The Consumer Guide to Ultrasonic Flowmeters

Seminar Presented by
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Seminar Outline

- ***Introduction***
- *Fluid Flow Fundamentals*
- *Flowmeter Technology*
- *Flowmeter Performance*
- *Consumer Guide*

Introduction

- *Working Definition of a Process*
- *Why Measure Flow?*

Working Definition of a Process

- *A process is anything that changes*

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Why Measure Flow?

- *Flow measurements provide information about the process*
- *The information that is needed depends on the process*

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Why Measure Flow?

- *Custody transfer*
  - *Measurements are often required to determine the total quantity of fluid that passed through the flowmeter for billing purposes*

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Why Measure Flow?

- *Monitor the process*
  - *Flow measurements can be used to ensure that the process is operating satisfactorily*

Why Measure Flow?

- *Improve the process*
  - *Flow measurements can be used for heat and material balance calculations that can be used to improve the process*

Why Measure Flow?

- *Monitor a safety parameter*
  - *Flow measurements can be used to ensure that critical portions of the process operate safely*

Seminar Outline

- *Introduction*
- ***Fluid Flow Fundamentals***
- *Flowmeter Technology*
- *Flowmeter Performance*
- *Consumer Guide*

Fluid Flow Fundamentals

- ***Temperature***
- *Pressure*
- *Density and Fluid Expansion*
- *Types of Flow*
- *Inside Pipe Diameter*
- *Viscosity*
- *Reynolds Number and Velocity Profile*
- *Hydraulic Phenomena*

Temperature

- *Measure of relative hotness/coldness*
  - *Water freezes at 0°C (32°F)*
  - *Water boils at 100°C (212°F)*

Temperature

- *Removing heat from fluid lowers temperature*
  - *If all heat is removed, absolute zero temperature is reached at approximately -273°C (-460°F)*

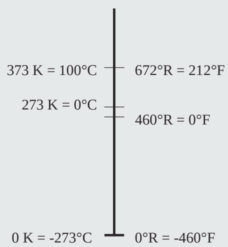
Temperature

- *Absolute temperature scales are relative to absolute zero temperature*
  - *Absolute zero temperature = 0 K (0°R)*
    - *Kelvin = °C + 273*
    - *° Rankin = °F + 460*

Temperature

- *<u>Absolute</u> temperature is important for flow measurement*

Temperature



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Temperature

Problem

- *The temperature of a process increases from 20°C to 60°C. For the purposes of flow measurement, by what percentage has the temperature increased?*

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Temperature

- *It is tempting to answer that the temperature tripled (60/20), but the ratio of the absolute temperatures is important for flow measurement*
  - *(60+273)/(20+273) = 1.137*
  - *13.7% increase*

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Fluid Flow Fundamentals

- *Temperature*
- ***Pressure***
- *Density and Fluid Expansion*
- *Types of Flow*
- *Inside Pipe Diameter*
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Pressure

- *Pressure is defined as the ratio of a force divided by the area over which it is exerted (P=F/A)*

Pressure

Problem

- *What is the pressure exerted on a table by a 2 inch cube weighing 5 pounds?*
  - *(5 lb) / (4 inch^2) = 1.25 lb/in^2*
  - *If the cube were balanced on a 0.1 inch diameter rod, the pressure on the table would be 636 lb/in^2*

Pressure

- *Atmospheric pressure is caused by the force exerted by the atmosphere on the surface of the earth*
  - *2.31 feet WC / psi*
  - *10.2 meters WC / bar*

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Pressure

- *Removing gas from a container lowers the pressure in the container*
  - *If all gas is removed, absolute zero pressure (full vacuum) is reached at approximately -1.01325 bar (-14.696 psig)*

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Pressure

- *Absolute pressure scales are relative to absolute zero pressure*
  - *Absolute zero pressure*
    - *Full vacuum = 0 bar abs (0 psia)*
    - *bar abs = bar + 1.01325*
    - *psia = psig + 14.696*

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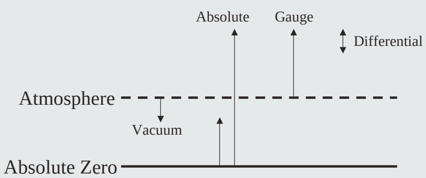
Pressure



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Pressure

- *Absolute pressure is important for flow measurement*

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Pressure

Problem

- *The pressure of a process increases from 1 bar to 3 bar. For the purposes of flow measurement, by what percentage has the pressure increased?*

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Pressure

- *It is tempting to answer that the pressure tripled (3/1), but the ratio of the absolute pressures is important for flow measurement*
  - *(3+1.01325)/(1+1.01325) = 1.993*
  - *99.3% increase*

Fluid Flow Fundamentals

- *Temperature*
- *Pressure*
- ***Density and Fluid Expansion***
- *Types of Flow*
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Density and Fluid Expansion

- *Density is defined as the ratio of the mass of a fluid divided its volume* ($\rho = m/V$)

Density and Fluid Expansion

- *Specific Gravity of a liquid is the ratio of its operating density to that of water at standard conditions*
  - $SG = \rho_{liquid} / \rho_{water\ at\ standard\ conditions}$

Density and Fluid Expansion

Problem

- *What is the density of air in a 3.2 ft3 filled cylinder that has a weight of 28.2 and 32.4 pounds before and after filling respectively?*

Density and Fluid Expansion

- *The weight of the air in the empty cylinder is taken into account*
  - *Mass* $=(32.4-28.2)+(3.2\bullet 0.075)$
    $= 4.44$ *lb*
  - *Volume* $= 3.2\ ft^3$
  - *Density* $= 4.44/3.2 = 1.39\ lb/ft^3$

Density and Fluid Expansion

- *The density of most liquids is nearly unaffected by pressure*
- *Expansion of liquids*
  - $V = V_0 (1 + \beta \bullet \Delta T)$
    - *V = new volume*
    - V_0 *= old volume*
    - *β = cubical coefficient of expansion*
    - *ΔT = temperature change*

Density and Fluid Expansion

Problem

- *What is the change in density of a liquid caused by a 10°C temperature rise where β is 0.0009 per °C ?*

Density and Fluid Expansion

- *Calculate the new volume*
  - $V = V_0 (1 + 0.0009 \bullet 10) = 1.009\ V_0$
  - *The volume of the liquid increased to 1.009 times the old volume, so the new density is (1/1.009) or 0.991 times the old density*

Density and Fluid Expansion

- *Expansion of solids*
  - $V = V_0 (1 + \beta \bullet \Delta T)$
    - *where* $\beta = 3 \bullet \alpha$
    - α = *linear coefficient of expansion*
- *Temperature coefficient*
  - *Stainless steel temperature coefficient is approximately 0.5% per 100°C*

Density and Fluid Expansion

Problem

- *What is the increase in size of metal caused by a 50°C temperature rise where the metal has a temperature coefficient of 0.5% per 100°C ?*

Density and Fluid Expansion

- *Calculate the change in size*
  - *(0.5 • 50) = 0.25%*
  - *Metals (such as stainless steel) can exhibit significant expansion*

Density and Fluid Expansion

- *Boyle's Law states the the volume of an ideal gas at constant temperature varies inversely with absolute pressure*
  - $V = K / P$

Density and Fluid Expansion

- *New volume can be calculated*
  - $V = K / P$
  - $V_0 = K / P_0$
- *Dividing one equation by the other yields*
  - $V/V_0 = P_0 / P$

Density and Fluid Expansion

Problem

- *How is the volume of an ideal gas at constant temperature and a pressure of 28 psig affected by a 5 psig pressure increase?*

Density and Fluid Expansion

- *Calculate the new volume*
  - $V/V_0 = (28+14.7) / (28+5+14.7) = 0.895$
  - $V = 0.895\ V_0$
  - *Volume decreased by 10.5%*

Density and Fluid Expansion

- *Charles' Law states the the volume of an ideal gas at constant pressure varies directly with absolute temperature*
  - $V = K \bullet T$

Density and Fluid Expansion

- *New volume can be calculated*
  - $V = K \bullet T$
  - $V_0 = K \bullet T_0$
- *Dividing one equation by the other yields*
  - $V/V_0 = T / T_0$

Density and Fluid Expansion

Problem

- *How is the volume of an ideal gas at constant pressure and a temperature of 15ºC affected by a 10ºC decrease in temperature?*

Density and Fluid Expansion

- *Calculate the new volume*
  - $V/V_0 = (273+15-10) / (273+15) = 0.965$
  - $V = 0.965\ V_0$
  - *Volume decreased by 3.5%*

Density and Fluid Expansion

- *Ideal Gas Law combines Boyle's and Charles' Laws*
  - $PV = n\ R\ T$

Density and Fluid Expansion

- *New volume can be calculated*
  - $P \bullet V = n \bullet R \bullet T$
  - $P_0 \bullet V_0 = n \bullet R \bullet T_0$
- *Dividing one equation by the other yields*
  - $V/V_0 = (P_0/P) \bullet (T / T_0)$

