

Wet Gas Ultrasonic Meter Diagnostics

ASGMT USM Diagnostics Advanced Overview

Duane Harris, Endress+Hauser, Inc.

1. Introduction

Pipeline Operators have used Ultrasonic meters commercially for gas custody transfer applications since the late '90's. These meters' combination of operating features, including superior rangeability and on-board diagnostics have made this the technology of choice for most high volume gas metering applications. As user comfort with, and capabilities of, the technology has increased and the size and cost of ultrasonic meters has decreased, Operators and Manufacturers continue to stretch the envelope of application possibilities. This includes use in upstream, midstream, and downstream markets with sometimes corrosive and high CO₂ applications, where the technology previously couldn't work or didn't make economic sense.

With these meters' proliferation both in numbers and use-cases, the need to apply "smart meter" diagnostics is of increased importance to identify and address operating issues early that may affect measurement accuracy. Near real-time data requirements are demanded by wide-spread business restructuring of gas transportation Pipelines into MLP's (Master Limited Partnerships) in the wake of de-regulation. These new business structures require daily cash-out and balancing in many cases, and monthly accounting settlement of transportation accounts in all cases, so the facility to recognize and fix measurement problems within an accounting period (i.e., prior to month-end business close) is imperative to avoid what have become in the MLP era, painful PPA's (prior period adjustments).

Meter manufacturers have long touted the diagnostic aspect of USM technology and over the intervening years since first publication of AGA TMC Report No. 9 in 1998, the companion software used for diagnostic analysis of meter performance has greatly improved through continuing development of the root meter technology and through field operating experience. Smart and consistent analysis of USM diagnostics can flag operating problems early, permit users to determine if measurement integrity/accuracy are in doubt and allows operators to take proactive steps to resolve issues on a close to real-time basis to avoid the business pain caused by the need for out-of-period gas accounting adjustments.

Improved software function however does not cover all bases so it is incumbent on operators to develop an understanding of both basic and extended USM diagnostics to recognize when problems may be occurring so remedial action can be taken before significant impact on fiscal measurement occurs. Manufacturers also have a responsibility to deploy diagnostic software with clear guidance for application with ease-of-use as a priority, and many have responded with automated diagnostic evaluation of USM's via these software tools.

Given the variety of operating environments and the way USM diagnostics work, there are challenges to dial in the specific information you are looking for. Diagnostics can 1) definitively flag problems and 2) provide insight on the degree to which such problems affect measurement accuracy. Some operating problems, such as failed hardware or noise, are easy to spot and rectify, but in most cases a holistic approach to collecting and interpreting diagnostic information is needed to relate meter behavior to causes that may affect measurement accuracy.

General explanation of how USM diagnostics work in common with most manufacturers leads to deeper discussion and exposition how they relate to specific metering problems follows. Using diagnostic profiles for the USM helps provide a roadmap for recognizing abnormal meter response and relating that response to pipeline operating conditions that may skew gas measurement. Actual operating examples of field measurement problems identified through use of these diagnostics are presented herein along with remedies. Discussion of automating diagnostics, data reduction and piping

facilities design, is included with a view toward providing operating personnel information regarding best practice deployment of USM's and subsequent application of diagnostic evaluation.

2 Basic Diagnostics & Operating Environment for Wet Gas

It is important to take an eyes open approach to facilities design especially when reviewing wet gas measurement facilities. One of the key challenges with wet gas measurement is the actual Gas Volume Fraction (GVF) vs the Liquid Volume Fraction (LVF). Today the concept of wet gas measurement would consist of a 100% GVF to 98% GVF or a 0% LVF to 2% LVF under normal operations. Realizing upset conditions can occur that may significantly exceed the 2% LVF however the meter station is not designed to be a multiphase measurement facility.

Many problems can be avoided during the design phase by taking prudent steps to address the better known issues that typically cause measurement error with USM's; for e.g.:

- **noise concerns** (for e.g. as caused by pinched valves generating interfering ultrasonic noise),
- **meter fouling** (for e.g., collection of liquids in a meter run) and
- **profile disturbance generators** (for e.g., bends and blind tees that may generate swirl and/or asymmetry in the flow profile.
- **Flow conditioners** (for upstream Wet Gas facilities typically do not operate with a flow conditioner.

It must be emphasized that diagnostics can identify but not fix problems. Any steps taken at the design phase to minimize the occurrence and subsequent impact of issues is highly desirable, and a guiding design principle might be: "Don't design problems into a meter stations". Additionally, any meter station design features that can ease routine and "special", or remedial, maintenance should also be considered and deployed when feasible. (for e.g., access to the meter runs and electronics; potential need to remove and replace a meter run; access to, and facility for, cleaning meter runs and meter... These factors should be considered during station design.)

Diagnostics common to all USM's are:

- Automatic Gain/Power Control
- Speed of Sound (SOS)
- Path Velocity
- Signal-to-noise ratio (SNR)
- Transducer Performance
- Turbulence

Additional diagnostic parameters may include the following:

- Profile Factor
- Symmetry

Brief explanations of the nature and relevance of these basic diagnostics follow, but these diagnostics need to be related to the context of the meter's operating principal and environment so users can make the connection between what the **diagnostics reflect in an operating meter's response and what those outputs suggest is happening with the gas inside the pipe**... What happens with gas flow in the pipeline, and its effects on meter performance, are what drive accuracy problems that need to be recognized and fixed.

More often than not, if there is a problem inside the pipe that the meter's diagnostics are responding to, more than one diagnostic will show anomalous output. It is the combination of these diagnostic responses and evaluation of them that

guides users toward the specific cause of degraded and/or changed meter performance that may affect measurement accuracy. A holistic approach in evaluating these diagnostics is needed to paint the full picture of meter response and in deducing whether meter accuracy is impaired. Possible remedial actions include:

- Repair and/or replacement of components
- Removal, cleaning and replacement of individual transducers
- Cleaning of meter, meter run and/or FC, either in-situ or by removal
- Repair and/or replacement of secondary components (transmitters, etc.)

2.1 Transducer Gain Level

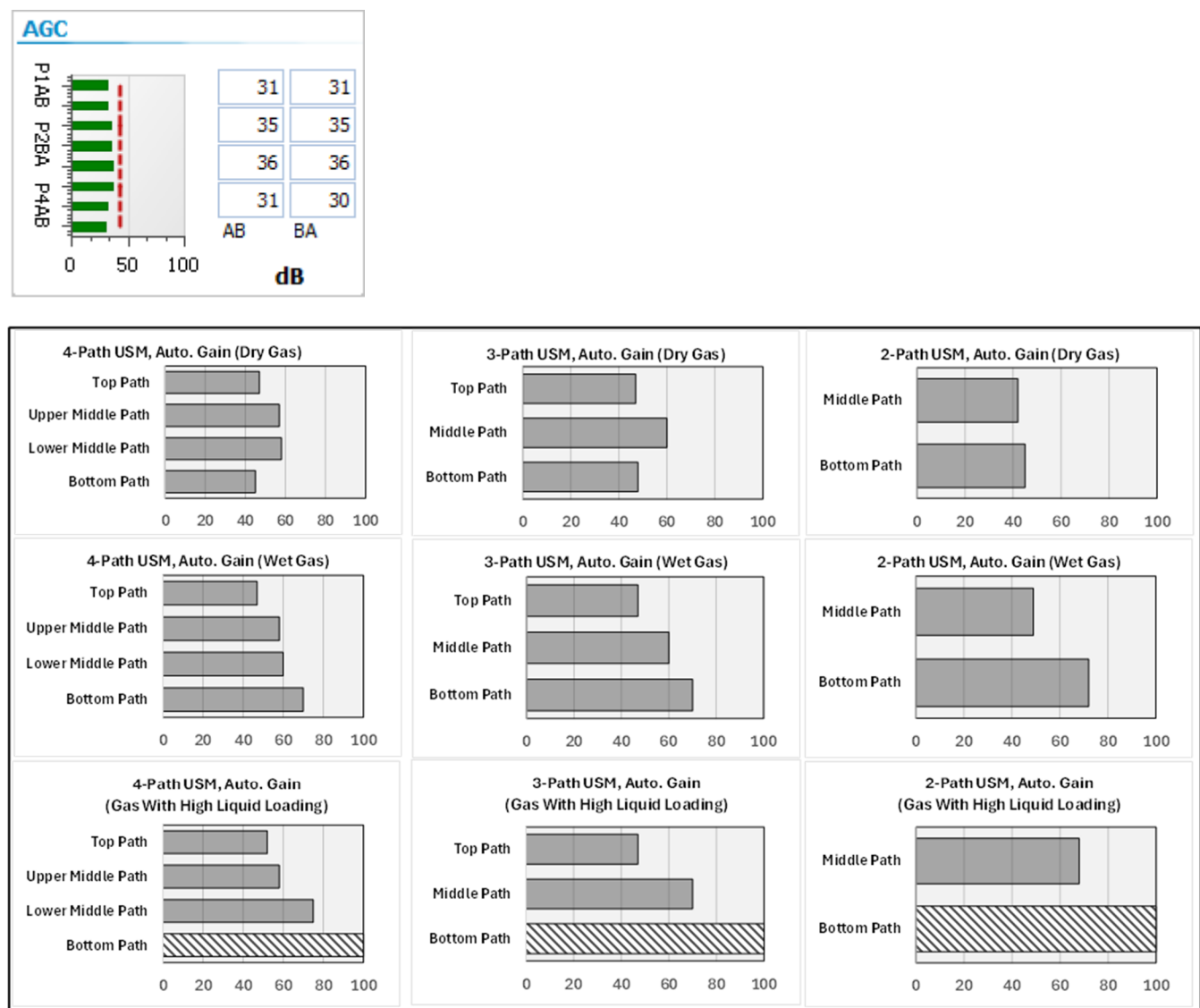


Figure 1 - Automatic Gain/Power Control (dB)

