From Data to Decisions: Next-Generation Diagnostics in Gas Multipath Ultrasonic Meters

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Fuelling the Future

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Class Agenda

- Advantages of using Ultrasonic Meters
- History of Ultrasonic Meters
- Basic Principle of Operation of Ultrasonic Meters
- Effects of upstream piping on Ultrasonic meters and using Flow Conditioners
- General Diagnostic Information
- Advanced Diagnostic Information
- Diagnostic Examples
- Q & A

Advantages of using Ultrasonic Meters

- Large Turndown Ratio (>50-1)
- Naturally Bi-Directional
- Tolerant of Wet Gas Applications
- No pressure loss across the meter
- No routine maintenance
- Fault Tolerant (path substitution)
- High accuracy and linearity
- Advanced diagnostics using Software

Brief History of Ultrasonic Meters

- First developments of Ultrasonic technology started around 1920’s
  - Fluid velocity measurement in closed conduits with sonic pulses
  - With discovery that transmission and reception of repetitive sound bursts could be used to describe the location and speed of moving objects
  - This principle was soon used to build sonar and radar arrays
- First meters for gas applications began development in the 1970’s
  - With the development of economical high-speed electronics and digital signal processing in the late 1970s that a repeatable instrument with sufficient resolution for gas applications was devised.
- First Ultrasonic meters were manufactured in the late 1980’s/early 1990’s
  - Once digital signal processing was available and was also economical USM were manufactured in the late 80’s and early 90’s.
- Technical Note M-96-2-3, *Ultrasonic Flow Measurement for Natural Gas Applications* is published in 1996
- AGA 9 (Rev 1)is approved in 1998

Basic Principle of Operation of Ultrasonic Meters

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, a voltage is applied to the piezo-ceramic element so that it vibrates mechanically.

These vibrations are then transferred through a 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.

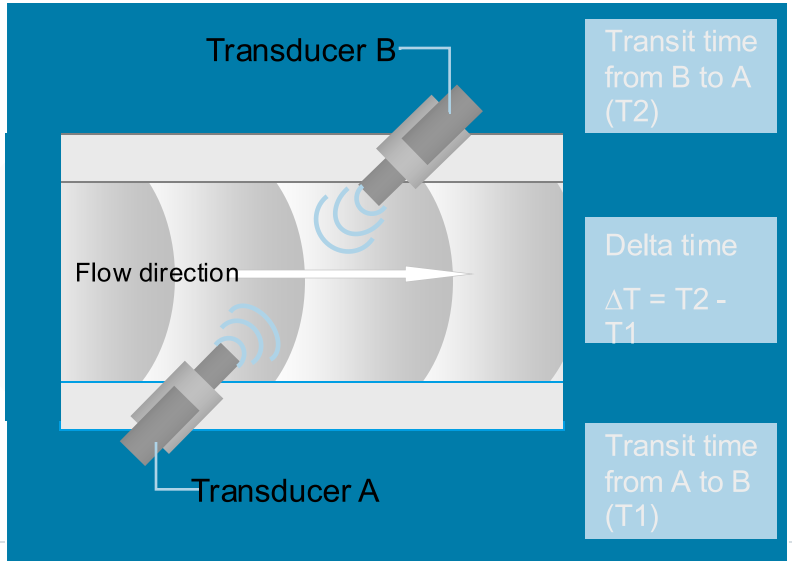
Basic Principle of Operation of Ultrasonic Meters

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

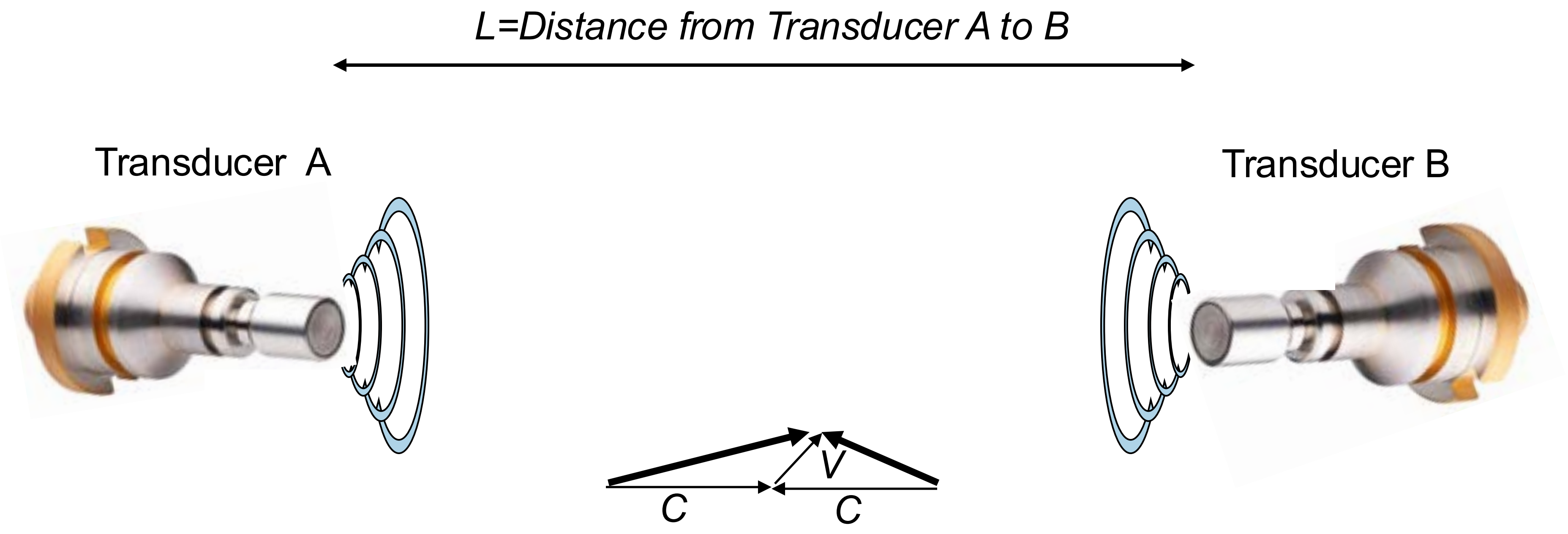
Crossing a pipe by ultra sound

- 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

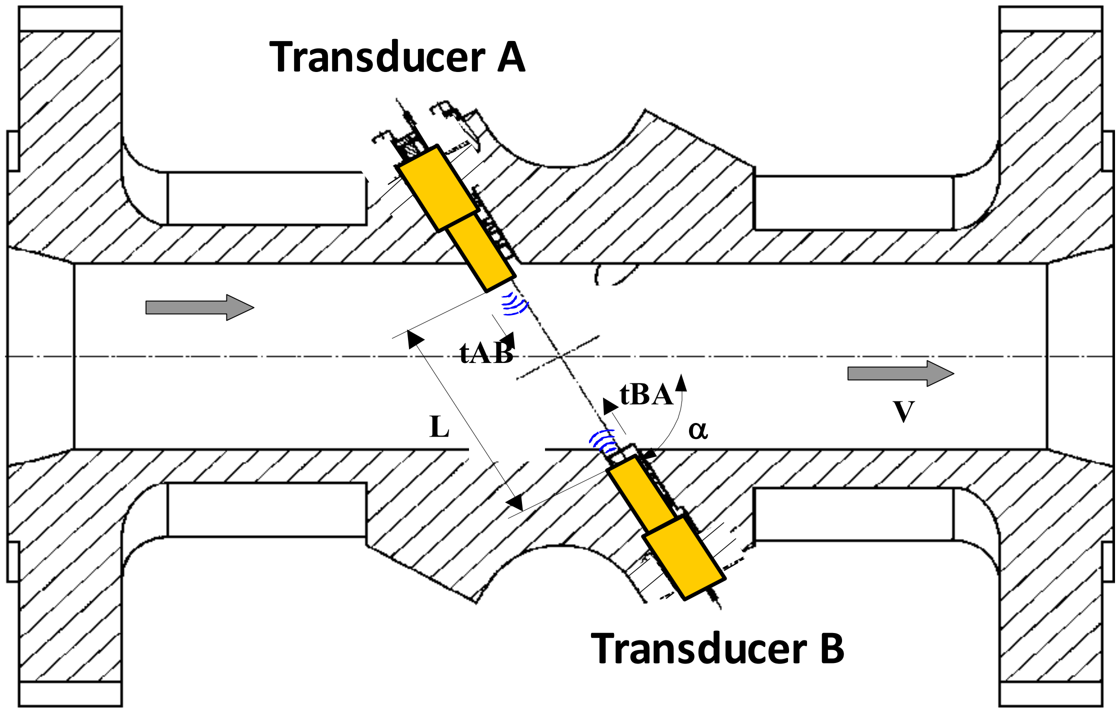
Propagation Delay of an Ultrasonic Pulse



