The Consumer Guide to Vortex Shedding and Fluidic 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)*

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Temperature

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

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Temperature

- *Absolute temperature is important for flow measurement*

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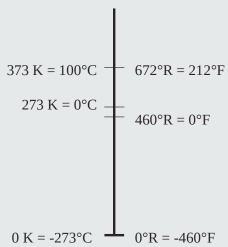
Temperature



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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*

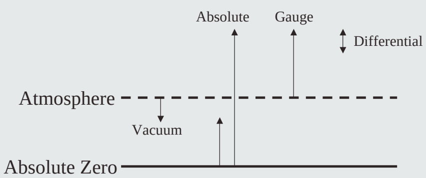
Pressure

- *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



Pressure

- *Absolute pressure is important for flow measurement*

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?*

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*

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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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Density and Fluid Expansion

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

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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*

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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 ?*

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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*

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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*
  - $V = K / P$

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Density and Fluid Expansion

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

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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?*

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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?*

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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%*

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Density and Fluid Expansion

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

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Density and Fluid Expansion

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

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*
  - $V/V_0 = 0.895 \cdot 0.965 = 0.864$
  - $V = 0.864\ V_0$
  - *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 inside 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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Velocity Profile and Reynolds Number

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

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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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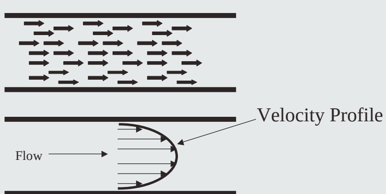
Velocity Profile and Reynolds Number

- *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*

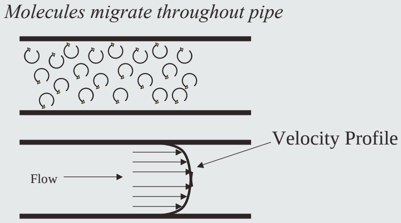
Velocity Profile and Reynolds Number

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



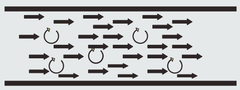
Velocity Profile and Reynolds Number

- *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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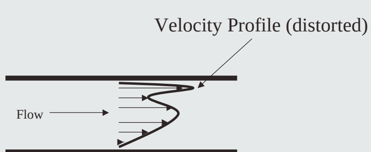
Velocity Profile and Reynolds Number

- *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*

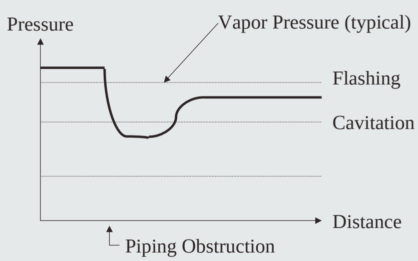
Hydraulic Phenomena

- *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

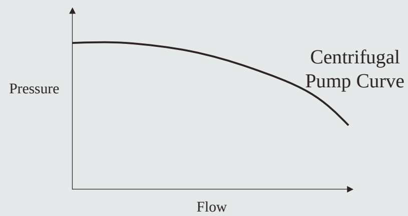


Hydraulic Phenomena

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

Hydraulic Phenomena

- *Energy Considerations*



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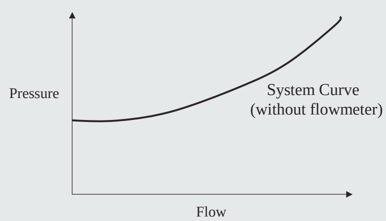
Hydraulic Phenomena

- *Energy Considerations*



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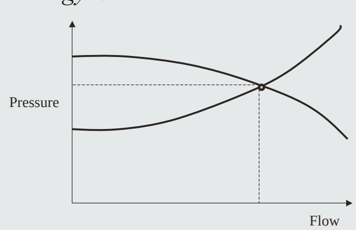
Hydraulic Phenomena

- *Energy Considerations*



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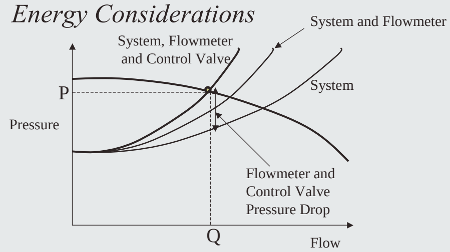
Hydraulic Phenomena

- *Energy Considerations*



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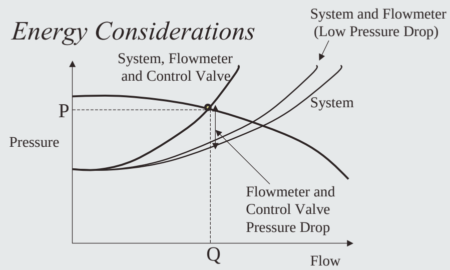
Hydraulic Phenomena

