The Consumer Guide to Differential Pressure Flow Transmitters

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*

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Fluid Flow Fundamentals

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

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Temperature

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

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Temperature

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

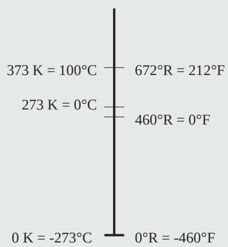
Temperature

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

Temperature

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

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*

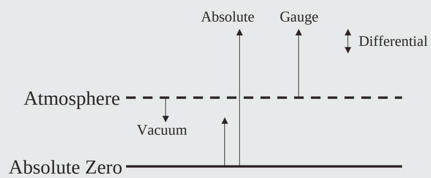
Pressure

- *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)*

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*

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*
- *Inside Pipe Diameter*
- *Viscosity*
- *Reynolds Number and Velocity Profile*
- *Hydraulic Phenomena*

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•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*
  - *$V = V_0 (1 + \beta \cdot \Delta T)$*
    - *where $\beta = 3 \cdot \alpha$*
    - *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 <u>absolute</u> 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*
  - $V = K \cdot T$

Density and Fluid Expansion

- *New volume can be calculated*
  - $V = K \cdot T$
  - $V_0 = K \cdot T_0$
- *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*
  - $V/V_0 = (P_0/P) \bullet (T / T_0)$

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?*

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%*

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*

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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)*

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Types of Flow

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

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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

- *Temperature*
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- ***Inside Pipe Diameter***
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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

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

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

- *Temperature*
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- *Viscosity*
- ***Reynolds Number and Velocity Profile***
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Velocity Profile and Reynolds Number

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

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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

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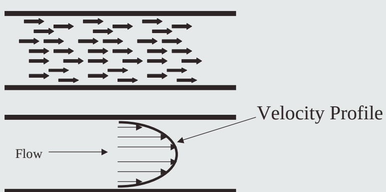
Velocity Profile and Reynolds Number

- *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*

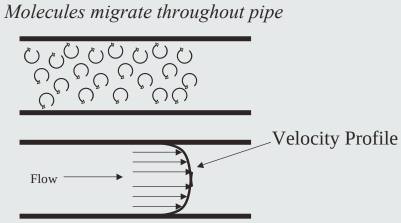
Velocity Profile and Reynolds Number

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



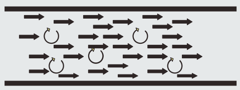
Velocity Profile and Reynolds Number

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



Velocity Profile and Reynolds Number

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



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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*

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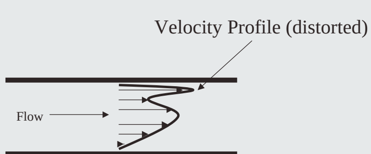
Velocity Profile and Reynolds Number

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



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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

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

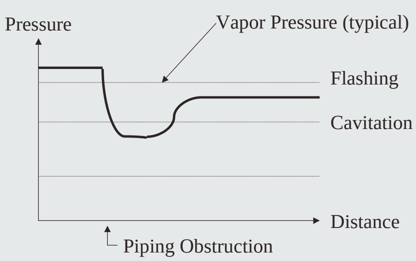
Hydraulic Phenomena

- *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

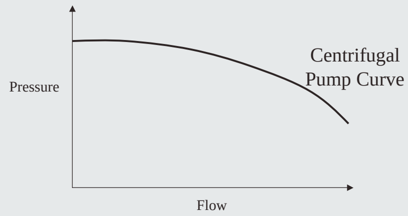


Hydraulic Phenomena

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

Hydraulic Phenomena

- *Energy Considerations*



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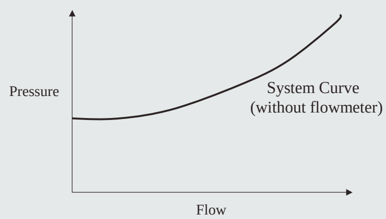
Hydraulic Phenomena

- *Energy Considerations*



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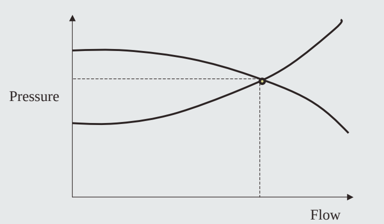
Hydraulic Phenomena

- *Energy Considerations*



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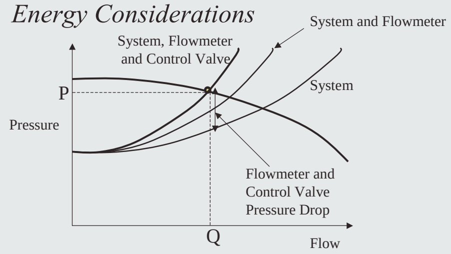
Hydraulic Phenomena