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

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

USM Operating Principle



Travel Time Difference

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

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

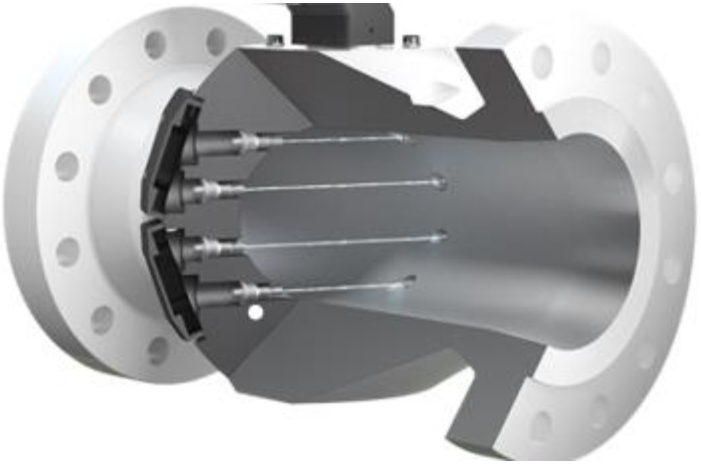
Path velocity

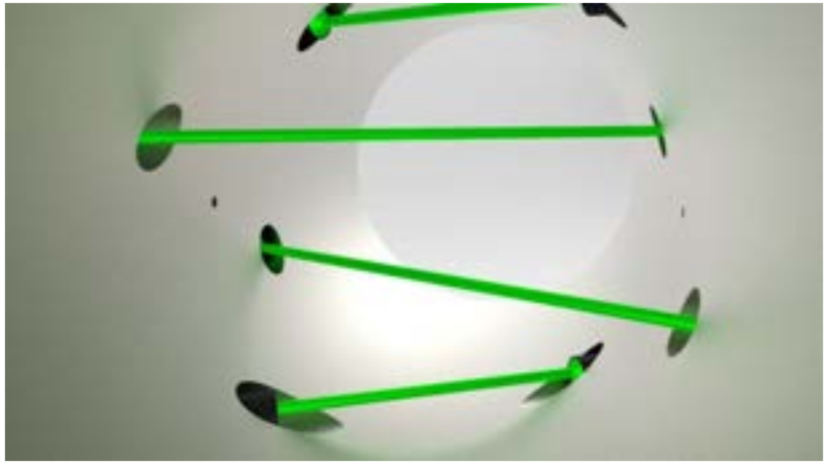
$$v_{Pfad} = \frac{L}{2 \cdot \cos\alpha}\left(\frac{1}{t_{AB}} - \frac{1}{t_{BA}}\right)$$

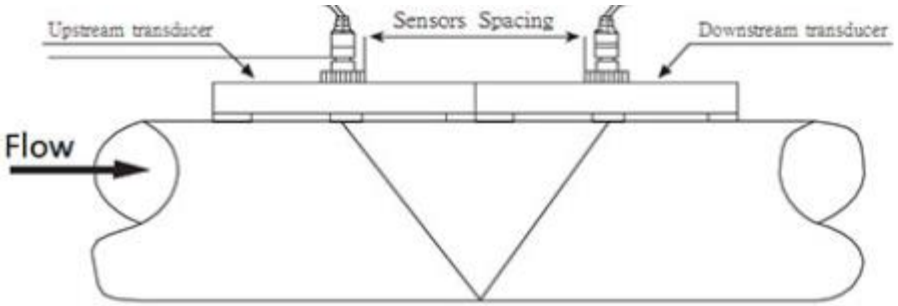
Sound Velocity

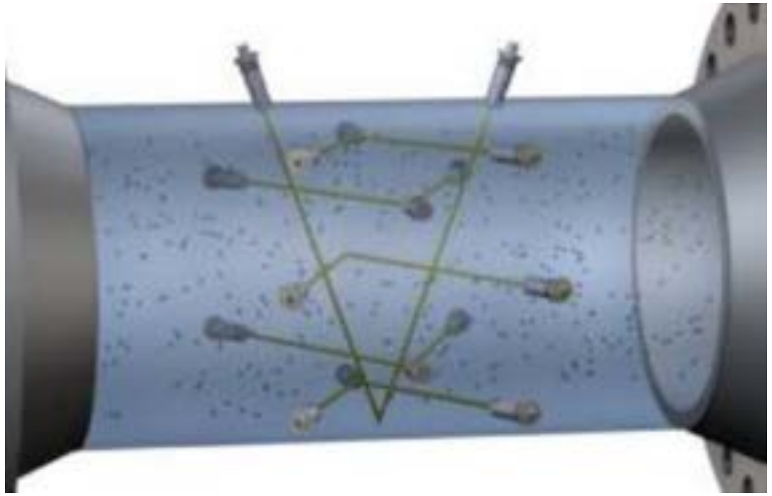
$$c = \frac{L}{2}\left(\frac{1}{t_{AB}} + \frac{1}{t_{BA}}\right)$$

