RECOGNITION AND RESOLUTION OF PROBLEMS WITH GAS ULTRASONIC FLOW METERS

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Application Engineer

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BRIEF HISTORY OF ULTRASONIC METERS

- First developments of Ultrasonic technology started around 1920's
- First meters for gas applications began development in the 1970's
- First Ultrasonic meters were manufactured in the late 1980's/early 1990's
- Technical Note M-96-2-3, *Ultrasonic Flow Measurement for Natural Gas Applications* is published in 1996
- AGA 9 is approved in 1998

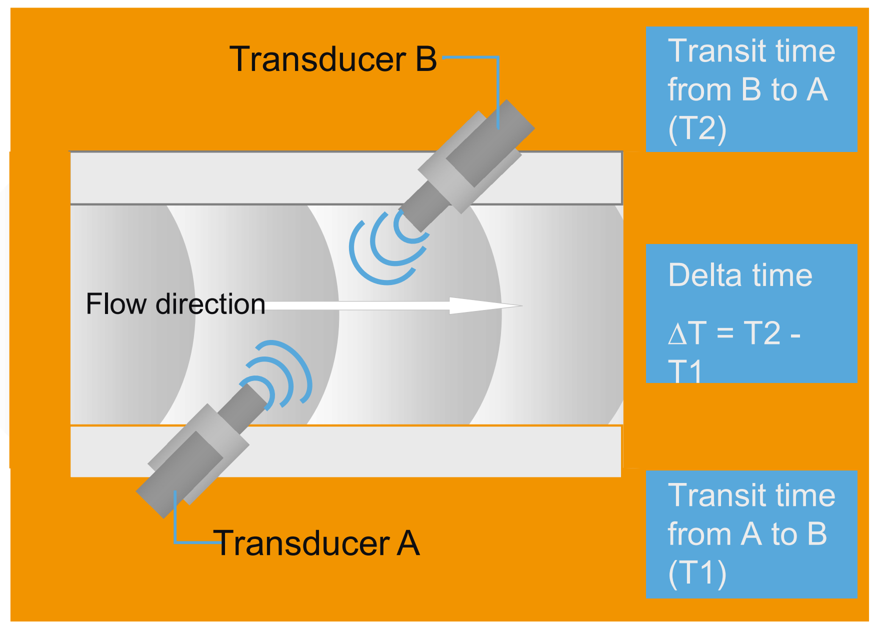
BASIC PRINCIPLE OF OPERATION OF ULTRASONIC METERS

Crossing a river

- A boat crossing a river diagonally with the flow needs less time than a boat crossing the river against the flow
- The stronger the current the faster the crossing with the flow and the slower the crossing against it
- The difference between the two transit times depends directly on the current (Flow) velocity
- This effect relates to the principle of operation in the ultrasonic flow meter

Crossing a pipe by ultra sound

- The two diagonally opposed transducers function alternatively as transmitters and receivers
- The sound signal emitted from Transducer A is accelerated by the flow
- The sound signal emitted from Transducer B is slowed by the flow
- The difference between the two transit times (T1 & T2) is directly proportional to the mean flow rate
- From the mean flow rate the volumetric flow can then be calculated

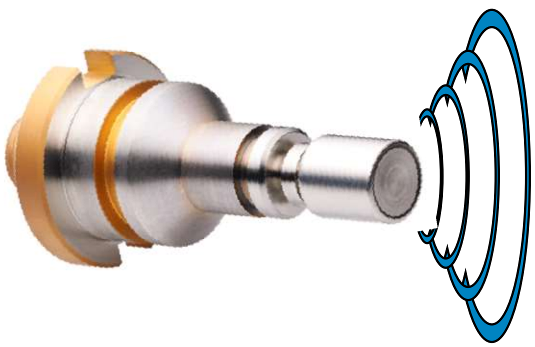


Basic Principle of Operation of Ultrasonic Meters

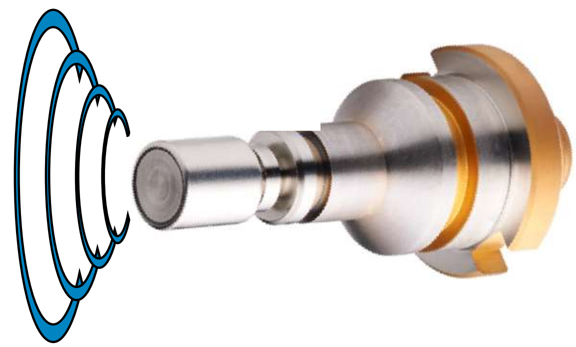
Propagation Delay of an Ultrasonic Pulse

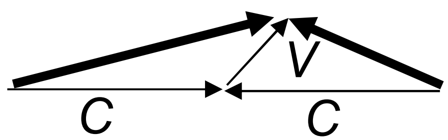
L=Distance from Transducer A to B

Transducer A



Transducer B

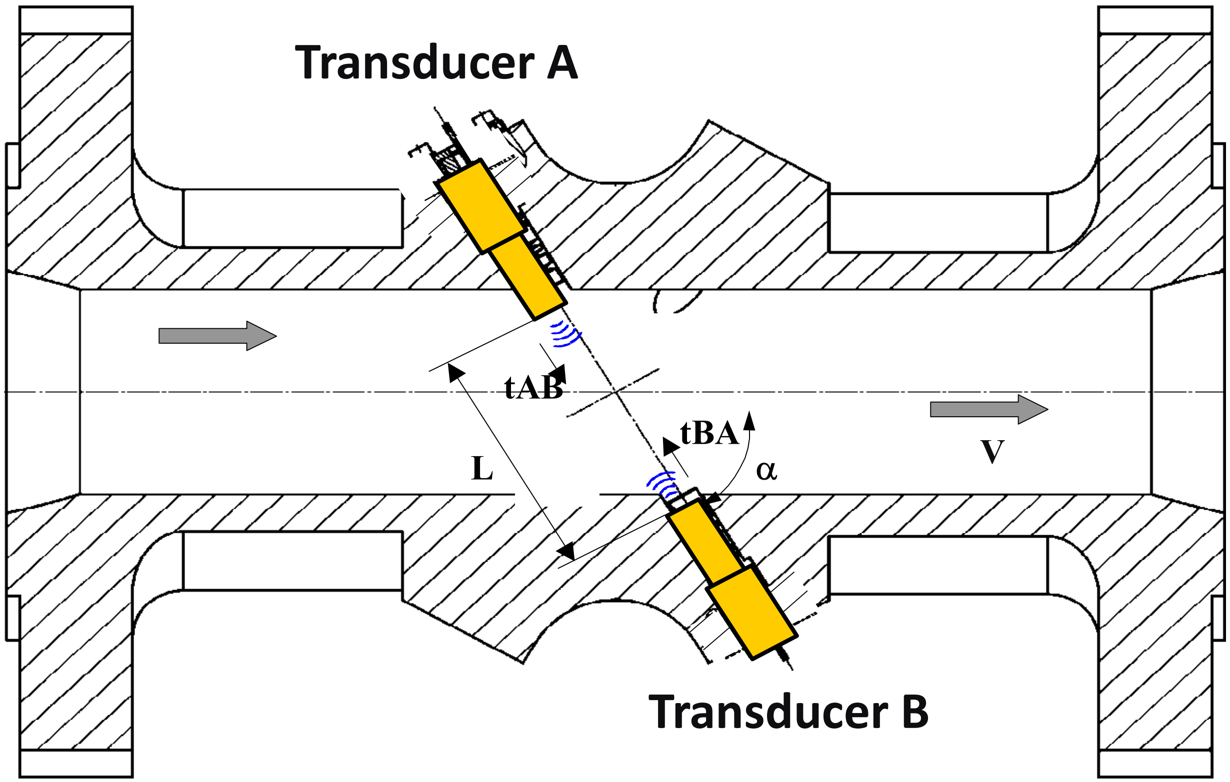




$$t_{BA} = \frac{L}{c - v_{gas} \cdot \cos\alpha}$$

$$t_{AB} = \frac{L}{c + v_{gas} \cdot \cos\alpha}$$

USM Operating Principle



Travel Time Difference

$$t_{AB} = \frac{L}{c + v \cdot \cos\alpha}$$

$$t_{BA} = \frac{L}{c - v \cdot \cos\alpha}$$

Path velocity

$$v_{Pfad} = \frac{L}{2 \cdot \cos\alpha}\left(\frac{1}{t_{AB}} - \frac{1}{t_{BA}}\right)$$

Sound Velocity

$$c = \frac{L}{2}\left(\frac{1}{t_{AB}} + \frac{1}{t_{BA}}\right)$$

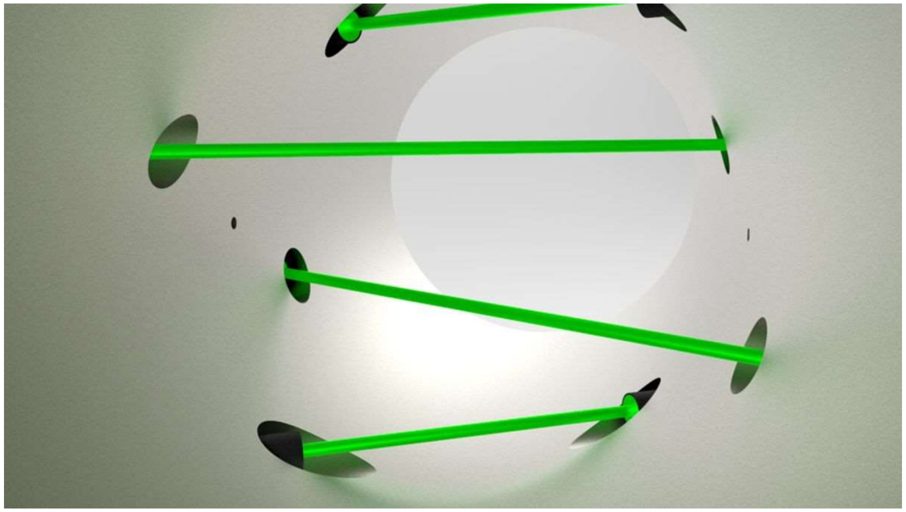
Piezo-electric Effect

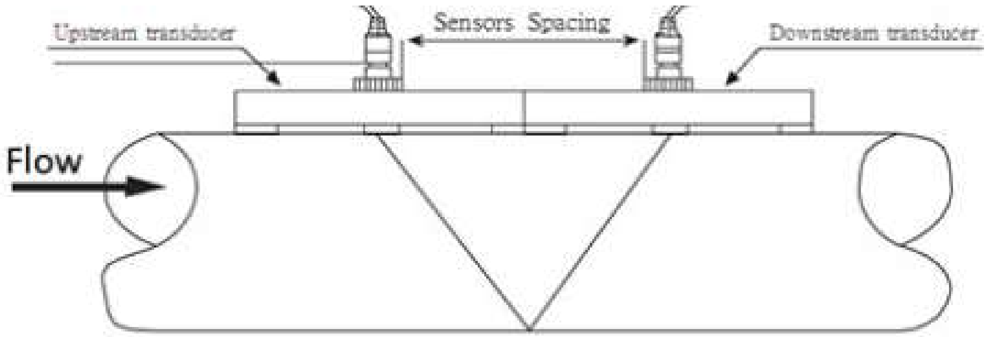
The ultrasonic transducers operate alternately as a transmitter and receiver. Each transducer has a piezo-ceramic element that is coupled with a diaphragm. To transmit signals, an alternating current is applied to the piezo-ceramic element so that it vibrates mechanically.