Dry vs. Wet Gas vs. Gas with High Liquid Loading Bar Graphs for 4-Path, 3-Path, 2-Path USMs[†]

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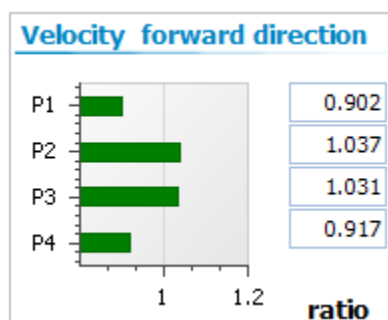
Pulse signals received by transducers from their path companions are amplified with automatic gain controls to improve pulse detection. Gains typically increase when signal recognition becomes more difficult such as in noisy environments, (for e.g. when gas rates are higher), or if debris is collecting on the transducer. Gains can also go high if a transducer is damaged or failing. It is often useful to compare gain levels as pairs by using the ratio of their levels to determine if one or the other of the transducers is struggling to detect signals. A high gain level on one side of a path might occur if the transducer concerned faces a noise source or if selective deposition occurs fouling the transducer face.

2.2 Average & Per Path SoS

Speed of Sound (SoS) is a critical and powerful diagnostic tool available in ultrasonic meters from which users can determine if a meter's **functional** performance has shifted. Two tests can be made using meter "measured" values for SoS: 1) an absolute comparison of meter corrected SoS versus that calculated from the gas' thermodynamic properties and 2) a per path comparison to determine if an outlier on a particular path suggests it's path length has changed, or more commonly, if pulse misdetection is occurring (path length changes are due either to meter configuration input errors, physical installation errors or debris build-up on transducer faces).

USM's depend on time and distance (clock and path length) to make accurate pulse transit time measurements and the absolute SoS comparison discussed below validates both. But this diagnostic does not by itself assure that meter accuracy isn't impacted by other factors such as fouling that result in bad flow profiles or diametric reduction.

2.3 Per Path Gas Velocity

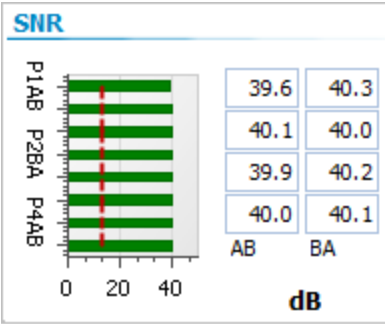


Maps of the per path gas velocities should be made from meter logfiles at each flow rate during meter flow calibration and during meter commissioning, or default values for relative velocity patterns need to be established. Profile and symmetry factors are often used to set default values, which technique is used in evaluating whether the relative path velocities have shifted, leading users to understand if disturbed flow profiles are present. These defaults can then be used to determine if flow profile has shifted.

USM's are flow profile dependent as regards maintaining meter accuracy, and as explained in the operating principals below, if a flow profile at a given flow rate differs significantly from that experienced by the meter at flow calibration, there is a shift in meter factor, or to put it more bluntly, a bias error is introduced because the bulk velocity calculation in the field has a different result than in the calibration lab.

Disturbing elements such as blind tees, out of- and in-plane bends, headers and meter run blockage with debris, can cause flow disturbances that the flow conditioner might not remove. Additionally, fouling of the meter run with liquids, black powder, asphaltines, paraffin, etc., can cause the flow pattern to change with resulting flow measurement inaccuracies. Profile analysis indicates a possible shift in meter output and depending on the severity of profile discrepancy might suggest the nature of the problem, but most times a visual inspection of the meter run is needed.

2.4 SNR



Signal to Noise Ratio, or SNR, indicates when the background noise approaches the limits of automatic gain adjustments. SNR values approaching a 1:1 level usually signify that ambient noise has made pulse detection impossible. “Ambient noise” refers to the ultrasonic noise present in the gas flow stream and is most often generated by throttled control valves. If there is too much noise, pulse signal detection becomes impossible and measurement stops.

2.5 Accepted Pulses

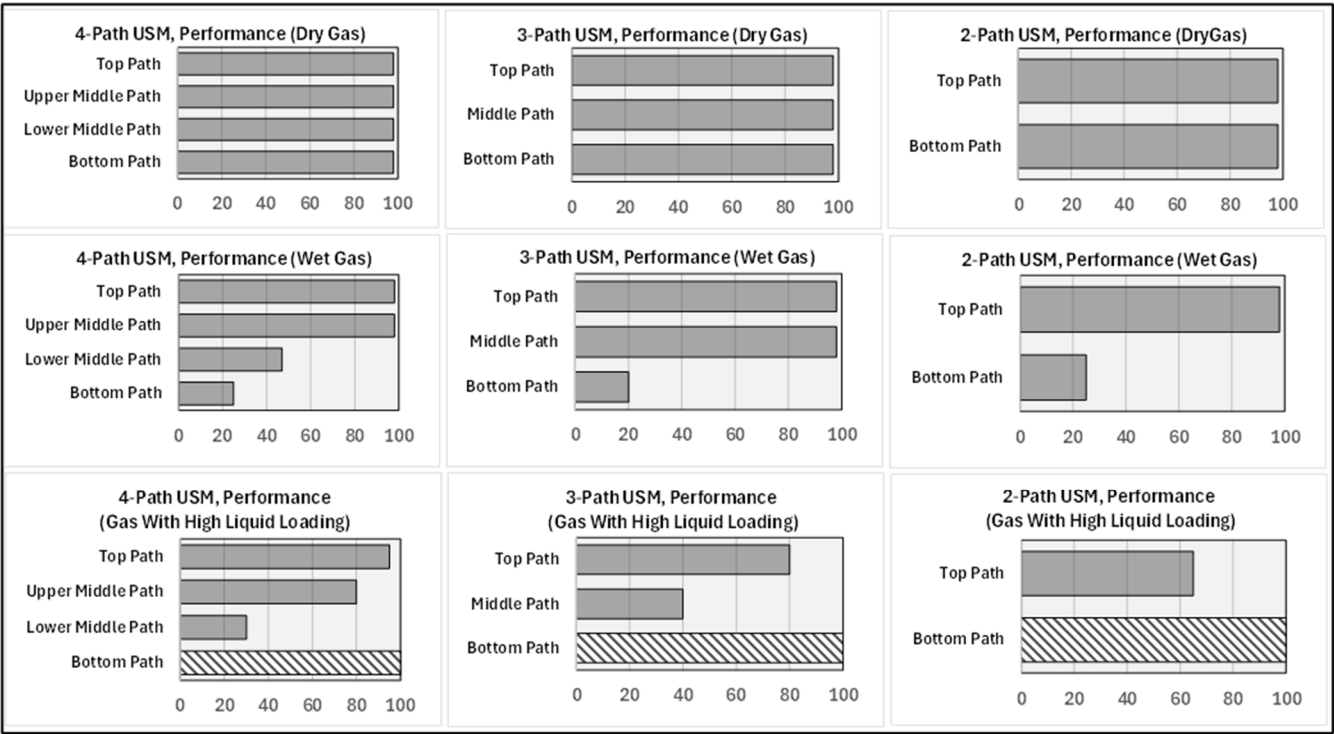
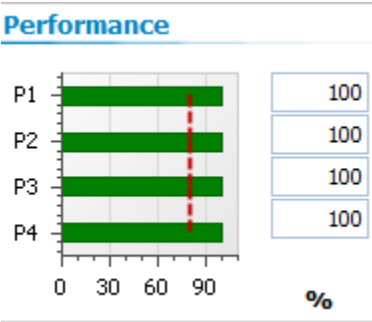


Figure 2 - Transducer Performance (Percent)

Dry vs. Wet Gas vs. Gas with High Liquid Loading Bar Graphs for 4-Path, 3-Path, 2-Path USMs[†]

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All USM’s employ detection criteria to validate transducer pulses that are used for transit time measurements. When these criteria are not met, the pulse is rejected. Rejection rates are noted in diagnostics by logging the number of accepted pulses. Noise, damaged transducers or fouling, among other mechanisms, might cause pulses to be rejected and high rejection rates should be evaluated for cause in tandem with other diagnostics. This might include visual inspection of the meter run or transducers and a review of detection criteria to insure they are relevant to the operating environment.