Path Configurations

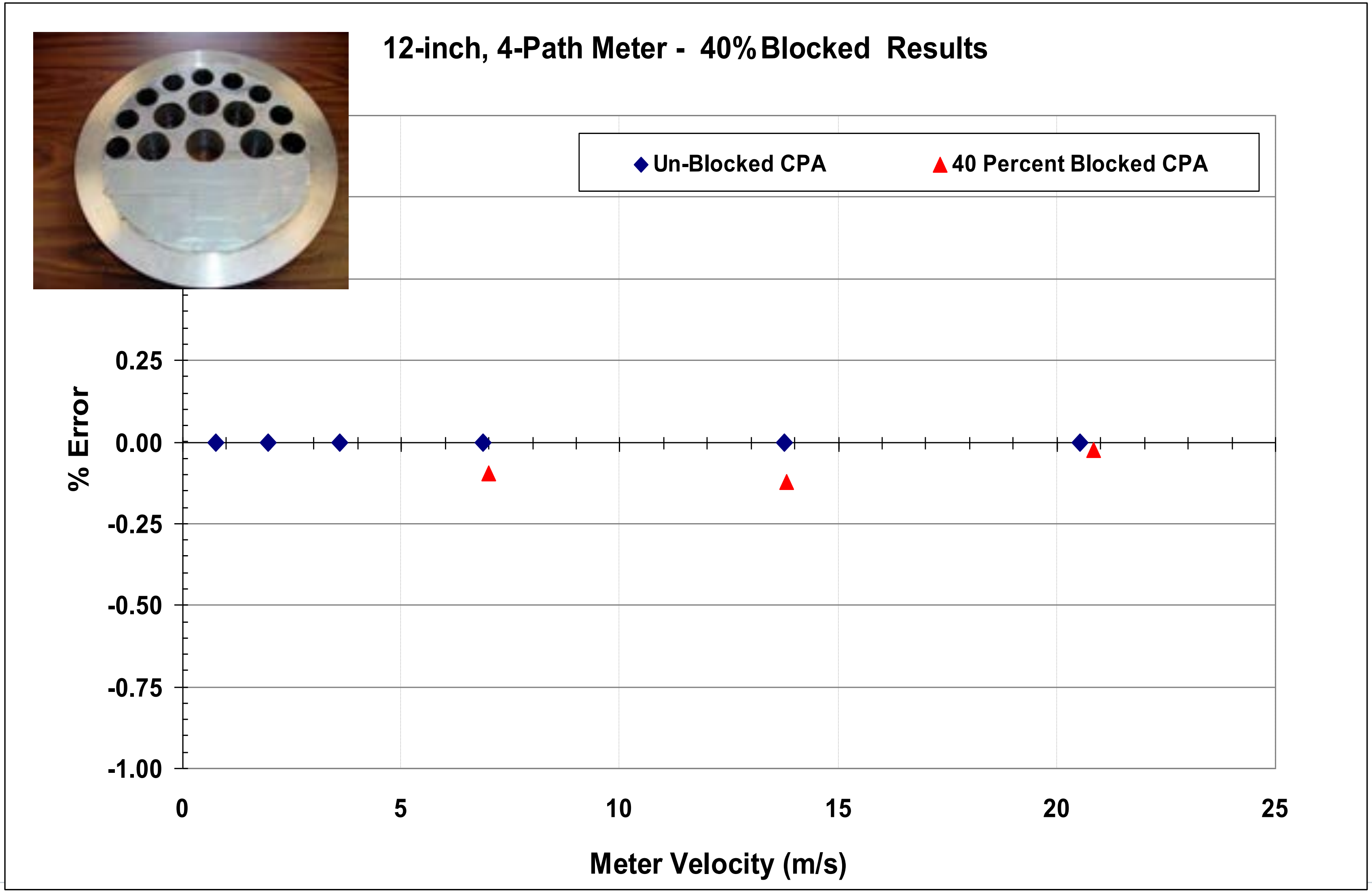








Ultrasonic measurement testing



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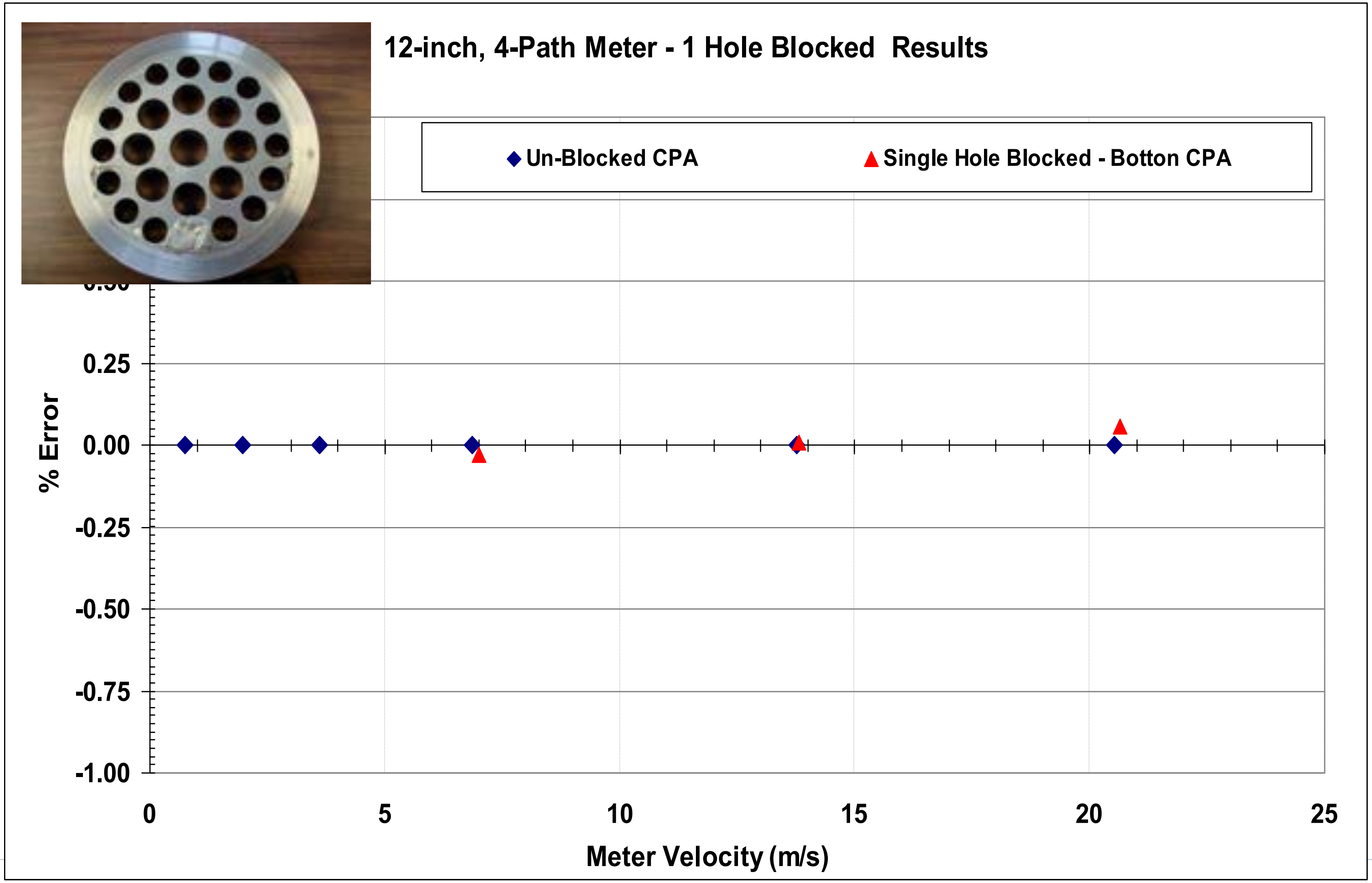
Ultrasonic measurement



