TEST RESULTS OF A NEW DESIGN ULTRASONIC GAS FLOW METER

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Abstract

These days, ultrasonic gas flow meters are readily accepted for custody transfer measurement. Successful application of these kind of meters in turn drives the technology, resulting in new design concepts being implemented. As part of various new designs aiming to improve meter performance and the economics of fabrication, Instromet have developed a new meter featuring – among other characteristics – a reduced bore. In addition, a special variant was designed for wet gas measurement.

In order to verify the performance of the new design concepts, Instromet teamed up with Ruhrgas AG for a series of perturbation tests with distorted flow profiles. These tests were carried out at the "HDV Lintorf" test facility in Germany, owned by Ruhrgas. This paper discusses the results of these tests and compares them to results obtained with the conventional design of this meter.

In addition, there is a short description of the techniques used in high-pressure gas metering at Ruhrgas along with an overview of present and possible future needs for ultrasonic gas meters in large high-pressure networks.

Introduction

Ruhrgas AG is Germany's leading gas merchant company. As a private-sector enterprise, it provides secure, economic gas supplies from foreign (83%) and domestic (17%) sources based on long-term purchase contracts. Customers include foreign and German gas merchant companies, local distribution companies, power stations and industry. Last year's total gas sendout was 50.6 billion m^3. The company's supply infrastructure comprises more than 10,700 km of pipeline (including pipelines owned by joint venture companies), 26 compressor stations and numerous company-owned and rented underground storage facilities with a total working gas volume of around 4.8 billion m^3. Together with third-party pipelines, Ruhrgas monitors a network totalling some 12,000 km.

These figures indicate the importance of gas metering for Ruhrgas. Together with the services provided to other companies, Ruhrgas monitors more than 2,000 gas metering stations for their metrological performance. At larger metering stations there are often two independent meters installed in series. The philosophy behind this 'back-up metering' is to have two meters employing different measuring principles to detect long-term changes of the main meter. So far, back-up meters have been mostly vortex meters, but more and more ultrasonic meters are now being used at new stations and in station retrofits. Back-up metering is the most likely installation case for USM in the Ruhrgas network. One interesting example of a different philosophy is Gasunie's delivering station "Oude Statenzijl" on the Dutch/German border, which is used for supplies to Ruhrgas. This station will be equipped with several meter runs each with two USM installed in series to allow bi-directional measurements. Since the same measuring principle is employed in this special case, extensive experimental investigations were performed at the high-pressure test facility in Westerbork to ensure that possible influences caused by the upstream piping are kept to a minimum.

Generally, all meter types eligible for installation in the Ruhrgas network – i.e. meters which either have PTB approval for fiscal metering or are about to obtain approval – are tested at Ruhrgas for internal approval. The investigations focus mainly on meter sensitivity to upstream flow perturbations. The meters are tested with high-pressure natural gas downstream of bend configurations or regulators. The criterion for Ruhrgas approval is essentially the criterion for turbine meters according to ISO 9951, which requires the additional errors due to flow perturbation to be within 1/3 of the maximum permissible error (i.e. within +/-0.66% below 20% of meter capacity and +/-0.33% above 20% of meter capacity). These tests are performed in close co-operation with the manufacturers.

High-pressure test facility "HDV Lintorf"

Apart from the well known *pigsar* test facility, which has been the German national standard for a cubic metre of high-pressure natural gas since October 1999, Ruhrgas operates a second high-pressure test facility known as "HDV Lintorf". This facility is used for testing gas meters, valves and regulators at flow rates between 100m^3/hr and 8,000 m^3/h at pressures ranging from 10bar to 45bar using natural gas (with a maximum volume flow rate at reference conditions of approx. 100,000 m^3/hr). The Lintorf facility is designed to simulate ideal flow conditions as well as flow conditions which are typical of fiscal metering stations such as multiple-bend configurations. The main activities concern R&D projects for Ruhrgas, internal meter type approvals and services for other companies.

The test facility (Figure 1) is arranged in a bypass of a pressure regulating station. The pressure and flow rates are adjusted using a regulator and a flow control valve. The gas first enters the 5 parallel reference meter runs which are equipped with orifice plates. A turbine meter is installed upstream of the orifice meter runs for comparison purposes. For the tests presented here, a second turbine meter was installed downstream of the test section.

The orifice meters are individually calibrated at the Delft Hydraulics Laboratory water test facility. Thus for each meter run and each orifice plate, individual calibration curves for the discharge coefficient, C_d, are used, giving a maximum uncertainty for C_d of $e_{Cd} = \pm 0.22\%$ (2σ). The combined measurement uncertainty of the test meter installed in the test section and the reference meter, i.e. the uncertainty of the meter deviation or meter error, strongly depends on the differential pressure and the number of orifice lines in operation. It is between $e_{Qt} = \pm 0.26\%$ and ±0.4% (2σ, the latter value represents the rare situation in which one metering line is in operation and flow rates are low).

As part of the recent GERG intercomparison campaign [1] of the European high-pressure test facilities, it was shown that the repeatability and reproducibility of the HDV Lintorf facility are as good as those of the other European facilities. The metering differences between Lintorf and the other test rigs are well within the above-mentioned metering uncertainties.

