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Paper 8.3

Diagnostic Fingerprint – A New Method for Fully Automated Accuracy Monitoring in Ultrasonic Meters

Stephan Schäfer
SICK AG

Toralf Dietz
SICK AG

Thomas Horst
SICK AG

Konrad Peterka
OÖ. Ferngas Netz GmbH

Volker Herrmann
SICK AG

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Diagnostic Fingerprint – A New Method for Fully Automated Accuracy Monitoring in Ultrasonic Meters

Stephan Schäfer, SICK AG
Toralf Dietz, SICK AG
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1 Introduction

Due to their advantages, advanced ultrasonic gas meters are used in gas quantity metrology on a steadily increasing scale, and they stopped being regarded as "exotic" a long time ago. The multitude of diagnostic information that can be provided by the meter is unique. However, the user is often not able to benefit from this information unless he can fall back on specialist assistance in evaluating the data. Therefore, the question is more and more how to make this variety of information controllable for the "non-expert" as well as the experienced user.

The visual processing and representation of the diagnostic indicators in a status report as a momentary analysis is a first step in this direction. The preparation of the status reports on a regular basis enables a comparative trend analysis and hence a further simplification of evaluation. It is not necessary anymore to analyze the absolute values of the indicators, but instead only their change in comparison with a reference status.

The introduced approach of a flow-dependent data recording within the device offers new opportunities. Dependent on the flow velocity, the device stores and updates only those diagnostic data sets that represent the current status. Consequently, the current diagnostic data may be compared with reference data stored in the device (e.g. from commissioning) at any time. The device itself monitors the differences between the reference data and the current data and prompts the user to check the device status only if required. A review of these data by the user on a regular basis is not necessary.

2 Basics of the Diagnosis on Ultrasonic Gas Meters

Generally, internal and external diagnostic methods may be distinguished. For the internal diagnostic method, the indicators are only deduced from the measured and diagnostic values of the meter. For external diagnoses, measured and diagnostic values of the meter are compared with values provided by independent data sources. The calculation of the theoretical sonic velocity from the gas composition and the comparison thereof with the velocity measured in the ultrasonic gas meter can be mentioned here as an example. The external diagnostic method also includes the concept of permanent series connection where the measured values of two independent meters are directly compared and analysed.

One of the fundamental advantages of ultrasonic gas meters is the opportunity of diagnosing the device status and hence the quality of the measured value by means of device data acquired internally. In principle, this enables the identification of any problems caused by device components (ultrasonic sensor, cables, and electronics) or the application (contamination, blocked flow conditioners, changed flow situations, liquid contents in the flow). Multi-path meters are unique measuring instruments because they are additionally able to compare diagnostic values internally and continuously between the individual measuring paths that are independent of each other.

In principle, the measured value sensing, or calculation, of all modern ultrasonic gas meters is based on the transit time of signals emitted in a defined manner. The ultrasonic signal emitted by the transmitter travels at sonic velocity through the medium to be measured and is picked up by a receiver on the opposite side of the meter. The transmitter-receiver combination is called the "measuring path". The measuring path may either extend directly between the transmitter and the receiver or be arranged spatially within the meter body with single or multiple reflections. A substantial point is that the measuring path is not arranged vertically to the flow axis (Figure 1).

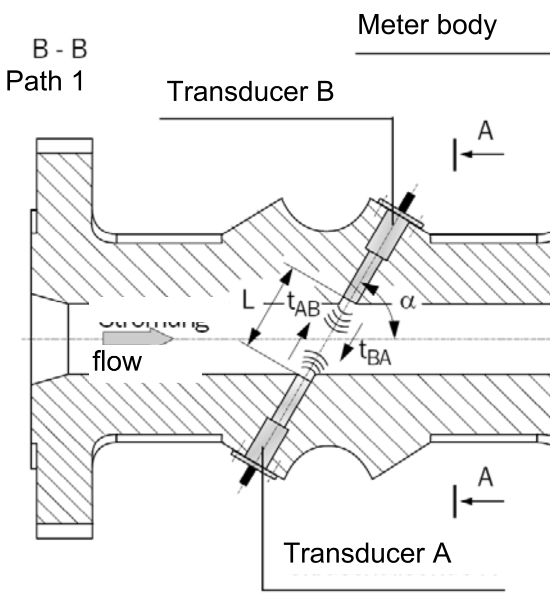


Figure 1: Principle of ultrasonic flow measurement

The vectorial superimposition of the velocities of sound and flow results in the effective propagation velocity of the emitted signal. If the sensors are caused to work continuously and alternately both as transmitters and receivers, the signal is accordingly sent with and opposite to the gas flow. This results in a different effective propagation velocity between the two directions and enables the determination of different transit times of the signals. The difference of the transit times represents the mean flow velocity of the sound-penetrated space between the two sensors.

Thus, the primary measured variable of ultrasonic gas meters is the signal transit time that is given by:

- the geometry of the measuring path (path length L and angle α to the pipe axis) and
- the effective propagation velocity (vectorial addition of sound velocity c and flow velocity v_{gas}).

Signal transit time with the flow direction:

$$t_{AB} = \frac{L}{c + v_{gas} \cdot \cos\alpha} \tag{1}$$

Signal transit time opposite to the flow direction:

$$t_{BA} = \frac{L}{c - v_{gas} \cdot \cos\alpha} \tag{2}$$

Mean flow velocity on the measuring path:

$$v_{gas} = \frac{L}{2 \cdot \cos\alpha}\left(\frac{1}{t_{AB}} - \frac{1}{t_{BA}}\right) \tag{3}$$

The quality of the measured value is substantially determined by the precision in the detection of the arrival time of the emitted signal at the receiving transducer. In the simplest case, the transmitter is electrically excited by a signal burst. In order to generate an adequate acoustic amplitude, the burst is generally composed of several consecutive sinusoidal oscillations. At the receiver, the acoustic signal is reconverted to an electric signal.

Due to the acoustic attenuation of the signal in the gas and due to potential acoustic sources of interference (e.g. pressure regulators), the incoming signal is significantly attenuated and may be superimposed by interfering signals (Figure 2). Simple electronic threshold triggers for signal detection often are unable to deal with the deteriorated signals. In the past, the transit time measurement did not reach the necessary precision and stability until complex signal processing methods were used. This popularized the ultrasonic gas meter in gas quantity measurement.