2.6 Turbulence

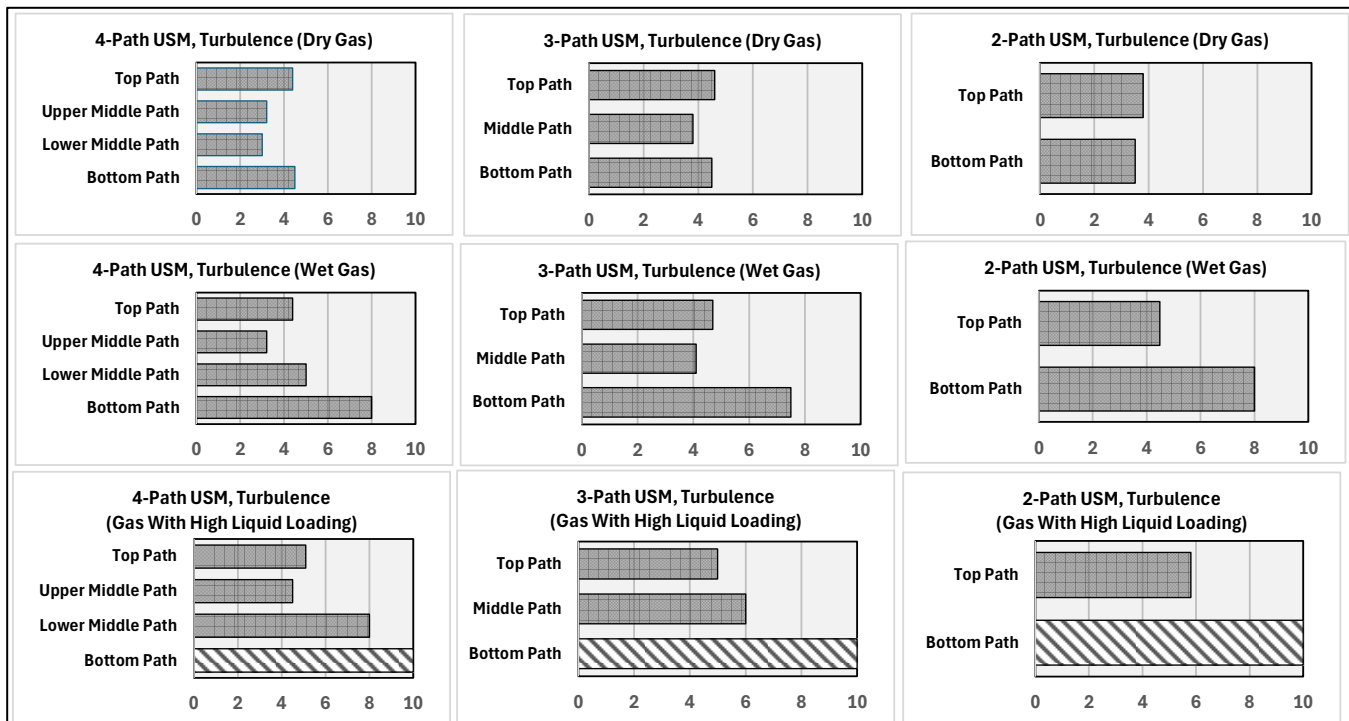


Figure 3 - Turbulence (Percent)

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USMs send multiple pulses per second in each direction, for each path, and this information is used to compute an average upstream and downstream transit time once per second. Each of these individual readings will not be the same, due to the nature of gas flow having some profile variability from one moment to the next.

The term Turbulence is not a measure of the fluid turbulence as defined in classical fluid dynamics and is not related to the flowing Reynolds number. It is used to describe the variability of each path’s gas velocity. Meters generally compute Turbulence by calculating the standard deviation of each path’s transit times.

3.0 Error Propositions, Operating Environment and USM Diagnostic Responses

A number of error propositions or possible modes of error were postulated above on the basis of the meter's operating principal with emphasis on 2 main areas:

1. Accurate, predictable bulk velocity calculation based on a stable and well characterized flow profile and,
2. Accurate pulse transit time measurement based on stable pulse detection with known path lengths.

In validating bulk velocity calculations, evaluation of "no-changes" in flow profile is required. Additionally, stable pulse detection and transit time measurements are needed, and are validated using SoS analysis.

3.1 Environmental Factors

A number of factors relating to potential profile distortion mechanisms were suggested above and recommendations made regarding flow profile review, as-installed versus as-calibrated. Additional external factors that should be considered for general effects are:

Factor	Influence on Flow	Diagnostic Response	Error
Flow Range; too low, too high	@ $v < 2$ fps, can cause gas stratification; @ $v > 130$ fps (line size dependent)	Per path SoS doesn't agree on low end; signal loss at high velocities (>130 fps)	Profile and temperature issues skew both corrected and uncorrected output; transit time errors on missed pulses
Temperature	@ $v < 2$ fps, can cause gas stratification	Per path SoS doesn't agree	Profile and temperature issues skew both corrected and uncorrected output
Pressure	High DP's can cause liquid drop out, pulsation causes time varying velocities	May see liquids: • w/high turbulence • velocity profile shift Pulsation w/unsteady profile and varying velocity outputs	Area blockage causes error in uncorrected volume calculation Liquids cause change in velocity profile. Pulsation skews average velocity value and meter doesn't track
Weather	At low velocities can contribute to stratification, liquid drop out.	Free liquids or freeze offs occur • High turbulence • Increased gains • Skewed velocity profile Signal rejection	Bad velocity measurements, area reduction.
Gas composition	Rich compositions subject to retrograde condensation; CO ₂ may attenuate signals	Free liquids or freeze offs occur • High turbulence • Increased gains • Skewed velocity profile Signal rejection	Bad velocity measurements, area reduction.
Contaminants Fouling potential (liquids, etc.)	Adheres to pipe wall; skews flow profile. Liquids block part of meter run, foul sensors.	Free liquids or freeze offs occur • High turbulence • Increased gains • Skewed velocity profile • Signal rejection	Bad velocity measurements, area reduction.
Fluid dynamic disturbances	Tees, protrusions, etc. cause disturbed velocity profiles	• High turbulence • Skewed velocity profile	Unstable velocity measurements, non-matching profiles might indicated bias error from installation effect.
Electrical interface (EMI, RFI)	Pulse accumulated Errors, Timing errors	SoS	Missed or added pulses can affect measurement totals
Electronics drift	Timing errors, scaling errors	SoS	Rare
Thermal expansion, pipe work, etc.	Path length errors	Per path SoS	Effect generally negligible
Ultrasonic noise	May cause no measurement	SNR < 1	Measurement outage
Foreign object	Skew flow profile	Per path velocity pattern, or Profile and Symmetry factors out of limits.	Unstable velocity measurements, non-matching profiles might indicated bias error from installation effect.

These environmental factors need be considered during the design, commissioning and operational phases of placing the USM station in-service and in maintaining a performance log over its installed life.

3.2 Design Factors

1. Meter sizing: check operating range, $Q_{\max}$ at $P_{\min}$, $Q_{\min}$ at $P_{\max}$.
2. Meter run design & construction: honed?, spool lengths, flow conditioner
3. Entry and exit piping: possible flow disturbance generators, noise attenuators
4. Installation: siphon drains, inspection ports, clean out tees, maintenance access and removal route
5. Throttled valves: Pressure or Flow control valves installed near a meter, location proximate to the meter, valve type, $Q_{\max}/\min$; ΔP .
6. Gas Composition: liquids, high CO₂, corrosive elements
7. Ancillary facilities: RTU, meter building, on-line GC, sample probe location, Data transfer
8. Calibration requirements: flow range, operating requirements.
9. Documentation: from Mfg. (material cert's), Flow Lab (cal cert), et al.

3.3 Commissioning Factors

1. Inspect meter run assembly: insure it is field installed identically as to that tested at the flow lab (labs commonly mark spools and provide an accompanying sketch)
2. Inspect Meter calibration certificate: insure the meter factor determined at the calibration lab is input to the meter's SPU; insure the appropriate linearization factors have been applied.
3. Log Files: insure that the diagnostic log files extracted during the flow calibration are accessible
4. Firmware & Software: Insure the correct version of firmware is installed in the meter, insure the appropriate version of software is installed on technician laptops.
5. Check Input/Output connections
6. Check Pulse scaling; insure it correlates with meter factor and calibration certificate; check pulse wave-form; check error frequency.
7. Copy, Save and date-stamp a meter config file.
8. Characterize As-Installed Diagnostics: Flow the meter at a variety of rates if possible: capture logfile data at each rate.
9. Inspection: Make a full routine inspection per company procedure; complete documentation and note commissioning date.
10. Records: Follow Company policy regarding retention of records as pertains to commissioning logs and Inspection Report.
11. Review diagnostic responses from calibration and commissioning logfile data for velocity profile, and other diagnostics comparison.
12. Make a flowing SoS check if not done as part of 9 above.

3.4 Factors in Routine Maintenance

1. Calibration Routine: Start by calibrating secondary devices, P, T and GC. Next, collect recent gas analysis and make meter inspection. By calibrating secondary devices first, one minimizes the possibility of an SoS error during meter inspection.
2. Collect diagnostic logfile and run against Manufacturer's maintenance/inspection tool.
3. Check for problems with:

- a. Meter vs. AGA 10 SoS: possible data input issue; otherwise, check gas stream unnormalized totals and if +/-2% of 100%, consider GC error (integration, calibration, unknown specie).
 - b. Per Path SoS Spread: if wide vis-à-vis baseline, check for pulse detection issues.
 - c. Velocity Profile
 - d. Turbulence
 - e. SNR
 - f. Transducer Gains
4. Save Logfiles, Session files, etc.

