Ultrasonic flowmeters meeting the flow measurement challenges of MACT RSR 63.670 --from Flare to Steam to Fuel Gas Measurement

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Global Product Manager
Flow Measurement in a Typical Flare System

Flare, Steam, Fuel Gas, CFD, flare. IQ

PILOT FLAME TIP

STEAM INJECTION

FLASHBACK PREVENTION SECTION

STEAM/AIR

FUEL GAS

PURGE GAS

MAKЕUP WATER

FLASHBACK SEAL DRUM

KNOCKOUT DRUM

Makeup water

Hydrocarbon/Oil water

Flare gas recovery system

Flare

Fuel gas

Steam

Flare main header

Flare lateral

DCS

RAW MATERIALS

PROCESS UNITS

SW: Flare IQ

Flare IQ

Meter Fuel Gas

Fuel Gas

Steam

Flare

Enough Straight Runs? CFD

Air

Fuel Gas

AIR

FUEL GAS

SPARK IGNITION DEVICE

Meter Fuel Gas

Meter Steam

Meter Fuel Gas
Refinery Sector Rule (RSR)

63.670

OVERVIEW OF REGULATION

• Includes ALL sources, not just new sources
• Flares must control, maintain and demonstrate a 96.5% combustion efficiency or a 98% destruction efficiency
• Flares must maintain a minimum combustion zone Net Heating Value of 270 BTU/scf and report values every 15 minutes
• Flares must operate with no visible emissions, except for periods not to exceed a total of 5 minutes during any 2 consecutive hours
• Flare tip pilot flame must be maintained and velocities may not exceed 400 ft/s
• Operators must measure and control all assist flows to assure that the combustion zone stays above the minimum Net Heating value
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum accuracy requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>±1% over normal measured range or 2.8 °C, whichever is greater</td>
</tr>
<tr>
<td>Flow rate for all flows other than flare vent gas</td>
<td>±5% over normal measured range or 0.5 GPM, whichever is greater for liquid flow</td>
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<td></td>
<td>±5% over normal measured range or 10 CFM, whichever is greater for gas flow</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>Flare vent gas flow rate</td>
<td>±20% of flow rate at velocities raging from 0.1 to 1 ft/s</td>
</tr>
<tr>
<td></td>
<td>±5% of flow rate at velocities greater than 1 ft/s</td>
</tr>
<tr>
<td>Pressure</td>
<td>±5% over normal operating range or 0.12 kilopascals, whichever is greater</td>
</tr>
<tr>
<td>Net heating value by calorimeter</td>
<td>±2% of span</td>
</tr>
<tr>
<td>Net heating value by gas chromatograph</td>
<td>As specified in performance specification 9 of 40 CFR part 60, appendix B</td>
</tr>
<tr>
<td>Hydrogen analyzer</td>
<td>±2% over the concentration measured or 0.1 volume percent, whichever is greater</td>
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</table>
## RSR 63.670 Flow Measurement Challenges

### TABLE 13 - CALIBRATION AND QUALITY CONTROL REQUIREMENTS FOR CPMS

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<tr>
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- **Low Flow Accuracy**
- **Cross Flow Complication**
- **High Flow Capability**
- **Turndown Ratio (Rangeability)**
- **High CO2 and High H2 Applications**
- **Lack of Straight Runs**
- **Cost of Ownership**
Transit-time Based Ultrasonic Flowmeter

Time = Distance / velocity

**NO FLOW**

\[ t_{up} = \frac{P}{c} \]
\[ t_{dn} = \frac{P}{c} \]
\[ \Delta t = t_{up} - t_{dn} = 0 \]

**WITH FLOW**

\[ t_{up} = \frac{P}{c - V \sin \theta} \]
\[ t_{dn} = \frac{P}{c + V \sin \theta} \]
\[ \Delta t = t_{up} - t_{dn} \]
Theory cont.: Transit Time Technique

\[
\frac{1}{t_{dn}} = \frac{c - V \sin \theta}{P} \quad \text{and} \quad \frac{1}{t_{dn}} = \frac{c + V \sin \theta}{P}
\]
\[
\frac{1}{t_{dn}} - \frac{1}{t_{up}} = \frac{c + V \sin \theta}{P} - \frac{c - V \sin \theta}{P}
\]
\[
\frac{1}{t_{dn}} - \frac{1}{t_{up}} = \frac{2V \sin \theta}{P}
\]

\[V = \frac{P}{2 \sin \theta} \left( \frac{1}{t_{dn}} - \frac{1}{t_{up}} \right)\]

