The Consumer Guide to Magnetic Flowmeters

Seminar Presented by
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Seminar Outline

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

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Introduction

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

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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*

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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*

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Why Measure Flow?

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

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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)*

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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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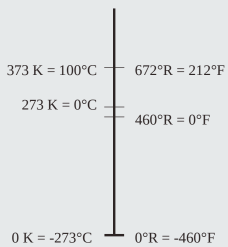
Temperature



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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

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Pressure

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

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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*

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Pressure

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

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Pressure

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

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Pressure

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

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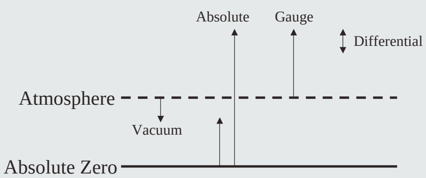
Pressure



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Pressure

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

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Pressure

<u>Problem</u>

- *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 <u>absolute</u> 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 (ρ=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*
  - $SG = \rho_{liquid} / \rho_{water\ at\ standard\ conditions}$

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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?*

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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*

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

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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 ?*

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Density and Fluid Expansion

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

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Fluid Flow Fundamentals

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- ***Types of Flow***
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- *Hydraulic Phenomena*

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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 ($W = \rho \cdot Q$)
  - $lb/ft^3 \cdot ft^3/sec = lb/sec$
  - $kg/m^3 \cdot m^3/sec = kg/sec$
  - standard cubic feet per minute (scfm)
  - standard liters per minute (slpm)
  - standard cubic centimeters per minute(sccm)

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Types of Flow

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

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Fluid Flow Fundamentals

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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*

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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*

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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*

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Viscosity

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

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Viscosity

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

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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*

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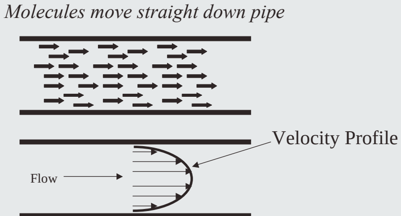
Velocity Profile and Reynolds Number

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



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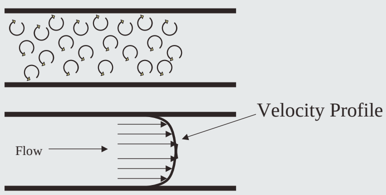
Velocity Profile and Reynolds Number

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



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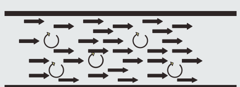
Velocity Profile and Reynolds Number

- *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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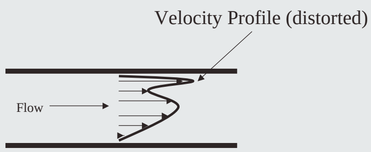
Velocity Profile and Reynolds Number

- *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*

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Fluid Flow Fundamentals

- *Temperature*
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- ***Hydraulic Phenomena***

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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*

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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*

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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*

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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*

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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*

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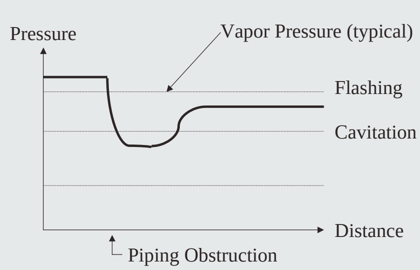
Hydraulic Phenomena



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Hydraulic Phenomena

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

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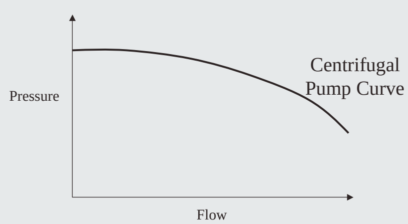
Hydraulic Phenomena

- *Energy Considerations*



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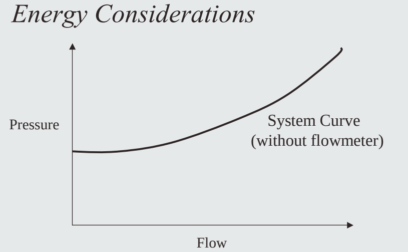
Hydraulic Phenomena

- *Energy Considerations*



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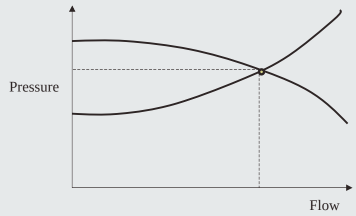
Hydraulic Phenomena