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Density and Fluid Expansion

Problem

- *How is the volume of an ideal gas at affected by a 10.5% decrease in volume due to temperature and a 3.5% decrease in volume due to pressure?*

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Density and Fluid Expansion

- *Calculate the new volume*
  - $V/V_0 = 0.895 \bullet 0.965 = 0.864$
  - $V = 0.864\ V_0$
  - *Volume decreased by 13.6%*

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Density and Fluid Expansion

- *Non-Ideal Gas Law takes into account non-ideal behavior*
  - $PV = n R T Z$

Density and Fluid Expansion

- *New volume can be calculated*
  - $P \bullet V = n \bullet R \bullet T \bullet Z$
  - $P_0 \bullet V_0 = n \bullet R \bullet T_0 \bullet Z_0$
- *Dividing one equation by the other yields*
  - $V/V_0 = (P_0/P) \bullet (T / T_0) \bullet (Z / Z_0)$

Fluid Flow Fundamentals

- *Temperature*
- *Pressure*
- *Density and Fluid Expansion*
- ***Types of Flow***
- *Inside Pipe Diameter*
- *Viscosity*
- *Reynolds Number and Velocity Profile*
- *Hydraulic Phenomena*

Types of Flow

- *$Q = A \cdot v$*
  - *Q is the volumetric flow rate*
  - *A is the cross-sectional area of the pipe*
  - *v is the average velocity of the fluid in the pipe*

Types of Flow

- *Typical Volumetric Flow Units($Q = A \cdot v$)*
  - $ft^2 \cdot ft/sec = ft^3/sec$
  - $m^2 \cdot m/sec = m^3/sec$
  - *gallons per minute (gpm)*
  - *liters per minute (lpm)*
  - *cubic centimeters per minute (ccm)*

Types of Flow

- *$W = \rho \cdot Q$*
  - *W is the mass flow rate*
  - *ρ is the fluid density*
  - *Q is the volumetric flow rate*

Types of Flow

- *Typical Mass Flow Units ($W = \rho \bullet Q$)*
  - *$lb/ft^3 \bullet ft^3/sec = lb/sec$*
  - *$kg/m^3 \bullet m^3/sec = kg/sec$*
  - *standard cubic feet per minute (scfm)*
  - *standard liters per minute (slpm)*
  - *standard cubic centimeters per minute(sccm)*

Types of Flow

- $Q = A \bullet v$
- $W = \rho \bullet Q$
  - Q *volumetric flow rate*
  - W *mass flow rate*
  - v *fluid velocity*
  - $\frac{1}{2} \rho v^2$ *inferential flow rate*

Fluid Flow Fundamentals

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Inside Pipe Diameter

- *The <u>inside</u> pipe diameter (ID) is important for flow measurement*
  - *Pipes of the same size have the same outside diameter (OD)*
    - *Welding considerations*
  - *Pipe wall thickness, and hence its ID, is determined by its schedule*

Inside Pipe Diameter

- *Pipe wall thickness increases with increasing pipe schedule*
  - *Schedule 40 pipes are considered "standard" wall thickness*
  - *Schedule 5 pipes have thin walls*
  - *Schedule 160 pipes have thick walls*

Inside Pipe Diameter

- *Nominal pipe size*
  - *For pipe sizes 12-inch and smaller, the nominal pipe size is the approximate ID of a Schedule 40 pipe*
  - *For pipe sizes 14-inch and larger, the nominal pipe size is the OD of the pipe*

Fluid Flow Fundamentals

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Viscosity

- *Viscosity is the ability of the fluid to flow over itself*
- *Units*
  - *cP, cSt*
  - *Saybolt Universal (at 100ºF, 210 ºF)*
  - *Saybolt Furol (at 122ºF, 210 ºF)*

Viscosity

- *Viscosity can be highly temperature dependent*
  - *Water*
  - *Honey at 40°F, 80°F, and 120°F*
  - *Peanut butter*

Fluid Flow Fundamentals

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- ***Reynolds Number and Velocity Profile***
- *Hydraulic Phenomena*

Velocity Profile and Reynolds Number

- *Reynolds number is the ratio of inertial forces to viscous forces in the flowing stream*
  - $R_D = 3160 \cdot Q_{gpm} \cdot SG / (\mu_{cP} \cdot D_{in})$

Velocity Profile and Reynolds Number

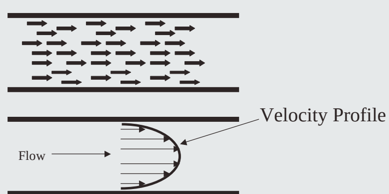
- *Reynolds number can be used as an indication of how the fluid is flowing in the pipe*
- *Flow regimes based on R_D*
  - *Laminar* < 2000
  - *Transitional* 2000 - 4000
  - *Turbulent* > 4000

Velocity Profile and Reynolds Number

- *Not all molecules in the pipe flow at the same velocity*
- *Molecules near the pipe wall move slower; molecules in the center of the pipe move faster*

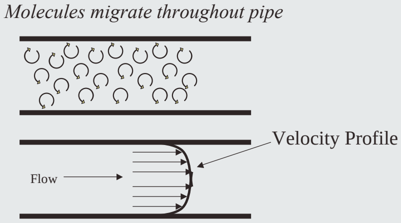
Velocity Profile and Reynolds Number

- *Laminar Flow Regime*
  - *Molecules move straight down pipe*



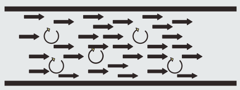
Velocity Profile and Reynolds Number

- *Turbulent Flow Regime*
  - *Molecules migrate throughout pipe*



Velocity Profile and Reynolds Number

- *Transitional Flow Regime*
  - *Molecules exhibit both laminar and turbulent behavior*

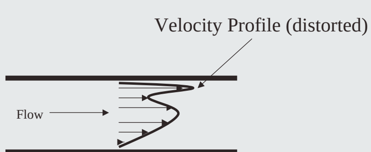


Velocity Profile and Reynolds Number

- *Many flowmeters require a good velocity profile to operate accurately*
- *Obstructions in the piping system can distort the velocity profile*
  - *Elbows, tees, fittings, valves*

Velocity Profile and Reynolds Number

- *A distorted velocity profile can introduce significant errors into the measurement of most flowmeters*



Velocity Profile and Reynolds Number

- *Good velocity profiles can be developed*
  - *Straight run upstream and downstream*
    - *No fittings or valves*
    - *Upstream is usually longer and more important*
  - *Flow conditioner*
  - *Locate control valve downstream of flowmeter*

Fluid Flow Fundamentals

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- *Viscosity*
- *Reynolds Number and Velocity Profile*
- ***Hydraulic Phenomena***

Hydraulic Phenomena

- *Vapor pressure is defined as the pressure at which a liquid and its vapor can exist in equilibrium*
  - *The vapor pressure of water at 100°C is atmospheric pressure (1.01325 bar abs) because water and steam can coexist*

Hydraulic Phenomena

- *A saturated vapor is in equilibrium with its liquid at its vapor pressure*
  - *Saturated steam at atmospheric pressure is at a temperature of 100°C*

Hydraulic Phenomena

- *A superheated vapor is a saturated vapor that is at a higher temperature than its saturation temperature*
  - *Steam at atmospheric pressure that is at 150°C is a superheated vapor with 50°C of superheat*

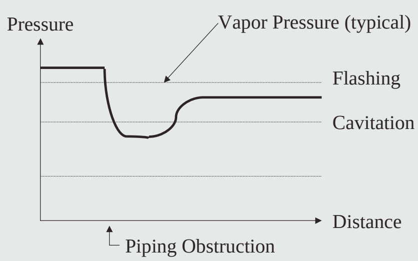
Hydraulic Phenomena

- *Flashing is the formation of gas (bubbles) in a liquid after the pressure of the liquid falls below its vapor pressure*
  - *Reducing the pressure of water at 100°C below atmospheric pressure (say 0.7 bar abs) will cause the water to boil*

Hydraulic Phenomena

- *Cavitation is the formation and subsequent collapse of gas (bubbles) in a liquid after the pressure of the liquid falls below and then rises above its vapor pressure*
  - *Can cause severe damage in pumps and valves*

Hydraulic Phenomena

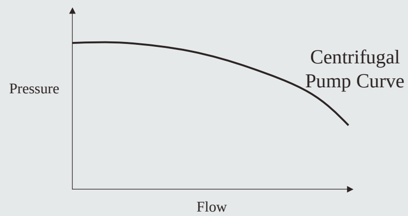


Hydraulic Phenomena

- *Energy Considerations*
  - *Claims are sometimes made that flowmeters with a lower pressure drop will save energy*

Hydraulic Phenomena

- *Energy Considerations*



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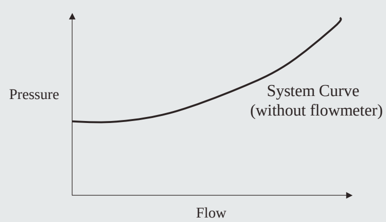
Hydraulic Phenomena