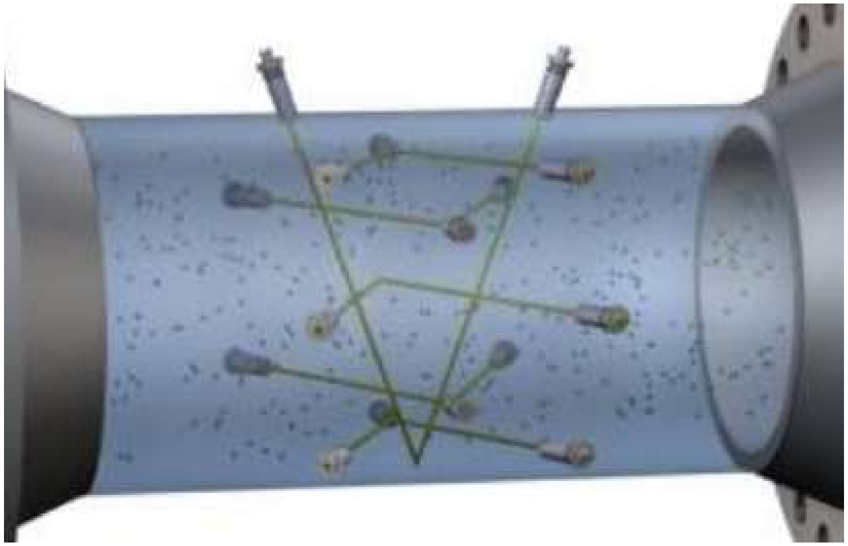
These vibrations are then transferred trough the diaphragm to the gas. The vibrations propagate as acoustic waves in the gas and strike the diaphragm on the opposite transducer after a propagation time that depends on the speed of sound and the gas velocity.

The waves are transferred to the piezo-ceramic element in the form of mechanical vibrations. They are then converted into an electrical signal by the inverse piezoelectric effect and used for further signal analysis.

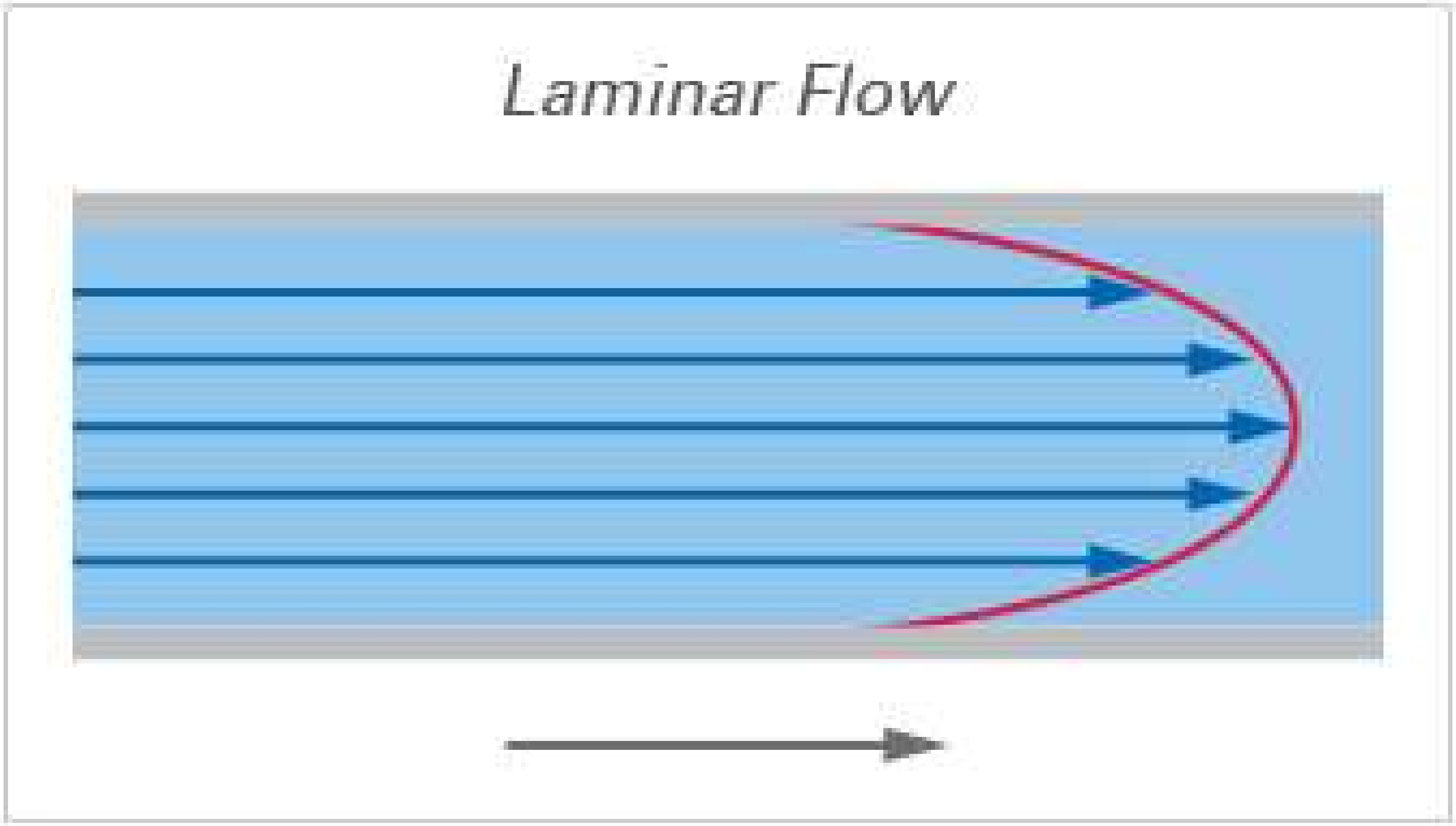
PATH CONFIGURATIONS





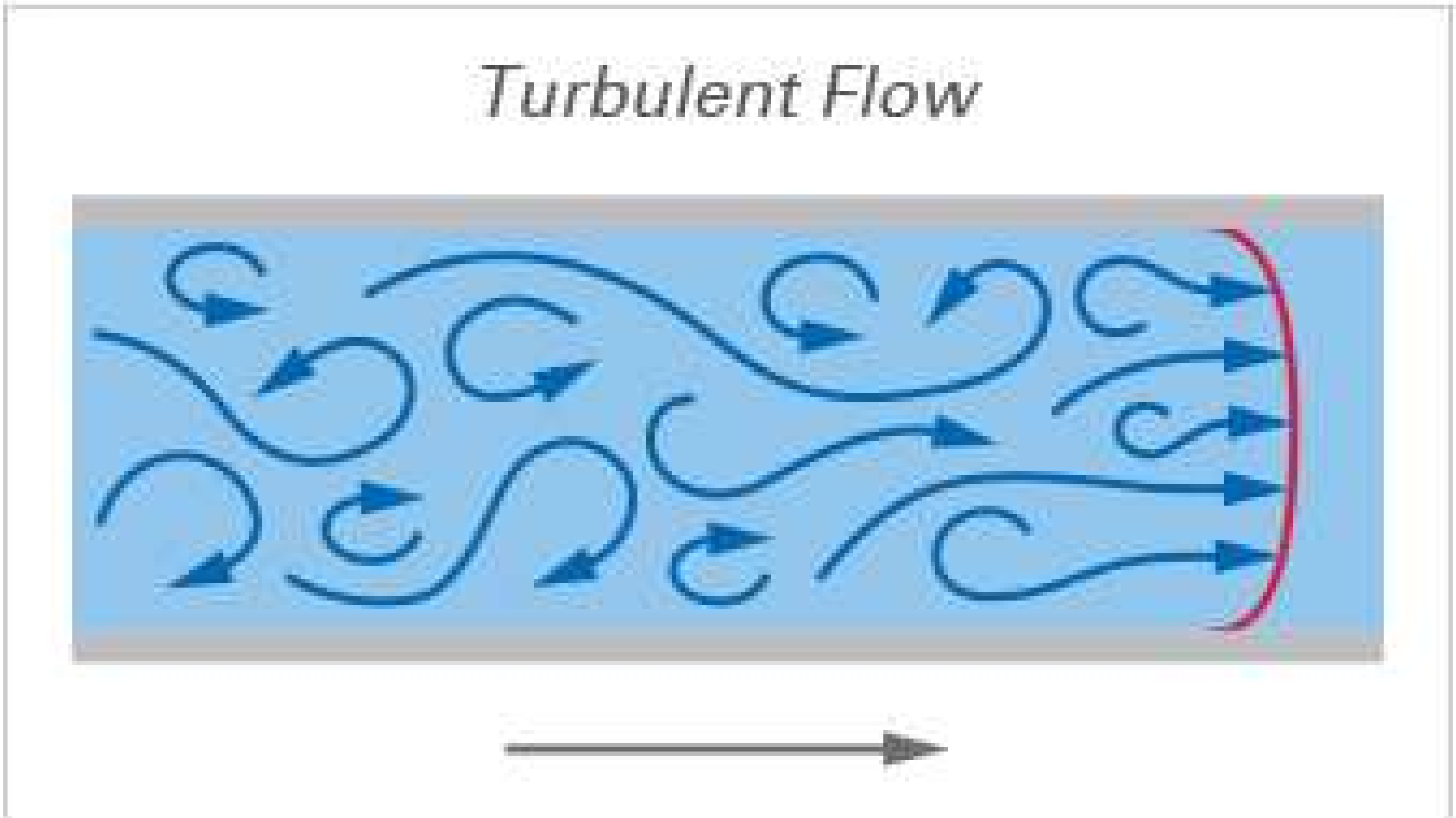


BASIC PRINCIPLE OF OPERATION OF ULTRASONIC METER



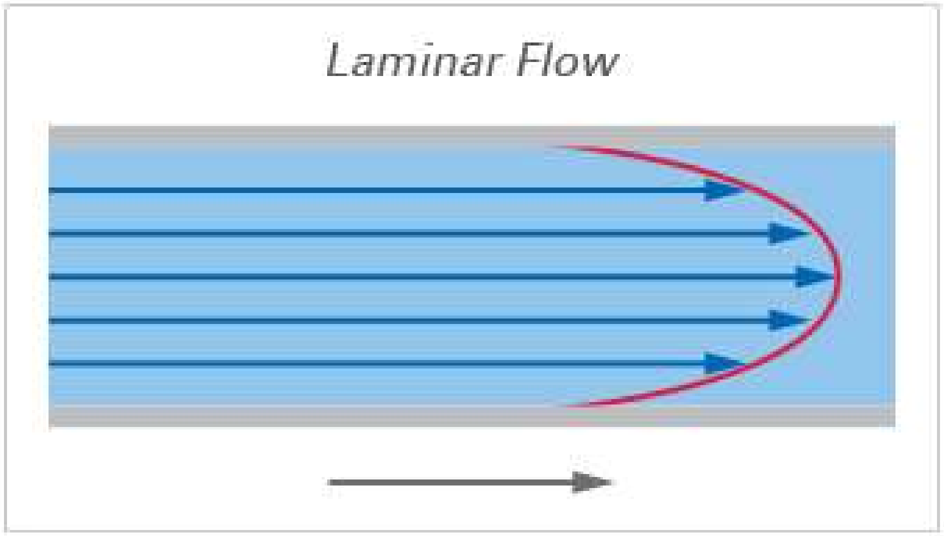
Laminar flow profile. Arrows represent the distribution of velocities.

