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REALISATION OF COMPACT METERING RUNS WITH ULTRASONIC GAS FLOW METERS AND REDUCING MEASUREMENT UNCERTAINTY.

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1 Abstract

This paper presents the results of the application of an ultrasonic gas flow meter in combination with a flow conditioner. This development aims at both reducing measurement uncertainty and the possibility of realising compact (short) metering runs, requiring less investment in piping and installation while maintaining good accuracy.

For this purpose a package of a four-path ultrasonic gas flow meter with inlet pipe section and a modified Spearman (NEL) design flow conditioner placed at 3D upstream of the meter was found to be a good combination for reducing variability in the flow profile. This set-up was extensively tested at the Ruhrgas test facility in Lintorf.

The test results demonstrate that combining an ultrasonic gas flow meter with a flow conditioner improves measurement uncertainty (due to installation effects) and reduces the required straight inlet of the ultrasonic meter by 50%, offering the potential of a compact installation.

2 Introduction

Since the introduction in the market in first half of the nineties, ultrasonic gas flow meters are being used more frequently for custody transfer measurement. Predominant advantages of ultrasonic gas flow meters are the capability of bi-directional measurement and lack of pressure drop. These advantages make ultrasonic meters the natural choice in gas transmission systems, either as main meter, backup meter or check meter.

The main development goals have been to design meters that have minimal sensitivity to flow profile effects and that would not need flow conditioning devices. Meanwhile increasing competition in gas industry calls for reduced uncertainty and lower cost of ownership; at the same time it appears that pressure drop is not always much of a handicap. For this reason using ultrasonic gas flow meters with flow conditioners can be seen from a different perspective.

Issues addressed in this paper are:

- the selection of an appropriate type of flow conditioner
- the optimal position of the flow conditioner with respect to the meter
- verification of the performance (installation effects) in various configurations (perturbation tests: single bend, double bend, downstream of reductions)
- the simulation of a single path meter
- the evaluation of measurement uncertainty of a simulated single path meter, in combination with a flow conditioner and without.

3 Types of flow conditioners

Today a variety of flow conditioners is available on the market and can be found in literature, for example [1], [2]. Several types of flow conditioners are known, referenced by names such as: Zanker (original design: plate + honeycomb), Tube bundle, Sprenkle, ACMA, Étoile, Gallagher, Laws, Nova / K-Lab, Spearman (NEL) [3], [4], Zanker (new design : plate only) and Vortab.

These flow conditioners can be divided in a number of categories:

3.1 Axial flow guides

Examples of these are the tube bundle (with 7 or 19 parallel tubes), the ACMA flow conditioner and the Étoile flow conditioner. The main purpose of these flow conditioners is to remove the swirl component from the gas flow. It is acknowledged that this may be of importance for meters that are sensitive to swirl, such as some turbine meters, orifice meters and some ultrasonic meters. These axial flow guides have little advantage with regard to restoring asymmetric distortion in the velocity profile of the moving gas. In fact these may even have an adverse effect in this respect as the asymmetry is preserved and the turbulence that would assist to eliminate the asymmetry is reduced by these flow conditioners.

The ultrasonic meter used in this test measures swirl and compensates for swirl and therefore using anti swirl devices would not be of any advantage. In addition to this, the results of many calibrations of Instromet's ultrasonic gas flow meters (in terms of the adjust factor) show a larger spread for meters being calibrated with tube bundles compared to meters being calibrated with other types of flow conditioners or without flow conditioner. It also appears that minor variations due to the manufacturing process of these flow conditioners can have a serious impact. For these reasons the axial flow guide type of flow conditioners are not recommended in combination with the ultrasonic meters of this test program.

3.2 Perforated plates

Examples of these are the Laws flow conditioner, the Nova / K-Lab plate, the Spearman (NEL) plate and the new Zanker design. Many flow conditioners used today are of this perforated plate type, to be placed in a cross section of the conduit. Usually these plates have a number of holes of different diameters, arranged in a pattern of concentric rings. This hole pattern is supposed to reshape the velocity profile of the flowing medium. At a particular ratio of the thickness of the plate to the diameter of the conduit, these plates are also effective in removing swirl. Therefore these plates are nowadays also called "thick plates". At the same time a flow conditioner increases the level of turbulence which accelerates the resettling of flow profiles to a fully developed turbulent flow profile. However, as the flow conditioner is a disturbance of its own with respect to the gas flow, it will typically take 6 to 16 diameters of pipe length for the flow profile to resettle to the intended flow profile. Once the profile has arrived at the fully developed turbulent state, it is fairly stable.

