SICK AG WHITEPAPER

CONTRIBUTING TO ECONOMIC UPSTREAM GAS METERING WITH A DUAL-PATH ULTRASONIC FLOW METERING SOLUTION

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Diversification in gas production worldwide with an increasing production of unconventional natural gas, such as shale gas, leads to an increasing number of gas wells. For the purpose of production control and well monitoring, the gas production from these wells is typically measured by a gas flow meter close to the wellhead or at the gathering station where the gas often contains liquids and contaminants due to limited gas treatment equipment on a wellhead skid. In addition, there is a requirement for high rangeability, since the output of the well changes over time and is generally not predictable. Since the amount of wells significantly increase with shale gas and coal seam gas production, there is also a need for high availability and low maintenance equipment.

In order to cover the demand, an innovative approach for an ultrasonic gas flow meter that provides high reliability, high rangeability, and Class 1 uncertainty in dry conditions (acc. ISO 17089-1), without the need for an individual high-pressure natural gas calibration, is described in this white paper.

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ECONOMIC UPSTREAM GAS METERING

INTRODUCTION

The increasing global demand for energy drives a need for diversification in gas production and puts a stronger focus on the development of unconventional natural gas sources, such as shale gas and coal seam gas. As a direct consequence, the number of unconventional gas wells is increasing worldwide.

Monitoring of unconventional gas production is commonly done via a gas flow meter close to the wellhead or at the gathering station. Depending on the reservoir and the quality of the gas treatment equipment on the wellhead, the gas may contain liquids and contaminants. They can, depending on their volume fraction, degrade the flow meter measurement performance and, therefore, the monitoring reliability. Furthermore, the output of the gas well may fluctuate unpredictably on relatively short time scales and will, depending on the maturity of the gas production, generally decline over longer time periods. Monitoring of a time-varying production rate requires a rugged flow meter with high turn-down and with minimized operational costs to meet economic requirements.

Gas metering points in this production environment are traditionally equipped with differential pressure meters even though new technology gas meters like ultrasonic meters provide several advantages over differential pressure technologies. Gas producers have experienced in the last years that the lower operational expenditures and technology benefits of ultrasonic meters compensate for the higher initial investment which results in the fact that ultrasonic meters for gas production applications become more and more accepted.

This paper describes an innovative approach for an ultrasonic gas flow meter that provides high reliability, high rangeability, and Class 1 uncertainty in dry conditions (acc. ISO 17089-1) without the need for an individual high-pressure natural gas calibration. Compared to the prices of small size flow meters.

The paper summarizes the technical challenges that have been overcome in order to ensure a proper meter performance in high-pressure natural gas without high-pressure calibration. Both, low-pressure and high-pressure calibration lab results are presented as well as wet gas test results with water and oil components. Additional measures make the meter highly resistant even against high Liquid Volume Fraction (LVF) and provide reliable liquid detection capabilities, by using meter diagnostics. This results in an accurate and economic upstream ultrasonic meter with large turn-down that indicates the presence of liquids on a real-time basis.

INITIAL MOTIVATION

Dynamic (wet) calibration has become a standard for Class 1 gas flow meters in order to ensure a high level of measurement accuracy in the field. ISO17089-1 recommends using calibration conditions such as pressure, temperature, and flow rate similar to the designated operating conditions of the meter and to include upstream and downstream piping with flow conditioners whenever possible. [1]

The type of gas, pressure, and temperature clearly have an effect on the flow profile inside ultrasonic meters and thus on the calibration result. Those effects are largely understood while influences from geometric meter tolerances, upstream piping characteristics, and effects from flange connections have been less investigated. Usually, these effects are neglected during flow calibration of ultrasonic meter packages. That is why there is a clear trend to calibrate meter packages in order to reduce the influencing factors that may cause a higher uncertainty of measurement in the final installation.

Ultrasonic meters that meet Class 1 performance requirements, are mainly multipath ultrasonic meters with three or more paths for custody transfer applications. Meters for gas production applications have to be rugged, provide highly available readings with good reliability, and must be economic in CapEx and OpEx. Additionally, the gas stream in gas production applications may contain contaminants and liquids where 4-path meters have not shown an advantage in accuracy over dual-path meters. [2] Based on these considerations, a decision has been taken for a more economic dual-path concept that should meet Class 1 performance requirements. For this, it is necessary to

(1) understand the effects of changing operating conditions on the meter performance and
(2) to identify the major factors affecting the meter performance and to keep them down to an uncritical level of variation.

The main challenges for the realization of the project were:

- Create a dual-path meter with high accuracy and reproducibility.
- Reduce flow profile variations from manufacturing tolerances and installation effects.
- Develop a factory test procedure to guarantee Class 1 performance.

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METER DESIGN

To ensure a reliable and thorough technical basis for the new ultrasonic dual-path meter, a well proven custody approach is employed. Sensor technology, electronics, manufacturing standards, and data processing algorithms are applied which have been already used during the last decade with the FLOWSIC600 custody gas flow meter. It combines both high accuracy and long-term stability for custody transfer and gas storage applications.

It has been shown that upstream piping conditions, such as steps and wall roughness, do not have a significant effect on the accuracy of multipath custody ultrasonic flow meters. [3, 4] However, for dual-path meters, it can be assumed that their effect on measuring performance is more significant. This has been confirmed by initial tests with a welded design for the initial upstream meter design.