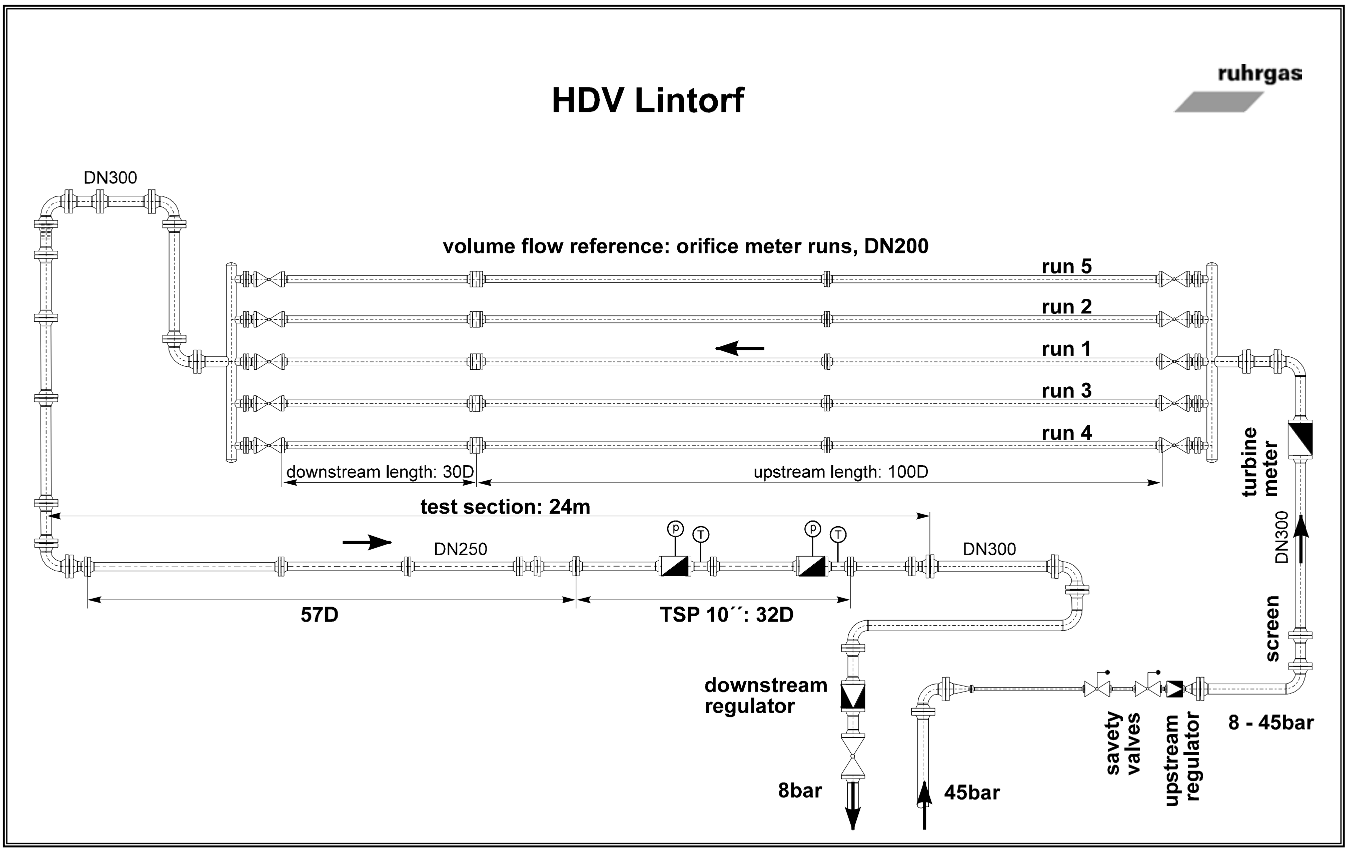


Figure 1: The HDV Lintorf high-pressure test facility

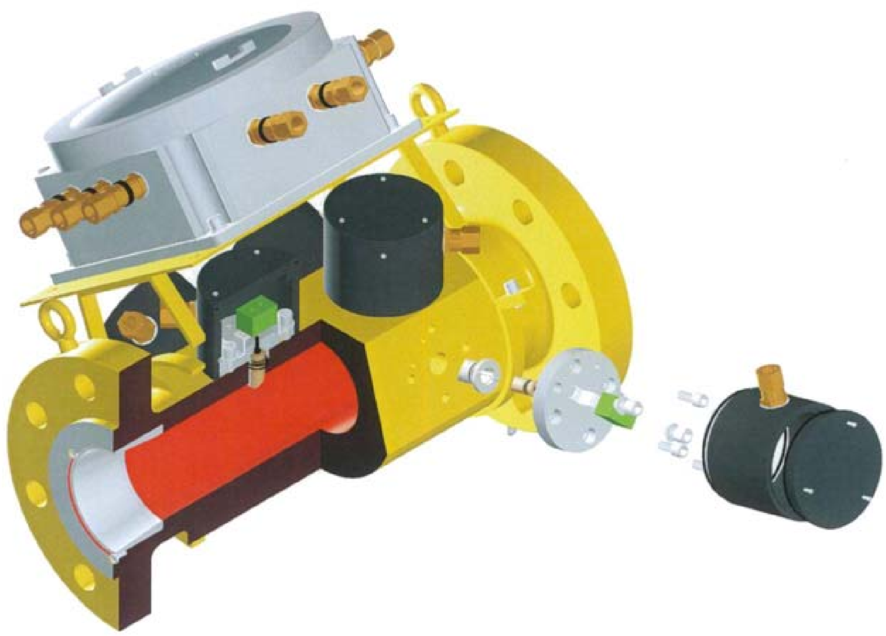
Test Meter

The meter under investigation was a 8’’ Instromet Q.Sonic-3 Compact. This meter is a relatively new variant of the existing Instromet Q.Sonic-3 with the following two major improvements:

- Modified meter body: no welded transducer pockets, newly designed transducers are installed in special casings directly on the meter body; see Figure 2. The operating frequency of the transducers has been changed to 200 kHz.
- The inner diameter of the meter has been reduced in order to minimise possible influences of perturbed flow profiles through the acceleration of the flow within the meter; see Figure 2. A contraction and expansion at the inlet and the outlet of the meter ensure smooth inward and outward flow. (Figure 2 also shows the configuration of the three paths: The two double-reflection paths, also called “swirl-paths”, cover the near wall region of the flow profile, the single bouncing path leads through the pipe center line).

