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Technical Paper

An innovative approach to increase diagnostic sensitivity in ultrasonic flow meters

Daniel Heinig, SICK AG
Jörg Wenzel, SICK AG
Dr. Alexander Nerowski, SICK AG
Toralf Dietz, SICK AG

Preamble

Operators for custody transfer of natural gas require a fiscal meter that measures with highest reliability within the required accuracy limits throughout the lifetime. Whenever this requirement is not fulfilled due to changed process/flow conditions or changes to the meter, the user needs to be warned in real-time. For instance, inner pipe wall corrosion and contamination can in many field situations not be excluded.

To ensure such warning, the analysis of diagnostic parameters offered by modern ultrasonic flow meter is essential. Another approach is adding metering redundancy.

In the first approach it is very important to have a long-term history of these diagnostics or applied fingerprint concept where current status is compared with initial/ideal data. Both support a properly determination if a meter is still operating within the appropriate limits.

In the second approach two main concepts can be realized:

- Combining a fiscal and a check meter in one meter body [1].

- Permanent serial metering with two independent fiscal meters or even within one meter body [2]

The main and check meter concept involves using a single path USM next to the fiscal multipath meter.

Papers have shown that single path USMs are significantly affected by abnormal measurement and are ideal to be employed as an early warning system before fiscal accuracy gets affected. This paper summarizes test results from previous years and discusses an innovative approach on how to bring the diagnostic sensitivity of a one path system into a standard four path Westinghouse designed USM. The concept is based on additional virtual path measurement, without the requirement of having a fully redundant measurement system.

1. Introduction

In this day and age, the measuring accuracy of a gas metering station is the critical factor. Worldwide, more and more electronic precision meters are used, or conventional technologies are being replaced with more modern ultrasonic gas flow meters to minimize measurement uncertainty.

Precision is critical, even before commissioning. Choosing the right measuring instruments for pressure and temperature measurement, determining the gas properties, proper station design and finally the selection of the gas meter is an important part of precision. However, various factors have impact on that uncertainty, such as installation effects, e.g. due to pipe bends, tees or valves. Also, compressors or pressure regulator can adversely impact gas meters with various technologies.

Ultimately, all systems are subject to changes during operation. For example, they can be caused by corrosion due to condensates or other liquids or contamination.

Compared with other gas meters, modern ultrasonic gas flow meters have the key advantage of monitoring further diagnostic parameters in addition to the measured value.

2. Diagnostic data and analysis

2.1 Overview of diagnostic data

Besides the measured values for flow rate and speed of sound, modern ultrasonic gas flow meters also provide many diagnostic values. Monitoring and evaluation of the device diagnostic information can deliver key information on changes in the system status, before they affect the measuring results.

For example, relevant diagnostic indicators include the following:

- Signal-to-Noise Ratio (SNR)
- Average Gain Control (AGC)
- Turbulence

Diagnostic values derived from the individual path velocities are helpful to identify changes in the flow profile. In a 4- or 8-direct path layout, they include the following examples:

- Profile factor (quotient of the path speeds of the middle to outer paths)
- Symmetry (quotient of the path speeds of the two upper to the two lower paths)
- Swirl (quotient of the path speeds of crossing path planes)

Figure 1 Ultrasonic gas flow meter, 4-path, direct path layout

Figure 2 Ultrasonic gas flow meter, 8-path, direct path layout

Figure 3 Ultrasonic gas flow meter, 4-path + 1-path (4+1), direct path layout

To increase the reliability in diagnostic indication of an ultrasonic gas flow meter, additional use of an independent diagnostic system based on a 1-path system with the main gas meters has proven itself. Both measuring systems are installed compactly in one meter body – the system is called 4+1 or 2plex. The diametrical 1-path system measures the flow rate of the gas in the middle of the pipe. This path position is particularly sensitive to changes in the flow profile.

While a 4- or 8-path system is a robust design, and compensates changes in the flow profile and its impact on the measured value, the changes impact the measured value directly in a 1-path system.