- *Energy Considerations*



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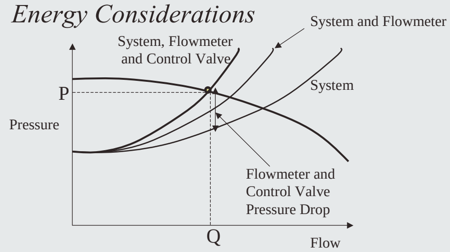
Hydraulic Phenomena

- *Energy Considerations*



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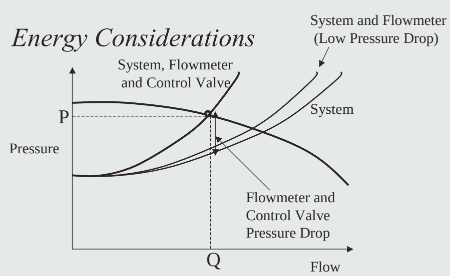
Hydraulic Phenomena

- *Energy Considerations*



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Hydraulic Phenomena

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

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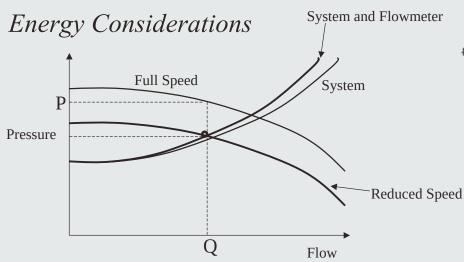
Hydraulic Phenomena

- *Energy Considerations*



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Hydraulic Phenomena

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

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Seminar Outline

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

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Magnetic Flowmeter Technology

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

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Principle of Operation

- *Faraday's Law of Electromagnetic Induction defines the magnitude of the voltage induced in a conductive medium moving at a right angle through a magnetic field*
  - *Most notably applied to electrical power generation*

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Principle of Operation

- *Faraday's Law*

$$E = constant \cdot B \cdot L \cdot v$$

  - *B is the magnetic flux density*
  - *L is the path length*
  - *v is the velocity of the medium*

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Principle of Operation

- ***Experiment***
  - *Galvanometer with wire between terminals*
  - *Horseshoe magnet*
  - *Moving the wire through the magnetic field moves the galvanometer indicator*
    - *Moving wire in opposite direction moves indicator in opposite direction*
    - *Moving wire faster moves indicator higher*

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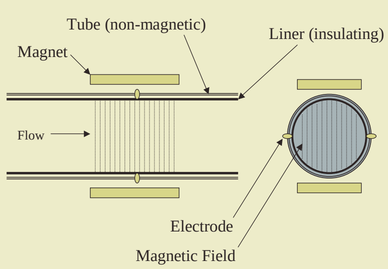
Principle of Operation



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Principle of Operation

- *Magnetic flowmeters direct electromagnetic energy into the flowing stream*
- *Voltage induced at the electrodes by the conductive flowing stream is used to determine the velocity of fluid passing through the flowmeter*

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Principle of Operation

- *Induced voltage*

$$E = constant \cdot B \cdot D \cdot v$$

- *Substituting* $Q = A \cdot v$ *and assuming that A, B, and D are constant yields:*

$$E = constant \cdot Q$$

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Principle of Operation

- *The induced voltage at the electrodes is directly proportional to the flow rate*

$$E \; \alpha \; Q$$

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Principle of Operation AC Excitation

- *Magnet is excited by an AC waveform*
- *Voltage waveform at electrode is also an AC waveform*

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Principle of Operation AC Excitation

- *AC excitation was subject to:*
  - *Stray voltages in the process liquid*
  - *Electrochemical voltage potential between the electrode and process fluid*

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Principle of Operation AC Excitation

- *AC excitation was subject to:*
  - *Inductive coupling of the magnets within the flowmeter*
  - *Capacitive coupling between signal and power circuits*
  - *Capacitive coupling between interconnection wiring*

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Principle of Operation
AC Excitation

- *Zero adjustments were used to compensate for these influences and the effect of electrode coating*
  - *Percent of full scale accuracy*

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Principle of Operation
AC Excitation

- *Feeding power to the primary element, then back to the transmitter reduces the possibility of inducing voltage from the power wiring*
  - *Electromagnet is the large power draw*
  - *Signal voltage could be induced from wiring carrying current to the magnet*