A more detailed description of the new meter and first test results was given in [5].

The first improvement should make manufacturing of the meter easier and thus to make the meter less costly.



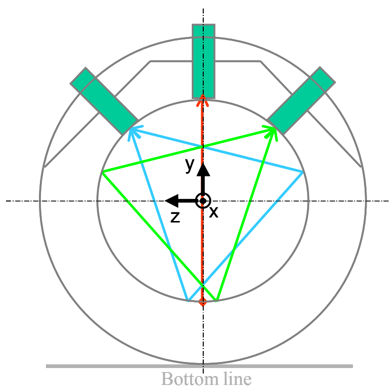


Figure 2: New design of the Instromet Q.Sonic-3 USM with its path configuration, co-ordinate system as in Figures 3, 4

The second improvement should make the meter less sensitive to flow perturbations. This was demonstrated by CFD calculations. The flow downstream of a single 90° bend was simulated using the CFD software Fluent. 10D downstream of this perturbation, the deviation in the new Q.Sonic-3 design was lower than in the old design; see Figure 3. One can see that the dent, which is typical of 90° perturbations, becomes smaller in the accelerated flow. Moreover, the transverse velocity components, i.e. the secondary flow, become smaller. This effect indeed has a positive effect on the metering behaviour, as will be shown below.

Instromet are planning to make further improvements to this meter for wet gas metering. These will include a slight change to the path configuration in order to avoid effects of liquid deposits on the path reflections. However, it is unlikely that these changes will in any way influence the conclusions resulting from the tests described below.

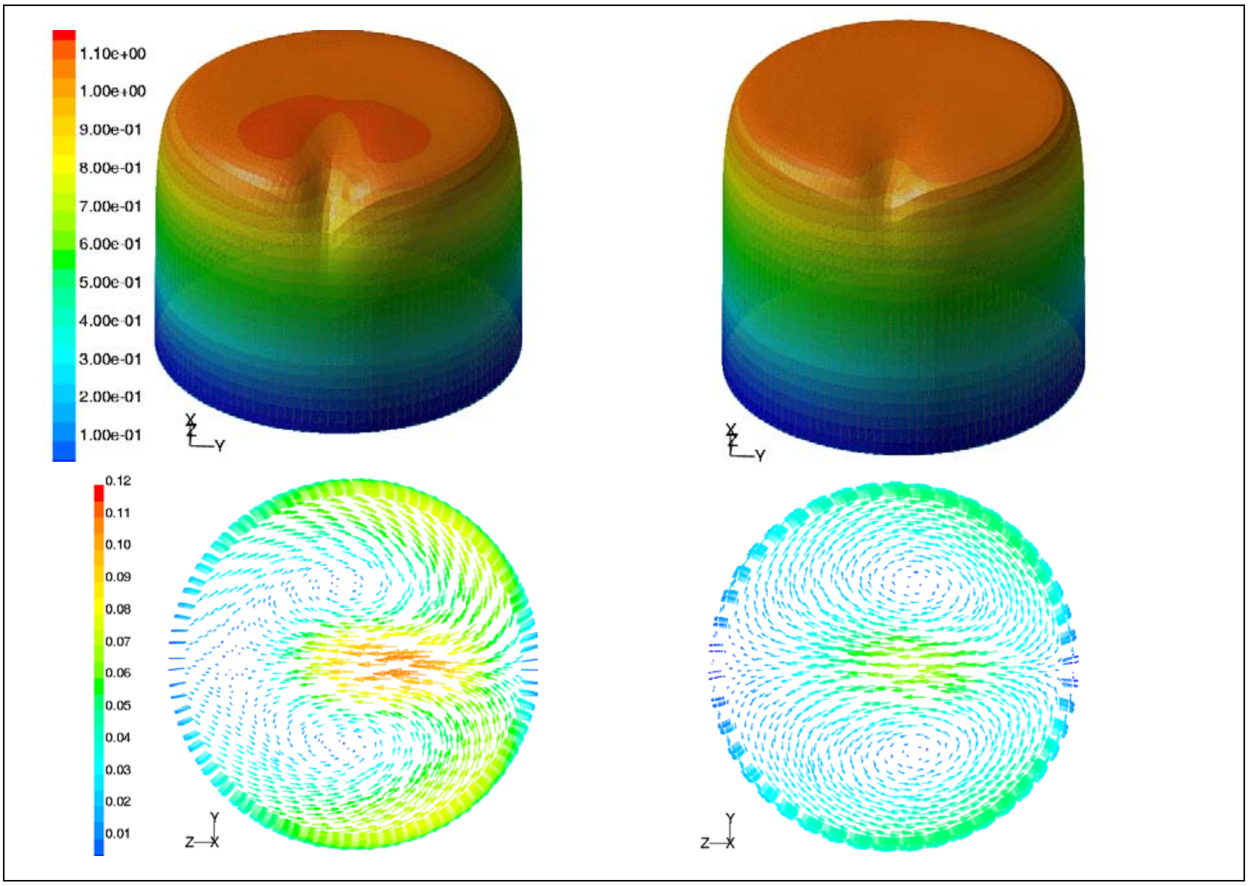


Figure 3: Effect of flow acceleration inside the meter on the perturbed flow profile downstream of a 90° bend as shown in Figure 4, left side, calculated via CFD simulations with Fluent; left: without contraction; right: with contraction. Top graphs: profiles in main flow direction; bottom graphs: transverse velocity components looking against the flow. Co-ordinate system according to Figure 4.