3.5 Special Maintenance

Components Replacement: From time to time, it may be necessary to replace components on a USM: the main parts of the meter are the signal processing electronics and the transducers. Neither of these has a significant failure history, however manufacturers do have specific procedures and Approval Data to support their use as regards electronics or transducer replacement.

Electronics: An SPU may require replacement if subject to a power transient like a lightning strike. If this is the case,

1. Secure copies of meter configuration file, calibration files including log files and certificates.
2. Follow Manufacturer instructions on how to transfer meter set-up from configuration file to program SPU.
3. Review implementation of meter and linearization factors; insure they match calibration values
4. Review output of meter, Diagnostic outputs as compared to those from calibration.
5. Sanity check on volume output(s): pulse scaling, accumulation, etc.

Transducers:

1. Secure copies of meter configuration files
2. Follow Manufacturer instructions on transducer change out:
 - a. Mechanical
 - b. Electrical
 - c. Programming of SPU w/new delay times, transducer characteristics.
3. Follow Manufacturer procedure to check indicated path SoS versus expected base-line.
4. Update soft copy and hard copy records with new transducer information and log files.

Conclusions

During the past several years the industry has learned a lot about USM wet gas operational issues. The traditional 5 diagnostic features, gain, signal-to-noise, performance, path velocities SOS, and turbulence have helped the industry monitor the USM. These 6 features provide a lot of information about the meter's health. Getting an initial baseline on the meter at the time of installation, and monitoring these features on a routine basis can generally identify metering problems in advance of failure.

Most operational problems with gas USM's are typically a slug of liquids moves the USM and takes a few seconds for the meter to recover after the slug has passed. Typical problems historically with the USM are fluid dynamics (i.e., disturbed flow profile) or related to meter performance outright (for e.g., a failed electronics), but can be recognized by diagnostics.

Originally the more advanced diagnostic indicators, such as Turbulence, were showing promise as tools to better focus on meter performance that has moved into a key diagnostic for wet gas measurement integrity to quickly identify

potential measurement problems on a real-time basis. This all depends on how the knowledge of diagnostics can be refined both in raw and interpreted forms.

As the industry learns more about not only the USM, and the operation of their own measurement system, the value of gas ultrasonic meter technology will continue to be recognized through wide-spread use. The USM industry is still relatively young and continuously improving technology will provide more tools to help solve today's measurement problems tomorrow.

REFERENCES

1. AGA Report No. 9, "Measurement of Gas by Multipath Ultrasonic Meters", 4th Edition 2022, American Gas Association.
2. AGA Report No 10, *Speed of Sound in Natural Gas and Other Related Hydrocarbon Gases*, July 2002, American Gas Association, 515 Wilson Boulevard, Arlington, VA 22209
3. GPA WG 77 Proposed Tentative Standard Working Group 77 Draft 2025, Multi-Path Ultrasonic Metering of gas at or Near Dew Point

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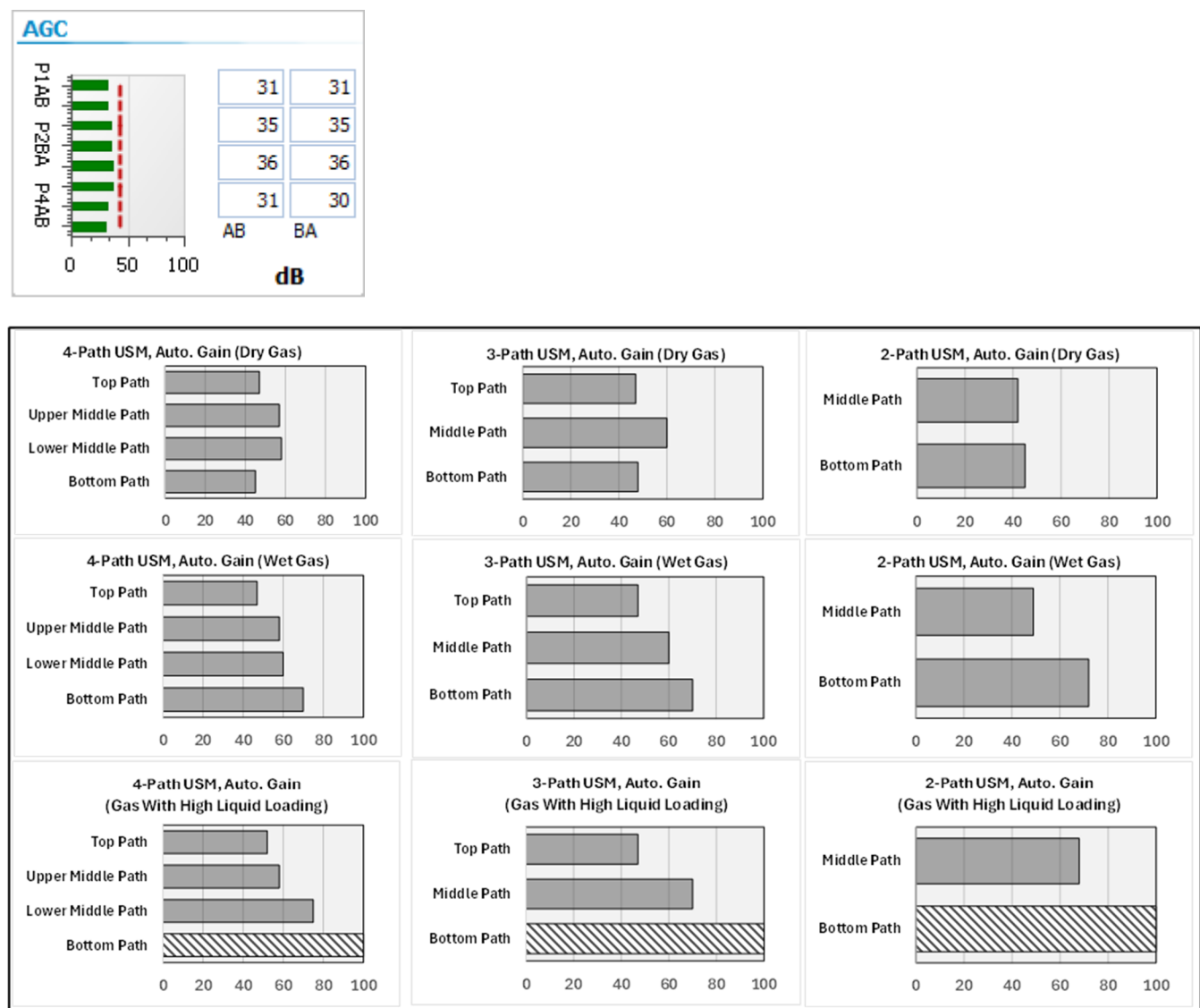


Figure 1 - Automatic Gain/Power Control (dB)

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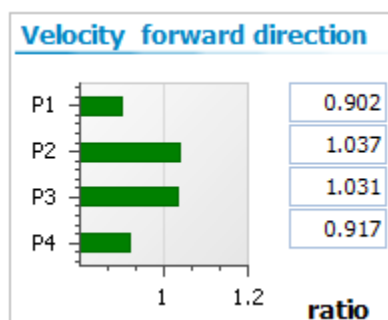
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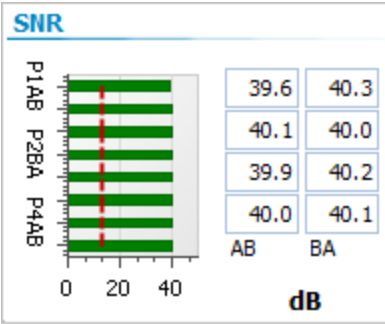