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Principle of Operation
DC Excitation

- *Pulsed DC excitation reduces drift by turning the magnet on and off*

Magnet On = Signal + Noise

Magnet Off = Noise

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Principle of Operation DC Excitation

- *Noise is canceled by subtracting these two measurements*

Signal + Noise – Noise = Signal

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Principle of Operation DC Excitation

- *DC magnetic flowmeters automatically self-zero*
  - *Percent of rate accuracy*
  - *The 4mA analog output zero adjustment is not set automatically and still maintains a percent of full scale accuracy*

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Principle of Operation DC Excitation

- *Response time can be compromised*

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Magnetic Flowmeter Technology

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

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Magnetic Flowmeter Designs

- *Ceramic*
- *Electrodeless*
- *Low Flow*
- *Medium Flow*
- *High Flow*

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Magnetic Flowmeter Designs

- *High Noise*
- *Low Conductivity*
- *Partially-full*
- *Response - Fast*
- *Sanitary*
- *Two-wire*

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Magnetic Flowmeter Designs

- *External/Internal Coils*
- *Flanged*
- *Wafer*
- *Miniature*

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Magnetic Flowmeter Technology

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

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Magnetic Transmitter Designs

- *Analog*
  - *Electrical components subject to drift*
  - *AC and DC designs*
  - *Four-wire design*

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Magnetic Transmitter Designs

- *Digital*
  - *Microprocessor is less susceptible to drift*
  - *Mathematical characterization in software*
  - *Remote communication (with HART)*
  - *Four-wire design*
  - *Mostly DC designs*
    - *Can usually retrofit AC magnetic flowmeters using the existing primary element*

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Magnetic Transmitter Designs

- *Digital (Two-wire)*
  - *Microprocessor is less susceptible to drift*
  - *Mathematical characterization in software*
  - *Remote communication (with HART)*
  - *Two-wire design*
    - *Installation savings*
    - *Low flow performance degraded*
    - *Response time degraded*

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Magnetic Transmitter Designs

- *Digital (Battery Power)*
  - *Microprocessor is less susceptible to drift*
  - *Used for totalization*
    - *Wake up occasionally*
    - *Slow response*

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Magnetic Flowmeter Transmitter Designs

- *Fieldbus*
  - *Microprocessor is less susceptible to drift*
  - *Mathematical characterizations in software*
  - *Multi-drop wiring*
  - *Remote communication*
  - *Issues with multiple protocols*

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Magnetic Flowmeter Technology

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

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Installation

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

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Fluid Characteristics

- *Liquids only*
  - *Water*
  - *Slurries*
- *Electrical conductivity of liquid must be above minimum conductivity*

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Fluid Characteristics

- *Within accurate flow range*
- *Corrosion and erosion*
- *Electrode coating*
  - *Cleaning technique*
  - *High impedance electronics*

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Fluid Characteristics

- *Immiscible liquids*
- *Ferromagnetic liquids*
- *Hot/cold liquids*
  - *Ceramic liner damage due to sudden temperature change*
- *Gas in liquid stream*

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Piping and Hydraulics

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

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Piping and Hydraulics

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

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Piping and Hydraulics

- *Sizing*
  - *Smaller sizes generally result in better accuracy*
  - *Larger sizes lower velocity and can reduce pressure drop and erosion*

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Piping and Hydraulics

- *Use proper mating flange*
  - *0.5 inch wafers installed between 1 inch flanges*
- *Wetted parts compatible with liquid*

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Grounding

- *Primaries with internal grounding electrodes need no additional grounding*

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Grounding

- *Non-conductive pipe*
  - *Install grounding rings upstream and downstream of primary and electrically bond transmitter to both*
- *Conductive pipe*
  - *Electrically bond flowmeter to upstream and downstream flange (or grounding ring)*

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Electrical

- *Integral primary/transmitter reduce wiring cost*
- *Remote mounting can increase conductivity limit*

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Electrical

- *Wiring*
  - *Low voltage power supply can eliminate power conduit*
  - *Two-wire magnetic flowmeters eliminate power wiring*
  - *Fieldbus reduces wiring*

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Ambient Conditions

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

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Setup Information

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

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Setup Information

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

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Magnetic Flowmeter Technology