- *Energy Considerations*



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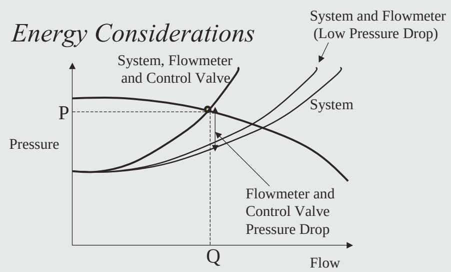
Hydraulic Phenomena

- *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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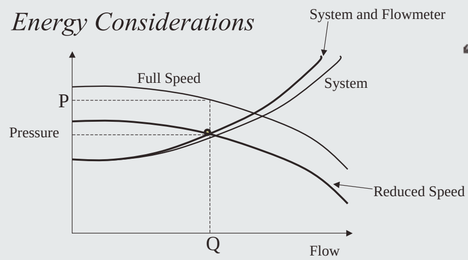
Hydraulic Phenomena

- *Energy Considerations*



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*

Seminar Outline

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

Differential Pressure Flowmeter Technology

- ***Principle of Operation***
- *Primary Flow Elements*
- *Transmitter Designs*
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

Principle of Operation

- *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)*

Principle of Operation

- *Bernoulli's equation states that energy is approximately conserved across a constriction in a pipe*
  - *Static energy (pressure head)*
  - *Kinetic energy (velocity head)*
  - *Potential energy (elevation head)*

Principle of Operation

- *Bernoulli's equation*
  - *$P/(\rho \bullet g) + \frac{1}{2}v^2/g + y = \text{constant}$*

P = absolute pressure
ρ = density
g = acceleration of gravity
v = fluid velocity
y = elevation

Principle of Operation

- *Equation of Continuity*
  - *$Q = A \bullet v$*

Q = flow (volumetric)
A = cross-sectional area
v = fluid velocity (average)

Principle of Operation

- *Apply the equation of continuity and Bernoulli's equation for flow in a horizontal pipe*
  - *Acceleration of gravity is constant*
  - *No elevation change*

Principle of Operation

- *Apply Bernoulli's equation upstream and downstream of a restriction*
- $P_1 + ½\ \rho \bullet v_1^2 = P_2 + ½\ \rho \bullet v_2^2$

Principle of Operation

- *Solve for the pressure difference and use the equation of continuity*
- $(P_1 - P_2) = ½\ \rho \bullet v_2^2 - ½\ \rho \bullet v_1^2$

  $= ½\ \rho\ [v_2^2 - v_1^2]$

  $= ½\ \rho\ [(A_1/A_2)^2 – 1] \bullet v_1^2$

  $= ½\ \rho\ [(A_1/A_2)^2 – 1] \bullet Q^2/A_1^2$

  $= constant \bullet \rho \bullet Q^2$

Principle of Operation

- $\Delta P = constant \bullet \rho \bullet Q^2$
  - *Fluid density affects the measurement*
  - *Pressure drop is proportional to the square of the flow rate*
    - *Squared output flowmeter*
    - *Double the flow… four times the differential*

Principle of Operation

- *Q = constant • $(\Delta P/\rho)^{1/2}$*
  - *Fluid density affects the measurement*
  - *Flow rate is proportional to the square root of the differential pressure produced*
    - *Often called "square root flowmeter"*

Principle of Operation

- *Q is proportional to $1/\rho^{1/2}$*
- *Fluid density affects the measurement by approximately -1/2% per % density change*

Principle of Operation

- *Liquid density changes are usually small*
- *Gas and vapor density changes can be large and may need compensation for accurate flow measurement*
  - *Flow computers*
  - *Multivariable differential pressure transmitters*

Principle of Operation

Problem

- *What is the effect on a differential pressure flowmeter when the operating pressure of a gas is increased from 6 to 7 bar?*
  - *To simplify calculations, assume that atmospheric pressure is 1 bar abs*

Principle of Operation

- *The ratio of the densities is (7+1)/(6+1) = 1.14*
  - *The density of the gas increased 14 percent*
- *The flow measurement is proportional to the inverse of the square root of the density which is $(1/1.14)^{1/2} = 0.94$*
  - *The flow measurement will be approximately 6 percent low*

Principle of Operation

Problem

- *Calculate the differential pressures produced at various percentages of full scale flow*
  - *Assume 0-100% flow corresponds to 0-100 differential pressure units*

Principle of Operation

Differential pressure as a function of flow

Flow	*ΔP*	
100 %	*100*	*dp units*
50 %	*25*	*" "*
20 %	*4*	*" "*
10 %	*1*	*" "*

Principle of Operation

- *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.*

Principle of Operation

Problem

- *What is the differential pressure turndown for a 10:1 flow range?*
  - *$0.1^2 = 0.01$, so at 10% flow the differential pressure is 1/100 of the differential pressure at 100% flow*
  - *The differential pressure turndown is 100:1*

Principle of Operation

- *Noise can create problems at low flow rates*
  - *0-10% flow corresponds to 0-1 dp units*
  - *90-100% flow corresponds to 81-100% dp units*

Principle of Operation

- *Noise at low flow rates can be reduced by low flow characterization*
  - *Force to zero*
  - *Linear relationship at low flow rates*