- *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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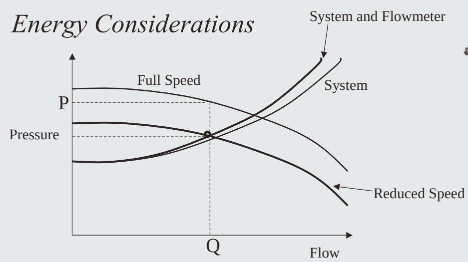
Hydraulic Phenomena

- *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*

Vortex Shedding and Fluidic Flowmeter Technology

- ***Principle of Operation***
- *Vortex Shedder Sensing Systems*
- *Flowmeter Designs*
- *Transmitter Designs*
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

Principle of Operation

- *Fluidic flowmeters are flowmeters that generate oscillations as a result of flow*
  - *The number of oscillations can be related to the flow rate*

Principle of Operation

- *Examples of fluidic phenomena*
  - *Wind whistling through branches of trees*
  - *Swirls downstream of a rock in a flowing stream*
  - *Flag waving in breeze*

Principle of Operation

- *Fluidic flowmeters*
  - *Fluidic flowmeter (Coanda effect)*
  - *Vortex precession flowmeter (swirl)*
  - *Vortex shedding flowmeter*

Coanda Effect Fluidic Flowmeter

- *Coanda Effect*
  - *Flow tends to attach itself to flat surface*
- *Fluidic oscillator*
  - *Passages allow portion of flow to feed back and impinge on incoming stream*
  - *Alternating attachment*

Coanda Effect Fluidic Flowmeter

- *Frequency of alternating attachments is proportional to flow*
  - *Doubling the flow doubles the number of attachments*

Coanda Effect Fluidic Flowmeter

- *Reynolds number constraints*
  - *Over 500*

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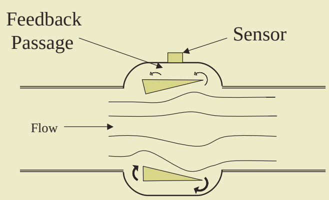
Coanda Effect Fluidic Flowmeter



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Coanda Effect Fluidic Flowmeter

- *Sensors*
  - *Deflection*
  - *Thermal*

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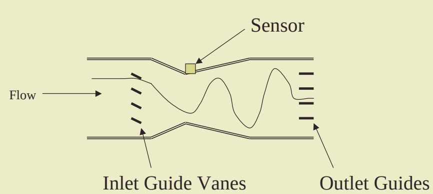
Vortex Precession Flowmeter

- *Often called a "swirlmeter"*
- *Inlet vanes cause the flow to spin and form a cyclone*
- *The tip of the cyclone moves around the inside pipe wall (precession)*
- *Outlet vanes remove swirl from the flow*

Vortex Precession Flowmeter

- *Speed that vortex rotates around the pipe is proportional to flow*
  - *Doubling the flow doubles the precession*

Vortex Precession Flowmeter



Vortex Precession Flowmeter

- *Sensors*
  - *Piezoelectric*

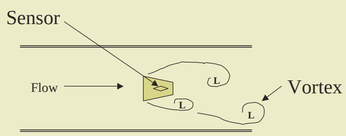
Vortex Shedding Flowmeter

- *An obstruction (bluff body or strut) is located in the flow stream*
  - *Low flow - fluid flows around obstruction*
  - *High flow - alternating vortices are formed*
    - *Number of vortices formed is proportional to fluid velocity*

Vortex Shedding Flowmeter

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

Vortex Shedding Flowmeter



Vortex Shedding Flowmeter

- *Bluff body is typically approximately 20% of the pipe ID*
  - *Pressure drop across similar vortex shedders in the same service is similar*
    - *For liquids: 5 psid at 15 ft/sec*
      400 mbar at 5 m/s

Vortex Shedding Flowmeter

Problem

- *What is the approximate pressure drop across a vortex shedder at 7.5 ft/sec?*

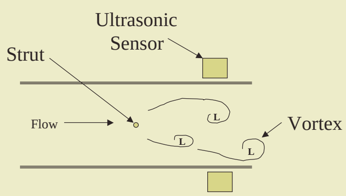
Vortex Shedding Flowmeter

- *(5 • 7.5/15) = 2.5 psig might be tempting, but in the turbulent flow regime, the pressure drop across a restriction varies as the square of the flow*
  - *Double the flow, four times the differential*
  - *The pressure drop will be 5 • $(7.5/15)^2$ = 1.25 psig approximately*

Vortex Shedding Flowmeter

- *Strut design is like a "piano wire"*
  - *Gas flow measurement*
  - *Low pressure drop*