2.1 Diagnostic Indicators of the Ultrasonic Signal

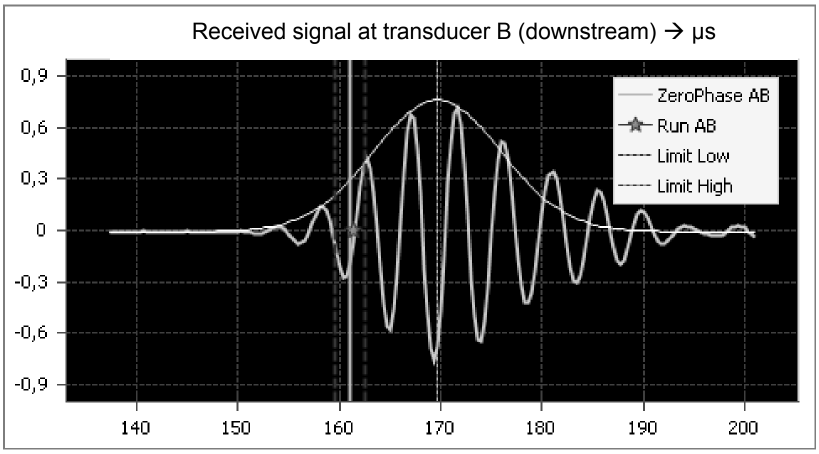


Figure 2: Transit time detection in the received ultrasonic signal

Today, digital signal processing methods have become generally accepted in all modern multi-path ultrasonic gas meters due to the efficient microprocessor technology. As a result, the following additional internal indicators are available for the evaluation of the received ultrasonic signals, apart from the primary measuring variable of signal transit time:

- Reception gain
- Signal-to-noise ratio
- Signal quality
- Turbulence

These indicators will be briefly introduced below.

Reception gain

The attenuation of the emitted signal on its way to the receiver depends on the density and composition of the gas. Certain gases such as carbon dioxide show a significantly higher attenuation in the operating frequency range of typical ultrasonic transducers than other gases. The electronic receiver systems are equipped with controllable receiving amplifiers in order to optimally scale the signals to the operating range of the analogue-to-digital converters (ADCs). Voltage-controlled amplifiers are common. The required amount of control voltage and thus the reception gain is calculated by the processor.

Figure 3: Heavily contaminated sensors of a meter downstream of an oil separator system

Therefore, the reception gain is directly connected with the signal path and its components, being the transmitter, transmission medium (gas), and receiver. Since the amplified signal has to reach a certain amplitude, any increase of the reception gain is an indicator of a weaker incoming signal. The reason for this can be a contamination of the sensor diaphragms (Figure 3), sensor aging, or problems within the electronic transmitter and/or receiver systems.

Signal-to-noise ratio

As the name already suggests, the signal-to-noise ratio (SNR) is a parameter for the ratio of the undisturbed useful signal to the superimposed noise signal. The SNR term is commonly used with the decibel unit (dB).

Sound waves may physically be described as spatially propagating pressure waves as well. Physically, ultrasonic sensors are nothing else but dynamic pressure sensors that are capable of converting slightest pressure variations of a few Pascal into an electric signal. Depending on the constructive design of the sensor, this characteristic is of a more or less broadband form around the operating frequency. As a result, the sensor picks up interference signals in the vicinity of its operating frequency as well as in a frequency range defined by its bandwidth (Figure 4). If the SNR is too small, the transit time evaluation will not be able anymore to determine the signal arrival time with the required precision, and the quality of the measured value will decrease.

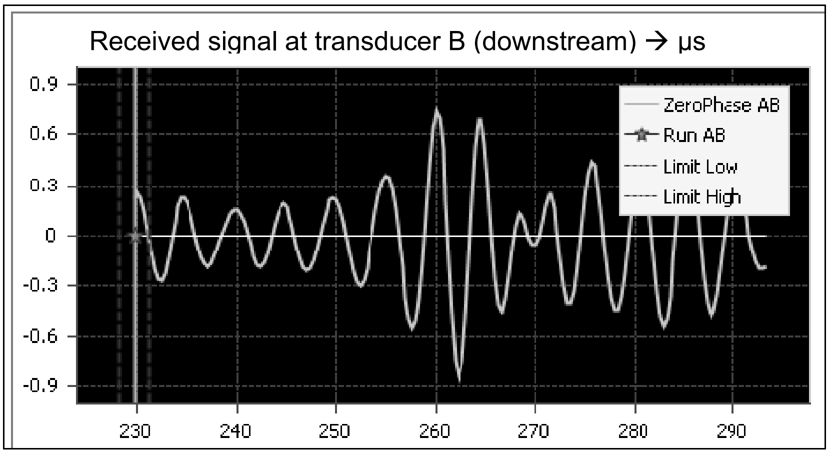


Figure 4: Received signal with low signal-to-noise ratio

The monitoring and analysis of the SNR is important when the ultrasonic gas meter is used close to pressure regulators. An abrupt deterioration of the SNR indicates a new or modified source of disturbing noise. This can be caused, for example, by a material rupture in the cage of the pressure regulator. Therefore, the analysis of the diagnostic indicator SNR may also provide conclusions on the condition of the facility.

Signal quality

Since the received signal burst has multiple signal zero crossings, a simple zero crossing triggering is too unreliable as a means of transit time detection. The robustness of the transit time detection may be increased significantly by evaluating the entirety of the received signal. This is exactly achieved by signal correlation techniques. One variant is the use of a model signal that corresponds to an ideal, undisturbed signal curve. When this model signal is correlated with the received signal, it is possible to derive a characteristic number for the difference between the real and the model signal. This characteristic number takes account of the differences in the amplitude curve and phase response of the signal, thus representing the signal quality. If the actually received signal corresponds to the theoretically anticipated model signal, the difference is zero and the signal quality optimal.

Turbulence

The flow velocity is characterized by a slight fluctuation around its mean value. This natural, statistical fluctuation is also called the degree of Turbulence. The Turbulence may be determined metrologically as standard deviation S_v of the normally distributed velocity measurands around their mean value $\bar{v}$. A change of the Turbulence values is always an indicator of a change in the distribution of the measured path velocity values over time.

$$Turbulence = \frac{S_v}{\bar{v}} = \frac{\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(v_i - \frac{1}{N}\sum_{j=1}^{N}v_j\right)^2}}{\frac{1}{N}\sum_{j=1}^{N}v_j} \tag{3}$$

Changes in the Turbulence values are caused by mechanical disturbances in the pipe section upstream of the meter. Partially blocked flow conditioners or partly opened valves may serve as examples.

When evaluating the Turbulence indicator, the measured sound velocities of the individual paths should also be taken into account since trigger errors could distort the indicators when the signal transit time is measured. As the relative differences of the measured sound velocities on the individual measuring paths are usually in the per-thousand range, a path with a trigger error may be identified by a conspicuous sound velocity difference (Figure 5).