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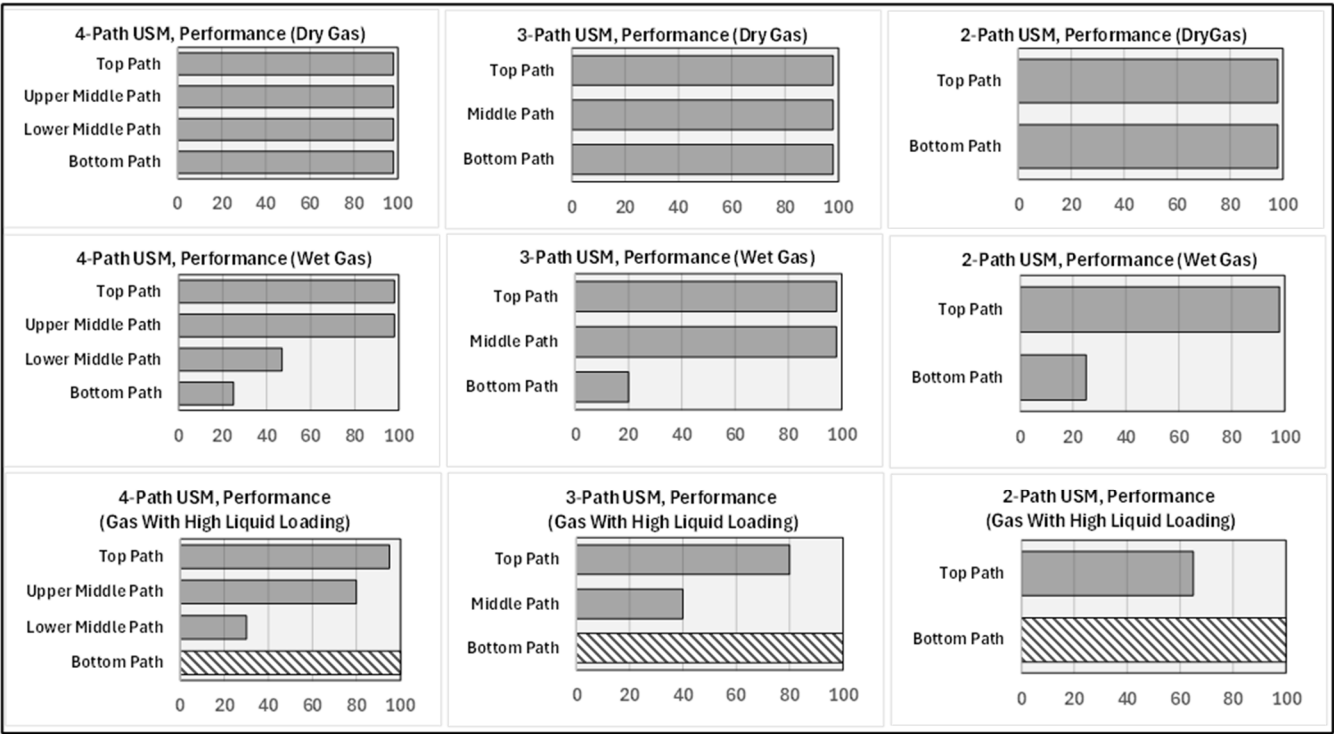
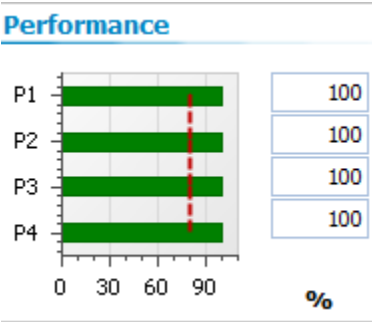


Figure 2 - Transducer Performance (Percent)

Dry vs. Wet Gas vs. Gas with High Liquid Loading Bar Graphs for 4-Path, 3-Path, 2-Path USMs[†]

[†] Hatched lines inside the bottom bar graph for “Gas with High Liquid Loading” indicate zero or no reading.

All USM’s employ detection criteria to validate transducer pulses that are used for transit time measurements. When these criteria are not met, the pulse is rejected. Rejection rates are noted in diagnostics by logging the number of accepted pulses. Noise, damaged transducers or fouling, among other mechanisms, might cause pulses to be rejected and high rejection rates should be evaluated for cause in tandem with other diagnostics. This might include visual inspection of the meter run or transducers and a review of detection criteria to insure they are relevant to the operating environment.

2.6 Turbulence

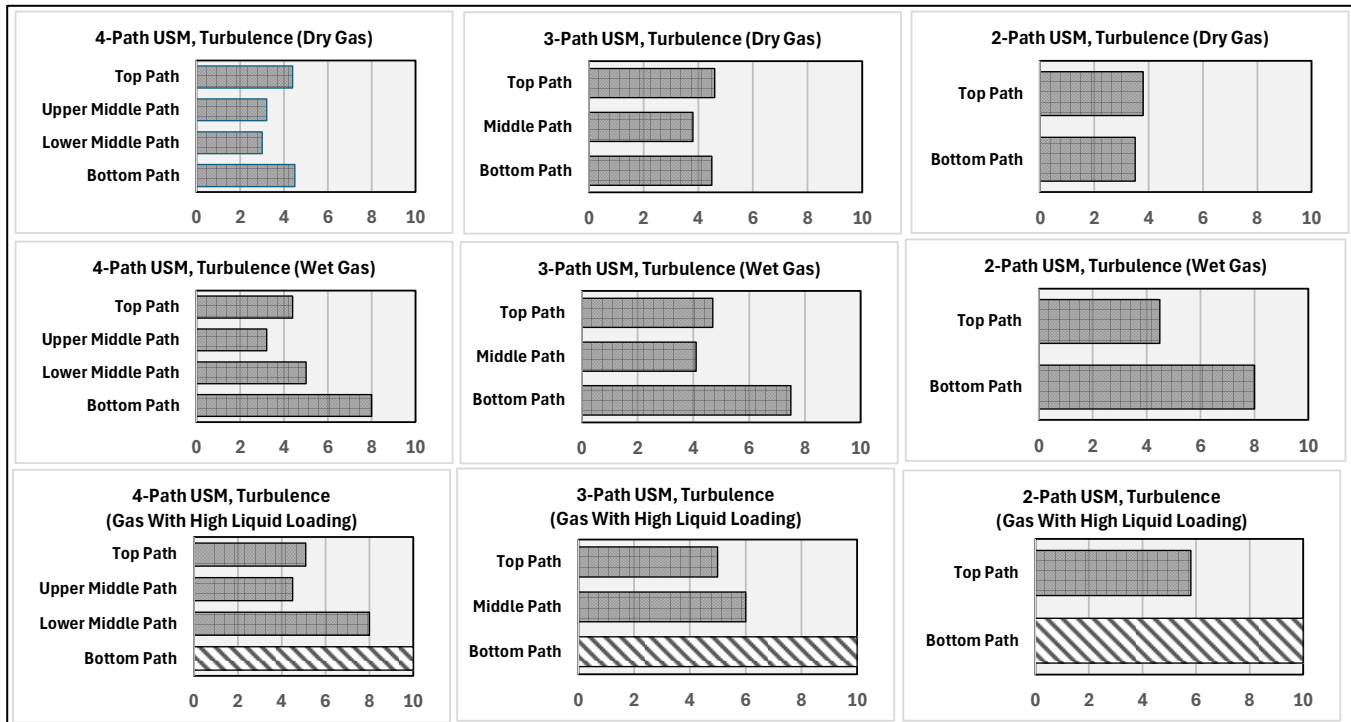


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The term Turbulence is not a measure of the fluid turbulence as defined in classical fluid dynamics and is not related to the flowing Reynolds number. It is used to describe the variability of each path’s gas velocity. Meters generally compute Turbulence by calculating the standard deviation of each path’s transit times.

3.0 Error Propositions, Operating Environment and USM Diagnostic Responses

A number of error propositions or possible modes of error were postulated above on the basis of the meter's operating principal with emphasis on 2 main areas:

1. Accurate, predictable bulk velocity calculation based on a stable and well characterized flow profile and,
2. Accurate pulse transit time measurement based on stable pulse detection with known path lengths.

In validating bulk velocity calculations, evaluation of "no-changes" in flow profile is required. Additionally, stable pulse detection and transit time measurements are needed, and are validated using SoS analysis.

3.1 Environmental Factors

A number of factors relating to potential profile distortion mechanisms were suggested above and recommendations made regarding flow profile review, as-installed versus as-calibrated. Additional external factors that should be considered for general effects are:

Factor	Influence on Flow	Diagnostic Response	Error
Flow Range; too low, too high	@ $v < 2$ fps, can cause gas stratification; @ $v > 130$ fps (line size dependent)	Per path SoS doesn't agree on low end; signal loss at high velocities (>130 fps)	Profile and temperature issues skew both corrected and uncorrected output; transit time errors on missed pulses
Temperature	@ $v < 2$ fps, can cause gas stratification	Per path SoS doesn't agree	Profile and temperature issues skew both corrected and uncorrected output
Pressure	High DP's can cause liquid drop out, pulsation causes time varying velocities	May see liquids: • w/high turbulence • velocity profile shift Pulsation w/unsteady profile and varying velocity outputs	Area blockage causes error in uncorrected volume calculation Liquids cause change in velocity profile. Pulsation skews average velocity value and meter doesn't track
Weather	At low velocities can contribute to stratification, liquid drop out.	Free liquids or freeze offs occur • High turbulence • Increased gains • Skewed velocity profile Signal rejection	Bad velocity measurements, area reduction.
Gas composition	Rich compositions subject to retrograde condensation; CO ₂ may attenuate signals	Free liquids or freeze offs occur • High turbulence • Increased gains • Skewed velocity profile Signal rejection	Bad velocity measurements, area reduction.
Contaminants Fouling potential (liquids, etc.)	Adheres to pipe wall; skews flow profile. Liquids block part of meter run, foul sensors.	Free liquids or freeze offs occur • High turbulence • Increased gains • Skewed velocity profile • Signal rejection	Bad velocity measurements, area reduction.
Fluid dynamic disturbances	Tees, protrusions, etc. cause disturbed velocity profiles	• High turbulence • Skewed velocity profile	Unstable velocity measurements, non-matching profiles might indicated bias error from installation effect.
Electrical interface (EMI, RFI)	Pulse accumulated Errors, Timing errors	SoS	Missed or added pulses can affect measurement totals
Electronics drift	Timing errors, scaling errors	SoS	Rare
Thermal expansion, pipe work, etc.	Path length errors	Per path SoS	Effect generally negligible
Ultrasonic noise	May cause no measurement	SNR < 1	Measurement outage
Foreign object	Skew flow profile	Per path velocity pattern, or Profile and Symmetry factors out of limits.	Unstable velocity measurements, non-matching profiles might indicated bias error from installation effect.

