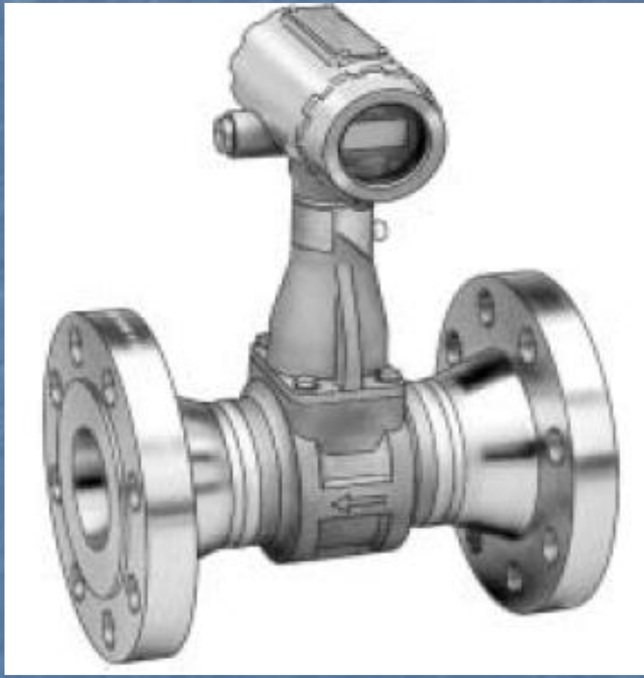
Utility Flow Metering for Steam and Chilled Water
A Tutorial for the 2012 IDEA Distribution Workshop

Richard Gruskos and Chris Maslak
of Kessler Ellis Products

Flow Metering Principles-
Flow Meters and Flow Computers



Utility Distribution and Customer Metering Concerns

- Service pressure, temperature, energy
- Expected customer load (flow rates)
- Service Reliability & Service Interruptions
- Billing Accuracy
- Scheduled Maintenance
- Information and Expertise Sharing
- Proposed installation location
- Steam Quality

Basic Input Measurements of Flowing Process Conditions

- Differential Pressure
- Static Pressure
- Temperature
- Volume Flow Rate
- Velocity
- Fluid properties are computed by temperature and/or pressure

Fluid Properties

- Density of Water or Saturated and Superheated Steam can be implied from measured (absolute) pressure and/or temperature and internally stored fluid properties
- Other properties: energy/unit mass, isentropic exponent, and viscosity are also computed
- Unfortunately steam quality is not implied and removing condensate is a installation requirement

Attributes of Flow Meters

- Accurate Flow Rate Range at fluid density
- Mandatory Installation Piping Requirements
- Available output signal type(s)
- Uncertainty (or accuracy)
- Basis of Calibration
- Application of required Correction Factors
- Maintenance required
- Flow profile and flow swirl effects

Attributes of Installation Site

- Fluid state and available inlet and outlet pipe runs
- Elevation above sea level affects barometric pressure
- Process noise in the differential pressure sensing lines at the steam/water interface
- Wet leg compensation of static pressure transmitters
- Winter demand/Summer demand and related flow rates
- Vibration in piping systems
- Electrical Interference & Electrical Grounding alternatives
- Interconnections to Building Controls
- Condensate recovery from customer site

Estimating Overall Metering Uncertainty

- Define the intended operating region of flow rate, temperature, and pressure at the site
- Identify the uncertainty in the volume flow rate measurement
- Identify the uncertainty in the inferred steam density as a result of uncertainty in the steam temperature and pressure
- RMS the individual error components to arrive at the estimated uncertainty of steam mass flow
- Similar process is used in liquid BTU systems

Survey of Commercial Flow Meter Types

- Vortex Flow Meters
- Orifice Plate Square Law Meters
- Contoured Inlet Square Law Meters (Nozzles, V-Cone, Accelebar)
- Averaging Pitot Square Law Flow Meters
- Gilflo and ILVA Types
- Target Flow Meters
- Insertion Turbine and Insertion Vortex Flow Meters
- Shunt Flow Meter (Bypass or Compound Flow Meter)
- Ultrasonic Flow Meter
- Condensate Flow Meter

Survey of Steam and Condensate Flow Meter Techniques

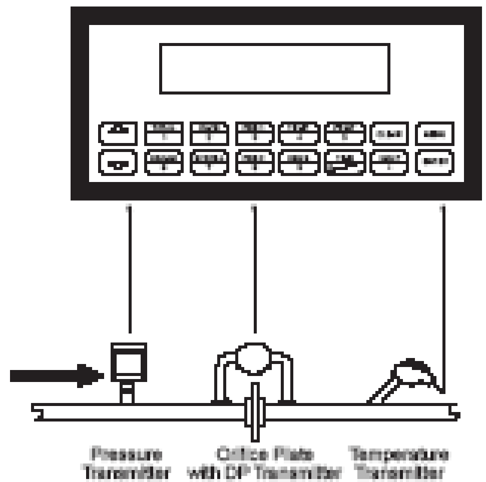
Basic Techniques

- Measure steam into facility
  - measure the volume flow rate in steam line
  - compute the fluid properties of steam from T & P
  - compute (and sum) mass flow rate as:
  - mass flow = density * volume flow
  - Energy flow = enthalpy * mass flow
- Measure only condensate out from facility
  - requires collection and metering of ALL condensate
  - assumes no unintentional entry of process water into condensate collection