The relative comparison of the measured flow volumes or flow velocities by the 4- or 8-path system to the 1-path system does provide an indication of changing flow conditions. Tests have shown, that the deviation between both systems is significant even before the measurement of the fiscal measurement is impacted. The measured values are generally compared in the flow computer or other data processing units in the system.

Measuring system	Available diagnostic indicators
A) 4- or 8-path system	- Signal-to-noise ratio - Average gain control (AGC) - Turbulence - Symmetry - Profile factor - Swirl (8-path only)
B) 4- or 8-path system plus additional 1-path system	- All indicators of A) - Comparison of volumes or flow speeds of the two systems

Table 1: Comparison of Ultrasonic meter configuration and available diagnostics

2.2 Handling diagnostic data

Three methods are recommended to comprehensively evaluate diagnostic indicators and derive conclusions on the measurement quality in a system:

1. **Current diagnostic data**
   - Statement on the current device status (OK, Warning, Alarm)
   - Snapshot of absolute values
2. **Trend analyses**
   - Comparison of the diagnostic values at the time of calibration, commissioning and the current time
   - Creation of ‘fingerprints’, i.e. freezing snapshots of diagnostic values at the compared times.
   - Identification of slowly changing process conditions (e.g. corrosion)
3. **Speed classification [3]**
   - Diagnostic values like turbulence or values on path relations depend on the gas velocity.
   - As a result, the typical values and thresholds are broken down into speed classes.

Modern ultrasonic gas flow meters employ user-friendly software solutions to support the configuration, data collection, evaluation and analysis of diagnostic indicators. Tools like archive diagnostics, trend analyses and fingerprint assistance are used.

In addition, information can also be read out and processed using volume conversion devices or higher-level process control systems via digital interfaces like RS485 Modbus or Ethernet.

2.3 Interpretation of diagnostic data

There are numerous studies and publications on test programs which allow conclusions on potential influences on measuring accuracy based on changes in diagnostic indicators due to changes in the measurement conditions.

The following are three major influencing factors on measurement and diagnostic values:

1. Changes in the flow profile due to blocked, defective or contaminated flow conditioners and corrosion and contamination of inner pipe wall.
2. Noise influences by pressure regulators
3. Changes in gas temperature, pressure and composition

This paper will focus in particular on point 1 in detail in the following section.

A series of tests conducted jointly by SICK AG and DNV GL in 2011 showed how corrosion and contamination can be detected [4].

In the test program, pipe sections and gas meters with varying levels of corrosion were studied on a gas flow test bench. The resulting errors of measurement were determined and diagnostic data was evaluated.

The FLOWSIC600 2plex (4+1 design) gas meter with a nominal pipe size of DN100/4 inch was used in the test. This meter combines 4-path measuring system and a 1-path diagnostic system in on meter body. Both systems are independent of one another and react differently to changes in the process conditions, in particular of the flow profile. The concept permits a relative comparison of the volumetric measurements of the two gas meters.

Diagram 1 shows the reaction of the calibrated 4-path system to corrosion in the inlet piping. The change is within the test bench uncertainty range of +/-0.3%. Measurements were conducted at 20 bar on the test bench of KEMA (now DNV GL) in Groningen, Netherlands.