Flow conditioner out of alignment

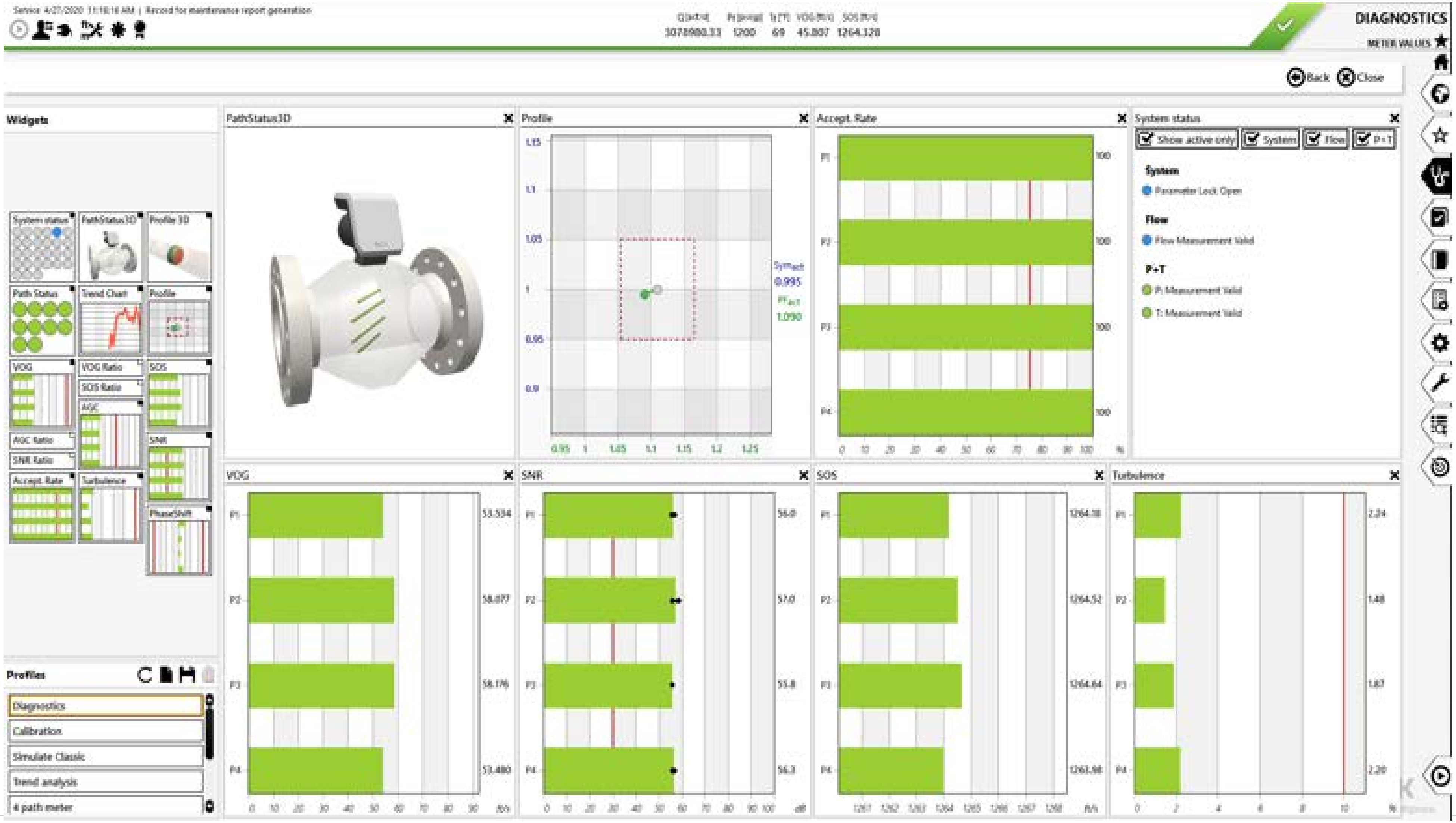
GENERAL DIAGNOSTIC INFORMATION

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

DIAGNOSTICS PAGE



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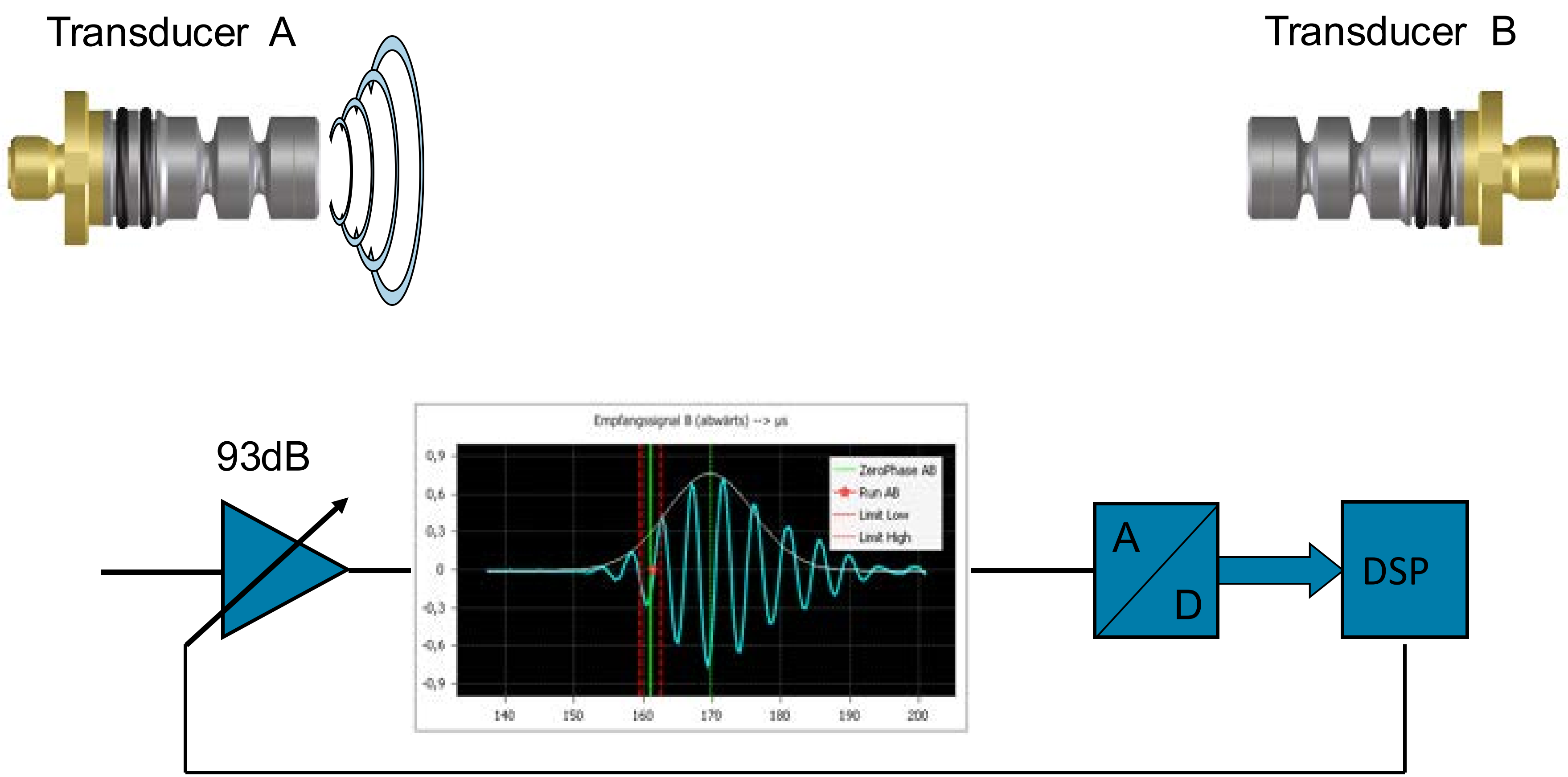
Ultrasonic measurement