District Energy

Steam Metering

Steam Mass & Steam Heat Illustration



Calculations

Mass Flow

Mass Flow = volume flow • density (T, p)

Heat Flow

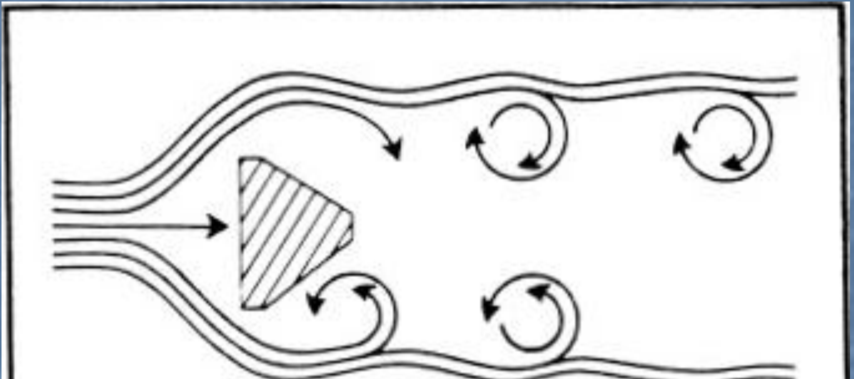
Heat Flow = Volume flow • density (T, p) • Sp. Enthalpy of steam (T, p)

Vortex Flow Meter Principles

- Flow around non-streamlined shape produces alternating vortices at higher velocities whose shedding frequency is essentially linear with volume flow through the meter run
- Calibrated by manufacturer on water
- Corrections can be applied for effects of flowing temperature on the meter run (K drops with Tf)
- Mass flow can be computed from volume flow and flowing density
- Full bore and reduced bore models available

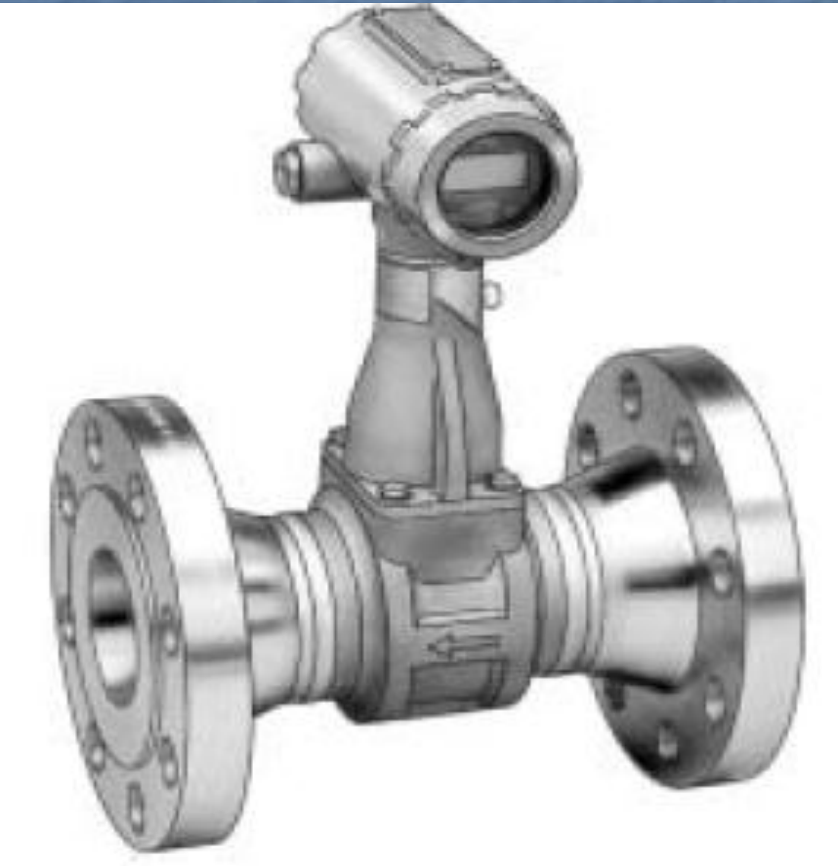
Some important observations

- Grounding of piping and signal common to earth
- Mounting shedder bar horizontal reduces adverse impact of condensate hitting bar
- Use adjustable trigger sensitivity if false output @ no flow (this reduces range of the meter)
- Avoid accidental, duplicate corrections


Formation of vortices at higher velocities

Vortex Advantages

- Most popular steam flow meter
- Accuracy of +/- 1% of volume flow rate
- Wide flow turn-down range 15:1 type
- Pulse and analog output signals available
- Swirlmeter for short piping runs
- Reduced bore meters for existing meter runs and resizing