Since \( \sin \theta = \frac{L}{P} \),
\[V = \frac{P^2}{2L} \left( \frac{1}{t_{dn}} - \frac{1}{t_{up}} \right)\]

**Soundspeed**

\[c = \sqrt{\frac{\gamma RT}{M}}\]

- \(\gamma = 1.404\) (adiabatic constant)
- \(R = 8.314\) J/mol K (gas constant)
- \(T\) - Temperature (°K)
- \(M\) - Molecular mass (kg/mol)

<table>
<thead>
<tr>
<th>Gas</th>
<th>(C) (ft/s, m/s)</th>
<th>Liquid</th>
<th>(C) (ft/s, m/s)</th>
<th>Solid</th>
<th>(C) (ft/s, m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1125, 343</td>
<td>Water (68°F, 20 °C)</td>
<td>4862, 1462</td>
<td>SS116</td>
<td>10236, 3120</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>1400, 427</td>
<td>Water (450°F, 262°C)</td>
<td>4003, 1220</td>
<td>CS1018</td>
<td>10598, 3230</td>
</tr>
<tr>
<td>Steam</td>
<td>1640, 500</td>
<td>Kerosene</td>
<td>4344, 1324</td>
<td>Copper</td>
<td>7415, 2269</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1150, 351</td>
<td>HC (400°F, 204°C)</td>
<td>3500, 1067*</td>
<td>NT wedge</td>
<td>8150, 2484</td>
</tr>
<tr>
<td>Oxygen</td>
<td>1070, 326</td>
<td>HC (600°F, 316°C)</td>
<td>3000, 914*</td>
<td>PVC</td>
<td>7874, 2400</td>
</tr>
</tbody>
</table>

*Approximate value

- **H2**: 4165 ft/s, 1270 m/s

**Accuracy** = \(100\% \ast \frac{C^2}{2L} \delta(\Delta t) / V_0\)
Flare Gas: History

- EXXON, BAYTOWN, TX
- Joint-Venture
- Measuring Flare Gas
- $$$ Savings

1980 - Project Begins
1982 - First Installation @ Exxon
1998 - 1200+ Installations Worldwide

Impedance-Matched Metallurgically Sealed Transducers

United States Patent
4,754,650
July 8, 1988

Applicant
Smilling et al.

Assignee
Pamplin

Inventors
Jack W. Smilling

Date of Patent
July 8, 1988

Inventors Assigned
Patent Number
Pamplin

Inventors
Jack W. Smilling

Inventors
Pamplin

Abstract

A new class of gas ultrasonic flow meters are provided. Such meters are suitable for measuring fluid flow rates. They are particularly suitable for measuring gas flow rates.

The present invention relates to gas ultrasonic flow meters. Such meters are typically used to measure the volume flow rate of gas. The present invention provides a new class of gas ultrasonic flow meters that are simple in design and inexpensive to manufacture.

The present invention provides an apparatus for measuring gas flow rates. The apparatus includes a transducer that produces an ultrasonic signal. This signal is then transmitted through the gas to be measured. The signal is then detected by a receiver that provides a signal proportional to the gas flow rate. The present invention is particularly useful for measuring gas flow rates in unobstructed spaces. It is also useful for measuring gas flow rates in areas where traditional gas flow meters would be impractical or impossible to use.

The present invention provides an apparatus for measuring gas flow rates that is simple in design and inexpensive to manufacture. It is particularly useful for measuring gas flow rates in unobstructed spaces. The present invention is also useful for measuring gas flow rates in areas where traditional gas flow meters would be impractical or impossible to use.

The present invention is particularly useful in applications where accurate measurement of gas flow rates is critical. This includes, but is not limited to, applications such as natural gas distribution, chemical processing, and power generation. The present invention provides a reliable and accurate method for measuring gas flow rates in these applications.

The present invention is also useful in applications where traditional gas flow meters would be impractical or impossible to use. This includes applications such as measuring gas flow rates in unobstructed spaces, where traditional gas flow meters would be impractical or impossible to use. The present invention provides a reliable and accurate method for measuring gas flow rates in these applications.

The present invention is also useful in applications where traditional gas flow meters would be impractical or impossible to use. This includes applications such as measuring gas flow rates in unobstructed spaces, where traditional gas flow meters would be impractical or impossible to use. The present invention provides a reliable and accurate method for measuring gas flow rates in these applications.
Flare Gas Flowmeter: “Flow-cell”

When ultrasonic transducers are arranged relative to each other to make a flow measurement, a “flow-cell” is created.

