Energy and Flow Measurement for Hydronic Systems

Presented By:

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Why Measure Thermal Energy?

To control something, you must first measure it…

Lord Kelvin

Non-Electric Utilities:

Chilled Water, Hot Water, Condenser Water
Saturated Steam
Natural Gas & Compressed Air
Typical Btu Measurement Applications

Campus Environments

Metering each building provides:

- Basis for cost allocation
- Growth planning data
- Promotes conservation
- Basis for LEED points
Typical Btu Measurement Applications

Central Plants

- Accurate kW/ton monitoring
- Boiler efficiency
- Chiller/Boiler staging
- Basis for LEED points
Typical Btu Measurement Applications

Submetering Within Buildings

[Diagram showing submetering within building floors]
Hydronic Cooling/Heating System

Heat Load Calculation:

\[ \text{Btu Rate} = \text{Flow Rate} \times \Delta T \times \text{Specific Heat} \times \text{Density} \]
Btu Measurement Accuracy Evaluation
Sources of Error Using Traditional Methods

- **Flow**
  - Meter accuracy
  - Signal D/A conversion
  - Control input offset

- **Temperature**
  - Sensor accuracy
  - Transmitter accuracy
  - Sensor matching
  - Signal transmission error
  - Control input offset

- **Resolution**
  - Of inputs
  - Of calculations

- **Specific heat corrections**
Building Automation or SCADA System

Traditional Approach to Energy Measurement in Hydronic Systems
The effect of using typical HVAC grade flow and temperature sensors into standard analog control system inputs for energy measurement is widely misunderstood.
Btu Measurement Accuracy Evaluation
Sources of Error Using Traditional Methods

Example: 6” pipe, 300 gpm, 10 degree F delta-T

- Flow Measurement Error
  - Combined Error = 1.6% of reading
- Temperature Differential (RTDs)
  - Combined Error = 0.5 to over 1 degree F

Total Energy Error = > 5% to 10% of Rate
Btu Measurement
With a Factory-Calibrated System

Btu Meter, Flow Meter and Matched Temperature Sensors Installed as a Complete, Factory-Calibrated System
Btu Measurement Accuracy Evaluation
Btu Measurement System

Flow Measurement Accuracy (turbine):
  +/- 0.5% to 1% of reading over wide flow range

Delta Temperature Measurement Accuracy:
  +/- 0.15°F  (+/- 1.5% of reading @ 10° delta-T)

Calculation Accuracy:
  +/- 0.05%
Error Analysis: Btu System

Typical HVAC flow velocity and 10 degree F delta-T

- Flow Meter (frequency output)
  - Combined Error = 0.5 to 1% of reading

- Bath Calibrated & Matched Temperature Sensors
  - Combined Error = 0.15 deg. F
    = 1.5% of reading

- Computational Error
  - Combined Error = 0.05 % of reading

Total Energy Error = 1.58 to 1.8% of Rate
Btu Measurement System

[Diagram showing a Btu Measurement System with components labeled as follows:
- Btu Meter
- Flow sensor
- Serial network communication to control system
- Campus chilled water loop
- Building load
- High "T" Sensor
- Low "T" Sensor]
Compact Btu Meters
For light commercial and residential use

- Inline flow meter, temperature sensors and BTU meter in a single compact package
- Low voltage or battery power
- Network or pulse output
- Typical sizes range from ½” through 2”
Temperature Sensors for Btu Measurement

- Should be calibrated and characterized over an application specific temperature range.
- Consider using a signal conditioner (transmitter) to provide current based output signal for stability over long wire runs vs. trying to control lead lengths.
- Consider the total differential temperature accuracy (including A/D conversion and transmitter error) relative to the actual delta-T to determine if the error (uncertainty) is acceptable.
Flow Meter Selection for Btu Measurement

Choose the flow meter that is most appropriate for the application or specification:

- Inline Turbine
- Insertion Turbine
- Inline Mag
- Insertion Mag
- Inline DP
- Insertion DP (Annular Element)
- Inline Ultrasonic
- Clamp-on Ultrasonic
- Inline Vortex:
- Insertion Vortex
Hot Tap Installation Detail
for Thermowell in Welded Pipe

INSTALLATION KIT COMPONENTS
1" NPT WELDED BRANCH OUTLET
1" CLOSE NIPPLE
1" FULL PORT BALL VALVE

HOT TAP ADAPTER
"O" RING SEAL
POSITION CLAMPING NUT
DO NOT OVER TIGHTEN

7/8" DIA MIN HOLE SIZE
WITHDRAWAL STOP
5-1/2"

DEPTH GAGE
NON-REMOVABLE CONDUIT BOX

THERMOWELL SHOWN WITHDRAWN INTO HOT TAP ADAPTER
Output Signal Options for BTU Meters:

• Pulse for Energy Total
• Analog (4-20 mA) for Instantaneous Load, GPM, Temps
• Serial Network Communication (LAN)

Open Communication protocols:

- BACnet® (MS/TP & IP)
- Modbus RTU (RS-485 & TCP/IP)
- LONWORKS® (FTTP)
- Industrial: Profibus & HART

(Proprietary ?)
Benefits of Btu Meters with Serial Network Communications

• Improved data accuracy
• All flow, temperature, and energy data available with a single network connection
• Reduces the need for additional controllers by eliminating the hard analog input points typically required for the BTU calculation.
• Reduced installation costs for wire and conduit
• Seamless Totalization Values throughout Network
Important Considerations for a Btu Measurement System

- System & Component Traceability
- Calibrated & matched temperature sensors with clearly defined differential error
- Standard Building Control Network communications protocol
- Single source for all system components and factory calibration of the entire system
- Serviceability & Re-calibration
Flow Meters
Measurement & Selection

Flow Measurement

A. Water
B. Steam
C. Gas
A. Definitions and Relationships

Rangeability – the range over which an instrument can measure
(i.e. 1-30 ft/s, 10-100 GPM)

Turndown – the instrument range specified as a ratio of high measured value to low measured value
(i.e. In above examples 30:1, 10:1)

Effective Turndown – the instrument range as related to the maximum flow of the specific application
(i.e. 1-30 ft/s, 30:1 turndown, 4 ft/s design max, yields a 4:1 effective turndown)
A. Definitions and Relationships

Accuracy – The ability of an instrument to make the measurement as referenced to a standard

Repeatability – The deviation of multiple measurements of the same quantity under the same conditions. Not a measure of absolute accuracy.

Linearity – The departure of the calibration curve from a straight line. Not a measure of absolute accuracy.
Typical Water Flow Meter Types

• **Turbine** – Best cost vs. performance
  - Insertion Turbine (1 ¼ - 72” pipes)
  - In-line Turbine (small pipes)
• **Full Bore Mag** – Highest accuracy
• **Insertion Mag** – no moving parts
• **Full Bore & Insertion Vortex Shedding**
• **Clamp-on Ultrasonic**
Differentiate “wet calibration” of the primary flow element vs. “calibration” of the transmitter.

Transmitters and electronics can be adjusted or “calibrated” against multi-meters and signal generators that may be “traceable to NIST standards”, but that have nothing to do with flow measurement.  

*(Some vendors use the term “NIST Traceable Calibration” very loosely, selling an un-calibrated primary element with a “calibrated” transmitter.)*
Calibration

Questions to ask:
Is every meter individually wet-calibrated?
How is the meter calibrated?
What is the calibration standard?
Installation Considerations - Straight Pipe Run Requirements

Most (All) flow meters require minimum lengths of straight pipe before and after the meter location to maintain accuracy.

Example of straight pipe run recommendation:
Velocity Profile of Water in Pipes

• Velocity profile is distorted by pipe obstructions and direction changes.

