pipe upstream of the orifice is sufficient to correct wall effects on the flow pattern. Therefore, mill run pipe of the same schedule may be used for added straight lengths needed to meet the requirements listed in Table 1-2. A pair of break-



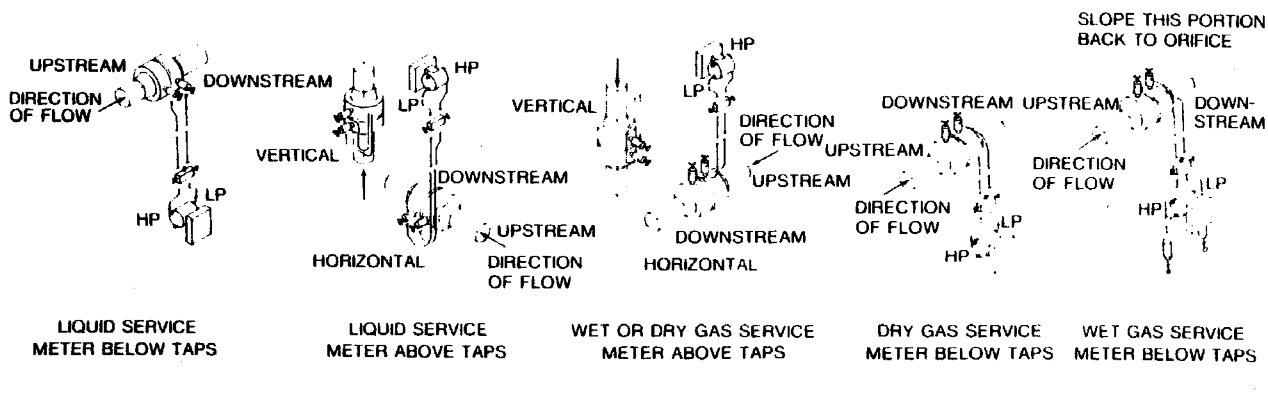
NOTES:

1. Keep impulse leads to minimum length.
2. Provide positive slope, at least 1/12 for all leads. This avoids pocketing and provides positive venting or draining.
3. Connect high-pressure side of instrument to upstream tap.
4. For liquid service in vertical lines, up-flow is preferred to avoid vapor or trash buildup above the plate.
5. Install meters below taps for liquid, steam, or condensable vapor service.
6. Install meters above the taps for gas service.
7. For steam service both fill-tees (condensate pots) must be installed at same centerline elevation as upper tap.
8. Flow meter installations for vena contracta or pipe tap connections are similar to those shown for flange taps.

Figure 1-11—Close-Coupled Flowmeters

out flanges may be installed, without affecting accuracy, at a minimum of 5 diameters downstream from the orifice to allow inspection of the meter run bore.

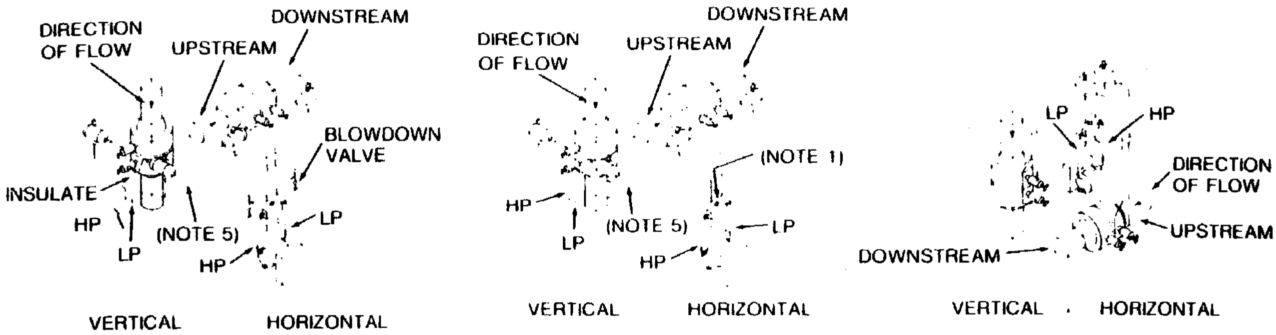
Out-of-roundness tolerance varies with the *d/D* ratio. When the *d/D* ratio is 0.70, the out-of-roundness tolerance is 0.5 percent for the upstream sections and 1 percent for the downstream sections. For tolerances for other *d/D* ratios see ANSI/API 2530. It is recommended that all meter runs be designed as if for a 0.70 minimum *d/D* ratio. If published orifice coefficients are used, the diameters of the pipe should match published diameters within 0.5 percent for flange taps and within 0.2 percent for pipe taps.



NOTES:

1. Keep meter leads as short as possible (20 feet maximum).
2. 3/4-inch (20 millimeter) fill-tees usually provide sufficient condensate volume for most instruments.
3. Provide secondary process block valves with equalizing bypass. Three-valve or five-valve manifolds may be used.
4. For liquid meters above an orifice, provide a seal leg below each tap. Drain facilities may be desirable.
5. For vapor meters above an orifice, provide continuous slope back to taps.
6. For dry gas meters below an orifice, drip pots may be eliminated.
7. For wet gas meters below an orifice, slope upper section of impulse leads back to orifice and provide suitably sized drip pots at lower meter connections.
8. Where redundant impulse line blocks are not required, a single tube-fitting type bypasss valve may be used.

Figure 1-12—Remotely Mounted Flowmeters for Liquid and Gas Service



STEAM SERVICE
METER BELOW TAPS
(with condensate pots and blowdown)

STEAM OR VAPOR SERVICE
METER BELOW TAPS
(with condensate pots and no blowdown)

STEAM OR VAPOR SERVICE
METER BELOW TAPS
(with condensate pots above meter)

NOTES:
1. Generally 3/4-inch (20 millimeter) tees provide sufficient capacity condensate pots.
2. When required, provide blowdown connections above the three- or five-valve manifold block. Blowdown through block or instrument may cause damage due to high temperature.
3. Install tees or pots level with upper tap.
4. Slope leads of 1/12 or more.
5. Vent valves are optional, but highly desirable. Their vent port should be oriented away from normal operator approach.
6. Where pots are installed above the meter to provide liquid seal for either steam or condensable vapor, the impulse leads should be insulated between the orifice tap and the pot only; except in cases where winterizing is required.
7. Insulation is not required where the meter is above the orifice and the pots are installed at the taps; except in cases where winterizing is required.
8. It is important to connect leads to the appropriate bottom or end connections, as illustrated, to provide the proper seal.
9. Where redundant impulse line blocks are not required, a single tube-fitting type bypass valve may be used.

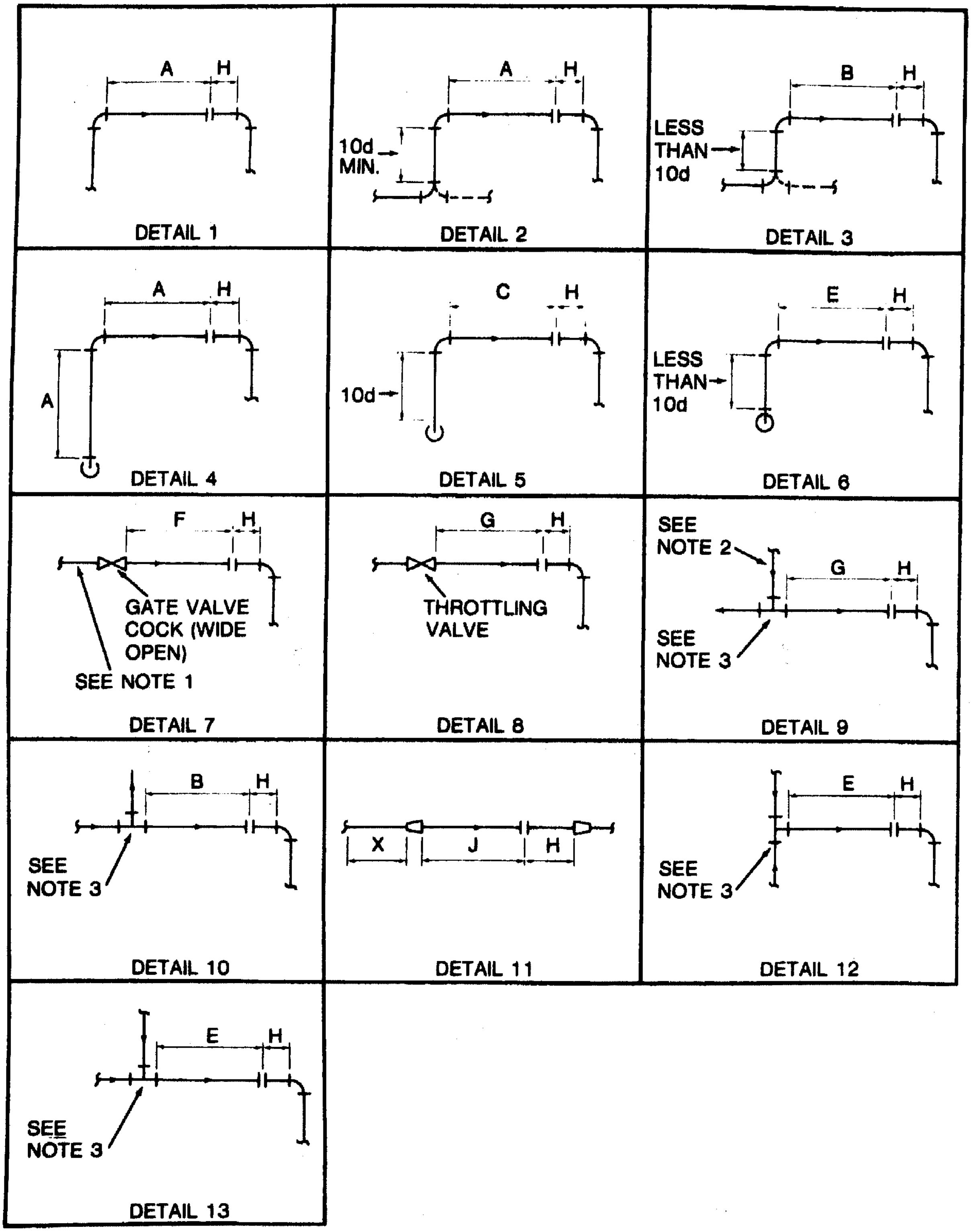
Figure 1-13—Remotely Mounted Flowmeters for Steam or Condensable Service