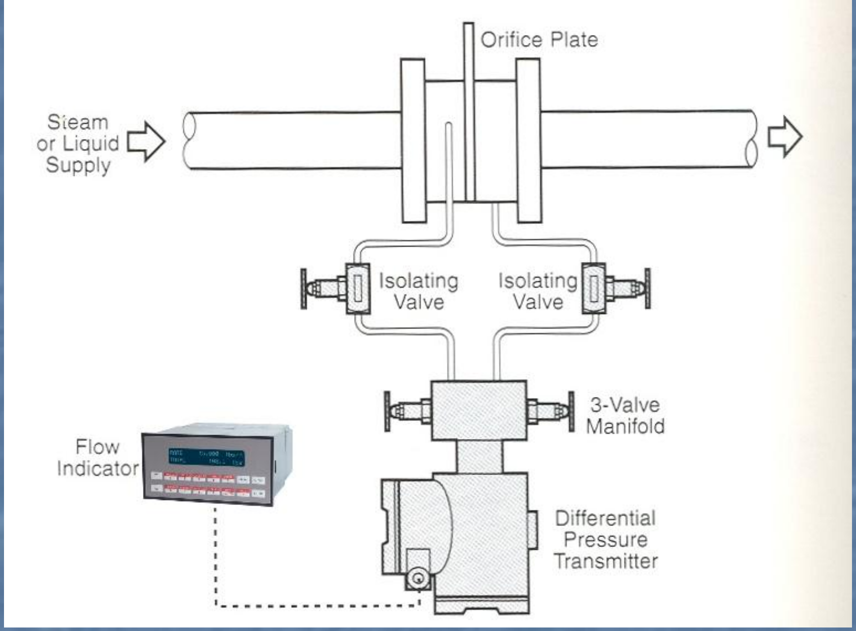


Orifice Flow Meter Principles

- Orifice Meters are the bench mark “Square-law” flow meter others are compared against
- Includes various orifice styles and pressure tap locations
- Intended for limited accurate flow range of 4:1 but can be increased to a usable 20:1 range if stacked (high and low range) DP transmitters are used on primary element
- Generally not calibrated but rather “sized” with standardized methods and so fabricated and installed
- Corrections required include: correction for density, dimensional changes with temperature Fa, Y1 correction for velocity of approach, and sometimes Cd verses Rn

Typical Installation

- Orifice Beta Ratio typically chosen to provide 100" H2O at Maximum Flow and nominal line pressure
- Normal Flow is typically 70% of Maximum Flow



Considerations for Installation

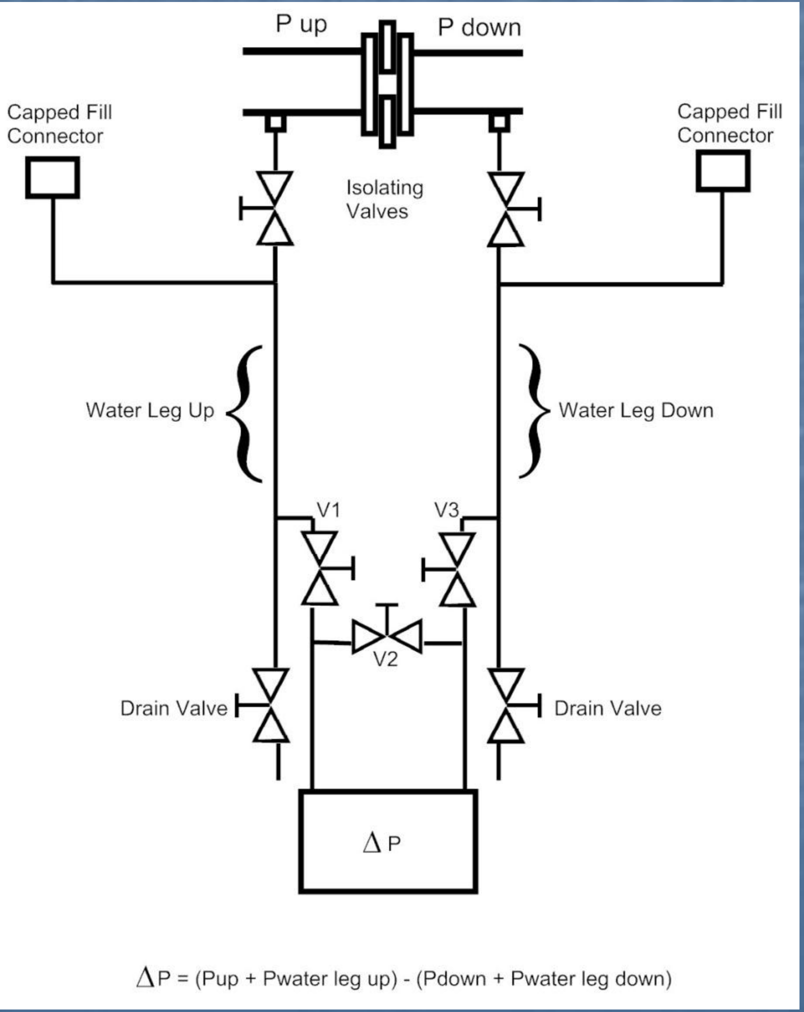
- The Uncertainty of an orifice meter run is approximately +/- 0.5% to +/- 1%
- The metering code for orifice plates dictate the straight inlet and outlet pipe run requirements for the installation (40 pipe diameters are now called out)
- Also restrictions on weld and gasket protrusion and positioning of the orifice plate

Some comments on 3-Valve Manifold used with Differential Pressure Transmitters in Steam

- Differential pressure transmitters are not intended to see high steam temperatures
- The differential pressure transmitter is located below the orifice plate and connected to orifice taps by inclined sense lines that should be filled equally with water
- Sense lines should initially be equally filled to keep equal water legs to leveled delta P transmitter ports
- To check for proper transmitter output at no flow: Close inlet valve, open bypass valve to produce 0.0" delta P. Close bypass and open inlet to return to normal service.
- Valve sequencing is important to avoid imbalance in legs