Typical variations that increase the uncertainty of a dual-path ultrasonic meter are:

- Misalignments of flanges due to tolerances in flange connections
- Gaps between connection flanges
- Influences of welding on pipe roundness
- Manufacturing tolerances of upstream piping

The influence of these variations on the flow profile and reproducibility of the dual-path meter decrease with increasing distance to the measurement section. Consequently, the upstream meter section has been increased to a length of 10 x nominal diameter. This increases the distance from flow disturbances and allows the meter manufacturer to control the upstream pipe conditions close to the measurement section. The meter design as shown in figure 1 has proven to be very beneficial in wet gas conditions. [5]

Figure 1: FLOWSIC600 DRU

Another measure to reduce sensitivity of a dual-path meter to the individual characteristics of a specific installation is to enhance the ruggedness of the meter against variations in the flow profile. This can be achieved by optimizing the linearity of the meter over the Reynolds number. For symmetrical profiles in turbulent flows, variations of the flow profile are predominantly caused by change in the Reynolds number. Gätke [6] has defined a position at which flow characteristics show minimal dependency on profile variations. This point is located in 0.4* radius distance to the pipe wall. FLOWSIC600 DRU ultrasonic paths are positioned accordingly, hence making the meter less sensitive to flow profile variations.

A flow conditioner upstream of the meter is required to achieve a stable and symmetrical flow profile and ensure measurement performance with typical causes of turbulence such as elbows in the upstream piping. The type of flow conditioner has been chosen under consideration of a proper flow straightening effect. While the conditioner should ideally not limit the turn-down ratio of the ultrasonic meter. In several tests the CPA Type 55E has been found to provide a good compromise for this purpose. A typical meter installation setup is shown in figure 2.

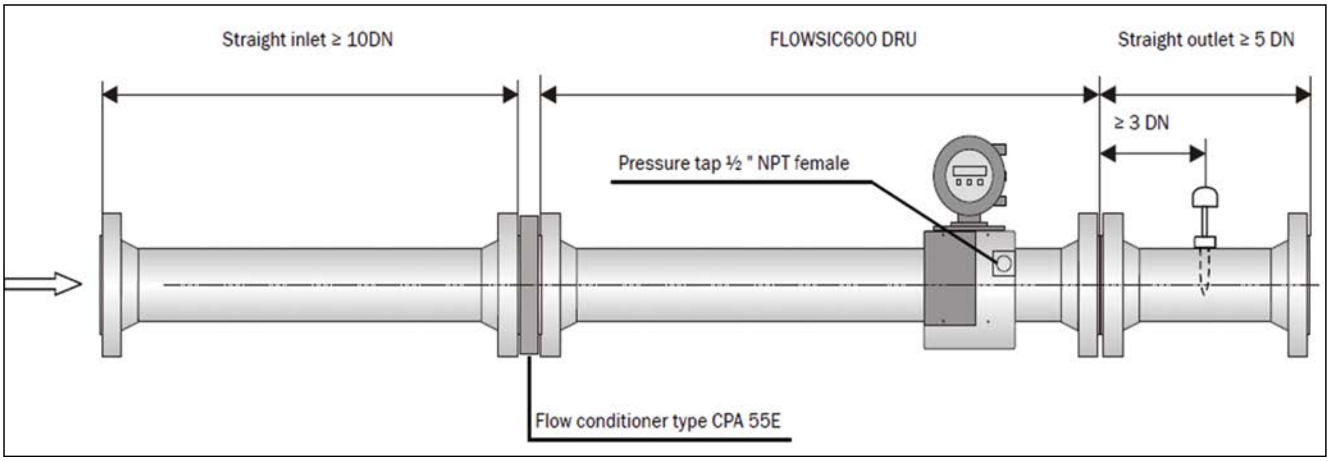
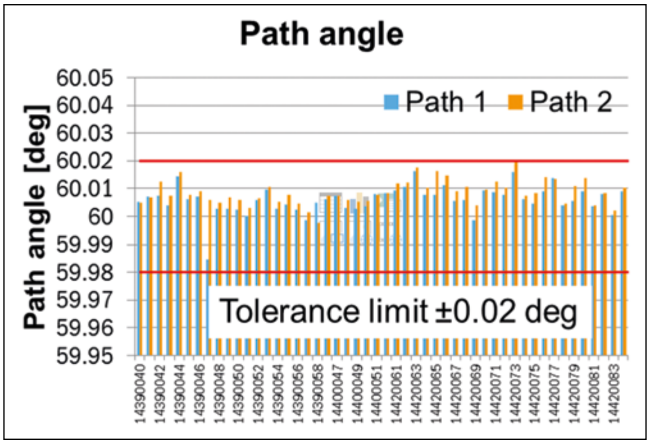


Figure 2: Meter installation setup

The meter body is manufactured from a steel bar in one machining step with utmost precision. The geometric dimensions of each meter body are measured precisely afterwards to prove compliance of tolerance criteria. Figure 3 and 4 show the low level of variations on a sample of 25 machined meter bodies.



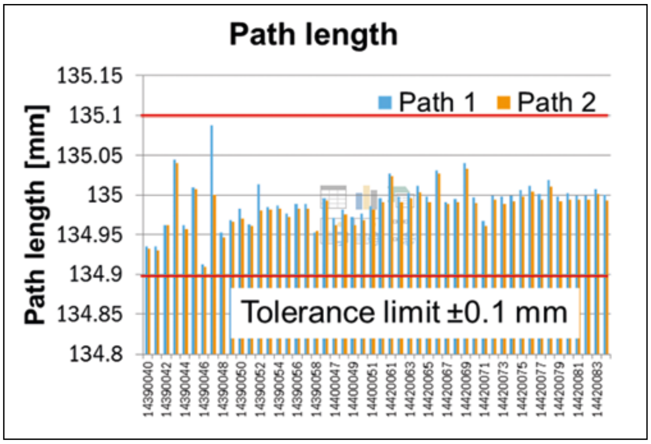


Figure 3 and 4: Tolerances in meter body geometry of the machined meter design

TEST RESULTS

Ambient air flow tests

Applying the design aspects and improved manufacturing tolerances from chapter 3, a set of 25 meters was tested in a seven point flow test at SICK‘s ambient air flow lab. Figure 5 shows the as-found results of the test. At a glance, the Class 1 accuracy requirements are met with the dual-path meter. This is a direct consequence of the high-precision design approach and associated narrow tolerance bands.