Principle of Operation

- *Square root relationship generally applies when operating above the Reynolds number constraint for the primary flow element*
  - *Operating below the constraint causes the flow equation to become linear with differential pressure (and viscosity)*
  - *Applying the incorrect equation will result in flow measurement error*

Principle of Operation

Problem

- *If the Reynolds number at 100% flow is 10,000, what is the turndown for accurate measurement if the primary flow element must operate in the turbulent flow regime?*
  - *10,000/4000, or 2.5:1*

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Principle of Operation

Problem

- *Will the flowmeter operate at 10% flow?*
  - *It will create a differential pressure… however, Reynolds number will be below the constraint, so the flow measurement will not conform to the square root equation (and will not be accurate)*

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Differential Pressure Flowmeter Technology

- *Principle of Operation*
- ***Primary Flow Elements***
- *Transmitter Designs*
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

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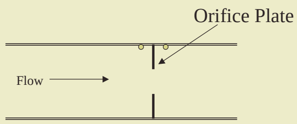
Orifice Plate
Primary Flow Element



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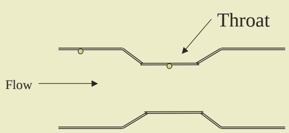
Venturi
Primary Flow Element



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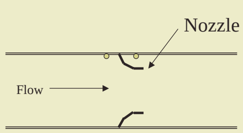
Flow Nozzle
Primary Flow Element



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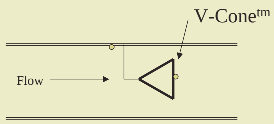
V-Cone^{tm} Primary Flow Element



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Differential Pressure Flowmeter Technology

- *Principle of Operation*
- *Primary Flow Elements*
- ***Transmitter Designs***
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

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Differential Pressure Sensor Designs

- *Capacitance*
- *Differential Transformer*
- *Force Balance*
- *Piezoelectric*
- *Potentiometer*
- *Silicon Resonance*
- *Strain Gage*

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Differential Pressure Transmitter Designs

- *Analog*
  - *Electrical components subject to drift*
    - *Ambient temperature*
    - *Process temperature*
  - *Two-wire design*

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Differential Pressure Transmitter Designs

- *Digital*
  - *Microprocessor is less susceptible to drift*
    - *Ambient temperature*
    - *Process temperature*
    - *Temperature characterization in software*
  - *Remote communication (with HART)*
  - *Two-wire design*

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Differential Pressure Transmitter Designs

- *Fieldbus*
  - *Microprocessor is less susceptible to drift*
    - *Ambient temperature*
    - *Process temperature*
    - *Temperature characterization in software*
  - *Remote communication*
  - *Issues with multiple protocols*
  - *Multi-drop wiring*

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Differential Pressure Transmitter Designs

- *Mechanical design*
  - *Spacing between connections*
    - *Orifice flange taps*
  - *Traditional*
    - *Larger diaphragm/housing*
  - *Coplanar*
    - *Smaller diaphragm/housing*

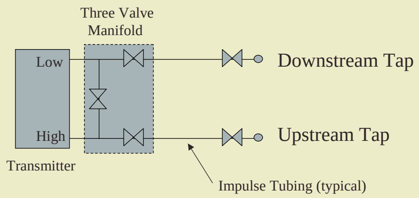
Differential Pressure Transmitter Designs

- *High static pressure design*
  - *Typically lower performance*
- *Safety design*
  - *Automatic diagnostics*
  - *Redundancy*
  - *Reliable components*

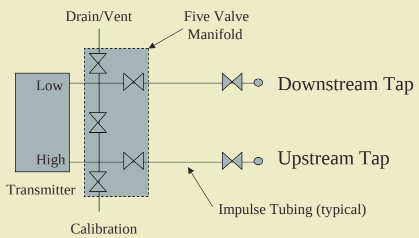
Differential Pressure Multi-Valve Manifold Designs

- *Multi-valve manifolds are used to isolate the transmitter from service for maintenance and calibration*
  - *One-piece integral assembly*
  - *Mounted on transmitter*

Differential Pressure Multi-Valve Manifold Designs



Differential Pressure Multi-Valve Manifold Designs



Differential Pressure Multi-Valve Manifold Designs

- *Removal from service*
  - *Open bypass valve (hydraulic jumper)*
  - *Close block valves*
  - *Be sure to close bypass valve to calibrate*
  - *Use calibration and vent/drain valves (five valve manifold)*

Differential Pressure Multi-Valve Manifold Designs

- *Return to service*
  - *Open bypass valve (hydraulic jumper)*
  - *Open block valves*
  - *Close bypass valve*

Differential Pressure Multi-Valve Manifold Designs

- *Removal and return to service procedure may be different when flow of fluid in tubing/transmitter is dangerous*
  - *High pressure superheated steam*

Differential Pressure Flowmeter Technology

- *Principle of Operation*
- *Primary Flow Elements*
- *Transmitter Designs*
- ***Installation***
- *Accessories*
- *Other Flowmeter Technologies*

