IMPACT OF REGULATOR NOISE ON ULTRSONIC FLOW METERS IN NATURAL GAS

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ABSTRACT

The impact of pressure regulator noise on the performance of ultrasonic meters has been discussed for several years now. This is one of the problems still to be solved in ultrasonic flow metering technology. Engineers have so far attempted to solve the problem by installing complex spatial pipe arrangements at high costs to reduce interfering noise levels.

The issue has been examined systematically both in field tests in the measuring station of a transportation pipeline and on the E.ON Ruhrgas high-pressure test facility in Lintorf to determine the limits of use and potential applications of an ultrasonic gas meter with chordal path layout in combination with a regulator. The tests made on a 16-inch meter in the measuring station confirmed that proper functioning of the meter with respect to pressure differential and flow rate can be guaranteed even under the most extreme conditions.

For further systematic testing on the Lintorf high-pressure test facility, an 8-inch ultrasonic meter was equipped with two four-path systems working independently of each other. This approach made it possible to directly compare a system with 210 kHz ultrasonic sensors with the latest technology of 350 kHz sensors. It was found that the 350 kHz sensors are clearly less sensitive to interfering noise signals and therefore improve measurement reliability under worst case conditions. Based on auto-diagnosis parameters such as signal-to-noise ratio and performance, the meter was confirmed to be capable of clearly detecting and rejecting disturbed signals.

The paper describes the test results and the information derived with respect to an expanded use of ultrasonic technology.

1. INTRODUCTION

Pressure regulators are a major source of noise in gas pipelines. In recent years, continuous optimization of the regulator design has led to a noticeable noise reduction, in particular in the audible range. However, the amount of noise generated at frequencies above the audible range may be problematic for ultrasonic gas flow meters. The reliability and accuracy of the signal transit time detected and thus the quality of the measured value provided by an ultrasonic gas meter are defined by the minimum signal level differential required between the sensor sound pulse to be analyzed and the signal interfering with the sound pulse (the signal-to-noise ratio). The spectral distribution of noise and its dependence on the pressure difference and flow rate at the regulator are of particular interest in this paper. Fig. 1 is a general presentation of the situation.

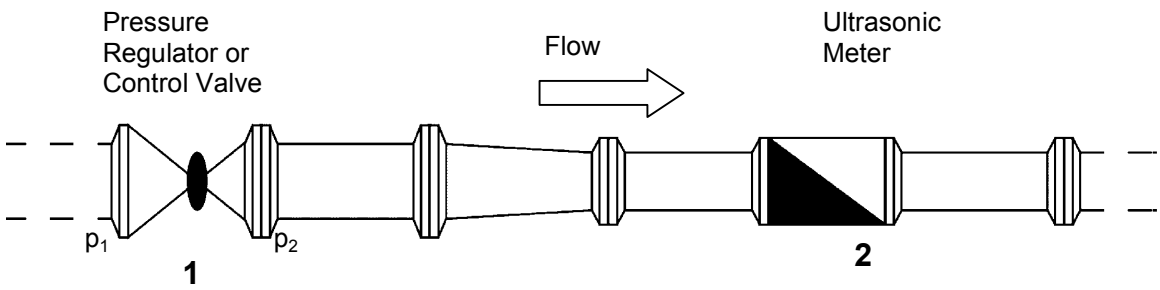


Fig. 1: Pressure regulator or control valve applied together with ultrasonic meter

1.1 INTERFERING NOISE FROM GAS PRESSURE REGULATORS

Energy loss and the consequential noise generated during pressure reduction are proportional to the flow rate and pressure difference. These relationships of noise sound pressure were already referred to in other literature [1]:

$$p_{noise} = f(\sqrt{Q}, \frac{p_1 - p_2}{p_2}) \tag{1}$$

$p_{1,2}$ pressure upstream (1) and downstream (2)

Q flowrate

The following approximation of the noise level produced by a sonic nozzle can be found e.g. in [2]:

$$L_{noise}[dB] \sim 93dB + 10 \cdot \log(Q \cdot c^2) - 10 \cdot \log\left[1 + 6\left(\frac{p_2}{p_1 - p_2}\right)^{2.5}\right] \tag{2}$$

L_{noise} sound pressure level

c speed of sound

For verification of this equation, the noise level emitted by a compressed air gun was recorded and the frequency spectra of a real signal and the theoretical model were compared. Fig. 2 shows the result of this test. A sufficient degree of congruence in the frequency range in question could be found.

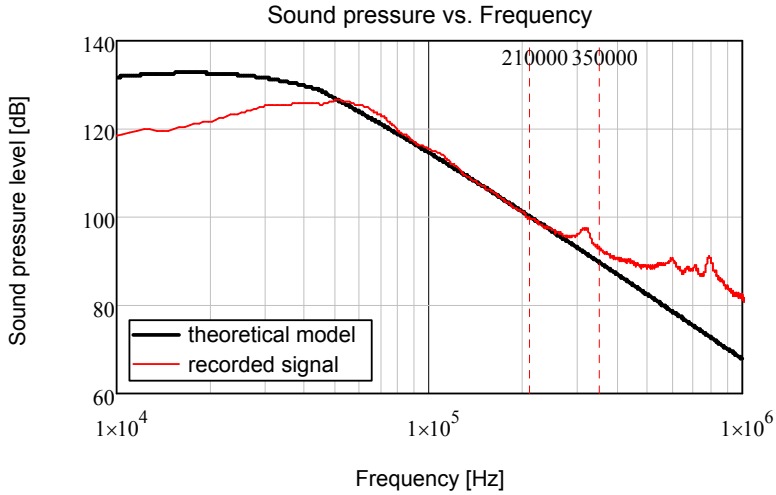


Fig. 2: Noise spectrum of a pressure regulator, simulated by means of a compressed air gun

A pressure regulator generates sound waves over a wide frequency range that may well be in the typical working frequency ranges of ultrasonic gas sensors (80...200 kHz). These sound waves travel through the gas from where they originate and superimpose the ultrasonic sound pulses emitted by an ultrasonic gas meter at the location where it is installed. It should be noted in this context that the gas industry uses various types of regulators that differ with respect to noise emission behavior. The rough approximations contained in this paper are only intended to assess the nature of noise generation.

1.2 SIGNAL-TO-NOISE RATIO (SNR)

To further investigate the matter, the ratio of

- useful signal (sound burst emitted) to
- interfering signal (broadband sound signal of pressure regulator)

will be examined.