Vortex Shedding Flowmeter



Vortex Shedding and Fluidic Flowmeter Technology

- *Principle of Operation*
- ***Vortex Shedder Sensing Systems***
- *Flowmeter Designs*
- *Transmitter Designs*
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

Vortex Shedding Flowmeter Sensing Systems

- *Shedder and sensing system tradeoffs are made in the design process to:*
  - *operate linearly*
  - *operate at low velocity*
  - *operate at low Reynolds numbers*

Vortex Shedding Flowmeter Sensing Systems

- *Shedder and sensing system tradeoffs are made in the design process to:*
  - *reduce the effect of short straight run*
  - *reduce the effects of misalignment*
  - *reduce the effects of vibration*

Vortex Shedding Flowmeter Sensing Systems

- *Shedder and sensing system tradeoffs are made in the design process to:*
  - *reduce the possibility of leaks*
    - *All-welded body designs*

Vortex Shedding Flowmeter Sensing Systems

- *Hydraulic energy to operate the sensing system is usually provided by the fluid*
  - *Flowmeter turns off at low velocity*

Vortex Shedding Flowmeter Sensing Systems

- *Velocity constraint is a function of density*
  - *Lower density increases low velocity limit*
  - *Higher density decreases low velocity limit*

Vortex Shedding Flowmeter Sensing Systems

- *Typical Velocity Constraints*
  - *Water* — *0.35 m/s* — *1 ft/sec*
  - *Free air* — *6.5 m/s* — *21 ft/sec*
  - *Air (8 bar)* — *3.5 m/s* — *11.5 ft/sec*

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Vortex Shedding Flowmeter Sensing Systems

- *Reynolds Number Constraint*
- *Sufficient Reynolds number is needed to generate oscillations*
  - *Flowmeter turns off at low Reynolds numbers*

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Vortex Shedding Flowmeter Sensing Systems

- *Reynolds number constraints*
  - *Linear operation* — *over 10-30,000*
  - *Turn off* — *3-10,000*
  - *Nonlinear* — *between turn off / linear*
  - *Small sizes*
    - *Lower Reynolds number limits*

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Vortex Shedding Flowmeter Sensing Systems

- *Both Reynolds number and velocity constraints must be satisfied for vortex shedding flowmeters to operate*

Vortex Shedding Flowmeter Sensing Systems

Problem

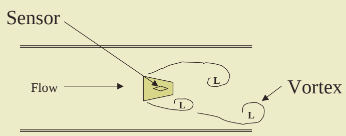
- *Will a vortex shedding flowmeter measure the flow of a liquid operating at a Reynolds number of 1,000,000 at a velocity of 0.1 m/s?*
  - *No --- the velocity is below the minimum velocity constraint*

Vortex Shedding Flowmeter Sensing Systems

Problem

- *Will a vortex shedding flowmeter measure the flow of a liquid operating at a Reynolds number of 100 at a velocity of 10 m/s?*
  - *No --- the velocity is below the minimum Reynolds number constraint*

Vortex Shedding Sensor Deflection



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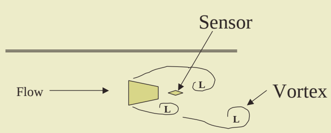
Vortex Shedding Sensor Deflection



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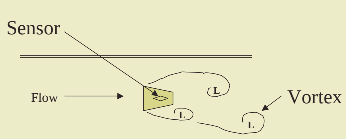
Vortex Shedding Sensor Differential Pressure



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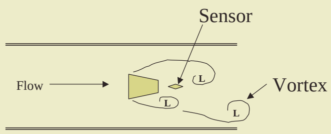
Vortex Shedding Sensor Differential Pressure



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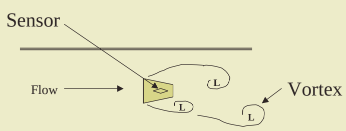
Vortex Shedding Sensor Shedder Twist



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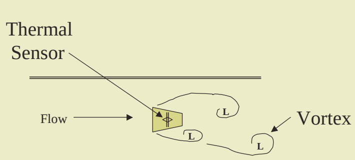
Vortex Shedding Sensor Thermal



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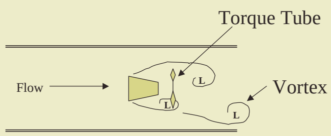
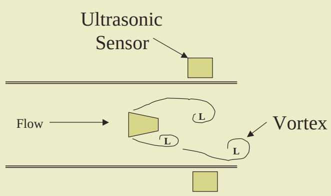
Vortex Shedding Sensor Torque Tube



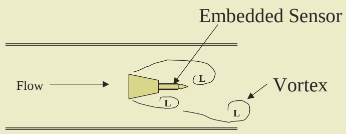
Vortex Shedding Sensor Ultrasonic



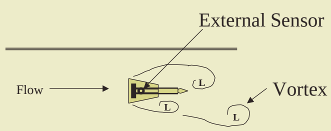
Vortex Shedding Flowmeter Sensing Systems