- *Energy Considerations*



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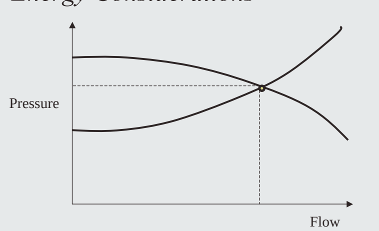
Hydraulic Phenomena

- *Energy Considerations*



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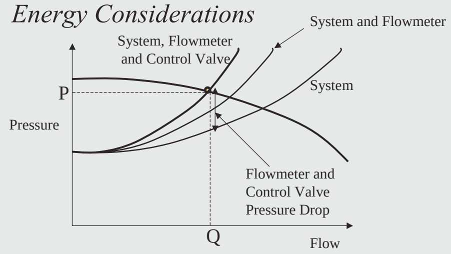
Hydraulic Phenomena

- *Energy Considerations*



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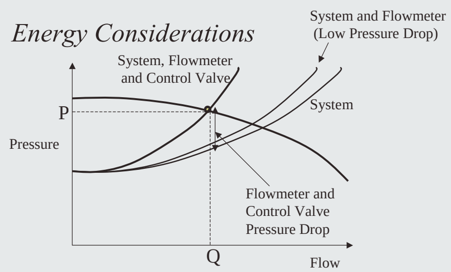
Hydraulic Phenomena

- *Energy Considerations*



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Hydraulic Phenomena

- *Energy Considerations*
  - *The pump operates at the same flow and pressure, so no energy savings are achieved by installing a flowmeter with a lower pressure drop*

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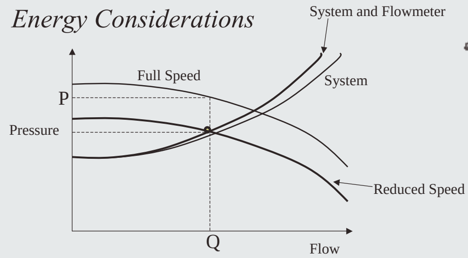
Hydraulic Phenomena

- *Energy Considerations*



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Hydraulic Phenomena

- *Energy Considerations*
  - *Operating the pump at a reduced speed generates the same flow but requires a lower pump discharge pressure*
    - *Hydraulic energy generated by the pump better matches the load*
    - *Energy savings are proportional to the cube of the speed*

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Seminar Outline

- *Introduction*
- *Fluid Flow Fundamentals*
- ***Flowmeter Technology***
- *Flowmeter Performance*
- *Consumer Guide*

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Ultrasonic Flowmeter Technology

- ***Principle of Operation***
- *Path Geometry*
- *Correlation Designs*
- *Flowmeter Designs*
- *Transmitter Designs*
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

Principle of Operation

- *Ultrasonic flowmeters direct ultrasonic energy into the flowing stream*
- *Information from the remnants of this energy is used to determine the velocity of fluid passing through the flowmeter*

Principle of Operation

- *Sensing the remnants is predicated upon a complete ultrasonic circuit*
  - *Transmitting device*
  - *Entry pipe wall (and liner)*
  - *Fluid (and reflections off pipe wall)*
  - *Exit pipe wall (and liner)*
  - *Receiving device*

Principle of Operation

- *To function properly, all parts of the ultrasonic circuit must allow sufficient energy to pass*

Principle of Operation

- *Weak signals may cause the flowmeter to be erratic or cease to function*
  - *Paint*
  - *Dry ultrasonic coupling compound*
  - *Pipe wall coating or corrosion*
  - *Poorly bonded liner*
  - *Tuberculation (barnacles)*

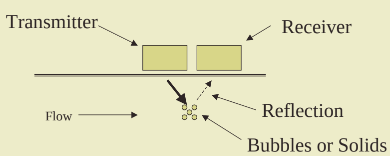
Principle of Operation

- *Ultrasonic noise may cause the flowmeter to be erratic or cease to function*
  - *Nearby radio transmitter*
  - *Control valve with "quiet" trim*

Principle of Operation Doppler Ultrasonic

- *Doppler ultrasonic flowmeters reflect ultrasonic energy from particles, bubbles and/or eddies flowing in the fluid*

Principle of Operation Doppler Ultrasonic



Principle of Operation Doppler Ultrasonic

- *Under no flow conditions, the frequencies of the ultrasonic beam and its reflection are the same*
- *With flow in the pipe, the difference between the frequency of the beam and its reflection increases proportional to fluid velocity*

Principle of Operation Doppler Ultrasonic

- *Doppler Equation*

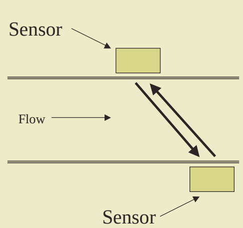
$$v_f = K \bullet \Delta f$$

  - *K = constant*
  - *v_f = velocity of fluid where ultrasonic energy is reflected*
  - *Δf = difference between the transmitted and reflected frequencies*

Principle of Operation Transit Time Ultrasonic

- *Transit time (time-of-flight) ultrasonic flowmeters alternately transmit ultrasonic energy into the fluid in the direction and against the direction of flow*

Principle of Operation Transit Time Ultrasonic

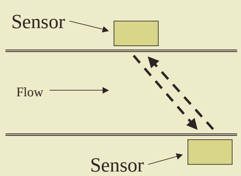


Principle of Operation Transit Time Ultrasonic

- *The time difference between ultrasonic energy moving upstream and downstream in the fluid is used to determine fluid velocity*

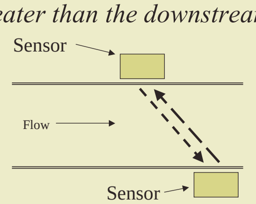
Principle of Operation Transit Time Ultrasonic

- *Under no flow conditions, the time for the ultrasonic energy to travel upstream and downstream are the same*



Principle of Operation Transit Time Ultrasonic

- *With flow in the pipe, the time for the ultrasonic energy to travel upstream will be greater than the downstream time*



Principle of Operation Transit Time Ultrasonic

- *Transit Time Equation*

$$v_p = \frac{K \bullet (T_u - T_d)}{T_u \bullet T_d}$$

  - v_p = *average fluid velocity in the path*
  - K = *constant*
  - T_u = *upstream transit time in fluid*
  - T_d = *downstream transit time in fluid*

Principle of Operation Transit Time Ultrasonic

- T_u *and* T_d *are dependent upon the speed of sound in the fluid*
- *Some designs use measurements and equations that are not dependent upon the speed of sound in the fluid*

Principle of Operation Pulse Repetition Ultrasonic

- *Pulse repetition (sing-around) ultrasonic flowmeters alternately transmit ultrasonic energy into the fluid in the direction and against the direction of flow*
- *The receipt of one ultrasonic pulse triggers the sending of a new ultrasonic pulse*

Principle of Operation Pulse Repetition Ultrasonic

- *The frequency that the pulses are repeated is used to determine fluid velocity*

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Principle of Operation Pulse Repetition Ultrasonic

- *Pulse Repetition Equation*

$$v_p = K \bullet (f_u - f_d)$$

  - v_p = *average fluid velocity in the path*
  - K = *constant*
  - f_u = *frequency of upstream transit time period*
  - f_d = *frequency of downstream transit time period*

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Principle of Operation Phase Shift Ultrasonic

- *Phase shift ultrasonic flowmeters measure the phase shift between two continuous cyclic ultrasonic signals traveling in the direction and against the direction of flow*

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Principle of Operation
Phase Shift Ultrasonic

- *Phase Shift Equation (constant frequency)*

$$v_p = \frac{K \bullet (\gamma_u - \gamma_d)}{\gamma_u \bullet \gamma_d}$$

  - v_p = *average fluid velocity in the path*
  - K = *constant*
  - γ_u = *upstream phase angle*
  - γ_d = *downstream phase angle*

Principle of Operation
Phase Shift Ultrasonic

- *Phase Shift Equation (varying frequency)*

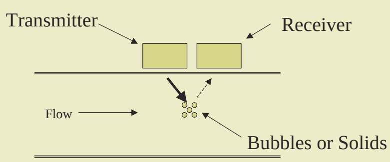
$$v_p = \frac{K \bullet (f_u - f_d)}{½ (f_u + f_d)}$$

  - v_p = *average fluid velocity in the path*
  - K = *constant*
  - f_u = *upstream frequency*
  - f_d = *downstream frequency*

Ultrasonic Flowmeter Technology

- *Principle of Operation*
- ***Path Geometry***
- *Correlation Designs*
- *Flowmeter Designs*
- *Transmitter Designs*
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

Doppler Path Geometry



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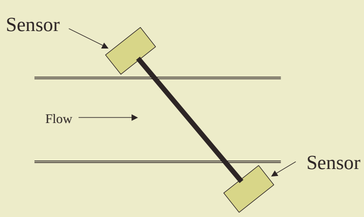
Single Path Geometry



