Fluidic Flowmeters

PRODUCT INFORMATION

PI14-2
Rev: 1
March 2002

Model 141 Flowmeters
Functional Overview

DESCRIPTION

The Model 141 Flowmeters (Figure 1) work on the fluid phenomenon of the Coanda effect (see page 7 for details), providing accurate, reliable volumetric flow measurement that is linear with flowrate. They feature:

- Accurate and repeatable flow measurement
- High turndown (typically 15 to 1)
- No moving parts to damage or wear
- Undamaged by flow overranges of up to 400%
- Large selection of meters
- Two-wire transmitter or remote signal converter for installation flexibility
- No meter body calibration shift, minimizing maintenance requirements
- Output linear with flowrate
- Rugged and reliable sensor
- Highly immune to shock and vibration

FIGURE 1 Series 14 Flowmeter

A wide variety of flow applications can be accommodated by the Series 14 Flowmeters. High turndown (typically 15 to 1) and accuracies as good as 1.25% of rate make them an ideal choice for many processes.

They also offer low installation and maintenance costs. All versions are supplied with wafer end connections, eliminating the need for flanges. Optional flanges are available to mate with existing pipe configurations. Interchangeable sensors and signal conditioners are utilized to keep spare parts inventory to a minimum.

Moreover, the Model 141 Flowmeters are rugged, can withstand harsh industrial environments, and are highly immune to vibration and shocks (both pipe and fluid-induced). Because these flowmeters are based on the Coanda Effect, there are no moving parts to damage or wear. They will continue to perform within specification even after being subjected to flow overranges as high as 400%.

VERSIONS

The most economical flowmeter system uses the Model 141 with the two-wire transmitter. This combination is recommended for most general purpose flow applications requiring a 4-20 mA analog output. Model 141 Flowmeters offer a wide operating temperature [standard -40 to 176^{0}C (-40 to 350^{0}F), optional -196 to 176^{0}C (-320 to 350^{0}F)], immunity to the effects of sensor dirt buildup (coating), and a high turndown (typically 15:1).

The Model 141 can also be used with a deflection sensor signal converter, which uses 120 Vac power. This unit can replace the two-wire transmitter for flow applications requiring a pulse output or where nominal 24 Vdc loop power is not available.

PERFORMANCE SPECIFICATIONS

METER BODY

Accuracy

1.25 to 1.5% of flowrate. Includes the combined effects of conformity, hysteresis, deadband, and repeatability errors.

Meters can be supplied calibrated for a specific flow range. This typically results in accuracies better than 0.75% of rate. Table 1 lists the accuracy for each meter size and the minimum required Reynolds for the stated accuracy.

TABLE 1 Minimum Reynolds Number

METER SIZE in (mm)	1 (25)	1 ½ (38)	2 (50)	3 (76)
ACCURACY (%)	1.25	1.25	1.25	1.5
R_D NUMBER	10000	15000	20000	30000

The Reynolds Number (R_D) is based on pipe diameter and can be determined from the following equation:

$$R_D = \frac{VD}{\nu}$$

where

R_D = Reynolds Number
V = Velocity in ft/s or m/s
D = Actual inside pipe diameter in ft or m
ν = Kinematic viscosity in ft^2/s or m^2/s

For convenience, R_D can be determined from the following hybrid equation:

$$R_D = \frac{3162\ (GPM)}{(\text{Pipe ID. In.})\ (\text{Centistokes})}$$

Repeatability
0.20% of flow rate

Ambient Temperature Effect
1% of flowrate per 148^{0}C (300^{0}F)

Flow Overrange Protection
Flow overranges of up to 400% of full scale will not damage the meter body or the sensor.

Position Effect
The flowmeter can be mounted in horizontal, vertical or inclined pipelines having an upwards direction of flow with no effect on performance. It is important that the pipe be kept full of fluid for accurate flow measurement.

Minimum Pipe Requirements
Ten pipe diameters upstream and five pipe diameters downstream of straight piping.