Principle of Operation

- *The quality of measurement is predicated on:*
  - *Proper installation of the primary flow element*
  - *Proper operation of the primary flow element (for example, Reynolds number)*
  - *Accurate measurement of the differential pressure*

Installation

- *Fluid Characteristics*
- *Piping and Hydraulics*
- *Impulse Tubing*
- *Electrical*
- *Ambient Conditions*
- *Calibration*

Fluid Characteristics

- *Reynolds number within constraints*
- *Fluid must not plug impulse tubing*
  - *Solids*
  - *Purge fluids*
  - *Diaphragm seals (added measurement error)*

Fluid Characteristics

- *Within accurate flow range*
- *Corrosion and erosion*
  - *Flowmeter*
  - *Exotic (thin) diaphragm materials*
- *Coating*
- *Gas in liquid stream*
- *Immiscible fluids*

Piping and Hydraulics

- *For liquids, keep flowmeter full*
  - *Hydraulic design*
    - *Vertical riser preferred*
    - *Avoid inverted U-tube*
  - *Be careful when flowing by gravity*

Piping and Hydraulics

- *For gases, avoid accumulation of liquid*
  - *Hydraulic design*
    - *Vertical riser preferred*
    - *Avoid U-tube*

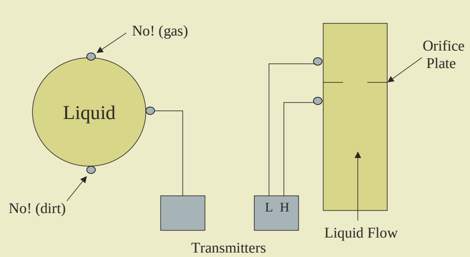
Piping and Hydraulics

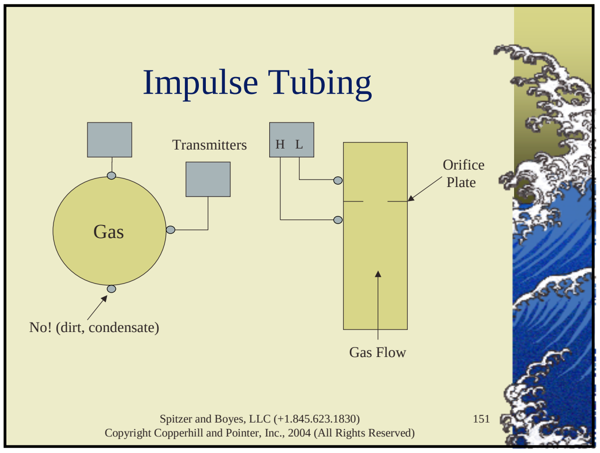
- *Maintain good velocity profile*
  - *Locate control valve downstream of flowmeter*
  - *Provide adequate straight run*
    - *Locate most straight run upstream*
    - *Install flow conditioner*
  - *Use full face gaskets*

Piping and Hydraulics

- *Wetted parts compatible with fluid*
- *Pipe quality*
  - *Use smooth round pipe with known inside diameter, wall thickness, and material*
  - *Purchasing the flowmeter and piping section controls pipe quality*

Impulse Tubing




Impulse Tubing
Transmitters
H L
Orifice Plate
Gas
No! (dirt, condensate)
Gas Flow
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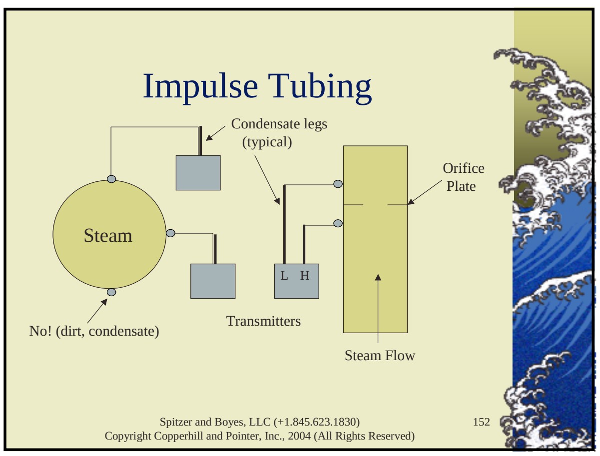
Impulse Tubing
Condensate legs (typical)
Orifice Plate
Steam
L H
No! (dirt, condensate)
Transmitters
Steam Flow
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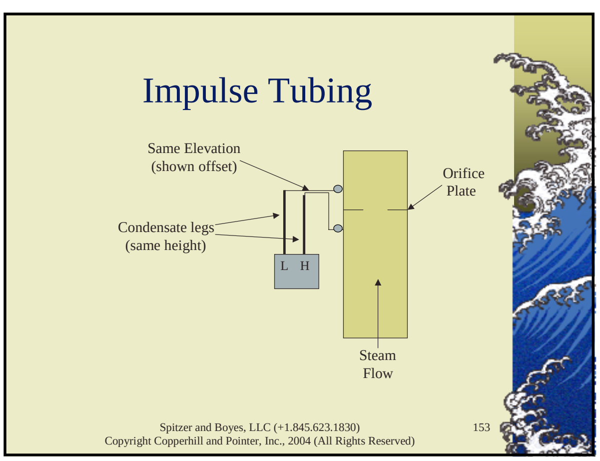
Impulse Tubing
Same Elevation (shown offset)
Orifice Plate
Condensate legs (same height)
L H
Steam Flow
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Impulse Tubing