Draining Sense Lines

- If legs are drained to purge contaminates then water legs take time to refill and stabilize. Meter errors can occur in the interim. Manually refill at fill points with V2 closed
- Do not simultaneously open all 3 valves in manifold. Water legs can be imbalanced and water flushed downstream



Some comments on sizing differential pressure meters for steam service

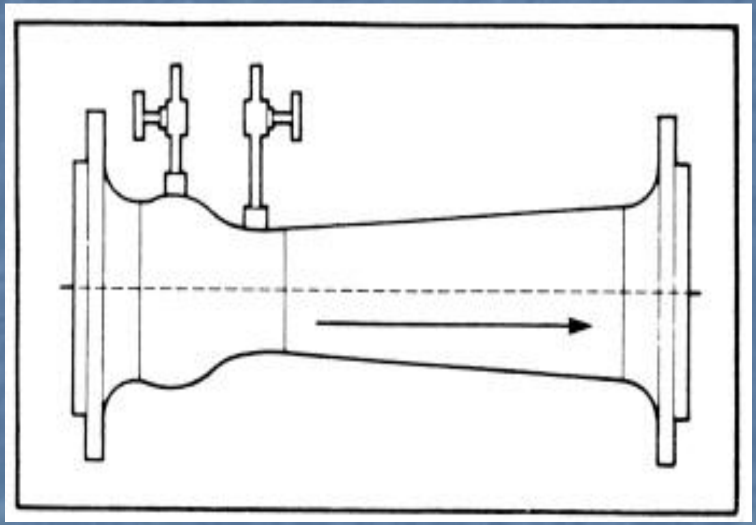
- Steam process noise may limit useful differential pressure to above 0.25” (Is 1” more practical?)
- Note that orifice sizing sheets only compute many key values at the “Normal” flow rate
- Sizing sheets often compute inaccurate values for saturated steam density and isentropic exponent. ASME Steam Tables may be selected.
- Expected test results should include Y1 at each flow rate (Need to re-run at other flow rates)

Contoured Inlet, Square Law Flow Meter Principles

- Class includes Nozzle, Venturi, Wedge
- Industry standard sizing equations
- That standard also places long installation straight pipe run requirements on these
- Low maintenance
- Better accuracy than orifice type
- V-Cone and Accelebar are proprietary types intended for improved performance

Venturi and Nozzle and Wedge

- Shape of nozzle or venturi is intended to create a predictable flow pattern
- Follows many other characteristics of orifice flow meters
- Unique equation for Y1



Special case of a V-Cone

- Calibrated on water
- Condensate can pass easily through meter
- Shorter inlet/outlet pipe runs required
- Performance is very independent of Rn
- Unique, proprietary equation for Y1

Standard design concepts

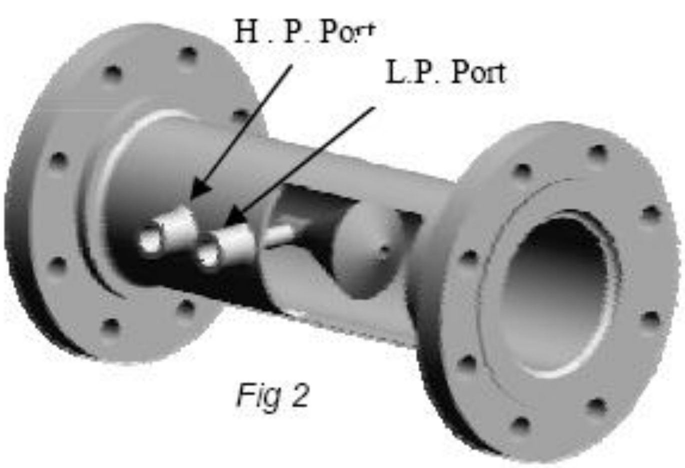


Fig 2

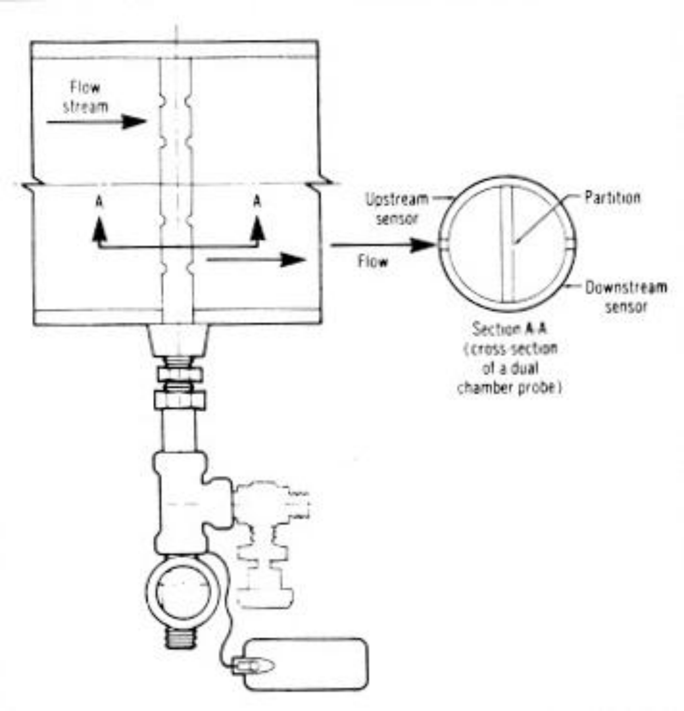
V-Cone with Welded Construction :