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



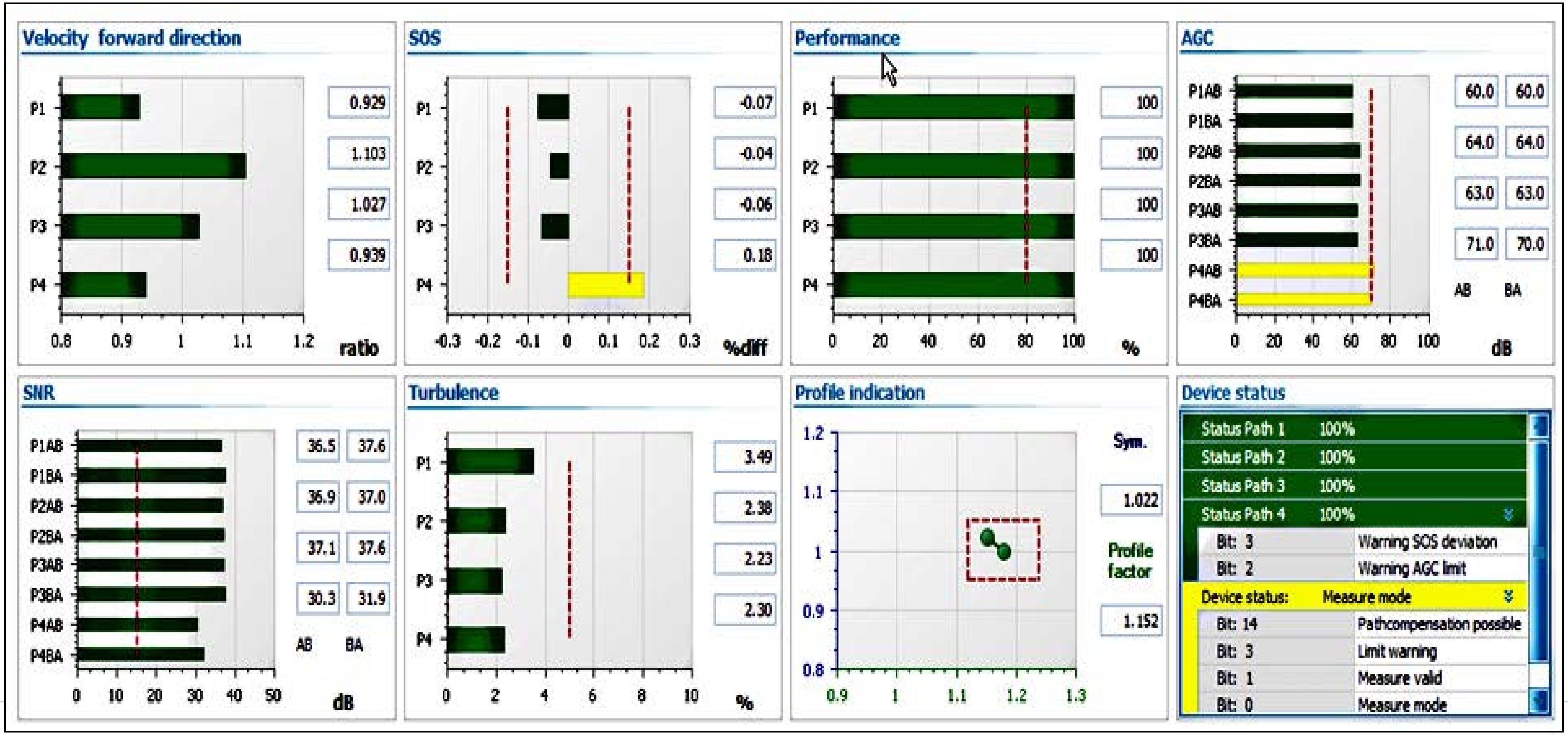
AGC ~ Receiving amplitude

Ultrasonic measurement

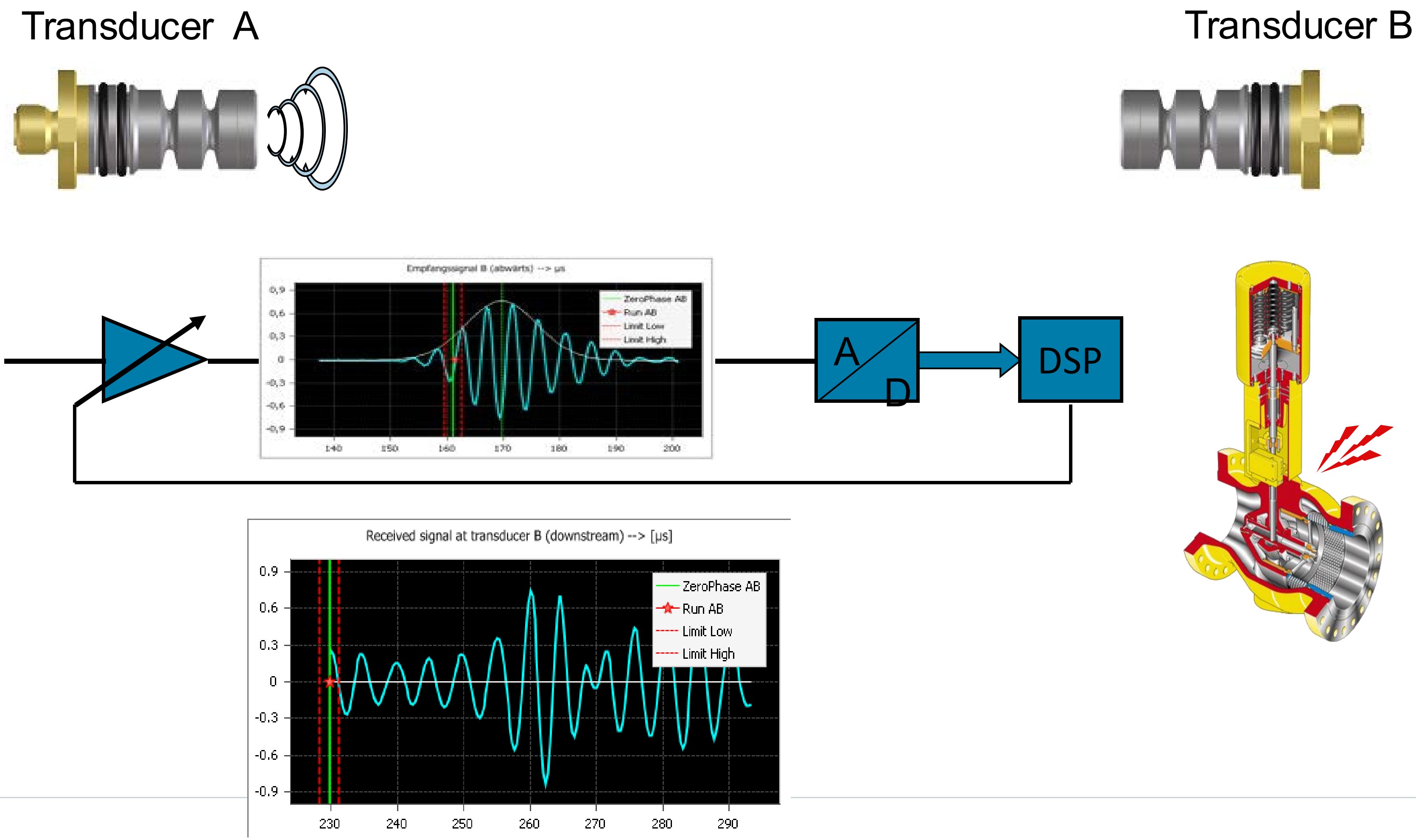
Basics of Gain

- 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

AGC diagnostic



SNR – Signal to Noise Ratio

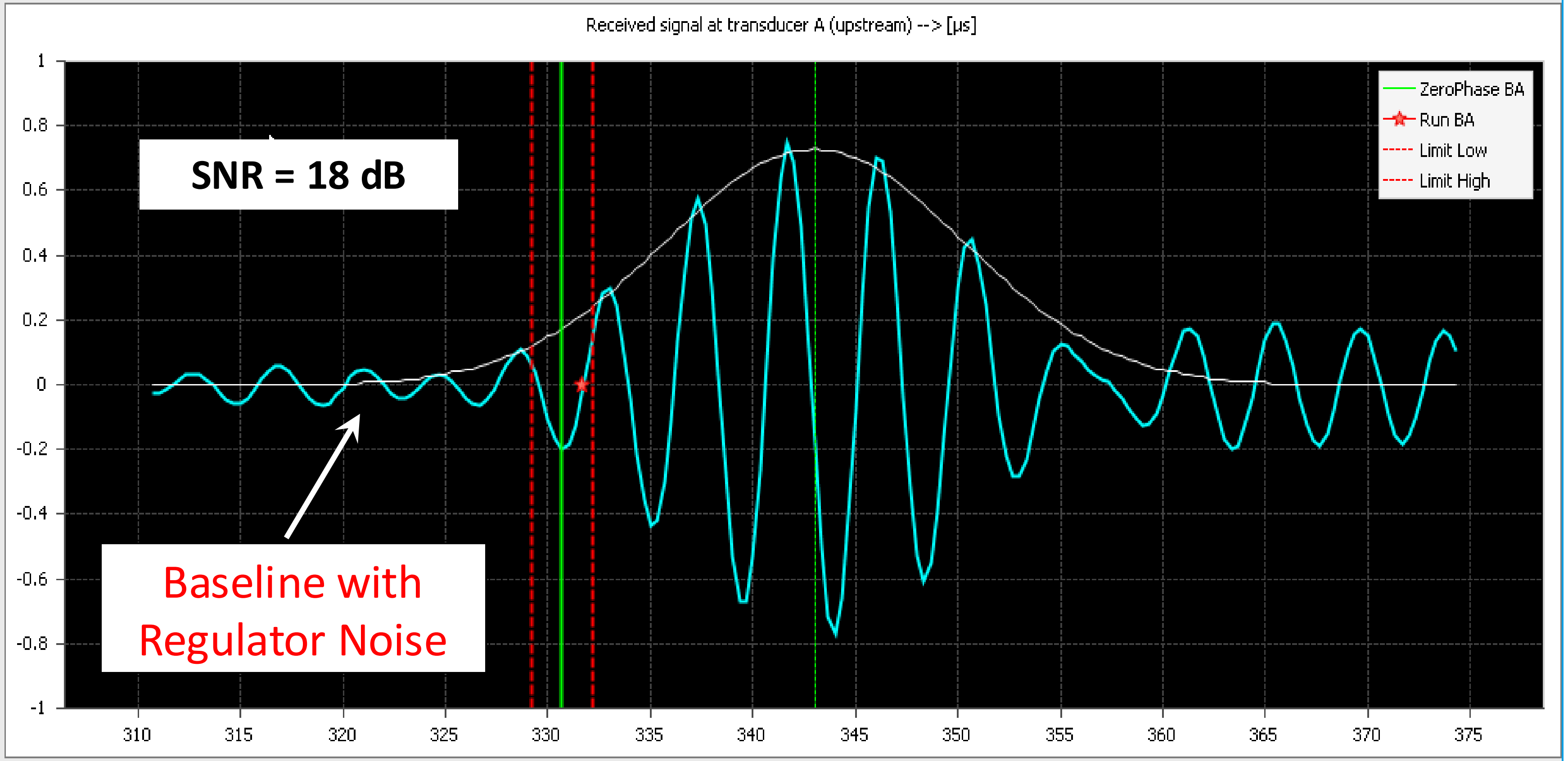


Basics about SNR

- 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

Noise Sources- Disturbances

Upstream transducer – Regulator downstream



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Benefit of ultrasonic measurement: Speed of sound

Velocity of sound waves moving through a medium.
Dependent on:
- Pressure
- Temperature
- Gas composition (can indicate gas quality in blends)

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

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

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
- A maintenance alarm is often triggered at 80% performance, but the meter won't fail a path until about 25%.