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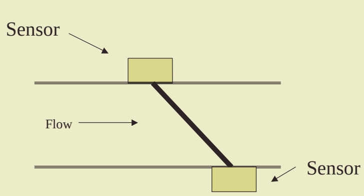
Single Path Geometry



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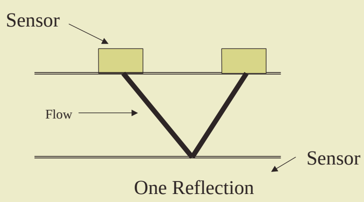
Single Path Geometry



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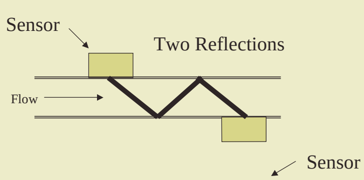
Single Path Geometry



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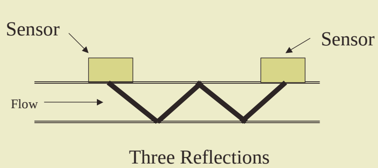
Single Path Geometry



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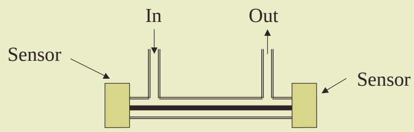
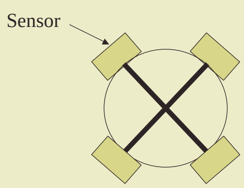
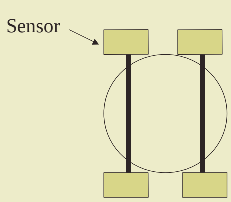
Single Path Geometry



Multiple Path Geometry



Chordal Path Geometry



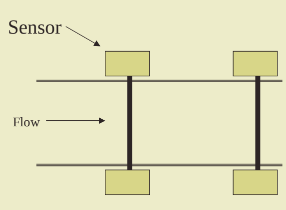
Ultrasonic Flowmeter Technology

- *Principle of Operation*
- *Path Geometry*
- ***Correlation Flowmeters***
- *Flowmeter Designs*
- *Transmitter Designs*
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

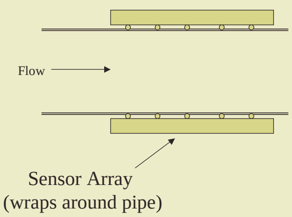
Correlation Flowmeters Principle of Operation

- *Correlation flowmeters determine fluid velocity by measuring parameters associated with the flowing stream at different places in the piping*

Correlation Flowmeters Ultrasonic



Correlation Flowmeters Pressure Sensor Array



Ultrasonic Flowmeter Technology

- *Principle of Operation*
- *Path Geometry*
- *Correlation Designs*
- ***Flowmeter Designs***
- *Transmitter Designs*
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

Ultrasonic Flowmeter Designs

- *Liquid*
  - *Portable and Handheld*
  - *Clamp-on*
  - *Spool*
  - *Probe (wetted)*
- *Gas, Stack Gas and Flare Gas*

Ultrasonic Flowmeter Designs

- *Non-wetted design allows installation without shutting down flow*
  - *Portable and Handheld*
  - *Clamp-on*
- *Wetted design requires shutdown*
  - *Spool*
  - *Clamp-on spool*
  - *Probe (wetted)*

Ultrasonic Flowmeter Technology

- *Principle of Operation*
- *Path Geometry*
- *Correlation Designs*
- *Flowmeter Designs*
- ***Transmitter Designs***
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

Ultrasonic Transmitter Designs

- *Analog*
  - *Electrical components subject to drift*
  - *Transit time more difficult to implement than Doppler*
  - *Mathematical corrections difficult*
  - *Four-wire design*

Ultrasonic Transmitter Designs

- *Digital*
  - *Microprocessor is less susceptible to drift*
  - *Transit time algorithms easier to implement*
  - *Mathematical corrections in software*
  - *Four-wire design*
  - *Remote communication (with HART)*

Ultrasonic Transmitter Designs

- *Fieldbus*
  - *Microprocessor is less susceptible to drift*
  - *Transit time algorithms easier to implement*
  - *Mathematical corrections in software*
  - *Multi-drop wiring*
  - *Remote communication*
  - *Issues with multiple protocols*

Ultrasonic Flowmeter Technology

- *Principle of Operation*
- *Path Geometry*
- *Correlation Designs*
- *Flowmeter Designs*
- *Transmitter Designs*
- ***Installation***
- *Accessories*
- *Other Flowmeter Technologies*

Installation

- *Fluid Characteristics*
- *Piping and Hydraulics*
- *Ultrasonic Continuity*
- *Electrical*
- *Ambient Conditions*
- *Setup Information*

Fluid Characteristics

- *Fluid must conduct ultrasonic energy*
  - *Water*
  - *Coal slurry*
  - *Low pressure gases (vacuum) can have few molecules*
- *Varying speed of sound in fluid*

Fluid Characteristics

- *Within accurate flow range*
- *Corrosion and erosion*
- *Gas in liquid stream*
- *Immiscible fluids*

Fluid Characteristics

- *Doppler*
  - *Typically requires 25-100 ppm of 25-100 micron bubbles or particles to reflect ultrasonic energy*
    - *Too many causes sensing at pipe wall*
    - *Too few may result in weak or non-representative reflection*

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Piping and Hydraulics

- *Keep flowmeter full of liquid*
  - *Hydraulic design*
    - *Vertical riser preferred*
    - *Avoid inverted U-tube*
  - *Be careful when flowing by gravity*

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Piping and Hydraulics

- *Maintain good velocity profile*
  - *Locate control valve downstream of flowmeter*
  - *Provide adequate straight run*
    - *Locate most straight run upstream*
    - *Install flow conditioner*
  - *Use full face gaskets*

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Piping and Hydraulics

- *Wetted parts compatible with fluid*
- *Pipe quality*
  - *Use smooth round pipe with known inside diameter, wall thickness, and material*
    - *Ultrasonic flowmeters measure velocity and infer volumetric flow assuming a known inside pipe diameter, wall thickness, and material*
  - *Spool design controls pipe quality*

Piping and Hydraulics

- *Path length*
  - *Internal coating*
    - *Shortens path*
    - *Weakens reflections*
  - *Corrosion and erosion*
    - *Lengthens path*
  - *Distance between clamp-on transit time sensors must be accurate*
  - *Speed of sound in pipe*

Piping and Hydraulics

- *Avoid piping configurations that could cause reflections of ultrasonic energy*
- *Avoid "low noise" valve trim*

Ultrasonic Continuity

- *Clamp-on*
  - *Clean sensor/pipe interface - grease, paint*
  - *Conductive pipe material*
  - *Lining bonded to pipe*
  - *Lining material conductive*
  - *Conductive fluid*
  - *Clean reflective surfaces (multi-traverse)*

Ultrasonic Continuity

- *Wetted sensors (probe)*
  - *Clean sensor/fluid interface*
  - *Conductive fluid*
  - *Clean reflective surfaces (multi-traverse)*

Electrical

- *Integral sensors reduce wiring cost*
- *Avoid areas of electrical noise*
  - *AM radio stations*
  - *Variable speed drives*
- *Wiring*
  - *Low voltage power supply can eliminate power conduit*
  - *Fieldbus reduces wiring*

Ambient Conditions

- *Outdoor applications (-20 to 60°C)*
  - *Many designs are for indoor locations*
- *Hazardous locations*
  - *Many designs are general purpose*

Setup Information

- *GIGO (garbage in – garbage out)*
- *Entering correct information correctly is critical*
  - *Dimensions*
  - *Materials of construction*
  - *Fluid properties*

Setup Information

- *Failure to use correct information can cause significant error and startup problems*

Setup Information

Problem

- *For a 6-inch pipe, what is the difference in diameter and area between schedule 40 and 80 pipe?*

Setup Information

- *Both pipes are 6-inch, but the schedule 40 and 80 diameters are 6.065 and 5.761 inches respectively.*
  - *The diameters differ by approximately 5%*
  - *The cross-sectional areas differ by approximately 9%*

Ultrasonic Flowmeter Technology

- *Principle of Operation*
- *Path Geometry*
- *Correlation Designs*
- *Flowmeter Designs*
- *Transmitter Designs*
- *Installation*
- ***Accessories***
- *Other Flowmeter Technologies*

Accessories

- *Sensors*
  - *NEMA 4, 6P, and IP65, 67, 68*

Accessories

- *Transmitter*
  - *NEMA 4X and IP65, 67*
  - *Analog output*
  - *Pulse output*
  - *Totalization and alarms*
  - *Data logging*
  - *HART, Foundation Fieldbus, Profibus*

Ultrasonic Flowmeter Technology

- *Principle of Operation*
- *Path Geometry*
- *Correlation Designs*
- *Flowmeter Designs*
- *Transmitter Designs*
- *Installation*
- *Accessories*
- ***Other Flowmeter Technologies***