BASIC PRINCIPLE OF OPERATION OF ULTRASONIC METER

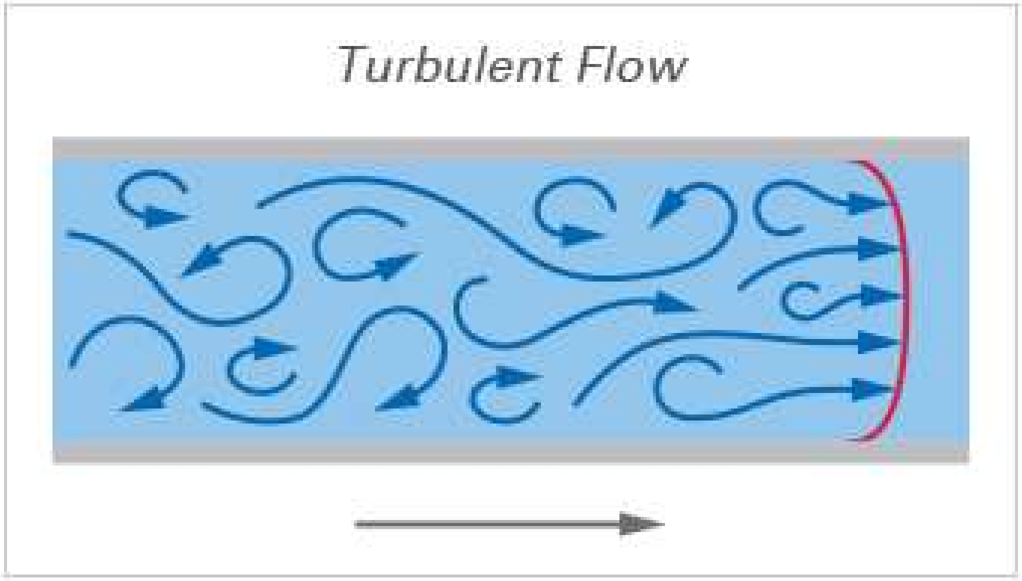


Turbulent flow profile. Arrows represent the distribution of velocities.

LAMINAR TO TURBULENT

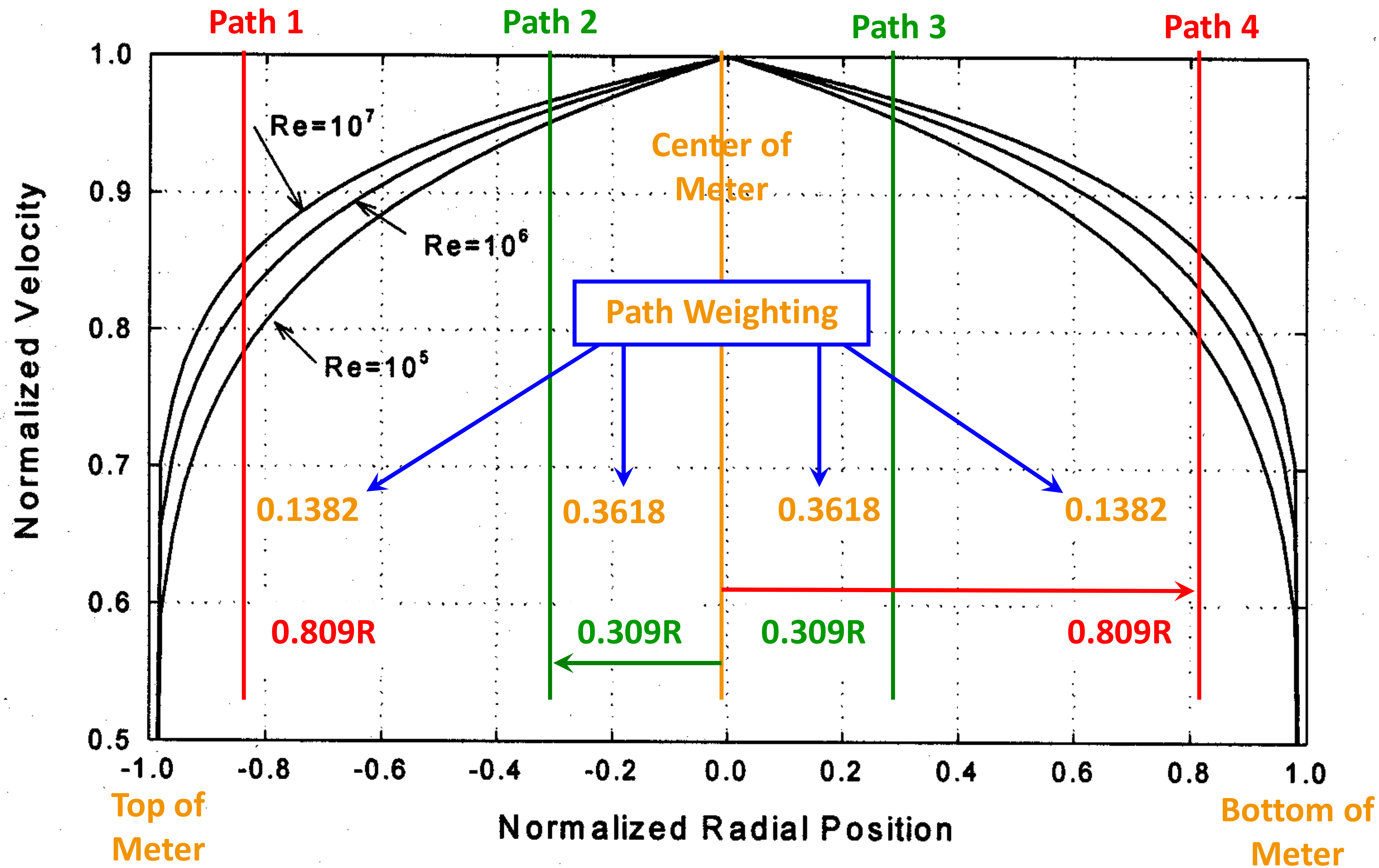


Laminar flow profile. Arrows represent the distribution of velocities.

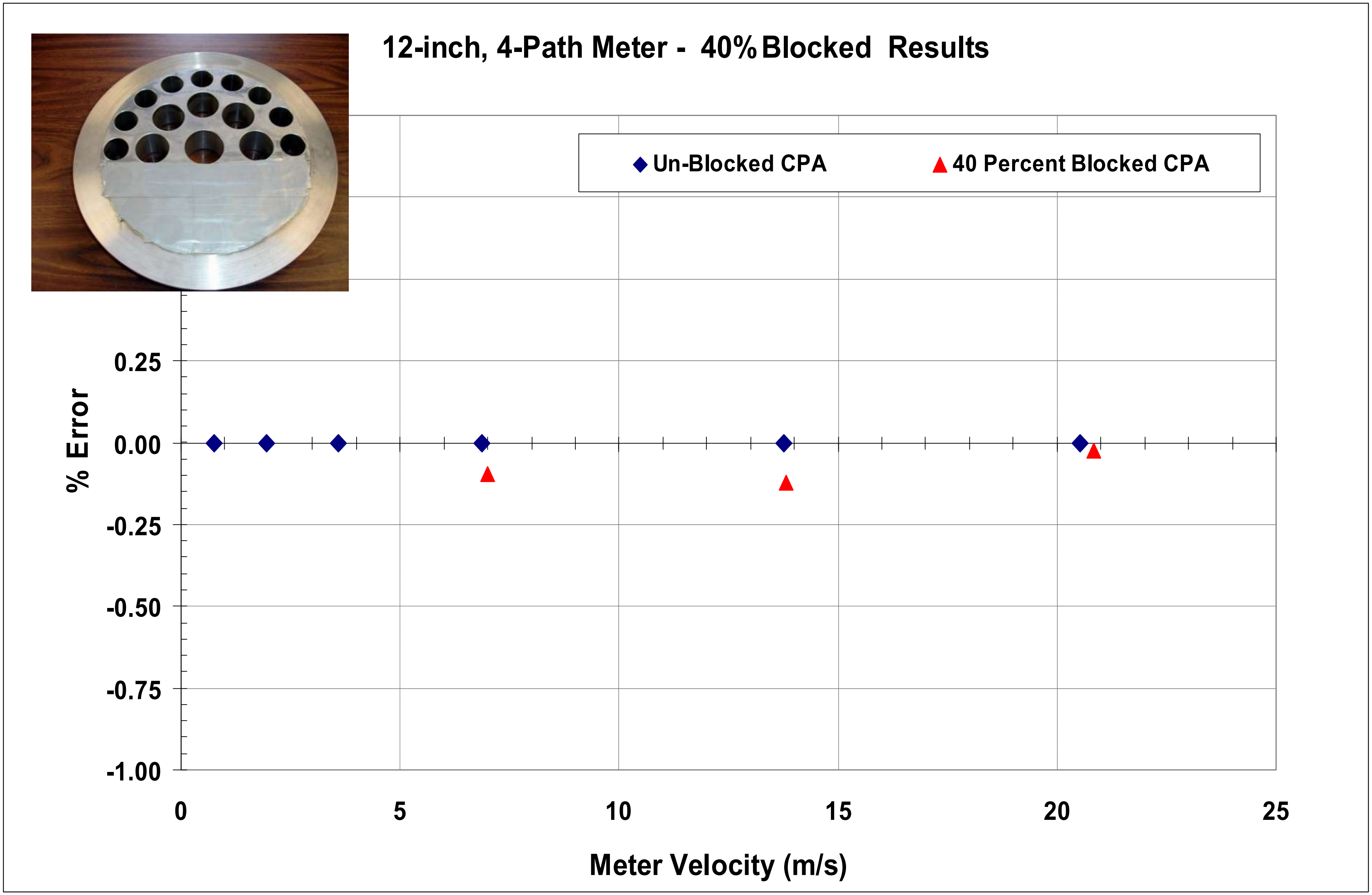


Turbulent flow profile. Arrows represent the distribution of velocities.