Ultrasonic measurement

Advanced Diagnostics

Most meters provide additional (advanced) diagnostics

- Advanced diagnostics provide additional meter performance analysis

- Advanced diagnostics include:

  - **Profile factor- is the shape within tolerance**
  - **Symmetry- Has the shape changed from previous**
  - **Turbulence- Has turbulence increased.**

- Advanced diagnostics permit a more detailed analysis

  of process conditions

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 than 1
- 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

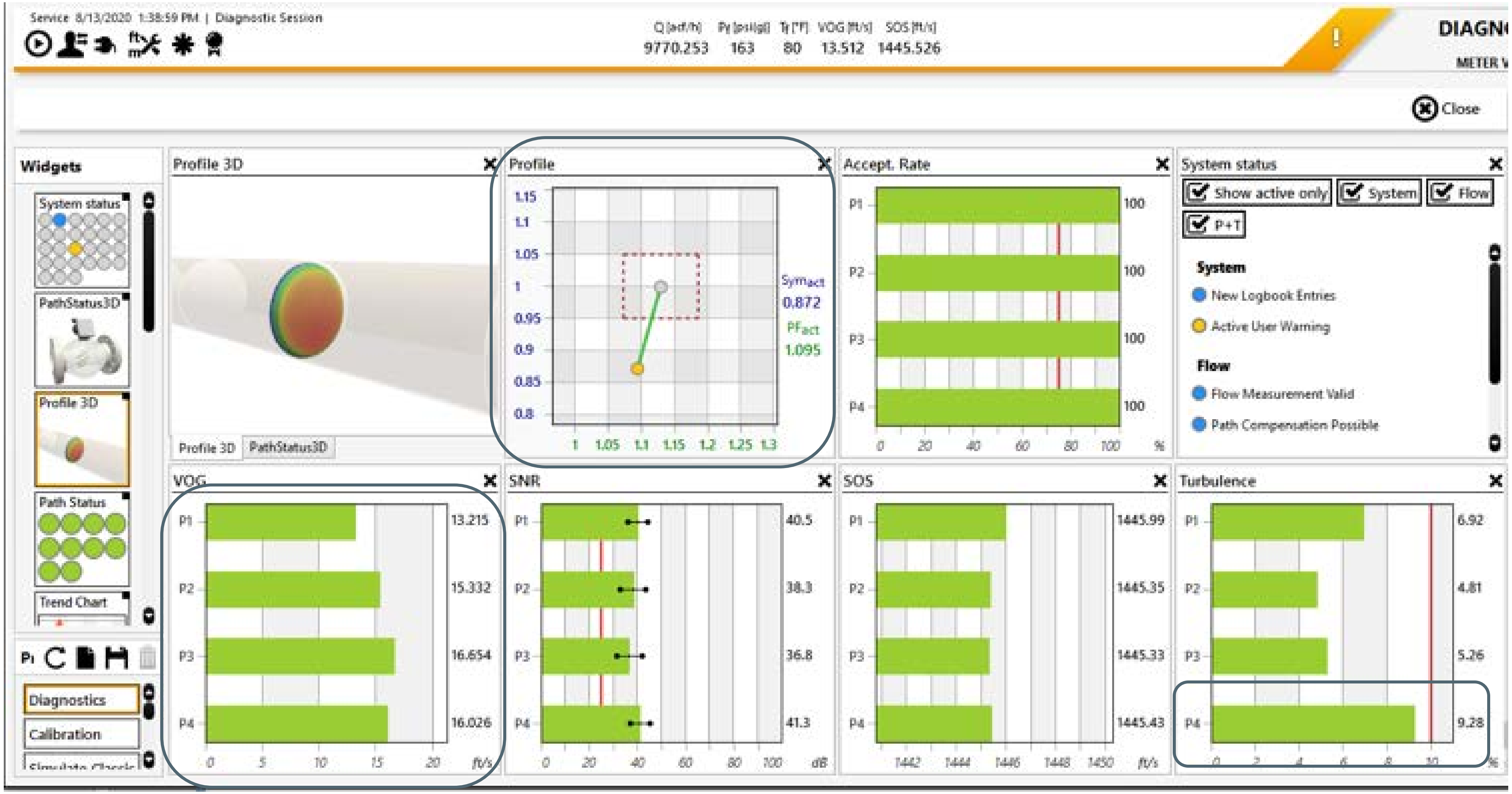
- USMs sample each transducer pair several times per second
- The average transit times of many samples is used to compute the flow rate
- Each transit time measurement during the sampling period for each update period has some variation
- The variability of all samples, when compared to the average,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

Summary

- Advanced diagnostics include Profile Factor, Symmetry, and Turbulence
- Turbulence best diagnostic to identify blocked flow conditioners, pulsation and possibly 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 help 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

DIAGNOSTIC EXAMPLE



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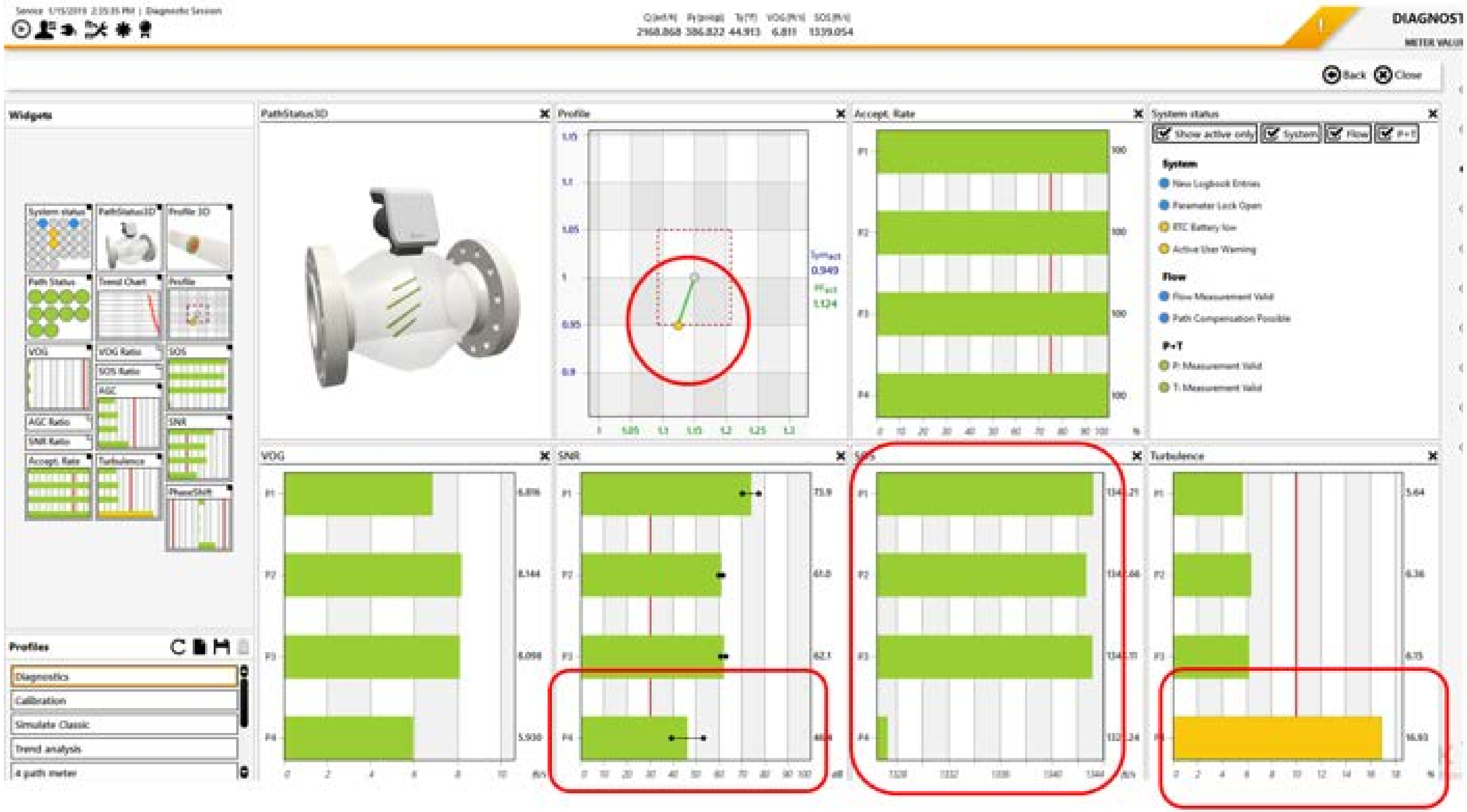
DIAGNOSTICS EXAMPLE