Minimum Flowrates
The values shown in Table 2 are for water with a viscosity of 1.0 cSt and a specific gravity of 1.0. To determine the minimum flowrate in GPM for liquids with other viscosities and specific gravities, perform the following calculations:

1. Multiply the kinematic viscosity (in cSt) by the flowmeter size in inches.
2. Divide the minimum flowrate (from Table 2) by the square root of the specific gravity.

The minimum flowrate will be the larger of the two values. For example, for a liquid with a viscosity of 1.0 cSt and a specific gravity of 0.8 in a 1" (25 mm) meter, the minimum flowrate would be determined as follows:

Viscosity effect:

Qmin = 1.0 cSt x 1" = 1.0 GPM

Specific gravity effect:

Qmin = 3.25/√0.8 = 3.63 GPM

The minimum flowrate would be 3.63 GPM, the larger of the two calculated values.

TABLE 2 Minimum Flowrates

FLOW UNITS	1 (25)	1 ½ (38)	2 (50)	3 (76)
GPM	3.25	7.60	10.5	23.0
L/S	0.2	0.48	0.68	1.45

Minimum Linear Flowrate vs. Liquid Viscosity
Figures 2 through 5 depict the effect of viscosity on the minimum linear flowrate and the minimum operating flowrate. As the viscosity increases, the minimum flowrate required also increases.

FIGURE 2 Minimum Flowrate vs. Liquid Viscosity for 1" (25 mm) Meter

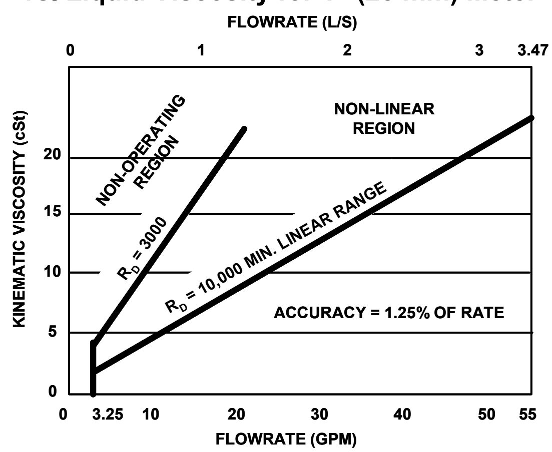


FIGURE 3 Minimum Flowrate vs. Liquid Viscosity for 1 ½" (38 mm) Meter

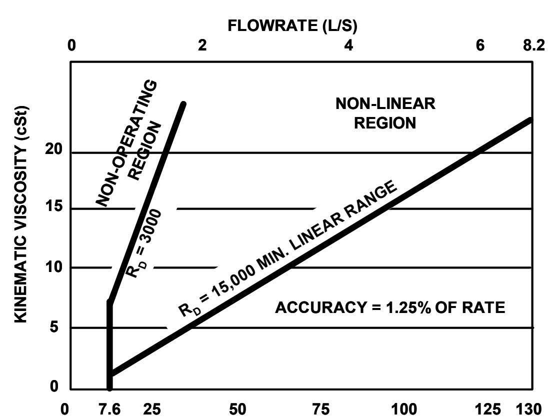


FIGURE 4 Minimum Flowrate vs. Liquid Viscosity for 2” (50 mm) Meter

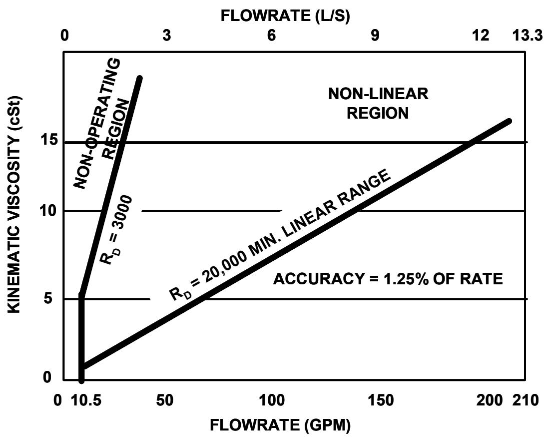
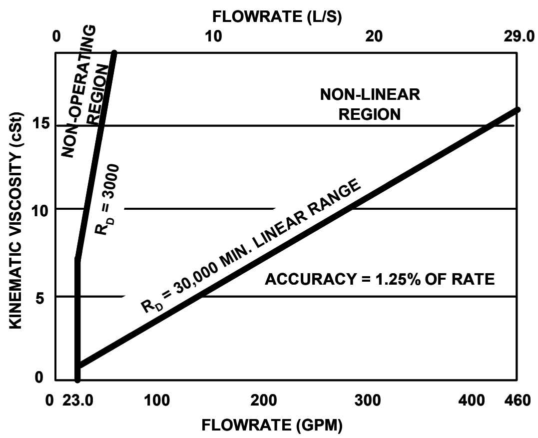