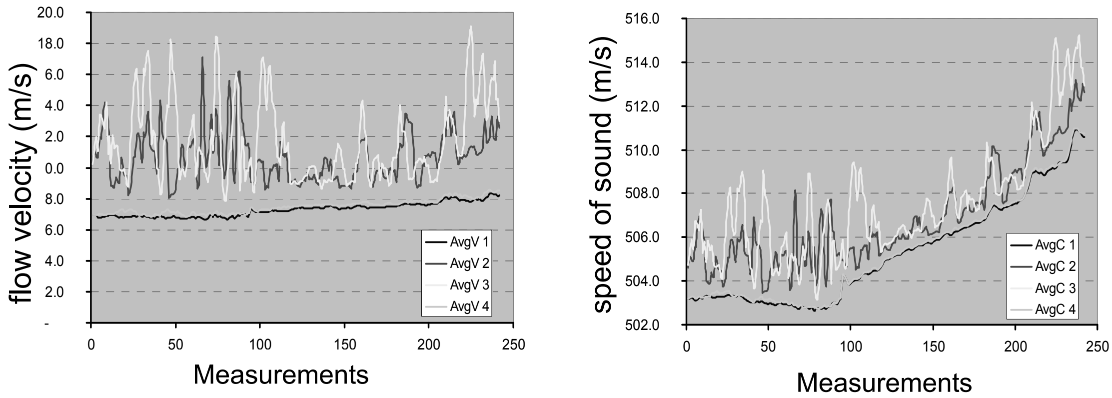


Figure 5: Conspicuous turbulence on the paths 2 and 3. The analysis of a series of 250 measured values is shown here as an example

The left diagram in Figure 5 shows the curve of the individual path velocities during the observation time. The significantly increased variance of the measured values for the paths 2 and 3 is conspicuous. An examination of the sound velocities – depicted on the right side – clearly reveals that the observed “Turbulence” in this case is caused by problems with the transit time measurement.

2.2 Diagnostic Indicators of the Flow Profile

By providing information on the velocity distribution in the pipe section, multi-path ultrasonic gas meters offer outstanding opportunities for the diagnosis of flow conditions. Different indicators may be derived from the ratios of the individual path velocities when a suitable number of measuring paths is arranged spatially in the meter. The presentation below refers to the “Westinghouse” path layout used in the FLOWSIC600 with four measuring paths arranged in parallel (Figure 6).

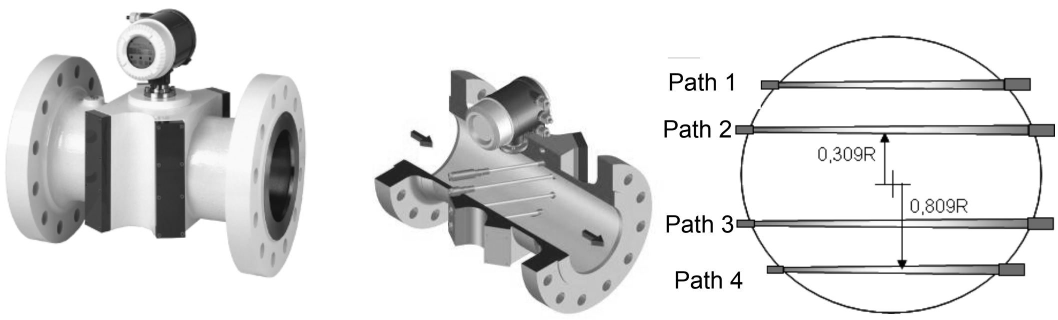


Figure 6: Path layout in the FLOWSIC600 ultrasonic gas meter

Figure 7 shows the path velocity ratios in relation to the average measured flow velocity. As the relative path velocity ratios remain comparatively constant, changes may be identified more easily than by examining the absolute path velocities.

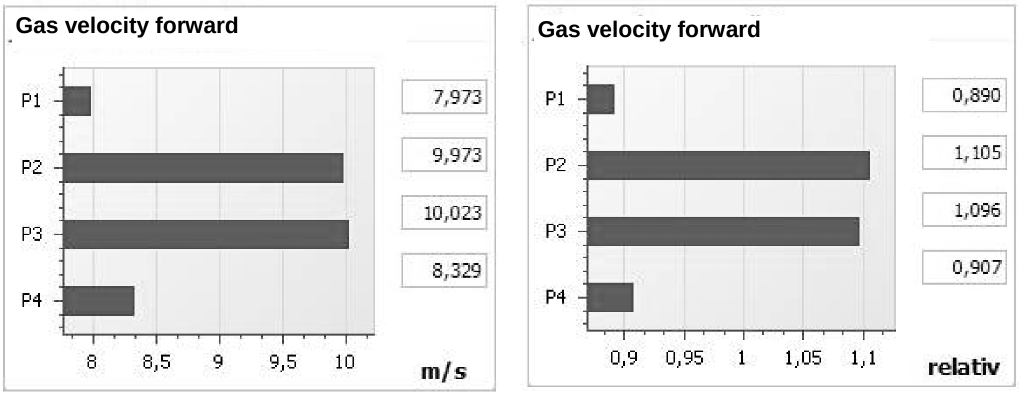


Figure 7: Path velocity ratios in relation to the average measured flow velocity.

For the path layout depicted here, the typical ratios observed are 0.89 for the paths 1 and 4, and 1.04 for the paths 2 and 3, each time compared to the average flow velocity. This is because the outer paths 1 and 4 are arranged closer to the pipe wall and the local flow velocities are lower at this position than in the centre of the pipe section. Two characteristic indicators may be derived from these four path velocities:

- Profile Factor
- Symmetry

The evaluation of the flow profile is significantly simplified thereby.

Profile factor

The *Profile Factor* indicator is calculated from the path velocities by dividing the sum of the inner paths 2 and 3 by the sum of the outer paths 1 and 4:

$$PF = \frac{v_2 + v_3}{v_1 + v_4} \qquad (5)$$

For the typical path ratios of 0.89 (outer paths) and 1.04 (inner paths), the Profile Factor is 1.17. The value of the Profile Factor varies in dependence on the design of the measuring facility, the type of flow conditioner (if employed), and the distance of the conditioner from the meter. With respect to the facility, the Profile Factor may, therefore, deviate from the typical value. Hence, the observation of the trend of the Profile Factor in the specific installation is more important than the absolute value itself.

Symmetry

A further diagnostic indicator may be derived by dividing the sum of the path velocities of the paths 1 and 2 by the sum of the path velocities of the paths 3 and 4. This indicator is called Symmetry.

$$Sym = \frac{v_1 + v_2}{v_3 + v_4} \tag{6}$$

For the sake of completeness, it should be mentioned that a third, independent diagnostic indicator for the flow profile is available by dividing the sum of the path velocities of the paths 1 and 3 by the sum of the path velocities of the paths 2 and 4.

$$XSym = \frac{v_1 + v_3}{v_2 + v_4} \tag{7}$$

Due to the symmetry conditions in a rotationally symmetrical flow profile without any transverse flows, these two indicators together amount to exactly 1.