The theory of noise emission and propagation is described comprehensively in [2]. Basically, sound waves in a gaseous medium always propagate in a directional fashion from their source. The sound pressure at a certain point is proportional to the amplitude of the sound-emitting source and decreases exponentially with the distance l to the source of sound. During its propagation, the sound wave is weakened as a result of interactions with the medium (attenuation α). Sound energy is transformed into thermal energy due to the viscosity of, and heat conduction in the medium. The attenuation is very dependent on the medium and on the signal frequency f_{sig} used. Since, in the case under investigation, a similar medium is used all the time, this relation can be simplified as follows:

$$\alpha = f(f_{sig}^{\ 2}) \tag{3}$$

If a sound wave hits an interface, its energy will be distributed into a different direction. The ratio of wavelength and dimensions of the disturbing object play a major role here. On the one hand, there will be diffraction effects, which is why “one can hear around a corner”. On

the other hand, the sound wave can be reflected. The ratio of reflector to transmitter surface area defines the resulting reflection signal loss [2]. The ratio of useful signal to interfering signal can thus be expressed as follows, taking into account attenuation, geometric distances and reflection signal losses:

$$\frac{L_{S,2}}{L_{N,2}} = \frac{L_{S,0} \cdot k_{bounce} \cdot e^{-\alpha(2\pi \cdot f) \cdot l_{path}}}{L_{N,0}(2\pi \cdot f) \cdot k_{damp} \cdot e^{-\alpha(2\pi \cdot f) \cdot l_{1,2}}} \tag{4}$$

$L_{N,0}$	noise sound level emitted by the pressure regulator
$L_{S,0}$	signal sound level emitted by the ultrasonic transducer
$L_{N,2}; L_{S,2}$	noise and signal at the receiving ultrasonic transducer
k_{bounce}	reflection signal loss; $k \leq 1$
k_{damp}	noise damping measures; $k \leq 1$
$\alpha(2\pi \cdot f)$	acoustic attenuation
$l_{path}; l_{1,2}$	distance between the ultrasonic transducer; pressure regulator and ultrasonic flow meter respectively

Equation (5) defines the ratio in equation (4) as a logarithmic measure in the unit *dB*. If a logarithmic measure is also used for attenuation α, the signal-to-noise ratio can also be expressed as follows using equations (4) and (5):

$$SNR = 20 \cdot \log\left(\frac{L_{S,2}}{L_{N,2}}\right)[dB] \tag{5}$$

$$\begin{aligned} SNR = {} & 20\log(L_{S,0}) + 20\log(k_{bounce}) - \alpha(2\pi f) \cdot l_{path} \\ & - 20\log\big(L_{N,0}(2\pi f)\big) - 20\log(k_{bounce}) + \alpha(2\pi f) \cdot l_{1,2} \end{aligned} \tag{6}$$

2 POSSIBLE SOLUTIONS

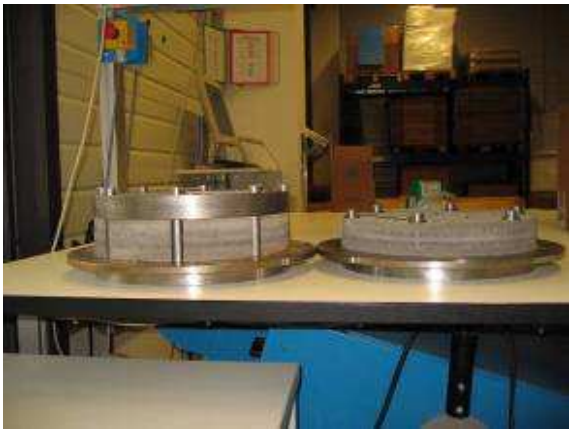
From equation (6) the measures can be derived that are necessary to optimize the SNR and thus the measured value quality of an ultrasonic gas meter. Measures can be taken to reduce the sound level of the interfering signal or to increase the sound level of the useful signal. Both solutions increase the SNR.

2.1 REDUCTION OF THE SOUND LEVEL OF THE INTERFERING SIGNAL

The interfering noise sound level depends on the type of pressure regulator used. The noise produced can be attenuated by appropriate acoustic measures. To date, engineers have attempted to solve the problem by installing complex and costly spatial pipe arrangements [3] to reduce interfering noise levels. In installations that require a flow conditioner and where the noise source is upstream the flow conditioner already provides a considerable attenuation of the noise level. For the PTB type flow conditioner, which is shown in Fig. 3a), an attenuation of 6 dB was recorded across the entire frequency range. A further improvement of the noise attenuation can be achieved if the flow conditioner is combined with metal foam

panels [4], see Fig. 3b). Because of the different thickness and structural density of the metal foam panels, an acoustically selective attenuation system can be created which is adapted to the working frequency of the ultrasonic transducers. This leads to further attenuation amounting to 3–6 dB. Because these structures are always symmetrical, this type of muffler can be used in conjunction with ultrasonic gas flow meters in bidirectional operation.

a) PTB design



b) Metal foam structure for noise attenuation [4]

Fig. 3: Flow conditioner

2.2 INCREASE THE SOUND LEVEL OF THE SIGNAL

Path Layout

The sound burst emitted from the transmitting ultrasonic sensor is attenuated in the same way as the interfering signal. The geometric distances between the ultrasonic sensors of a measurement path should therefore be as short as possible to ensure maximum useful signal levels at the receiving ultrasonic sensor. It is also obvious that each point of reflection in the measuring path normally further weakens the useful signal level.

The signal level chart in Fig. 4 may serve as an exemplary illustration. It shows the signal level passing from the transmitter to the receiver of the ultrasonic measuring path for a single-reflection arrangement in contrast to a direct arrangement. This is a theoretic consideration according to equation (3). The sensor frequency and the angle between measuring path and flow axis shall be the same in both cases. The signal emitted at the position of the transmitter (level A) is attenuated on its way to the receiver. While the direct signal still has about e.g. 70 % (level B) of its original level in this example when it arrives at the receiver, the bounced signal is further attenuated because it travels twice the distance, and because there is an additional loss at the point of reflection.

The noise level in the received signal consists of both electric noise caused by the signal amplifiers and additive noise signals collected by the receiving sensor. Modern, closed-loop amplifier electronics modules (automatic gain control AGC) allow dynamic amplification ranges of 86 dB (1 : 20,000) to be processed without any limitation through electronic noise.