• Friction from the pipe wall “conditions” the velocity profile, eventually flattening the profile. (based on velocity and viscosity typically found in HVAC applications)

• LAMINAR Flow is needed
Straight Pipe Run Requirements

Actual upstream/downstream dimensions typically depend on type of pipe obstruction & meter type. Consider both “supply” and “return” for available pipe run.

![Evaluating Upstream Piping Conditions](chart)

- Better
- Straight Pipe
- Single Bend
- Pipe Reduction or Enlargement
- Outflowing Tees
- Inflowing Tees
- Worse
- Multiple Bends in Same Plane
- Multiple Bends Out of Plane
- Valve
Straight Run Requirements
Industry Standard   (Reality)

FLOW DIRECTION

9+ Diameters

Meter Location

Minimum downstream straight run distance

5 pipe diameters to single elbow

10 pipe diameters from a single elbow with 9 or more diameters upstream of the elbow

Minimum upstream straight run distance
General Piping Requirements

Insert meter at any angle to the run pipe in upper 1/2 of pipe. (Meter must always be perpendicular to the pipe)

THIS AREA ACCEPTABLE

Horizontal Run Pipe

Installation in vertical run pipes is also acceptable (Meter must always be perpendicular to the pipe)

FLOW

30% Downstream 70% Upstream

Available Straight Run*
Basic Flow Meter Configurations:

Basic Configurations (measuring what):

• Full Bore/Inline (volume or velocity)
• Insertion (velocity)
• Clamp-on (velocity)
A “full bore” or “inline” type flow meter occupies an entire pipe section. All flow must go through it.

**Basic Features:**
- Controlled measurement area = high accuracy
- Cost increases with size
- Installation or service requires shutdown (or bypass)
An “insertion type” flow meter measures flow velocity at a specific point (or several points) inside the pipe.

**Basic Features:**
- Price is independent of pipe size
- Hot tap feature allows installation and service with no shutdown – no bypass required
Clamp-on Type Flow Meters (velocity)

A “clamp-on type” flow meter is non-invasive and measures flow velocity along a specific pathway inside the pipe via ultrasonic sound waves (Doppler effect or transit-time differential).

Basic Features:
• Accuracy depends on proper installation.
• Price is independent of line size.
• Non-invasive installation.
Turbine Flow Meter Principle of Operation

Water strikes the blades of the turbine causing it to spin. The speed of the turbine is directly proportional to the velocity of the water. Turbine technology is inherently linear and repeatable, and is even used as a calibration standard in many applications.
Straight Run Requirements
ONICON Single Turbine Meter

- Minimum downstream straight run distance: 5 pipe diameters to any valve, elbow, fitting, etc.
- Minimum upstream straight run distance: 20 pipe diameters to any valve, elbow, fitting, etc.
Magnetic Flow - Principle of Operation
Faraday’s Law of Induction

- Four electrodes measure the induced voltage on opposite sides of the flow sensor. The two voltage readings are sampled and averaged.
- The induced voltage is directly proportional to the flow velocity and is independent of the fluid temperature, pressure or viscosity.
In-Line Mag Meter Principle of Operation

Accurate measurement depends on the generation of a uniform magnetic field.
In-Line Straight Run: 3d up & 2d downstream

Insertion Straight Pipe Run Requirements

<table>
<thead>
<tr>
<th>Upstream obstruction</th>
<th>Straight run required upstream of meter location</th>
<th>Straight run required downstream of meter location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single bend preceded by ( \geq 9 ) diameters of straight pipe</td>
<td>10 Diameters</td>
<td>5 Diameters</td>
</tr>
<tr>
<td>Pipe size reduction / expansion in straight pipe run</td>
<td>10 Diameters</td>
<td>5 Diameters</td>
</tr>
<tr>
<td>Single bend preceded by ( \leq 9 ) diameters of straight pipe</td>
<td>15 Diameters</td>
<td>5 Diameters</td>
</tr>
<tr>
<td>Outflowing tee / Pump outflow</td>
<td>20 Diameters</td>
<td>5 Diameters</td>
</tr>
<tr>
<td>Multiple bends out of plane</td>
<td>30 Diameters</td>
<td>5 Diameters</td>
</tr>
<tr>
<td>Modulating valve</td>
<td>30 Diameters</td>
<td>5 Diameters</td>
</tr>
</tbody>
</table>
Ultrasonic Transit Time

