Diagnostic Analysis of Velocity Profile using an 8-path Gas Ultrasonic Meter

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Contents

• Introduction – why 8-paths?
• Swirl and multipath USMs
• 8-path type approval results
• USM diagnostic parameters
• Comparison of 4-path and 8-path profile diagnostics, with and without flow conditioners
Introduction – why 8-paths?

• The original promise of gas USMs was that they would deliver the benefits of being non-intrusive and low maintenance

• However, with experience, use of flow conditioning has become very common

• There is an underlying assumption in the early multipath designs that each path supplies a measure of axial velocity

Westinghouse patents filed 1968 & 1975
British Gas (BG) patent filed 1986

History of Caldon meters

- 1970’s – Westinghouse Leading Edge Flow Meter (LEFM) technology applied in a range of industrial applications
  - Nuclear, petroleum leak detection, hydroelectric
History of Caldon meters

• 1989
  – LEFM technology acquired by Caldon Inc.
  – Initial focus was on applications in the nuclear industry
• 1999
  – 8-path liquid meter re-introduced into the LEFM product line

History of Caldon meters

• Circa 1980 – Hydro electric power industry
  – First 8-path meters installed in turbine penstocks by Accusonic and Westinghouse (later Caldon)
Technique described by Lowell in 1977

Flow Measurement in Open Channels and Closed Conduits

Volume 1

Proceedings of the Symposium on Flow Measurement in Open Channels and Closed Conduits held at the National Bureau of Standards in Gaithersburg, Maryland on February 23-25, 1977

What’s the difference relative to BG?

• Lowell said:
  – “errors can be reduced by the addition of one or more acoustic paths, at the same elevations as the original ones but installed at the opposite angle. Exact cancelation of errors can be accomplished on the crossed paths and an estimated of the cross-flow component used to adjust the readings on the non-crossed paths”
The effects of swirl

- Non-axial flow components (swirl) result in systematic errors in individual path velocities

4-path, planar config. (Westinghouse 1975)
- With a planar arrangement, swirl only cancels when perfectly centred
4-path, planar config. (Westinghouse 1975)

- 60 degree path angle, swirl error = 0.45 %

4-path, non-planar config. (BG 1986)

- In this case swirl cancelation relies on combination of dissimilar chords
4-path, non-planar config. (BG 1986)

- 60 degree path angle, swirl error = -1.09 %

Eight-path crossed plane design

- Swirl error = 0 % (analytical)
Why not use a flow conditioner?

Conditioner initial profile complexity

- The complex profiles created by flow conditioners are not fully symmetric about the pipe centre and have to travel some distance downstream before they smooth out.
Velocity profile integration errors
• The conditioner presents a slightly ‘lumpy’ profile, but the ultrasonic meter prefers a relatively smooth profile, even if asymmetric

ISO 17089
• “Installing a flow conditioner at any position in the meter run upstream of the USM will cause a change of the meter’s indicated flowrate. This change depends on many factors (e.g. flow conditioner type, meter type, position relative to the USM, flow perturbation upstream of the flow conditioner, etc.) . . . To avoid this additional uncertainty, the best option is that the USM is calibrated with the actual flow conditioner and meter tube as one package (USMP).”
Implications

• If a flow conditioner is to be used the meter should be calibrated along with its flow conditioner in the correct location and orientation
• This setup should be carefully maintained in the field
An alternative solution

• If we dispense with the flow conditioner, then the maintenance concerns (and pressure loss) are eliminated, and only the meter itself need be sent to the lab for calibration.

• Potential objections:

  • Does this involve a compromise in terms of accuracy?

  • How can velocity profile diagnostics be used in the absence of a flow conditioner?

Installation effect testing
**Installation effect testing**

- Tests performed using bend configurations as prescribed by ISO17089 and OIML R137 (2012)

<table>
<thead>
<tr>
<th>Test</th>
<th>Test conditions</th>
<th>Remedies</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Reference conditions</td>
<td>approx. 10 D straight line</td>
</tr>
<tr>
<td>b</td>
<td>A single 90° bend</td>
<td>radius elbow 1.5 D</td>
</tr>
<tr>
<td>c</td>
<td>Double out-of-plane bend</td>
<td>rotating right radius elbow 1.5 D</td>
</tr>
<tr>
<td>d</td>
<td>Double out-of-plane bend</td>
<td>rotating left radius elbow 1.5 D</td>
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</tbody>
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**Installation changes for each disturbance**

- 5D
- 15D
- CPA
Installation test acceptance criteria

• AGA 9 & ISO 17089
  – Additional error due to the installation configuration < 0.3%