FIGURE 5 Minimum Flowrate vs. Liquid Viscosity for 3” (76 mm) Meter



ELECTRONICS

Accuracy

0.1% of full scale for the two-wire transmitter and signal converter. Includes the combined effects of conformity, hysteresis, deadband, and repeatability errors.

Supply Voltage Effect

Two-Wire Transmitter: None within the transmitter’s operating range.
Signal Converter: Less than 0.1% per Vac.

FUNCTIONAL SPECIFICATIONS

METER BODY

Flowrate Limits

The flowrates shown in Table 3 are for water with a viscosity of 1.0 cSt and a specific gravity of 1.0. Table 4 lists the upper range limits (URLs) for a 20 mA output. For example, a 2” (50 mm) meter can be calibrated to have a 4-20 mA output for flow ranges from 0-40 to 0-210 GPM.

TABLE 3 Flowrate Limits

FLOW UNITS	METER SIZE in (mm)							
	1 (25)		1 ½ (38)		2 (50)		3 (76)	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
GPM	3.25	55.0	7.6	130	10.5	210	23.0	460
L/S	0.21	3.47	0.48	8.20	0.66	13.3	1.45	29.0

NOTE: *To obtain the minimum flow for liquids other than water at standard conditions, refer to the minimum flowrate specifications.*

TABLE 4 Flowrate Upper Range Limits

FLOW UNITS	METER SIZE			
	1	1 ½	2	3
GPM	10-55	22-130	40-210	125-460
L/S	0.63-3.47	1.39-8.20	2.52-13.3	7.88-29.0

Static Pressure Limits

Maximum working pressure is equal to the flange ratings, which are listed in Table 5. Flange ratings are based on ANSI B16.5.

TABLE 5 Static Pressure Limits Flange Class (lbs.)
(Maximum Connecting Flange Rating)

END CONNECTIONS	METER SIZE			
	1 (25)	1 ½ (38)	2 (50)	3 (76)
STANDARD (Flangeless)	150, 300, or 600	150, 300, or 600	150	150
OPTIONAL (Welded-On Flanges)	150, 300, or 600	150, 300, or 600	150, 300, or 600	150 or 300

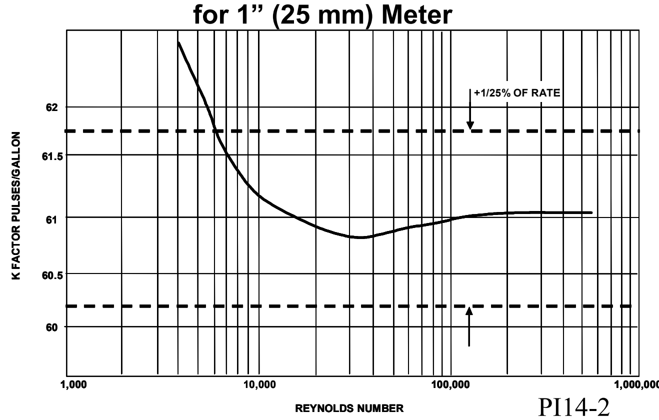
K Factor

The K Factor is the ratio of pulses to gallons of flowing fluid. Nominal K Factors are listed in Table 6. K Factors vary slightly from meter to meter. The actual K Factor for each meter is determined by averaging its K Factor over the operating range. Figure 6 shows a typical K Factor vs. R_D curve for a 1” (25 mm) meter.