- *Vibration effects*
- *Acceleration compensation*
  - *Fishtail design with embedded sensor*
  - *Fishtail design with counterbalancing*
  - *Torque tube design*
  - *Shedder twist design*

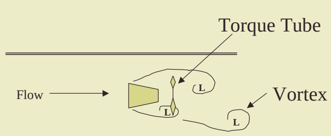
Vortex Shedding Sensor Fishtail Design



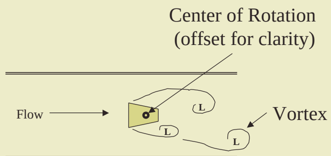
Vortex Shedding Sensor Fishtail Design



Vortex Shedding Sensor Torque Tube



Vortex Shedding Sensor Shedder Twist



Vortex Shedding Flowmeter Sensing Systems

- *Early designs were not balanced*
- *Subsequent designs were balanced*
- *No mass designs (such as thermal and ultrasonic) do not have to be acceleration compensated*

Vortex Shedding Sensor Multivariable

- *Embedded temperature sensors*
- *Embedded flow computer*
  - *Pressure and temperature compensation*
  - *Reynolds number compensation*

Vortex Shedding and Fluidic Flowmeter Technology

- *Principle of Operation*
- *Vortex Shedder Sensing Systems*
- ***Flowmeter Designs***
- *Transmitter Designs*
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

Vortex Shedding and Fluidic Flowmeter Designs

- *Liquid*
- *Gas*
- *Steam*
- *All-welded*
- *Low Flow*
- *High Flow*
- *Metal (other than CS / SS)*

Plastic/Polymer
Sanitary
Two-wire

Vortex Shedding and Fluidic Flowmeter Technology

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Vortex Shedding Transmitter Designs

- *Analog*
  - *Electrical components subject to drift*
  - *Analog filtering and damping*
    - *Mathematical algorithms difficult to implement*
  - *Two-wire design*

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Vortex Shedding Transmitter Designs

- *Digital*
  - *Microprocessor is less susceptible to drift*
  - *Digital filtering*
    - *Sophisticated mathematical algorithms*
  - *Two-wire design*
  - *Remote communication (with HART)*

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Vortex Shedding Transmitter Designs

- *Fieldbus*
  - *Microprocessor is less susceptible to drift*
  - *Digital filtering*
    - *Sophisticated mathematical algorithms*
  - *Multi-drop wiring*
  - *Remote communication*
  - *Issues with multiple protocols*

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Vortex Shedding and Fluidic Flowmeter Technology

- *Principle of Operation*
- *Vortex Shedder Sensing Systems*
- *Flowmeter Designs*
- *Transmitter Designs*
- ***Installation***
- *Accessories*
- *Other Flowmeter Technologies*

Installation

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

Fluid Characteristics

- *Single phase*
  - *Liquid*
  - *Gas*
  - *Vapor*
- *Relatively clean*

Fluid Characteristics

- *No gas in liquid stream*
- *Small amounts of liquid in gas/vapor stream*
- *Immiscible fluids*

Fluid Characteristics

- *Within accurate flow range*
- *Corrosion and erosion*
  - *Wetted parts compatible with fluid*
- *Slug flow can damage flowmeter*

Fluid Characteristics

- *Gas/vapor applications without compensation*
  - *Relatively constant temperature*
  - *Relatively constant pressure*
  - *Relatively constant composition*

Piping and Hydraulics

- *Pipe quality*
  - *Use smooth round pipe*
  - *Use correct schedule pipe for flowmeter*
    - *Compensate K-factor for schedule*

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

- *For liquid applications, keep the flowmeter full of liquid*
  - *Hydraulic design*
    - *Orient to self-fill and self-drain*
    - *Vertical riser preferred*
    - *Avoid inverted U-tube*

Piping and Hydraulics

- *For liquid applications, keep the flowmeter full of liquid*
  - *Hydraulic design*
    - *Do not flow downwards*
    - *Be careful when flowing by gravity*

Piping and Hydraulics

- *For gas/vapor applications, keep the flowmeter full of gas/vapor*
  - *Hydraulic design*
    - *Vertical riser preferred*
    - *Avoid U-tube*

Piping and Hydraulics

- *Liquids and condensable gas (vapor)*
  - *Do not locate transmitter below pipe*
- *Condensable gas (vapor)*
  - *In horizontal piping, orient shedder in horizontal plane*

Piping and Hydraulics

- *High temperature fluids*
  - *Insulate per supplier instructions*
    - *Too much insulation can damage equipment*
  - *Locate transmitter on side of pipe*