Flange tap orifice flanges are either of the screwed, slip-on, or weld-neck type. If slip-on or threaded flanges are used, all burrs must be removed after drilling the taps through the pipe. When slip-on flanges are used, additional care must be taken to see that all weld splatters are removed from the flange face. Any reduction of the diameter or distortion of the pipe caused by welding should be eliminated. If weld-neck flanges are used, it is essential that the flange bore be the same as the pipe internal diameter and that the bore be concentric and parallel with the pipe. If there is any internal roughness at the weld, it should be ground smooth. Wherever highest accuracy is required, the internal diameter of the pipe shall be bored to diameters and tolerances indicated in ANSI/API 2530 for a distance of at least 4 pipe diameters preceding the orifice or nozzle and at least 2 pipe diameters downstream of the inlet face of the orifice or nozzle. The bored portions shall be concentric with the flange bolt circles and be flared into the unbored portions at an included angle of not more than 30 degrees. It is desirable to use a tapered mandrel to position the welding-neck flange during welding. Flange taps should be properly oriented during installation.

Before installation, all orifice run fabrications should be inspected for dimensions, straightness, absence of burrs and welding deposits, and internal roundness. Where welding-neck flanges have been used, concentricity of the pipe with the flange neck should be checked. It is essential that the flange bore be the same as the internal diameter of the pipe. For gas measurements, the tolerances should be in accordance with ANSI/API 2530.

For liquid service where the taps are horizontal, sufficient clearance should be available between adjacent lines for installation of block valves and fittings. Taps at 45 degrees below horizontal may be used to permit closer spacing of adjacent piping.

Before installation, orifice plate bores should be inspected for concentricity, roundness, sharpness, and absence of burrs and nicks. The bore should be measured with a micrometer, and the reading should be checked against that stamped on the paddle handle. If a bevel-edge orifice plate it to be installed, the beveled edge must face downstream. The quadrant-edge orifice plate, on the other hand, is installed with the rounded edge upstream. For services requiring high accuracy, the orifice plate must be positioned carefully between the raised face flanges to ensure that the bore is concentric within 3 percent of the inside diameter of the meter run. For ordinary services, the inside diameter of the flange bolt circle may be utilized to facilitate centering the orifice plate. A centered orifice in a circular bore is a highly reproducible device. The flow coefficients can easily be repeated to within +0.10 percent in metering runs of the longer straight lengths given in Table 1-2. The inside diameter of the gasket must not be smaller than the inside diameter of the pipe, and the gasket must be positioned concentrically. Orifice plates supported in ring-type joint holders



NOTE: See Table 1-2 for *d/D* values, run requirements, and detail notes.

Figure 1-9—Straight Run Required

will be positioned within the concentricity tolerances of the ring groove and the orifice bore within the ring.

Installation of orifice plates should be postponed until after the lines have been flushed out. This will prevent debris from piling up in front of the orifice plates. It will also prevent any debris that might be dislodged during initial circulation from damaging the edges of the orifice plate.

1.3.5.7 Accessibility of Primary Elements

It is advisable to locate the orifice or other primary element so that it is accessible from grade, a walkway, or platform. However, if the orifice is not over 15 feet above grade, it should be accessible from a movable platform or portable ladder.

1.4 Differential Measuring Devices

Several types of measuring devices are used to determine the differential produced by the primary element. Flow is proportional to the square root of the differential; therefore, in order to maintain accuracy at low flow readings, a rangeability greater than three to one is not recommended.

For flow recorders, the charts most generally used are the 0 to 10 square root charts. Square root charts are available with various linear secondary scales for recording pressure, level or temperature on the same chart. A suitable meter factor is multiplied by the reading to give the actual flow. By judicious sizing of the orifice, meter factors can be obtained in round figures. However, when the physical properties of the flowing stream change, it is much more convenient to change meter factors than it is to change the orifice plate or the meter range.

A large variety of special charts are offered as standard by various flow recorder manufacturers. Some users require direct reading charts or scales wherever practicable (or some reasonable combination of standard chart graduation with a whole number factor, preferably factors in multiples of 10).

For calibration of the flow measuring or differential device, a manometer or large multiturn test gage should be used to read the differential input. It is most convenient for the calibration devices to be graduated in the same units as the meter range (for example, inches of water). Pneumatic outputs may be read on the same type of device. Electronic devices would utilize a high-quality volt or ammeter which would read these units directly, rather than on a square root or other scale related to the readout device. Total flow may be obtained by planimetering flow charts or by equipping the meter with an integrator. Corrections must be applied for changes in the condition of the flowing stream.

Many flow transmitters are available only as blind transmitters, without direct reading scales. An output indicator with a 0 to 10 square root or other suitable scale may be furnished with this type of transmitter. An output indicator will allow flow to be read at the transmitter or control valve location, but it should not be used to calibrate the transmitter.

Some of the devices mentioned in 1.4.1 through 1.4.3 are usually supplied as blind transmitters without direct flow scales. In this case an output indicator with a 0 to 10 square root, or other suitable scale, may be furnished so that flow can be read at the transmitter or control valve location. This device should not be used to calibrate the transmitter.

1.4.1 DIAPHRAGM TRANSMITTERS

Force- or motion-balance differential pressure transmitters of the diaphragm type are extensively used on refinery units. To provide overrange protection and damping, the body or capsule is liquid-filled. The transmission signal may be either pneumatic or electronic. These instruments generally are used without a seal or condensate pot because of their low displacement and corrosion-resistant construction. Line mounting is preferred if the location is accessible and the vibration level is not too high. Gas meters are mounted slightly above the line to allow liquids to drain back. Liquid meters are mounted below the line to allow gas bubbles to work back to the line. If leads are short enough, the transmitter may be mounted level with the center of the line. With this arrangement, it makes little difference in accuracy if the opposite legs of the connecting piping contain liquid or vapor in different amounts.

Piping arrangements for diaphragm transmitters are shown in Figure 1-11. If remote rather than close-coupled mounting is necessary, the piping may be similar to that shown in Figures 1-12 and 1-13.

1.4.2 BELLOWS METERS

In the bellows-type meter, the bellows is opposed by a calibrated spring system and is filled to prevent rupturing when overpressured and to provide pulsation damping.

Bellows meters can be either line-mounted or remotely mounted at grade or on platforms. Seal chambers or condensate pots are not generally used. A ¾-inch (20-millimeter) tee has sufficient volume for a liquid seal or as a condensate pot in steam or condensable vapor service for instruments that displace less than 1 cubic inch (24 cubic millimeters) with full-scale deviation. However, if the displacement is much greater than 1 cubic inch (16 cm^3), or if the differential of the instrument is low in comparision to the column displacement, regular condensate pots should be used.

Bellows meters have both top and bottom body connections. The top connections are used for liquid flow installations, and the bottom connections are used for gas flow installations to avoid the error caused by trapping gas or liquid, respectively, in the meter body. It is desirable to use ½-inch (12-millimeter) connections, which may require rotating the body chambers in some cases, where both ½-inch and ¼-inch (6-millimeter) connections are provided. It is suggested that the alternate tapped opening can be used as a drain or vent.

Typical meter piping is shown in Figures 1-12 and 1-13.

1.4.3 MANOMETERS

The simplest measuring device is the glass manometer, which may vary in form from the simple U-tube to the more highly developed single-tube devices. These are of little use in refineries, except as test devices and as indicators on nonhazardous low-pressure streams. A manometer with manifold is shown in Figure 1-14.