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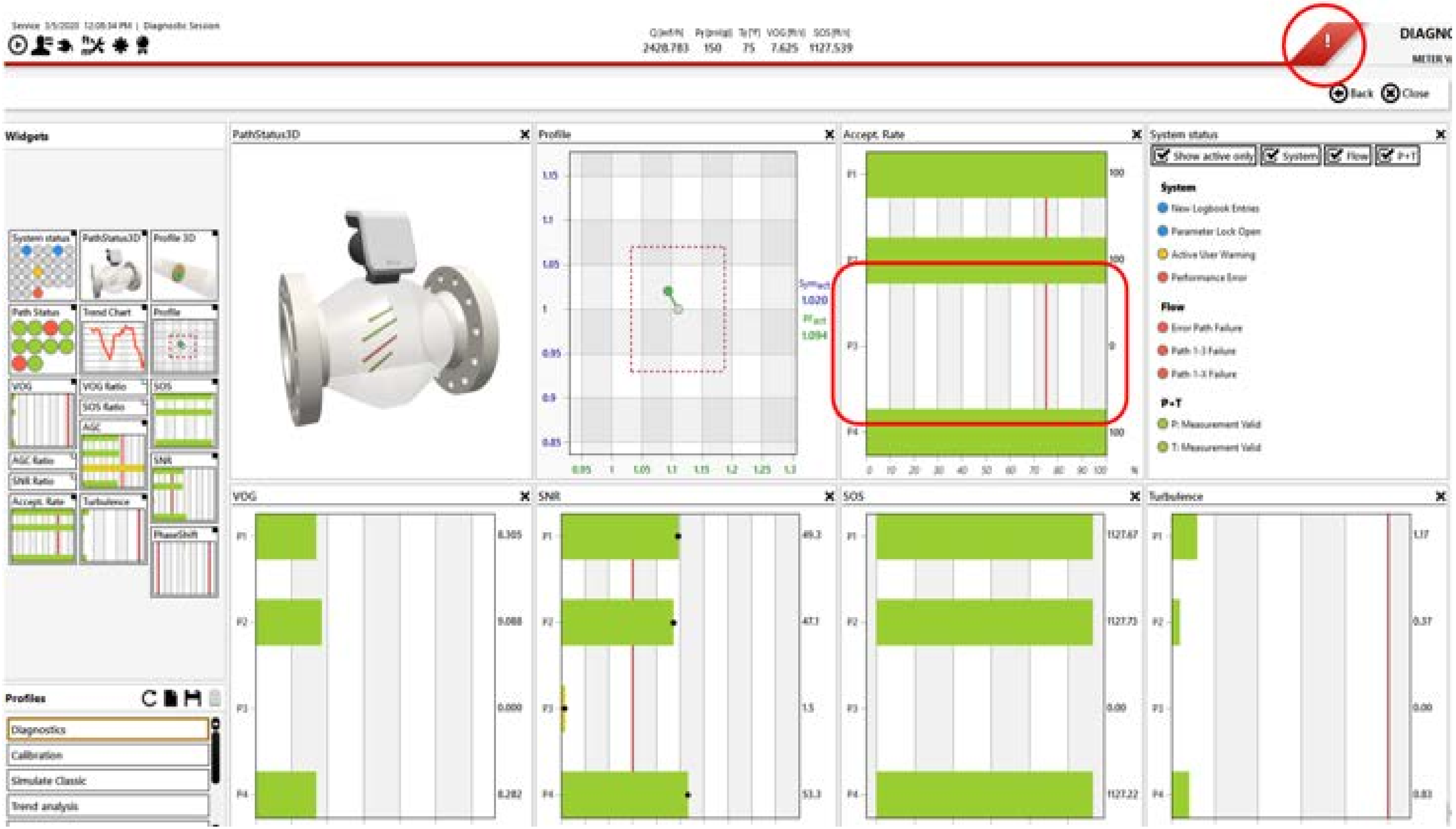
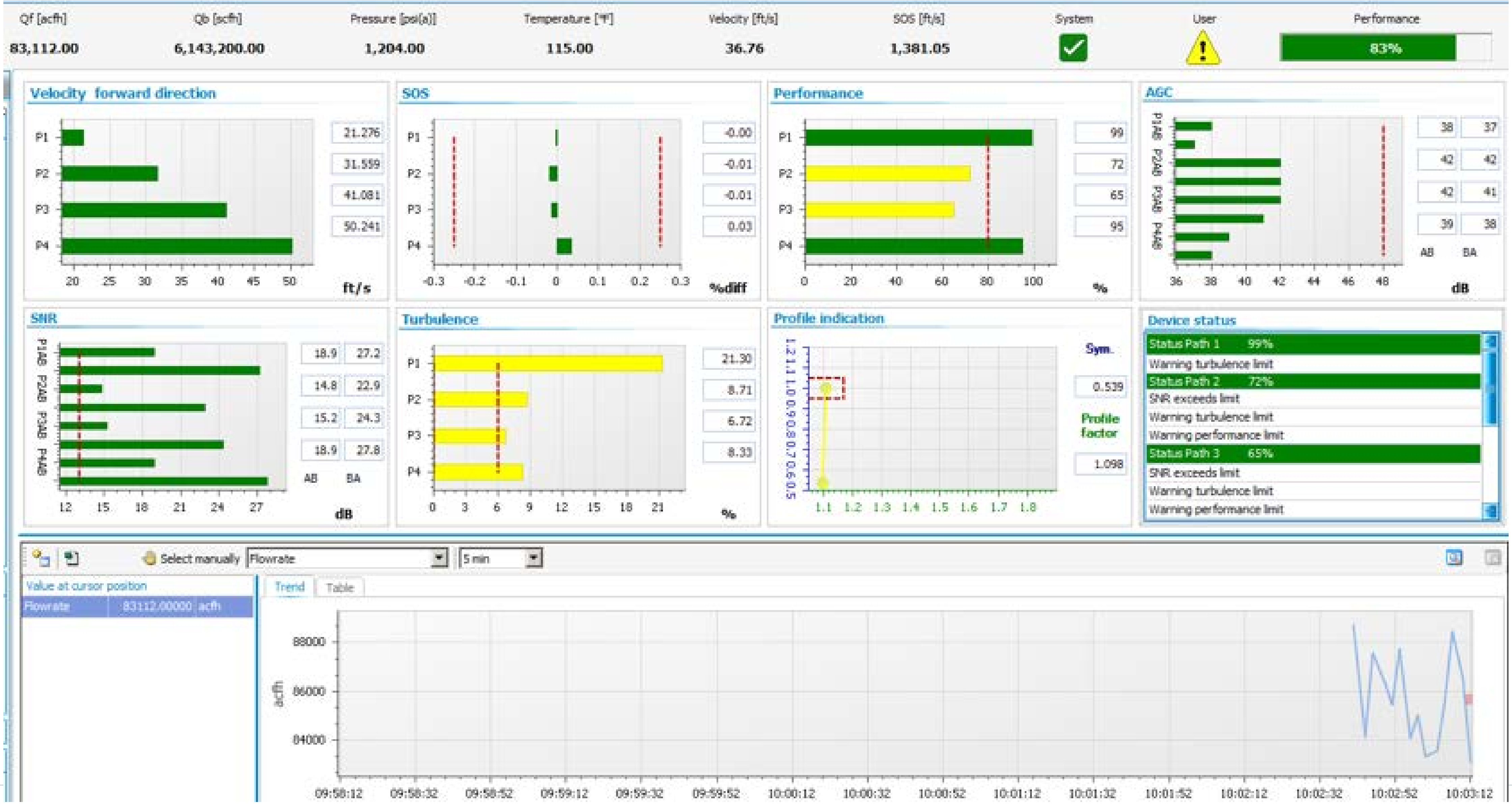
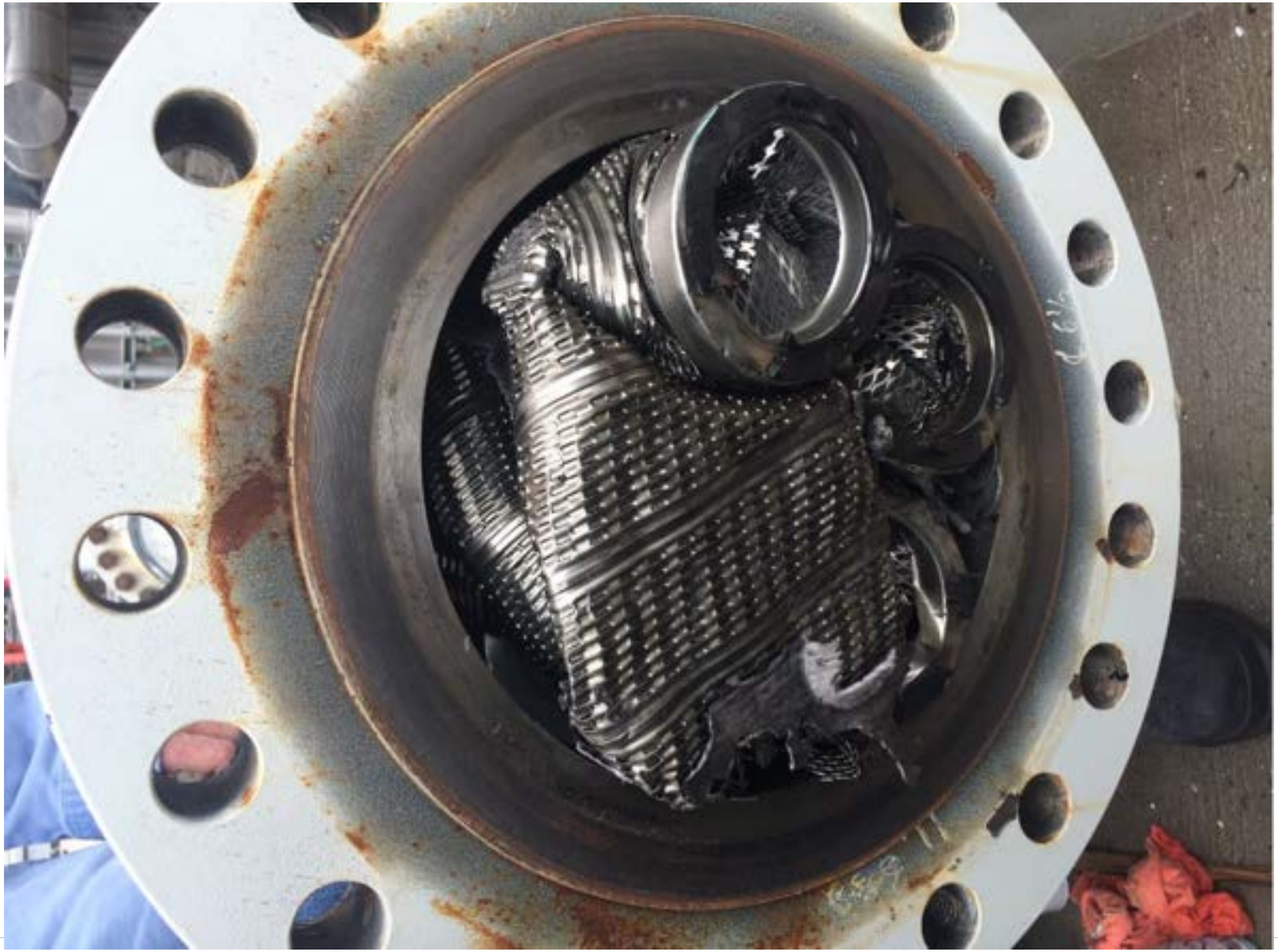