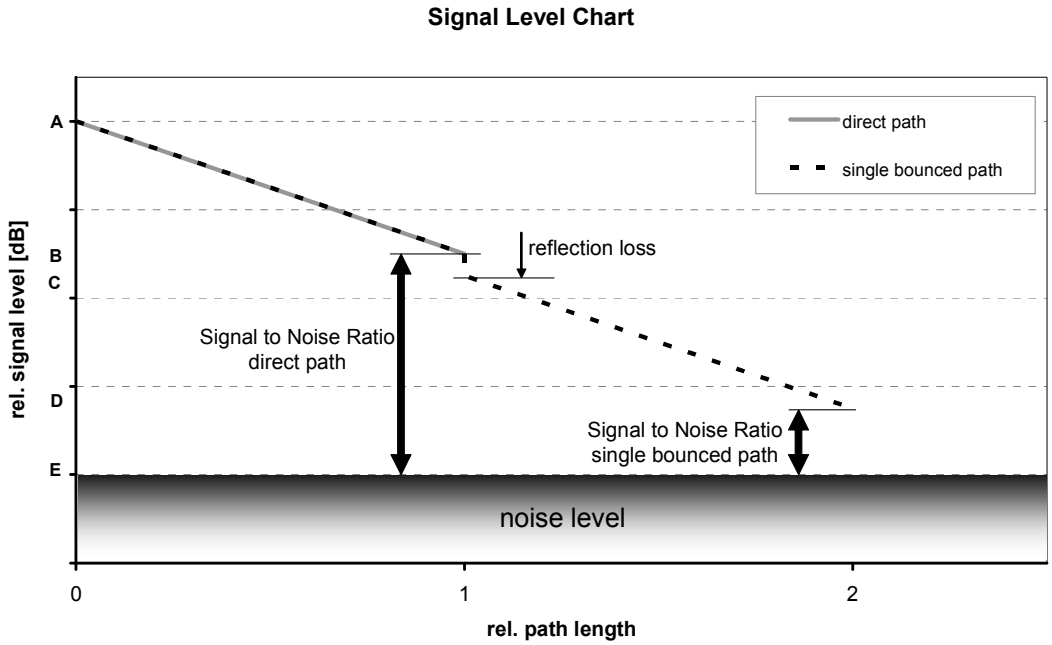


Fig. 4: Signal level chart, basic principle

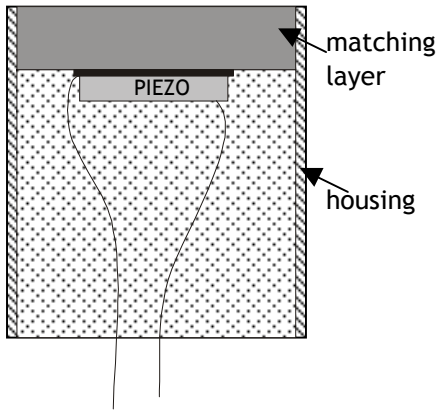
Ultrasonic Sensors

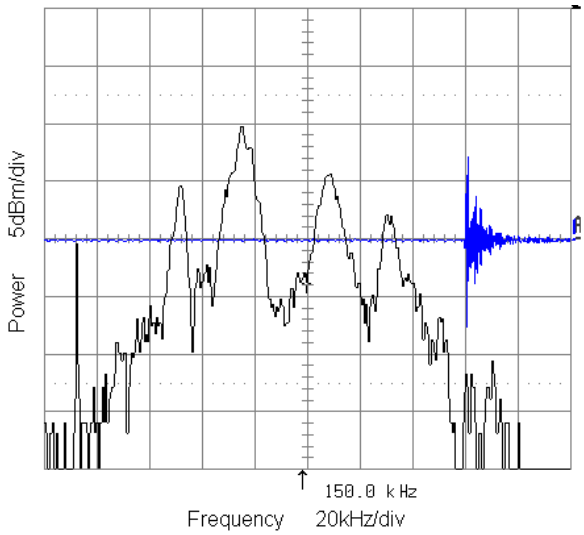
Transducers for ultrasonic gas metering are usually of a piezo-ceramic type. The piezoelectric transducer itself is basically a thin disc. Two different vibration modes can be distinguished:

- the radial vibration mode and
- the thickness vibration mode.

If an alternating voltage is applied to the electrodes of the piezo-ceramic elements, their geometry will change. This generates a mechanical oscillation with the frequency of the alternating voltage. The maximum usable electric energy is limited because of the intrinsically safe design of the sensor circuits, which is required in this specific application. Further, because of the acoustic impedance jump between the oscillating surface and the gaseous medium, only a small portion of the energy is transmitted into the medium. In order to achieve the necessary efficiency of the energy transformation and to increase the sound pressure transmitted into the gas, the mechanical oscillation amplitude is amplified by a coupled mechanical oscillator.

Due to their simple design, bimorph transducers (see Fig. 5a) are widely used. These transducers have an acoustic matching layer which adheres to the ceramic element and performs this energy transformation. This layer is made of epoxy resins using hollow glass spheres and its thickness is dependent on the working frequency of the ultrasonic sensor. The alternating electrical field excites the piezoelectric disc so that it starts oscillating radially. The radial movement is transformed into an axial movement by the adhering matching layer. Great shear forces must be transmitted by the adhesive layer. In order to protect the epoxy resin of the matching layer from the material-changing effects of gaseous components such as hydrogen sulfide, the layer may be covered by a thin metal foil. However, this leads to a reduction in the amplitude of the transmitted acoustic signal and in the reception sensitivity [5].





a) Schematic diagram

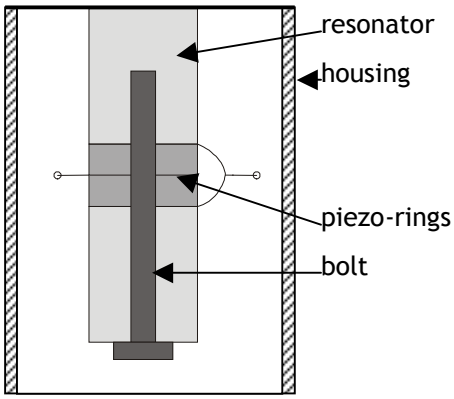
b) Acoustic spectrum of the emitted sound signal

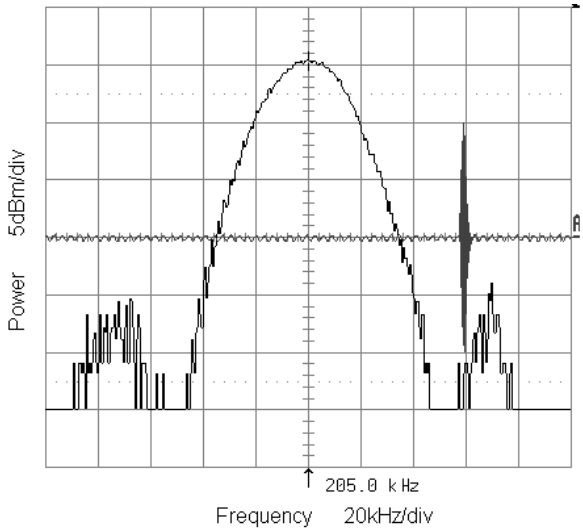
Fig. 5: Bimorph transducer

This sensor type is characterized by a sound that means different pure tones which are close to each other. This is of course also reflected in the spectrum of absolute amounts of the acoustic signal (Fig. 5b). These sensors are therefore also often referred to as broadband sensors. In order to be able to generate maximum sound energy, the sensor is run in the resonance region with the greatest amplitudes (transmitter side). On the reception side, the additional, neighboring resonance regions are problematic, where possible noise signals superimpose the received measuring signal.

The acoustic matching layer could be left out if it were possible to achieve sufficient vibration amplitudes at the sound emitting surface. This idea leads to a stacked piezoelectric transducer in the form of a resonance converter. A metallic spring-mass-system is used to increase the amplitude at resonance (see Fig. 6a). Utilizing numerical optimization of mechanical and electrical parameters it is possible to produce sensors which exhibit

- sufficient bandwidth for short signals at great amplitude, and
- a maximum acoustic efficiency.





a) Schematic diagram

b) Acoustic spectrum of the emitted sound signal

Fig. 6: Stacked ultrasonic transducer

This sensor concept is characterized by pure tone resonance mode and a well-defined working range (see Fig. 6b). There are several advantages:

- the energy is efficiently transformed into acoustic energy,
- the transducer is hermetically sealed and has a full metal housing and
- the bandwidth allows relatively short pulse signals.