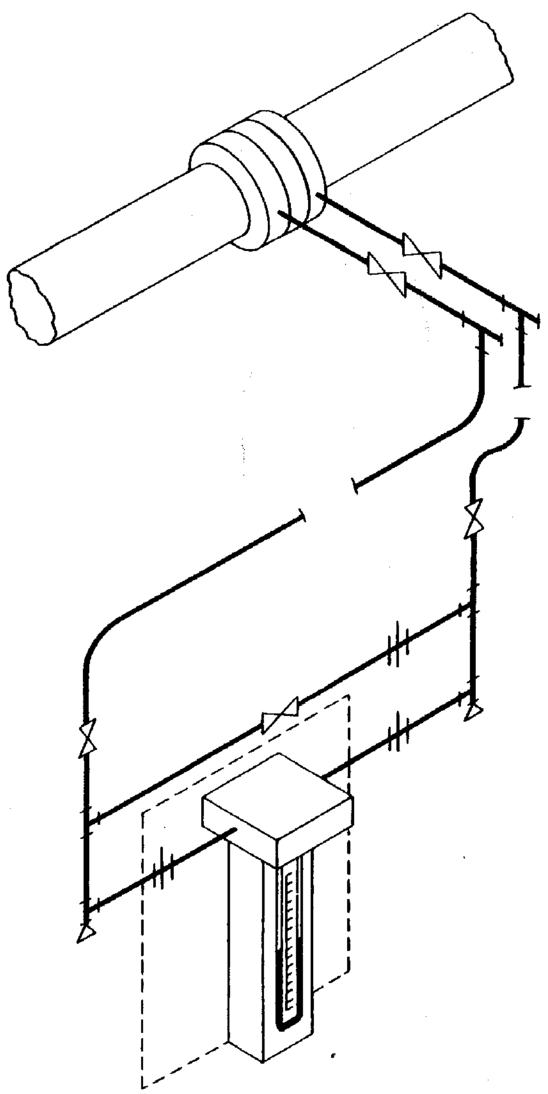


Figure 1-14—Glass Tube Manometer

1.5 Connecting Piping

1.5.1 METER LOCATION

Flow recorders, indicators, controllers, or remotely mounted transmitters should be mounted at a convenient height of about 4 or 5 feet (1.2 or 1.5 meters) above grade, platforms, walkways, or other permanent means of access. Close-coupled meters are preferred. They should be conveniently placed for easy maintenance and for making zero checks with a manometer or test gage. The mounting location of a flow transmitter must be carefully selected because it is susceptible to damage or malfunctioning caused by vibration. The transmitter output gage in a flow control installation should be visible from both the control valve and the control valve bypass. This arrangement will facilitate emergency local and manual control. If clear access is available to the space below a meter, a rolling platform or ladder of moderate height may be used.

1.5.2 METER LEADS

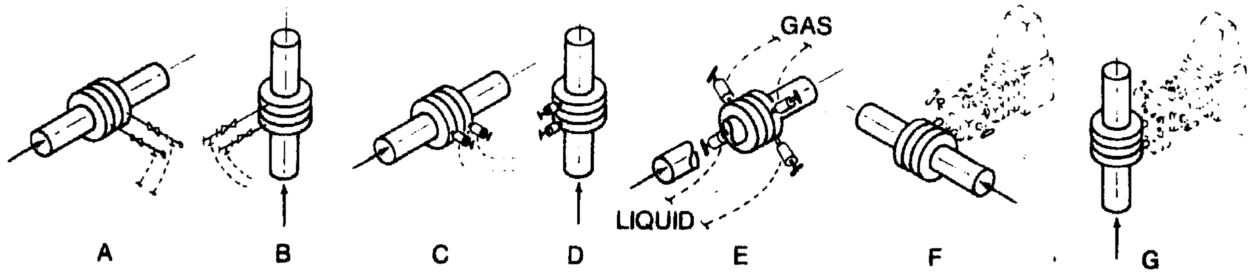
Meter leads should be as short as possible, preferably not exceeding 20 feet (6 meters). For liquid measurement the leads should slope at least 1 inch per foot (25 millimeters per 30 centimeters) downward from the orifice taps. For gas measurement the leads should slope upward at least 1 inch per foot from the orifice taps, or downward toward the drain pots if the meter must be mounted below the orifice run.

Meter piping should be designed and installed in accordance with the piping specification for the service involved. It is preferable to use ⅜-inch (10-millimeter) outside diameter or ½-inch (12-millimeter) outside diameter stainless steel type 304 or better tubing for meter impulse leads. In special cases or where user preference dictates, ½-inch (12-millimeter) Schedule 80 or heavier pipe may be used.

All locally mounted instruments and lead lines handling water or process fluids which may freeze, become excessively viscous, or form hydrates in cold weather should be installed in accordance with RP 550, Part I, Section 8.

Attention should be given to meter-connecting piping and manifolding as a source of meter inaccuracy. There may be more liquid head in one meter lead than the other because of differences in specific gravity, temperature, or amount of gas or water in the leads. For example, if the meter is 100 inches (2.5 meters) below the orifice with one side filled with water and the other side filled with a liquid of 0.65 specific gravity, the zero error will be 35 percent of full scale for a 100-inch (2.5-meter) range. It should be noted that, at times, most hydrocarbon streams will contain water.

Mounting the meter or transmitter close-coupled to the meter taps eliminates the possibility of error from specific gravity differences or vapor binding.



NOTES:
1. A and B—Standard gate valves with Schedule 160 nipples and fittings provide convenient tap cleanout connections. Gate valves must be staggered for installation clearance, which requires extra space.
2. C and D—Special orifice tap valves with dual side taps, one flush-plugged, can be used for a purge connection. The male inlet threads directly to the orifice tap. Pipe fittings are not required. This type of valve can be installed without spreading flanges.
3. E—Alternate 45-degree taps (off the top for gas; off the bottom for liquid) may also be used.
4. F and G—Special direct-connected orifice manifolds permit closest possible coupling of meter to orifice and completely supports meter in various vertical positions. Rod-out connections are available after removing transmitter. Considerably more space is required between adjacent piping. Adjustable inlets accommodate 1/8-inch to 1/4-inch (3 to 6 millimeter) orifice plates. Direct connected orifice manifolds require simplified field adaption to transmitters and are available in various configurations.
5. Vents and drains are not shown.

Figure 1-10—Orifice Flange Connections

Small-size orifices are subject to plugging in all but the cleanest service.

1.3.5.5 Static Pressure and Temperature Measurement Locations

When metering gases, a static pressure tap should be installed in the main line near the primary measuring device. Either an upstream or a downstream pressure tap can be used, but the appropriate expansion factor must be employed for the type of tap selected. Pressure measurement from the downstream tap is recommended. This method is more commonly used because a given change in differential pressure causes less variation, based on downstream pressure, in the value of the expansion factor. However, the upstream tap may be used if variations in the expansion factor are to be neglected. The tap location is sometimes specified in some custody transfer installations by contractual requirements. A common practice is to use the downstream differential tap instead of a separate tap. Neither the upstream nor the downstream tap of flange taps gives a true measurement of line pressure, nor does the downstream tap of vena contracta taps. However, the error in flow rate is both small and predictable. Measurement of the static pressure is required to correct the apparent reading to a measurement of the actual flow.

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1.3.5.6 Installation and Inspection of Metering Runs

Meter run pipe or tubing should be carefully selected for a uniform, but unpolished, internal surface free of striations and grooves. It should also be selected for roundness, for concentricity of inside and outside diameters, and for conformance with published diameters. Some refiners prefer to buy specially selected pipe or tubing for meter runs. Others prefer to buy preassembled meter runs of select, calipered pipe, complete with orifice flanges for installations where accuracy is important. Fifteen diameters of the special pipe upstream of the orifice is sufficient to correct wall effects on the flow pattern. Therefore, mill run pipe of the same schedule may be used for added straight lengths needed to meet the requirements listed in Table 1-2. A pair of break-

1.5.3 METER MANIFOLDS

Manifolds are necessary on all differential-measuring devices for checking zero and for putting the meter into or out of service. Figures 1-10 through 1-13 show only the use of tubing and tube fitting installations.

1.5.3.1 Close-Coupled Meters

There are three generally acceptable methods of valving close-coupled meters to provide process blocks at the orifice and an equalizing bypass valve at the meter.

1. Conventional line-class gate valves may be installed with rigid pipe nipples between the flange and the valve and short impluse leads terminating at a special bypass manifold valve attached directly to the meter. These bypass manifolds have generally universal adaptations to fit most manufacturers' meters. See Figures 1-10 and 1-11.
2. Special orifice flange valves may be installed with male inlets to fit directly into the orifice flange with impulse leads and a bypass manifold valve as in Method 1 above. See Figures 1-10 and 1-11.
3. A special combination orifice flange block and bypass manifold may be installed, which permits the closest possible direct coupling of the meter to the orifice flanges and supports the meter. See Figure 1-10 F and G.

Methods 1 and 2 provide greater flexibility in meter location, but do require a meter support bracket. Generally speaking, present practice has all but eliminated a combination tube-fitting bypass valve arrangement because of simpler, cleaner installations made possible with the direct-connected manifold equalizing valve.

1.5.3.2 Grade-Mounted or Semi-Remote Installations

Grade-mounted or semi-remote installations require additional considerations. Conventional gate valves or the special orifice tap valves described in 1.5.3.1 (Methods 1 and 2) are generally used at the orifice flanges for the main process blocks. Valving at the meter requires several different configurations depending upon individual requirements. Three separate types are described below and illustrated in Figures 1-12 and 1-13.

1. For remotely mounted meters where the orifice flange blocks are easily accessible, a single tube-fitting type bypass valve may be used.
2. To provide for greater ease of maintenance and for safety, redundant impulse line blocks may be added at the meter. These can be either screwed valves with tube-fitting adaptors, or they may be a similar type of valve with integral tube-fitting ends.
3. The bypass-equalizing valve must be installed between the redundant impulse line blocks and the meter. The bypass may be either a single tight shutoff-, globe- or needle-type valve or a double block-and-bleed arrangement to assure positive shutoff.

Special three-valve and five-valve block manifolds that provide reliable, convenient, and simplified installations are suitable alternatives to individual valve assemblies.

Special process or maintenance considerations sometimes require the addition of drain or blowdown valves, condensate drip legs (with or without pots), and vents (with or without pots). These are illustrated in Figure 1-11 for liquid, gas, and steam or wet vapor services.