Test Programme

The meter was tested under the following conditions:

1. Basic test (25D undisturbed upstream length) on *pigsar* at 17 and 30bar. The meter was calibrated with respect to the 17bar results of *pigsar*.
2. Basic test (43D undisturbed upstream length) on Lintorf at 10, 25 and 40bar,
3. Test 11D, 15D and 20D downstream of a single 90° bend configuration,
4. Test 11D and 20D downstream of a double-bend-out-of-plane configuration.

The configurations are shown in Figure 4. Figure 5 shows the perturbation test configuration involving the double bend out of plane.

Most perturbation tests were performed at 10bar, but some were also performed at 40bar to investigate the Reynolds number influence. The radius of curvature of the bends used was 1.5D.

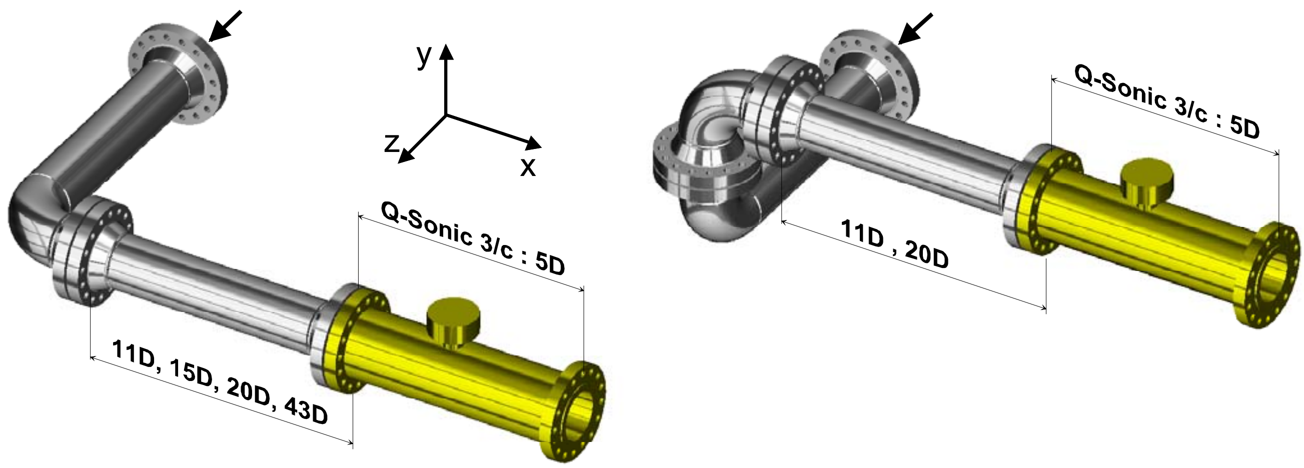


Figure 4: Test configuration; Left: Basic tests and single 90°-bend tests;
Right: double-bend-out-of-plane configuration

The tests at 11D were also performed with the meter turned 90°, 180° and 270° around its axis in order to investigate the influence of the meter's azimuthal position with respect to the perturbation.

After meter calibration on *pigsar*, the parameters of the USM remained constant. Log files were taken for all cases. The pulse output of the meter was used for all tests.

Although the test meter has an maximum flow capacity of 2,500m³/hr, which corresponds to a mean gas velocity of 27m/s, the meter was treated as a G1000 during the tests with a maximum capacity of 1600m³/hr, which corresponds a to mean gas velocity of 15m/s at the meter inlet. The reason for this was that the maximum flow velocity in Ruhrgas facilities is in the order of 15m/s. Secondly, as already indicated above, the most common installation position of this meter is the back-up position upstream of a gas turbine meter, which has the aforementioned maximum flow rate.

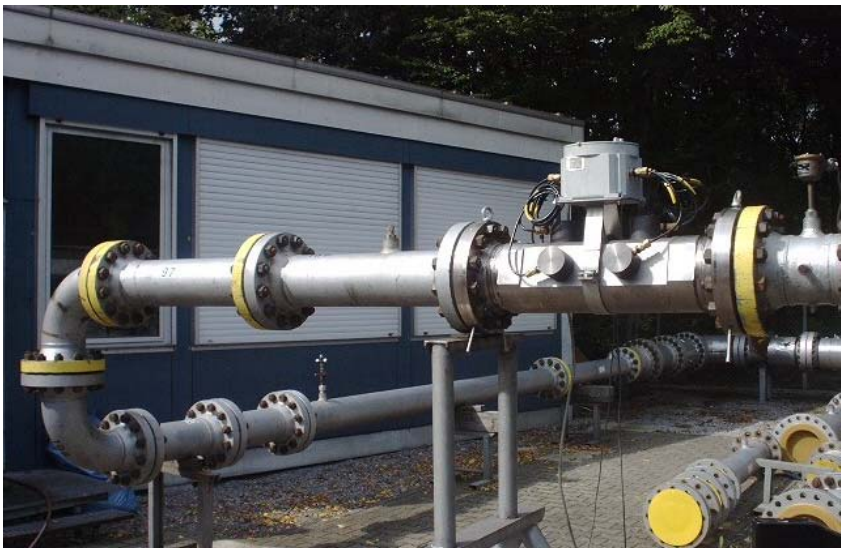


Figure 5: Test set-up for the double-bend-out-of-plane configuration

Results

Figures 6 to 10 show most of the test results. In these graphs, the term 'deviation' describes the relative difference between the test meter indication and the facility's reference meter indications. The reference value for the abscissa is Q_{max} = 2,500m³/hr.