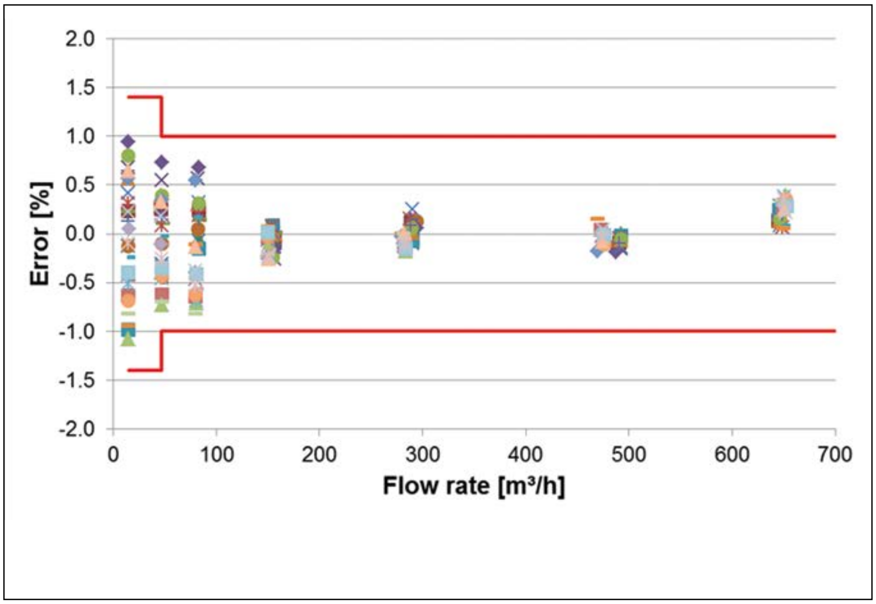


Figure 5: As-found results from seven point ambient air flow test of 25 meters over flow rate

The meter-to-meter variations are less than ± 0.5% for flow rates > 100 m^3/h. The meters show a very high linearity, in particular for higher flow rates. It can also be seen in figure 7 that the meter-to-meter variations increase with low flow rates. This can be explained by two effects:

First, the Reynolds number decreases with decreasing flow velocity and causes a less stable flow profile due to the lower inertial forces in the fluid. For example, the Reynolds number at Q_{min} is approximately 4500, representing a “transition” flow which is not fully turbulent. The effect of the Reynolds number on the uncertainty of measurement can be seen in figure 6. It depicts the as-found error of the 25 meters over the Reynolds number.

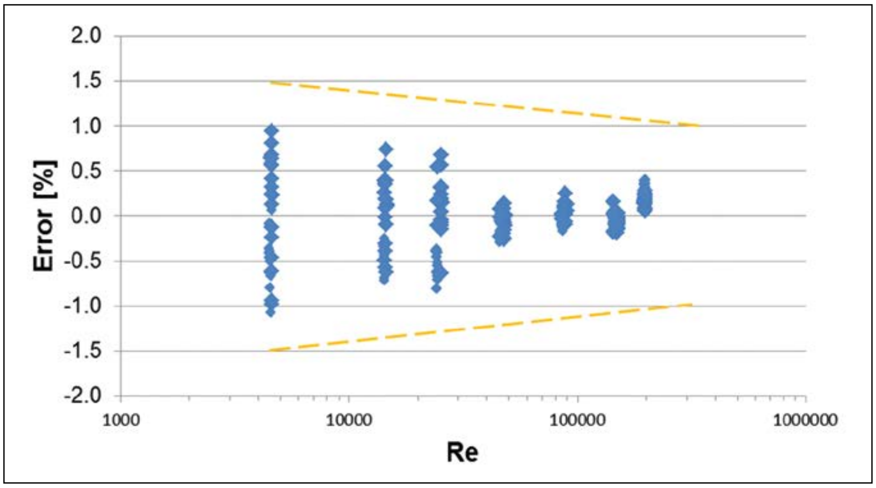


Figure 6: As-found results from 7-point ambient air flow test of 25 meters over Re

Second, the total uncertainty of measurement of an ultrasonic flow meter is mainly defined by the error of the transit-time difference determination. While the uncertainty budget of all other influencing factors are independent from the flow rate, the uncertainty of transit time difference measurement increases at lower flow rates (figure 7).