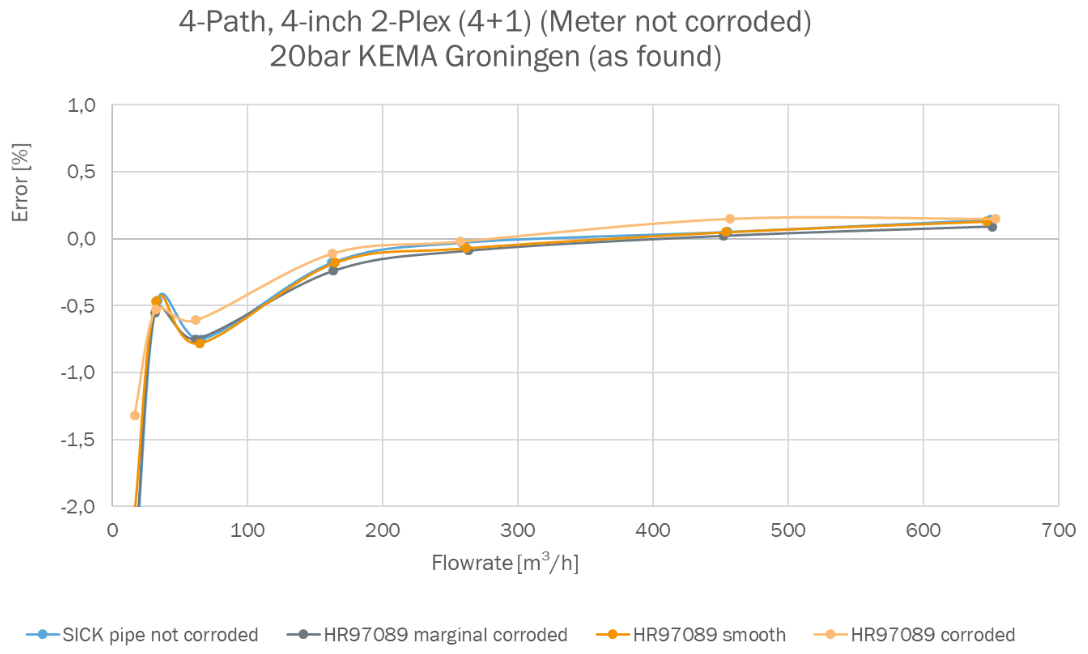

Diagram 1 Error curve of FLOWSIC600 4-Path. Meter not corroded, inlet pipe corroded [4]

Diagram 2 shows the change of the profile factor depending on the corrosion in the inlet piping of the meter. The meter itself is corrosion-free. The profile factor change is proportional to the corrosion.

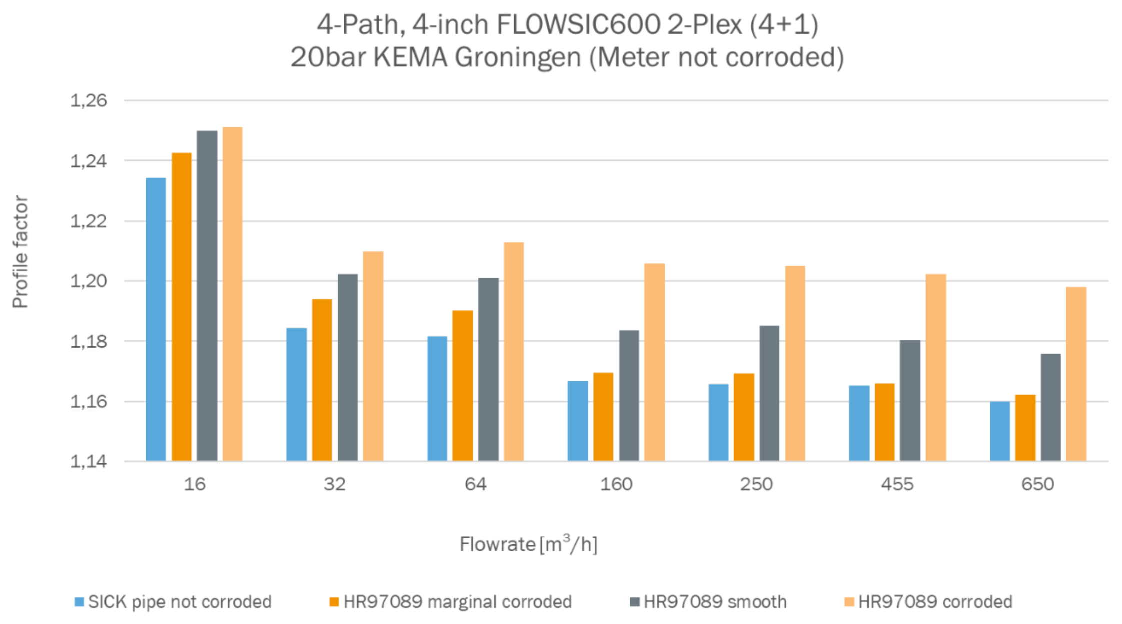

Diagram 2 Profile factor change with different inlet pipe corrosions, meter not corroded [4]