- *Liquids* — *avoid collection of gas*
- *Gas* — *avoid collection of liquid*
- *Vapor* — *form condensate legs*
- *Hot* — *locate transmitter far from taps*
- *Cold* — *insulate and/or heat trace*

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Electrical

- *Wiring*
  - *Two-wire design (no power conduit)*
  - *Fieldbus reduces wiring*
- *Avoid areas of electrical noise*
  - *Radios*
  - *High voltages*
  - *Variable speed drives*

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Ambient Conditions

- *Outdoor applications (-40 to 80°C)*
  - *Avoid direct sunlight (especially low ranges)*
  - *Support transmitter well*
- *Hazardous locations*
  - *Some designs may be general purpose*

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Calibration

- *GIGO (garbage in – garbage out)*
- *Entering correct information correctly is critical*
  - *Calibration range*

Calibration

- *Internal alignment (digital transmitters)*
  - *Pressure source*
  - *Digital indication in transmitter*
  - *Digital output indication in transmitter*
  - *Analog signal*

Calibration

- *Zero in field*
  - *Position effects*
  - *Pressure effects*

Differential Pressure Flowmeter Technology

- *Principle of Operation*
- *Primary Flow Elements*
- *Transmitter Designs*
- *Installation*
- ***Accessories***
- *Other Flowmeter Technologies*

Accessories

- *Wetted parts*
  - *Diaphragm (thin)*
  - *Flanges*
  - *Drain/vent valves*
  - *Materials*
    - *Stainless steel, Monel, Hastelloy, tantalum*
  - *O-rings/gaskets (TFE, Viton^{tm})*

Accessories

- *Non-wetted parts*
  - *Fill fluids*
    - *Silicone, halocarbon*
  - *External housing*

Accessories

- *Transmitter*
  - *NEMA 4X and IP67 (IP68)*
  - *Hazardous locations*
  - *Intrinsically safe*
  - *HART, Foundation Fieldbus, Profibus*
  - *Mounting bracket*

Differential Pressure Flowmeter Technology

- *Principle of Operation*
- *Primary Flow Elements*
- *Transmitter Designs*
- *Installation*
- *Accessories*
- ***Other Flowmeter Technologies***

Other Flowmeter Technologies

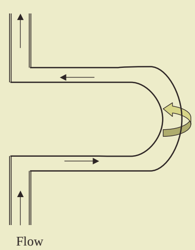
- *Coriolis Mass*
- *Differential Pressure*
- *Magnetic*
- *Positive Displacement*
- *Target*
- *Thermal*
- *Turbine*
- *Ultrasonic*
- *Vortex Shedding*

Insertion

Coriolis Mass Flowmeter

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

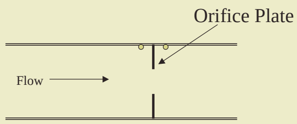
Coriolis Mass Flowmeter



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)*

Orifice Plate Primary Flow Element



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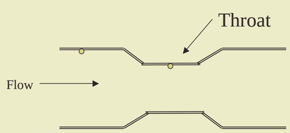
Venturi Primary Flow Element



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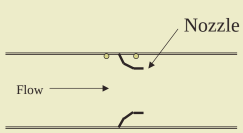
Flow Nozzle Primary Flow Element



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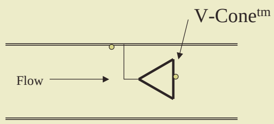
V-Cone^{tm} Primary Flow Element



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Differential Pressure Flowmeter

- *Pressure drop is proportional to the square of the fluid flow rate*
  - *$\Delta p \propto Q^2$ or $Q \propto sqrt(\Delta p)$*
  - *Double the flow… four times the differential*

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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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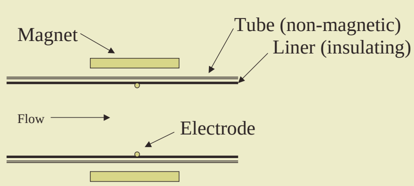
Magnetic Flowmeter