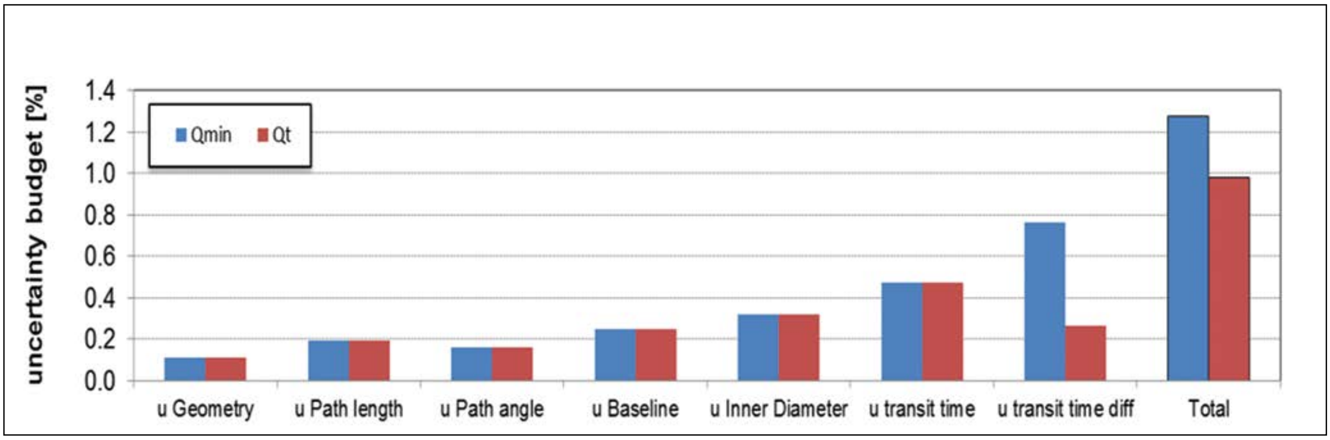


Figure 7: Uncertainty budget of dual-path USM with k = 3

The results in figure 7 are encouraging, since the meter-to-meter variations and the linearity of the meters are good and improve with higher Reynolds numbers. Higher Reynolds numbers can be expected in the target operating conditions.

The intelligent meter electronics corrects for geometry changes of the meter body caused by temperature and pressure variations as well as for changes in the flow profile caused by a change of the Reynolds number. These corrections are made based on advanced mathematical models and typically contain an uncertainty. In order to calculate the estimated total uncertainty caused by operation of the meter in operating conditions with high-pressure natural gas instead of ambient air, the uncertainty budgets of the test labs and the uncertainty of the internal corrections have to be considered. All single uncertainties are normally distributed and considered with a 95% confidence level (k = 2):

$$u_{trans} = \sqrt{u_{test\ lab,\ lp}^2 + u_{test\ lab,\ hp}^2 + u_{corr,\ geom}^2 + u_{corr,\ Re}^2} \leq 0{,}32\%\ (k = 2)$$

The following individual uncertainties apply:

$u_{test\ lab,\ lp} \leq 0{,}2\%$ (Test lab uncertainty of ambient air test stand)
$u_{test\ lab,\ hp} \leq 0{,}2\%$ (Typical harmonized lab uncertainty of high-pressure test labs)
$u_{corr,\ geom} \leq 0{,}1\%$ (Uncertainty of geometric correction function) [7])
$u_{corr,\ Re} \leq 0{,}1\%$ (Uncertainty of Reynolds number correction)

The ambient air test results give the required margin for the additional uncertainty of ± 0.32% when the increasing Reynolds number at high-pressure is considered. Thus, it can be expected that the meter will stay within the error limits even in high-pressure natural gas.

High-pressure natural gas tests

In order to answer that question, 10 out of the 25 meters were tested at traceable European high-pressure natural gas test benches. Tests were performed at two different test benches at 4 bar and 50 bar. 4 bar was chosen to verify the flowmeter characteristics at slightly elevated pressures from atmospheric while the 50 bar tests represented a typical operational pressure of the meter. Figure 8 shows the as-found results of the tests in high-pressure natural gas.

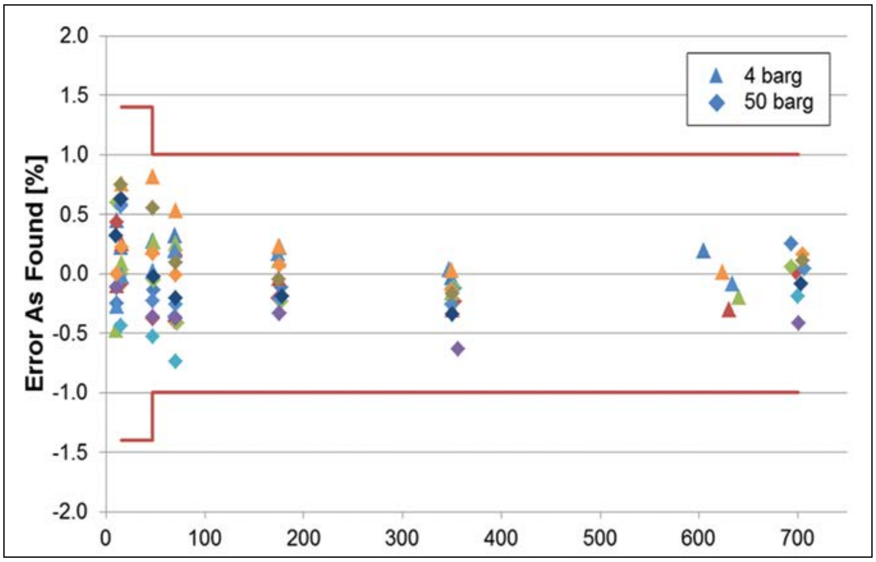


Figure 8: As-Found results of 10 meters in high-pressure natural gas

The results confirm the high linearity of the meter characteristics and are within the expected additional uncertainty of ≤ 0.34%. All test results are well within the Class 1 performance requirements of ISO 17089-1. The meter-to-meter variations are within the expected range. Significant differences between the 4 bar tests and the 50 bar tests could not be found.

If the test results are plotted over the Reynolds number (figure 9), it can be found that the spread of as-found errors further declines with increasing Reynolds numbers. No systematic bias can be found. It can be assumed that the spread of error will converge to a level of approx. ± 0.5% which may represent the physical limitations in uncertainty of a dual-path meter.