Diagram 3 considers the measured flow rate of the 4- and 1-path system relative to one another. Here too, a clear deviation is apparent which grows systematically with the increasing corrosion of the inlet piping.

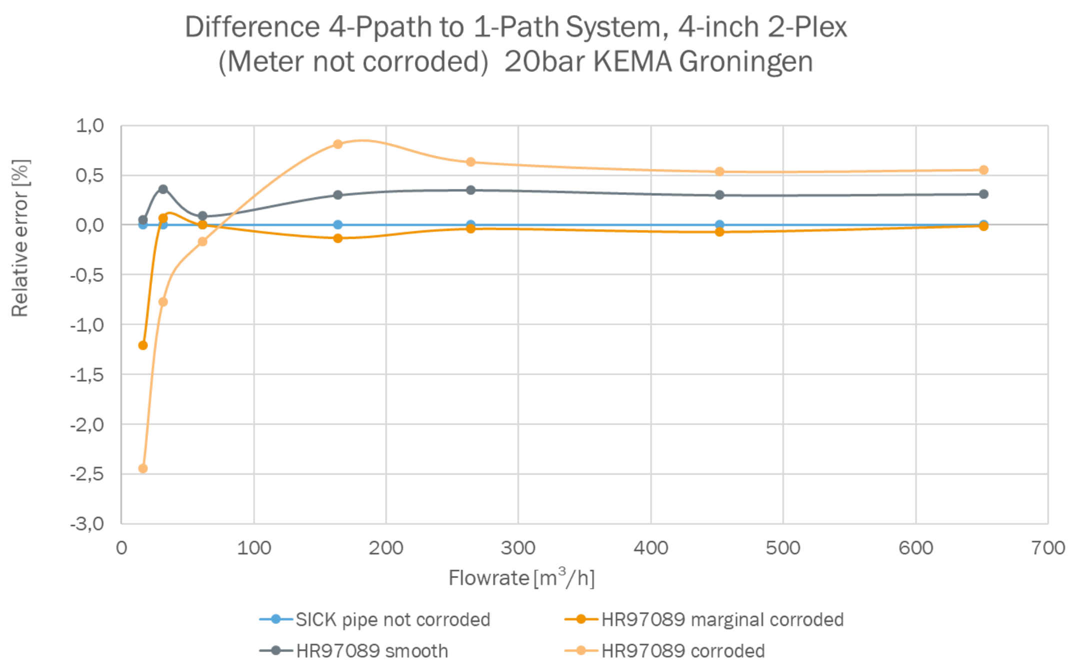

Diagram 3 Relative error curves (4- vs 1-path system), meter not corroded, inlet pipes corroded [4]

The result of the tests shows that both the profile factor and a comparison of the volumes measured in both measuring systems reveal a clear correlation to the corrosion or contamination of the inner pipe wall.

The diagnostic indicators show a particularly clear picture of when the meter body is protected against corrosion. For example, this can be ensured by selecting the right material or by nickel coating.

Another test series in 2007 [5] examined how faults in flow conditioners affect measuring errors of ultrasonic gas flow meter, and whether device diagnostics can diagnose the change clearly. A FLOWSIC600 2plex, 12 inch was used in the test.

Figure 4 CPA flow conditioner with simulated blocked hole, used during test [5]

Here too, it was found that the comparison of the 1-path measurement to the 4-path measurement reveals significant deviations before the measurement of the calibrated measurement is influenced. Blockage of one hole in the flow conditioner plate already allows the system to determine a relative deviation of the 1-path system of up to -0.85%, while the 4-path system continues to measure with a high level of accuracy (see diagrams 4 and 5).