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

Magnetic Flowmeter



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*

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*

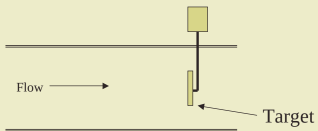
Positive Displacement Flowmeter

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

Target Flowmeter

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

Target Flowmeter



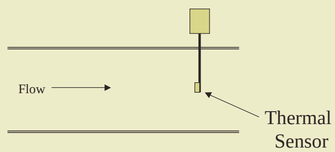
Thermal Flowmeter

- *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*

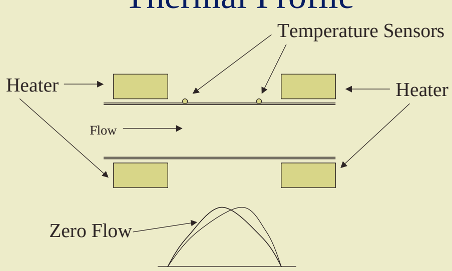
Thermal Flowmeter
Hot Wire Anemometer



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*

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*

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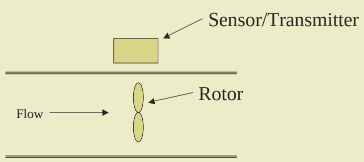
Turbine Flowmeter



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Turbine Flowmeter

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

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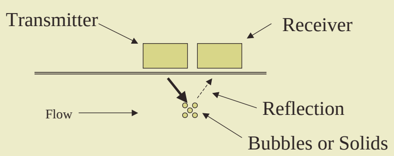
Ultrasonic - Doppler

- *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*

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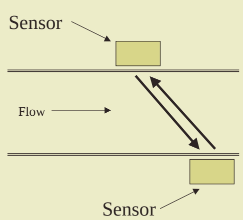
Ultrasonic - Transit Time



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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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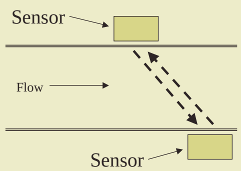
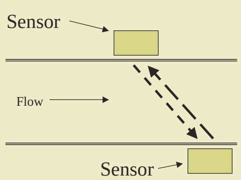
Ultrasonic - Transit Time

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



Ultrasonic - Transit Time

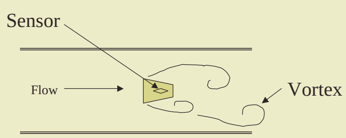
- *With flow in the pipe, the time for the ultrasonic energy to travel upstream will be greater than the downstream time*



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



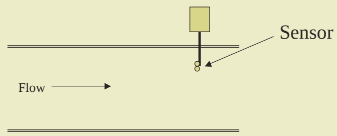
Vortex Shedding Flowmeter

- *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



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Seminar Outline

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

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Flowmeter Performance

- ***Flowmeter Performance***
- *Performance Statements*
- *Reference Performance*
- *Actual Performance*
- *Supplier Claims*

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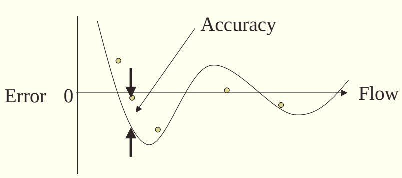
Flowmeter Performance

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

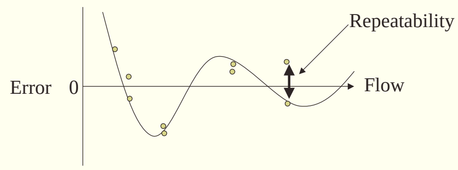
Flowmeter Performance



Flowmeter Performance

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

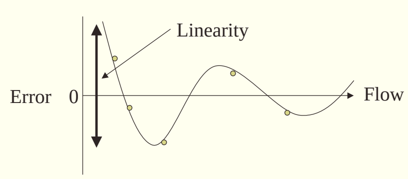
Flowmeter Performance



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*

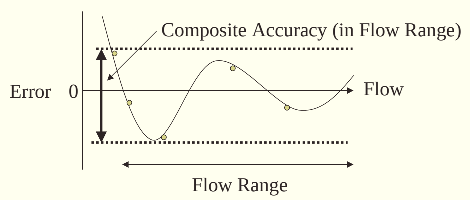
Flowmeter Performance



Flowmeter Performance

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

Flowmeter Performance



Flowmeter Performance

- *Flowmeter Performance*
- ***Performance Statements***
- *Reference Performance*
- *Actual Performance*
- *Supplier Claims*

Performance Statements

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

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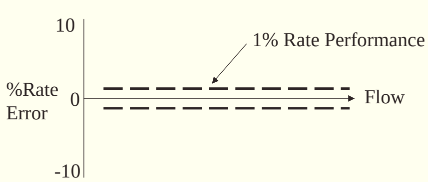
Performance Statements