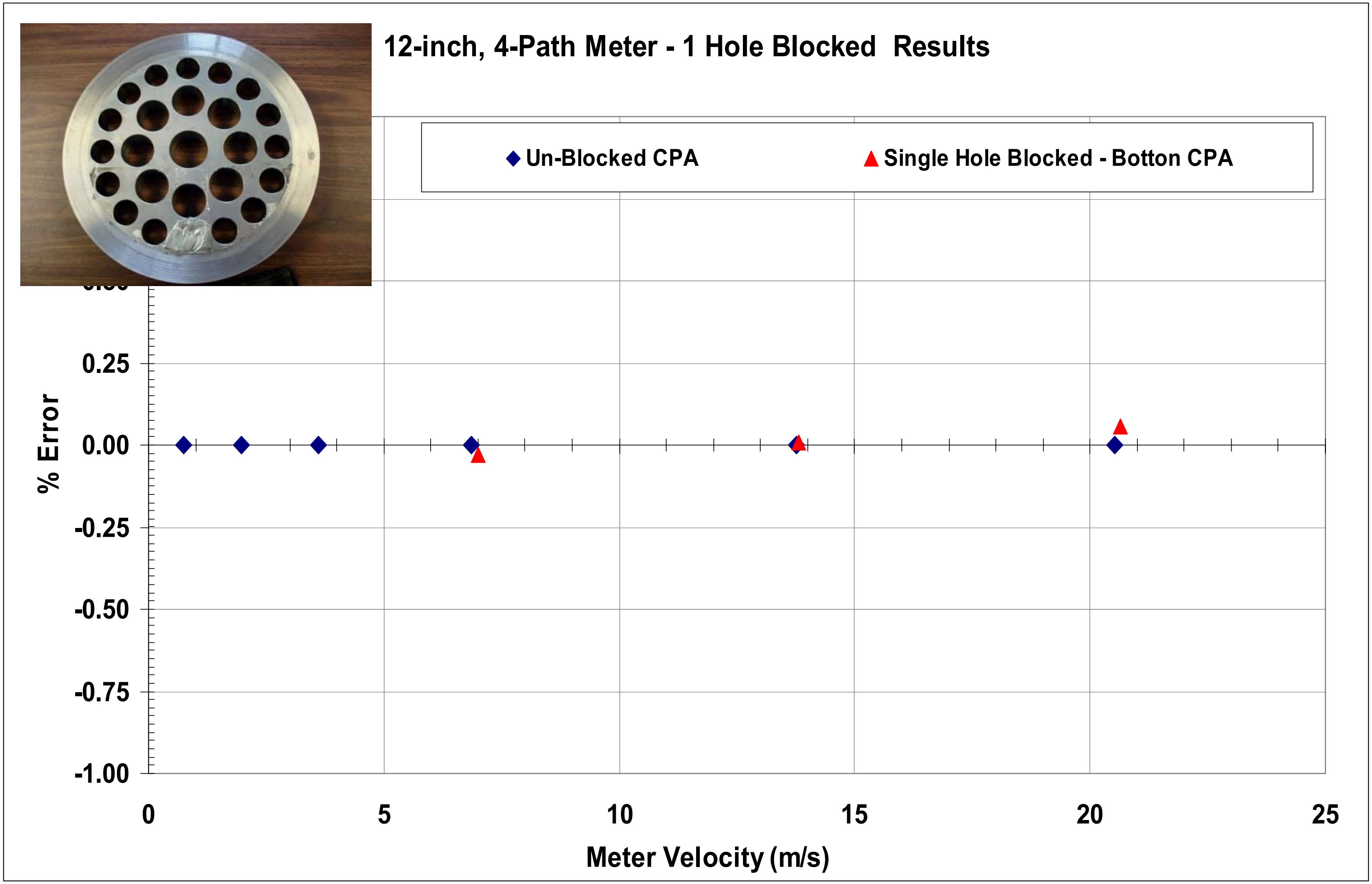
Flow Profile & The Westinghouse Design



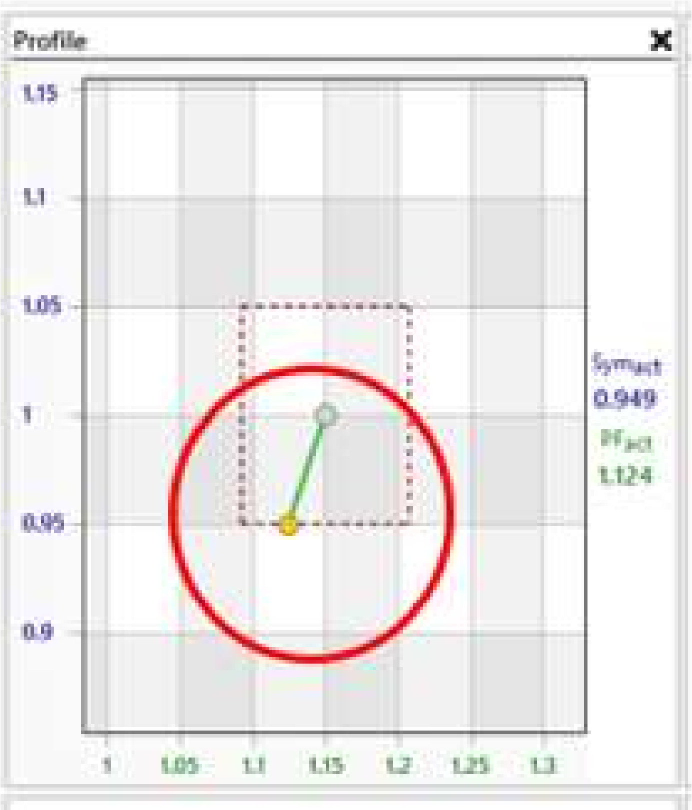
ULTRASONIC MEASUREMENT TESTING



ULTRASONIC MEASUREMENT



FLOW CONDITIONER OUT OF ALIGNMENT



THIS FLOW CONDITIONER WAS OUT OF ALIGNMENT CAUSING THE FLOW PROFILE TO SHIFT AND INDICATE A LIMIT WARNING. UPON INSPECTION, THE PROBLEM WAS CORRECTED AND THE WARNING CLEARED.

OVERVIEW OF AGA 9

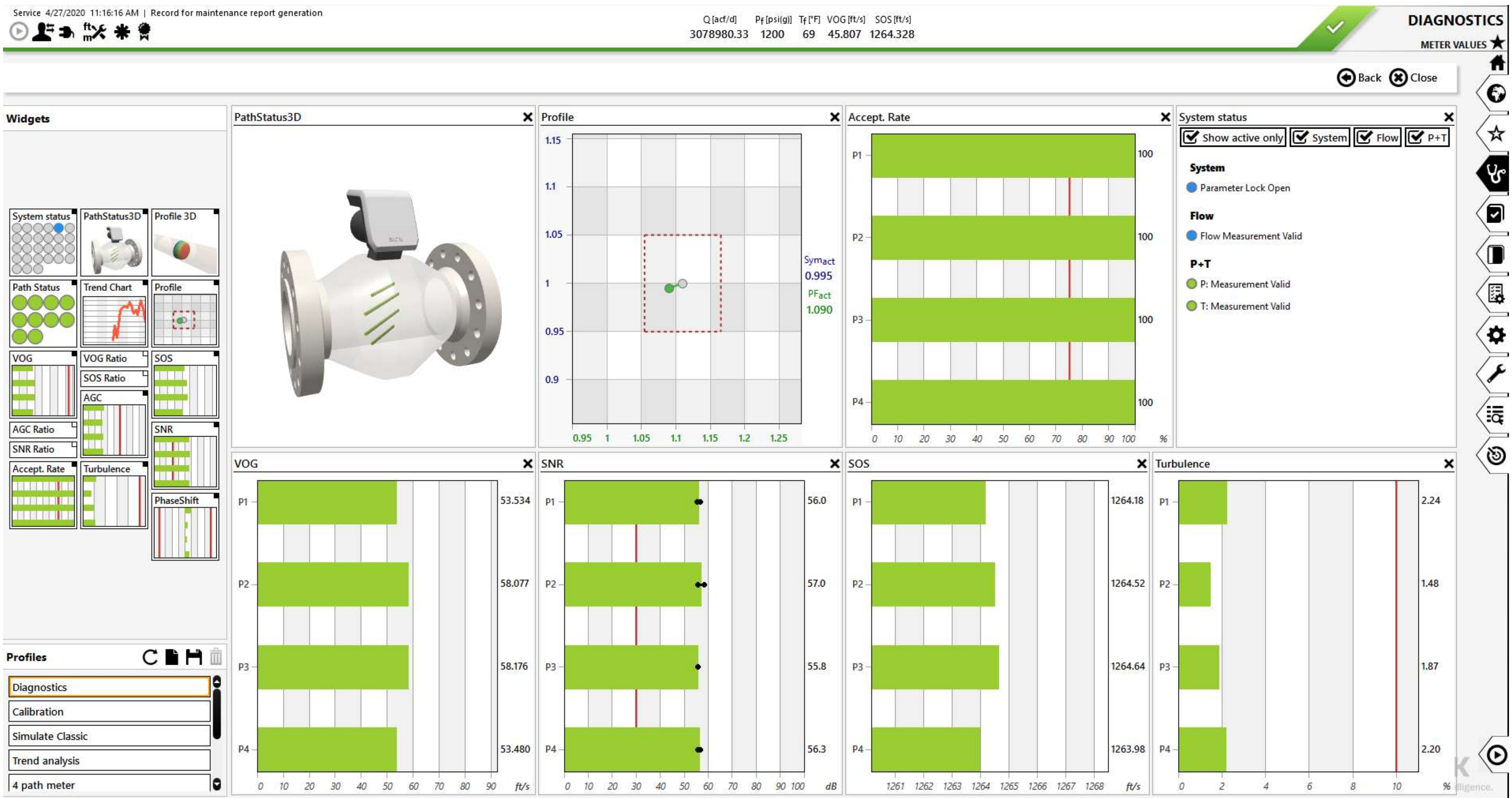
RECOMMENDED PRACTICE FOR USING ULTRASONIC METERS

- Section 1: Provides information on the scope of the document
- Section 2: Terminology and Definitions
- Section 3: Operating conditions the USM should meet
- Section 4: Ultrasonic Meter requirements
- Section 5: Ultrasonic Meter Performance requirements
- Section 6: How the Manufacturer will perform tests on USM prior to shipping
- Section 7: Design considerations when using USM
- Section 8: Field Verification Requirements
- Section 9: (Added in Second Edition) USM Uncertainty Determination

GENERAL DIAGNOSTIC INFORMATION

DIAGNOSTICS PAGE

NO ISSUES WITH THIS METER



ULTRASONIC MEASUREMENT

There are generally 5 parameters for diagnosic purposes available:

- **Receiver amplification (AGC)**
  - Amplitude of the received signal depends on pressure, meter size and specific damping influence
  - Increased AGC value indicates a weaker received signal
- **Signal to Noise Ratio (SNR)**
  - Ratio between the received signal energy and noise level
  - Indication of the acoustic signal quality
- **Acceptance rate (Performance)**
  - Ratio between valid measured signals compared to the number of signals sent
  - Indication how plausibility of the measurement
- **Speed of Sound**
  - Independent measurement value specific to gas composition, pressure and temperature
  - Indication of the accuracy of the signal run time measurement
- **Gas Velocity**
  - Velocity of each path