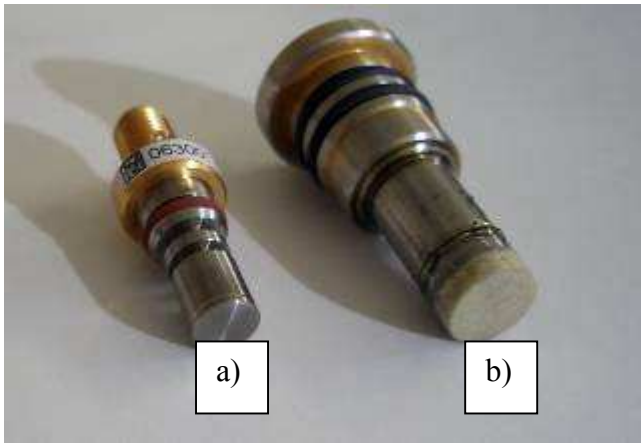


Fig. 7: Examples of the two different transducer designs
a) without and b) with the matching layer

<u>Signal Processing</u>

Generally, the SNR may be improved with the help of signal averaging methods or signal coding. However, specifically in gas flow metering applications the problem is that the signal path is modulated due to turbulence in the flowing gas. This limits the efficiency of the averaging and encoding methods. According to the signal theory, correlation methods provide optimum results in signal transit time measurements, but they cause great computational load during the digital signal processing.

If the SNR falls below a minimum threshold defined by the signal processing algorithm, faulty measurements of the signal transit time may occur. This must be prevented through adequate monitoring and analysis of the received signal quality, otherwise significant measuring errors of the gas velocity would occur.

3 NOISE-INSENSITIVE DESIGN OF ULTRASONIC GAS FLOW METERS

Based on the previous general explanations, optimization criteria applicable to ultrasonic gas flow meters near pressure regulators can easily be derived:

1. Selection of ultrasonic sensors with a working frequency which is as high as possible because
    - the noise signals emitted by the pressure regulator are significantly weakened at frequencies greater than 100 kHz;
    - the frequency-dependent attenuation of the noise signals at a given distance to the pressure regulator causes lower noise levels compared with lower frequencies.
2. Selection of ultrasonic sensors which work within a very defined frequency range which minimizes the collection of undesired noise signal components.
3. Selection of a suitable path layout in order to ensure a maximum ultrasonic burst signal level.
4. Selection of a signal processing method which
    - makes only minimum demands on the required SNR;
    - securely avoids faulty triggering and thus prevents biased measuring results.

The aforementioned requirements have been considered in the development of a noise-insensitive ultrasonic gas flow meter (FLOWSIC600) tested in this paper. The ultrasonic transducers mounted in the meter are stacked type transducers, which work according to the thickness vibration principle, and are available with working frequencies of 210 kHz and 350 kHz (Fig. 9). The path layout is the chordal direct path design with four independent paths which are configured in parallel in one plane (see Fig. 8) so as to cover the entire cross-section of the pipe. This layout also boasts the advantage that it is very insensitive to turbulent flow profiles.

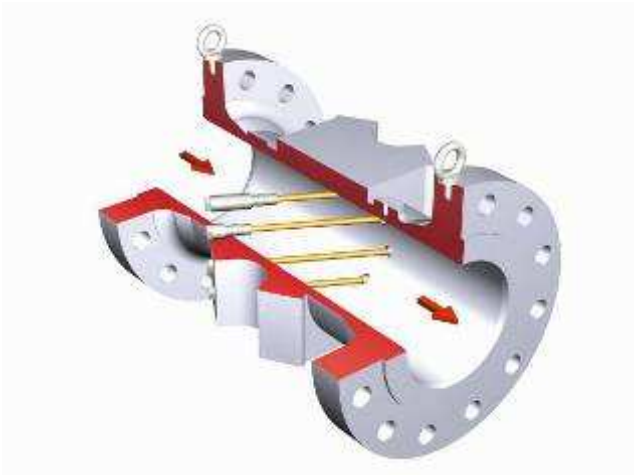


Fig. 8: Chordal 4-path layout of the FLOWSIC600

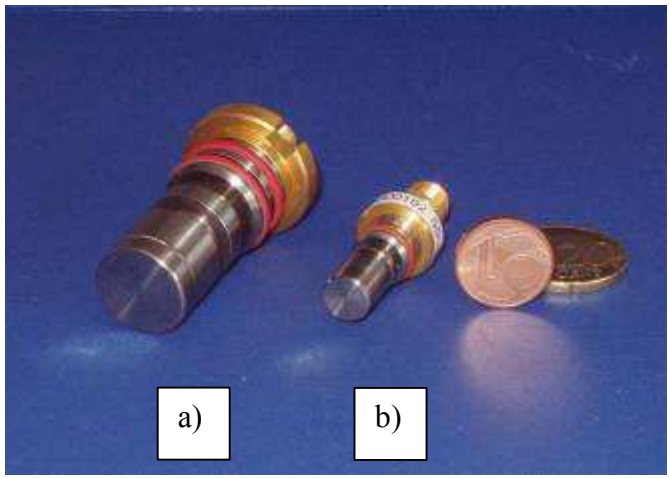
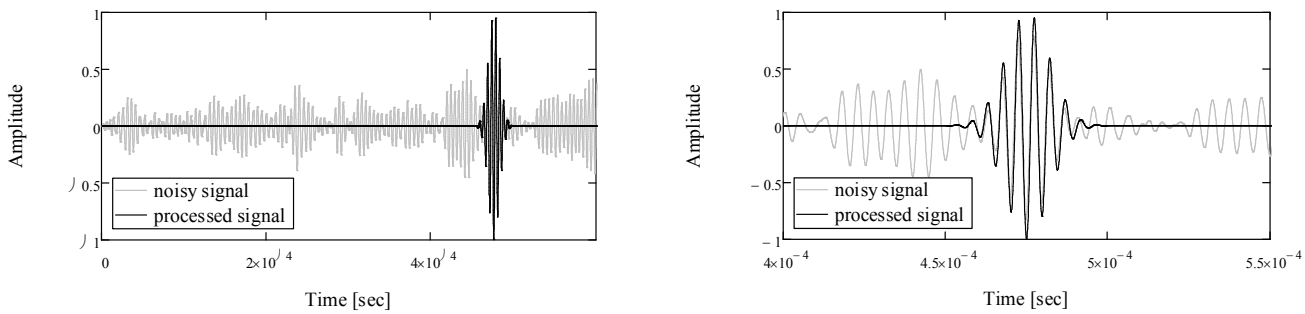