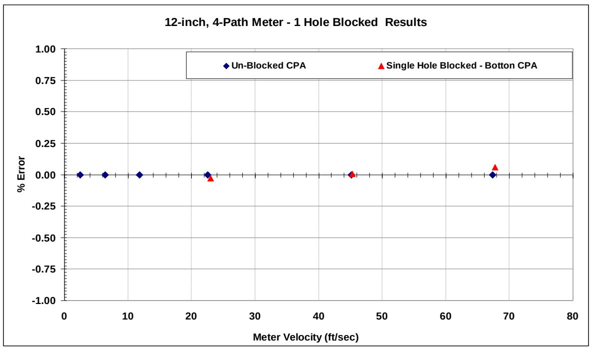

Diagram 4 Error of 4-Path system with 1 blocked hole CPA FC [5]

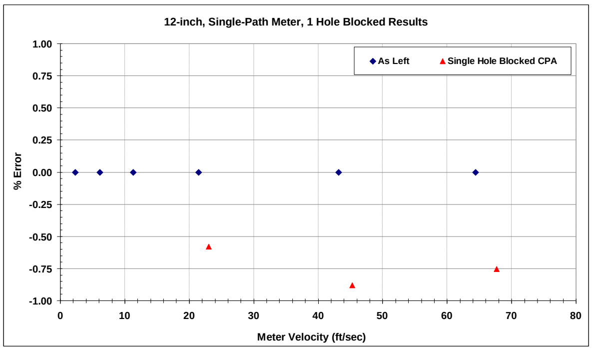

Diagram 5 Error of 1-path system with 1 blocked hole CPA FC [5]

The two papers mentioned above reveal the benefit of diagnostic data with regard to evaluation of measuring accuracy. Systematic recording and evaluation of diagnostic information is a useful element for holistic determination of measurement quality.

3. Condition Based Indicator (CBI)

As diagnosis with a 1-path system in a calibrated gas meter has multiple advantages, SICK has developed an innovative and patented approach of extended diagnostic capabilities for standard devices with 4- or 8-path designs - a concept to integrate the diagnostic sensitivity of the 1-path system into the reliable Westinghouse design.

The Condition Based Indicator (CBI) is an additional diagnostic indicator based on a diametrical-paths, which is fully integrated in a 4-path or 8-path system (Figure 5).

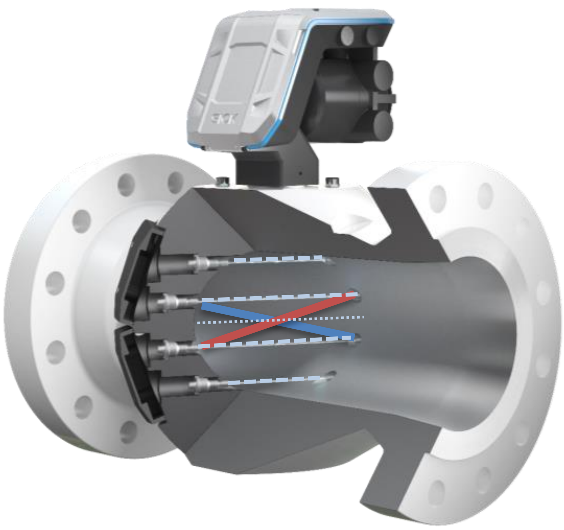

Figure 5 FLOWSIC600-XT with diametrical path

In addition to sensor signal transmission in one measurement path level, during each measuring cycle, the sensor sends one signal from measuring path 2 to measuring path 3 and vice versa (red X and blue Y path in Figure 5). Both diametrical measurement paths record the flow profile in the sensitive middle as in a 1-path measuring system does.