Piping and Hydraulics

- *Sanitary applications*
  - *Orient to self-fill and self-drain*
  - *Compatible with cleaning solutions*

Piping and Hydraulics

- *Mount the flowmeter between flanges that are parallel, axially aligned, and proper spacing*

Piping and Hydraulics

- *Locate the flowmeter so as to reduce vibration*
  - *Especially smaller pipe sizes*
- *When vibration problems occur, try rotating the flowmeter by 90 degrees*

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Electrical

- *Integral sensors reduce wiring cost*
- *Wiring*
  - *Low voltage power supply can eliminate power conduit*
  - *Fieldbus reduces wiring*

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Ambient Conditions

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

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Setup Information

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

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Setup Information

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

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Vortex Shedding and Fluidic Flowmeter Technology

- *Principle of Operation*
- *Vortex Shedder Sensing Systems*
- *Flowmeter Designs*
- *Transmitter Designs*
- *Installation*
- ***Accessories***
- *Other Flowmeter Technologies*

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Accessories

- *Body*
  - *NEMA 4X and IP67*
  - *Isolation valve*
  - *High pressure*
  - *High temperature*
  - *High temperature purge fitting*
  - *Dual sensor design*

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Accessories

- *Transmitter*
  - *NEMA 4X and IP67*
  - *Analog output*
  - *Pulse output*
  - *Totalization and alarms*
  - *HART, Foundation Fieldbus, Profibus*

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Accessories

- *Body and Transmitter*
  - *Dry calibration*
  - *Wet calibration*

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Vortex Shedding and Fluidic Flowmeter Technology

- *Principle of Operation*
- *Vortex Shedder Sensing Systems*
- *Flowmeter Designs*
- *Transmitter Designs*
- *Installation*
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- ***Other Flowmeter Technologies***

Other Flowmeter Technologies

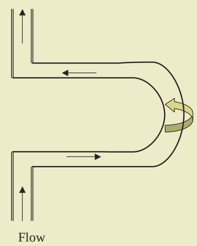
- *Coriolis Mass*
- *Differential Pressure*
- *Magnetic*
- *Positive Displacement*
- *Target*
- *Thermal*
- *Turbine*
- *Ultrasonic*
- *Vortex Shedding*

Insertion

Coriolis Mass Flowmeter

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

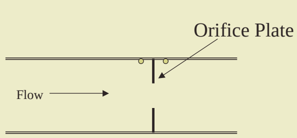
Coriolis Mass Flowmeter



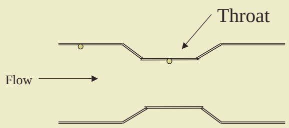
Differential Pressure Flowmeter

- *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



Venturi
Primary Flow Element



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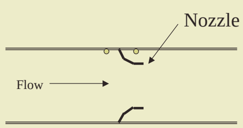
Flow Nozzle
Primary Flow Element



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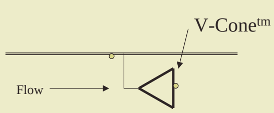
V-Cone^{tm}
Primary Flow Element



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Differential Pressure Flowmeter

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

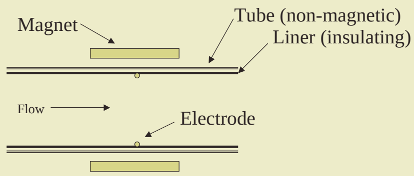
Differential Pressure Flowmeter

- *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.*

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*

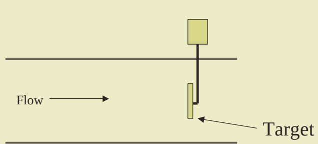
Positive Displacement Flowmeter

- *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



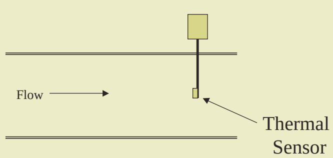
Thermal Flowmeter

- *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*

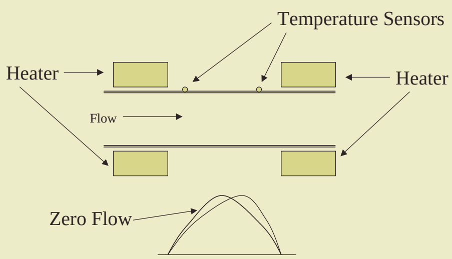
Thermal Flowmeter
Hot Wire Anemometer



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*

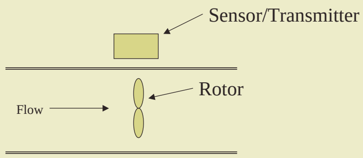
Thermal Flowmeter
Thermal Profile



Turbine Flowmeter

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

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*

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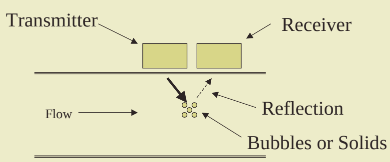
Ultrasonic - Doppler