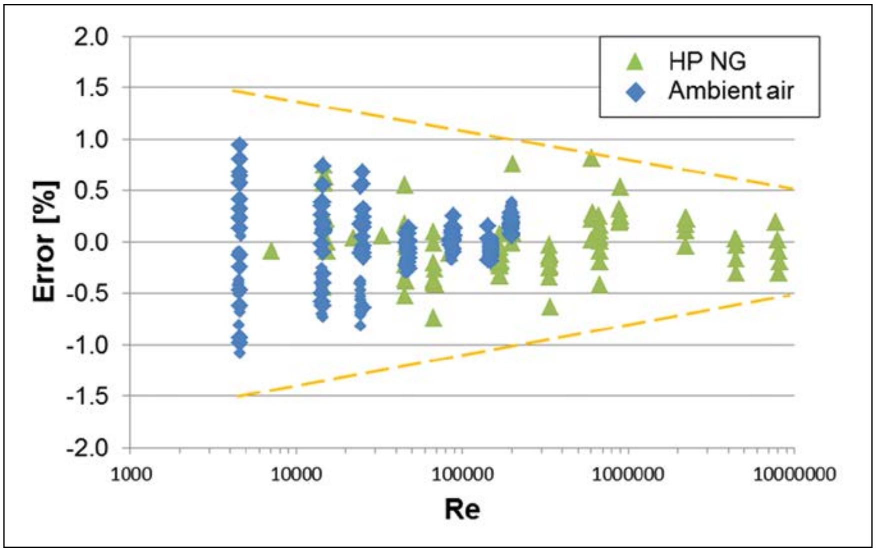


Figure 9: Test results from ambient air and high-pressure natural gas over Re

ENSURING PRODUCTION ENVIRONMENT RUGGEDNESS

Another vital aspect for a meter at gathering stations and gas processing plants is a high ruggedness against liquids and pollutants that may occur in the gas stream.

Several concepts for ultrasonic meters exist to provide a higher tolerance in polluted gas streams. SICK has tested and realized numerous meters in upstream applications using different concepts over the past 5 years. [5] Based on this experience and the valued cooperation with our customers, SICK has found an optimal combination of meter design aspects and diagnostic functions for services with wet or potentially wet gas.

Liquid indication

It has been shown that ultrasonic meters are highly capable, even within gas production applications with wet gas and that the diagnostic values provide valuable information that may indicate the presence of liquids. [2] Since ultrasonic meters as well as orifice meters tend to over-register with the presence of liquids, indicating this presence can be a valuable diagnostic feature. Thus, the diagnostic data from wet gas tests with the current meter design have been analyzed in detail and a concept for a liquid detection algorithm has been developed.

The simplified detection algorithm is shown in figure 10. The algorithm uses standard diagnostic parameters such as speed of sound and turbulence in order to identify a potential presence of wet gas with LVF of typically > 0.5%. This is typically the amount of LVF where significant over-registering of a meter starts. In a next step, the algorithm was validated during a Joint Industry Project (JIP) at the DNV-GL in the Netherlands in 2014 where SICK participated with the FLOWSIC600 DRU meter concept. It was proven that the algorithm typically detects liquid volume fractions of 0.5% or more with a confidence level of > 95% in laboratory conditions. This liquid detection algorithm has now been implemented into the FLOWSIC600 DRU in order to gain field experience and real application data with the new diagnostic feature that can provide valuable information about potential liquids in the gas stream. It must be pointed out, that the Liquid Indication Diagnosis is not used to compensate for over-reading of the meter caused by liquids in the gas.

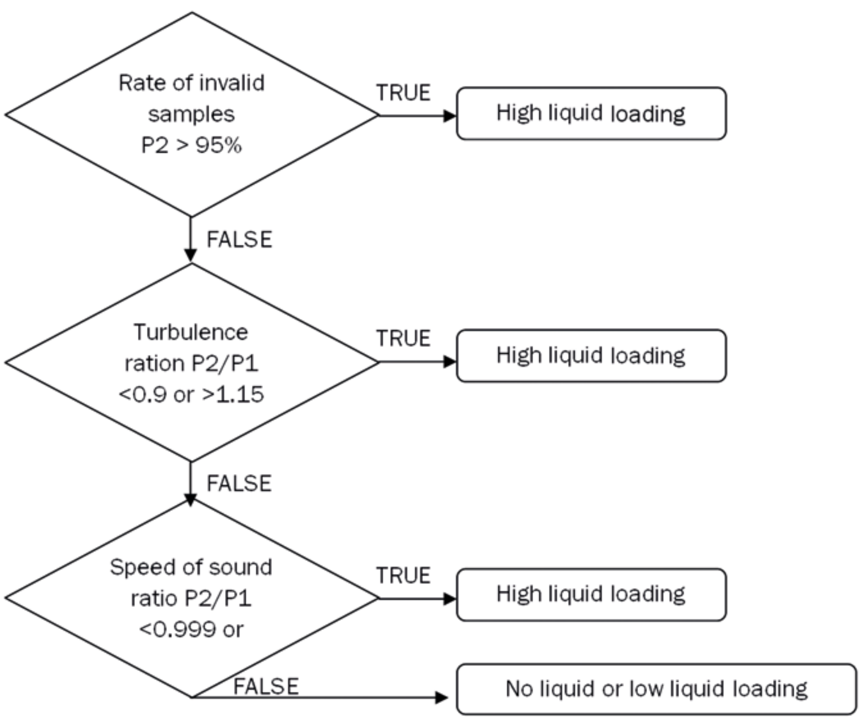


Figure 10: Simplified algorithm of Liquid Indication Diagnosis by SICK

Wet gas test results

Wet gas tests at different test facilities as well as field experience in numerous wellhead applications contributed to increase SICK's knowledge of wet gas measurement over the last ten years. The latest test was the Joint Industry Project "US meters in wet gas applications" by DNV GL [8], where the meter was tested in two-phase flows with the liquid phase being water, oil or a mixture of water and oil. Variations in Froude number, Lockhart-Martinelli-Parameter and Density Ratio were tested over more than 200 test points. The results were in line with the results from former tests with the meter concept.