DIAGNOSTICS AND TROUBLESHOOTING



Discovered this filter blocking the flow conditioner. Actually, there were 4 filter elements blocking the flow conditioner



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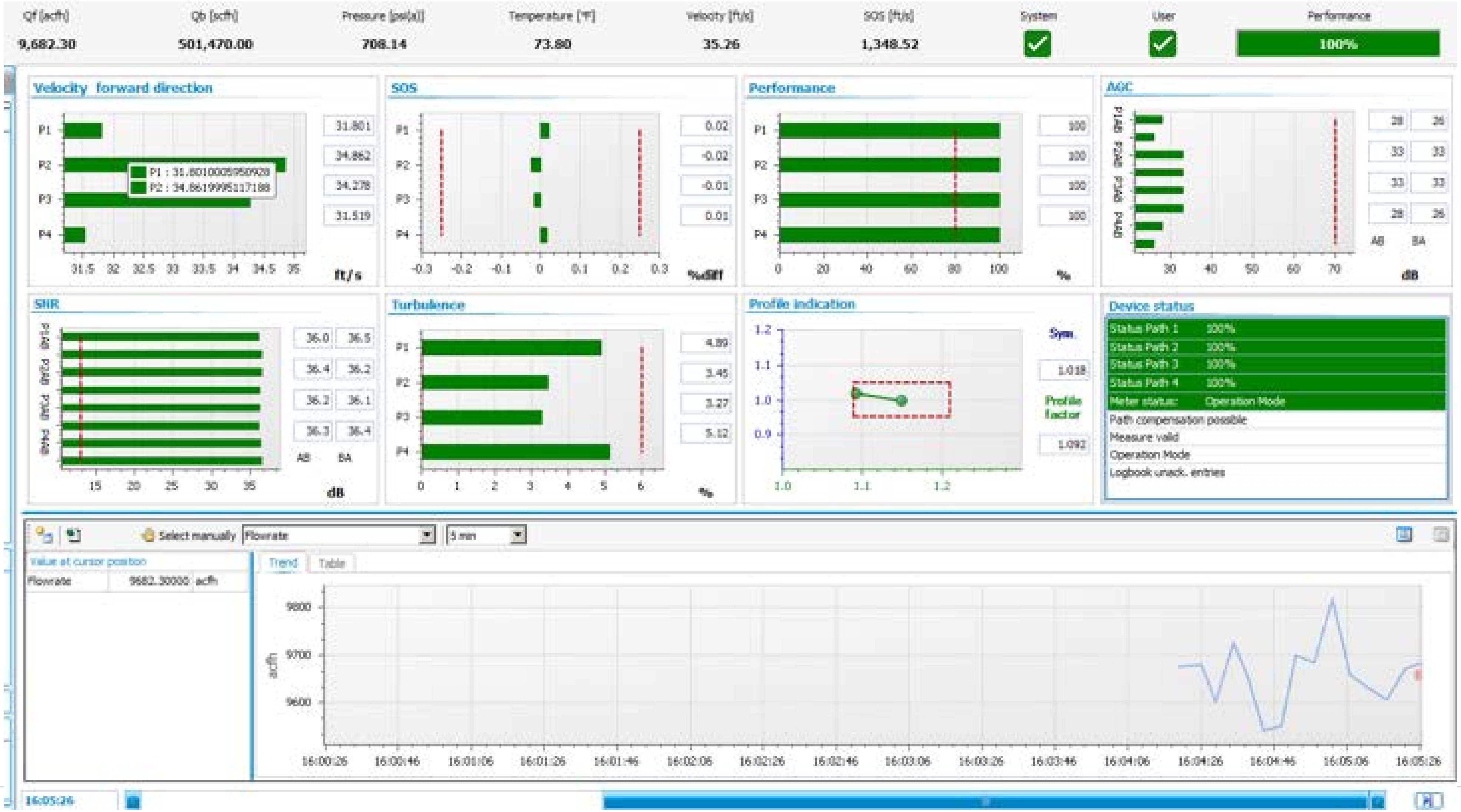
Diagnostics and troubleshooting

The customer stated the flow profile indicator was jumping inside and outside the box at commissioning. Instructed the customer to open the run and they discovered this FC blockage.



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Questions?

Thank you for your attention!!

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