Fig. 9: High performance ultrasonic transducer, a)210 kHz and b) 350 kHz

Further robustness is achieved by the signal processing technology in the investigated ultrasonic gas flow meter. A model-based correlation method is used in combination with several plausibility criteria, so that even at a minimum SNR of just 6 dB the position of the ultrasonic signal burst is clearly detected in the received signal, see Fig. 10.



a) noisy signal at SNR = 6 dB

b) zoomed detail showing the ultrasonic burst

Fig. 10: Signal processing in the FLOWSIC 600 with the example of a noisy signal reception (SNR = 6 dB)

In the received signal, the signal processing algorithm determines the signal portion which comes closest to the signal model. Thanks to an extensive plausibility check, it can be ensured that the measured value is correct even at a performance of as low as 5 % (i.e. 95 out of 100 received signals had to be rejected). The signal is evaluated with respect to:

- the position in a time frame (not too early or too late)
- the amplitude (not too small or overloaded)
- the SNR (above the minimum required level) and
- the degree of congruence with the model signal

Only if all of these criteria are met, will a threefold transit time calculation be conducted according to different criteria in the signal. At least two of the three calculated transit times must be identical for the result to be validated.

4 RESULTS

This chapter presents results obtained from tests on the high-pressure test rig of E.ON Ruhrgas in Lintorf and at an M&R station. On the high-pressure test rig, the already proven 210 kHz sensors were directly compared with the newly developed 350 kHz sensors under near-field conditions. At an M&R station, a FLOWSIC600 fitted with 210 kHz sensors was tested under most extreme conditions for a regulator installed downstream of a flow meter.

4.1 210 KHZ SENSORS VS. 350 KHZ SENSORS TESTED AT THE LINTORF FACILITY

E.ON Ruhrgas operates a high-pressure test facility used for testing and optimizing bulk gas metering instruments. While the pigsar™ test rig [6] of E.ON Ruhrgas is used for high-precision calibration and verification of meters with natural gas under high pressure, the Lintorf facility [7] serves to

- test new measurement instruments under near-field conditions,
- investigate special factors influencing measurement behavior,
- optimize measurement instruments and other components,
- solve operational problems,
- examine new measurement technologies.

The test facility is shown in Fig. 11.

Fig. 11: Lintorf test facility

The configuration of the test facility is shown in Fig. 12. The pressure is controlled at the inlet to the test facility while the desired volume flow can be adjusted at the outlet using a flow control valve. The working standards (test rig standards) used are five parallel meter runs, four of which are orifice plate meter runs (DN 200) built according to ISO 5167 and calibrated with high accuracy. The other is a DN 150 meter run fitted with a turbine meter and an ultrasonic meter. The working standards provide reference values for the meters and

pressure regulators to be tested. A turbine flow meter (DN 300), which is permanently installed upstream of the working standards, and an ultrasonic flow meter (DN 300) permanently installed downstream of the test run are used for investigating long-term stability and for quality control purposes. The technical data are summarized in Table 1.

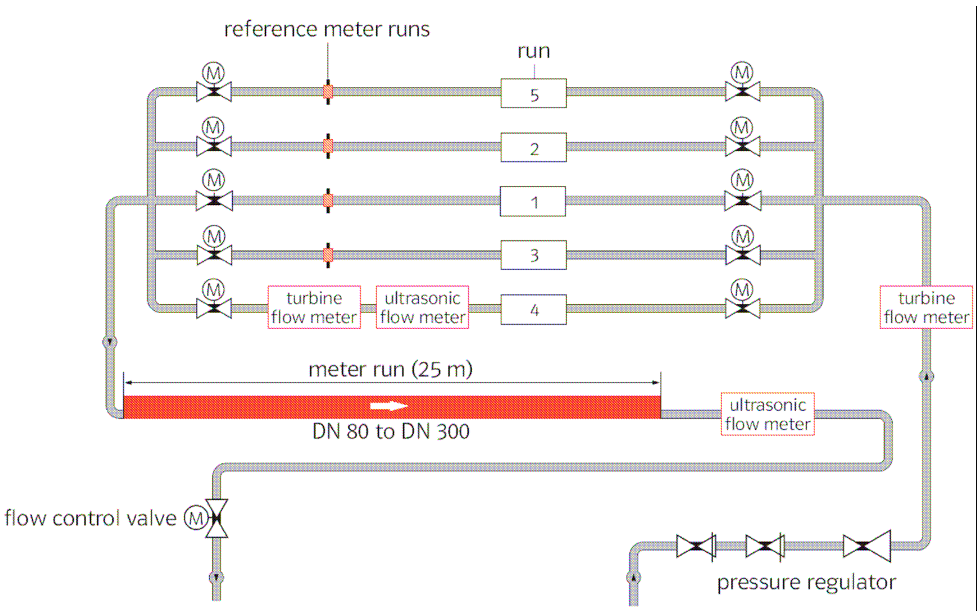


Fig. 12: Configuration of Lintorf test facility

Table 1: Technical data of Lintorf test facility

Flow range	100 m^3(N)/hr to 100,000 m^3(N)/hr
Pressure range	10 bar to 40 bar
Test gas	low-calorific natural gas (from the Netherlands)
Sizes	DN 80 to DN 300
Length of meter run	25 m
Working standards	orifice plates (calibrated individually), turbine and ultrasonic flow meters
Total uncertainty of measurement	0.3 %
Repeatability and reproducibility	0.1 %

4.2 TEST RESULTS FROM LINTORF TEST FACILITY

On the test rig, a regulator of RMG was installed upstream of the 8-inch ultrasonic meter tested. The distance between the regulator and ultrasonic meter was 15D. The regulator used was fitted with a sound damper to reduce audible sound. This regulator is normally always fitted with a sound damper. Fig. 13a) shows the regulator without sound damper and

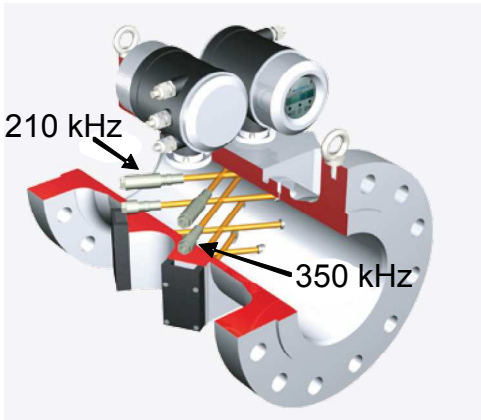
Fig. 13b) with sound damper. For test purposes, the systems were examined both with and without sound damper.

In the case of the ultrasonic meter tested (see Fig. 13c)) two independent systems were installed in one housing. The measurements were made with a four-path 210 kHz sensor system as well as with a four-path 350 kHz sensor system. The tests with the 350 kHz system were completely independent of the 210 kHz system tests to allow direct comparison of the two systems. Basically, two systems are installed in one housing to ensure identical test conditions. The path configurations of the two systems are presented in Fig. 13d).

a) Regulator without sound damper

b) Regulator with sound damper

c) Ultrasonic meter tested



d) 210 kHz and 350 kHz systems

Fig. 13: Test set-up at Lintorf facility

Fig. 14 describes the basic findings for the 210 kHz and 350 kHz systems (both systems were not calibrated before testing) with a non-disturbed upstream straight length of 66D. The regulator was not installed in the test run in this case. The measurement deviation is very low for system 1. The deviation for system 2 is approx. -0.5% and remains virtually constant over the entire flow range.