- *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*

 215

Performance Statements

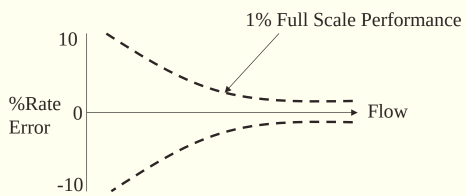


 216

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*

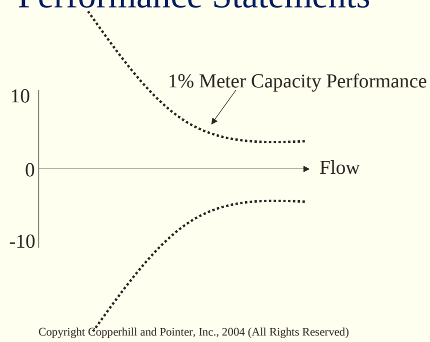
Performance Statements



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



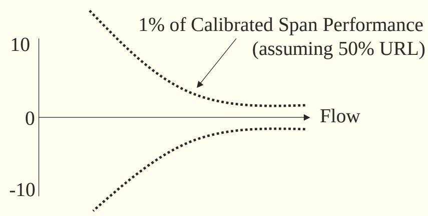
Performance Statements

- *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



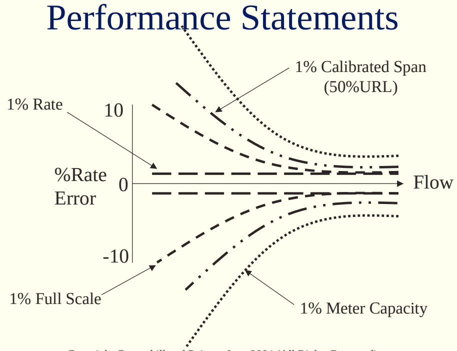
Performance Statements

- *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***
- *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

- *Performance of the primary flow element and the transmitter must be taken into account to determine performance of flowmeter system*

Reference Performance

- *Hypothetical primary flow element*
  - *1% rate* $R_d > 4000$ *and Q>10% FS*
  - *Otherwise undefined*
  - *Assumes correct design, construction, installation, calibration, and operation*

Reference Performance

- *Hypothetical differential pressure transmitter*
  - *0.10% calibrated span*
    - *Calibrated for 0-100 units*
    - *Factory calibrated at upper range limit (URL) of 400 units*

Reference Performance

Problem

- *What is the measurement error associated with the performance of the hypothetical differential pressure transmitter?*

Reference Performance

- *The calibrated span is 400, so the differential pressure measurement error is 0.10% of 400, or 0.4 units at all differential pressures*

Reference Performance

Problem

- *What is the flow measurement error associated with the performance of the hypothetical differential pressure transmitter?*

Reference Performance

Flow	*Diff. Pressure*	*Flow Measurement Error*
100	*100*	$1-\sqrt{(100\pm0.4)/100}$ *or 0.2 %rate*
50	*25*	$1-\sqrt{(25\pm0.4)/25}$ *or 0.8 “*
25	*6.25*	$1-\sqrt{(6.25\pm0.4)/6.25}$ *or 3.2 “*
10	*1.00*	$1-\sqrt{(1.00\pm0.4)/1.00}$ *or 18-23 “*

Reference Performance

Problem

- *What is the flow measurement error associated with the performance of the flow measurement system (primary flow element and differential pressure transmitter)?*

Reference Performance

- *System performance is the statistical combination of the errors associated with the components (primary flow element and transmitter)*
  - *System performance is not the mathematical sum of the individual errors*

Flowmeter Performance

- *Flowmeter Performance*
- *Performance Statements*
- *Reference Performance*
- ***Actual Performance***
- *Supplier Claims*

Actual Performance

- *Operating Effects*
  - *Ambient conditions*
    - *Humidity*
    - *Precipitation*
    - *Temperature*
    - *Pressure*
    - *Direct sunlight*
  - *Mounting Orientation*
  - *Stability (Drift)*

Actual Performance

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

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Actual Performance

- *Ambient Temperature and Pressure*
  - *Information available to evaluate actual performance*
    - *Temperature effect*
    - *Pressure effect*
  - *Effects can be significant, even though the numbers seem small*

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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*

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Actual Performance

- *Reference accuracy performance statements are often discussed*
- *Operating effects, such as temperature and pressure effects are often only mentioned with prompting*
  - *Progressive disclosure*

Actual Performance

- *Ambient Direct Sunlight*
  - *Can cause temporary calibration shift*
    - *Low range transmitters*

Actual Performance

- *Mounting Orientation*
  - *Bench calibration vs. field calibration*
    - *Up to 5 mbar (2 inch WC) shift*

Actual Performance

- *Stability*
  - *Drift over time*
    - *Usually faster at beginning of period*
  - *Specifications difficult to compare*
    - *Different ways over different periods of time*

Actual Performance

- *Combining Operating Effects*

$$\text{Estimated Error} = \sqrt{error_1^2 + error_2^2 + error_3^2 + \ldots}$$

where the errors in like units

Flowmeter Performance

- *Flowmeter Performance*
- *Performance Statements*
- *Reference Performance*
- *Actual Performance*
- ***Supplier Claims***

Supplier Claims

- *High Rangedown*
  - *Rangedown is the ratio of the maximum to minimum full scale ranges to which the differential pressure transmitter can be calibrated*
  - *Sometimes called turndown*

Supplier Claims

Example

- *The rangedown a differential pressure transmitter that can be calibrated from 0-12.5 mbar to 0-1000 mbar is:*
  - *1000/12.5, or 80:1*

Supplier Claims

- *The accuracy for these ranges is:*
  - *0-12.5 mbar 0.425% of set span*
  - *0-1000 mbar 0.075% of set span*