Averaging Pitot Tube Flow Meter Principles

- Class includes averaging pitot tube, annubar, verabar insertion type flow meter types
- Computation of implied fluid density and diff. pressure are used to compute velocity
- velocity and pipe area to compute volume flow
- density and volume flow to compute mass flow
- Low cost in large lines (Can be hot tapped)
- Lower differential pressure produced by device
- Lower pressure loss through meter run

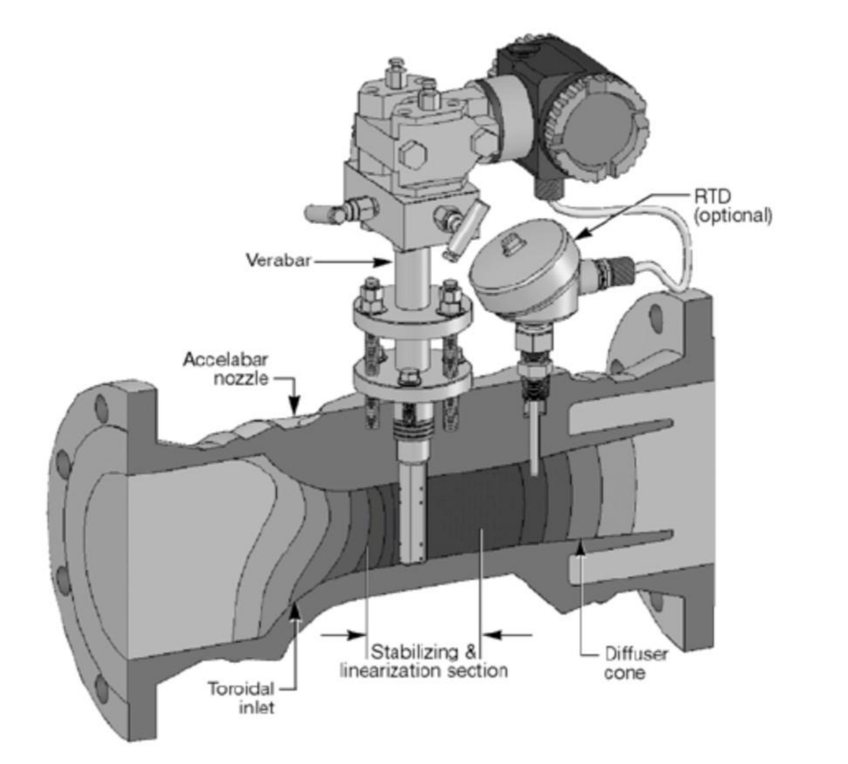
Averaging Pitot Tube Class

- Summary
  - square law device
- Advantages
  - inexpensive to install on larger line sizes
- Disadvantages
  - lower delta P developed
  - Remember 0.25”?



Accelabar -A Novel Configuration

- Toroidal inlet increases velocity at point of measurement
- Averaging pitot tube provides flow measurement
- Performance improved - similar to other contoured input devices

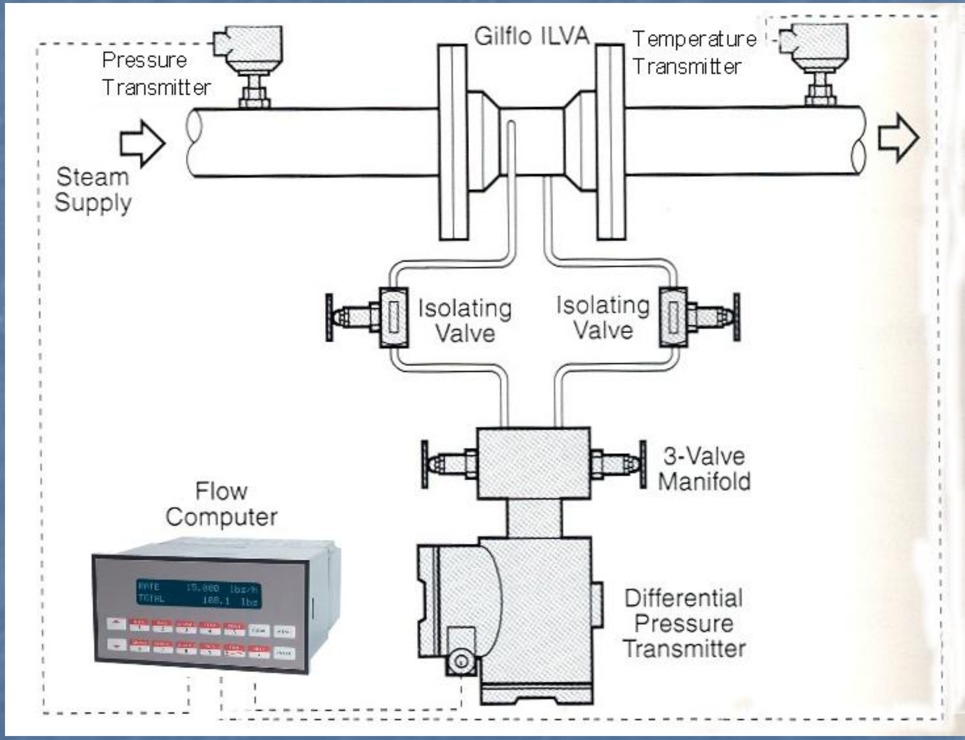


Gilflo and ILVA Flow Meter Principles

- Produces a differential pressure approximately linear with flow rate - movable cone pushes against spring with larger area at higher flows
- Much wider turn down range than other differential producers
- Linearization by table (or equation) and with temperature corrections for spring constant
- Factory calibrated on water- with results extrapolated for flowing density and temp.