2.3 Diagnostic Indicators of the Sound Velocity

In addition to the calculation of the measuring path's flow velocity, the sound velocity *c* in the gas may be calculated from the measured signal transit times as well. The value of *c* does not depend on the actual flow velocity:

$$c = \frac{L}{2}\left(\frac{1}{t_{AB}} + \frac{1}{t_{BA}}\right) \tag{8}$$

The measured sound velocity is the basis for most of the diagnostic opportunities provided by ultrasonic gas meters. It may be used for the internal as well as the external diagnosis. The simplest and most obvious approach to the internal diagnosis is to display and compare the relative sound velocity ratios of the measuring paths. For example, the sound velocity value of one path may be related to the mean value of all paths and depicted. Since the measured sound velocity does not depend on the flow velocity, the ratios must be very close to each other. For the FLOWSIC600, values in a range of less than ±0.05 % are typically found under normal operating conditions (Figure 8). In addition, each path may also be individually related to each of the other paths.

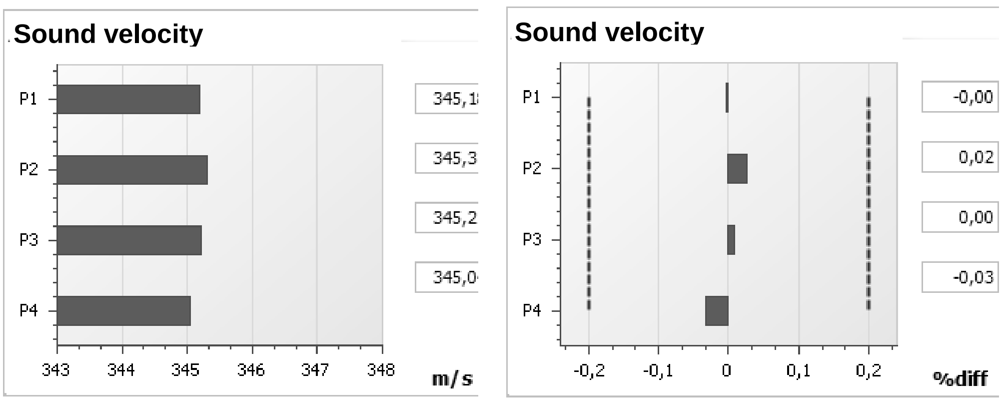


Figure 8: Representation of the absolute sound velocities on the measuring paths and their relative difference to the mean value

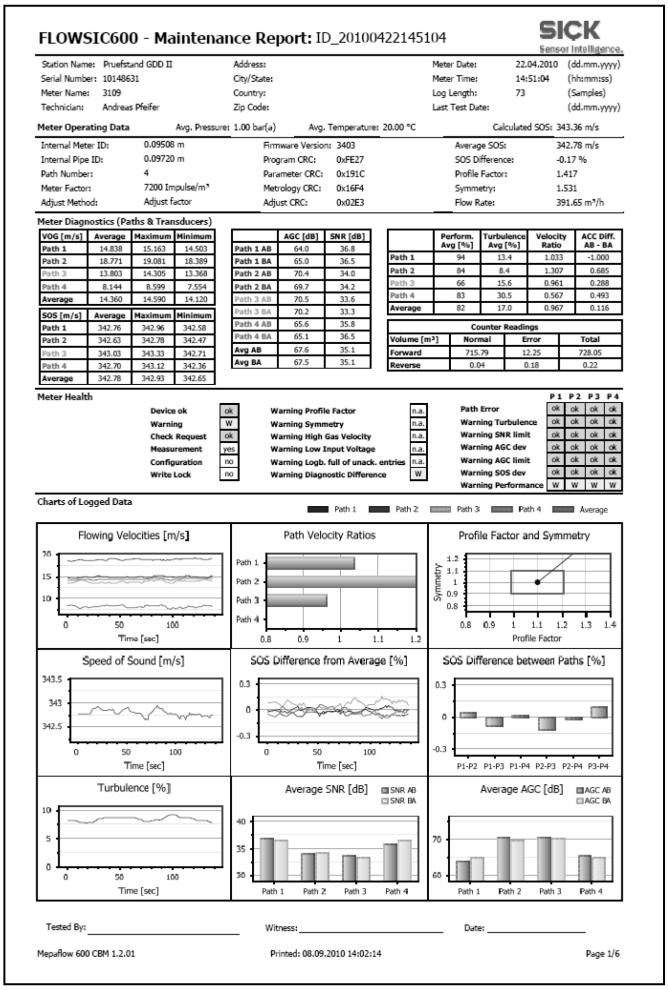
Another possibility of the external diagnosis is the comparison of the measured mean sound velocity with a theoretical sound velocity. The theoretical sound velocity may be calculated by means of suitable methods if the gas composition and the physical state parameters of pressure and temperature at the measuring point are known [1, 2].

The continuous comparison of the absolute sound velocities measured in the gas meter and determined by calculation offers a unique opportunity to monitor the entire measurement for changes, including gas chromatograph and sensor technology for pressure and temperature [3].

3 Methods for Diagnosing the Measured Value Quality

3.1 Momentary Analysis

The momentary analysis is the simplest assessment of the current state of an ultrasonic gas meter. All diagnostic data of the meter are concisely presented and evaluated in the form of a report (Figure 9). Nowadays, the graphical presentation in a report is state of the art due to the variety of the different diagnostic data that is supplied simultaneously.



FLOWSIC600 - Maintenance Report: ID_20100422145104

SICK Sensor Intelligence.

Station Name:	Pruefstand GDD II	Address:		Meter Date:	22.04.2010 (dd.mm.yyyy)
Serial Number:	10148631	City/State:		Meter Time:	14:51:04 (hh:mm:ss)
Meter Name:	3109	Country:		Log Length:	73 (Samples)
Technician:	Andreas Pfeifer	Zip Code:		Last Test Date:	(dd.mm.yyyy)

Meter Operating Data Avg. Pressure: 1.00 bar(a) Avg. Temperature: 20.00 °C Calculated SOS: 343.36 m/s

Internal Meter ID:	0.09508 m	Firmware Version:	3403	Average SOS:	342.78 m/s
Internal Pipe ID:	0.09720 m	Program CRC:	0xFE27	SOS Difference:	-0.17 %
Path Number:	4	Parameter CRC:	0x191C	Profile Factor:	1.417
Meter Factor:	7200 Impulse/m³	Metrology CRC:	0x16F4	Symmetry:	1.531
Adjust Method:	Adjust factor	Adjust CRC:	0x02E3	Flow Rate:	391.65 m³/h

Meter Diagnostics (Paths & Transducers)

VOG [m/s]	Average	Maximum	Minimum
Path 1	14.838	15.163	14.503
Path 2	18.771	19.081	18.389
Path 3	13.803	14.305	13.368
Path 4	8.144	8.599	7.554
Average	14.360	14.590	14.120

SOS [m/s]	Average	Maximum	Minimum
Path 1	342.76	342.96	342.58
Path 2	342.63	342.78	342.47
Path 3	343.03	343.33	342.71
Path 4	342.70	343.12	342.36
Average	342.78	342.93	342.65