Other Flowmeter Technologies

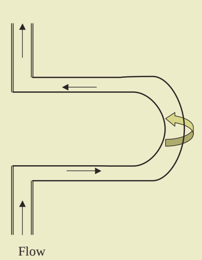
- *Coriolis Mass*
- *Differential Pressure*
- *Magnetic*
- *Positive Displacement*
- *Target*
- *Thermal*
- *Turbine*
- *Ultrasonic*
- *Vortex Shedding*

Insertion

Coriolis Mass Flowmeter

- *Coriolis mass flowmeters measure the force generated as the fluid moves towards/away from its center of rotation*

Coriolis Mass Flowmeter



Differential Pressure Flowmeter

- *A piping restriction is used to develop a pressure drop that is measured and used to infer fluid flow*
  - *Primary Flow Element*
  - *Transmitter (differential pressure)*

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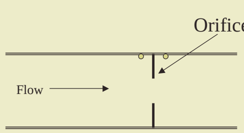
Orifice Plate
Primary Flow Element



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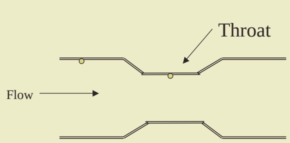
Venturi
Primary Flow Element



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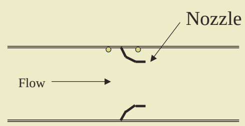
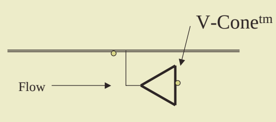
Flow Nozzle
Primary Flow Element



V-Cone^{tm}
Primary Flow Element



Differential Pressure Flowmeter

- *Pressure drop is proportional to the square of the fluid flow rate*
  - *Δp α Q^2 or Q α sqrt(Δp)*
  - *Double the flow… four times the differential*

Differential Pressure Flowmeter

- *Low flow measurement can be difficult*
  - *For example, only ¼ of the differential pressure is generated at 50 percent of the full scale flow rate. At 10 percent flow, the signal is only 1 percent of the differential pressure at full scale.*

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Magnetic Flowmeter

- *Fluid flow through a magnetic field generates a voltage at the electrodes that is proportional to fluid velocity*
  - *Primary Flow Element*
  - *Transmitter*

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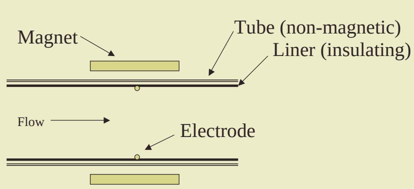
Magnetic Flowmeter



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Magnetic Flowmeter

- *Traditional AC excitation was susceptible to noise and drift*
  - *A low voltage signal is generated that is susceptible to noise and cross-talk at the excitation frequency*

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Magnetic Flowmeter

- *Pulsed DC excitation reduces drift by turning the magnet on and off*
  - *Noise (while the magnet is off) is subtracted from signal and noise (while the magnet is on) to reduce the effects of noise and cross-talk*
  - *Response time can be compromised*

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Positive Displacement Flowmeter

- *Positive displacement flowmeters measure flow by repeatedly entrapping fluid within the flowmeter*
  - *Moving parts with tight tolerances*
  - *Bearings*
  - *Many shapes*

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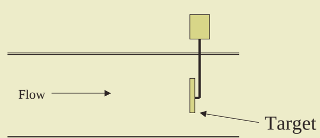
Target Flowmeter

- *Target flowmeters determine flow by measuring the force exerted on a body (target) suspended in the flow stream*

Target Flowmeter



Thermal Flowmeter

- *Thermal flowmeters use the thermal properties of the fluid to measure flow*
  - *Hot Wire Anemometer*
  - *Thermal Profile*

Thermal Flowmeter
Hot Wire Anemometer

- *Hot wire anemometers determine flow by measuring the amount of energy needed to heat a probe whose heat loss changes with flow rate*

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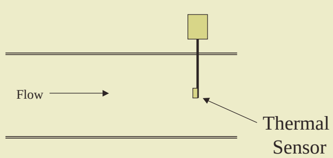
Thermal Flowmeter
Hot Wire Anemometer



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Thermal Flowmeter
Thermal Profile

- *Thermal profile flowmeters determine flow by measuring the temperature difference that results in a heated tube when the fluid transfers heat from the upstream portion to the downstream portion of the flowmeter*

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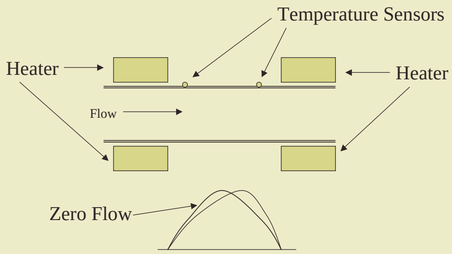
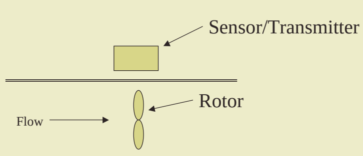
Thermal Flowmeter
Thermal Profile



Turbine Flowmeter

- *Fluid flow causes a rotor to spin whereby the rotor speed is proportional to fluid velocity*
  - *Primary Flow Element*
  - *Transmitter*

Turbine Flowmeter



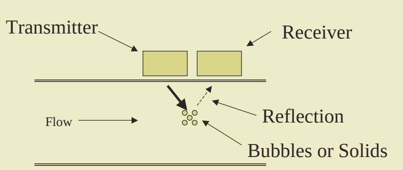
Turbine Flowmeter

- *The sensor detects the rotor blades*
- *The frequency of the rotor blades passing the sensor is proportional to fluid velocity*

Ultrasonic - Doppler

- *Doppler ultrasonic flowmeters reflect ultrasonic energy from particles, bubbles and/or eddies flowing in the fluid*

Ultrasonic - Doppler



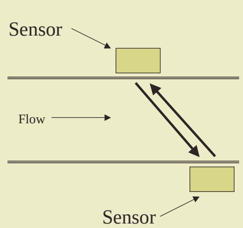
Ultrasonic - Doppler

- *Under no flow conditions, the frequencies of the ultrasonic beam and its reflection are the same*
- *With flow in the pipe, the difference between the frequency of the beam and its reflection increases proportional to fluid velocity*

Ultrasonic - Transit Time

- *Transit time (time-of-flight) ultrasonic flowmeters alternately transmit ultrasonic energy into the fluid in the direction and against the direction of flow*

Ultrasonic - Transit Time



Ultrasonic - Transit Time

- *The time difference between ultrasonic energy moving upstream and downstream in the fluid is used to determine fluid velocity*

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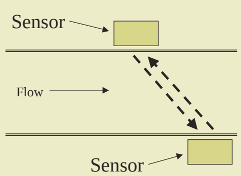
Ultrasonic - Transit Time

- *Under no flow conditions, the time for the ultrasonic energy to travel upstream and downstream are the same*



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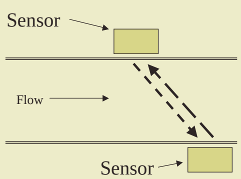
Ultrasonic - Transit Time

- *With flow in the pipe, the time for the ultrasonic energy to travel upstream will be greater than the downstream time*



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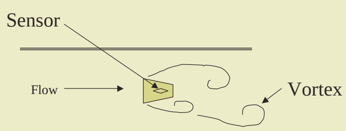
Vortex Shedding Flowmeter

- *A bluff body in the flow stream creates vortices whereby the number of vortices is proportional to the fluid velocity*
  - *Primary Flow Element*
  - *Transmitter*

Vortex Shedding Flowmeter



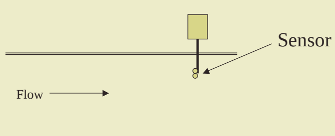
Vortex Shedding Flowmeter

- *The sensing system detects the vortices created*
- *The frequency of the vortices passing the sensing system is proportional to fluid velocity*

Insertion Flowmeter

- *Insertion flowmeter infer the flow in the entire pipe by measuring flow at one or more strategic locations in the pipe*
  - *Differential Pressure*
  - *Magnetic*
  - *Target*
  - *Thermal*
  - *Turbine*
  - *Vortex*

Insertion Flowmeter



Seminar Outline

- *Introduction*
- *Fluid Flow Fundamentals*
- *Flowmeter Technology*
- ***Flowmeter Performance***
- *Consumer Guide*

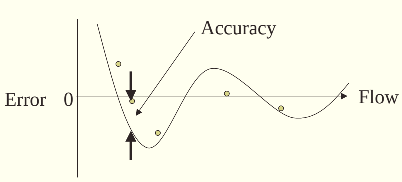
Flowmeter Performance

- ***Flowmeter Performance***
- *Performance Statements*
- *Reference Performance*
- *Pulse Output vs. Analog Output*
- *Actual Performance*
- *Supplier Claims*