Tests under basic conditions

Figures 6 and 7 show the meter deviations. The results can be summarised as follows:

- The basic tests for 10 and 25bar were performed at the beginning and at the end of the test programme with a time period of about 1 month in between. Figure 6 shows the good agreement between both curves, i.e. the meter remained stable during the tests.
- The deviations between the tests on *pigsar* and at Lintorf in the order of magnitude of 0.2% are well within the measurement uncertainties. This value is only slightly different to the usual test rig difference obtained in numerous intercomparisons between *pigsar* and Lintorf. This small difference is due to the different installation conditions at both facilities: At *pigsar* a tube bundle flow straightener was installed 25D upstream of the meter.
- Figure 7 shows the results for different operating pressures. The pressure influence becomes larger at lower flow rates. The mean difference between the maximum and minimum pressure is in the order of 0.3%. The influence of the operating pressure is actually lower due to the fact that normally the meter is calibrated and parameterised on the calibration facility for the scheduled pressure range. In this case this was done on *pigsar* for pressures around 10bar. Setting the parameters according to the high pressure would have led to lower differences between the 10bar and the 40bar error curve.

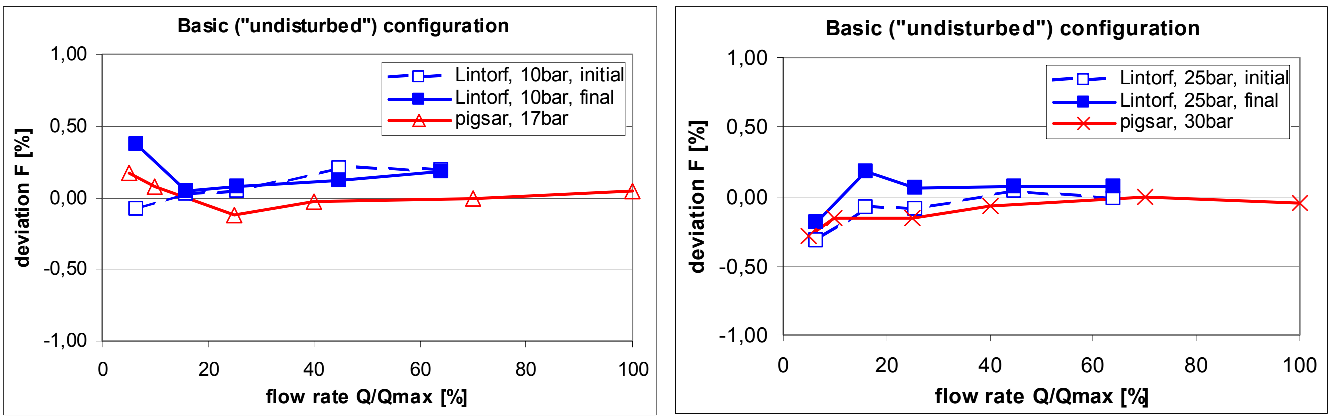


Figure 6: Deviation curves for the configuration with more than 40D undisturbed pipe flow upstream of the meter: Lintorf vs. *pigsar* results and initial vs. final curves at Lintorf.

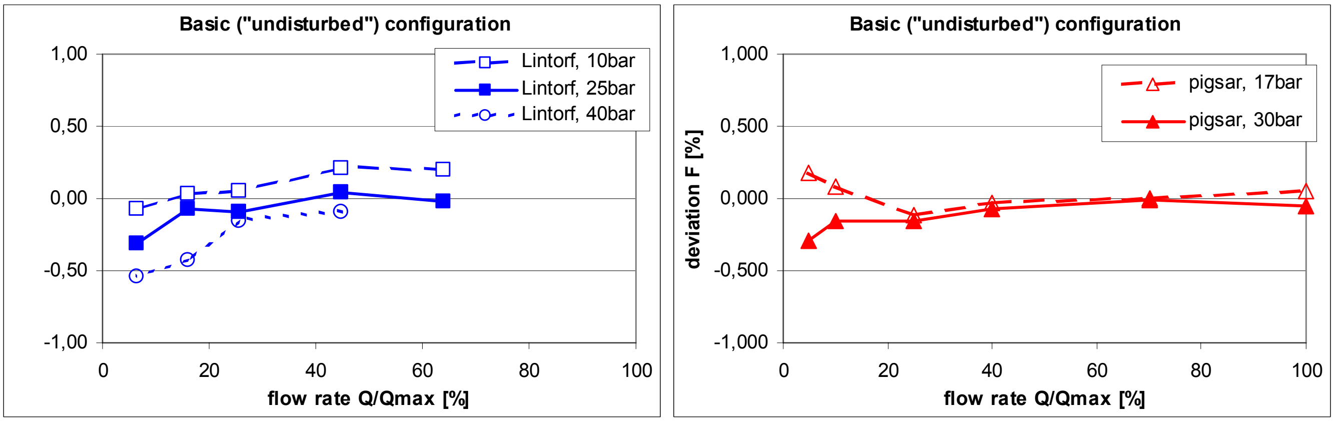


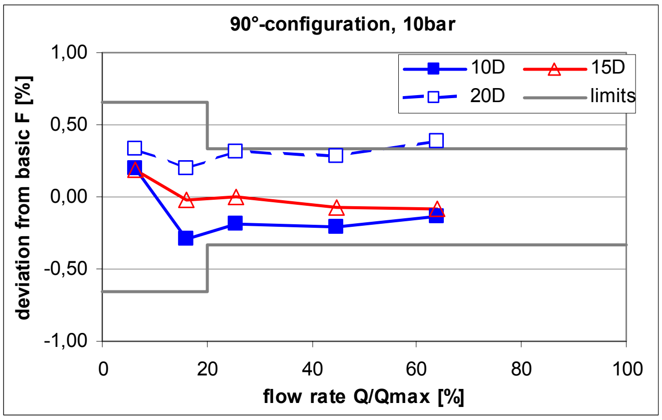
Figure 7: Deviation curves for the configuration with more than 40D undisturbed pipe flow upstream of the meter at different operating pressures