	AGC [dB]	SNR [dB]
Path 1 AB	64.0	36.8
Path 1 BA	65.0	36.5
Path 2 AB	70.4	34.0
Path 2 BA	69.7	34.2
Path 3 AB	70.5	33.6
Path 3 BA	70.2	33.3
Path 4 AB	65.6	35.8
Path 4 BA	65.1	36.5
Avg AB	67.6	35.1
Avg BA	67.5	35.1

	Perform. Avg [%]	Turbulence Avg [%]	Velocity Ratio	ACC Diff. AB - BA
Path 1	94	13.4	1.033	-1.000
Path 2	84	8.4	1.307	0.685
Path 3	66	15.6	0.961	0.288
Path 4	83	30.5	0.567	0.493
Average	82	17.0	0.967	0.116

Counter Readings			
Volume [m³]	Normal	Error	Total
Forward	715.79	12.25	728.05
Reverse	0.04	0.18	0.22

Meter Health

					P 1	P 2	P 3	P 4
Device ok	ok	Warning Profile Factor	n.a.	Path Error	ok	ok	ok	ok
Warning	W	Warning Symmetry	n.a.	Warning Turbulence	ok	ok	ok	ok
Check Request	ok	Warning High Gas Velocity	n.a.	Warning SNR limit	ok	ok	ok	ok
Measurement	yes	Warning Low Input Voltage	n.a.	Warning AGC dev	ok	ok	ok	ok
Configuration	no	Warning Logb. full of unack. entries	n.a.	Warning AGC limit	ok	ok	ok	ok
Write Lock	no	Warning Diagnostic Difference	W	Warning SOS dev	ok	ok	ok	ok
				Warning Performance	W	W	W	W

Charts of Logged Data

Tested By: ______ Witness: ______ Date: ______

Mepaflow 600 CBM 1.2.01 Printed: 08.09.2010 14:02:14 Page 1/6

Figure 9: FLOWSIC600 status report

In the FLOWSIC600 ultrasonic gas meter, all diagnostic indicators are continuously monitored with regard to the thresholds configured in the meter for the respective application. If one of the thresholds is exceeded, the "Warning" status will automatically prompt the user to perform a closer analysis of causes. By consistent usage of the colours red/yellow/green in the status report, the user's attention is drawn to the identified abnormalities and, thus, to potential problems.

The momentary analysis, however, only illustrates the state of the ultrasonic gas meter under the current operating conditions prevailing at the time of data acquisition. In order to configure the threshold values available in the meter and to evaluate the data presented in a meaningful way, the user needs a sound, fundamental understanding of ultrasonic technology.

3.2 Trend Analysis

The trend analysis (or “trending”) goes beyond the momentary analysis. It has the advantage of not evaluating the absolute value of the diagnostic indicators of an ultrasonic gas meter anymore, but instead their change in the course of time. This significantly reduces the device-specific detailed knowledge demanded from the user. After an intensive observation and evaluation of a meter during commissioning, diagnostic indicator values representative for the "good" state of the entire pipeline-meter system are stored. In the time following, the current values of the respective diagnostic indicators are compared with the stored values in order to judge the meter's stability. In case diagnostic indicators do not (or almost not) depend on gas pressure or flow rate, any irreversible changes of these diagnostic indicators are a reliable indicator of irreversible changes of the measuring facility, too. When using appropriate temporal resolution, e.g. average values per hour, it is even possible to distinguish between gradual changes (e.g. contamination) and sudden occurrences (e.g. partial blockage of a flow conditioner).

The trend analysis of an ultrasonic gas meter requires data acquisition on the meter on a regular basis as well as archiving of the data. For this purpose, it is advantageous to use remote inquiries (directly or network-based) for online data retrieval, and databases for structured data management. When the required infrastructure of remote data readout and data management is not available at the user's facility, the device-specific software offered by manufacturers may also be used. The MEPAFLOW600 CBM software contains a device-specific database management system for the online-created status reports. It further allows for summarizing several status reports into a trend report. The data of up to 60 monthly maintenance reports may thus be presented in a trend that documents the behaviour of the gas meter over several years.

3.3 Differential Analysis

Due to the infrastructure already available for data communication (e.g. DSfG [Digital Interface for Gas Measuring Instruments] bus system) and data management, the methods described above have become established in particular in the field of large gas quantity measurement. For many users of smaller measuring and regulating stations, however, the potentially huge data volume of the many and diverse diagnostic indicators represents a considerable challenge. The administrative and technology related changes necessary for proper data acquisition and analysis can often not be made due to lack of technical and staff resources. Hence, the historical data are not available for a meaningful trend analysis. As a result, the state of the meter cannot be reliably assessed in case of need.

This is where the method of the flow-dependent, adaptive differential analysis starts with the so-called "fingerprints". This new method was first developed and implemented for the FLOWSIC600. It enables the user at any time to compare the current indicators with an automatically recorded, initial reference state. The diagnostic indicators are no longer classified globally, but depend on the current flow velocity. Five velocity classes, logarithmically distributed from the minimum Q_{min} up to Q_{max}, are managed by the meter. By this approach, the entire measuring range of the meter may be evaluated at any time, irrespective of the flow at the time of the momentary analysis.

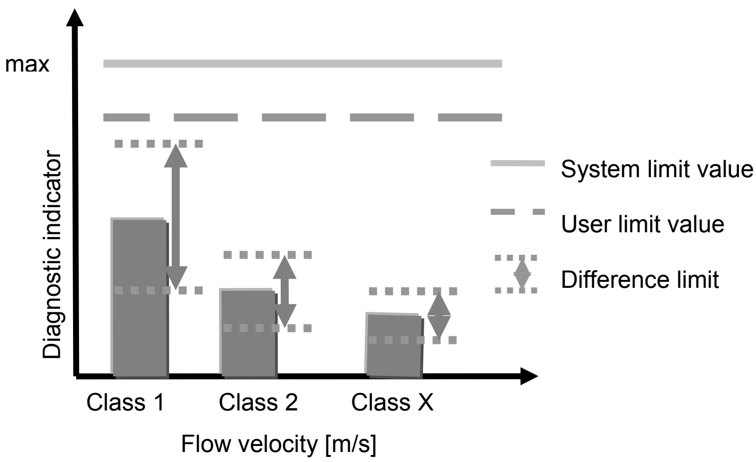


Figure 10: Principles for monitoring the diagnostic indicators

Indicators that might vary depending on the flow, such as Profile Factor or Turbulence, may be monitored much more closely in this way. It is no longer necessary to keep the indicator's value range as broad as if it had to be before (i.e. for the trend analysis) since it had to fit to the entire measuring range. Instead, the thresholds may be set much closer around the mean value that is representative for the specfic velocity class and for the specific application.