Flowmeter Performance

- *Accuracy is the ability of the flowmeter to produce a measurement that corresponds to its characteristic curve*

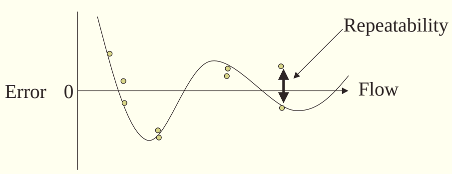
Flowmeter Performance



Flowmeter Performance

- *Repeatability is the ability of the flowmeter to reproduce a measurement each time a set of conditions is repeated*

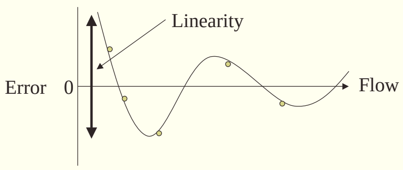
Flowmeter Performance



Flowmeter Performance

- *Linearity is the ability of the relationship between flow and flowmeter output (often called the characteristic curve or signature of the flowmeter) to approximate a linear relationship*

Flowmeter Performance



Flowmeter Performance

- *Flowmeter suppliers often specify the composite accuracy that represents the combined effects of repeatability, linearity and accuracy*

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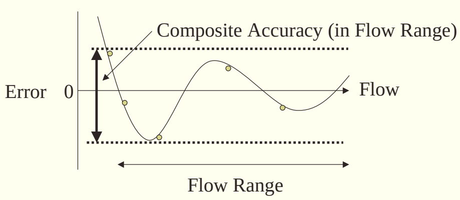
Flowmeter Performance



Flowmeter Performance

- *Flowmeter Performance*
- ***Performance Statements***
- *Reference Performance*
- *Pulse Output vs. Analog Output*
- *Actual Performance*
- *Supplier Claims*

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Performance Statements

- *Percent of rate*
- *Percent of full scale*
- *Percent of meter capacity (upper range limit)*
- *Percent of calibrated span*

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Performance Statements

- *1% of rate performance at different flow rates with a 0-100 unit flow range*
  - *100% flow → 0.01•100 1.00 unit*
  - *50% flow → 0.01•50 0.50 unit*
  - *25% flow → 0.01•25 0.25 unit*
  - *10% flow → 0.01•10 0.10 unit*

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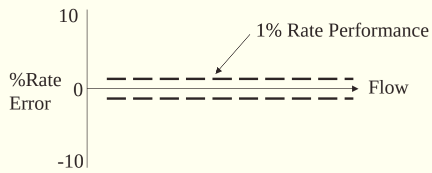
Performance Statements



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Performance Statements

- *1% of full scale performance at different flow rates with a 0-100 unit flow range*
  - *100% flow → 0.01•100 1 unit = 1% rate*
  - *50% flow → 0.01•100 1 unit = 2% rate*
  - *25% flow → 0.01•100 1 unit = 4% rate*
  - *10% flow → 0.01•100 1 unit = 10% rate*

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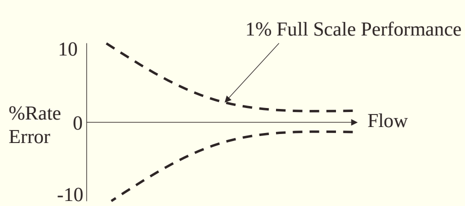
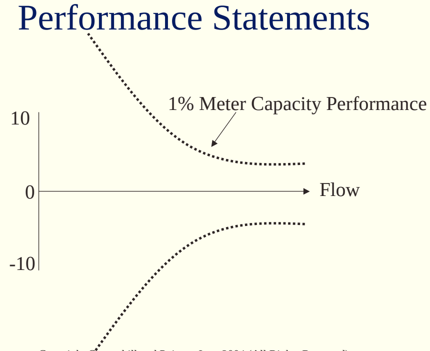
Performance Statements



Performance Statements

- *1% of meter capacity (or upper range limit) performance at different flow rates with a 0-100 unit flow range (URL=400)*
  - *100% flow → 0.01•400 4 units = 4% rate*
  - *50% flow → 0.01•400 4 units = 8% rate*
  - *25% flow → 0.01•400 4 units = 16% rate*
  - *10% flow → 0.01•400 4 units = 40% rate*

Performance Statements



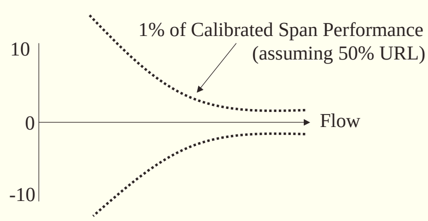
Performance Statements

- *Performance expressed as a percent of calibrated span is similar to full scale and meter capacity statements where the absolute error is a percentage of the calibrated span*

Performance Statements

- *1% of calibrated span performance at different flow rates with a 0-100 unit flow range (URL=400, calibrated span=200)*
  - *100% flow → 0.01•200   2 units = 2% rate*
  - *50% flow → 0.01•200   2 units = 4% rate*
  - *25% flow → 0.01•200   2 units = 8% rate*
  - *10% flow → 0.01•200   2 units = 20% rate*

Performance Statements



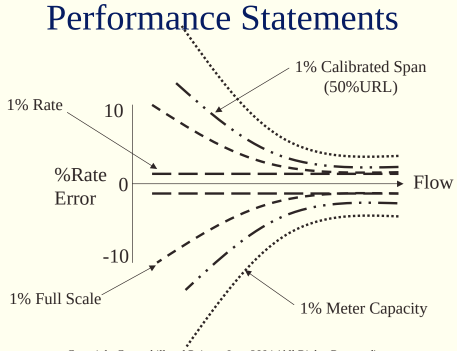
Performance Statements

- *A calibrated span statement becomes a full scale statement when the instrument is calibrated to full scale*
- *A calibrated span statement becomes a meter capacity statement when the instrument is calibrated at URL*

Performance Statements

- *Performance specified as a percent of rate, percent of full scale, percent of meter capacity, and percent of calibrated span are different*

Performance Statements



Performance Statements

- *Different and multiple performance statements may apply*
  - *0.05% full scale typical transmitter*
    0.10% full scale low range transmitter
  - *0.50% rate 50-100% full scale*
    0.25% full scale 10-50% full scale

Performance Statements

- *Performance statements apply over a range of operation*
- *Turndown is the ratio of the maximum flow that the flowmeter will measure within the stated accuracy to the minimum flow that can be measured within the stated accuracy*

Performance Statements

- *Performance statements can be manipulated because their meaning may not be clearly understood*
- *Technical assistance may be needed to analyze the statements*

Flowmeter Performance

- *Flowmeter Performance*
- *Performance Statements*
- ***Reference Performance***
- *Pulse Output vs. Analog Output*
- *Actual Performance*
- *Supplier Claims*

Reference Performance

- *Reference performance is the quality of measurement at a nominal set of operating conditions, such as:*
  - *Water at 20°C in ambient conditions of 20°C and 50 percent relative humidity*
  - *Long straight run*
  - *Pulse output*

Reference Performance

- *In the context of the industrial world, reference performance reflects performance under controlled laboratory conditions*

Reference Performance

- *Hypothetical flowmeter*
  - *1% rate 1-10 m/s*
  - *0.01 m/s 0.1-1 m/s*
  - *Undefined under 0.1 m/s*

Reference Performance

Example - Omission

- *Hypothetical flowmeter*
  - *1% rate 10-100% of flow*
  - *2% rate 5-10% of flow*
- *Percent of flow could be assumed to be percent of user's full scale*

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Reference Performance

Example - Omission

- *If full scale is not adjustable, the percent is a percent of meter capacity!*
  - *0-100 unit range with URL=400 units*
    - *1% rate 40-100 units*
    - *2% rate 20-40 units*

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Reference Performance

Example - Omission

- *Similarly, a percent of full scale statement could really be a percent of meter capacity statement*

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Reference Performance

Problem

- *If the full scale is not adjustable, what is the performance of a flowmeter with the following accuracy specifications?*
  - *1% full scale 10-100% flow*
  - *2%full scale 5-10% flow*

Reference Performance

Solution

- *Ultrasonic flowmeters can operate upwards of 20 m/s*
  - *Assume meter capacity is 20 m/s*
- *In typical applications, fluid velocity is below 3 m/s*
  - *Assume a user range of 0-2 m/s*

Reference Performance

Solution

- *The calculated accuracy is:*
  - *0.02*20 m/s 1-2 m/s*
    - *20% rate at 2 m/s*
    - *40% rate at 1 m/s*
  - *Undefined under 1 m/s*

Reference Performance

- *Rate statements at high velocity are often discussed*
- *Errors at lower velocity are often only mentioned with prompting*
  - *Progressive disclosure*

Flowmeter Performance

- *Flowmeter Performance*
- *Performance Statements*
- *Reference Performance*
- ***Pulse Output vs. Analog Output***
- *Actual Performance*
- *Supplier Claims*