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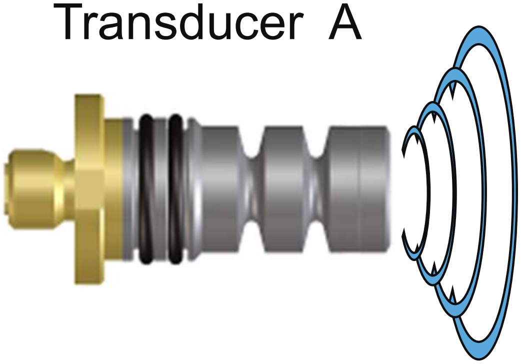
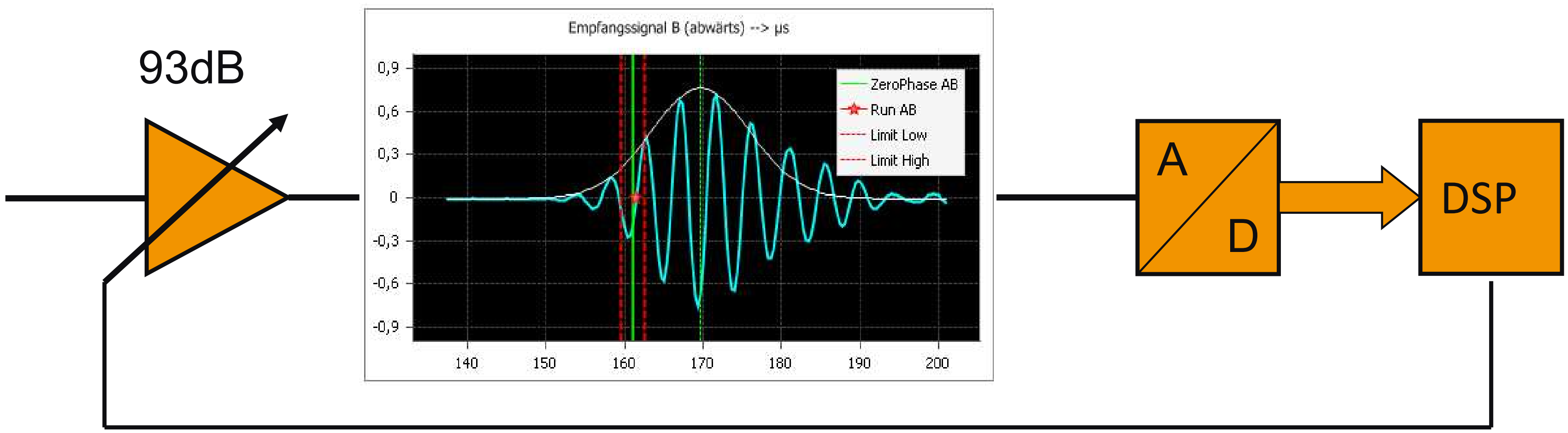
AGC – **A**utomatic **G**ain **C**ontrol

Transducer A



Transducer B

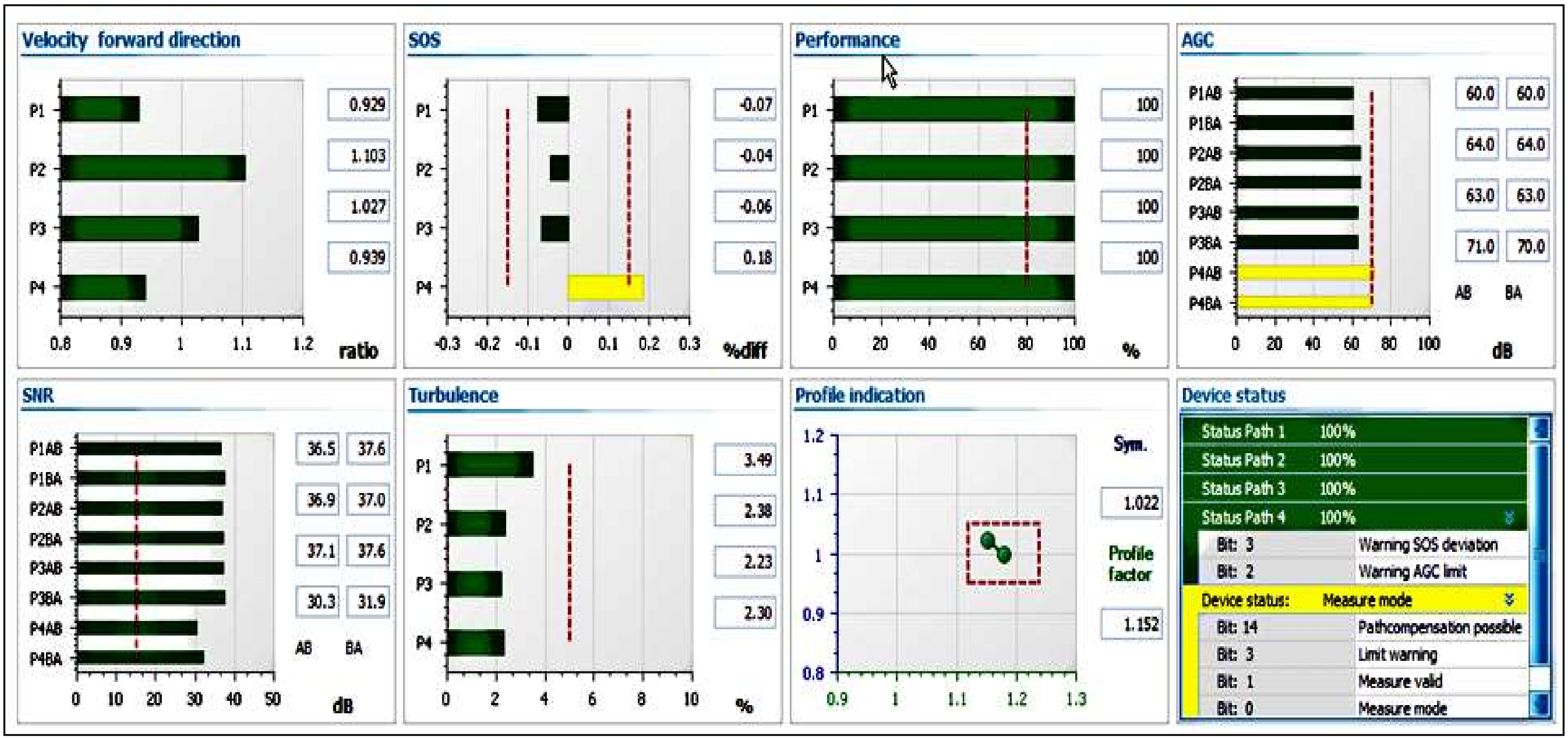


AGC ~ Receiving amplitude

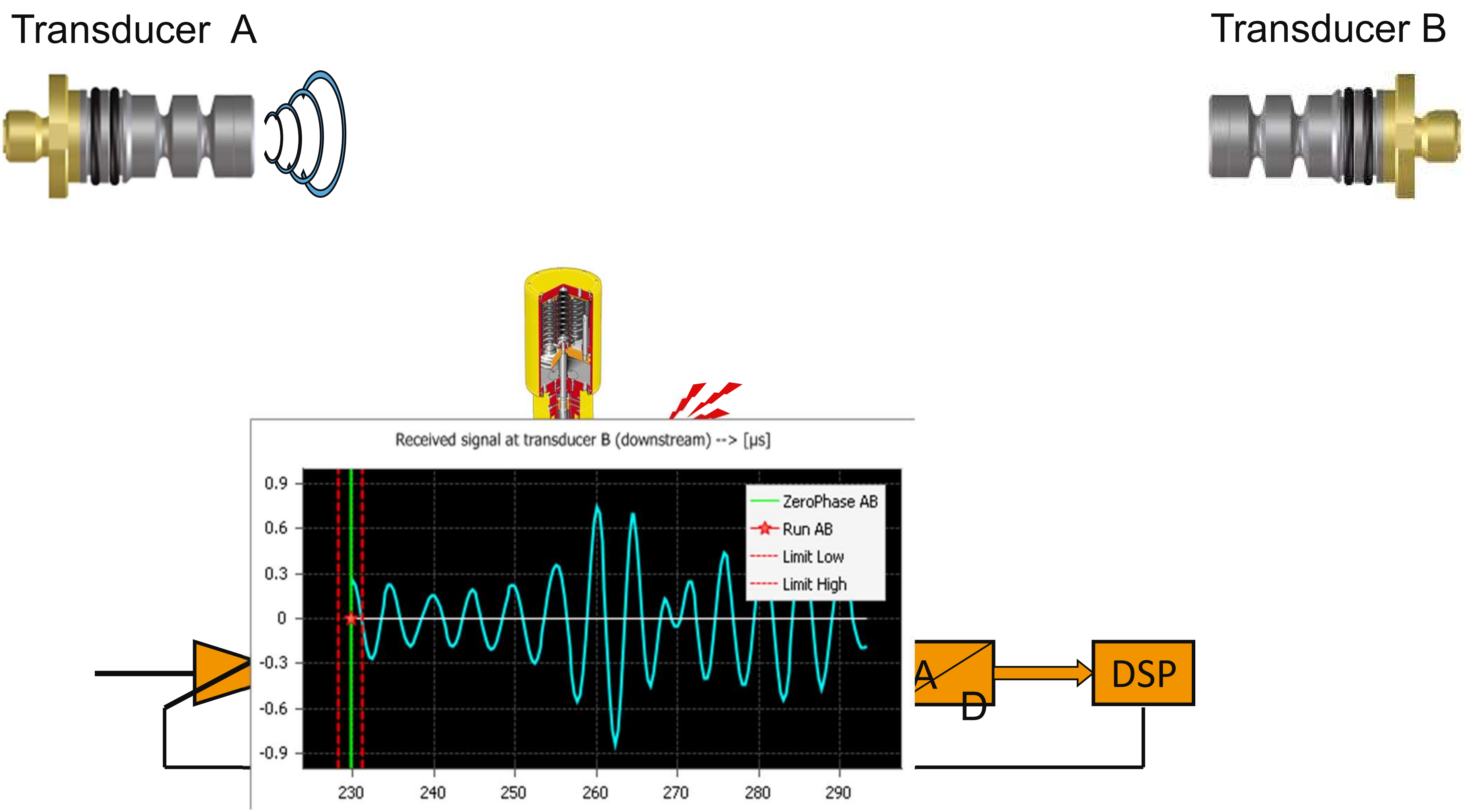
Basics of Gain

- Automatic operation in USMs
- Transducers are fired with a fixed energy
- Gain is a measure of how much amplification is needed to acquire the signal
- Amount of gain depends on several variables including:
  - Metering pressure
  - Gas velocity
  - Meter size (path length)
  - May increase due to contamination
- Contamination seldom causes gain to reach the maximum

ULTRASONIC MEASUREMENT



SNR – **S**ignal to **N**oise **R**atio



Basics about SNR

- SNR is a measure of signal strength to noise level
- SNR becomes important when control valves are near
- At very high gas velocities, SNR will decrease
- Different manufactures have different methods of presenting this information
- When the SNR gets low enough, performance will also decline