• OIML R137 (2012) Class 0.5
  – Error shift of less than 0.167 % at rates of 0.25, 0.4 and 1 x q_{max}
Significance of the 0.5 accuracy class

- In terms of installation effects the reduction of the allowable bias from 0.3 % to 0.167 % means a reduction in bias/uncertainty of around 0.1 %
- For a single 12-inch high pressure gas meter this can equate to around €350,000 per annum

Summary of test results and analysis

- 8-path data can also be broken down into four different 4-path arrangements
Comparison of 8-path results with published results downstream of bends from GERG and GRI projects.
Other meters with CPA and 10D vs 8-path without

![Diagram showing flow weighted mean error (%) for different meters with CPA and 10D vs 8-path without GRI and GERG.](image)

So what about the velocity profile diagnostics?
Preconceptions from meters with < 8-paths

A flow conditioner is needed to ensure transfer of calibration with low uncertainty.

Velocity profile diagnostics are then required to ensure that the calibration conditions are preserved.

• Could take the view that this is a circular argument and that by disproving the first point you invalidate the second one.

Multipath USM diagnostics

• Path level diagnostics
  – Signal detection (gain, SNR, performance)
  – VOS and transit time comparisons
  – Turbulence

• The 8-path meter provides a larger set of data for comparative analysis of the above

• Velocity profile diagnostics
  – Profile factor, asymmetry, swirl and cross-flow
Diagnostic definitions

• Profile factor (profile flatness)

Plane A

1 2
3 4

2 + 3
1 + 4

BG 1

A
B + C
A + D

A
B
C
D

1 2 3 4
5 6 7 8

2 + 3 + 6 + 7
1 + 4 + 5 + 8

Diagnostic definitions

• Asymmetry

Plane A

1 2
3 4

1 + 2
3 + 4

BG 1

A
A + B
A + B

B + C
C + D

A
B
C
D

1 2 3 4
5 6 7 8

1 + 2 + 5 + 6
3 + 4 + 7 + 8
Diagnostic definitions

• Cross-flow or Plane Balance

Limitations of 4-path velocity profile metrics

• Klaus Zanker, in a paper published at the NEL America’s Workshop in 2009, said:
  “In general four paths are not sufficient to resolve any arbitrary 3-dimensional flow field containing asymmetry, swirl, peaked or flat profile and cross flow.”

• Lowell in 1977 pointed out that a crossed pair of paths at each elevation in the meter resolves the swirl/cross-flow issue
Diagnostic definitions
• Transverse velocity at each chord height

Plane A

BG 1

Straight pipe baseline
**4-path planar (Westinghouse)**

Axial velocity profile

Transverse flow (swirl)

**4-path non-planar (British Gas)**

Axial velocity profile

Transverse flow (swirl)
8-path Caldon LEFM380Ci

Axial velocity profile

Transverse flow (swirl)

5D, single bend, paths horizontal
4-path planar (Westinghouse)

Axial velocity profile

Transverse flow (swirl)

4-path non-planar (British Gas)

Axial velocity profile

Transverse flow (swirl)
8-path Caldon LEFM380Ci

Axial velocity profile

Transverse flow (swirl)

5D, double bend, paths horizontal
4-path planar (Westinghouse)

Axial velocity profile

Transverse flow (swirl)

4-path non-planar (British Gas)

Axial velocity profile

Transverse flow (swirl)
8-path Caldon LEFM380Ci

Axial velocity profile

Transverse flow (swirl)

Double bend, 5D – CPA – 10D
Monitoring of profile factor and asymmetry

- Guidance for 4-path meters from the PRCI ‘Smart ultrasonic meter’ project (Zanker and Floyd, 2010):
  - Profile Factor: +/- 5%
  - Asymmetry: +/- 3%

- Guidance for 8-path meters (Caldon):
  - Profile Factor: +/- 10%
  - Asymmetry: +/- 6%
4-path planar (Westinghouse)

Flow Weighted Error Shift shown next to corresponding data series

- OIML R137 (2012)
- Severe disturbance

4-path non-planar (British Gas)

Flow Weighted Error Shift shown next to corresponding data series

- OIML R137 (2012)
- Severe disturbance
4-path non-planar – zoom in

8-path LEFM 380Ci – ALL DATA
Conclusion – questions

- Is it better to have a meter that requires strict control over the velocity profile or one that is insensitive to profile effects?
- Is the need to maintain the conditioner a risk you can manage or live with?
- What about the logistics and cost of calibrating the full package?
- What can a 4-path meter with conditioner deliver in terms of diagnostics, that an 8-path meter can’t?