It is known from previous tests that a regulator installed upstream of an ultrasonic meter affects the meter more strongly than a downstream regulator. The tests described in this paper only focused on the less favorable case where the regulator is installed at a distance of 15D upstream of the meter. The effects on the ultrasonic meter were examined for different pressure differentials across the regulator, absolute pressures and flow rates.

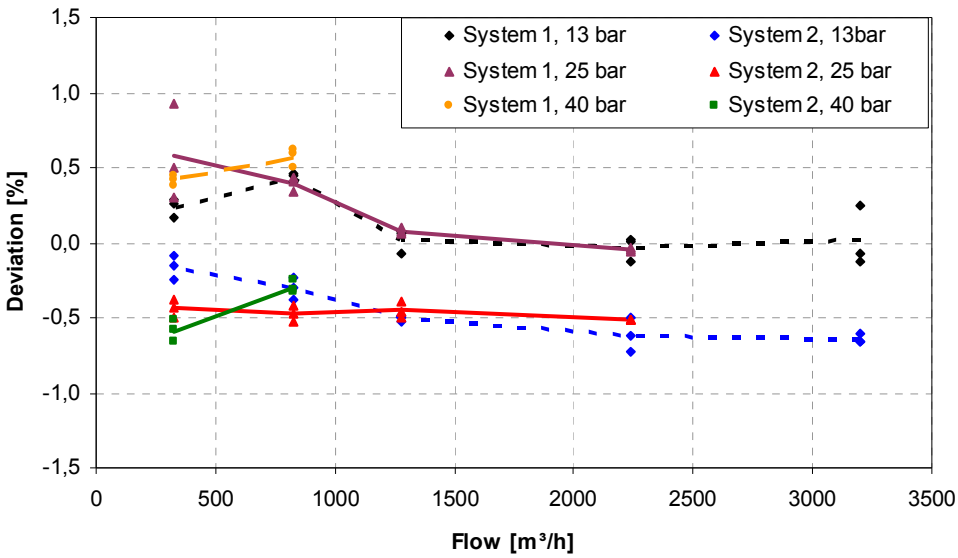
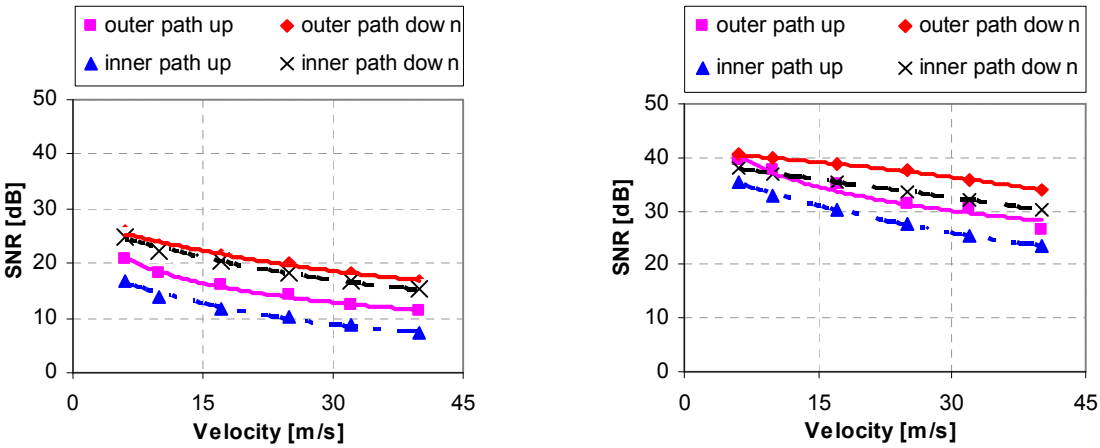


Fig. 14: Basic findings with 60D undisturbed upstream straight length (system 1: 210 kHz sensors, system 2: 350 kHz sensors)

In a first step, the regulator was installed together with the associated sound damper. The interfering effects can be very well evaluated based on the SNR. Fig. 15 directly compares the SNRs of the two systems for a pressure reduction from 40 bar to 10 bar across the regulator. It is obvious that the 350 kHz sensors are significantly less sensitive to the interfering sound emitted by the regulator than the 210 kHz sensors. With this high decrease in pressure and the extreme flow velocities (> 25 m/s), the conventional sensor system (210 kHz) is already at its stability limits. The meter did not fail but operation of the configuration tested in a situation where the pressure loss is so extreme should be limited to maximum flow velocities of 20 .. 25 m/s.



a) 210 kHz system b) 350 kHz system

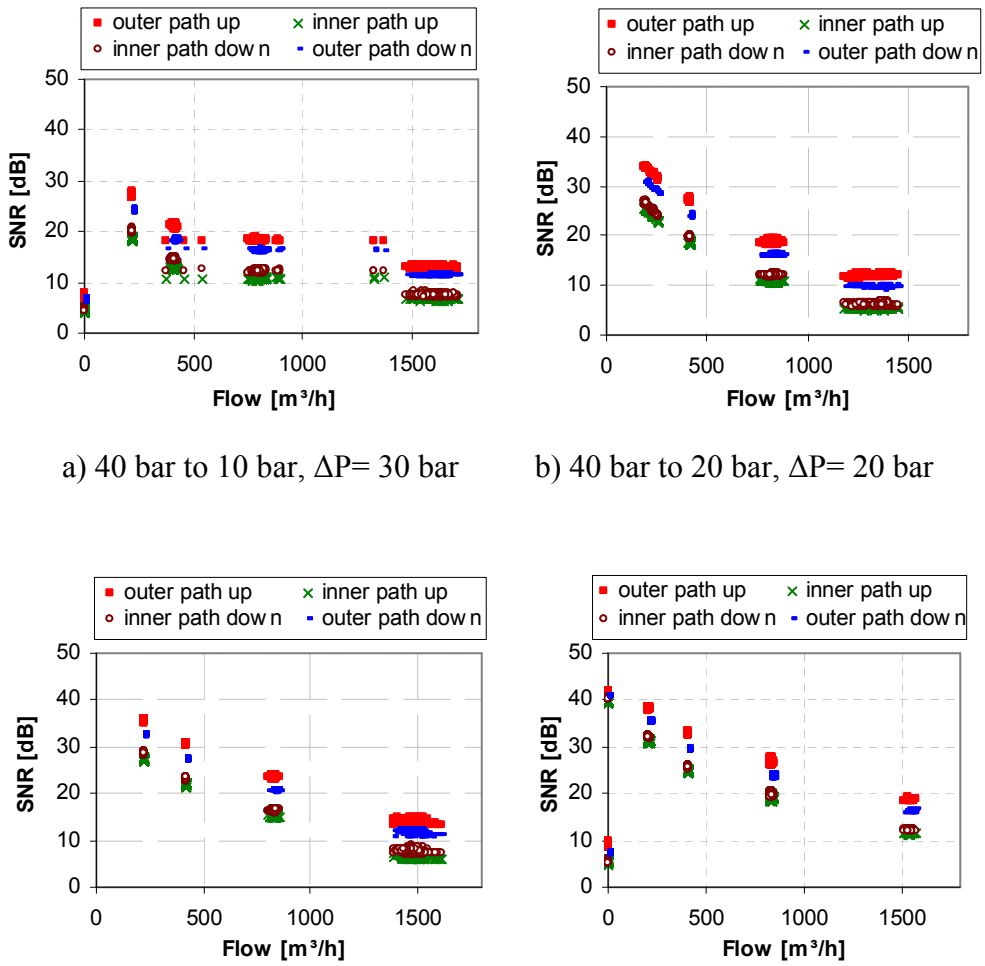
Fig. 15: SNR as a function of velocity for a pressure reduction from 40 bar to 10 bar across a regulator with sound damper