The dimensionless CBI factor is calculated from the mean gas velocity of the diametrical paths and the mean gas velocity of the 4- or 8-path system.

$$CBI = \frac{f(VOG_{PX}, VOG_{PY})}{f(VOG_{avg,4P,8P})}$$

No other hardware is required for the diametrical measurement and calculation of CBI. The latest generation of ultrasonic sensors is used to determine the additional diagnostic value (CBI). This is possible due to the physical propagation of the ultrasonic signal generated by the sensor. The signal generated is radiated based on the design of the sensor head in the form of a sound beam with a defined angle (Figure 6).

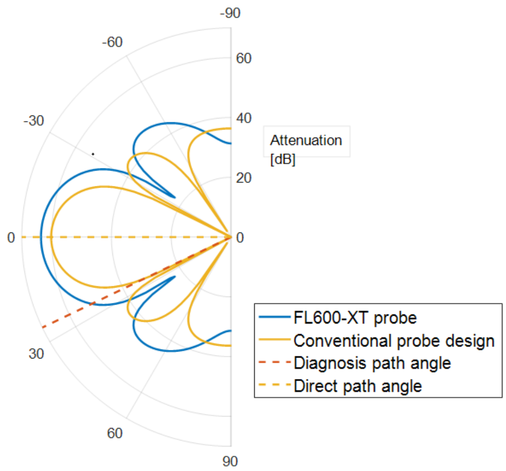

Figure 6 Radiation characteristic of the sound beam at speed of sound of 410 m/s

The emission characteristics ensure that not only the sensor directly opposite the signal emitting sensor receives the emitted signal, sensor in neighbor levels also do so (Figure 5). The signal received diametrical is weaker than that received by the sensor in the same measurement level. To date, applications for CBI are restricted to a nominal pipe size of 16-inch, natural gas applications and a maximum pressure of 100 bar.

3.1 CBI test measurement

The question to be answered is, does the CBI correlates to the physical 4+1 concept? And how does it react in various profile distorting conditions?

A test with a table demo unit has been performed as an initial test. The meter under test was a FLOWSIC600-XT 2plex (4+1), DN100/4 inch meter with a flow conditioner mounted directly in front of the inlet flange of the meter.

At first the as found base line with an unblocked flow conditioner was logged for the 1-path system and the CBI (blue “x” and “o” in Diagram 6). Secondly the flow conditioner was slightly blocked with a tape and the as found curve was logged for this setup again (orange “x” and “o” in Diagram 6). Thirdly the flow conditioner was stronger blocked with a tape and the as found curve was logged for this setup again (yellow “x” and “o” in Diagram 6).