Figure 11 shows a ramp-up/ramp-down test with increasing Lockhardt-Martinelli parameter, and density ratio (X_{LM}), indicating the "wetness" of the gas. FLOWSIC600 DRU continuously measured over the full test where at the maximum of X_{LM} = 0.9, an equivalent of 13.2% LVF was reached. It can also be seen, that the over-registering of the meter in wet gas can reach up to 150% which shows the importance of identification of these flow conditions. It can be seen at the beginning and end of the ramp that the meter readings are within an acceptable allocation accuracy range for X_{LM} < 0.1.

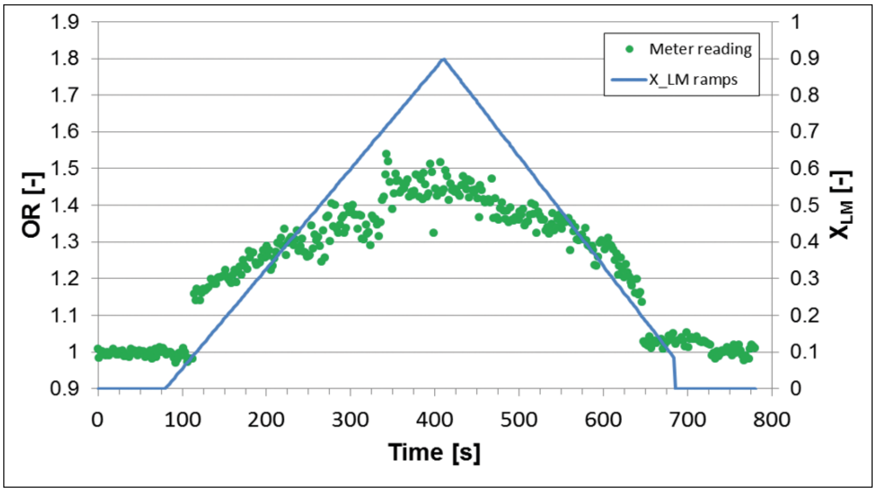


Figure 11: Over reading of USM in wet gas flow, ramp-up/ramp-down test

During the blind test, manufacturers were asked to label the measurement results based on the diagnostic informations from the meter with a traffic light system. SICK decided to set a “yellow” status for each test point where the diagnostic data indicated, that the meter readings may be affected by liquid entrainment.

Figure 12 shows the results over X_{LM} and Froude number Fr_G. It can be seen that > 80% of the green-labeled test points remain close to the actual gas reference flow rate and show an uncertainty of typically < 2.5%. For test points with higher liquid loads that caused the meter to over-register, this was typically indicated by the diagnostic data. It is also true that for some test points the meter over-registered while the meter diagnostics did not indicate this and vice versa.

SICK did not perform pre-tests at the test facility. This resulted in highly beneficial data being derived and enabled performance optimization of dual-path meters in wet gas applications.

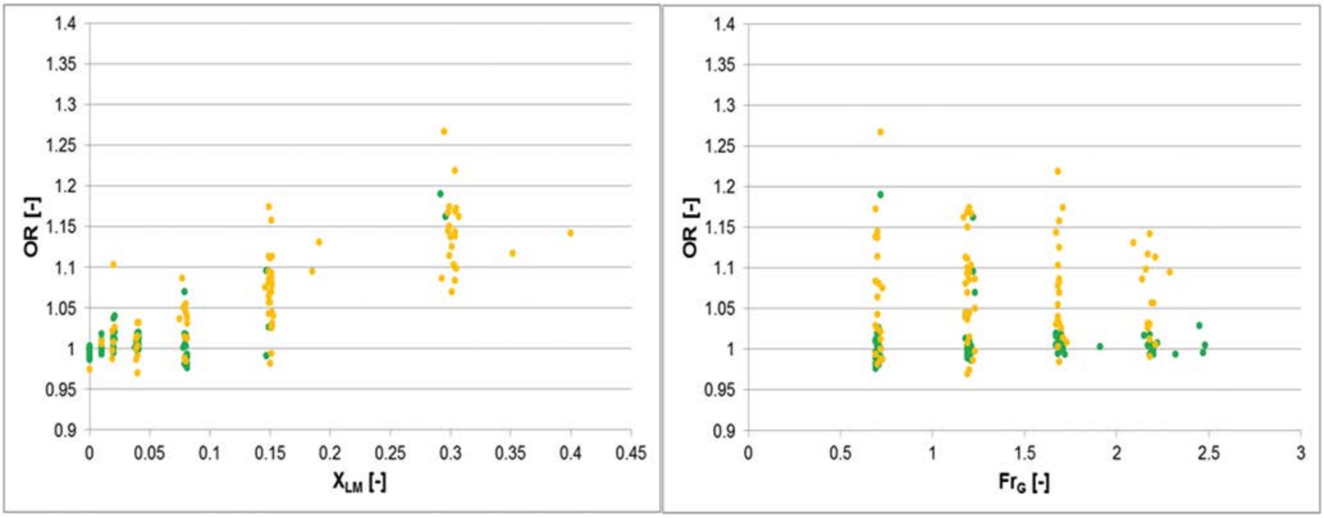


Figure 12: Wet gas test results over X_{LM} and Fr_G during testing

The evaluation method of the “Liquid Indication Diagnosis” was optimized and the traffic light system was newly applied to the test results after knowing the test matrix of the JIP.