Two types:
- Spool-piece
- Hot-tap (or cold-tap)

Configurations:

- Diagonal 45
- Mid Radius Bias 90
- 90-180 Diagonal
- Pipe Rack
- Off Diameter Diagonal 45
- Hole Saw
- Hot Tap Drill
Flare Gas Flowmeter: Advanced Performance

- Extended Velocity Range
- Low Flow Range
- Composition Compensation
  – CO₂, H₂, N₂ and Steam
An ultrasonic flowmeter has been developed and tested for high-velocity gas measurement up to 123.7 m/s in air. The accuracy of the new meter is demonstrated to be better than 3-4% with reference meter uncertainty included, and the relative standard deviation of the new meter is within 1.2%.
Flare Gas Flowmeter: High Flow Rate

Calibration Example: 38"

<table>
<thead>
<tr>
<th>Pt.</th>
<th>MtrRead</th>
<th>ACFH</th>
<th>ReyNo</th>
<th>LBMS</th>
<th>Velocity</th>
<th>Mtr Vel</th>
<th>Error</th>
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<tr>
<td>1</td>
<td>17.240</td>
<td>6979539.1</td>
<td>4551182</td>
<td>128.07</td>
<td>238.70</td>
<td>228.25</td>
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<tr>
<td>2</td>
<td>18.576</td>
<td>6596888.3</td>
<td>3964192</td>
<td>316.32</td>
<td>242.63</td>
<td>235.81</td>
<td>-2.806</td>
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<tr>
<td>3</td>
<td>13.864</td>
<td>5220771.6</td>
<td>3203704</td>
<td>93.34</td>
<td>194.41</td>
<td>184.96</td>
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<tr>
<td>4</td>
<td>11.610</td>
<td>4065750.6</td>
<td>2518721</td>
<td>73.04</td>
<td>149.54</td>
<td>132.85</td>
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<tr>
<td>5</td>
<td>8.020</td>
<td>2596785.8</td>
<td>1602907</td>
<td>40.54</td>
<td>95.51</td>
<td>92.42</td>
<td>-3.034</td>
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<tr>
<td>6</td>
<td>7.995</td>
<td>2035422.1</td>
<td>1247477</td>
<td>35.30</td>
<td>74.86</td>
<td>72.95</td>
<td>-7.556</td>
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<tr>
<td>7</td>
<td>6.538</td>
<td>1180470.4</td>
<td>654661.9</td>
<td>19.74</td>
<td>43.42</td>
<td>43.84</td>
<td>0.409</td>
</tr>
</tbody>
</table>

Average values for above results:
Press: 22,888 Pica
Density: 0.062807 lbm/ft³
Temp: 519.81 °R
Viscosity: 0.009566 lbm/sec/ft²
Compressibility factor: 0.99967

The calibration was performed in accordance with CEESI QA Manual (Rev. 1), Procedure No. 10 and MIL-STD 45662A.

This calibration is: [ ] As Found [ ] As Left
Low Flow Accuracy Testing

For flow velocities above 0.1 ft/s, the flowmeter accuracy is within 5%, and for flow velocities above 1 ft/s, the flowmeter accuracy is well within 4% (raw data).

- Path Length must balance signal strength and resolution.
- New T17 transducer improves signal strength by 3-4 times (10 dB).
- This allows a longer Path Length, improving low flow velocity accuracy.
- High flow velocities are also still measured.
Application of Two Crossed Paths

– Cancel/Reduce Cross Flow

CFD and experiments results and have shown:
• Two-cross path is the best practical solution to improve cross flow immunity.
• For one path, certain configurations are better than others in terms of immunity to cross flow.
Problem: Limited Straight Run
Solution: CFD models to compensate flow profiles

- Truly developed flow profiles in gas are not full until sometimes, up to 80D
- Ultrasonic Flare meters can compensate well at ~20D
- CFD models can be used to:
  - Define optimized meter location AND path configuration
  - Increase tolerance to non-perfect flow
  - Determine correction factors for know disturbances
  - Enable 2-5% accuracy
Flow Profile: Laminar, Transitional and Turbulent