Supplier Claims

- *0-1000 mbar (0.075% of set span)*

Flow	*Differential Pressure*	*Error*	*Flow Error*
100%	*1000 mbar*	*0.75 mbar*	*0.04% rate*
50%	*250 mbar*	*0.75 mbar*	*0.15% rate*
20%	*40 mbar*	*0.75 mbar*	*0.94% rate*

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Supplier Claims

- *0-12.5 mbar (0.425% of set span)*

Flow	*Differential Pressure*	*Error*	*Flow Error*
100%	*12.500 mbar*	*0.53 mbar*	*2.14% rate*
50%	*3.125 mbar*	*0.53 mbar*	*8.87% rate*
20%	*0.500 mbar*	*0.53 mbar*	*undefined*

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Supplier Claims

- *High Turndown*
  - *Turndown is the ratio of the maximum to minimum differential pressures that the differential pressure transmitter can measure within the stated accuracy*

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Supplier Claims

- *0-400 mbar (0.075% of set span)*

Flow	*Differential Pressure*	*Error*	*Flow Error*
100%	*400 mbar*	*0.3 mbar*	*0.04% rate*
50%	*100 mbar*	*0.3 mbar*	*0.15% rate*
20%	*16 mbar*	*0.3 mbar*	*0.94% rate*
10%	*4 mbar*	*0.3 mbar*	*3.82% rate*

Supplier Claims

- *High Accuracy*
  - *High accuracy claims often refer to high flow rates at reference conditions and imply high accuracy at all flow rates*

Supplier Claims

- *0-400 mbar (0.075% of set span)*

Flow	*Differential Pressure*	*Error*	*Flow Error*
100%	*400 mbar*	*0.3 mbar*	*0.04% rate*
50%	*100 mbar*	*0.3 mbar*	*0.15% rate*
20%	*16 mbar*	*0.3 mbar*	*0.94% rate*
10%	*4 mbar*	*0.3 mbar*	*3.82% rate*

Supplier Claims

- *High Accuracy*
  - *Often disguised by omission*
    - *"0.075% accuracy" (omits rate, full scale, meter capacity, calibrated span)*
  - *Reducing full scale can degrade accuracy of some transmitters*

Supplier Claims

- *High Accuracy*
  - *Accuracy generally does not take operating effects into account*
    - *Temperature effect*
    - *Pressure effect*
    - *Other effects*
      - *Humidity, precipitation, sunlight, stability*

Supplier Claims

- *Reduced Calibration*
  - *Improved stability (drift) specifications*
    - *Operating effects can be larger than stability*

Seminar Outline

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

Consumer Guide

User Equipment Selection Process

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

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*

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Supplier Data and Analysis

- *Ambient Limits*
  - *Temperature (-20 to 80°C typical)*
  - *Humidity, precipitation*
  - *NEMA 4X, IP67 (IP68 available)*
  - *Hazardous locations*
    - *Non-incendive, explosion-proof, intrinsically safe*

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Supplier Data and Analysis

- *Process Operating Limits*
  - *Pressure limit*
  - *Temperature limit (100-149°C)*
  - *Composition*
    - *Limited by materials of construction*

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Supplier Data and Analysis

- *Materials of Construction*
  - *Wetted parts and materials similar for most major suppliers*
    - *Specials (e.g., gold diaphragm for hydrogen)*
  - *Some designs have O-rings/gaskets*

Supplier Data and Analysis

- *Transmitter*
  - *Two-wire loop powered device*
    - *HART, Fieldbus*
  - *Alarms, totalization*
  - *Multivariable*

Supplier Data and Analysis

- *Reference Performance*
  - *Reference accuracy usually includes the effects of linearity, hysteresis, and repeatability*
  - *Performance may be degraded at smaller spans*

Supplier Data and Analysis

- *Operating Effects*
  - *Ambient Temperature*
    - *Assume 25°C for calculations*
  - *Process Pressure*
    - *Assume 7 bar for calculations*
  - *Transmitter Stability*
    - *Assume 12 months (1 year)*

Supplier Data and Analysis

- *Operating Effects*
  - *Power Supply*
    - *Typically 0.005% span per volt*
    - *Neglected in calculations*
  - *Mounting position effect*
    - *Neglected in calculations*
  - *Humidity, precipitation*
    - *Neglected in calculations*

Consumer Guide

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

Availability of Selected Features

- *Suppliers (12 major manufacturers) with factories in:*
  - *9 USA*
  - *5 China*
  - *4 Japan*
  - *3 Germany*
  - *1 Brazil, France, India, Italy,Singapore*

Availability of Selected Features

- *Approvals*
  - *Hazardous Locations*
  - *Safety*
  - *Housing (NEMA/IP rating)*

Availability of Selected Features

- *Ambient and wetted part temperature limits*
  - *Ambient may be derated in high ambient temperatures*

Availability of Selected Features

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

Review and Questions

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

The Consumer Guide to Differential Pressure Flow Transmitters

Seminar Presented by
David W. Spitzer
Spitzer and Boyes, LLC