Figure 7 FLOWSIC600-XT 2plex

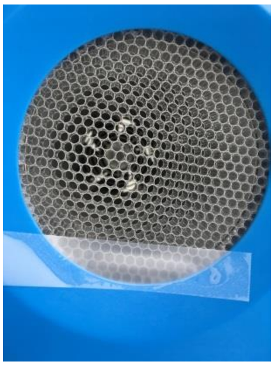

Figure 8 Slightly blocked FC

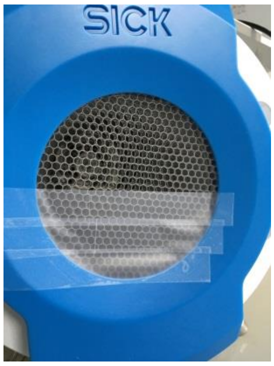

Figure 9 Strongly blocked FC

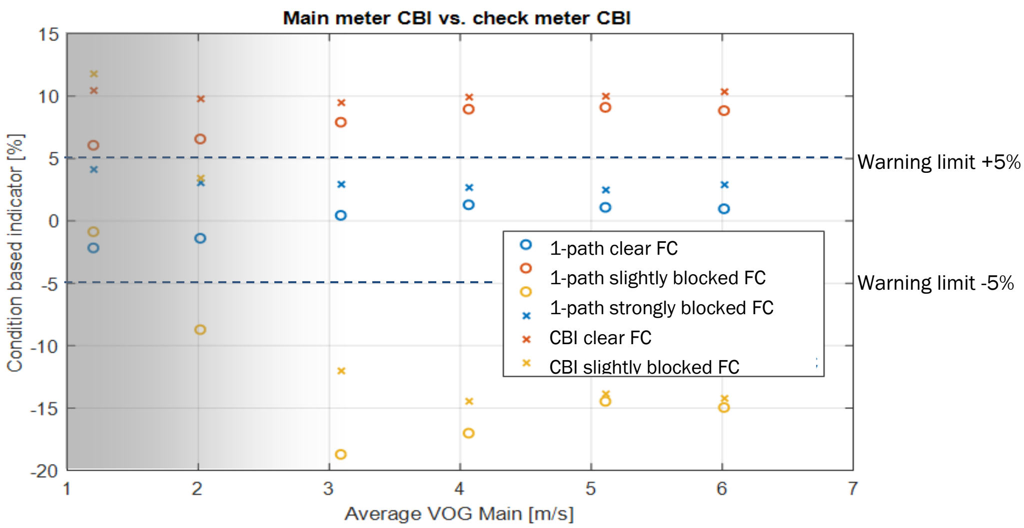

Diagram 6 CBI vs. 1-path correlation demo unit

The results show that the CBI correlates very well with the deviation between 1- and 4- path meters, especially from transition flow (v_t). That makes it largely independent of the gas velocity and sensitive to the flow profile alone. As soon as the flow situation changes, the factor changes in the scale of several percent and before the fiscal measurement is affected.

3.2 CBI classification

The CBI indicator is a new innovative diagnostic indicator. It provides additional information on the flow profile in one pipeline. The fundamental idea is based on the 4+1 concept, which combines robust measurement with improved diagnostic functions and has been used successfully for years.

The parameter is considered a supplement to the existing indicators, like profile and symmetry factor. Due to its high sensitivity (center line), it is also a valuable diagnostic value when viewed on its own.

3.3 CBI field test

In a field test, the CBI was studied on a FLOWSIC600-XT in a bi-directional measuring system (gas storage facility) over a 12 month period. Inlet piping arrangement is 3ND / FC /3ND.

Figure 10 Field test with FLOWSIC600-XT, investigating CBI

As the following diagram shows, the flow is relatively low in both, forward and reverse direction. It is also apparent that the flow profile changes via the flow direction and gas velocity. The fingerprint concept allows changes to be considered irrespective of the gas velocity. For example, multiple velocity classes are formed after commissioning for the flow and return direction of the gas flow rate for the fingerprint. Those values are used as a reference for all measured and diagnostic values. Individual warning thresholds can be assigned for every diagnostic tool.