Gilflo and ILVA

- Wide flow turn-down range w/differential pressure output
- Output DP nearly linear with flow
- Calibrated on water

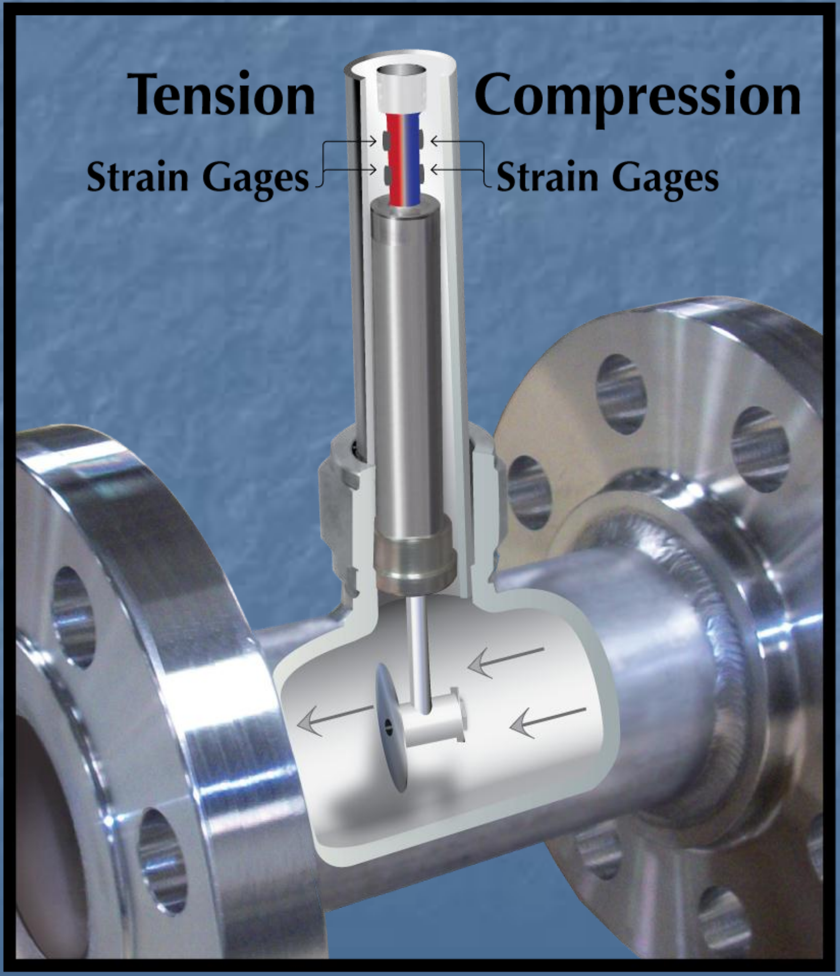


Target (or Obstruction) type Flow Meter Principles

- Essentially a square law flow meter with integral, direct strain gauge electrical output (No diff. pressure to deal with)
- Insertion and In-Line type available
- Size of target can be selected to create desired measurement range
- 15:1 flow range

Target Meter Equation

- Analog Output =
- Cd * Density * V^2 * At /2
- where:
  - Cd is empirical
  - Density is at flowing
  - V^2 velocity squared
  - At is area of target

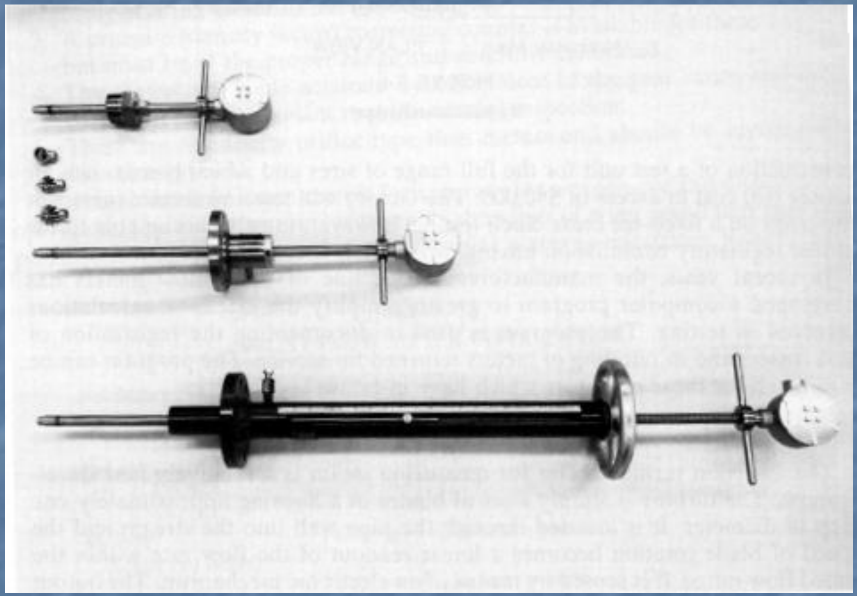


Linear Insertion-type Flow Meter Principles and Techniques

- Types included - Insertion Turbine and Insertion Vortex devices with pulse output linear with point velocity at the insertion depth and/or over its sensitive area
- Seeks to apply a mathematical corrections arrive at the average velocity in the line from that measured a known insertion depth from assumed flow profile
- Also applies mathematical corrections for its blockage effects and operating temperature on the meter run
- Pressure and/or temperature are used to imply steam density