These environmental factors need be considered during the design, commissioning and operational phases of placing the USM station in-service and in maintaining a performance log over its installed life.

3.2 Design Factors

1. Meter sizing: check operating range, $Q_{\max}$ at $P_{\min}$, $Q_{\min}$ at $P_{\max}$.
2. Meter run design & construction: honed?, spool lengths, flow conditioner
3. Entry and exit piping: possible flow disturbance generators, noise attenuators
4. Installation: siphon drains, inspection ports, clean out tees, maintenance access and removal route
5. Throttled valves: Pressure or Flow control valves installed near a meter, location proximate to the meter, valve type, $Q_{\max}/\min$; ΔP .
6. Gas Composition: liquids, high CO₂, corrosive elements
7. Ancillary facilities: RTU, meter building, on-line GC, sample probe location, Data transfer
8. Calibration requirements: flow range, operating requirements.
9. Documentation: from Mfg. (material cert's), Flow Lab (cal cert), et al.

3.3 Commissioning Factors

1. Inspect meter run assembly: insure it is field installed identically as to that tested at the flow lab (labs commonly mark spools and provide an accompanying sketch)
2. Inspect Meter calibration certificate: insure the meter factor determined at the calibration lab is input to the meter's SPU; insure the appropriate linearization factors have been applied.
3. Log Files: insure that the diagnostic log files extracted during the flow calibration are accessible
4. Firmware & Software: Insure the correct version of firmware is installed in the meter, insure the appropriate version of software is installed on technician laptops.
5. Check Input/Output connections
6. Check Pulse scaling; insure it correlates with meter factor and calibration certificate; check pulse wave-form; check error frequency.
7. Copy, Save and date-stamp a meter config file.
8. Characterize As-Installed Diagnostics: Flow the meter at a variety of rates if possible: capture logfile data at each rate.
9. Inspection: Make a full routine inspection per company procedure; complete documentation and note commissioning date.
10. Records: Follow Company policy regarding retention of records as pertains to commissioning logs and Inspection Report.
11. Review diagnostic responses from calibration and commissioning logfile data for velocity profile, and other diagnostics comparison.
12. Make a flowing SoS check if not done as part of 9 above.

3.4 Factors in Routine Maintenance

1. Calibration Routine: Start by calibrating secondary devices, P, T and GC. Next, collect recent gas analysis and make meter inspection. By calibrating secondary devices first, one minimizes the possibility of an SoS error during meter inspection.
2. Collect diagnostic logfile and run against Manufacturer's maintenance/inspection tool.
3. Check for problems with:

- a. Meter vs. AGA 10 SoS: possible data input issue; otherwise, check gas stream unnormalized totals and if $\pm 2\%$ of 100%, consider GC error (integration, calibration, unknown specie).
 - b. Per Path SoS Spread: if wide vis-à-vis baseline, check for pulse detection issues.
 - c. Velocity Profile
 - d. Turbulence
 - e. SNR
 - f. Transducer Gains
4. Save Logfiles, Session files, etc.

3.5 Special Maintenance

Components Replacement: From time to time, it may be necessary to replace components on a USM: the main parts of the meter are the signal processing electronics and the transducers. Neither of these has a significant failure history, however manufacturers do have specific procedures and Approval Data to support their use as regards electronics or transducer replacement.

Electronics: An SPU may require replacement if subject to a power transient like a lightning strike. If this is the case,

1. Secure copies of meter configuration file, calibration files including log files and certificates.
2. Follow Manufacturer instructions on how to transfer meter set-up from configuration file to program SPU.
3. Review implementation of meter and linearization factors; insure they match calibration values
4. Review output of meter, Diagnostic outputs as compared to those from calibration.
5. Sanity check on volume output(s): pulse scaling, accumulation, etc.

Transducers:

1. Secure copies of meter configuration files
2. Follow Manufacturer instructions on transducer change out:
 - a. Mechanical
 - b. Electrical
 - c. Programming of SPU w/new delay times, transducer characteristics.
3. Follow Manufacturer procedure to check indicated path SoS versus expected base-line.
4. Update soft copy and hard copy records with new transducer information and log files.

Conclusions

During the past several years the industry has learned a lot about USM wet gas operational issues. The traditional 5 diagnostic features, gain, signal-to-noise, performance, path velocities SOS, and turbulence have helped the industry monitor the USM. These 6 features provide a lot of information about the meter's health. Getting an initial baseline on the meter at the time of installation, and monitoring these features on a routine basis can generally identify metering problems in advance of failure.

Most operational problems with gas USM's are typically a slug of liquids moves the USM and takes a few seconds for the meter to recover after the slug has passed. Typical problems historically with the USM are fluid dynamics (i.e., disturbed flow profile) or related to meter performance outright (for e.g., a failed electronics), but can be recognized by diagnostics.

Originally the more advanced diagnostic indicators, such as Turbulence, were showing promise as tools to better focus on meter performance that has moved into a key diagnostic for wet gas measurement integrity to quickly identify

potential measurement problems on a real-time basis. This all depends on how the knowledge of diagnostics can be refined both in raw and interpreted forms.

As the industry learns more about not only the USM, and the operation of their own measurement system, the value of gas ultrasonic meter technology will continue to be recognized through wide-spread use. The USM industry is still relatively young and continuously improving technology will provide more tools to help solve today's measurement problems tomorrow.

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1. AGA Report No. 9, "Measurement of Gas by Multipath Ultrasonic Meters", 4th Edition 2022, American Gas Association.
2. AGA Report No 10, *Speed of Sound in Natural Gas and Other Related Hydrocarbon Gases*, July 2002, American Gas Association, 515 Wilson Boulevard, Arlington, VA 22209
3. GPA WG 77 Proposed Tentative Standard Working Group 77 Draft 2025, Multi-Path Ultrasonic Metering of gas at or Near Dew Point

Wet Gas Ultrasonic Meter Diagnostics

ASGMT USM Diagnostics Advanced Overview

Duane Harris, Endress+Hauser, Inc.

1. Introduction

Pipeline Operators have used Ultrasonic meters commercially for gas custody transfer applications since the late '90's. These meters' combination of operating features, including superior rangeability and on-board diagnostics have made this the technology of choice for most high volume gas metering applications. As user comfort with, and capabilities of, the technology has increased and the size and cost of ultrasonic meters has decreased, Operators and Manufacturers continue to stretch the envelope of application possibilities. This includes use in upstream, midstream, and downstream markets with sometimes corrosive and high CO₂ applications, where the technology previously couldn't work or didn't make economic sense.

With these meters' proliferation both in numbers and use-cases, the need to apply "smart meter" diagnostics is of increased importance to identify and address operating issues early that may affect measurement accuracy. Near real-time data requirements are demanded by wide-spread business restructuring of gas transportation Pipelines into MLP's (Master Limited Partnerships) in the wake of de-regulation. These new business structures require daily cash-out and balancing in many cases, and monthly accounting settlement of transportation accounts in all cases, so the facility to recognize and fix measurement problems within an accounting period (i.e., prior to month-end business close) is imperative to avoid what have become in the MLP era, painful PPA's (prior period adjustments).

Meter manufacturers have long touted the diagnostic aspect of USM technology and over the intervening years since first publication of AGA TMC Report No. 9 in 1998, the companion software used for diagnostic analysis of meter performance has greatly improved through continuing development of the root meter technology and through field operating experience. Smart and consistent analysis of USM diagnostics can flag operating problems early, permit users to determine if measurement integrity/accuracy are in doubt and allows operators to take proactive steps to resolve issues on a close to real-time basis to avoid the business pain caused by the need for out-of-period gas accounting adjustments.

Improved software function however does not cover all bases so it is incumbent on operators to develop an understanding of both basic and extended USM diagnostics to recognize when problems may be occurring so remedial action can be taken before significant impact on fiscal measurement occurs. Manufacturers also have a responsibility to deploy diagnostic software with clear guidance for application with ease-of-use as a priority, and many have responded with automated diagnostic evaluation of USM's via these software tools.

Given the variety of operating environments and the way USM diagnostics work, there are challenges to dial in the specific information you are looking for. Diagnostics can 1) definitively flag problems and 2) provide insight on the degree to which such problems affect measurement accuracy. Some operating problems, such as failed hardware or noise, are easy to spot and rectify, but in most cases a holistic approach to collecting and interpreting diagnostic information is needed to relate meter behavior to causes that may affect measurement accuracy.

General explanation of how USM diagnostics work in common with most manufacturers leads to deeper discussion and exposition how they relate to specific metering problems follows. Using diagnostic profiles for the USM helps provide a roadmap for recognizing abnormal meter response and relating that response to pipeline operating conditions that may skew gas measurement. Actual operating examples of field measurement problems identified through use of these diagnostics are presented herein along with remedies. Discussion of automating diagnostics, data reduction and piping

facilities design, is included with a view toward providing operating personnel information regarding best practice deployment of USM's and subsequent application of diagnostic evaluation.