Perturbation tests

Figures 8 to 10 show the differences between the meter deviations obtained under basic conditions and those obtained under perturbed conditions ("deviation from basic = $F_{perturbed}$ - F_{basic}"). The main results are:

- Most test points are within the +/-1/3 limits of the maximum permissible error. For the slightly higher deviations shown in Figure 8, further investigations are underway to obtain a complete picture.
- The influence of the double-bend-out-of-plane perturbation is negligible; see Figure 9. Due to the two swirl paths of the meter, the corrections for the swirl perturbations work just as well as for the Q.Sonic-5 meter, which has two single reflecting paths more.
- Figure 10 shows the results for the meter positioned 10D downstream of the perturbations, and turned around its axis by 90°, 180° and 270° (clockwise against direction of flow, with the piping as shown in Figure 4). The left graph shows a significant shift of about -0.5% for the 90° rotation of the meter with respect to the undisturbed condition. In this case the single bouncing path leads exactly between the two vorticies where the secondary flow is very large; see Figures 2 and 3. Moreover, the transducers of the single-bouncing paths are close to the main flow perturbation, the "dent" in the profile. This configuration is a very rare installation condition, and this effect can easily be avoided by positioning the meter with an offset angle.
- For the double-bend-out-of-plane perturbation (right graph in Figure 10) all installation conditions lead to error shifts that are within the limits.

The CFD-results presented in [3] already indicated, that the influence of the azimuthal position of USM on the meter reading is not negligible and might in certain positions be larger for the single 90°-bend perturbation than for the double-bend-out-of-plane perturbation.



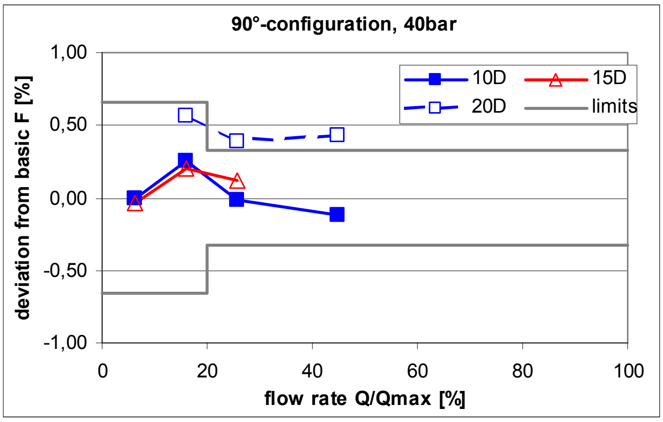
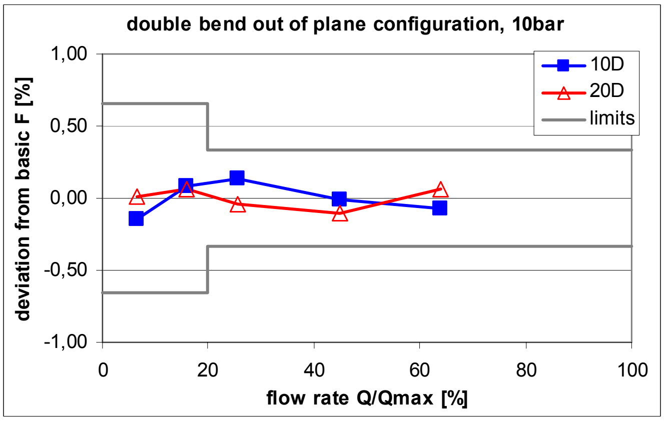


Figure 8: Deviations from undisturbed conditions for single 90° bend configurations for 10bar and 40bar



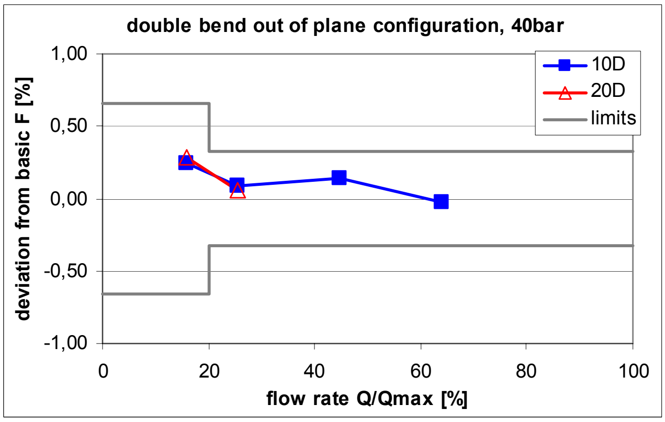
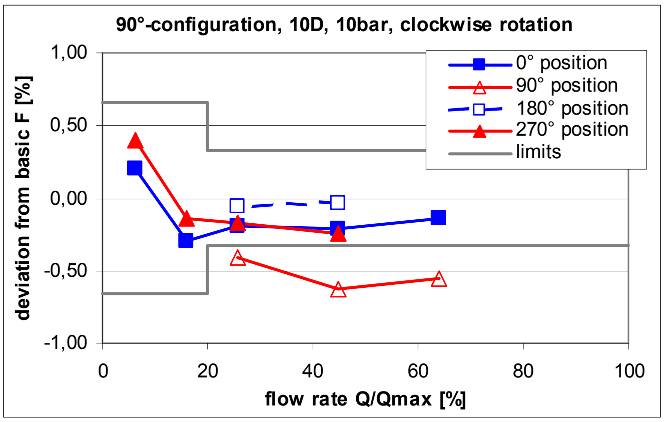