Manifolds usually are classified as three-valve manifolds, five-valve manifolds, or three-valve manifolds with drains (see Figures 1-10 through 1-13). Generally, three-valve manifolds are used in liquid service and with close-coupled transmitters (see Figure 1-11).

When the meter is close-coupled, the tap block valves may serve as two of the three valves of the meter manifold unless double blocking is required for removing the instrument while the line is in service. The five-valve manifold installation frequently is used with liquid-sealed meters, with meters in gas service, or with any remotely located installation to provide accessable secondary process blocks along with the double block and bleed bypass (see Figure 1-12). Generally, five-valve manifolds are used on custody transfer meters.

Half-inch (12-millimeter) stainless steel tubing should be used for impulse leads. Valving does not need to be stainless steel unless required by service conditions. Special manifolds with either three or five integral valves are available. Wherever a bypass double block-and-bleed arrangement is required, a five-valve manifold block assembly installation provides a more economical approach than individual valving and accompanying fittings.

1.5.4 SEALS, CONDENSATE POTS, AND KNOCKOUT POTS

In some services it is necessary to protect certain types of meters from the process fluid or to reduce potential errors caused by water or vapor in a meter lead. Seal chambers should be installed if these conditions are present, according to RP 550, Part I, Section 8.

In steam service, a means must be provided to maintain an equal liquid head on each side of the meter. A means should also be provided to permit prefilling the leads with the condensate to protect the instrument from excessive temperatures during startup. Generally, the ¾-inch (20-millimeter) filling tee suffices as an adequate condensate chamber, especially for low-displacement type meters. However, larger conventional condensate chambers may be preferred. When used, the long axis of the filling tee should be installed horizontally to provide the largest liquid-vapor interface and the least level change with volumetric displacement. Various examples are shown in Figure 1-13.

1.5.5 PURGING

Purging is needed to prevent the plugging of meter leads under the following conditions:

1. The flowing fluid contains solids.
2. The flowing fluid is either corrosive to meter parts or highly viscous.
3. The meter or meter piping cannot tolerate water or condensate.

The purge should be introduced as close to the transmitter as practical. The purge flow must be restricted so that it is uniform on both sides of the meter and does not cause a false differential. Restriction orifices, purge rotameters (preferably armored type), needle valves, or drilled gate valves are commonly used to control the volume of purge fluid. The drilled gate valve is desirable if frequent blowing back is required. The purge fluid should be clean and compatible with the process fluid. For additional information, see RP 550, Part I, Section 8.

1.6 Variable Area Meters

1.6.1 GENERAL

Variable area meters are often called rotameters. They work on the principle that a float within a vertical tapered tube will assume a position that is a function of the flow rate passing through the tube from the bottom. The float must have a density greater than the measured fluid. The area (annular area) through which the flow must pass is the difference between the internal area of the taper tube at the point of balance and the area of the float head. Since the internal area of the tube increases constantly and is continuously variable from bottom to top while the float head area remains constant, the term "variable area meter" is derived. At a constant differential pressure (ΔP), flow is directly proportional to area.

1.6.1.1 Applications

Variable area meters are often used when wide rangeability, linear output, or the measurement of very low flow rates is required. When local indication only is required, their cost (especially in small sizes) is very attractive.

1.6.1.2 Features

Variable area meters have the following characteristics:

1. Wide range of flow rate (frequently 10:1 or higher).
2. Accuracy of uncalibrated meters is typically ±2 percent of full scale; of a calibrated meter ±1 percent of rate over 10:1 range is not uncommon.
3. Good linearity.
4. High viscosity immunity.
5. Minimal effects of gas compressibility, since its expansion factor is near unity.
6. Common sizes are available from ⅛ inch to 2 inches (3 to 50 millimeters).

1.6.1.3 Typical Uses

Variable area meters are used in the following services:

1. Liquified petroleum gas or other volatile liquid measurement.
2. Freezing or congealing liquids such as waxes and asphalts. Steam-jacketed meters are available.
3. Streams with suspended solids, within reasonable limits.
4. Low flows, including purges.
5. Various acids.

1.6.1.4 Options

Variable area meters are available as indicators, transmitters, recorders, local pneumatic controllers, totalizers, or many combinations of the above, with or without alarms. Most meters are available with the through-flow or float extension design (see Figures 1-15 and 1-16). Protective armor and steam tracing are available in many designs.

1.6.1.5 Limitations

Variable area meters have the following limitations:

1. In large line sizes (especially when exotic materials of construction are required) rotameters become quite expensive.
2. Glass tube meters, unless protected by suitable armor, should not be used on hazardous service. Metal tube meters as well as armored meters are available for hazardous service.
3. The user is unable to check calibration or change range.
4. Meters having magnetically coupled indicators or transmitters are subject to error if ferrous metal particles accumulate.

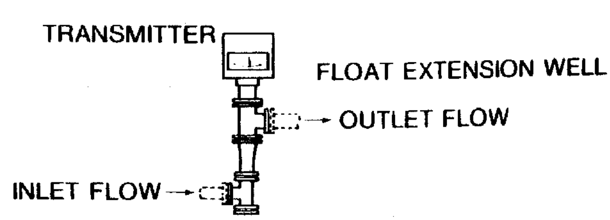


Figure 1-15—Extension Type Rotameter

1.6.2 INSTALLATION

1.6.2.1 Location and Mounting

The meter should be installed in a location that is free from vibration and where sufficient clearance is available for occasional float removal for service or inspection. The meter location should be visible and readily accessible for operation and maintenance. In general, when a meter is to be used in regulating service, it should be placed as close as possible to the throttling point, preferably with the valve located at the outlet fitting.

Rotameters must always be mounted vertically, with the outlet connection at the top of the meter and the inlet connection at the bottom.

1.6.2.2 Mainline Piping

Most variable area flow measurement is practically independent of upstream piping arrangements [4]. Elbows, globe or throttling valves, and other fittings have no effect on measurement accuracy if they are no closer than 5 diameters upstream of the meter. Typically with 0 diameters upstream, the inaccuracy will not exceed 5 percent.

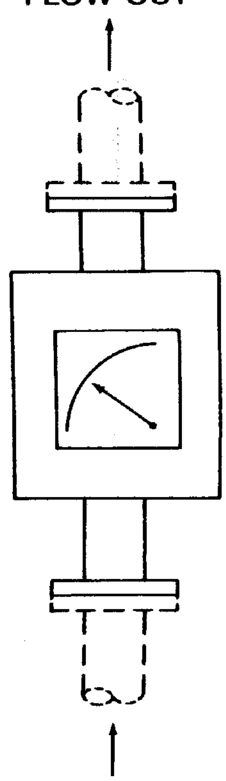


Figure 1-16—Through-Flow Type Rotameter

When connections are interchangeable (for vertical or horizontal connections), horizontal connections are recommended, if at all practicable, in the overall piping arrangement. Horizontal connections permit the use of the plugged vertical openings as convenient cleanout ports. The design of most rotameters permits the end fitting to be rotated in 90-degree increments allowing a convenient variety of connection arrangements. Rotameter piping connections are shown in Detail A of Figure 1-17.

All piping should be properly supported to prevent sagging caused by the weight of the meter. Care must be taken so that the piping arrangement does not impose any strain on the meter body.

1.6.2.3 Bypass Piping

Block and bypass valves, such as shown in Detail B of Figure 1-17 should be provided where operating conditions do not tolerate shutdown while servicing the meter.

The bypass line and valves should be the same size as the main line. Block valves should be installed upstream and downstream of the rotameter. A drain valve should be installed between the inlet block valve and the meter. A typical bypass arrangement is shown in Detail B of Figure 1-17.

When a rotameter installation includes a bypass, care must be taken to ensure that the bypass valve is tightly closed when the rotameter is in service. Only the downstream block valve may be used for throttling when flashing might be encountered.

1.6.2.4 Strainers

In smaller line sizes, it is sometimes advisable to locate a strainer upstream of the meter to prevent the float from being jammed with foreign material. This will also prevent the indicating scale on glass tube meters from being made illegible.

1.6.2.5 Purge Fluid

In installations where purging is necessary, the purge fluid may be injected at the top of the extension tube, as shown in Detail B of Figure 1-17, or at other connections provided in the instrument. Where the main-line pressure or purge fluid supply pressure may vary over short periods of time, it is advisable to use the purge rotameter differential regulator combination for automatic control of the purge rate of flow (see Section 8 of RP 550, Part I).

Consult the manufacturer's instruction bulletin for purge rate.