As illustrated in Figure 10, the System Limits set by the manufacturer are located at the verge of the signal quality becoming un-reliable under measuring. If you take into account that the parameters of the electronics, sensors and software support a large range in nominal diameters (DN50 ... > DN1000) and working pressure (ambient pressure up to several hundreds of bars), it is clear that System Limits are not suitable for a forward-looking diagnosis designed to meet the demands of a particular application. Hence, an additional set of limit values is made available to the user. These User Limits may be set already much closer to the plausible value ranges of the diagnostic indicators.

However, it is possible to narrow the representative value range even more and, hence, to improve the limit-based diagnostics further towards higher sensitivity. This is done by exploiting the fact that certain diagnostic indicators exhibit a clear, systematic dependency e.g. on the flow velocity.

Applying differential (opposite to trend) analysis to an ultrasonic meter while it is measuring means to automatically compare the diagnostic indicators' current values with the reference values *of their respective velocity class*.

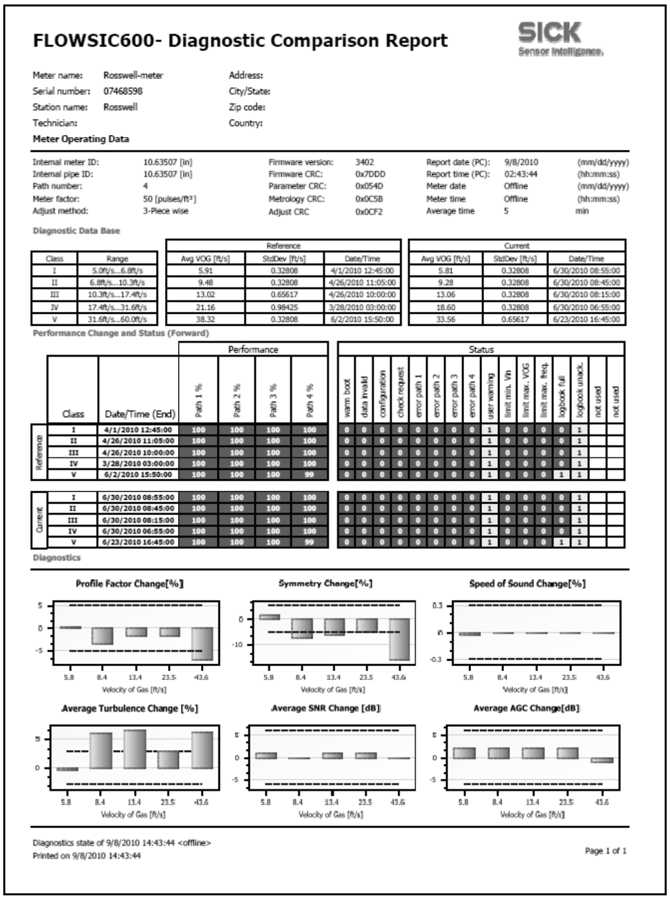


Figure 11: Status report of the differential diagnosis (Diagnostic Comparison Report)

After commissioning (or after resetting the data memory), the reference indicators are stored as mean values. They represent the meter's historical reference fingerprint in the given application. Once the reference indicators have been determined in any velocity class, the next mean values measured will be stored in the same velocity class, but as current indicators. The current indicators represent the "current fingerprint". This set of data is updated continuously while the reference fingerprint remains unchanged until it is manually reset. The velocity class wherein the fingerprint has to be updated is automatically selected based on the current flow velocity.

In order to generate the mean values for a certain velocity class, the flow velocity has to remain within this class for a certain time to ensure that the whole system remains at a stable operating point and that the values recorded are representative diagnostic indicators for the fingerprint. To separate by flow direction, for each velocity class there are two memories available. This enables a better detection of possible variations in the diagnostic indicators that depend on the flow direction. The information is graphically processed and presented in a compact form, and the user's attention is drawn to relevant information by colour coding (Figure 11).

As this method is implemented directly in the meter, the user's expenditure for data management is minimized, without having to suffer any losses of expressiveness. As for the momentary analysis, a dedicated set of individually configurable threshold values continuously monitored in the meter is available for the adaptive differential analysis as well.

In case the difference between the historical reference fingerprint and the current fingerprint indicates any relevant changes in the application, exceeding a threshold will activate the known "Warning" status.

Since historical diagnostic data are automatically taken into account, the probability of any erroneous activation of the warning can be reduced and thus the cost for any unnecessary labour assignment on site be saved. In the differential analysis, the methods of the momentary analysis and the trend analysis have been reduced to the essentials and combined in order to create a new quality of meter diagnosis.

4 Examples for successful application of Diagnostic Fingerprint method

4.1 Detection of liquid loading

The presence of liquid in the gas ("liquid loading" or "wet gas") can lead to significant deviations in the velocities of the individual paths which are reflected in the diagnostic indicators Symmetry, Profile Factor and Turbulence. There are basically two reasons for the observed deviations:

- First, the liquid generally reduces the cross section which is available for the gas flow. As qualitative tests showed, at low flow velocities, the liquid flows mainly at the bottom (Figure 12a, left), however, with increasing gas flow it creeps to higher sections of the pipe (Figure 12a, middle), until, at very high flow velocities, or in very turbulent flows, it gets dispersed through the gas itself (Figure 12a, right).
- Second, especially transducers in the lower part of the pipeline respective. the meter are prone to be covered (at least temporally) by liquid so that the performance and the path velocity of these transducers deviate significantly from the transducer of other paths.

Quantitative investigations concerning the problem of liquid loading were performed at the NEL Wet Gas Loop, East Kilbridge, on a 6-inch FLOWSIC600 4-path meter. Nitrogen was used for the gas phase and kerosene as liquid. The performance was tested for different pressure levels (15, 30 and 60 barg) at ambient temperature, the flow velocity was varied from 4 to 23 m/s. The liquid volume fraction was tested from 0 to 5 %. There was ca. 38 D upstream and 6 D downstream the meter of schedule 80 6-inch pipeline.

As expected, the effect of liquid present is especially strong on the path closest to the bottom of the meter. As can be seen from Figure 12b, for path 4 the Turbulence as well as the relative path velocity strongly deviate from their dry-gas-values if liquid is present. For path 4, already 0.1 % (0.25 %) liquid content reduces the path velocity by approximately 15 % (20 %) and increases the Turbulence by ca. 25 % (80 %) compared to the dry-gas-values. These deviations would be easily detectable by the Diagnostic Fingerprint based differential diagnosis as Figure 12c shows.

Similar to the Turbulence, the Symmetry and the Profile Factor start to deviate significantly from the mean values determined for dry gas when the liquid load is increased. Both indicators increase by roughly 5 % (10 %) when the liquid fraction increases from zero to 0.1 % (0.25 %) which is clearly outside the empirical plausibility range of ±3 %.

The investigations showed that based on the Diagnostic Fingerprint concept and employing the indicators Turbulence, Profile Factor and Symmetry, the redundant detection of liquid on the bottom of the meter (Figure 12a, left) as well creeping up the pipe wall (Figure 12a, middle) up to liquid being dispersed in the gas flow (Figure 12a, right) is possible.