Pulse Output vs. Analog Output

- *Most suppliers specify pulse output performance*
  - *Analog output performance is typically the pulse output performance plus an absolute error*

Pulse Output vs. Analog Output

Problem

- *What is the error associated with a 4-20mA analog output that has an error of 0.010 mA?*

Pulse Output vs. Analog Output

Solution

- *The conversion error is:*
  - *0.010/(20-4) = 0.06% of full scale*
- *Many flowmeters have analog output errors of 0.10% of full scale*

Pulse Output vs. Analog Output

Solution

Flow	*0.06% Full Scale*
100 units	*0.06*100/100 = 0.06% rate*
50 "	*0.06*100/50 = 0.12 "*
25 "	*0.06*100/25 = 0.24 "*
10 "	*0.06*100/10 = 0.60 "*

Pulse Output vs. Analog Output

Solution

Flow	0.10% Full Scale
100 units	0.10*100/100 = 0.10% rate
50 "	0.10*100/50 = 0.20 "
25 "	0.10*100/25 = 0.40 "
10 "	0.10*100/10 = 1.00 "

Pulse Output vs. Analog Output

- *Some suppliers cannot provide an analog output accuracy specification, so the performance of the analog output may be* ***undefined***

Pulse Output vs. Analog Output

- *In some flowmeter designs, the analog output error can be* ***larger*** *than the flowmeter accuracy*
  - *Often applies to flowmeters with percent of rate accuracy*
  - *Rate error increases at low flow rates*
  - *Others often include the analog output error in their pulse accuracy statement*

Pulse Output vs. Analog Output

- *Flowmeters with percent of full scale, meter capacity, and calibrated span often include the analog output error in their pulse accuracy statement*

Pulse Output vs. Analog Output

Example

- *An analog output error of 0.10% of full scale is usually neglected for a flowmeter that exhibits 1% of full scale performance.*

Flowmeter Performance

- *Flowmeter Performance*
- *Performance Statements*
- *Reference Performance*
- *Pulse Output vs. Analog Output*
- ***Actual Performance***
- *Supplier Claims*

Actual Performance

- *Operating Effects*
  - *Ambient conditions*
    - *Humidity*
    - *Precipitation*
    - *Temperature*
    - *Direct sunlight*

Actual Performance

- *Many flowmeters are rated to 10-90% relative humidity (non-condensing)*
  - *Outdoor locations are subject to 100% relative humidity and precipitation in various forms*

Actual Performance

- *Operating Effects*
  - *Can be significant, even though the numbers seem small*
  - *Not published by most suppliers*
    - *Information is not generally available to fairly evaluate actual performance*

Actual Performance

Example

- *The error (at 25 percent of scale and a 0°C ambient) associated with a temperature effect of 0.01% full scale per °C can be calculated as:*
  - *0.01*(20-0)/25, or 0.80% rate*

Actual Performance

- *Pipe Size vs. Path Length*
  - *Large pipe sizes increase path length and transit time*
    - *Ultrasonic energy can limit path length/size*
    - *Relatively accurate time measurement*

Actual Performance

- *Pipe Size vs. Path Length*
  - *Small pipe size decreases path length and transit time*
    - *Ultrasonic energy usually not a problem*
    - *Short path length decreases transit time and degrades time measurement (resolution issues)*

Actual Performance

- *Pipe Size vs. Path Length*
  - *To increase the path length and transit time, many small ultrasonic flowmeters:*
    - *use a U-shaped axial path*
    - *reflect the ultrasonic energy off the inside wall of the pipe (one or more times)*

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Actual Performance

- *Velocity Profile*
  - *Distorted velocity profile can affect performance*
    - *Provide adequate straight run*
    - *Locate most of the straight run upstream of the flowmeter*

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Actual Performance

- *Velocity Profile*
  - *Distorted velocity profile can affect performance*
    - *Install a flow conditioner*
    - *Increase the number of paths*
    - *Alter the path location (chordal)*

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Actual Performance

- *Pipe Diameter and Area*
  - *For ultrasonic flowmeters, reference performance describes the quality of the velocity measurement*

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Actual Performance

- *Pipe Diameter and Area*
  - *Flow measurement (volume) is inferred from velocity measurement assuming*
    - *Good pipe condition*
    - *Known pipe wall thickness and material*
    - *Known pipe diameter, wall thickness, and area*

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Actual Performance

- *Pipe Diameter and Area*
  - *Variations in the condition of the pipe can affect the area of flow, points of reflection, and path length*

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Actual Performance

- *Pipe Diameter and Area*
  - *Variations in the pipe wall thickness and material can affect the compensation for the time that the ultrasonic energy travels in the pipe wall*

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Actual Performance

- *Pipe Diameter and Area*
  - *Variations in the pipe diameter, wall thickness, and area affect the calculations used to infer a flow measurement (volume) from the velocity measurement*

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Actual Performance

- *Pipe Diameter and Area*
  - *Ultrasonic flowmeters assume that the pipe diameter and wall thickness is known*
  - *Pipe diameter and wall thickness is <u>not</u> known for existing pipe, unmeasured pipe, and spools that are not wet tested*

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Actual Performance

- *Fluid Properties*
  - *Reference accuracy is determined using a known fluid at known conditions*

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Actual Performance

- *Fluid Properties*
  - *Variation from reference conditions may require calibration correlations that can affect flowmeter performance*
    - *Different fluid composition*
    - *Different fluid temperature*

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Flowmeter Performance

- *Flowmeter Performance*
- *Performance Statements*
- *Reference Performance*
- *Analog Output vs. Pulse Output*
- *Actual Performance*
- ***Supplier Claims***

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Supplier Claims

- *High Turndown*
  - *Example - Hypothetical flowmeter*
    - *1% rate accuracy*
    - *1000:1 turndown*
  - *Sounds fantastic!*

Supplier Claims

- *High Turndown*
  - *Further investigation reveals*
    - *1% rate accuracy 0.5-10 m/s*
    - *0.005 m/s accuracy 0.01-0.5 m/s*
    - *Measures 0.01-10 m/s 1000:1 turndown*

Supplier Claims

- *High Turndown*
  - *Performance expressed as a percent of rate degrades below 0.5 m/s*
    - *5% rate 0.10 m/s*
    - *10% rate 0.05 m/s*
    - *50% rate 0.01 m/s*

Supplier Claims

- *Low Flow Operation*
  - *Flowmeter operates at low flows, but performance expressed as a percent of rate is degraded*
    - *5% rate 0.10 m/s*
    - *10% rate 0.05 m/s*
    - *50% rate 0.01 m/s*

Supplier Claims

- *High Accuracy*
  - *High accuracy claims often refer to high flow rates that may not be practical*
  - *Often disguised by omission*
    - *"0.25% accuracy" (omits rate, full scale, meter capacity, calibrated span)*

Supplier Claims

- *No Piping Obstructions*
  - *Most designs have no piping obstructions (especially clamp-on)*
  - *Some small designs are U-shaped*
  - *Wetted sensor designs can create a small void at the pipe wall*

Supplier Claims

- *Clamp-on and Measure Flow*
  - *Claims often include*
    - *No pressure drop*
    - *No moving parts*
    - *No wetted parts, so no problems with materials of construction*
    - *Universal applicability*

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Supplier Claims

- *Clamp-on and Measure Flow*
  - *Common problems*
    - *Ultrasonic path needs to be complete (pipe, liner, fluid…)*
    - *Pipe diameter, wall thickness, and area uncertainty*
    - *Uncertain condition of pipe*
    - *Velocity profile*

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Supplier Claims

- *Clamp-on and Measure Flow*
  - *Transit time problems*
    - *Some designs are affected by speed of sound in the fluid*
    - *Sensor positioning (path length)*
    - *Pipe coating*

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Supplier Claims

- *Clamp-on and Measure Flow*
  - *Doppler problems*
    - *Needs particles and bubbles within size and concentration limits (difficult to control)*
    - *Ultrasonic energy may penetrate too deep or not deep enough*

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Supplier Claims

- *Reynolds Number Compensation*
  - *Reynolds number effects can be as high as 20% rate at low Reynolds numbers*
  - *Claims include*
    - *Some ultrasonic flowmeters compensate for Reynolds number*

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Supplier Claims

- *Reynolds Number Compensation*
  - *Problems include*
    - *Compensation is dependent upon programmed or inferred fluid properties (viscosity, density, pipe size…)*

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Supplier Claims

- *Chordal Path*
  - *Claims include*
    - *More accurate measurement by avoiding the high centerline velocity*

Supplier Claims

- *Chordal Path*
  - *Claims include*
    - *Avoid inferring velocity profile from Reynolds number by determining the velocity profile from chordal and diametrical path measurements*

Supplier Claims

- *Speed of Sound in Fluid*
  - *Claims include*
    - *Some designs use equations that are not affected by variations in the speed of sound in the fluid*