1.6.2.6 Startup and Calibration

When the meter is put into operation, the valve should be opened slowly to prevent flow surges, which might damage

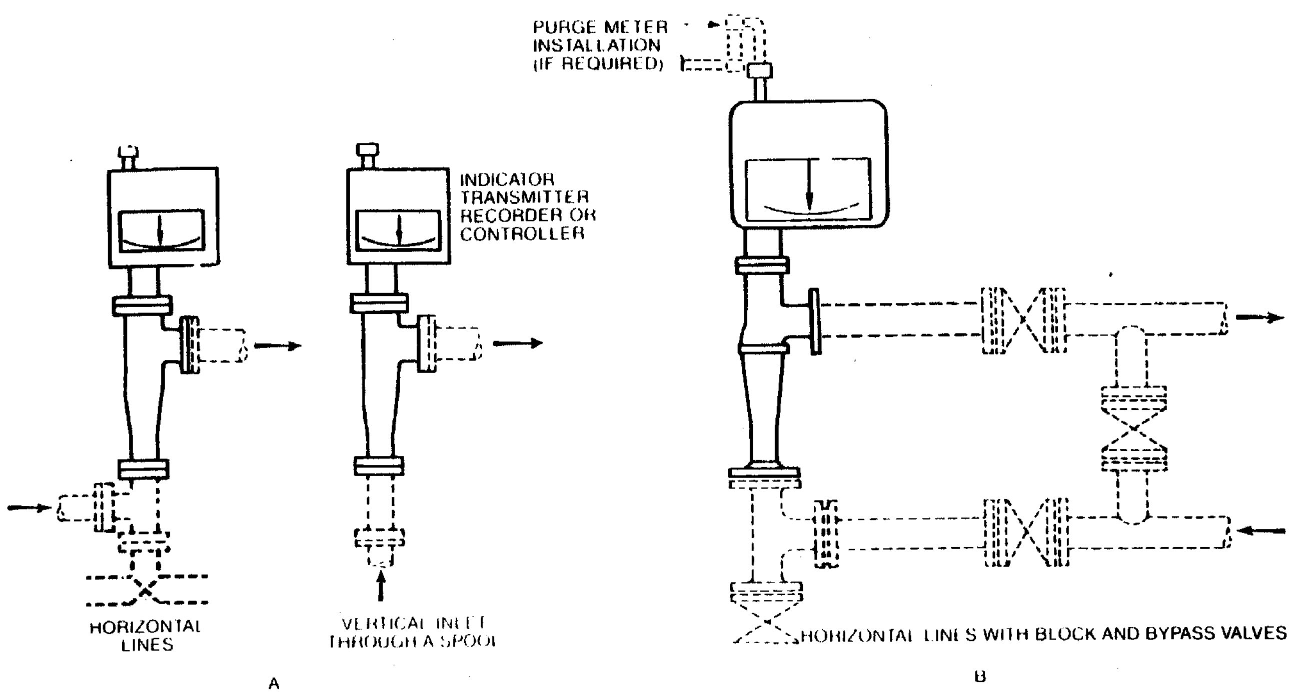


Figure 1-17—Rotameter Piping Connections

the float or other meter components. If the meter is purged, the purge flow must be started first.

Generally, no field calibration of rotameters is possible.

1.7 Target Flow Meters

1.7.1 GENERAL

The target flowmeter is a fluid flow measuring transmitter that generates an output signal directly proportional to the force applied on a target suspended in the fluid stream. Flow is measured as the square root of the transmitted signal. The meter is contained in a body that fits between flanges, or it may have short pipe sections extending upstream and downstream. A square-edge circular or a shaped metal target is secured to a beam, which holds the target at the center of the flow stream. The flow path is through the annular orifice around the target. The force on the target or the deflection of it becomes the variable that is related to flow rate by the square law (see Figure 1-16).

1.7.1.1 Applications

Target meters are sometimes used in refineries for measuring the flow of viscous hydrocarbon streams. They may also be used for the measurement of other liquids, gases, or vapors.

1.7.1.2 Features

Target meters have the following characteristics:

1. Accuracy is typically ±2 percent of full scale reading.
2. They are available in a wide range of line sizes, from ½ inch to 4 inches (15 to 100 millimeters).
3. They eliminate the need for pressure taps or purging.

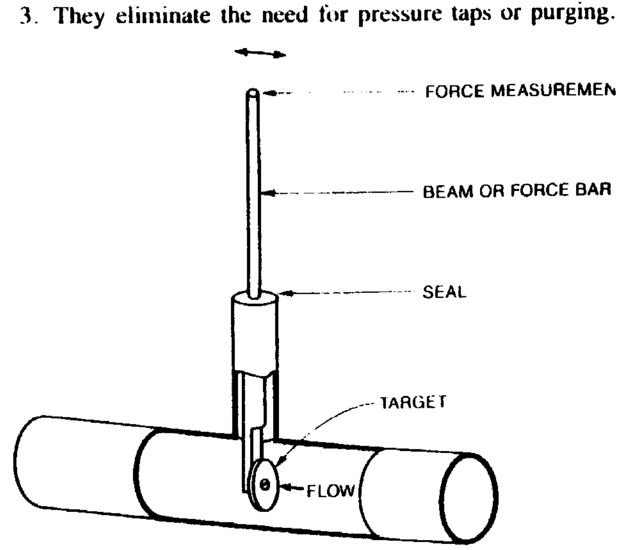


Figure 1-18—Target-Type Meter

4. They eliminate the need for heating when used for viscous flows.

1.7.1.3 Typical Uses

Target meters are used in the following services:

1. Viscous flows.
2. Hot asphalt.
3. Tars.

1.7.1.4 Options

Pneumatic or electronic transmission is available with either force-balance or motion-balance transmitters.

Meters may be of either welded or flanged construction and, depending on design, may be used in relatively high pressure, 1500 pounds per square inch (10350 kilopascals), and temperature, 500 F (260 C), applications.

1.7.1.5 Limitations

Target meters are limited by the following characteristics:

1. Relatively high pressure drop.
2. Normal usable range (3:1 as for an orifice plate).
3. Inability to calibrate in place.
4. Cost of blocks and bypasses.
5. Possible plugging of the flow stream by large pieces of foreign matter.
6. Possible damage to the meter by large pieces of foreign matter.

1.7.2 INSTALLATION

1.7.2.1 Location and Mounting

The target flowmeter can be installed in either horizontal or vertical lines. It should be located where it is accessible from grade, a platform, or a ladder.

The target flowmeter is line-mounted. It must be oriented with the directional arrow in accordance with flow direction. For better cooling on hot horizontal lines, the meter should be mounted with the head to the bottom or side. All piping should be sufficiently supported to prevent undue stress.

1.7.2.2 Mainline Piping

Standard orifice meter piping practice should be followed using meter run values of minimum 0.70 d/D. This standard practice includes the optional use of straightening vanes, where necessary, to reduce the run of straight pipe. (See Details 1 to 13 in Figure 1-9, and Table 1-2.)

1.7.2.3 Bypass Piping

Bypass piping is usually recommended on continuous service or in services requiring zero adjustment or calibration. Upstream and downstream block valves should be line size and located in accordance with orifice meter practices.

1.7.2.4 Strainers

Strainers are not normally required or recommended for target meter service.

1.7.2.5 Electrical Installation

Installations should be made in accordance with the manufacturer's recommendations (see RP 550, Part I, Section 7).

1.7.3 STARTUP AND CALIBRATION

On new installations, care must be used to assure that the process line is free of large, foreign matter that might damage the meter at initial startup.

The target flowmeter may be adjusted to zero by stopping all flow in the line, usually by bypassing, and adjusting the output to correspond to zero flow. Range adjustment is normally accomplished by removing the meter from the line and applying weights to the force bar in accordance with the manufacturer's instructions.

1.8 Turbine Meter

1.8.1 GENERAL

The turbine meter [2] is a volumetric, fluid flow measuring meter with a pulse train output, the frequency of which is linearly related to flowrate. A turbine (rotor) located directly in the flow stream rotates at a rate proportional to the average velocity of the fluid passing it and hence proportional to the volume of the fluid being measured. Rotation of the turbine is usually sensed either magnetically or inductively by a sensing coil located outside the flow stream (see Figure 1-19).

Alternatively, the rotary motion may be mechanically extracted from the body magnetically or by a shaft through a packing gland. In some cases, the pulses generated are conditioned before transmission by a preamplifier mounted directly on or adjacent to the meter.

1.8.1.1 Applications

Turbine meters are used primarily because of their accuracy and rangeability. The major application is the custody transfer of light products or light crude oils [2]. They are also used extensively for in-line product blending in refineries. Occasionally, turbine meters are used for refinery process flow measurement where highly accurate, wide range measurement of very small flow rates is required.

1.8.1.2 Features

Turbine meters have the following characteristics:

1. Accuracy of 0.25 percent of rate with a repeatability of 0.10 percent is typical. To obtain the highest possible accuracies, some form of meter proving is required [3].
2. Rangeability typically varies from 7:1 to 75:1, depending on meter design, fluid viscosity, and meter size.
3. A high flow rate for a given line size is obtainable. Line velocity may be as high as 25 to 30 feet (8 to 9 meters) per second.
4. Very low flow rate designs, as low as 0.005 gallons (0.02 liters) per minute (although normally nonlinear in these ranges) are available.
5. Availability of very wide temperature ranges, from −430 to 1000 F (−255 to 540 C) and pressure ratings (up to 50,000 pounds per square inch (350 MPa), depending on size).
6. Turbine meters are available for bidirectional flow (as a special design).