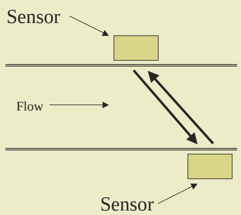
Ultrasonic - Doppler

- *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



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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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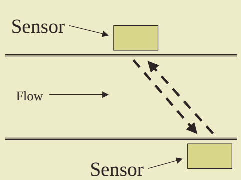
Ultrasonic - Transit Time

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



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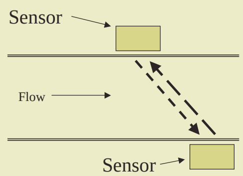
Ultrasonic - Transit Time

- *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*

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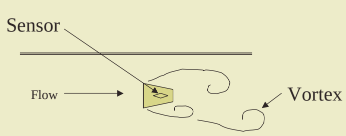
Vortex Shedding Flowmeter



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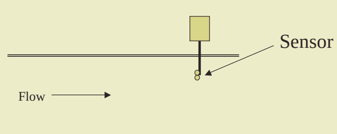
Vortex Shedding Flowmeter

- *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*

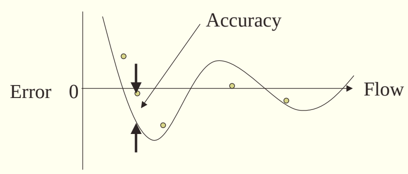
Flowmeter Performance

- ***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*

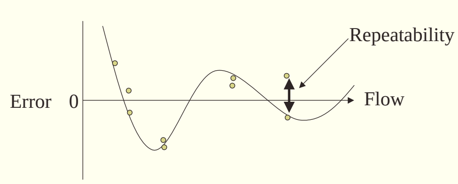
Flowmeter Performance



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*

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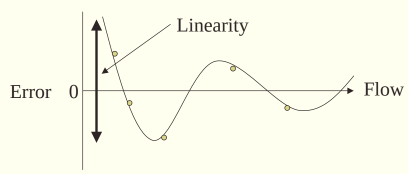
Flowmeter Performance



Flowmeter Performance

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

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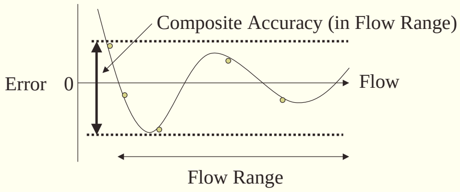
Flowmeter Performance



Flowmeter Performance

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

Performance Statements

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

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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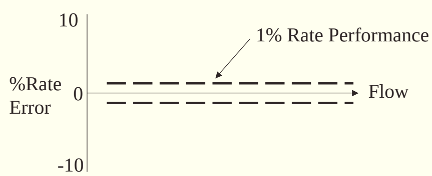
Performance Statements



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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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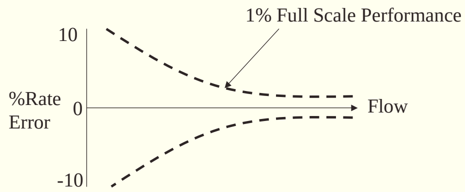
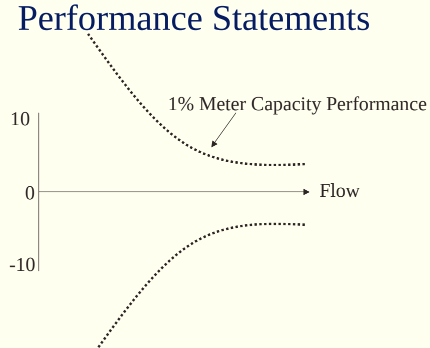
Performance Statements



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



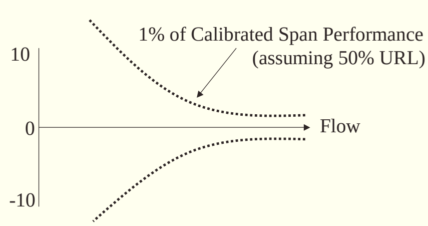
Performance Statements

- *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



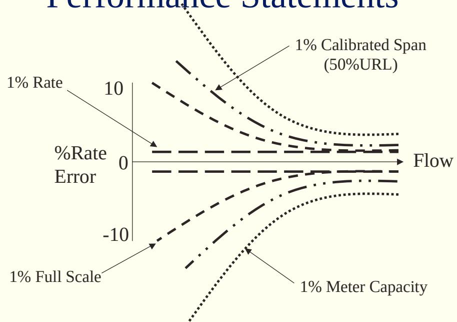
Performance Statements

- *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

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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*