2 Basic Diagnostics & Operating Environment for Wet Gas

It is important to take an eyes open approach to facilities design especially when reviewing wet gas measurement facilities. One of the key challenges with wet gas measurement is the actual Gas Volume Fraction (GVF) vs the Liquid Volume Fraction (LVF). Today the concept of wet gas measurement would consist of a 100% GVF to 98% GVF or a 0% LVF to 2% LVF under normal operations. Realizing upset conditions can occur that may significantly exceed the 2% LVF however the meter station is not designed to be a multiphase measurement facility.

Many problems can be avoided during the design phase by taking prudent steps to address the better known issues that typically cause measurement error with USM's; for e.g.:

- **noise concerns** (for e.g. as caused by pinched valves generating interfering ultrasonic noise),
- **meter fouling** (for e.g., collection of liquids in a meter run) and
- **profile disturbance generators** (for e.g., bends and blind tees that may generate swirl and/or asymmetry in the flow profile.
- **Flow conditioners** (for upstream Wet Gas facilities typically do not operate with a flow conditioner.

It must be emphasized that diagnostics can identify but not fix problems. Any steps taken at the design phase to minimize the occurrence and subsequent impact of issues is highly desirable, and a guiding design principle might be: "Don't design problems into a meter stations". Additionally, any meter station design features that can ease routine and "special", or remedial, maintenance should also be considered and deployed when feasible. (for e.g., access to the meter runs and electronics; potential need to remove and replace a meter run; access to, and facility for, cleaning meter runs and meter... These factors should be considered during station design.)

Diagnostics common to all USM's are:

- Automatic Gain/Power Control
- Speed of Sound (SOS)
- Path Velocity
- Signal-to-noise ratio (SNR)
- Transducer Performance
- Turbulence

Additional diagnostic parameters may include the following:

- Profile Factor
- Symmetry

Brief explanations of the nature and relevance of these basic diagnostics follow, but these diagnostics need to be related to the context of the meter's operating principal and environment so users can make the connection between what the **diagnostics reflect in an operating meter's response and what those outputs suggest is happening with the gas inside the pipe**... What happens with gas flow in the pipeline, and its effects on meter performance, are what drive accuracy problems that need to be recognized and fixed.

More often than not, if there is a problem inside the pipe that the meter's diagnostics are responding to, more than one diagnostic will show anomalous output. It is the combination of these diagnostic responses and evaluation of them that

guides users toward the specific cause of degraded and/or changed meter performance that may affect measurement accuracy. A holistic approach in evaluating these diagnostics is needed to paint the full picture of meter response and in deducing whether meter accuracy is impaired. Possible remedial actions include:

- Repair and/or replacement of components
- Removal, cleaning and replacement of individual transducers
- Cleaning of meter, meter run and/or FC, either in-situ or by removal
- Repair and/or replacement of secondary components (transmitters, etc.)

2.1 Transducer Gain Level

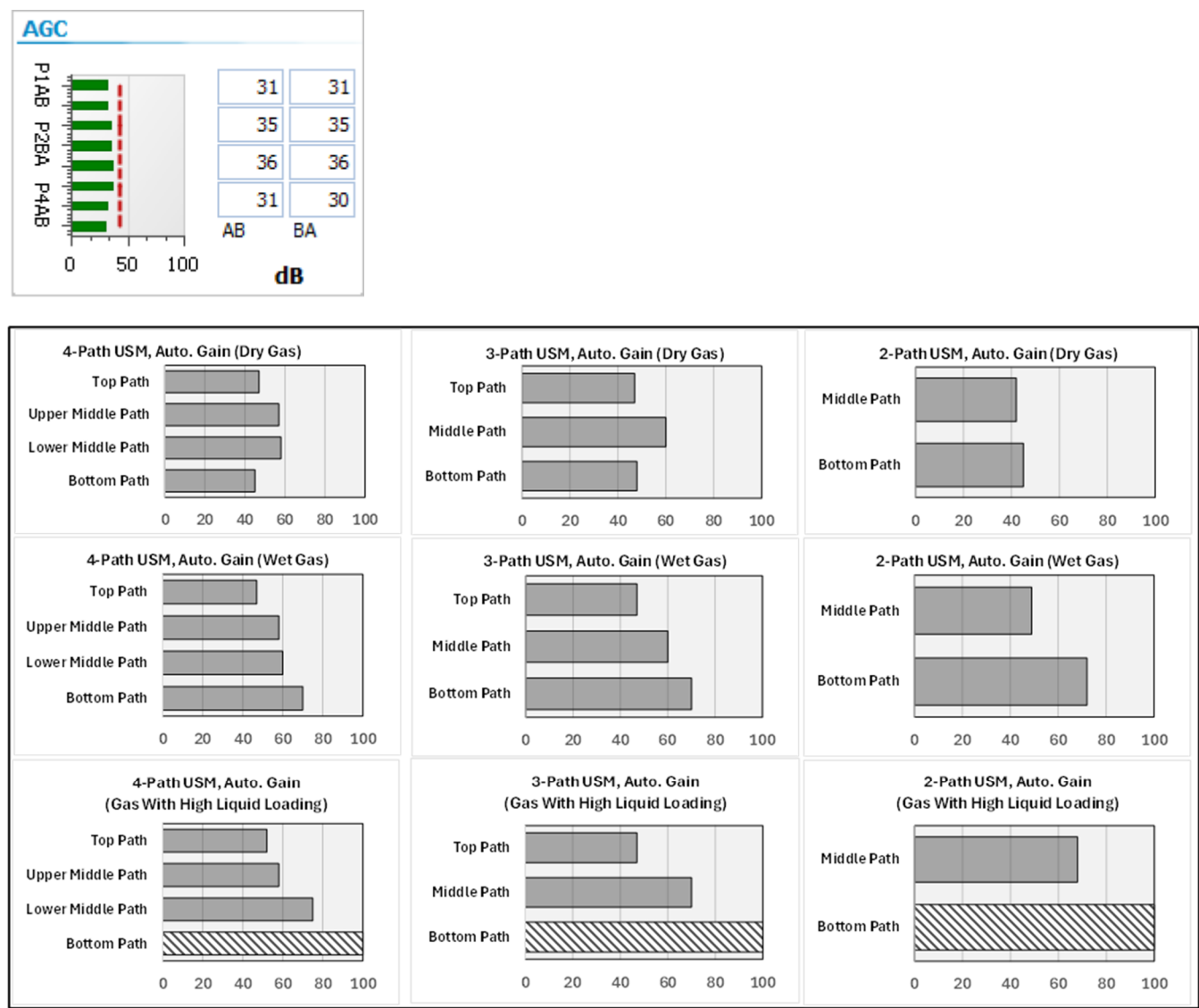


Figure 1 - Automatic Gain/Power Control (dB)

Dry vs. Wet Gas vs. Gas with High Liquid Loading Bar Graphs for 4-Path, 3-Path, 2-Path USMs[†]

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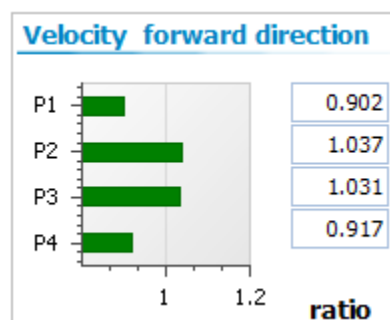
Pulse signals received by transducers from their path companions are amplified with automatic gain controls to improve pulse detection. Gains typically increase when signal recognition becomes more difficult such as in noisy environments, (for e.g. when gas rates are higher), or if debris is collecting on the transducer. Gains can also go high if a transducer is damaged or failing. It is often useful to compare gain levels as pairs by using the ratio of their levels to determine if one or the other of the transducers is struggling to detect signals. A high gain level on one side of a path might occur if the transducer concerned faces a noise source or if selective deposition occurs fouling the transducer face.

2.2 Average & Per Path SoS

Speed of Sound (SoS) is a critical and powerful diagnostic tool available in ultrasonic meters from which users can determine if a meter's **functional** performance has shifted. Two tests can be made using meter "measured" values for SoS: 1) an absolute comparison of meter corrected SoS versus that calculated from the gas' thermodynamic properties and 2) a per path comparison to determine if an outlier on a particular path suggests it's path length has changed, or more commonly, if pulse misdetection is occurring (path length changes are due either to meter configuration input errors, physical installation errors or debris build-up on transducer faces).

USM's depend on time and distance (clock and path length) to make accurate pulse transit time measurements and the absolute SoS comparison discussed below validates both. But this diagnostic does not by itself assure that meter accuracy isn't impacted by other factors such as fouling that result in bad flow profiles or diametric reduction.

2.3 Per Path Gas Velocity

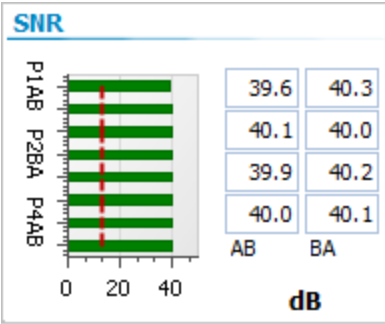


Maps of the per path gas velocities should be made from meter logfiles at each flow rate during meter flow calibration and during meter commissioning, or default values for relative velocity patterns need to be established. Profile and symmetry factors are often used to set default values, which technique is used in evaluating whether the relative path velocities have shifted, leading users to understand if disturbed flow profiles are present. These defaults can then be used to determine if flow profile has shifted.