Figure 13 shows the results after this optimization. All test points with two-phase flow conditions that significantly affected the meter accuracy are now thoroughly detected by the diagnostic data and indicated by a “yellow” traffic light.

Obviously, it is easy to adapt meter diagnostics in post-processing. However, we are convinced that the meter performance and meter diagnostics will improve with the optimized diagnosis in the field as well. Results from various ongoing field installations will be presented soon.

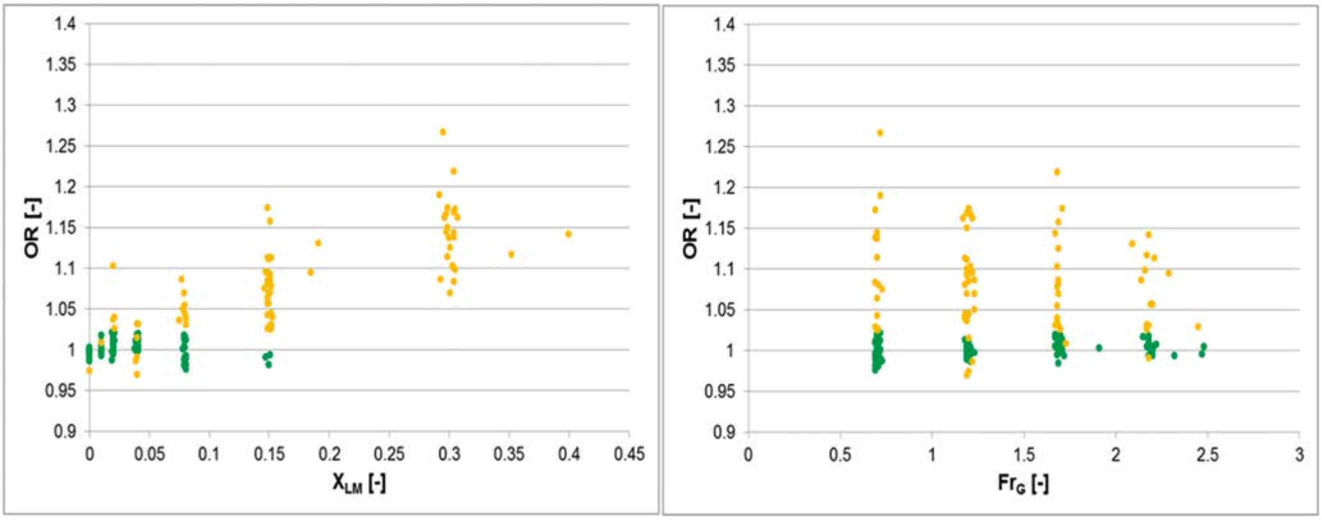


Figure 13: Wet gas test results over X_{LM} and Fr_G after improvements

Finally, the results from the JIP have verified the meters capability to

- withstand wet gas flow conditions in mixtures with water and oil,
- provide highly accurate readings in dry gas before and after the test,
- provide readings with acceptable accuracy for allocation metering up to 0.5% LVF of the gas stream,
- provide continuous readings even with heavy liquid loads,
- reliably detect the presence of liquids that affect the meter‘s readings.

FIELD EXPERIENCE

For a time period of 90 days, the USM was installed in series downstream of a single-chamber orifice meter at a shale gas well pad in the USA. The wellpad was equipped with six gas production wells each connected to a three-phase separator. The produced gas was gathered in a 3” pipeline at approx. 90 bar and routed through the metering run in order to measure the wellpad production rate for billing purposes.

The wellpad production rate over the test period was very low in the first days, increasing over time, but remained unstable with an average hourly flow rate ranging from 0 to 180 m^3/h (figure 14). The SCADA system registered hourly data of both meters.

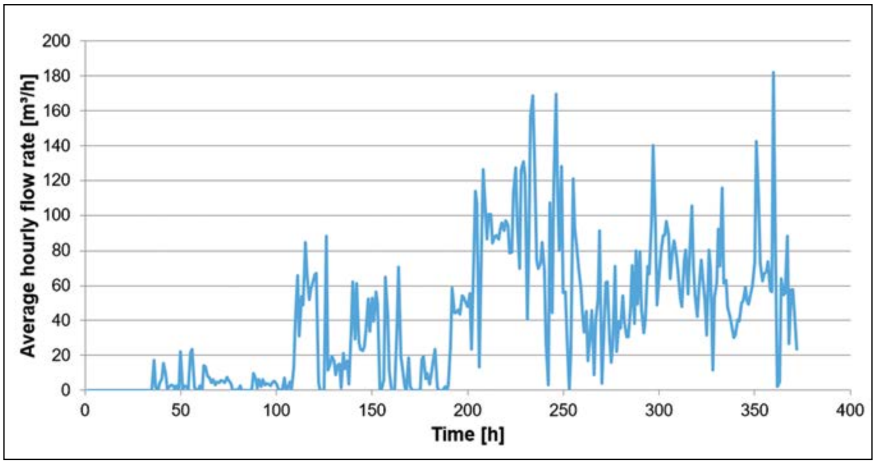


Figure 14: Average hourly gas flow rate of wellpad

Over the time period, three different orifice plates were used in order to keep the differential pressure at the orifice plate in a valid range for the differential pressure transmitter. The USM has a rangeability of > 100:1 starting at a Q_{min} of 5 m^3/h.