ULTRASONIC MEASUREMENT

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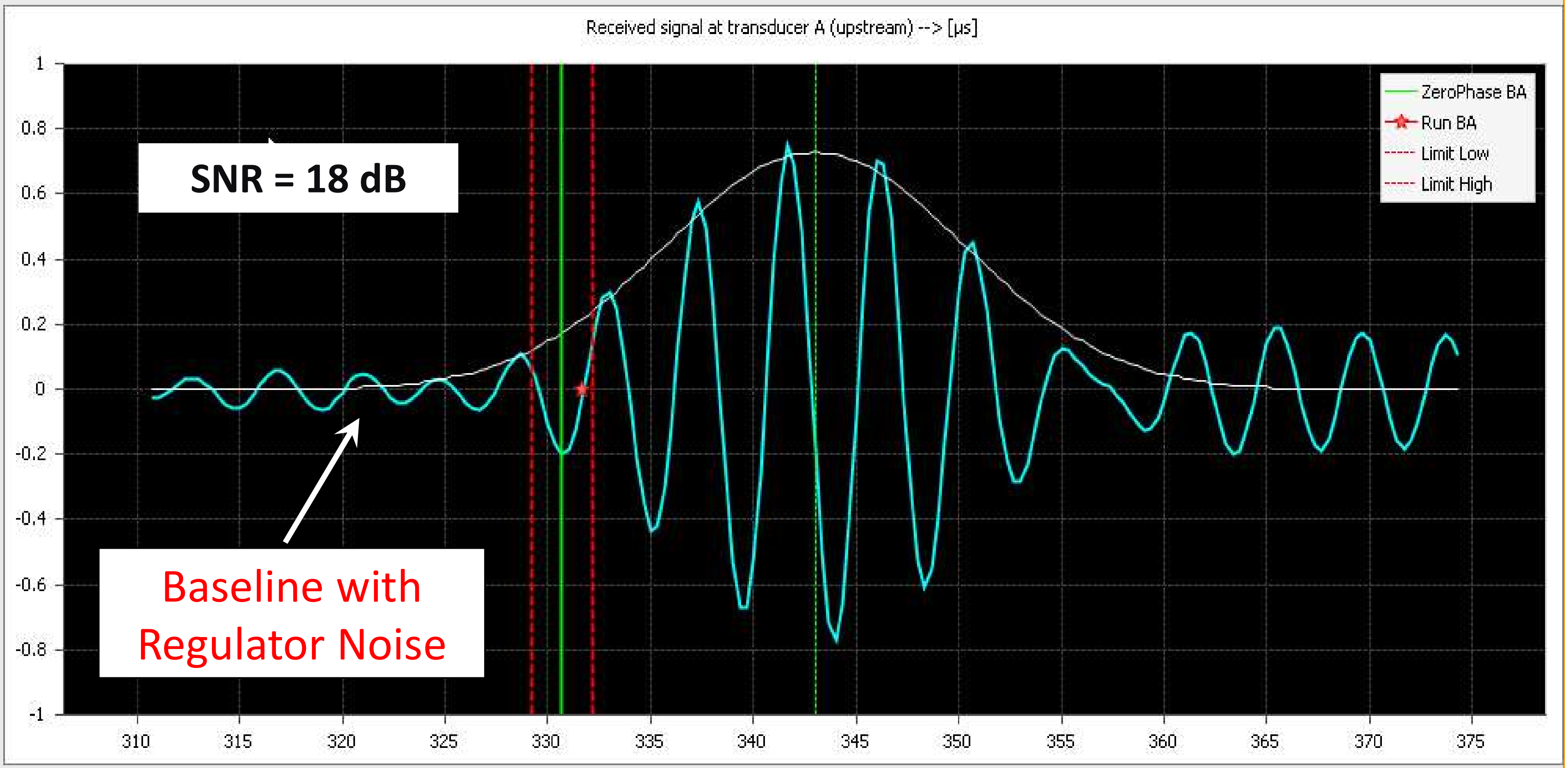
Upstream transducer – Regulator downstream



ULTRASONIC MEASUREMENT

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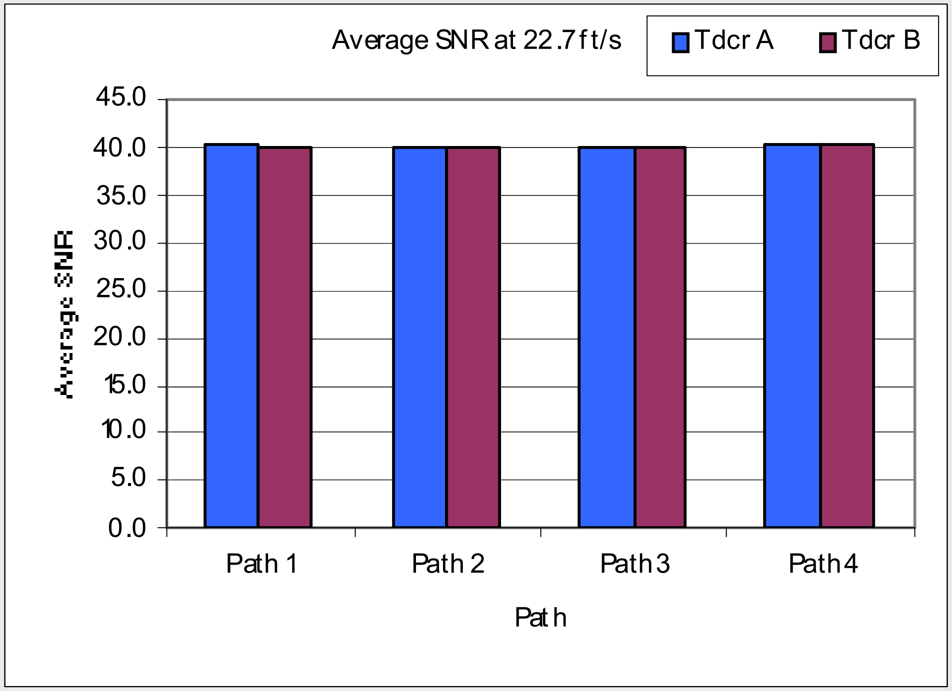
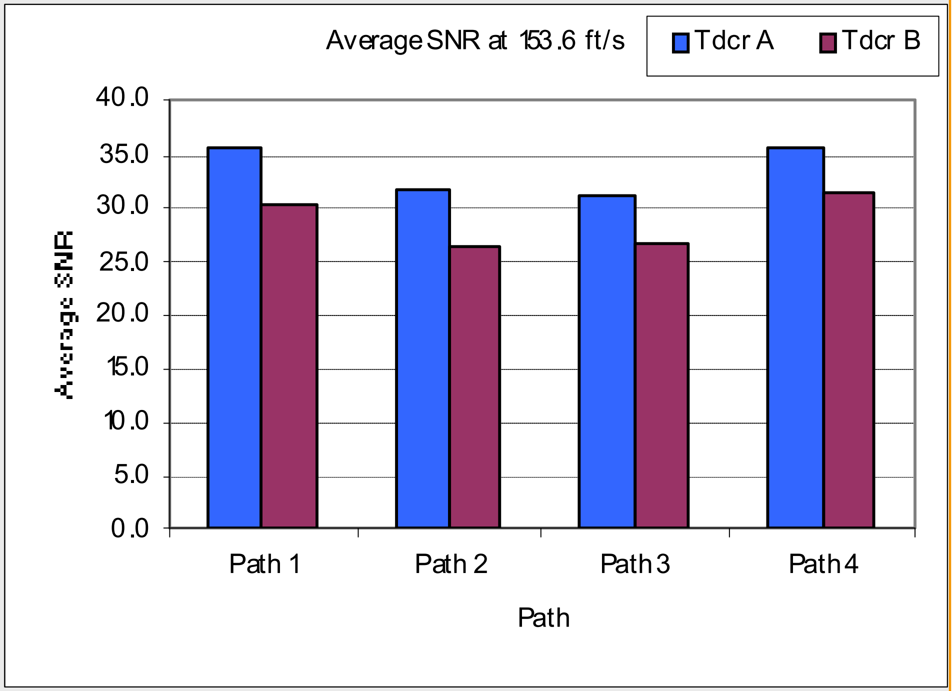
SNR at high Velocities





Benefit of ultrasonic measurement: Speed of sound

Velocity of sound waves moving through a medium.
Dependent on:
- Pressure
- Temperature
- Gas composition

$$c = \frac{L}{2}\left(\frac{1}{t_{AB}} + \frac{1}{t_{BA}}\right)$$

Temperature T in °C	Speed of sound c in $m \cdot s^{-1}$	Density of air ρ in $kg \cdot m^{-3}$	Acoustic impedance Z in $N \cdot s \cdot m^{-3}$
+35	351.88	1.1455	403.2
+30	349.02	1.1644	406.5
+25	346.13	1.1839	409.4
+20	343.21	1.2041	413.3
+15	340.27	1.2250	416.9
+10	337.31	1.2466	420.5
+5	334.32	1.2690	424.3
0	331.30	1.2922	428.0
−5	328.25	1.3163	432.1
−10	325.18	1.3413	436.1
−15	322.07	1.3673	440.3
−20	318.94	1.3943	444.6
−25	315.77	1.4224	449.1

Gas	Speed of Sound (m/s)
Argon	319
Helium	1007
Krypton	221
Xenon	178
Hydrogen	1270
Nitrogen	349
Oxygen	326
Carbon Dioxide	267
Sulfur Dioxide	201
Ethylene	327
Methane	446
Propane	258

ULTRASONIC MEASUREMENT

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Traditionally many have relied on SOS calculations and comparison to the meter's SOS as a verification of a meter's accuracy

This is a false assumption – A meter's SOS can be accurate compared to AGA 10, but the meter may not be measuring accurately

Why is this true?

Because the meter's SOS is not affected by velocity profile changes, but the meter's accuracy may!

ULTRASONIC MEASUREMENT

Basics of Signal Quality

- Generally referred to as Performance or Acceptance Rate
- Level of accepted pulses (displayed in percent)
- Reported by path
- 100% acceptance isn't required for accurate measurement
- Pulses are rejected if they fail certain criteria
- The most important part of pulse detection is to insure we don't pick the wrong waveform peak and thus have a bad transit time

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Flow Velocities

Most meters provide additional (advanced) diagnostics

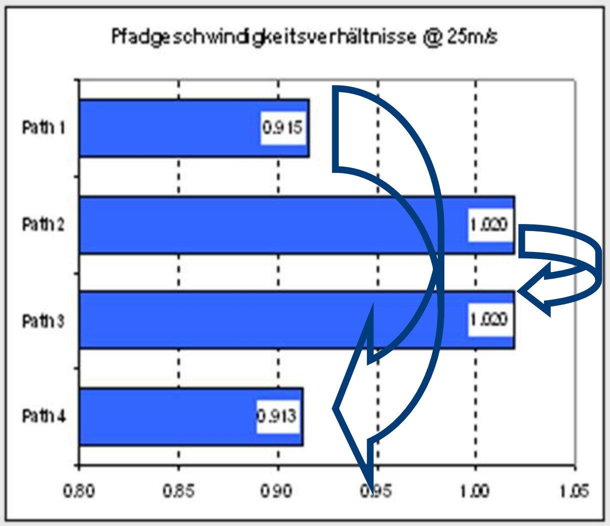
- Advanced diagnostics provide additional meter performance analysis

- Advanced diagnostics include:

  - **Profile factor**
  - **Symmetry**
  - **Turbulence**

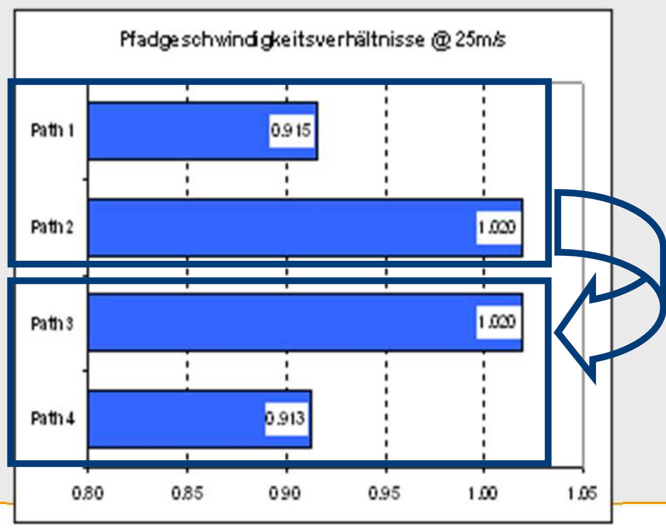
- Advanced diagnostics permit a more detailed analysis of process conditions