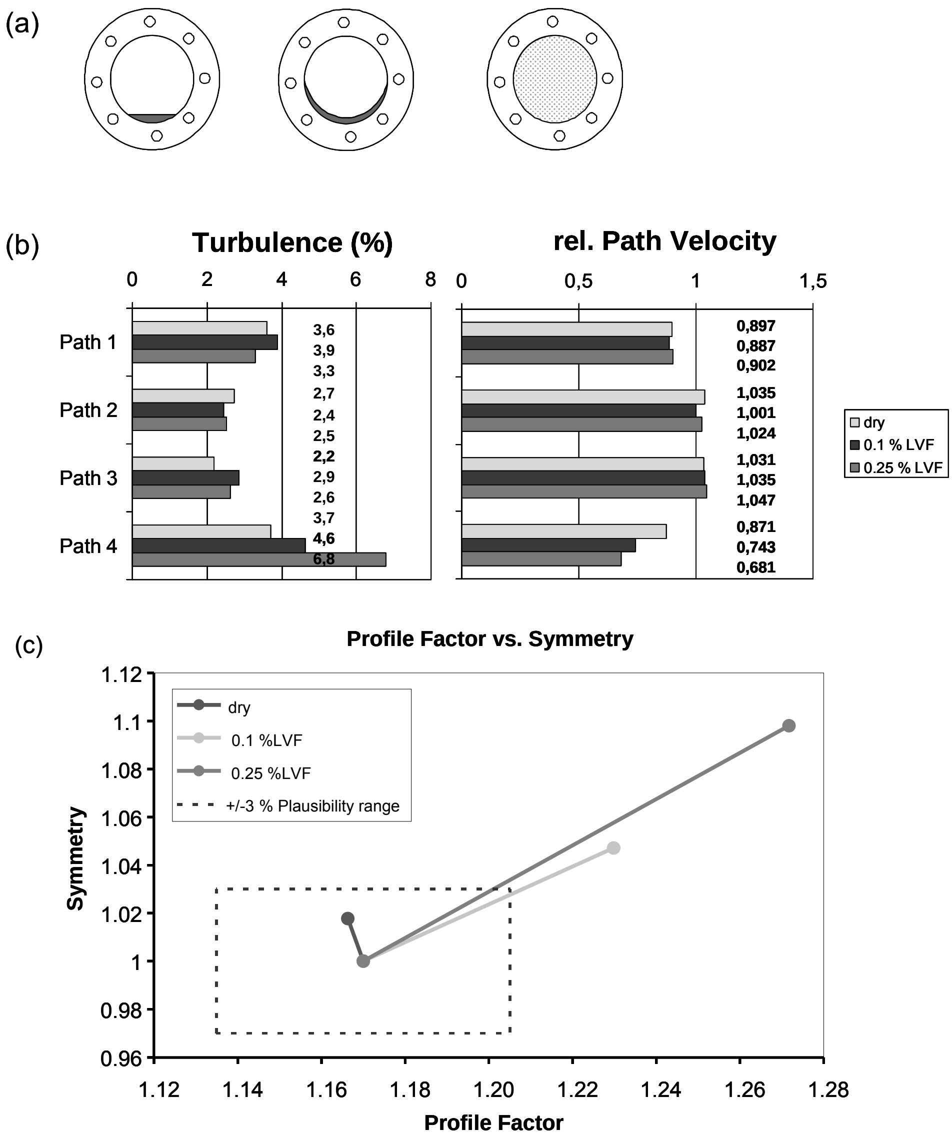


Figure 12: Liquid loading in the gas stream. Investigations performed at Wet Gas Loop, NEL East Kilbridge (details see text).

At this point it is important to state that the main intention of the Diagnostic Fingerprint based monitoring is to provide the user with a reliable qualitative warning system which works

- automated,
- oriented on the conditions of the specific application and
- under consideration of the flow velocity dependence of prominent diagnostic indicators.

Diagnostic Fingerprint monitoring is not intended as a system giving quantitative relations between the different diagnostic indicators and e.g. the flow velocity, a task much to complex to be handled automatically. Nevertheless, further investigations of the relation between liquid loading and performance of the paths and behaviour of the the diagnostic indicators are required.

4.2 Detection of wall roughness due to corrosion

Another example for the successful application of the Diagnostic Fingerprint concept is the increasing roughness of a pipeline or meter wall surface over time. This can occur, for example, by improper choice of material for the pipeline or the meter body so that corrosion can take place. In the case under investigation here, a 10-inch FLOWSIC600 – which contains two independently working ultrasonic meters – was routinely re-calibrated after ca. 4 years of service. At this occasion a clearly discernible increase in wall roughness (probably due to corrosion) was discovered (Figure 13a) and the meter was checked. For different volume flows the Profile Factor was determined for both meters (Figure 13b).

(a)

(b)

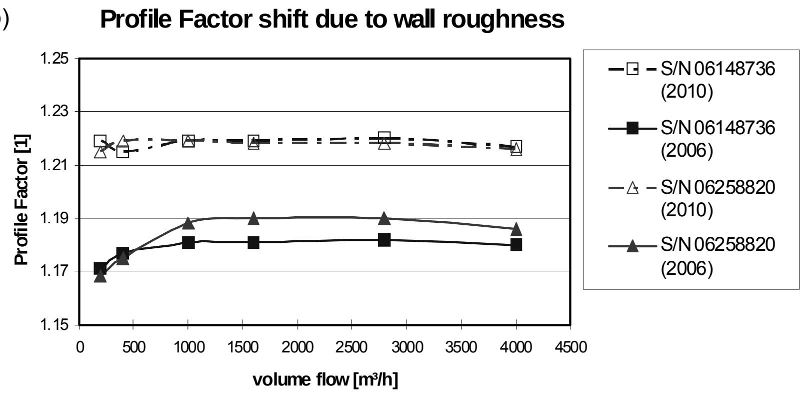


Figure 13: Profile Factor shift due to wall roughness.

The Profile Factors were determined as 1.18 (system 1) resp. 1.19 (system 2) in 2006. Within approximately four years, they increased to 1.22 implying a relative shift of +3.2 % (system 1) respective +2.5 % (system 2). As can be seen from the diagram in Figure 13, this change cannot merely be considered a statistical fluctuation but a significant shift probably correlated with increased wall roughness. From the appearance of the meter wall (Figure 13), the increase in wall roughness could be associated with corrosion leading to an effective decrease of the inner diameter. However, whether the inner diameter of 235 mm had actually changed by e.g. corrosion is not clear; theoretical estimates indicate that an error shift of 0.5 % would require a 0.25 % shift of the inner diameter, in this case 0.6 mm.