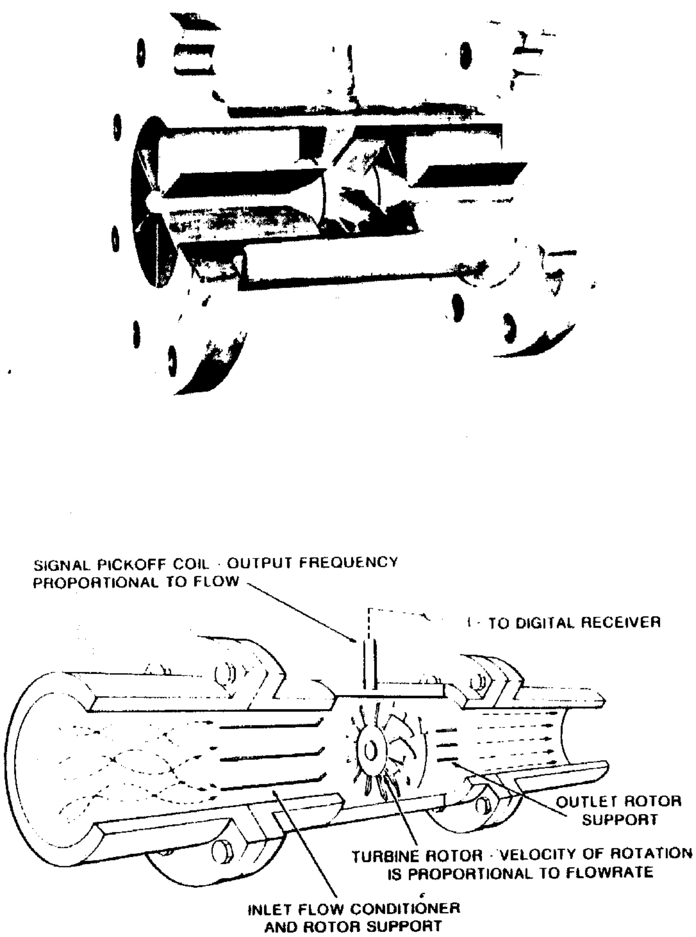


Figure 1-19—Turbine Meter

1.8.1.3 Typical Uses

Turbine meters are commonly used in the following services:

1. Custody transfer of light products or crude oils.
2. In-line product blending.
3. Very accurate volumetric totalization.
4. Low flow rates of additives.

1.8.1.4 Options

Generated pulse output may be scaled for direct totalization in engineering units. Also available are pulse-to-analog converters for control or recording applications. Their pulse output is ideally suited for batch control applications. If use is outside of the viscosity-immune range, compensation for nonlinearities is also available.

1.8.1.5 Limitations

Turbine meters are limited by the following characteristics:

1. Susceptible to wear or damage if process stream is dirty or nonlubricating.
2. Require considerable maintenance. Some meters must be returned to manufacturer for recalibration after bearing change.
3. Relatively high cost.
4. Strainers usually required.
5. Unavailability of provers for the operating limits of the meter.
6. Turbine meters have unique relationship between accuracy, rangeability, viscosity, and meter size. Highest accuracy is obtainable with low-viscosity fluids.
7. Susceptible to damage from overspeed.

1.8.2 INSTALLATION

1.8.2.1 Location and Mounting

The turbine meter is installed directly in the process line, using flanged, welded, or screwed connections. The line should be relatively free of vibration. If the meter includes an integrally mounted, direct-reading register, it should be positioned so that it can be easily read and maintained.

Turbine flowmeters are generally installed in horizontal lines. Some designs may be installed vertically, but calibrations for that position may be necessary. In some meter designs, special thrust bearings must be specified for vertical mountings to prevent excessive wear. It is usually necessary to specify the position for which the meter is to be calibrated.

1.8.2.2 Mainline Piping

Accuracy and repeatability of turbine meters are especially dependent upon upstream and downstream piping arrangements. In addition to sufficient upstream and downstream straight runs, flow straightening is normally required if the very high potential accuracy of a turbine meter is to be achieved [2].

Where optimum performance of flow measurement is required, means must be provided for automatic removal of air or gas which may be in the process stream. Gas entrainment can cause errors in repeatability and accuracy of the meter. Turbine meters should be installed so that they have a positive head of liquid upstream. This head should be equivalent to at least twice the anticipated pressure drop through the meter. To minimize cavitation problems in vacuum service or when operating with liquefied gases, a back pressure regulator should be provided downstream to maintain an adequate back pressure for proper operation of the meter [2].

Care should be exercised in the installation of flanged meters to ensure that the pipeline gaskets do not interfere with the flow pattern by protruding into the flow stream.

1.8.2.3 Bypass Piping

The need for bypass piping is determined by the application. It may be necessary to isolate or disassemble the flowmeter for maintenance purposes. In continuous service applications, where shutdown is considered undesirable, block and bypass valves must be provided to permit process operation while the meter is being serviced. Some of the conditions that may necessitate disassembly of the meter are damage caused by foreign material, wear, or a buildup of solids. If bypassed, the meter should be in the main run and the block valves should be line size and placed at least 10 diameters upstream and 5 diameters downstream of the meter [2]. The bypass valves must be capable of positive shutoff to prevent measurement errors.

1.8.2.4 Strainers

Generally, all turbine meter installations require strainers to prevent foreign matter from blocking or partially blocking the flow passages or lodging between the rotor and meter body. The strainer must be capable of removing particles of a size that might damage the rotor and bearings (see Table 1-3). The strainer should be located at least 10 pipe diameters upstream if a flow straightener is used [2]. Limitations on strainer mesh may be dependent on process applications in which the pressure drop due to excessive strainer plugging must be considered.

Table 1-3—Typical Screen Size for Light Hydrocarbons

Meter Size		
Inches	Millimeters	Mesh
⅜ or smaller	10 or smaller	200
½ - ¾	12-20	150
1 - 3	25-75	80
Larger than 3	Larger than 75	60

1.8.2.5 Electrical Installation

Generally, the signal from a turbine meter is low-level and of the pulse type, which makes it especially susceptible to noise pickup. Shielding of signal wires is recommended to eliminate spurious counts. If the transmission distance is more than 10 feet (3 meters) and a low-level signal is used to achieve greater rangeability, a preamplifier may be required. High-level signals may often be transmitted as much as 500 feet (150 meters). Consult the manufacturer's instruction bulletin for details. (Refer to RP 550, Part I, Section 7.)

1.8.3 STARTUP AND CALIBRATION

Care must be used to prevent damage to the meter at initial startup. It should be placed in service only after the process line has been flushed and hydrostatically tested. If strainers are used, they should be cleaned after flushing and periodically during operation. Plugged strainers may break loose and sweep downstream, demolishing the meter internals. Flow should be introduced slowly to the meter to prevent damage to the impeller blades as a result of sudden hydraulic impact or overspeed.

The calibration factor expressed in electrical pulses generated per unit volume of throughput is normally called a K (meter) factor. The K factor, which may be dependent on fluid conditions, is determined when the flowmeter is calibrated and is inherent in that particular meter. Generally, the K factors of meters vary even within the same size. This can be attributed to the different hydraulic characteristics of each individual meter. No adjustment may be made to the primary sensor [2].

1.9 Magnetic Flowmeters (Magmeters)

1.9.1 GENERAL

A magnetic flowmeter measures the volumetric rate of flow of any liquid that has the required measure of electrical conductivity. Most petroleum hydrocarbons have insufficient conductivity to be measured with a magnetic flowmeter. For this reason, its use in the petroleum industry is restricted to certain services, such as water, acids, emulsions, and certain other solutions.

The meter consists of two parts, the magnetic flowmeter primary installed directly in the process line and a secondary element, the electronic transmitter. The meter generates a signal proportional to the volume of the flow.

The magnetic flowmeter operates on the principle of an electrical generator. It is based on Faraday's law of electromagnetic induction: when a conductor cuts across magnetic lines of flux, a voltage will be induced in the conductor that is directly proportional to the rate (velocity) at which the lines of flux are being cut. In the case of a magnetic flowmeter, the actual spool piece is an insulated section of pipe. An alternating magnetic field is impressed across it, and the process fluid itself becomes the moving conductor that cuts across the flux. A voltage that is proportional to the velocity of the process fluid is then induced and extracted via two metal electrodes located on opposite sides of the meter (see Figure 1-20). This small alternating current (AC) voltage is then amplified and conditioned by the secondary transducer. Some magnetic flowmeters are excited by a pulsed direct current (DC) signal to eliminate noise and zero drift.

1.9.1.1 Applications

Magnetic flowmeters are widely applied on slurries, since they are obstructionless, and on corrosive fluids, since only the liner and electrodes are in contact with the process stream. They are suitable for very viscous fluids or where negligible pressure drop is desired.

1.9.1.2 Features

Magnetic flowmeters have the following characteristics:

1. Accuracy of the magnetic flowmeter is typically ±0.5 percent of full scale. One percent, even ½ percent, of actual flow rate is available from some manufacturers.
2. The magnetic flowmeter responds only to the velocity of the flow stream and, therefore, is independent of density, viscosity, and static pressure.
3. Since this type of meter tends to average the velocity profile between the electrodes, neither long runs of upstream or downstream pipe nor flow straighteners are needed, unless percent of rate accuracy is required.

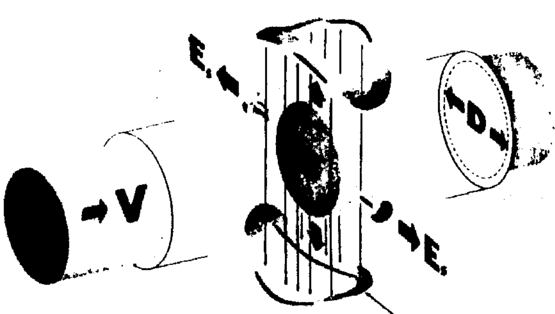


Figure 1-20—Magnetic Flowmeter

4. Rangeability is 10/1 or greater.
5. Bidirectional flow may be measured.
6. Temperatures from −40 to 500 F (−40 to 260 C) may be handled.
7. Pressures from full vacuum to 30,000 pounds per square inch (204 megapascals) are possible.
8. There is negligible pressure drop.
9. A large variety of sizes are available, from $^1/_{10}$ inch to 96 inches (2.5 millimeters to 2.5 meters), or even larger.