Figure 9: Deviations from undisturbed conditions for double-bend-out-of-plane configurations for 10bar and 40bar



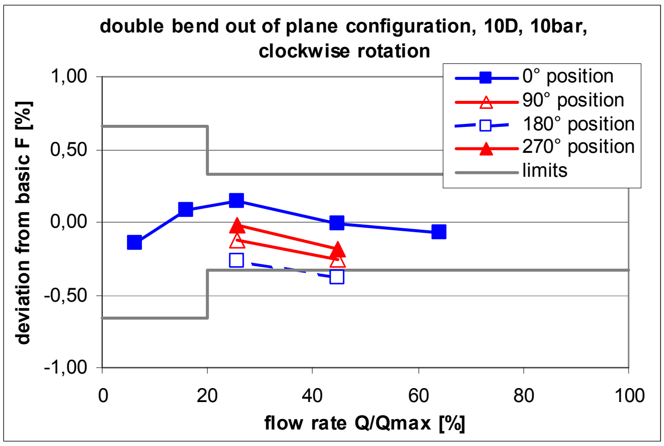


Figure 10: Deviations from undisturbed conditions for different positions of the meter relative to the perturbation at 10D downstream of a single 90° bend and a double-bend-out-of-plane configuration

Comparison of test results with the conventional meter design

The conventional design of this Q.Sonic-3 meter (6'') was tested at the Lintorf facility under similar conditions. The results were presented in [2]. As part of those tests, the influence of the meter's azimuthal position relative to the single 90° perturbation (10D upstream of the meter) was also analysed in detail. The results show that the flow perturbation has a strong influence when the meter is turned between 30° and 150° (clockwise against direction of flow, with the piping as shown in Figure 4). This behaviour is similar to that of the new meter design, but the bias at 90° is much lower for the new design, which shows that area reduction in the new meter is an improvement. For all other positions, the additional error in those tests was acceptable.

Detailed USM results

It is well known that one major advantage of USMs are their diagnostic features. Values such as relative path velocities, velocity of sound, relative velocity of sound, gain factors, etc. can be used to check the meter's long-term performance and generally detect possible metering errors. Some examples are given in Figures 11 and 12:

- Figure 11 shows the single-path data for a complete test run under undisturbed conditions. The single path velocities relative to the mean velocity are as expected for a fully developed turbulent flow. The relative velocity of the single bouncing path (path no. 2) is approximately 1.025, the relative velocities of the swirl paths (paths 1 and 3) are around of 0.99. At lower flow rates one can already detect some deviations from the fully developed flow profile.
- The comparison of the measured VOS for the three paths with the calculated VOS via AGA 8 gives maximum differences of 0.3%, which is acceptable for a meter of this size. The good agreement between all three VOSs shows that all three paths are working well.
- In contrast to Figure 11, Figure 12 shows the detailed data for the perturbed conditions. For both kind of perturbations the relative velocity of path no. 2 is reduced to approximately 1 due to the more homogeneous flow profile in the direction of flow. As is typical for the double-bend-out-of-plane perturbation, the swirl paths (no. 1 and 3) change drastically in opposite directions. In case of the 90° perturbation all relative path velocities are close to 1.

On the basis of these log file data from the calibration and from the field installation one can easily detect influences caused by flow perturbations or incorrect path lengths.

The gain factor was within the accepted limits in all cases, which shows that there was no noise influence. Also, the number of accepted measurements was always near 15, which is the upper limit.

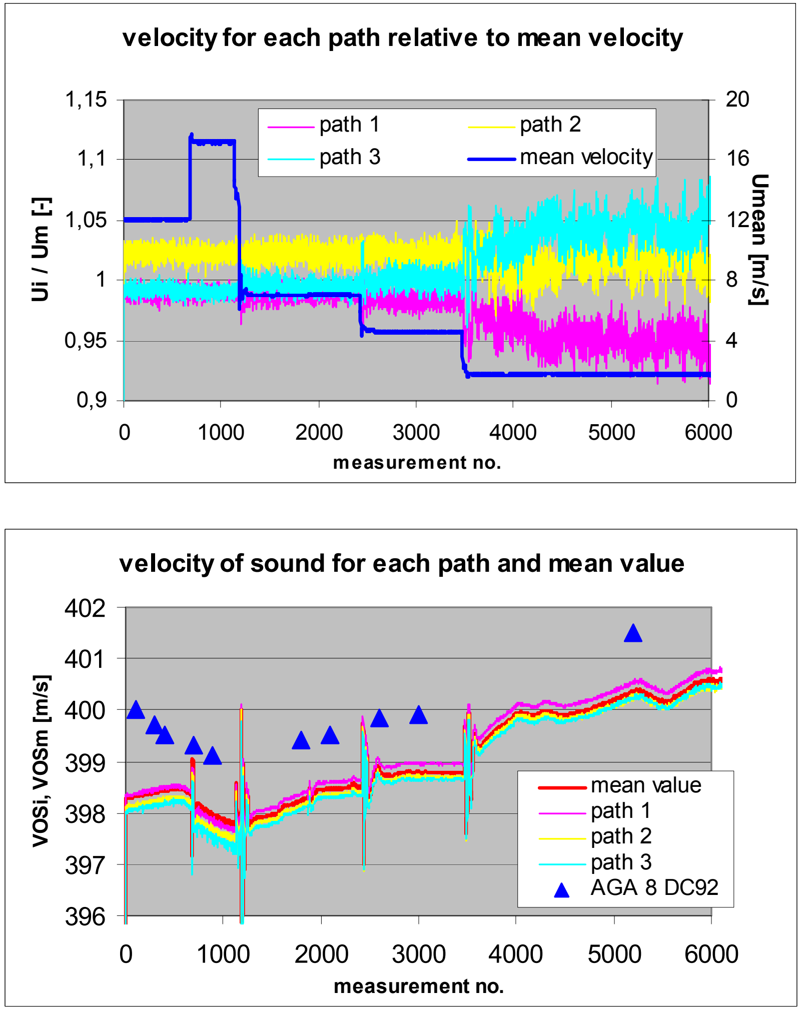


Figure 11: USM diagnostics: Single-path information for the tests without flow perturbation (43D upstream length, 10bar)