One transducer sends out a signal, in the direction of the flow of the fluid, which is reflected off of the far wall of the pipe and received by the other transducer.
Ultrasonic Transit Time

The process is then repeated in the opposite direction against the flow.
Ultrasonic Transit Time

By measuring the difference between transit times of ultrasonic waves travelling between two transducers, the processor accurately determines the flow velocity and direction of the fluid in the pipe.
Inline Differential Pressure

Traditional DP
Venturi / Orifice Plate
(liquids, steam & gases)

Limited Turndown
Principle of Vortex Shedding

When any liquid, gas or vapor in motion hits a solid body in its path, it flows around it, shedding vortices alternately on either side of the body.

The frequency of the vortices is directly proportional to the velocity of the flow.
Swirl Meters – What is a Swirl Meter?

- Like a vortex meter, swirl meters use the detection of pressure pulsations in establishing a frequency of pulsations relative to flow rate.
- Pulsations are formed within the meter using swirling vanes instead of separating the flow into vortices.
- Swirl meters require only 3D upstream and 1D downstream.
  - Vortex meters require a minimum of 15D upstream and 5 D downstream.
- Meters may be installed horizontally or vertically.
  - Must be full at all times of operation.
Swirl Meters – Cut-a-way

- Sensor
- De-Swirler
- Swirler
- Meter Body
Vortex/Swirl Meters – Installation Lengths

Vortex

- 15D
- 50D
- 25D
- Reduction

Swirl Meter

- Straight Pipe
- Process Control Valve
- 90° Elbow
- Reduction

Dimensions:
- 1D
- 3D
- 5D
- 25D
Mass Flow Measurement of Saturated Steam

Traditional Method: Flow, Temp and Pressure

- More complex to install
- Determining mass flow uncertainty is more involved

Recent Trend: Integral Density Compensation

- Less complex to install
- High accuracy easily achieved
Steam Meter Sizing
Challenges with HVAC Applications

Steam meters must be sized based on true system pressure and flow conditions for proper operation. Unfortunately, steam systems are not well understood and are typically oversized in the HVAC world, leading to the following problems:

- Choosing meters based on pipe size, without regard to operating conditions (meter size = pipe size = oversized!)
- Using PRV (pressure reducing valve) ratings to predict max flow conditions, especially when redundant PRV’s are used.
- Using total equipment load data to predict max flow conditions.
- Changing system pressure significantly after meters are sized and submitted.
Thermal Mass Flow Meter
Natural Gas & Compressed Air
Principle of Operation

Thermal mass flow meters directly measure the mass of the flowing gas by utilizing the principle of convective heat transfer.

Each Meter has a pair of encapsulated platinum sensors that are in direct contact with the gas.

The reference sensor measures the ambient gas temperature.

The flow sensor is self-heated.
Principle of Operation

As gas flows by the heated flow sensor, our proprietary sensing circuitry maintains a constant temperature differential between the two sensors.

The energy (mW) required to maintain this temperature differential is directly proportional to the mass flow.

There is no need for additional temperature or pressure compensation!

Note: Requires 8-15 diameters of straight run – Application Dependent
Hydraunic & Gas Utilities Metering Considerations

- Factory Calibrated BTU Sytem - Traceability
- Temp Sensor Pairing – improved BTU Calc
- Flow Metering Selection – Cost/Application
- Integration with Energy Monitoring System
- Serviceability
Hydraunic & Gas Utilities Metering
Benefits / Results

• Utilities Cost Allocation
• Central Utilities Growth Planning
• Promote Conservation
• Acquire LEED points
Energy and Flow Measurement for Hydronic Systems

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