While they are influenced by the noise emitted by the regulator, the 350 kHz sensor signals are still sufficiently strong with respect to the SNR. It would be possible to use the meter for this extreme pressure reduction and the high flow rates in the configuration tested without

further measures such as sound attenuation being required. The measurement error was within ± 0.5 % for both systems. As the 350 kHz sensors were prototypes, the tests focused on sensitivity to interfering noise rather than on measurement accuracy at this stage of development.

The results plotted in Fig. 15 were obtained for the greatest pressure differential across the regulator that was feasible on the test rig (10 bar to 40 bar test pressure). No further tests were made for this configuration as the results obtained were good and the 350 kHz sensor system proved robust to interfering noise and was sufficiently strong under most extreme conditions.

The following figure presents results for the regulator with the sound damper removed. It should be noted in this context that the regulator is normally always used with a sound damper. The tests were made to determine the limits of the 350 kHz sensors. The system with the 210 kHz sensors already failed in these tests at low flow rates and pressure differentials across the regulator from Δp 10 bar. With the 350 kHz system, the meter did not fail until higher flow rates were set. Some results are shown in the following as examples.



a) 40 bar to 10 bar, ΔP= 30 bar

b) 40 bar to 20 bar, ΔP= 20 bar

c) 40 bar to 25 bar, ΔP= 15 bar

d) 25 bar to 10 bar, ΔP= 15 bar

Fig. 16: SNR over flow for 350 kHz system at different pressure differentials across the regulator

It would not be possible to use the meter in this configuration without sound damper for the operating parameters tested here. It is also obvious that the 350 kHz sensors are a significant improvement compared to the 210 kHz sensors. Fig. 16 shows how the ultrasonic meter is influenced by flow rate, pressure differential and absolute pressure. The SNR falls, though with a decreasing gradient, as flow rate increases. It is also clear from Fig. 16a), Fig. 16b) and Fig. 16c) that the influencing effect is only slightly stronger for higher pressure differentials. Fig. 16c) and Fig. 16d) plot the results for a constant pressure differential of 15 bar and different absolute pressures. The influencing effect is stronger in this case for higher pressures (40 bar to 25 bar) than for lower pressures (25 bar to 10 bar) at the same pressure differential of ΔP=15 bar. Testing at low absolute pressures and extrapolation of the results to higher pressures is considered critical.

4.3 USE OF A FLOWSIC600 IN AN M&R STATION

In an M&R station, a FLOWSIC600 ultrasonic gas meter with standard sensors (210 kHz) was installed near a regulator. The risk was that the pressure regulator would produce noise interfering with the ultrasonic meter because of the very high flow velocities and pressure differentials across the regulator. To investigate the matter, some tests were made in a station. The meter run configuration is shown in Fig. 17.

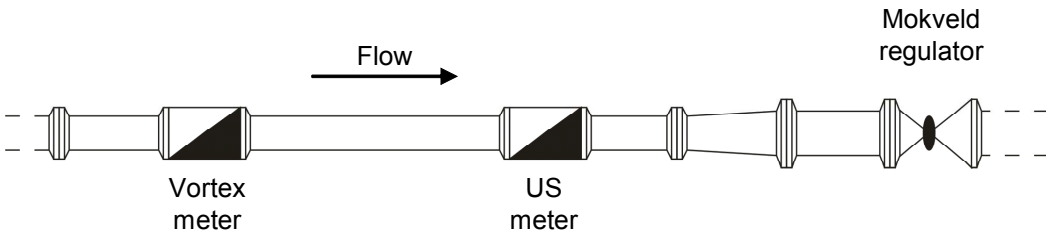


Fig. 17: Meter run configuration

The ultrasonic meter used had a nominal width of 16-inch and the downstream regulator a nominal width of 20-inch. A flow rate of up to 500,000 m³(n)/h may be set for the meter run at a pressure of 50 bar to 85 bar and a pressure reduction across the regulator of 0 bar to 30 bar.

Several flow rates and pressure differentials across the regulator were set for the tests. The deviation between the vortex meter and the ultrasonic meter was measured. The diagnosis parameters of the ultrasonic meter were also recorded to be able to better analyse the influencing effect of the regulator on the ultrasonic meter. In this context, the parameters

- relative number of faulty signals (performance) and
- calculated signal-to-noise ratio (SNR)

proved very useful for determining and assessing regulator influence.

An acoustic broadband pressure sensor was installed between the regulator and the ultrasonic meter to measure the noise in the gas line. Fig. 18 plots the frequency spectrum of the noise measured. The graph shows the results for higher pressure differentials from 23 bar to 30 bar and for various flow velocities. It can be seen from the graph that flow velocity has a significant effect on the noise level produced by the regulator. In the frequency range of the 210 kHz ultrasonic meter sensors the interfering noise measured is between 128 dB and

136 dB. Fig. 19 presents the SNRs obtained from the tests made. The log files were analyzed for each measurement point.