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

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Accessories

- *Primary*
  - *NEMA 4, 6P, and IP67, 68*
  - *Temporary submersion*
  - *Direct burial*
  - *Ultrasonic cleaner*

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Accessories

- *Transmitter*
  - *NEMA 4, 4X and IP65, 67*
  - *Analog outputs*
    - *Active/passive*
    - *Dual/split range*
  - *Pulse output*
  - *Totalization and alarms*
  - *HART, Foundation Fieldbus, Profibus*

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Accessories

- *Transmitter*
  - *Empty pipe detection*
  - *Intrinsically safe electrode wiring*
    - *Gas inside pipe*
  - *Electrode cleaning*
    - *Ultrasonic*
    - *High voltage*
    - *High impedance input (millions of meg-ohms)*

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Magnetic Flowmeter Technology

- *Principle of Operation*
- *Flowmeter Designs*
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- *Installation*
- *Accessories*
- ***Other Flowmeter Technologies***

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Other Flowmeter Technologies

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

Insertion

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Coriolis Mass Flowmeter

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

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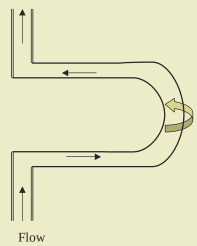
Coriolis Mass Flowmeter



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Differential Pressure Flowmeter

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

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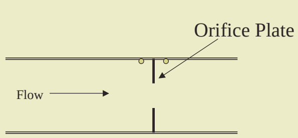
Orifice Plate
Primary Flow Element



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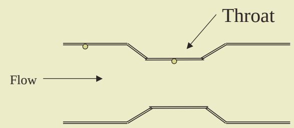
Venturi
Primary Flow Element



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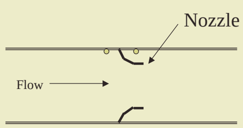
Flow Nozzle
Primary Flow Element



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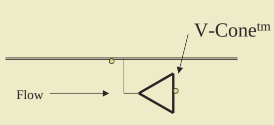
V-Cone[tm]
Primary Flow Element



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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*

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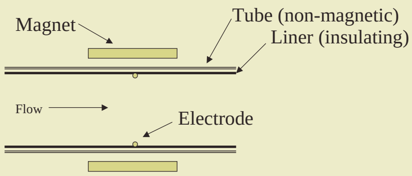
Magnetic Flowmeter



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Magnetic Flowmeter

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

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Magnetic Flowmeter

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

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Positive Displacement Flowmeter

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

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Target Flowmeter

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

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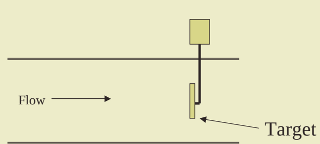
Target Flowmeter



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Thermal Flowmeter

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

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Thermal Flowmeter
Hot Wire Anemometer

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

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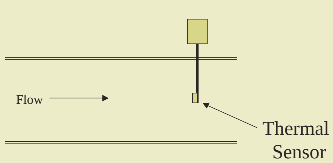
Thermal Flowmeter
Hot Wire Anemometer



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Thermal Flowmeter Thermal Profile

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

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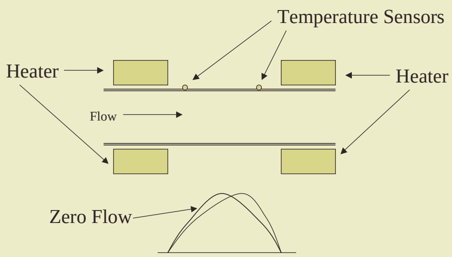
Thermal Flowmeter Thermal Profile



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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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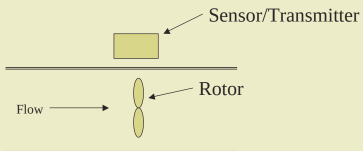
Turbine Flowmeter



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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*

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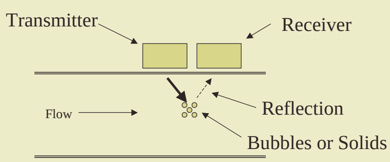
Ultrasonic - Doppler



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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*

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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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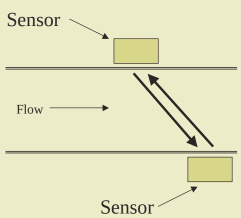
Ultrasonic - Transit Time