Profile factor and Symmetry



$$PF = \frac{v_2 + v_3}{v_1 + v_4}$$

Profile factor: 1.116



$$Sym = \frac{v_1 + v_2}{v_3 + v_4}$$

Symmetry: 1.001

$$XSym = \frac{v_1 + v_3}{v_2 + v_4}$$

XSymmetry: 1.001

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Profile factor

- Profile Factor is a summary of the path ratios
- Definition is defined as (Path 2 + 3)/(Path 1 + 4)
- Since Path Ratios for 2 & 3 are larger than Paths 1 & 4, the Profile Factor is usually greater
- Typical profile factor for a Chordal meter is between 1.11 and 1.18
- Profile Factor is a simple method of identifying changes in the profile
- Profile Factor is generally stable from 3-5 fps up to meter capacity

Symmetry

- Symmetry is a summary of the path ratios similar to Profile Factor
- Definition is defined as (Path 1 + 2)/(Path 3 + 4)
- If profile is symmetrical from top to bottom on a Chordal meter, the Symmetry value should be 1.00
- Distorted profiles will cause the Symmetry value to either be above or below 1.00, depending upon the distortion
- This additional diagnostic parameter helps verify consistent profile
- It is possible to have a correct Profile Factor, but have a distorted profile – Symmetry provides a second check

Turbulence Indication

- USMs sample each transducer pair several times per second
- The average transit times of many samples is used to compute the flow rate
- Each transit time measurement during the sampling period for each update period has some variation
- The variability of all samples, when compared to the average, provides in indication of the velocity stability. This variability is called Turbulence
- May be the easiest method of identifying flow conditioner blockage

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Summary

- Advanced diagnostics include Profile Factor, Symmetry, and Turbulence
- Turbulence best diagnostic to identify blocked flow conditioners, pulsation and one indicator for liquid detection
- Symmetry combined with Profile Factor helps validate gas velocity profile hasn´t changed
- Small changes (<5%) in Profile Factor / Symmetry may only constitute a minor increase in measurement uncertainty
- Interface software and collection log files necessary to validate proper USM operation, including control valve noise issues
- Understanding what the diagnostics are telling you makes it very easy to identify what problems the meter may be encountering

DIAGNOSTICS EXAMPLES

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DIAGNOSTIC EXAMPLE

THE FLOW PROFILE INDICATION IS OUTSIDE THE BOX. CUSTOMER FOUND A SMALL BLOCKAGE ON HIS FLOW CONDITIONER CAUSING A DISTURBANCE IN THE FLOW PROFILE.

DIAGNOSTICS EXAMPLE

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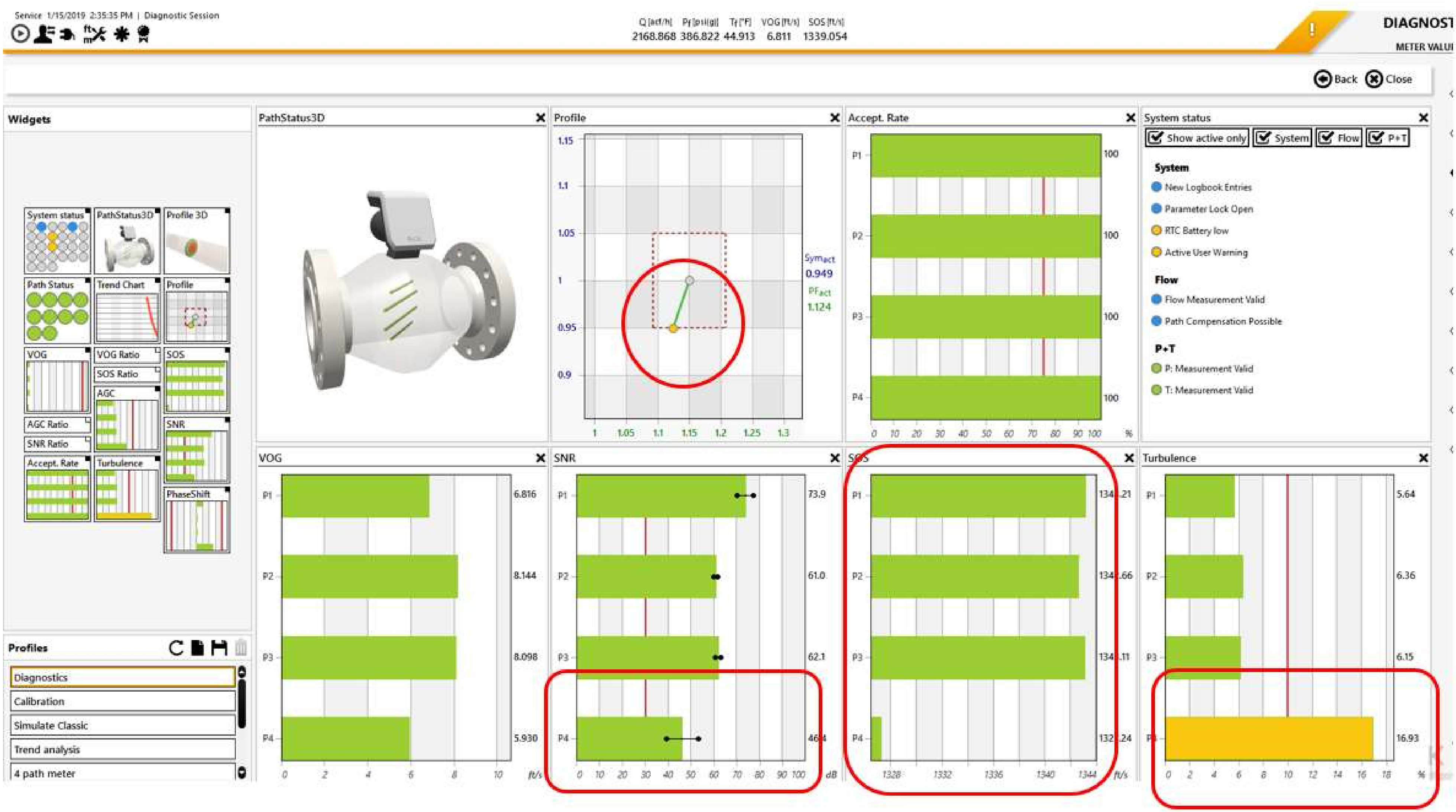
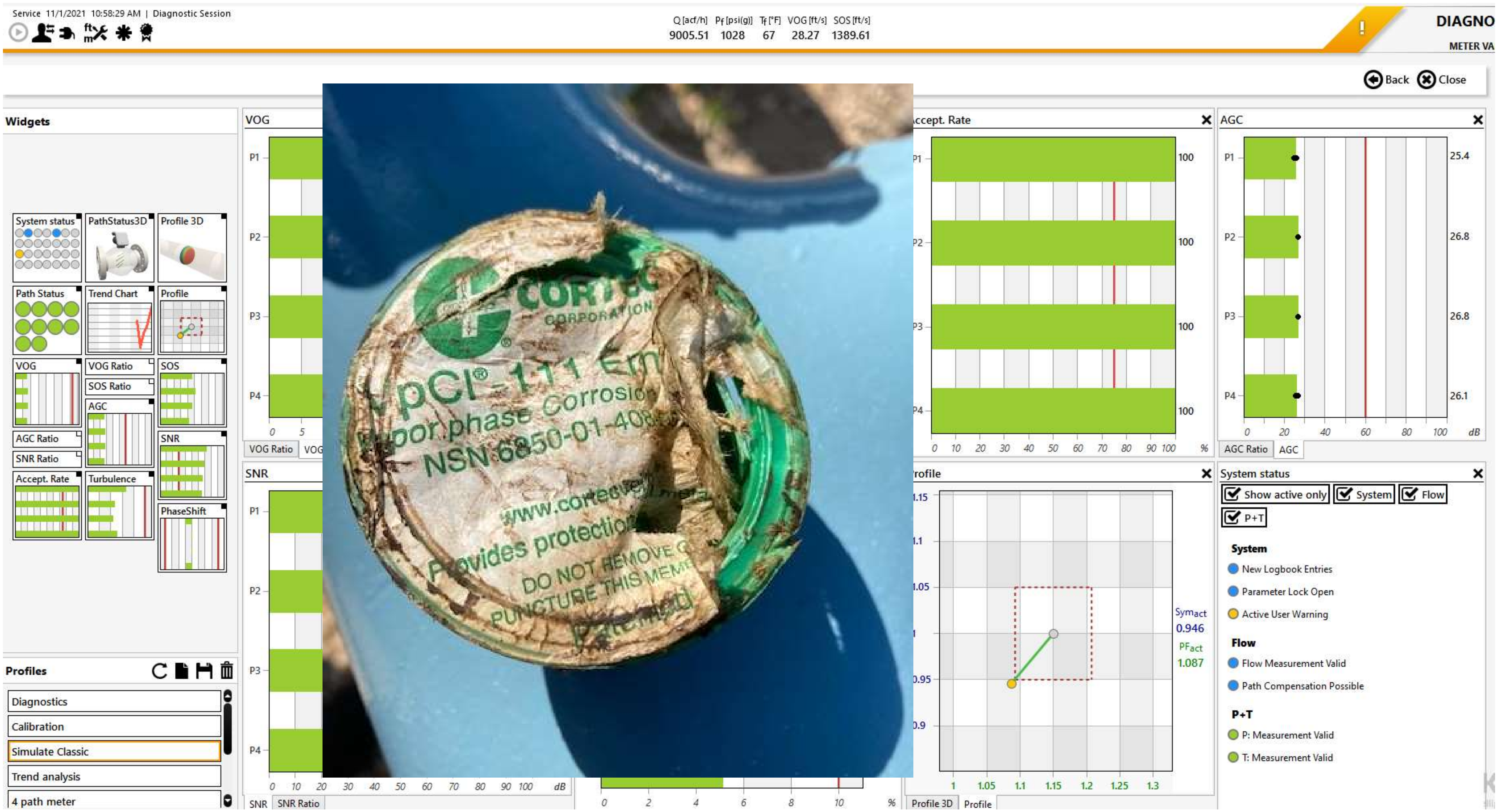
IN THIS EXAMPLE, THE PROFILE IS OUTSIDE THE BOX, LOW SNR ON PATH 4, SOS DEVIATION ON PATH 4 AND HIGH TURBULENCE ON PATH 4. THIS WAS AN INDICATION OF SOME BUILD UP ON THE BOTTOM OF THE METER RUN.