TABLE 6 Nominal K Factors

METER SIZE in (mm)			
1 (25)	1 ½ (38)	2 (50)	3 (76)
62	17	11	3.1

FIGURE 6 Typical K Factor vs. R_D Curve for 1” (25 mm) Meter



Operating Temperatures

Standard: -40 to 176^0C (-40 to 350^0F)
Optional: -196 to 176^0C (-320 to 350^0F)
NOTE: Optional Cryogenic Sensor requires use of four-wire signal conditioner.

Pressure Loss

Figures 7 and 8 are graphs of pressure loss versus flowrate in U.S. and metric units, respectively. These pressures are for water with a density of 62.43 lb/ft^3. The pressure loss for water with other densities or other fluids can be found using the following equation:

$\Delta P = X_1 Q^2 y$

where

ΔP = Pressure loss in PSI or kappa
X_1 = Pressure loss coefficient from Table 7
Q = Flowrate in GPM or l/s
y = Density at flowing conditions in lb/ft^3 or N/m^3

FIGURE 7 Pressure Loss vs. Flowrate in U.S. Units

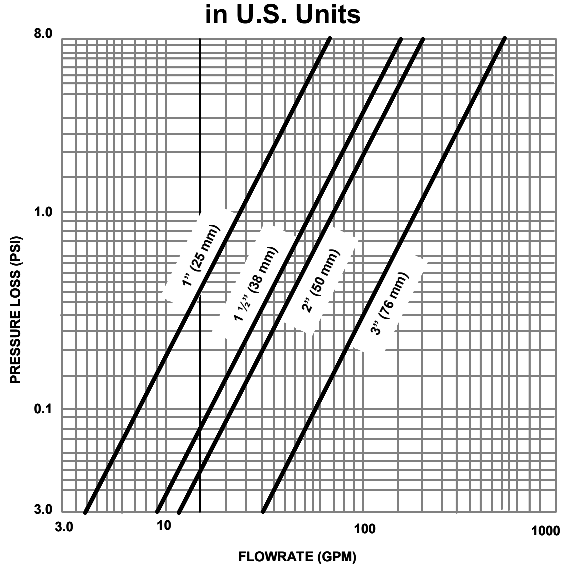


FIGURE 8 Pressure Loss vs. Flowrate in Metric Units

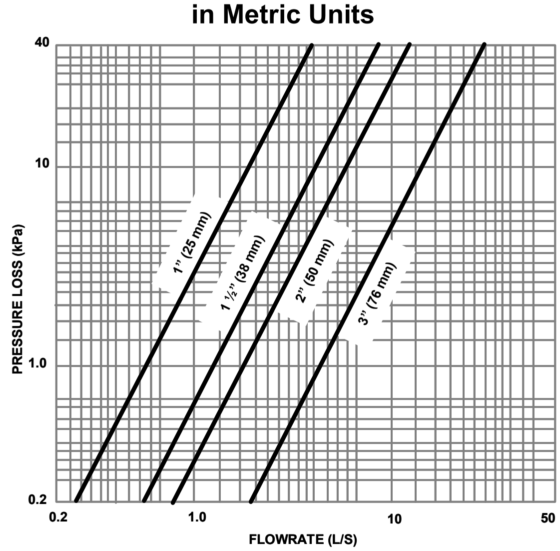


TABLE 7 Pressure Loss Coefficients

METER SIZE in (mm)	PRESSURE LOSS COEFFICIENT, ENGLISH	PRESSURE LOSS COEFFICIENT, METRIC
1 (25)	3.058×10^{-5}	3.373×10^{-4}
1 ½ (38)	5.655×10^{-6}	6.237×10^{-5}
2 (50)	3.471×10^{-6}	3.828×10^{-5}
3 (76)	5.532×10^{-7}	6.101×10^{-6}

Minimum Back Pressure

Any condition that contributes to flashing or cavitation should be avoided, as faulty signals may occur. The minimum back pressure required to insure proper operation of the flowmeter can be found by using the equation below. If the actual downstream pressure is less than the minimum back pressure, flashing may occur.