USM's are flow profile dependent as regards maintaining meter accuracy, and as explained in the operating principals below, if a flow profile at a given flow rate differs significantly from that experienced by the meter at flow calibration, there is a shift in meter factor, or to put it more bluntly, a bias error is introduced because the bulk velocity calculation in the field has a different result than in the calibration lab.

Disturbing elements such as blind tees, out of- and in-plane bends, headers and meter run blockage with debris, can cause flow disturbances that the flow conditioner might not remove. Additionally, fouling of the meter run with liquids, black powder, asphaltines, paraffin, etc., can cause the flow pattern to change with resulting flow measurement inaccuracies. Profile analysis indicates a possible shift in meter output and depending on the severity of profile discrepancy might suggest the nature of the problem, but most times a visual inspection of the meter run is needed.

2.4 SNR



Signal to Noise Ratio, or SNR, indicates when the background noise approaches the limits of automatic gain adjustments. SNR values approaching a 1:1 level usually signify that ambient noise has made pulse detection impossible. “Ambient noise” refers to the ultrasonic noise present in the gas flow stream and is most often generated by throttled control valves. If there is too much noise, pulse signal detection becomes impossible and measurement stops.

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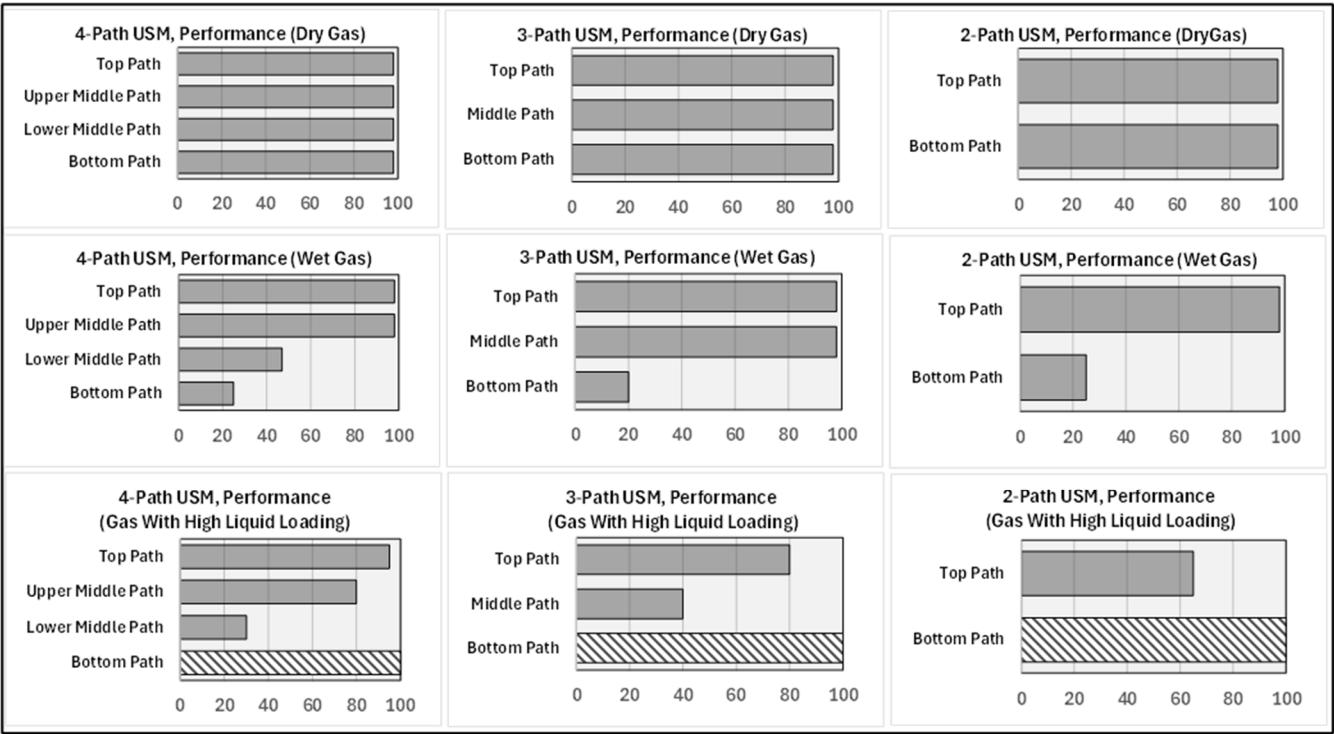
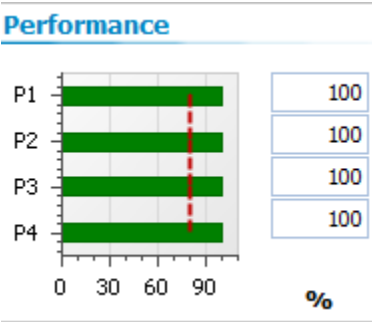


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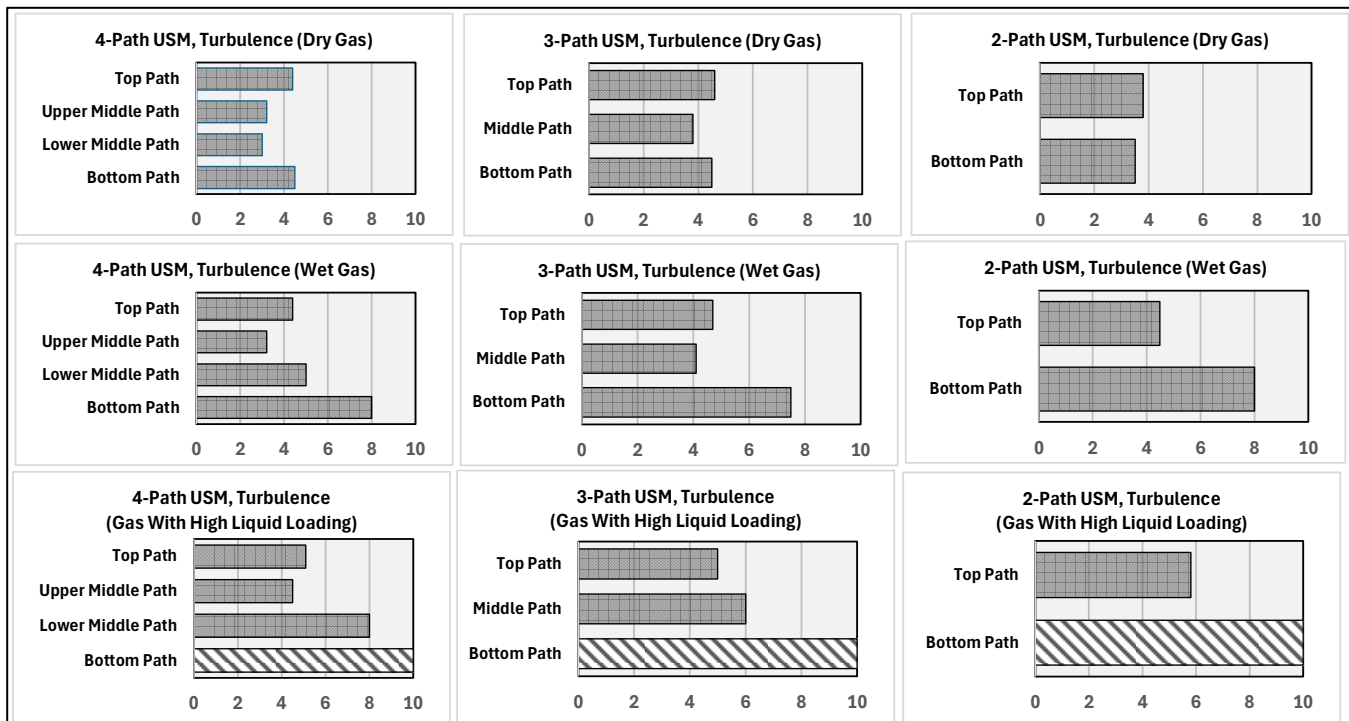


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4. Update soft copy and hard copy records with new transducer information and log files.

Conclusions

During the past several years the industry has learned a lot about USM wet gas operational issues. The traditional 5 diagnostic features, gain, signal-to-noise, performance, path velocities SOS, and turbulence have helped the industry monitor the USM. These 6 features provide a lot of information about the meter's health. Getting an initial baseline on the meter at the time of installation, and monitoring these features on a routine basis can generally identify metering problems in advance of failure.

Most operational problems with gas USM's are typically a slug of liquids moves the USM and takes a few seconds for the meter to recover after the slug has passed. Typical problems historically with the USM are fluid dynamics (i.e., disturbed flow profile) or related to meter performance outright (for e.g., a failed electronics), but can be recognized by diagnostics.

Originally the more advanced diagnostic indicators, such as Turbulence, were showing promise as tools to better focus on meter performance that has moved into a key diagnostic for wet gas measurement integrity to quickly identify

potential measurement problems on a real-time basis. This all depends on how the knowledge of diagnostics can be refined both in raw and interpreted forms.

As the industry learns more about not only the USM, and the operation of their own measurement system, the value of gas ultrasonic meter technology will continue to be recognized through wide-spread use. The USM industry is still relatively young and continuously improving technology will provide more tools to help solve today's measurement problems tomorrow.

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