Representative Insertion Turbine Flow Meters

- Intended for mounting on full port isolation valve
  - Can be fully retracted into housing
  - Close isolation valve
  - Service meter head



Some Pro's and Con's of Insertion Types

- Pro's
  - 10:1 - 20:1 Turndown
  - Measures velocity to +/- 1%
  - Can be hot tapped into existing lines
  - Access for maintenance
  - Low pressure drop
  - Inexpensive initial cost in large line sizes
- Con's
  - Not as accurate as in-line techniques
  - Dependent on flow profile & swirl & empirical data
  - Turbine type needs regular, seasonal maintenance
  - External leakage around seals potential area of concern

Additional Steam Metering Techniques

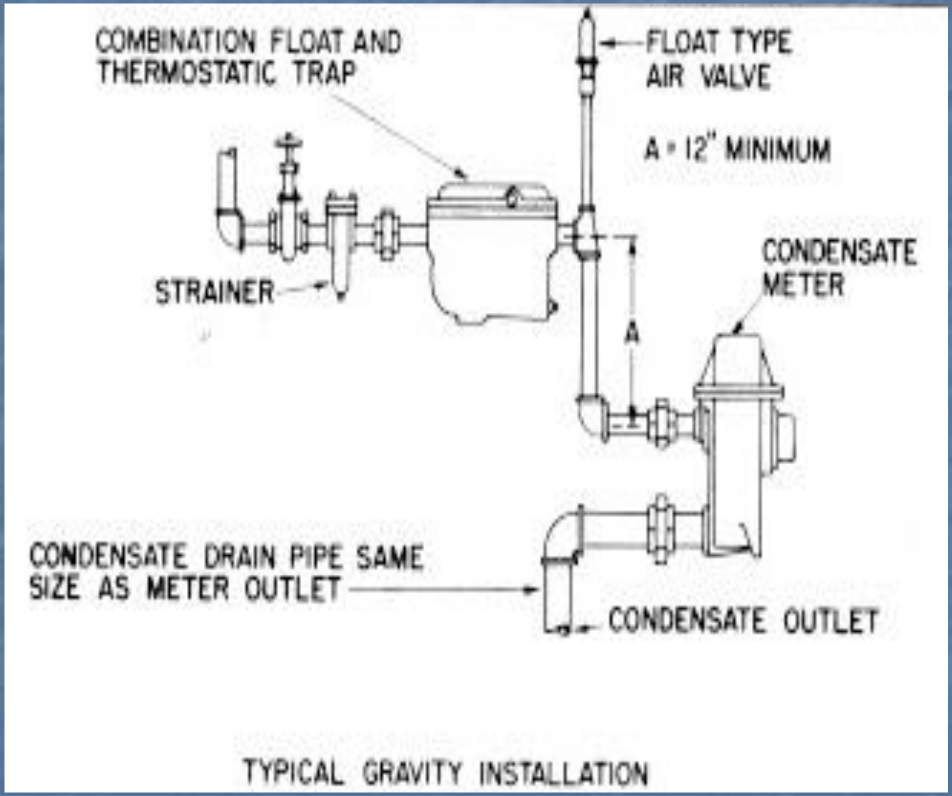
- Shunt Flow Meter
- Flow Meter Manifold -applications where two or more flow meters are used to achieve the required turndown range
  - Series connection involves 2 meters plus one control valve and manifold controller unit
  - Parallel connection involves base meter system that brings one or more larger meter on line as the flow rate increases

Condensate Flow Meter Principles and Techniques

- Suitable for totalization of condensate (which is assumed to follow inlet steam usage).
- The condensate flow pattern may be irregular, particularly in pumped condensate systems
- Output linear with volume flow
- May include an electronic pulser on shaft
- Calibrated on water for equivalent pounds of water at 140 F reference temperature
- Mathematical corrections can be applied for other condensate temperatures
- Steam line can be sensed for energy calculations

Condensate Meter

- Pro's
  - wide measurement range
- Con's
  - 2-3 year maintenance
  - Requires <u>all</u> but <u>only</u> condensate be metered



Ultrasonic type Flow Meter Principles and Techniques

- Measures average velocity of material passing through a narrow ultrasonic beam in the flow meter run by measuring the transit time in two directions using two oriented sensors a known distance apart. Assumes uniform velocity profile outside of the beam
- Computes volume flow rate from pipe area and velocity and density from temperature/pressure
- Applies mathematical corrections for operating temperature induced changes in the meter run