Flow Profile Regimes

Laminar

- Stratified, parabolic profile
  - $Re = 0$ to 2000

Transitional

- Undefined profile
  - $Re = 2000$ to 4000

Turbulent

- Flattened profile
  - $Re = >4000$
Assumption: Fully Developed Flow Profile

• **Straight-Run Requirements**

• 20D Upstream/5-10D Downstream

• **Disturbances**
  • bends
  • valves
  • tees
  • insertions
CASE Study: A US Refinery

- Define optimized meter location AND path configuration
- Determine correction factors for the disturbance
- Enable 4-5% accuracy with a total straight run of 6D
  - *Without CFD, this would be a 15% accurate meter at best!*

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BHGE Ultrasonic Steam Meter

Steam Applications: Two Ranges

High Temperature and Pressure ✤ > 200°C, to 24 MPa

Superheated Steam

Low Temperature and Pressure ✤ <250°C, <1.7 MPa

Saturated Steam
Steam Flow Meter: Flowcell and Cold-Tap

Low temperature & pressure

IMA71 Insertion Mechanism Holder
- Adapted from Flare Gas Flowmeter
- **Low pressure** removal/insertion
- Spool Piece
- **Cold-Tap only (NOT Hot-Tap)**
- CS, SS, 2”/3” 150/300lb. ANSI flange port
- No NDF (Noise Dampening Fitting)
- Pipe size 4” to 48”/path length: 5.6” to 13”
- **Bias 90 or Diagonal 45**
- High Temp packing
- Gasket: Spiral Wound

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BHGE Ultrasonic Steam Flowmeters

**Total Cost of Ownership**
- No pressure drop
- Minimum/None Maintenance
- Accuracy across the range (low flow)
- Large Rangeability (high turndown ratio)

<table>
<thead>
<tr>
<th></th>
<th>Initial Meter Cost</th>
<th>$ to cover Range-ability</th>
<th>$ to overcome pressure drop</th>
<th>$ for Maintenance (calibration, service or repair)</th>
<th>Total Cost of Measurement / Ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULTRASOUND</td>
<td>$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>$</td>
</tr>
<tr>
<td>VORTEX</td>
<td>$</td>
<td>NA</td>
<td>$</td>
<td>$</td>
<td>$$$$</td>
</tr>
<tr>
<td>ORIFICE PLATE</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$$$$$$$</td>
</tr>
<tr>
<td>TURBINE</td>
<td>$</td>
<td>NA</td>
<td>$</td>
<td>$</td>
<td>$$$$</td>
</tr>
</tbody>
</table>

GS868 Specifications

**Operation and Performance**

**Fluid Types**
Saturated and superheated steam

**Pipe Sizes**
2 in to 48 in NB (50 mm to 1200 mm DN)

**Pipe Materials**
All metals. Consult GE for other materials.

**Flow Accuracy (Velocity)**
±1% to 2% of reading typical

Accuracy depends on pipe size and whether measurement is one-path or two-path. Accuracy to ±0.5% of reading may be achievable with process calibration.

**Repeatability**
±0.2% to 0.5% of reading

**Range (Bidirectional)**
-150 to 150 ft/s (~46 to 46 m/s)

**Rangeability (Overall)**
1500:1
Fuel Gas

Value Proposition:

• No moving parts
• No pressure drop
• Wide rangeability with 150 to 1 turndown ratio
• Non-obstructive flow measurement
• Tolerance to dirty streams
• Low maintenance

BHGE Ultrasonic Gas Meters

ZXG/Z2G/Z1G

XGM/T5

PanaFlow
Ultrasonic Flowmeters can help to comply...including Flare, Steam, and Fuel Gas
Steam Flow Meter: BWT Technology

High temperature & pressure

BWT® System
- BWT1 Style Transducer
- Buffer - keep transducer cool
- Max Velocity: 120 ft/sec (37 m/sec)
- Max Steam Temp: 842 F (450 C)*
- Transducer Removable

FTPA (FTPA3) Buffers
- 150# to 2500# Flange rating
- Min pressure: 200 psia
- Max Pressure: To Flange Rating
- Path Length: 6 to 12”
- 1-1/2’’ Lap Joint Flange
- Gasket: KammProfile
- * Special Mineral coated gasket for steam temp to 550C

FIPA Buffers
- 150# to 300# Flange Rating
- Extra Isolation
- Min Pressure: 30 psia
- Max Pressure: To Flange Rating
- Path Length: 6 to 12”
- 1-1/2” Lap Joint Flange
  - with 1”isolation flange
- Gasket: KammProfile
  - Garlock™ Graphite

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