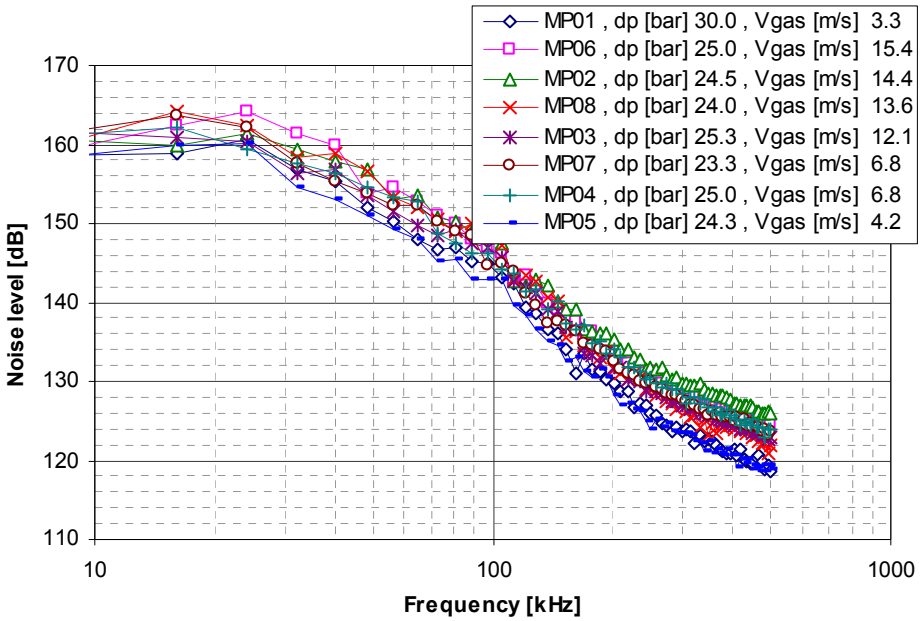


Fig. 18: Noise Level

From the diagnosis data, the lowest SNR of the four paths was selected and presented. Average meter performance was 98% .. 100% for all flow rates and pressure differentials tested.

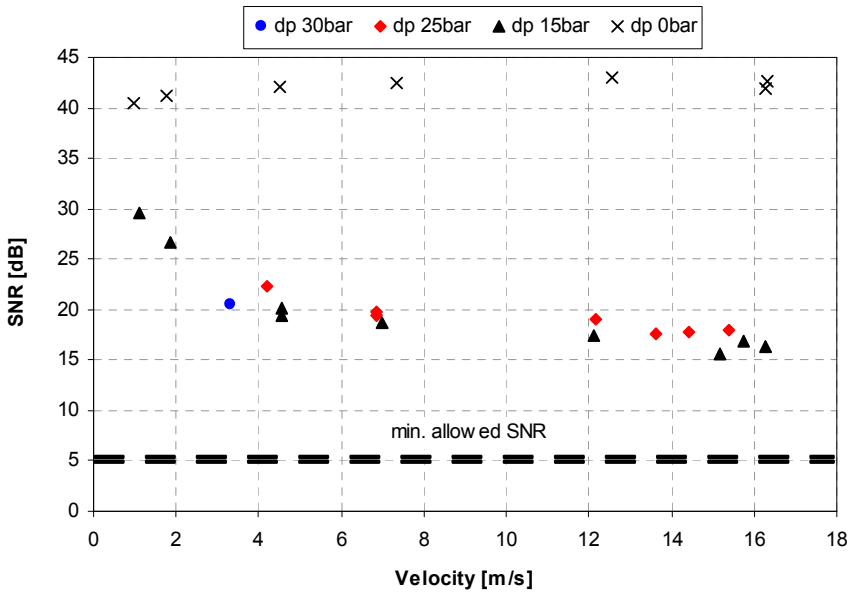


Fig. 19: SNR of ultrasonic meter

As can be seen from Fig. 19, the SNR is above 40 dB for a 0 bar pressure differential across the regulator. While the meter is influenced by pressure differentials across the regulator, the

distance to the critical 5 dB level is still sufficient to ensure reliable measurements even for the extreme conditions tested here. It is also obvious that the effect of flow velocity at constant pressure differentials on the SNR and thus on meter performance increases, though with a decreasing curve gradient, as velocity increases.

Fig. 20 shows the deviation between the vortex meter and ultrasonic meter. The ultrasonic meter was not high pressure-tested before the tests. The results are therefore very satisfactory. With the positive results obtained, the ultrasonic meter was calibrated on the pigsar™ and used in the M&R station.

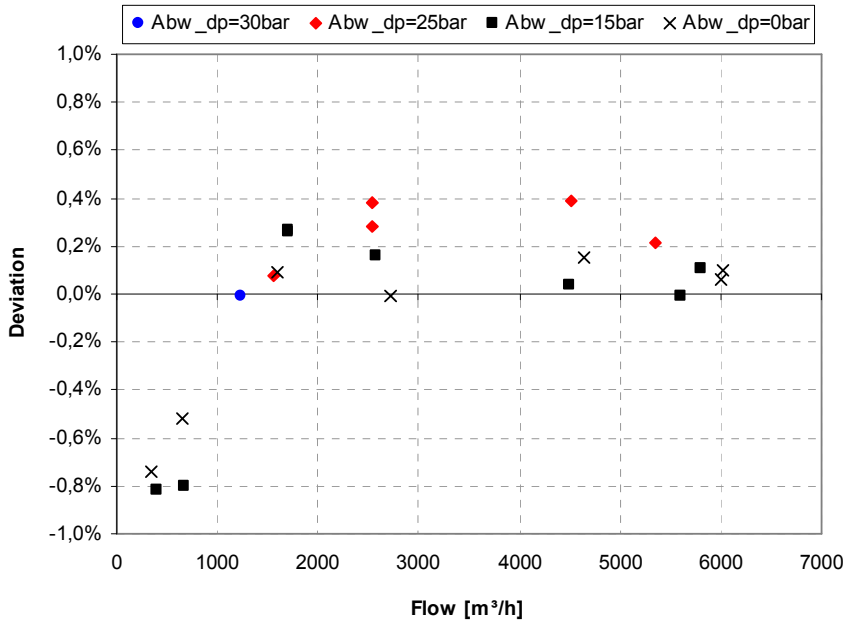


Fig. 20: Deviation between ultrasonic and vortex meters

5 CONCLUSION AND OUTLOOK

This paper presents the relationship between interfering noise emitted by a regulator and an ultrasonic meter. Theoretic considerations describe how an ultrasonic meter is influenced by interfering noise. Aside from theoretic considerations, the paper includes results from both tests in the field and on a test rig. The results define the limits of the application and show that good results were obtained from the field test even under most extreme conditions.

Different regulators have different characteristics with respect to interfering noise emission, in particular in the ultrasonic range (100 kHz .. 400 kHz of interest here) so prior to system design the following should be considered

- The interfering effects of a regulator and potential noise should be determined.
- Different regulators / control valves or the same valves with different trims will generate different noise spectrums. The results contained in this paper only apply to the regulator examined here and the FLOWSIC600.
- The tests did not examine in how far nominal pipe width is important but from theory it can be expected.

The tests focused on the more critical application where the regulator is installed upstream of the meter. Under these conditions, the meter reached its limits. But, compared to the proven 210 kHz sensors, the newly developed 350 kHz sensors again considerably improved the meter's robustness to interfering noise in the pipelines and good results were obtained under the extreme conditions tested. The 350 kHz system did not reach its limits until it was installed and tested with the modified regulator. For this the built-in sound damper was removed. But this situation is not to be expected for practical operations as the regulator is normally always used in standard configuration. The tests show that the FLOWIC600 may be used in installation configurations that have not been possible using traditional ultrasonic technology.

The 350 kHz sensors will be optimized further and again tested on the Lintorf test rig. The solution with the 350 kHz sensors is an attractive alternative to the use of noise-reducing devices such as sound dampers, flow straighteners or complex piping. Development work will therefore be continued.

6 REFERENCES

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