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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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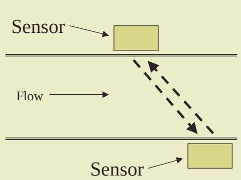
Ultrasonic - Transit Time

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



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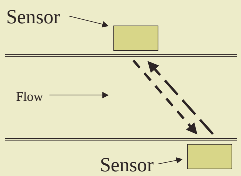
Ultrasonic - Transit Time

- *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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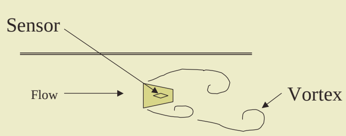
Vortex Shedding Flowmeter



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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*

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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*

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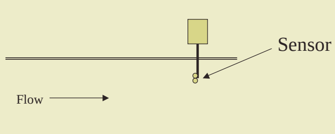
Insertion Flowmeter



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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*
- *Pulse Output vs. Analog Output*
- *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*

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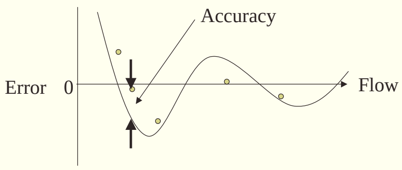
Flowmeter Performance



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Flowmeter Performance

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

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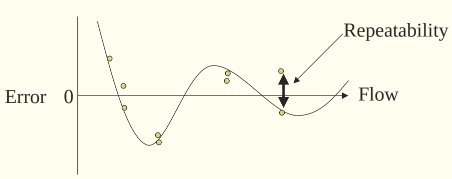
Flowmeter Performance



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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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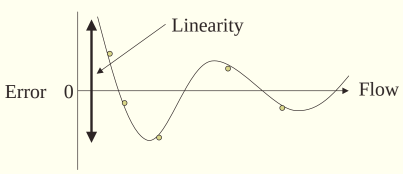
Flowmeter Performance



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Flowmeter Performance

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

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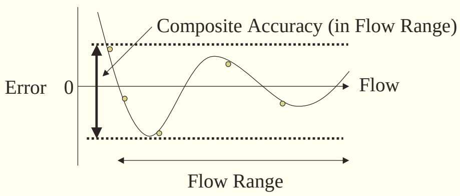
Flowmeter Performance



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Flowmeter Performance

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

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Performance Statements

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

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Performance Statements

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

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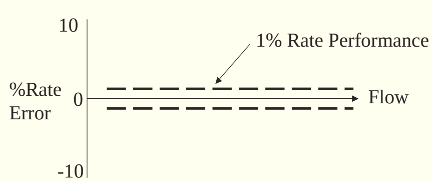
Performance Statements



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Performance Statements

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

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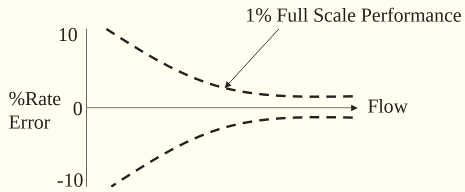
Performance Statements



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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*

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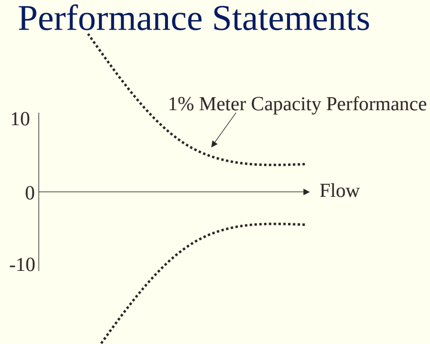
Performance Statements



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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*

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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*

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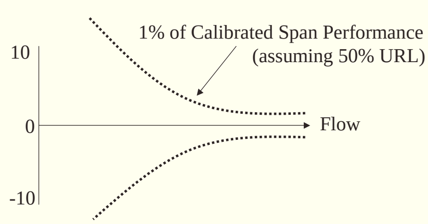
Performance Statements



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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*

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Performance Statements

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

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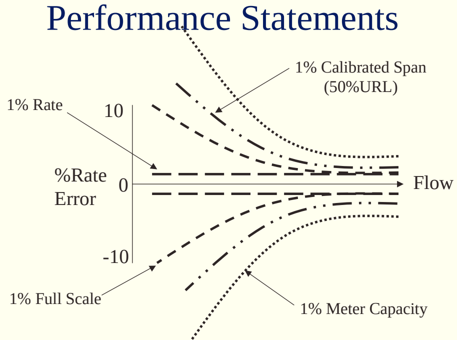
Performance Statements