DIAGNOSTICS EXAMPLE

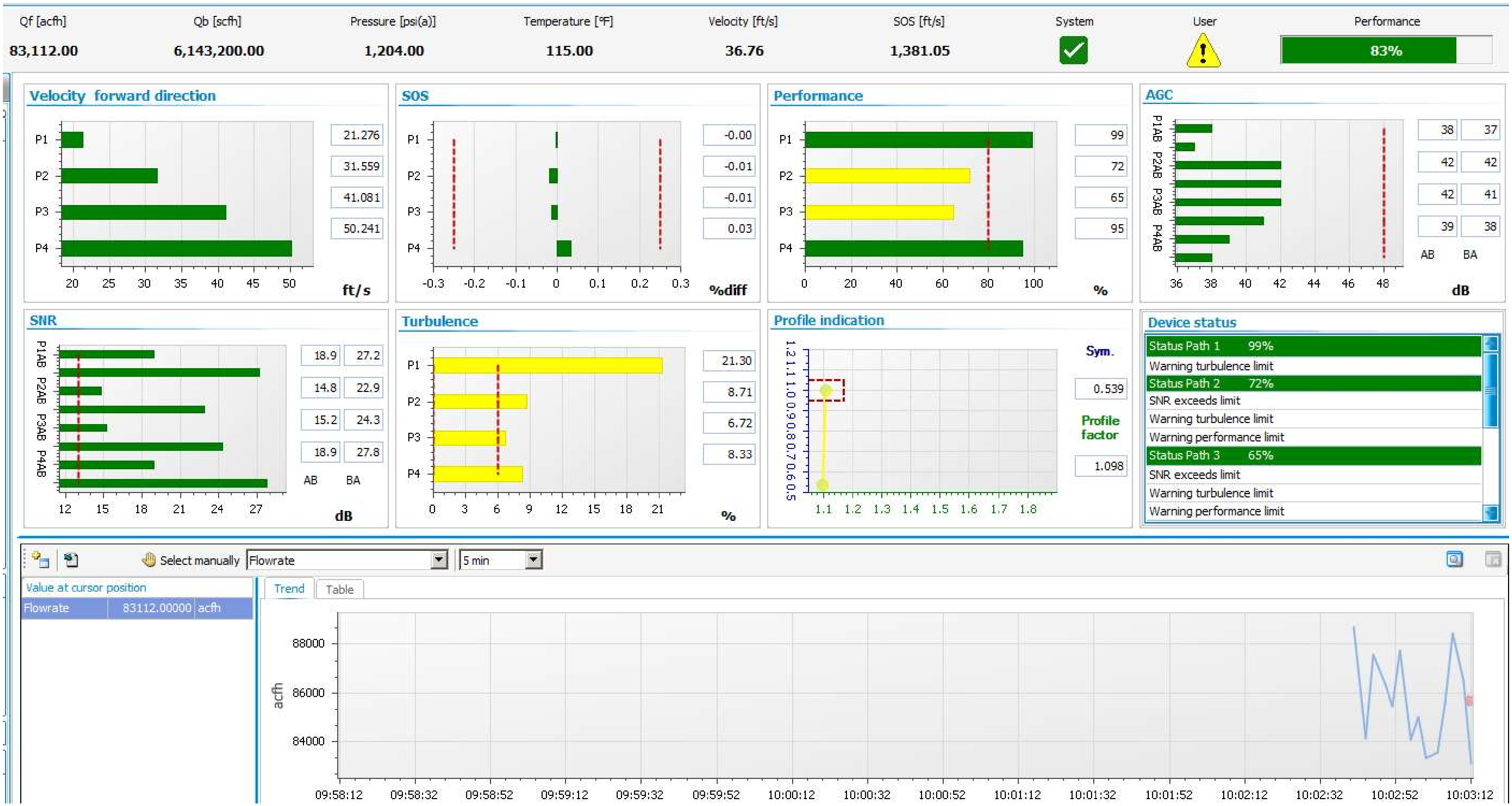
Customer had issues with a new installation that was indicating a warning limit related to the symmetry and profile factor. Upon inspection, a corrosion inhibitor was found blocking the flow conditioner.

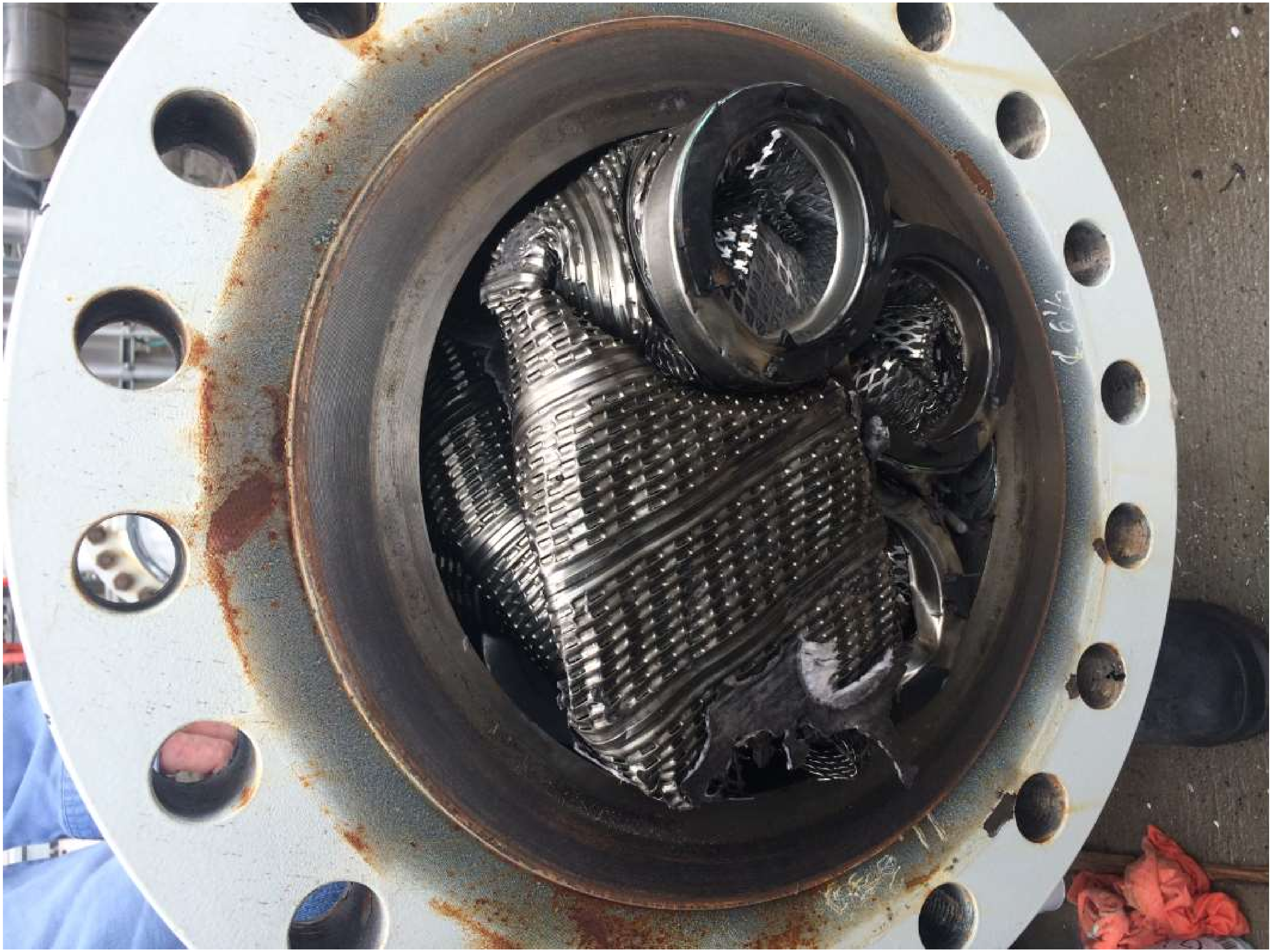


DIAGNOSTIC EXAMPLE

IN THIS EXAMPLE, PATH 3 IS SHOWING A FAILURE. THIS COULD BE A BAD ELECTRONICS BOARD, BLOCKED TRANSDUCER OR FAILED TRANSDUCER. CUSTOMER WAS ASKED TO PERFORM A SWAP TEST TO DETERMINE THE CAUSE OF THE FAILURE. THE TRANSDUCER CABLES WERE SWAPPED BETWEEN PATHS 2 AND 3. AFTER SWAPPING, PATH 3 CONTINUED TO FAIL INDICATING A BAD ELECTRONICS BOARD.

DIAGNOSTICS AND TROUBLESHOOTING





DIAGNOSTICS AND TROUBLESHOOTING

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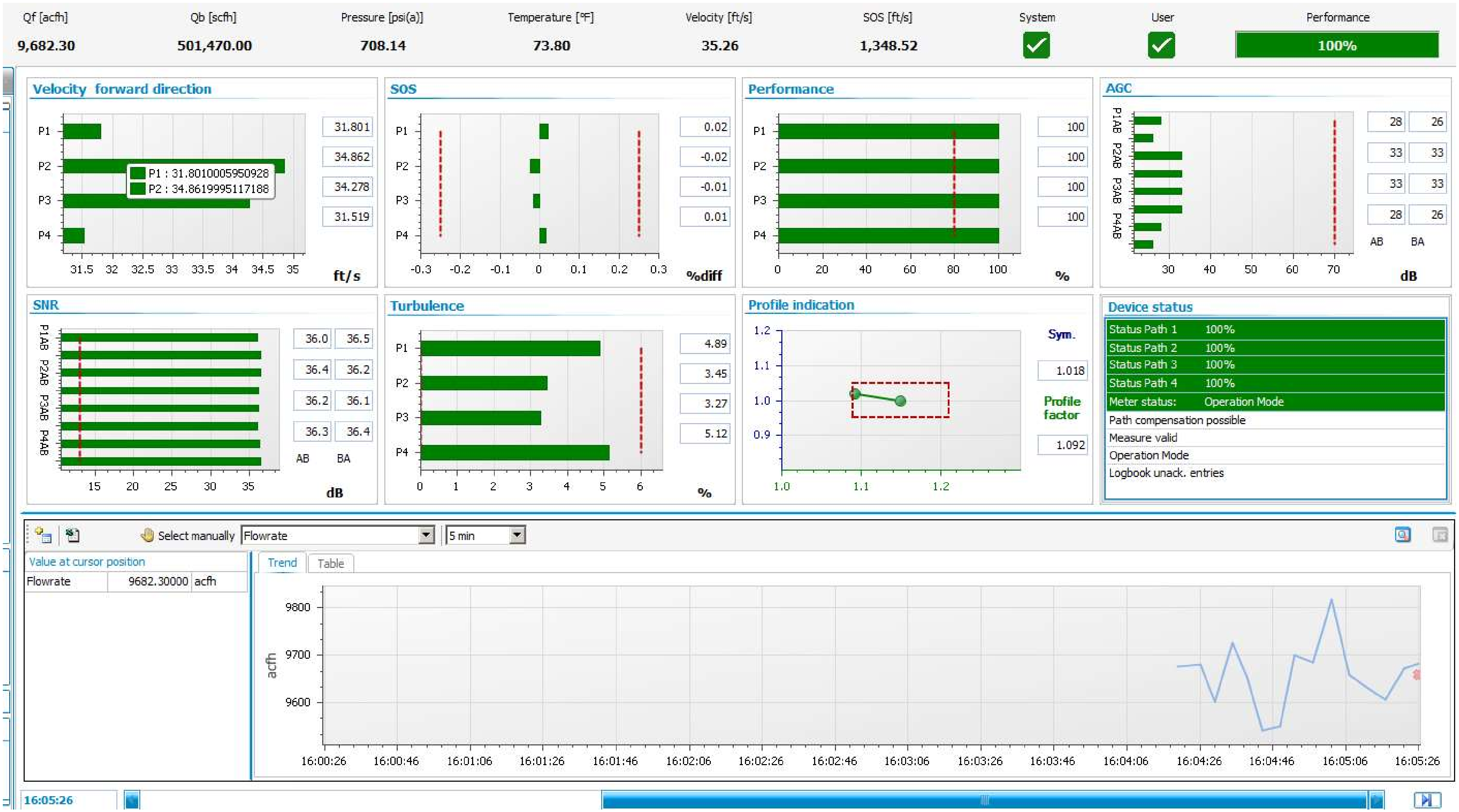

MANY THANKS FOR YOUR ATTENTION

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