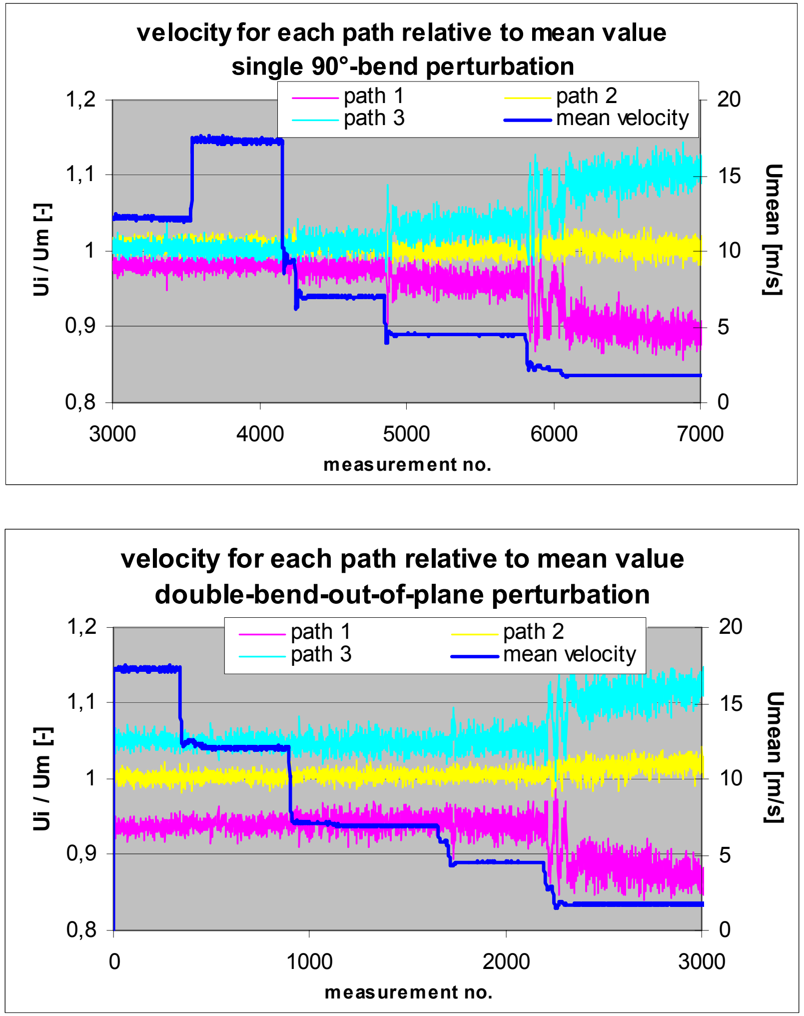


Figure 12: USM diagnostics: Single-path information for the tests 10D downstream of the 90° bend (top) and double-bend-out-of-plane configuration (bottom)

Conclusions

The Q.Sonic-3 Compact

- The behaviour of this meter in perturbed conditions compared to the conventional design is better due to the area reduction in the meter.
- The new, simpler design of the transducer pockets has no effect on meter accuracy, i.e. the transducers mounted in these casings work equally well in the welded pockets.
- Compared to the Q.Sonic-5, there may be higher uncertainties downstream of special larger flow perturbations because the two single bouncing paths are missing in the Q.Sonic-3; this has to be considered when planning the meter run.
- For flow perturbations involving swirl the meter works well and there is no additional uncertainty.
- Hence, meter installation 10D downstream of a perturbation is generally acceptable, if the perturbation is not too strong.
- A comparison with the tests conducted by SwRI with the conventional design of this meter, presented in [4], shows that the meter tested here is less sensitive downstream of the double-bend-out-of-plane perturbation.

General remarks on USM metering

In the past Ruhrgas investigated the behaviour of several types of ultrasonic meters from different manufacturers for their sensitivity to flow perturbations. Generally speaking, ultrasonic meters are very promising types of flow meters. Nevertheless it must be stated that – for low flow perturbations such as those shown in Figure 4 – all types of meters tested so far do need at least the 10D straight inlet lengths required by PTB. In some cases the meters were only just within the limit of "1/3 of the allowed maximum permissible error (+/-1% above 20%, +/-2% below 20% of the meter capacity)" when installed 10D downstream of flow perturbations. But most of the test results were within the +/-1% accuracy band. Where very low metering uncertainties are desired, i.e. to make sure that flow perturbations have an minimum impact on metering, 20D upstream straight lengths are recommended, especially if larger flow perturbations must be expected. It is therefore recommended to assess the risks resulting from flow perturbations on a case-by-case basis. Analysis of the single path velocities can give some indication as to whether or not the flow is perturbed. The tests at Lintorf on the new gas turbine meters featuring integrated flow straighteners have shown that USMs are not yet able to provide the same level of insensitivity to flow perturbation as these GTMs. However, in contrast to USMs, which have negligible pressure loss, these GTMs have the disadvantage of large pressure losses. Moreover, USMs are suited much better for wet gas metering, e.g. in offshore applications and storage facilities.

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