$P_G = (3\ \Delta P) + (1.25)(P_V) - (P_{ATM})$

where

P_G = Gauge pressure in PSI or kPa five pipe diameters downstream of flowmeter
ΔP = Calculated pressure loss
P_V = Vapor pressure at line conditions in PSI or kPa absolute
P_{ATM} = Atmospheric pressure in PSI or kPa absolute

ELECTRONICS

Operating Temperature

Two-Wire Transmitter: -40 to 85^0C (-40 to 185^0F)
Signal Converter: -30 to 50^0C (-22 to 122^0F)

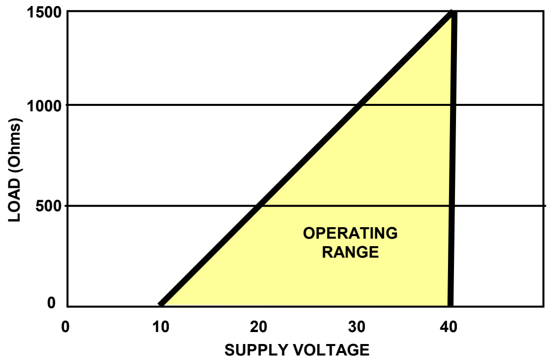
Output Signal

Two-Wire Transmitter: The analog output is 4-20 mA with a maximum load of 1500 ohms.
Signal Converter: The signal converter provides a pulse and an analog output. The pulse has a rise/fall time of 1 µsec with a maximum of 0.005 µF. The scaled pulse width is 50-70 msec. The analog output is 4-20 mA with a maximum load of 600 ohms. NOTE: This converter must be used with Optional Cryogenic Sensor.

Power Requirements

Two-Wire Transmitter: Compliance voltage is 10 Vdc. See Figure 9 for operating range.
Signal Converter: 120 Vac, +10%, =15%, 50-60 Hz, 13 W (max.)

FIGURE 9 Load Requirements



$$\text{MAX LOAD} = \frac{(V_s - 10)\ \text{Volts}}{0.020\ \text{Amps}}$$

PHYSICAL SPECIFICATIONS

MATERIALS OF CONSTRUCTIONS

Process Wetted Parts

Meter Body: Cast Stainless Steel
1" (25 mm): 316 SS (ASTM A296 grade CF8M)
1 ½" (38 mm), 2" (50 mm), and 3" (76 mm): 316L SS (ASTM A296 grade CF3M)
Sensor: 316L SS with Hastelloy® C
O-Ring: Viton® A
Gasket: Teflon®
Optional Flange: 316L SS

Meter Non-Wetted Parts

Terminal Mounting Plate: 18-8 SS
Meter Body:
Cover: Aluminum
Gasket: Neoprene®
Two-Wire Transmitter:
Cover: Aluminum
Gasket: Neoprene
Housing: Low Cu Cast Aluminum
Signal Converter:
Enclosure: Carbon Steel
Gasket: Neoprene

Weights

Meter Body: See Table 8.

TABLE 8 Meter Body Weights

METER SIZE in (mm)	1 (25)	1 ½ (38)	2 (50)	3 (76)
WEIGHT lb (kg)	7 (3.2)	16 (7.3)	19 (8.6)	36 (16.3)

Two-Wire Transmitter: 3 lbs. (1.3 kg.)
Signal Converter: 12 lbs. (5.4 kg.)

Electrical Connections

Meter: ½" conduit connection
Two-Wire Transmitter: Two ½" NPT conduit connections
Signal Converter: Three ½" conduit connections

Process Connections

Standard: Wafer mounting (flangeless)
Optional: 150, 300 or 600 lb. flanges [600 lb. flanges not available on 3" (76 mm) size]

Enclosure Specification

Two-Wire Transmitter: NEMA 4/IP 65
Signal Converter: NEMA 4/IP 65
Meter Body: NEMA 4/IP 65

HAZARDOUS AREA CLASSIFICATIONS

Deflection Sensor Meter Body

FM approved for Class I, Division 1, Groups A, B, C and D; Class II, Division 1, Groups E, F and G; and Class III, Division 1 when connected per drawing number 15032-1419 and installed per manufacturer's instructions.