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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

- *0.25% rate 1-10 m/s*
  0.0025 m/s 0.1-1 m/s

Velocity (m/s)	*Error*	
10.0	*0.0250 m/s*	*0.25% rate*
1.0	*0.0025 m/s*	*0.25% rate*
0.5	*0.0025 m/s*	*0.50% rate*
0.1	*0.0025 m/s*	*2.50% rate*
under 0.1	*undefined*	*undefined*

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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*

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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*

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Reference Performance

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

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Reference Performance

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

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Reference Performance

Example - Omission

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

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Reference Performance

Example - Omission

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

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Reference Performance

Example - Omission

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

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Reference Performance

Problem

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

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Reference Performance

Solution

- *Magnetic flowmeters can operate upwards of 10 m/s*
  - *Assume meter capacity is 10 m/s*
- *In typical applications, liquid velocity is below 3 m/s*
  - *Assume a user range of 0-2 m/s*

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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 1 m/s*

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Reference Performance

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

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Flowmeter Performance

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

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Pulse Output vs. Analog Output

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

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Pulse Output vs. Analog Output

Problem

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

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Pulse Output vs. Analog Output

Solution

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

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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 "*

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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 "*

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Pulse Output vs. Analog Output

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

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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*

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Pulse Output vs. Analog Output

Problem

- *What is the performance of a magnetic flowmeter analog output at 25% of full scale flow when its reference accuracy (at that flow rate) is 0.25% rate plus 0.1% full scale?*
  - *0.25 + 0.1•100/25 = 0.65% rate*
  - *0.65% is almost triple 0.25%*

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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*

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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.*

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Flowmeter Performance

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

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Actual Performance

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

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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*

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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*

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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

- *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

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

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Actual Performance

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

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Flowmeter Performance

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

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Supplier Claims

- *High Turndown*
  - *Example - Hypothetical flowmeter*
    - *0.25% rate accuracy*
    - *1000:1 turndown*
  - *Sounds fantastic!*

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Supplier Claims

- *High Turndown*
  - *Further investigation reveals*
    - *0.25% rate accuracy 0.5-10 m/s*
    - *0.00125 m/s accuracy 0.01-0.5 m/s*
    - *Measures 0.01-10 m/s 1000:1 turndown*

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Supplier Claims

- *High Turndown*
  - *Performance expressed as a percent of rate degrades below 0.5 m/s*
    - *0.25% rate 0.50 m/s*
    - *1.25% rate 0.10 m/s*
    - *2.50% rate 0.05 m/s*
    - *12.50% rate 0.01 m/s*

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Supplier Claims

- *Low Flow Operation*
  - *Reference accuracy statement is claimed to be valid down to essentially zero flow*

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Supplier Claims

- *Low Flow Operation*
  - *Reference accuracy statement*
    - *0.25% rate accuracy   0.5-10 m/s*
    - *0.00125 m/s accuracy   0.01-0.5 m/s*

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Supplier Claims

- *Low Flow Operation*
  - *Flowmeter operates at low flows, but performance expressed as a percent of rate is degraded*
    - *1.25% rate   0.10 m/s*
    - *2.50% rate   0.05 m/s*
    - *12.50% rate   0.01 m/s*

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Supplier Claims

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

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Supplier Claims

- *No Piping Obstructions*
  - *Magnetic flowmeters have no piping obstructions*

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Seminar Outline

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

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Consumer Guide

User Equipment Selection Process

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

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Consumer Guide

User Equipment Selection Process

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

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Consumer Guide

User Equipment Selection Process

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

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Consumer Guide

Guide Provides First Four Items

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

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Consumer Guide

Guide Provides First Four Items

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

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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

- *Primary Limits*
  - *Size*
    - *1-3000+ mm*
  - *NEMA 4X, IP67 (IP68 available)*

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Supplier Data and Analysis

- *Primary Limits*
  - *Ambient temperature*
    - *Typically limited by process*
  - *Process temperature*
    - *-20 to 130°C typical*
    - *Higher for ceramic liners*

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Supplier Data and Analysis

- *Primary Limits*
  - *Liner - materials*
    - *Rubber, PTFE*
    - *Others (ceramic, FEP, PFA, soft rubber, hard rubber, EDPM, PVC, polypropylene, polyurethane)*

