NIST Experiences with Multipath Ultrasonic Flow Meters for Stack Applications

NIST Workshop
Improving Measurement for Smokestack Emissions

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How accurate can CEMS ultrasonic flow measurements be made?

- Single path?
- X-pattern?
- Other Multipath Configurations?
  - 2 path X-pattern Mid Radius
Application:
Power Plant Smokestack Flow Measurements

\[ \dot{m}_{\text{GHG}} = \int y_{\text{GHG}} \rho u \, dA \]

USM
Velocity

Usually measured by a single, diametric path
Application:
Custody Transfer of Pipeline Scale Natural Gas

Natural Gas Meter Station in Roswell New Mexico

Multipath Ultrasonic Flow meter

Flow

Measurement Performance Typically < 0.3 %
Flow is Complicated

Real stacks have swirl and turbulence
NIST’s Scale-Model Smokestack Simulator (SMSS)

Unique Capabilities
1) Generates complex smokestack-like flows in a 4 ft test section.
2) Measures the bulk flow to better than 0.7% uncertainty using NIST traceable flow standard

Test Bed to Assess the Performance of CEMS Multipath Ultrasonic Flow Meters
1) 8 path ultrasonic flow meter measures flow to better than 0.5%

2) Stack flow conditions (high swirl and skewed velocity profile) realized by sharp corner section

3) CEMS Flow Monitor installed in SMSS Test Section
   - Single path ultrasonic flow monitors
   - X-pattern ultrasonic flow monitor
CEMS USM Installed in 4ft Test Section of SMSS
(Ultrasonic Flow Meter Path Layout)

- USM pipe spool incorporates both single path and X-pattern designs
- Path 1 is vertically oriented at a 45° path angle with respect to pipe axis
- Paths 2 and 3 form a X-pattern configuration (i.e., crossing paths) and are oriented horizontally at a 45° angle with respect to pipe axis
Single Path Orientations

- Path orientation significantly affects measurement performance (absolute errors range from 5 % to 17 %)
• X-pattern ultrasonic flow meter compensated for swirl and had **errors of only 0.5 %** over entire flow range
• More immune to changes in flow pattern
1) **Flow complexity caused by the sharp corner** upstream of test section (*i.e.*, complexity due to flow installation effect)

2) **Flow complexities** due to installation effects *vary from stack to stack*

3) Do the results hold up for different flow complexities?
• 3ft diameter fan installed in air intake unit
• Air inlet velocity into cone without 3ft fan is approximately 3 m/s
• Cross flow velocity attributed to 3 ft fan is 5.5 m/s
1) CEMS flow meter and *Calibrated Reference Flow Meter* (i.e., an 8 path USM) are subjected to the cross flow

2) The 8 path ultrasonic flow meter (USM) by virtue of its design is largely immune to installation effects

3) Must verify the accuracy of 8 path before assessing CEMS
8 Path REF USM
(8 Path Reference Section Ultrasonic Flow Meter)

- Cross paths compensate for swirl (e.g., 1A and 1B)
- Paths in same plane compensate for velocity profile effects (e.g., 1A, 2A, 3A, 4A)
- Diagnostics of Multipath USM
  - Speed of sound
  - Average temperature
  - Estimate of turbulence intensity
8 Path Reference Section USM
(Sensitivity to Cross Flow)

- **Cycled fan on/off at 20 sec intervals**
- **Cross flow Introduced by Fan at Inlet**

![Diagram](image)
What is the effect of cross flow on the CEMS USM installed in the test section? Single path? Cross Path (or X-pattern)?

- Average flow velocity of 8 path USM remains constant to within 1% flow stability of the SMSS facility
- Demonstrates the 8 Path compensates for cross flow (i.e., swirl) and profile effects
$CF_2 = \frac{V_{\text{path2}}}{V_{\text{TEST}}}$

9 percent shift in calibration factor attributed to fan generated cross in air intake unit
Test Section
(CEMS USM Paths 2 & 3 Calibration Factor)

Results with Fan Off

$CF_{2+3}$

$V_{TEST} \ [m/s]$

Crossing paths reduce shift attributed to fan generated cross in air intake unit from 9% to 2%
Summary of Ultrasonic CEMS Flow Monitor

• Single path CEMS
  ❖ Absolute errors ranged from 5 % to 17 %
  ❖ Single path performance depends on installation angle
  ❖ Subject to load dependent calibration factor (3 %)
  ❖ Not immune to changes in upstream flow field (changed by 9 % due to fan cross flow)

• X-Pattern CEMS
  ❖ accuracy of 0.5 % in SMSS facility
  ❖ Calibration factor independent of load
  ❖ immune to changes in upstream flow field relative to single path (changed by 2 % due to fan cross flow)
Desired RATA Field Test
(NIST wish List)

• **Assess NIST calibrated 3D probe in Real Stack**
  o Compare Method 2F vs. NIST non-nulling Method
  o Repeat traverse with same probe to determine typical reproducibility errors at constant load
  o Repeat traverse with different 3D probe to assess probe specific uncertainties
  o Measure Stack Turbulence Level

• **Ideally, testing would be done at the same time with 2 X-pattern ultrasonic flow meters 90° apart**

• **Field test would occur at a power plant with natural gas fuel**
Questions?