Looking on the potential effect towards the performance, experiments showed that sandpaper covered wall surfaces exhibit a performance shift similar to what could be observed in the present case.

Therefore, there are good reasons to assume that a significant shift in the Profile Factor gives a clear hint towards potential performance shifts which both might be associated with e.g. increased surface roughness. Although the meter diagnostic’s behavior is not fully explained yet today, the continuous supervision of the Profile Factor by the Diagnostic Fingerprint method can provide a valuable diagnostic tool to warn the user of a potential performance shift indicating a required recalibration.

5 Current application in the field at the OÖ. Ferngas Netz GmbH

5.1 The OÖ. Ferngas Netz GmbH

The OÖ. Ferngas Netz GmbH is the leading natural gas grid provider in Upper Austria. With its grid (> 5,100 km) the OÖ. Ferngas Netz GmbH supplies more than 60,000 customers in the private and industrial sector as well as power stations and local distributors in over 200 communities in Upper Austria. The transported gas volume exceeds 3 billion m³ gas per year. Due to its connections to production and storage sites in Upper Austria and due to the close contacts to other federal states in Austria, the OÖ. Ferngas Netz GmbH can guarantee secure and reliable supply with natural gas.

For quality control purposes, the company uses check meter runs in big gas metering stations which were traditionally equipped with two turbine gas meters. These meters allow a performance check only from time to time. In recent years,in more and more metering stations one of the two turbine meters have been replaced by ultrasonic gas meters in order to run them in series as check and back-up meters providing continuous diagnosis.

The current project is another example for a replacement of custody turbine by two ultrasonic meters (FLOWSIC600 and FLOWSIC600 2plex). Both meters provide the automated internal diagnostics within the 4-path-system via the Diagnostic Fingerprints. To further enhance redundancy and in order to give the user a second independent quantitative check meter, the FLOWSIC600 2plex offers an additional 1-path-system [5].

At the metering station considered here it is measured the gas transfer from the OÖ. Ferngas Netz GmbH to the Elektrizitätswerk Wels AG as the local gas distributor. With a gas pressure range of 30 to 40 barg, the volume flow amounts to about 30,000 Nm³/h (≈ 90 mio Nm³/a).

5.2 The application of the Diagnostic Fingerprints in the FLOWSIC600

The FLOWSIC600 2plex meter from which the data shall be presented here was commissioned in early summer 2010. Therefore, the data shown in Figure 14 are relatively fresh and have to be corroborated over the next month and year. Furthermore, gas flow through the metering station will turn up during the winter month as the demand of the gas run powerplant will increase during that time.

As can be seen from Figure 14, three out of five diagnostic indicators classes are filled already during the present low-flow period. (The application-adapted gas flow ranges in total from 0.3 to 10 m/s.) Displayed are the changes for the diagnostic indicators

- Profile Factor
- Symmetry
- Speed of Sound
- Average Turbulence
- Average SNR
- Average AGC.

As can easily be seen, there have been no significant deviations between the Current and Reference classes as compared to the Diagnostic Comparison Limits as putatively defined for the present application (indicated by the red bars).

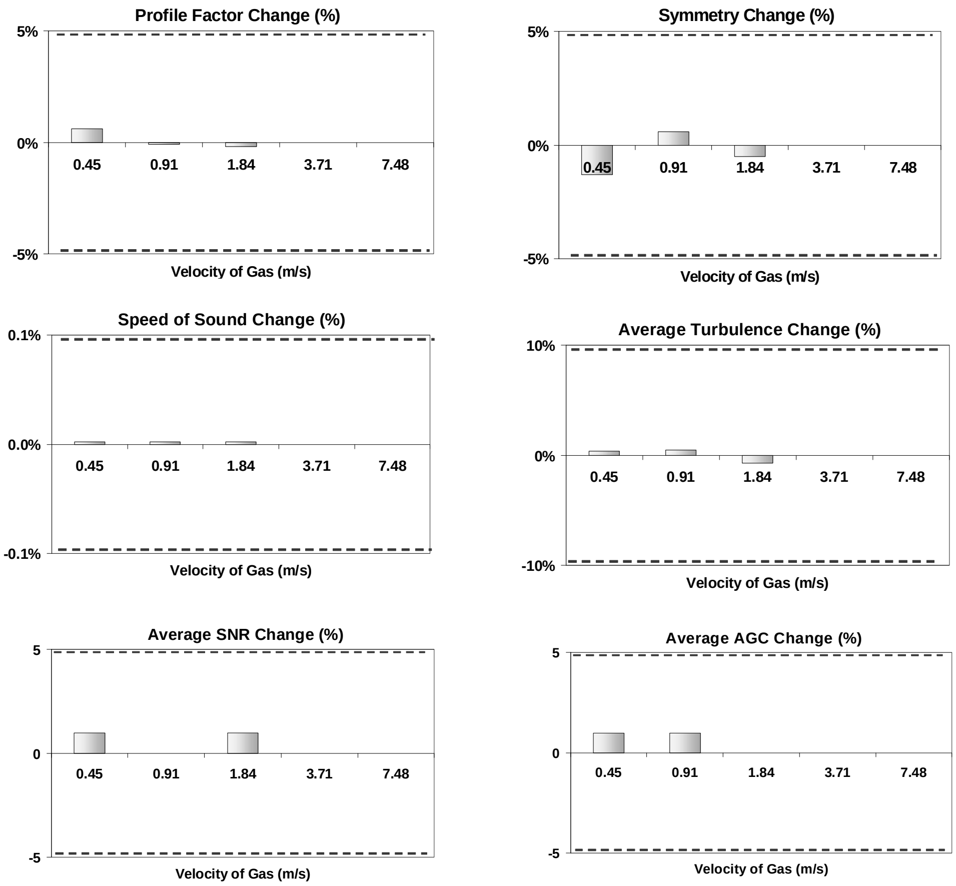


Figure 14: Overview of the diagnostic indicators as determined at the FLOWSIC600 2plex meter at the metering station of the Elektrizitätswerk Wels AG, Upper Austria.

6 Summary

As is already mentioned earlier, in general meter diagnosis is useful only if the user understands (and likes) it. Hence, the concept must be clear and reliable and adapted to the specific application. This holds true especially since many diagnostic indicators systematically depend upon the gas flow. Therefore, any comparison of these diagnostic indicators considering different gas flow classes – as presented here in the Diagnostic Fingerprint concept – allows for a specially sensitive detection of deviations over time which might indicate detrimental changes in the metering system.

The advantage of the diagnosis method described in this paper is based on the fact that – after initial configuration e.g. during commissioning – the whole “checking business“ is performed automatically and continuously by the meter itself. The user can select the level of sensitivity with which warnings are reported, so there is no reason to bother about over-alarming or insensitivity. The results do not depend any more on the technician’s interpretation but is color coded: green and yellow. The meter’s condition is visible on first sight – still all diagnostic data can be analyzed in detail.

7 Acknowledgements

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