Deflection Sensor Signal Converter

FM approved for Class I, Division 2, Groups A, B, C and D; NEMA 4. The Model 14 Converter acts as a barrier for flowmeter equipment located in hazardous locations as follows: Class I, Division 1, Groups A, B, C and D; Class II, Division 1, Groups E, F and G; and Class III, Division 1 when installed per drawing number 15032-1419.

Model 14 Two-Wire Transmitter (P/N 15973-10)

FM approved for Class I, Division 1, Groups A, B, C and D; Class II, Division 1, Groups E, F and G; and Class III, Division 1 when connected per drawing number 15032-1420 and installed per manufacturer's instructions.

FLOWMETER SELECTION PROCEDURE

Use the following procedure to select the proper flowmeter.

Step 1

Complete Table 9.

TABLE 9 Fluid Specifications

Fluid:		
Flowrates (GPM):	**Max.**	
	Min.	
	Normal	
Temperature (°F):	**Max.**	
	Min.	
	Normal	
Viscosity (centistokes) @ Normal Temp:		
Specific Gravity:		
Pressure (PSIG):	**Max.**	

Step 2

Determine which meter body and electronics are best suited for the process.

Either the two-wire transmitter or the deflection sensor signal converter can be selected. The two-wire transmitter, which provides a 4-20 mA signal, is the most economical. If a pulse output or a pulse output and a 4-20 mA signal are required, the deflection sensor signal converter should be used.

Step 3

Determine which size meter is required. To do this, compare the maximum flowrate with the values listed in Table 4. The best meter body to use is the smallest one that will handle the maximum flow. For example, a maximum flow of 50 GPM can be handled by a 1” (25 mm), 1 ½” (38 mm), or 2” (50 mm) meter body. However, choosing the 1” (25 mm) meter body will provide the lowest minimum flowrate, which will result in the highest turndown, and is the most economical choice.

Step 4

Determine the minimum measurable flow. By using the performance specifications, calculate the minimum measurable flowrate for the meter body chosen. If this minimum flow is not low enough, try the Model 140MX high viscosity/low flowrate meter.

Step 5

Verify the remaining specifications. Check the temperature and pressure requirements with the functional specifications.

Step 6

Define the model and part numbers required using the catalog model selection guides. The full catalog and the Fluidic Flowmeter section are only available for downloading on our web site at www.fluidicflowmeters.com.

In addition, the following process information should be supplied:

- Operating pressure and pipe size
- Process fluid, viscosity, specific gravity, temperature and particle size
- Full scale, normal and minimum flow rates
- Flange type and pressure rating where meter is to be installed (flanges must be same size as meter)

Flowmeter Bypass System

The measuring of large flowrates (in excess of 1,000 GPM) can be attained with a 1” (25 mm) Model 141 Flowmeter when used in a bypass system around an orifice plate (Figure 10). The bypass metering system technique is not a new one, as it has been used successfully for many years with rotometers. Engineering tests on the Model 141 Bypass System have proven that a small amount of bypassed fluid (typically 20-30 GPM at full scale) has no significant effect on the mainline orifice calibration.

The bypass system provides the measurement of a large flowrate by measuring a small percentage of the flow. This is accomplished by creating a pressure drop in the main pipeline via a standard orifice plate. A small pipeline around the orifice plate allows a small amount of fluid to “bypass” the mainline orifice plate. With a properly designed bypass system, there is a direct relationship between the small amount of fluid flowing in the bypass line to the flow of fluid in the main pipeline.