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Supplier Data and Analysis

- *Primary Limits*
  - *Electrode - materials*
    - *Stainless steel*
    - *Others (Hastelloy C, platinum, Monel)*
  - *Electrode seal - materials*
    - *Liner material*
    - *Viton, Kalrez O-rings*

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Supplier Data and Analysis

- *Process Operating Limits*
  - *Pressure*
    - *Most designs are rated under 50 bar*
    - *Special designs 1500-2000 bar*

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Supplier Data and Analysis

- *Process Operating Limits*
  - *Temperature*
    - *PTFE 130-150°C*
    - *PFA 180°C*
    - *Rubber/PP 70-90°C*
    - *Ceramic liners can be damaged by excessive temperature change*

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Supplier Data and Analysis

- *Process Operating Limits*
  - *Conductivity*
    - *Over 1-5 µS/cm*
    - *Low conductivity designs to 0.01 µS/cm*

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Supplier Data and Analysis

- *Primary Installation/Maintenance*
  - *Velocity profile*
    - *3-5D upstream typical*
    - *2-3D downstream typical*
    - *Some designs include straight run*
      - *Small diameters*

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Supplier Data and Analysis

- *Primary Installation/Maintenance*
  - *Electrode replacement*
    - *Field removable*
    - *Accuracy changes*
  - *Electrode maintenance*
    - *Coating*
    - *Corrosion*

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Supplier Data and Analysis

- *Primary Installation/Maintenance*
  - *Grounding ring maintenance*
    - *Check electrical connections*
    - *Corrosion*
  - *Grounding electrode*
    - *Electrode cleaning*

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Supplier Data and Analysis

- *Transmitter*
  - *4-wire device (separate power/analog wires)*
    - *Using DC power can eliminate power conduit*
  - *Typically measure forward and reverse flow*

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Supplier Data and Analysis

- *Transmitter*
  - *Outputs (active/passive)*
    - *Pulse*
    - *Analog (4-20 mA) (isolated)*
    - *Flow alarms*
    - *Empty pipe detection*
    - *Fault*

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Supplier Data and Analysis

- *Transmitter*
  - *Totalization*
    - *Forward, reverse, net, batch*

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Supplier Data and Analysis

- *Transmitter*
  - *Mounting*
    - *Integral*
    - *Remote*
      - *50-200 m*
      - *Distance can increase conductivity limit (preamp)*

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Supplier Data and Analysis

- *Transmitter*
  - *Hazardous locations*
    - *Many are general purpose*
    - *NEC500 - Division 2 (non-incendive)*
    - *NEC500 - Division 1*
    - *Zone 1 and Zone 2*
    - *Intrinsically safe*
      - *Electrodes*
      - *Two-wire transmitters*

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Supplier Data and Analysis

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

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Supplier Data and Analysis

- *Performance*
  - *Typically based on pulse output over a range of velocity*
    - *Performance degrades at low velocity*
  - *In some designs, reference accuracy is different for different ranges*

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Supplier Data and Analysis

- *Performance*
  - *Analog output accuracy*
    - *Adds 0.03-0.10% full scale (or more) to reference accuracy*
    - *Analog output is inferior to pulse output*
    - *Some suppliers could not quantify*
    - *Some suppliers include the analog output accuracy in the reference accuracy*

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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, pipe material, composition*
  - *Power supply voltage*

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Supplier Data and Analysis

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

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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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Flowmeter Categories

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

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Flowmeter Categories

- *Suppliers (70)*
- *Manufacturers (53)*
  - *11 USA*
  - *8 Czech Republic*
  - *8 China*
  - *7 Germany*
  - *7 Japan*
  - *5 Italy*

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Availability of Selected Features

- *Hazardous location approvals*
- *Submersible*
- *High pressure (over 100 bar)*
- *High input impedance (over 10^6 MΩ)*
- *Batching*

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Availability of Selected Features

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

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Models Grouped by Performance

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

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Models Grouped by Performance

- *Operating conditions*
  - *0-2 m/s calibration*
- *For each category and for each output (pulse/analog), magnetic flowmeters are grouped by their performance at 0.1 m/s*

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Review and Questions

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

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The Consumer Guide to Magnetic Flowmeters

Seminar Presented by

David W. Spitzer

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