1.9.1.3 Typical Uses

Magnetic flowmeters are commonly used to measure the following types of flows:

1. Slurries.
2. Acid streams.
3. Very small flows.
4. Very large flows.
5. Very viscous fluids.

1.9.1.4 Options

A wide variety of options are available for recording, indicating, controlling, totalizing, or batching. Percent of rate accuracy is one option. Various electrode cleaning devices are also available.

1.9.1.5 Limitations

Magnetic flowmeters are limited by the following characteristics:

1. The process fluid typically must have a conductivity of 2 micromhos per centimeter. Special conductivity units are available for fluids with a conductivity as low as 0.1 micromhos per centimeter.
2. Special care is required for erosive application.
3. Magnetic flowmeters cannot be calibrated in place.

1.9.2 INSTALLATION

1.9.2.1 Location and Mounting

Considerable care must be exercised when installing the flowmeter primary in the pipeline. Special attention must be given to prevent damage to the liner and to ensure proper grounding requirements are met. The manufacturer's installation recommendations should be followed. The transmitter is built on a rugged piece of pipe, but it should be handled as a precision instrument.

The transmitter should be accessible from grade or from a platform with enough space around it so that at least the top housing could be removed if necessary. At the very minimum, sufficient access room should be available to remove any inspection plates.

If the transmitter is to be underground or in a pit that might become water flooded, provision should be made to prevent it from being submerged, unless the meter is equipped with a special housing to permit operation while submerged. Submersion should be avoided if possible.

The magnetic flow transmitter tube may be installed in any position (vertical, horizontal, or at an angle), but it must run full of liquid to ensure accurate measurement. If mounted vertically, flow should be from bottom to top to assure a full pipe. When mounted horizontally, the electrode axis should not be in a vertical plane. A small chain of bubbles moving along the top of the flow line could prevent the top electrode from contacting the liquid.

Vertical mounting with a straight run on the inlet side and upward flow is recommended if an abrasive slurry is being measured. This arrangement distributes wear evenly.

1.9.2.2 Piping

Transmitter tubes are made of nonmagnetic materials, such as stainless steel, nickel chromium iron alloy[3], or fiberglass pipe. The nonmetallic tubes are used unlined, but the metal tubes are lined with a nonconducting material such as fluorocarbon, rubber, synthetic rubber, polyurethane, or glass to prevent short-circuiting the signal. Each transmitter assembly has definite operating condition limitations. Major limitations that should be considered are pressure, temperature, and corrosive and erosive properties. The operating conditions must not exceed the limits for the particular transmitter construction as outlined in the manufacturer's specifications.

When piping, the following precautions should be observed:

1. Care should be used in lifting the transmitter to avoid liner damage (see Figure 1-21). If the liner is damaged, it should be replaced or repaired before installation, using an approved procedure.
2. The protective end covers should be kept over the flange faces until final installation.
3. During installation, care should be exercised to prevent overheating by exposing the magnetic flowmeter tube or liner to nearby heat sources (for example, welding).
4. If a metal tube magnetic flowmeter has its liner brought out over the flange faces, the liner should not be forced between adjacent flanges. Rather, a gasket of material compatible with the process should be inserted between the adjacent pipe flange and the magnetic flowmeter flange. It is further recommended that a pipe spool be installed on each end fitting of the magnetic flowmeter while it is out of the pipeline to minimize the possibility of damage to the meter pipe and flange liner during mounting.
5. To avoid liner damage on new piping installations, it is desirable to bolt the adjoining pipe fittings or valves to the transmitter before installing it in the line. If this is not possible, it should be bolted in continuity from upstream to downstream piping. If piping is already installed, it is advisable to remove one or both adjoining pipe sections. In installations where there are no block valves or bypasses, it may be desirable to make up and install a flanged spool piece on each end of the transmitter.
6. Normally magmeters up to 12 inches (30 centimeters) in size require no support other than that required for an equal length of pipe, unless required for maintenance. The magmeter should not be used to support the adjacent piping. For larger sizes, depending upon size, construction, and the manufacturer's recommendations, a support structure may be necessary.
7. The piping should be designed for sufficient flexibility to prevent excessive forces from being transmitted to the electrically insulated flange faces. Particular attention should be paid to installations in vertical lines to ensure that the excessive weight of the transmitter or piping is not applied to the flange facing.
8. Several different types of flange connections are used. The general rule for all types is to make sure that the flange and its adjacent mating flange are properly aligned and that the bolts are tightened evenly.

[3]For example, Inconel.

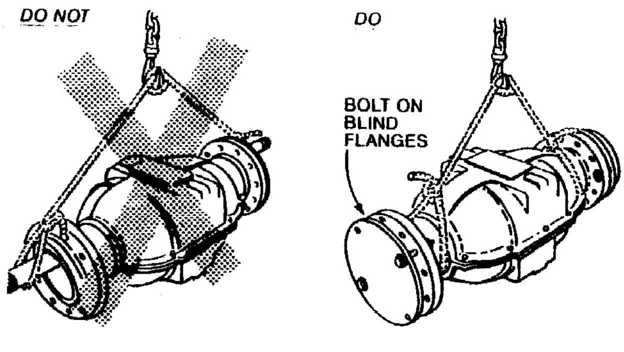
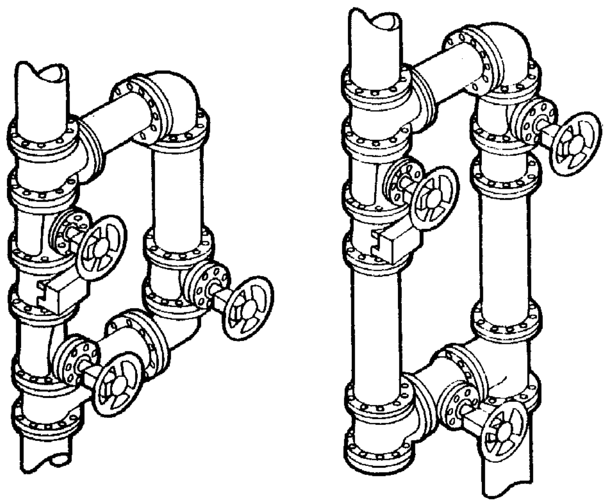


Figure 1-21—Handling a Magnetic Flowmeter

1.9.2.3 Bypass Piping

For applications that require frequent cleaning of the flow lines, the magmeter can be installed with block valves and a bypass valve to permit access to the tube interior without shutting down the process. Possible piping arrangements are shown in Figure 1-22. The bypass valve should be capable of positive shutoff to prevent measurement errors and wide opening. It should not be used as a throttling valve.

To permit checking the meter for zero flow, it is necessary to install the magmeter so that flow can be stopped with a full tube. For most continuous processes this will require a block and bypass arrangement. Certain magnetic flowmeters do not require zero adjustment.



A NORMAL BYPASS INSTALLATION

A BYPASS INSTALLATION WITH CLEAN-OUT TEE

Figure 1-22—Bypass Piping with Magmeter

1.9.2.4 Electrical Installation

Power should be supplied at a voltage and frequency within the tolerance specified by the manufacturer.

Special low-capacitance cable is used to carry the generated signal from the transmitter to the receiver. It must not be installed close to the power cable or in the same conduit as the power supply. The manufacturer's recommendations should be observed. See RP 550, Part I, Section 7.

Piping should always be grounded. The importance of proper grounding cannot be overemphasized. It is necessary for personnel safety and for satisfactory flow measurement. The manufacturer's instructions on grounding and jumper arrangement should be followed carefully. A continuous electrical contact to the same ground potential is necessary between the flowing liquid, the piping, and the magnetic flowmeter. This continuous contact is especially important if the conductivity of the liquid is low. How this contact is achieved depends upon the magmeter construction and whether adjacent piping is unlined metal, lined metal, or nonmetallic. Jumpers from the meter body to the piping are always required. If the meter is installed in nonmetallic piping, it is always necessary to make a grounding connection to the liquid. This connection is achieved by means of a metallic grounding ring between the flanges, unless internal grounding has been provided in the transmitter. This grounding connection is extremely important and must be done as recommended if the system is to operate properly.

Most magmeters have their signal and power connections enclosed in splashproof or explosionproof housings. The connections must be sealed in accordance with the manufacturer's instructions. Great care must be exercised in this area.

1.9.3 STARTUP AND CALIBRATION

No special procedures need be observed during startup since the meter is obstructionless. There are often electrical adjustments that must be made. The manufacturer's instruction bulletins should be consulted for these procedures.

1.10 Positive Displacement Meters

1.10.1 GENERAL

There are five main types of positive displacement meters: nutating disk, oscillating piston, fluted rotor, rotary (lobed impeller and sliding vane), and oval-shaped gear.

All positive displacement meters measure flow by mechanically trapping successive volumetric segments of the liquid passing through the meter. The number of segments is converted to shaft rotation. A gear train and a calibrator convert shaft rotation to appropriate volumetric units. The output is usually a mechanical register or ticket printer. Temperature compensators are available to correct the output as the fluid temperature changes. Pulse generators are available to provide pulse outputs for meter proving or remote readout.

1.10.1.1 Applications

Positive displacement meters are used because they are accurate over a wide flow range. They are often used for custody transfer [1], particularly for heavy or viscous fluids.

Occasionally, positive displacement meters are used for heavy product blending or for refinery process flows.