A Model 141 Flowmeter installed in such a system can provide an output corresponding directly to the flow of fluid in the main pipeline. The advantages of using a Model 141 Flowmeter Bypass System for large flows as compared to an ordinary differential pressure transmitter are:

- Increased rangeability
- Linear output
- Primary pulse output for direct accurate totalizing

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FIGURE 10 Flowmeter Bypass System

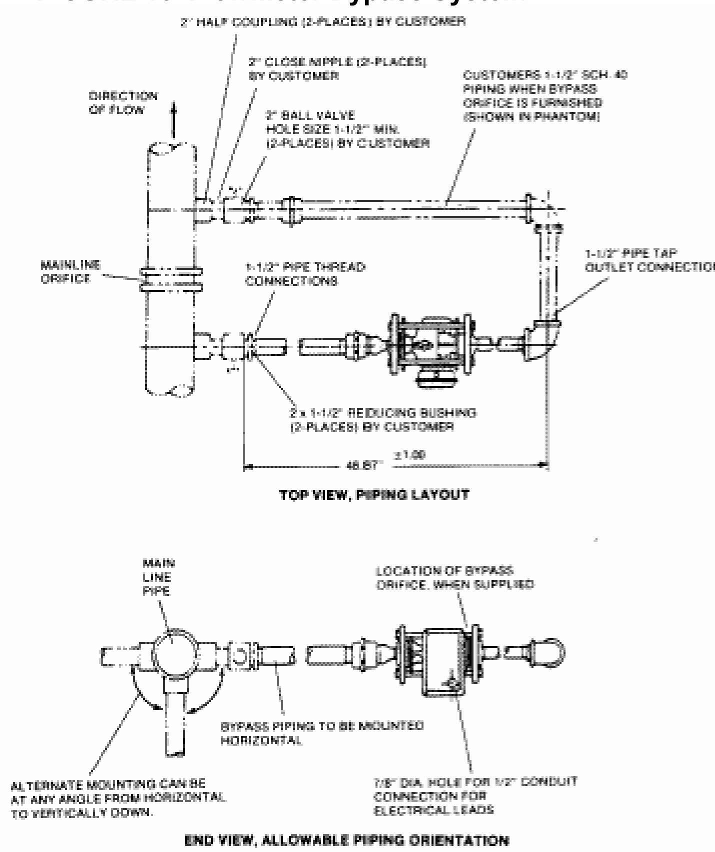


FIGURE 11 Two-Wire Transmitter

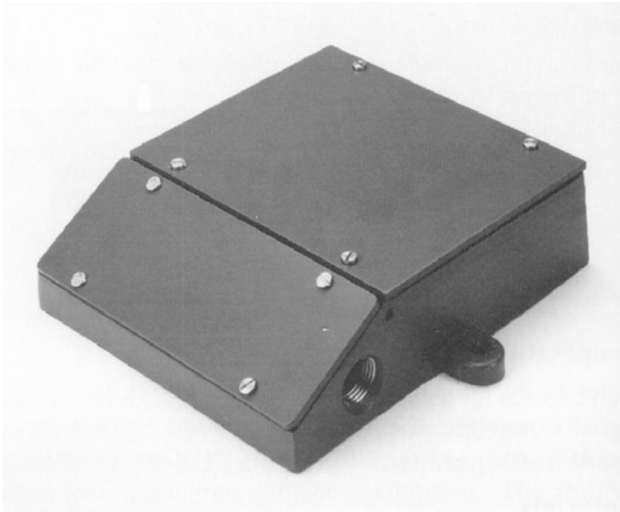
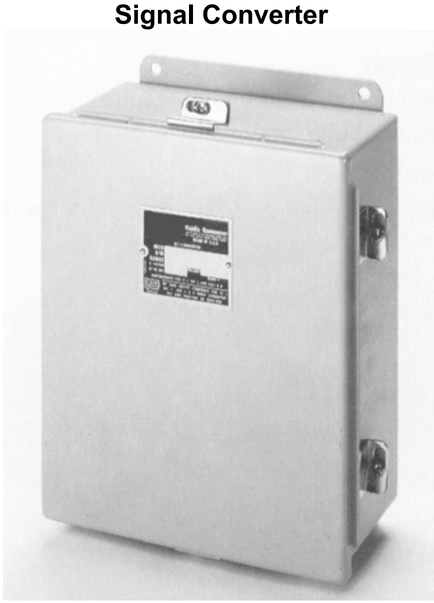