Figure 15 shows the evaluation of the SCADA data for the first test period over 15 days. The average hourly flow rate is plotted to the left Y-axis. The right Y-axis shows the “out-of-range rate” – the percentage of measurements that have been excluded before calculating the average hourly flow rate. This typically happened at the low-flow cutoff.

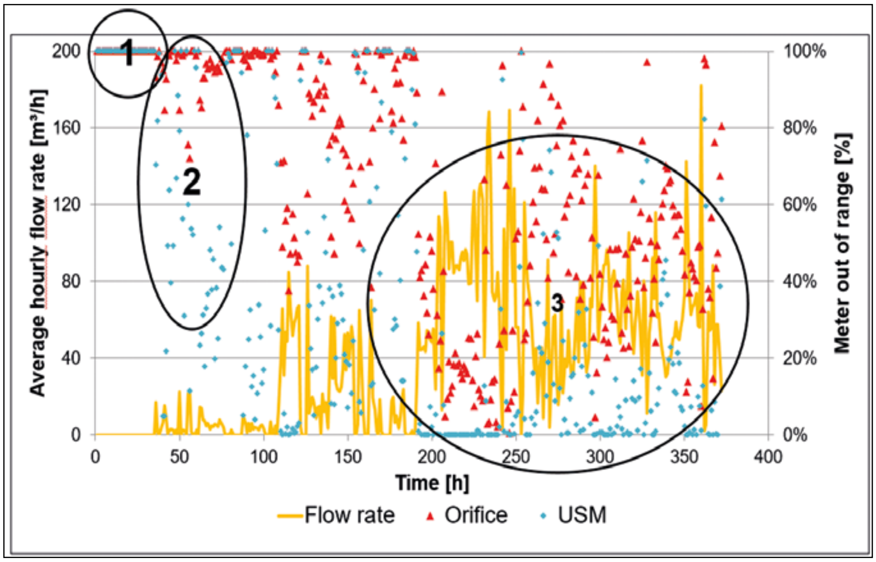


Figure 15: Flow rate and related “out-of-range“ rate for USM and orifice meter

It can be seen that both meters are temporarily out of their measuring range due to the dynamic wellpad flow rate. During this time, small amounts of gas pass the meters unregistered. Due to the higher measuring range of the USM, it can be seen that the USM shows lower “out-of-range” periods resulting in a higher availability of measurement and therefore less gas that is not accounted for.

The three phases in figure 15 can be described as follows:

1. When the wellpad flow rate is close to zero: Both the USM and the orifice meter have a 100% „out-of-range“ rate.
2. When the wellpad shows very small flow rates: The USM registers flow rates above the meter‘s zero-flow cutoff while still having periods of non-registering. The orifice meter is less capable of measuring low flow rates. The “out-of-range” period of the orifice meter is higher compared to the USM.
3. When the wellpad output has increased, but is very dynamic and still contains short periods with flow rates that are close to zero: The USM measures most of the gas flow with a low “out-of-range” period. The orifice meter still operates close to its lower dP limit resulting in 20 to 80 percent of “out-of-range” periods.

Table 1 shows a summary based on the SCADA records for both meters over the 90-day test period. The higher measurement range of the USM resulted in a significantly higher availability of the gas measurement. Even when the flow rates were low and one could tend to neglect the amount of gas that passed the orifice meter below its dP limit, it could be shown by the test that the value of “unaccounted” gas passing the orifice meter is of economic interest. This is particularly true when gas prices are down and operators have to optimize their production sites to be profitable.

	Orifice meter	USM	Difference
In range total flow volume (MCF)	216320	221379	5059
In range gas value (USD) (0.3 USD/MCF)	$ 719,949	$ 736,786	**+ $ 16,837**

Table 1: Summary based on SCADA records over 90-day test period

CONCLUSION

The use of ultrasonic meters in gas production applications, at gathering stations, or in gas processing plants, is not limited by the ultrasonic technology itself.

It has been shown that the combination of ultrasonic technology, a special meter design, low manufacturing tolerances, and minimal meter-to-meter variations allow transferring ambient air flow test results to high-pressure natural gas. Understanding the key influencing factors on the meter characteristics and keeping them at an uncritical level of variation is vital in order to meet Class 1 performance requirements.

Another critical requirement for meters in upstream applications is to be rugged against liquids and contaminants and to provide reliable readings under all circumstances. It has been shown by wet gas test results from former tests and the Joint Industry Project of DNV GL that several measures in sensor positioning and transducer design ensure continuous readings in wet gas conditions up to a X_{LM} of 0.9. Moreover, it can be shown that for $X_{LM} < 0.1$, which can be typically expected after the first stage of separation, the meter provides reliable readings with an accuracy which is usually acceptable for allocation purposes.

Based on wet gas tests and field experience from upstream applications, a new diagnostic feature has been presented that indicates the presence of liquids in the gas stream which may cause the meter to over-register significantly. In lab tests, LVF of > 0.5% could be reliably detected.The reliability of the new diagnostic feature of liquid detection and possible side effects on it will be investigated in various ongoing field applications.

Finally, it could be shown with field test data from a shale gas application that employment of customized ultrasonic meters for gas production applications can have substantial economic advantages even after a short time. Lower lifetime costs of USM are also significant.

The installed base of ultrasonic meters in gas production applications is rapidly increasing. Gas production companies may be forced to pay more attention to operational costs of wellhead equipment and overall profitability driven by worsening economic conditions for the oil and gas industry. Here, virtually maintenance-free ultrasonic meters customized for gas production applications can contribute to a more economical gas production not least thanks to their high turn-down ratio.

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Subject to change without notice

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