Supplier Claims

- *Clamp-on Angle of Refraction*
  - *The angle of ultrasonic refraction at the interface between the pipe wall and the fluid varies with speed of sound in the fluid and affects the flow measurement*
  - *Claims include*
    - *Measurement of the speed of sound in the fluid can be used to compensate the flow measurement*

Supplier Claims

- *Dimensional Uncertainty*
  - *Claims include*
    - *Spool construction are superior to clamp-on designs because their geometry is known and can be wet tested*

Supplier Claims

- *Shear Mode vs. Axial Beam*
  - *Shear mode beams typically take the shape of a cylinder between the sensors*
  - *Axial mode beams travel downstream within the pipe wall continually releasing a wide coherent beam of ultrasonic energy into the fluid*

Supplier Claims

- *Shear Mode vs. Axial Beam*
  - *Claims include*
    - *Changing velocity causes shear beams to move relative to the receiving sensor and affect the measurement*
    - *Excessively high velocity could cause shear beams to miss the receiving sensor*

Supplier Claims

- *Shear Mode vs. Axial Beam*
  - *Claims include*
    - *Axial beams (that are wider) will not shift away from the sensor*
    - *Axial beams (that are coherent) generate a stronger signal that is less susceptible to blockage by vapors in liquid service and moisture in gas service*

Supplier Claims

- *Zero Drift Correction*
  - *Claims include*
    - *Comparison of axial beam transit time measurements in the fluid and in the pipe wall can be used to constantly correct for zero drift while the fluid is flowing*

Supplier Claims

- *Accurate Time Measurement*
  - *Claims include*
    - *Accurate time measurement results in better flow measurement, especially in smaller pipes and at low flow rates*

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Seminar Outline

- *Introduction*
- *Fluid Flow Fundamentals*
- *Flowmeter Technology*
- *Flowmeter Performance*
- ***Consumer Guide***

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Consumer Guide

User Equipment Selection Process

- *Learn about the technology*
- *Find suitable vendors*
- *Obtain specifications*
- *Organize specifications*
- *Evaluate specifications*
- *Select equipment*

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Consumer Guide

User Equipment Selection Process

- *Performing this process takes time and therefore costs money*

Consumer Guide

User Equipment Selection Process

- *Haphazard implementation with limited knowledge of alternatives does not necessarily lead to a good equipment selection*

Consumer Guide

Guide Provides First Four Items

- ***Learn about the technology***
- ***Find suitable vendors***
- ***Obtain specifications***
- ***Organize specifications***
- *Evaluate specifications*
- *Select equipment*

Consumer Guide

Guide Provides First Four Items

- ***Information focused on technology***
- ***Comprehensive lists of suppliers and equipment***

Consumer Guide

Guide Provides First Four Items

- ***Significant specifications***
- ***Lists of equipment organized to facilitate evaluation***

Consumer Guide

User Equipment Selection Process

- *By providing the first four items, the Consumer Guides:*
  - *make technical evaluation and equipment selection easier, more comprehensive, and more efficient*

Consumer Guide

User Equipment Selection Process

- *By providing the first four items, the Consumer Guides:*
  - *allow selection from a larger number of suppliers*
  - *simplifies the overall selection process*

Consumer Guide

- ***Supplier Data and Analysis***
- *Attachments*
  - *Flowmeter categories*
  - *Availability of selected features*
  - *Models grouped by performance*

Supplier Data and Analysis

- *Sensor Limits*
  - *Size*
    - *6-10,000+ mm*
  - *Ambient temperature*
    - *-20 to 60°C typical*
  - *Wetted parts*
    - *Clamp-on has no wetted parts*
  - *NEMA 4X, IP65, 67*

Supplier Data and Analysis

- *Process Operating Limits*
  - *Pressure limit*
    - *Clamp-on has no restrictions*
  - *Temperature limit*
    - *150°C typical; 600°C max*
  - *Composition*
    - *Clamp-on has no restrictions*

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Supplier Data and Analysis

- *Process Operating Limits*
  - *Doppler*
    - *25-100 ppm of 25-100 micron bubbles/suspended solids*
  - *Transit Time*
    - *5 to 50% bubbles by volume (depends on design)*
    - *Suspended solids*

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Supplier Data and Analysis

- *Sensor Installation/Maintenance*
  - *Velocity profile*
    - *10-15D/5D typical*
    - *Condition of inside pipe wall*

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Supplier Data and Analysis

- *Sensor Installation/Maintenance*
  - *Sensor replacement*
    - *Clamp-on*
    - *Probe (wetted)*

Supplier Data and Analysis

- *Sensor Installation/Maintenance*
  - *Ultrasonic path*
    - *Fluid conductivity*
    - *Quality of reflections (multi-traverse)*
    - *"Quiet" valve trim*

Supplier Data and Analysis

- *Sensor Installation/Maintenance*
  - *Ultrasonic path*
    - *Sensor corrosion/coating (wetted)*
    - *Sensor coating (wetted)*
    - *Sensor/pipe connection (clamp-on)*
      - *Grease/gel*
      - *RTV*
      - *Epoxy*

Supplier Data and Analysis

- *Transmitter*
  - *4-wire device (separate power/analog wires)*
    - *Using DC power can eliminate power conduit*
  - *Typically measure forward and reverse flow*
  - *Alarms, totalization, batching*
  - *Multivariable (speed of sound in fluid)*

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Supplier Data and Analysis

- *Transmitter*
  - *Mounting*
    - *Integral*
    - *Remote*
    - *Spacing (distance)*

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Supplier Data and Analysis

- *Transmitter*
  - *Filtering is typically used*
  - *Multiple paths and traverses improve performance*
    - *Signal processing is more complex*
    - *More ultrasonic energy needed*

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Supplier Data and Analysis

- *Transmitter*
  - *Many models to not allow adjustment of full scale*
  - *Range adjustment mechanism provide insight into age of design*
    - *Analog (potentiometer)*
    - *Dip switch*
    - *Digital*

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Supplier Data and Analysis

- *Performance*
  - *Typically specified in velocity (not flow)*
  - *Specifications are often not clear as to whether the stated accuracy is the*
    - *Reference accuracy*
    - *Theoretical accuracy*
    - *Calibratable accuracy*
    - *Typical installed accuracy*

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Supplier Data and Analysis

- *Performance*
  - *Often assumes known pipe dimensions and pipe conditions*
  - *Performance can vary*
    - *Unmeasured pipe section*
    - *Measured pipe section*
    - *Calibrated spool*

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Supplier Data and Analysis

- *Performance*
  - *Typically based on pulse output*
  - *Analog output accuracy*
    - *Add 0.01% full scale*
    - *Add 0.10% rate plus 0.10% full scale*
    - *Some suppliers could not quantify*

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Supplier Data and Analysis

- *Performance*
  - *It can be difficult to compare the performance of different suppliers' equipment*

 317

Supplier Data and Analysis

- *Operating Effects*
  - *Ambient*
    - *Temperature, humidity*
  - *Process conditions*
    - *Temperature, pressure, pipe material, composition*
    - *Speed of sound affects angle of refraction between pipe wall and fluid (clamp-on)*

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Supplier Data and Analysis

- *Operating Effects*
  - *It can be difficult to compare the operating effects of different suppliers' equipment*

Consumer Guide

- *Supplier Data and Analysis*
- ***Attachments***
  - *Flowmeter categories*
  - *Availability of selected features*
  - *Models grouped by performance*
  - *Models grouped by supplier*

Flowmeter Categories

- *Summary of offerings*
  - *Fluid*
  - *Type*
  - *Pipe Material*
  - *Handheld/portable*
  - *Manufacturing location/source*

Flowmeter Categories

- *Suppliers (74)*
- *Manufacturers (61)*
  - *23 USA*
  - *8 Germany*
  - *6 Japan*
  - *5 UK*
  - *4 France, Russia*

Availability of Selected Features

- *Approvals*
  - *Nuclear feed water*
  - *Custody transfer*
  - *CEMS*

Availability of Selected Features

- *Transmitter*
  - *Hazardous locations*
  - *Integral, remote*
  - *Housing (NEMA/IP rating)*
  - *Data logging*

Availability of Selected Features

- *Sensors*
  - *Clamp-on*
  - *Hot tap*
  - *Removable*
  - *Internal*
  - *Housing (NEMA/IP rating)*
  - *Maximum temperature*

325

Availability of Selected Features

- *Communications*
  - *HART*
  - *Foundation Fieldbus*
  - *Profibus*

326

Models Grouped by Performance

- *Liquid*
  - *Portable and Handheld*
  - *Clamp-on*
  - *Spool*
  - *Probe (wetted)*
- *Gas, Stack Gas, Flare Gas*

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Models Grouped by Supplier

- *Alphabetical listing by supplier*

Review and Questions

- *Introduction*
- *Fluid Flow Fundamentals*
- *Flowmeter Technology*
- *Flowmeter Performance*
- *Consumer Guide*

The Consumer Guide to Ultrasonic Flowmeters

Seminar Presented by
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