FIGURE 12 Deflection Sensor Signal Converter



OSCILLATORY FLOWMETERS

Oscillatory Flowmeters utilize specially designed geometric shapes to create an environment where self-induced, sustained oscillations will occur. Oscillating flowmeters are inherently digital devices, that is, the basic measurement they read is a frequency. In a properly executed flowmeter, the frequency of its oscillations is proportional to volumetric flowrate. There are several categories of oscillatory flowmeters, each with a unique shape.

Volumetric Flowrate vs. Frequency

For any point in the operating region of the flowmeter, the frequency of oscillation will be related to the volumetric flowrate by the following equation:

$$F = KQ$$

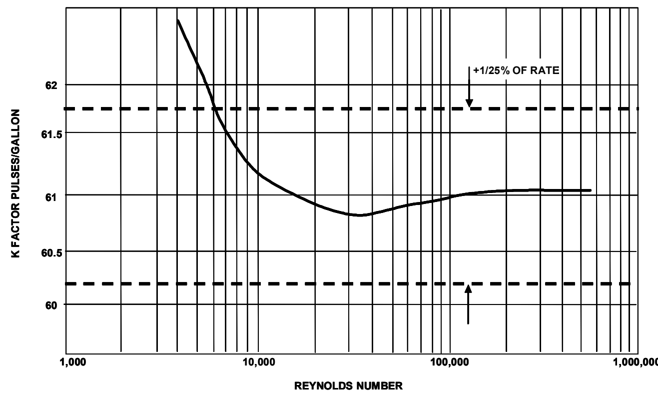
where

F is the frequency of oscillation
K is the calibration factor of the meter
Q is the volumetric flowrate

K Factor

It has been found that the K factor of oscillatory meters varies with Reynolds number. Because of this, it is convenient to plot the K factor versus the Reynolds number. If the meter was perfect, it would have a constant K factor at the Reynolds numbers, but this is not the case. All oscillatory meters exhibit a K factor curve that looks similar to Figure 13.

FIGURE 13 K Factor vs. Reynolds Number



How well the actual meter performs is a function of the design of the meter as well as the influence of the fluid flowing through it. There is a region on the curve where the K factor is essentially constant. This is the normal operating region for oscillating flowmeters. In this region, the accuracy is good enough to be stated as a percent of instantaneous flowrate.

Coanda Flowmeters

Coanda flowmeters are based on a phenomenon first observed in 1910 by Henri Coanda. Later in 1932, Coanda did further research and quantitized the phenomenon. Coanda discovered that as a free jet emerges from a nozzle or a conduit, it will tend to follow a nearby surface and will, in fact, attach to it.

The attachment to a surface is a result of a low pressure region that develops between the free stream and the wall. As the free stream moves past the wall, some of the fluid in that region will be entrained by the main stream. This causes the pressure in the region to decrease. As a result, the pressure in that region will begin to decrease. Because of this pressure differential, the free stream begins to deflect towards the wall. As more fluid is carried along with the main stream, the jets divert more and more to the wall unit it attaches to.

The geometric shape of the Coanda flowmeter produces a continuous, self-induced oscillation at a frequency that is linearly proportional to flowrate. As fluid passes through the meter, it will attach itself to one of the side walls as a result of the Coanda effect. A small portion of the flow is diverted through the feedback passage and travels around to the control port. This feedback flow disrupts the attachment of the main jet to the side wall. The main jet is now free and will attach itself to the other side wall due to the Coanda effect. The feedback action will repeat itself, and in this manner the meter body produces a sustained oscillation. As the main fluid stream oscillates between the two side walls, the flow in the feedback passages cycles between zero and maximum. The cycling of the flow in the feedback passages is detected by a sensor located in one of the feedback passages, while the sensor signal is conditioned by a signal converter. Figure 14 shows the cross-section of a Coanda flowmeter.

FIGURE 14 Cross-section of a Coanda Flowmeter