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Performance Statements

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

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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*
  - *2% rate 0.5-1 m/s*
  - *Turns off under 0.3 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*

Reference Performance

Example - Omission

- *If full scale is not adjustable, the percent is a percent of meter capacity!*
  - *0-2 m/s range with URL=10 m/s*
    - *1% rate 1-2 m/s*
    - *2% rate 0.5-1 m/s*
    - *Undefined 0.3-0.5 m/s*
    - *Turns off under 0.3 m/s*

Reference Performance

Example - Omission

- *Similarly, a percent of full scale statement could really be a percent of meter capacity statement*
  - *Especially raw pulse output*

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

- *Vortex shedding flowmeters can operate upwards of 10 m/s*
  - *Assume meter capacity is 10 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:*
  - *0.01*10 m/s 1-2 m/s*
    - *5% rate at 2 m/s*
    - *10% rate at 1 m/s*
  - *0.02*10 m/s 0.5-1 m/s*
    - *40% rate at 0.5 m/s*
  - *Undefined under 0.5 m/s*

Reference Performance

- *Rate statements at higher velocity are often discussed*
- *Degraded performance and turn off at lower velocities 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 <u>plus</u> an absolute error*

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Pulse Output vs. Analog Output

<u>Problem</u>

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

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Pulse Output vs. Analog Output

<u>Solution</u>

- *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*

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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

- *Operating Effects*
  - *Process conditions*
    - *Pressure*
    - *Temperature*
      - *Fluid expansion*
      - *Flowmeter expansion*
    - *Composition*

Actual Performance

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

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Actual Performance

- *Pipe Diameter and Area*
  - *Variations in the pipe diameter can affect the K-factor of the flowmeter*

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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*
    - *Different fluid pressure (gas/vapor)*

Flowmeter Performance

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

Supplier Claims

- *High Turndown*
  - *Ratio of the maximum flow that can be measured within the stated accuracy to the minimum flow that can be measured within the stated accuracy*

Supplier Claims

- *High Turndown*
  - *Example - Hypothetical flowmeter*
    - *1% rate accuracy*
    - *20:1 turndown*
  - *Sounds fantastic!*

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Supplier Claims

- *High Turndown*
  - *Further investigation reveals*
    - *1% rate accuracy 0.5-10 m/s*
      Actual turndown 20:1
    - *Undefined 0.3-0.5 m/s*
      Operating turndown 33:1

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Supplier Claims

- *High Turndown*
  - *Claims could be made based upon the operating flow rates that have undefined accuracy at low flow rates*
    - *Would be 33:1 instead of 20:1*

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Supplier Claims

- *High Turndown*
  - *Typical application (0-2 m/s)*
    - *1% rate accuracy 0.5-2 m/s*
      Actual turndown 4:1
    - *Undefined 0.3-0.5 m/s*
      Operating turndown 7:1

Supplier Claims

- *High Turndown*
  - *High turndown claims assume that Reynolds number is sufficiently high to not limit low flow operation*
    - *Low Reynolds numbers can cause*
      - *nonlinearity at low flow rates*
      - *turn off above minimum velocity limit*

Supplier Claims

- *High Turndown*
  - *High turndown claims assume pulse output*
    - *Use of the analog output degrades performance*

Supplier Claims

- *High Accuracy*
  - *High accuracy claims often refer to high flow rates that may not be practical*
  - *Use of the analog output degrades performance*

Supplier Claims

- *Percent of Full Scale Accuracy*
  - *Example - Hypothetical flowmeter*
    - *1% FS accuracy*
    - *20:1 turndown*
  - *Sounds fantastic!*

Supplier Claims

- *Percent of Full Scale Accuracy*
  - *Further investigation reveals*
    - *1% FS accuracy 0.5-10 m/s*
  - *Typical application (0-2 m/s)*
    - *1% rate accuracy 2 m/s*
    - *2% " " 1 m/s*
    - *4% " " 0.5 m/s*

Supplier Claims

- *Percent of Full Scale Accuracy*
  - *Full scale is meter capacity when:*
    - *using an un-scaled pulse output*
    - *the analog output has no full scale adjustment*

Supplier Claims

- *Percent of Full Scale Accuracy*
  - *Further investigation reveals*
    - *1% MC accuracy 0.5-10 m/s*
  - *Typical application (0-2 m/s)*
    - *5% rate accuracy 2 m/s*
    - *10% " " 1 m/s*
    - *20% " " 0.5 m/s*

Supplier Claims

- *Inexpensive*
  - *Lower performance*
  - *Plastic available*
  - *Economic alternative to other technologies*

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***

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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*

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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*

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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

- *Body and Sensor Limits*
  - *Size*
    - *4-750 mm*
  - *Ambient temperature*
    - *-20 to 60°C typical*
    - *Some designs are for indoor use only*