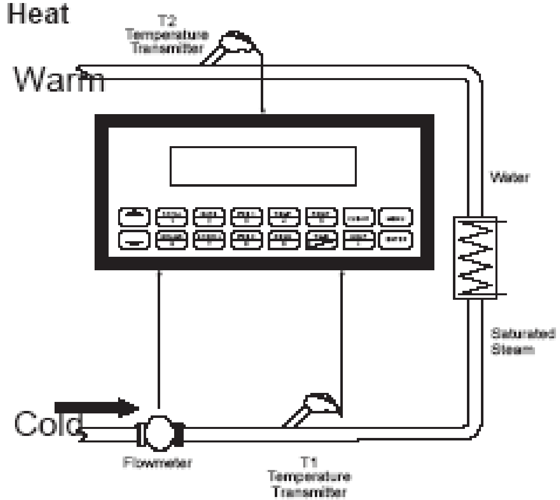
Ultrasonic Steam Flow Meter

- 2"-48"
- 20 Dia. up/10 Dia. down
- +/- 1% to 2% accuracy of velocity
- 0.1 to 150 fps
- Low pressure drop
- Tolerant of dirty systems
- Single or Multiple path
- Possible to mount on existing piping with care

A two-path PanaFlow meter system

District Energy
Chilled Water Metering

Liquid Delta Heat Illustration



Calculations

Water

Heat $= \text{Volume Flow} \cdot \rho(T1) \cdot [h(T_2) - h(T_1)]$

Other heat carrying liquids

Heat $= C \cdot \text{volume flow} \cdot (1 - \alpha \cdot (T_1 - T_{ref}))^2 \cdot \rho_{ref} \cdot (T_2 - T_1)$

α = Thermal expansion coefficient $\cdot 10^{-6}$
C = Mean specific heat
$\rho(T1)$ = Density of water at temperature T_1
$h(T1)$ = Specific enthalpy of water at temperature T_1
$h(T2)$ = Specific enthalpy of water at temperature T_2
ρ_{ref} = Reference density
T_{ref} = Reference temperature

More Liquid Meter Types

- Electromagnetic
  - +/- 0.25% to 1%
  - Useful over 100:1
  - Low maintenance
- Positive Displacement
  - +/- 0.25% to 0.5%
  - 10:1 or wider range
  - Requires maintenance
- In-Line Turbine
  - +/- 0.25% to 1%
  - 10:1 or wider range
  - Requires maintenance

Traditional and New Roles for Flow Computers

Flow Computer features, functions, and roles

- Uniform instrument functionality at customer sites
- Flexibility of getting all the Heat (Energy) and Mass computations for Steam or Chilled Water in one unit
- Support for all flow meter types and output signals
- User selectable units of measure (lbs, hlbs, klbs, ...
- Stored fluid properties for steam and water
- Internal interval data-logging for later retrieval
- Variety of conventional outputs
  - Scaled pulse, analog output, relay alarms
- Communication options for remote metering
  - Modbus RTU RS485, Modem, Modbus TCP Ethernet, BACNET
- Built in test and documentation aids

Overview of the Flow Computer for steam applications

- Steam Monitoring
  - Mass Flow Monitoring
    - Lbs/Hr, with totalization in lbs
  - Heat (Energy) Flow Monitoring
    - Btu(s) available relative to water at 32 degrees F
      - Total Heat of Steam
    - Btu(s) used relative to condensate temperature (at saturated pressure)
      - Net Heat of Steam
    - Btu(s) used relative to condensate return temperature
      - Delta Heat of Steam

Overview of the Flow Computer in chilled/heated water calculations

- Heated and Chilled Water Monitoring
  - Volume and Liquid Mass Flow Monitoring
    - Gallons per Minute
    - Lbs/Hr **(Density Compensation)**
  - Heat Flow Monitoring
    - BTU(s) stored in condensate (respect to water at 32 F)
      - Liquid sensible heat
    - BTU(s) extracted from heat carrying liquid by monitoring temperature change across process (ie. heat exchanger)
      - Liquid delta heat

Some Goals for Remote Metering

- Remote meter reading of totalizer(s) monthly
- Data-logging of customer interval usage
- Easy and flexible access to other site information
- Use available communication infrastructure
- Low installation and monthly operating costs
- Use a shared communication channel for all metering devices at the customer site
- Verification of proper operation and/or problem notification and/or remote problem solving
- Feed data into existing database and billing program
- Security and access

Communication Alternatives

- Some alternatives when using a public channel
  - Dial up modem - periodic polling every hour
    - Plain, old, telephone (with or without caller ID)
    - Cellular telephone
  - Internet - real time metering every minute
    - Local provider option -DSL, T1, Cable, Wireless
    - Modbus TCP information exchange
    - Firewalls and IT Managers
- Some alternatives-if private channel
  - Company fiber-optic network buried along with piping

Tough customer questions and Customer Owned Checking Meters

- My bill can't be that high! Is this thing working?
- Why are these utility guys in here working all the time?
- Customer scrutiny and engineering review of utility meters, calculations, procedures, test methods and maintenance
- Checking Meter - A customer owned steam metering system installed in series with utility owned steam meter for verification of billing and connection to HVAC system
- Sub-Metering- Multiple customer owned steam meters intended for customers internal use in allocating costs between various departments or tenants within a facility

Information gathering from Customer Site - Increased focus on Steam System Safety

- Auxiliary Measurements from customer site using the existing communication channel
- Examples of polling for expanded information:
  - Supply and return line pressures
  - Readings from existing condensate meter
  - Monitoring of proper Steam Trap Operation
  - Room Temperatures in man-hole or customer site
  - Potential Flooding of Man-Holes
  - Remote customer shut-off by motorized valve
  - Condensate lift pump operation
- User defined alarm notification

Questions for Kessler-Ellis Products?

- richard@kep.com
- Versatile and Economical Instrumentation for Utility Metering Applications