1.10.1.2 Features

Positive displacement meters have the following characteristics:

1. Typical accuracies are ±0.05 to 0.15 percent of actual flow. Highest accuracy requires some form of meter proving [3]. Typical repeatabilities are −0.02 to 0.05 percent.
2. Rangeability is typically 10:1 or more. Positive displacement meters have good rangeability and accuracy, particulary with heavy or viscous fluids.
3. Positive displacement meters come in a range of sizes from 0.1 gallon per minute (0.38 liter per minute) to 9000 gallons per minute (34000 liters per minute).

1.10.1.3 Typical Uses

Positive displacement meters are used in the following services:

1. Custody transfer [1].
2. Relatively heavy, viscous hydrocarbon streams.
3. Water, caustic, or acid measurement.
4. Volumetric totalization rather than rate of flow.

1.10.1.4 Optional Features

Positive displacement meters are available with the following options:

1. Temperature compensators to provide readout in 60 F (15 C) barrels. Some temperature compensators include a manual adjustment to permit setting an appropriate specific gravity.
2. Calibrators to correct the register reading after the meter is calibrated.
3. Ticket printers.
4. Pulse generators to provide pulse trains suitable for meter proving or remote transmission of flow data.
5. Pressure lubrication to allow the meter to be used with nonlubricating fluids.

1.10.2 INSTALLATION

1.10.2.1 Location and Mounting

Positive displacement meters are installed directly in the process piping. Since they are often unbalanced, they can be a source of piping vibration. Adequate foundations should be provided. Refer to the manufacturer's recommendations.

Positive displacement meters are normally installed in horizontal lines, although certain types are specifically designed for vertical lines. The meter register and ticket printer should be positioned for easy reading.

Adequate back pressure is required to eliminate the possibility of vapor release.

1.10.2.2 Mainline Piping

Meters should be installed so that the meter case or body does not carry piping strain. The piping should be arranged so that the meter is always full of liquid. For continuous process services, a bypass may be provided around a positive displacement meter. For custody transfer, bypasses are not provided.

Positive displacement meters should always be installed with an adequate strainer to prevent foreign matter from damaging the meter or causing excessive wear. Follow the meter manufacturer's recommendation on mesh size. Where excessive amounts of debris are entrained in the fluid, strainer pressure drop should be monitored. Otherwise, basket rupture can occur, resulting in meter damage.

The best positive displacement meter installation is one designed to avoid air or vapor in the piping. Otherwise, an air eliminator should be provided. Note, however, that air eliminators often leak or have inadequate capacity to protect the meter from slugs of air or vapor.

1.10.2.3 Limitations

The material selection and low internal clearances of positive displacement meters are usually designed to match a range of specific fluid properties and design conditions. Operating the meters outside of this design range may cause serious inaccuracy or premature meter failure.

1.10.3 STARTUP AND CALIBRATION

1.10.3.1 Startup

Positive displacement meters are often damaged or destroyed during the initial startup. The manufacturer's instructions should be followed during startup, as well as the following general guidelines:

1. Positive displacement meters should be installed in the line only after the piping has been flushed and hydrostatically tested.
2. The meter strainer basket should be installed after the piping has been flushed. Strainer pressure drop should be monitored and strainers should be cleaned as required.
3. Extreme care must be taken to vent air from the piping. Flow should be introduced slowly to prevent hydraulic shock. The meter should be "broken in" by running at reduced flow.
4. Custody transfer meters must be proved initially and at regular intervals [3].

1.10.3.2 Calibration

For custody transfer service, the piping should be designed to allow for easy meter proving.

1.11 Vortex Shedding Flowmeters

1.11.1 GENERAL

When a specially designed bluff body obstruction is placed in a liquid or gas stream, a vortex train is generated. This train of high- and low-pressure areas can be measured by sensors on the body or the pipe wall. The frequency of the pressure changes is directly and linearly related to the velocity of the fluid stream. Since flow in any pipeline is a function of cross-sectional area and velocity, there is a direct relationship between frequency and flowrate.

1.11.1.1 Applications

Vortex meters are used primarily because of their wide rangeability and accuracy. In certain cases, their relatively low cost may also dictate their use.

1.11.1.2 Features

Vortex meters have the following characteristics:

1. Wide rangeability (15:1 for liquids; 50:1 for gases).
2. Reasonable accuracy.
3. Sizes from 1 to 12 inches (2.5 to 30 centimeters) (larger sizes are insertion-type).

4. Linear output.
5. Pulse output (makes totalization easy and accurate).

1.11.1.3 Typical Uses

Vortex meters are commonly used in the following services:

1. Steam.
2. Cooling water.
3. Process water.
4. Light hydrocarbons where large turndown is required.
5. Any gas flow where large turndown is required.

1.11.1.4 Options

Either pulse or analog output is available. Local indicators are also available. Certain manufacturers offer two-wire transmitters.

1.11.1.5 Limitations

Vortex meters have the following limitations:

1. A limited range of construction materials is available.
2. On liquids, vortex meters should not be used for slurries or for high-viscosity liquids.
3. As with most flowmeters, users cannot check fluid calibration or change range without reducing rangeability.
4. Vortex meters have an upper temperature limit.
5. Bouncing ball types are limited to clean fluids.
6. Fully developed turbulent flow is required.
7. Most meters will not tolerate much greater than 50 percent overrange.

1.11.2 INSTALLATION

Vortex meters are installed directly in the process piping and are normally supported by the piping. They may usually be installed in any orientation.

A meter should be installed so that the meter body is not subjected to piping strain. In liquid applications, the piping should be arranged so that the meter is kept full.

Block and bypass valves may be provided when operating conditions do not permit shutdown.

1.11.3 STARTUP AND CALIBRATION

Vortex meters are sometimes damaged during startup of new installations due to debris in the line. The line should be flushed and hydrostatically tested before the meter is installed.

Since velocity profile is critical, it is imperative that gaskets do not protrude into the flow stream when flanged meters are installed.

Field calibration of vortex meters is usually unnecessary, except for electrically spanning the converter or adjusting the scaling factor on a pulse-output type.

REFERENCES

1. API *Manual of Petroleum Measurement Standards*, Chapter 5.2, "Measurement of Liquid Hydrocarbons By Displacement Meter Systems," First Edition, 1977.
2. API *Manual of Petroleum Measurement Standards*, Chapter 5.3, "Turbine Meters," First Edition, 1976.
3. API *Manual of Petroleum Measurement Standards*, Chapter 4, "Proving Systems," First Edition, 1978.
4. Spink, L.K., *Principles and Practice of Flow Meter Engineering*, The Foxboro Co., Foxboro, Massachusetts, Ninth Edition, 1967.
5. Lansford, W.M., *The Use of an Elbow in a Pipe Line for Determining the Rate of Flow in the Pipe*, University of Illinois, Urbana, Illinois, Bulletin No. 289, 1936.
6. Murdock, J.W., Holtz, C.J., Gregory, C., "Performance Characteristics of Elbow Flow Meters," ASME Paper 63-WA-17.
7. ANSI/API 2530, *Orifice Metering of Natural Gas, and Other Related Hydrocarbon Fluids*, AGA Report No. 3, American Gas Association, New York, New York, Second Edition, 1985.
8. PTC 19.5.4, *Instruments and Apparatus*, supplement to ASME Power Test Codes, American Society of Mechanical Engineers, New York, New York, February, 1959.
9. *Fluid Meters: Their Theory and Application*, report of ASME Research Committee on Fluid Meters, 6th edition, American Society of Mechanical Engineers, New York, New York, 1971.
10. Beitler, S.R., and Masson, D.J., "Calibration of Eccentric and Segmental Orifices in 4 and 6 inch Pipe Lines," *ASME Transactions*, 71, American Society of Mechanical Engineers, October, 1949.
11. Bogema, M., Spring, B. and Ramamoorthy, M.V., "Quadrant Edge Orifice Performance—Effect of Upstream Velocity Distribution," *ASME Transactions., Journal of Basic Engineering 84 Ser. D.* [1], December, 1962.
12. Sprenkle, R.E., and Courtright, N.S., "Straightening Vanes for Flow Measurement," *Mechanical Engineering* 80 [5], February, 1958.
13. Landstra, J.A., "Quarter-Circle Orifices," *Transactions, Institute Chemical Engineering*, 38 [4], pp. 26-32, 1960.
14. Bogema, M., and Monkmeyer, P.L., "The Quadrant Edge Orifice—A Fluid Meter for Low Reynolds Numbers," *ASME Transactions, Journal of Basic Engineering 82 Series D* [6], September, 1960.

15. Miller, R.W., *Flow Measurement Engineering Handbook*, McGraw-Hill, New York, New York, 1983.
16. Filban, T.J., and Griffin, W.A., "Small-Diameter-Orifice Metering," *ASME Transactions, Journal of Basic Engineering 82, Series D* [6], September, 1960.
17. Miner, L.O., "The Dall Flow Tube," *ASME Transactions 78*, April, 1956.
18. Hooper, L.J., "Calibration of Six Beth Flow Meters at Alden Hydraulic Laboratory," *ASME Transactions 72*, November, 1950.
19. Hooper, L.J., "Design and Calibration of the Lo-Loss Tube," *ASME Transactions 84*, Part II, December, 1962.
20. *Computation of Orifice Bores Using Corner Connections*, Barton Instrument Corporation, Monterey Park, California, 1954.
21. Sprenkle, R.E., "Piping Arrangements for Acceptable Flow Meter Accuracy," *ASME Transactions 67*, July 1945.
22. API Standard 2534, *Method of Measuring the Temperature of Petroleum and Petroleum Products*, 1965, (ANSI/ASTM D 1086).