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Supplier Data and Analysis

- *Body and Sensor Limits*
  - *Wetted parts*
    - *316SS, Hastelloy C, plastic, PVC, PFA*
  - *NEMA 4X, IP65, 67*

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Supplier Data and Analysis

- *Process Operating Limits*
  - *Pressure limit*
    - *10-50 bar typical*
    - *400 bar*
  - *Temperature limit*
    - *200°C typical; 400°C max*
    - *Many designs are limited to under 100°C*

Supplier Data and Analysis

- *Vibration (acceleration compensation)*
  - *High mass*
    - *Fishtail*
  - *Low mass*
    - *Small plate inside shedder*
    - *Differential pressure diaphragm*
- *Properly support flowmeter body*

Supplier Data and Analysis

- *Vibration (acceleration compensation)*
  - *No mass*
    - *Thermal*
    - *Ultrasonic*

Supplier Data and Analysis

- *Sensor Installation/Maintenance*
  - *Velocity profile*
    - *10-40D/5-10D typical*
    - *Some designs show reduced sensitivity to velocity profile effects*

Supplier Data and Analysis

- *Sensor Installation/Maintenance*
  - *Sensor replacement*
    - *While flowing (all-welded)*
    - *Depressurize pipe*
    - *Remove flowmeter body*

Supplier Data and Analysis

- *Sensor Installation/Maintenance*
  - *Sensor coating*
    - *Sensor corrosion/coating*
    - *Sensor coating*

Supplier Data and Analysis

- *Sensor Installation/Maintenance*
  - *Damage relatively thin components*
    - *Corrosion*
    - *Overpressure*

Supplier Data and Analysis

- *Transmitter*
  - *Two-wire design*
  - *3-wire design*
  - *4-wire device (separate power/analog wires)*

Supplier Data and Analysis

- *Transmitter*
  - *Typically measure forward flow*
    - *Some reverse flow designs*
  - *Alarms*
    - *Do not use for alarms below minimum velocity constraint*

Supplier Data and Analysis

- *Transmitter*
  - *Totalization*
  - *Multivariable*
    - *Gas pressure/temperature compensation*
    - *Mass flow*

Supplier Data and Analysis

- *Transmitter*
  - *Sensor/transmitter mounting*
    - *Integral*
    - *Remote*
    - *Spacing (distance)*

Supplier Data and Analysis

- *Transmitter*
  - *Filtering is typically used*
    - *Low flow cutoff*
  - *Many models to not allow adjustment of full scale*

Supplier Data and Analysis

- *Transmitter*
  - *Range adjustment mechanism provide insight into age of design*
    - *Analog (potentiometer)*
    - *Dip switch*
    - *Digital*

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Supplier Data and Analysis

- *Performance*
  - *Specifications are often not clear as to whether the stated accuracy is the*
    - *Reference accuracy*
    - *Typical installed accuracy*

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Supplier Data and Analysis

- *Performance*
  - *Typically based on pulse output*
  - *Analog output accuracy*
    - *Add 0.03-0.10% full scale to flowmeters with % rate statements (typical)*
    - *No adder for flowmeters with % full scale statement (typical)*
    - *Some suppliers could not quantify*

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Supplier Data and Analysis

- *Performance*
  - *Performance can vary and the flowmeter can turn off as viscosity increases and Reynolds number decreases below its constraint*

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Supplier Data and Analysis

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

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Supplier Data and Analysis

- *Operating Effects*
  - *Ambient*
    - *Temperature, humidity*
  - *Process conditions*
    - *Temperature, pressure, composition, viscosity, Reynolds number*
  - *Many suppliers do not quantify operating effects*

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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*

Flowmeter Categories

- *Summary of offerings*
  - *Categories*
  - *Manufacturing location/source*

Flowmeter Categories

- *Suppliers (53)*
- *Manufacturers (40)*
  - *15 USA*
  - *9 China*
  - *8 Japan*
  - *6 Germany*
  - *3 India*

Availability of Selected Features

- *Sensor and measurement type*
- *Remove sensor under flowing conditions*
- *Hazardous location approvals*
- *High pressure (over 100 bar)*
- *High temperature (over 200°C)*
- *Pressure and temperature compensation*

Availability of Selected Features

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

Models Grouped by Performance

- *Types of magnetic flowmeters*
- *Outputs*
  - *Pulse/analog*

Models Grouped by Performance

- *Operating conditions*
  - *0-2 m/s calibration (water)*
  - *0-20 m/s calibration (free air)*
- *For each size, vortex shedding and fluidic flowmeters are grouped by their performance at 0.6 m/s (water) and 6 m/s (free air)*

Review and Questions

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

The Consumer Guide to Vortex Shedding and Fluidic Flowmeters

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