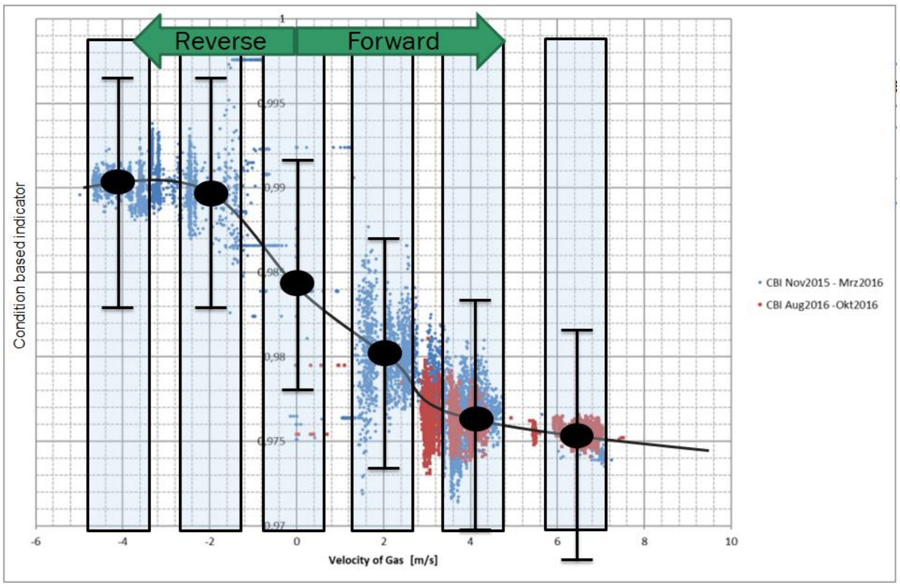

Figure 11 Fingerprint with CBI in field test

3.4 CBI summary

As an additional diagnostic value, the Condition Based Indicator is a valuable indicator for detecting changes in the flow profile, caused by contamination, corrosion or blocked flow conditioners for example.

The CBI is part of the diagnostic fingerprint, and is recorded permanently in the device. Using the user-interface software (FLOWgate™), the fingerprint can be visualized over the entire history of the gas meter. That allows rapid and simple comparison of the current system status to the commissioning status at any time. It helps decide whether the gas meter needs to be maintained or recalibrated.

To date, applications for CBI are restricted to a nominal pipe size of 16-inch, natural gas applications and a maximum pressure of 100 bar.

As the CBI is measured and calculated with the available hardware of a 4-path or 8-path standard device, it has no impact on mean time between failure (MTBF) of the meter.

4. Conclusion

This paper looked at the measured and diagnostic data of recent years, which allows influences on the measurement uncertainty to be detected.

Even if the error of measurement of a gas meter cannot currently be named during operation, there are reliable approaches to identify influences on these in real-time. The diagnostic function of a gas meter has played a key role for years. Numerous publications in recent decades have shown what diagnostic indicators can do. Combined with the physical design of a system, such as a permanent series connection of two gas meters, failure to identify influences on the measurement uncertainty can be minimized, and recalibration periods under national law may even be extended which will lead to additional savings in expenses.

The fact that the diagnostic function plays an important role in ultrasonic gas flow meters is also shown by the fact that the new revision of ISO 17089 will focus more on the use of diagnostic data and the associated field verification.

The CBI indicator is another innovative approach to improve the diagnostic capabilities of standard ultrasonic gas flow meters. The concepts of the 4+1 design, which has been used for many years, can now also be used in standard 4- or 8-path devices. CBI is another piece of the puzzle on the way to determining measurement uncertainty during operation.

5. Abbreviations

AGC – Average Gain Control

CBI – Condition based indicator

FC – Flow conditioner

MTBF – Mean Time Between Failure

ND – Nominal diameter

PTB – Physikalisch technische Bundesanstalt

Q- Flow rate

Q_t – transient flow rate

Q_{max} – maximum flow rate

SNR – Signal to Noise Ratio

SOS – Speed of Sound

VOG – Velocity of Gas

6. References

[1] MessEV: Verordnung über das Inverkehrbringen und die Bereitstellung von Messgeräten auf dem Markt sowie über ihre Verwendung und Eichung (Mess- und Eichverordnung – MessEV). 11.December 2014

[2] Messgeräte für Gas TR-G 18.; PTB; https://www.ptb.de; 2017

[3] Dr. Schäfer, S, Dietz, T., Horst, T., Peterka, K, Dr. Herrmann, V.: Diagnostic Fingerprint – A new method for fully automated accuracy monitoring in ultrasonic meters. 28th North Sea Flow Measurement Workshop, 2010

[4] Horst, T., Jakschik, A., Dietz, T. und Riezebos, H.: Considerations on the influence of deposits or changes in wall roughness on the validity of the calibration and long term accuracy of ultrasonic gas flow meters. 29th North Sea Flow Measurement Workshop 2011

[5] Lansing, J., Dr. Herrmann, V., Dietz, T.: The relevance of two different path layouts for diagnostic purposes in one ultrasonic meter. 25th North Sea Flow Measurement Workshop, 2007