3.3 Combination of perforated plate and axial flow guide

The original Zanker design and the Gallagher flow conditioner (GFC) are examples of this type of flow conditioner. The axial flow guide can be placed upstream of the perforated plate (GFC) or downstream of the perforated plate (Zanker). With respect to the effectiveness of these flow conditioners in combination with our ultrasonic meters, it is not to be expected that these combinations offer better results than a single perforated plate.

3.4 Remaining types of flow conditioners

This category contains flow conditioners such as the Vortab or the Sprenkle. The Vortab flow conditioner consists of multiple specially shaped intrusions into the conduit, creating a turbulence pattern that reshapes the flow profile. The Sprenkle flow conditioner can also be seen as an assembly of multiple (3) perforated plates at short distance. The latter kind of flow conditioner is known for the large pressure drop that it creates.

4 Using a flow conditioner in combination with an ultrasonic meter

From the categories as discussed above, the perforated plate is considered to be the most promising type of flow conditioner for our purpose. Of the various plates, for practical and economic reasons the Spearman (NEL) plate was selected. During the development of the package of an ultrasonic meter with inlet pipe and flow conditioner, the plate was modified for obtaining the best performance.

Placing a flow conditioner at short distances from the ultrasonic meter is clearly the most suitable approach when the target is to develop a flow measuring installation of minimum dimensions. In this situation, the flow profile in the meter has not yet arrived at the fully developed turbulent state. The flow profile in the meter will now have a characteristic shape determined by the flow conditioner. This reduces the sensitivity of the meter to flow profile effects due to the installation. When using this method the meter should be calibrated with the same flow conditioner at the position (relative to the meter) that it is designed for.

5 Test object

The meter that was used for the tests presented in this paper is shown in Figure 1. This meter has an inner diameter of 8 inch. Matching 5D, 3D and 2D inlet pipes were used for all tests. During all tests, the meter's parameters were left at the default factory settings. The meter was not adjusted during the test program.
This meter was built according to a new design based on the proprietary design of Instromet Ultrasonics. Similar to the usual design it employs two double reflection paths. Furthermore, it employs two single reflection paths. Using two single reflection (axial) paths instead of one (as used in the 3-path meter design by Instromet) offers an improvement of the uncertainty due to the effects of asymmetric flow profiles.

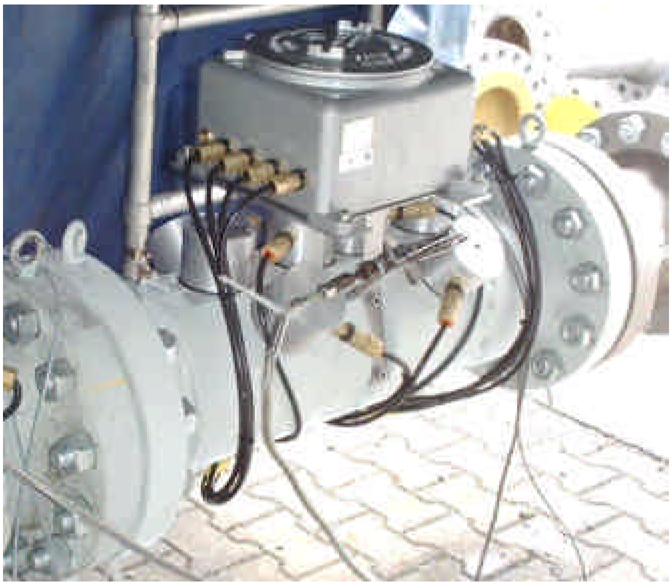

Figure 1. Q.Sonic four-path meter diameter 8 inch, used for the tests

The flow conditioner tested in combination with the ultrasonic meter is a perforated plate of the Spearman (NEL) design adapted by Instromet for optimal performance in combination with the ultrasonic meter. This adapted Spearman flow conditioner has an overall porosity of 48%. The flow conditioner is shown in Figure 2.

Upstream side　　　　　　　　　　Downstream side

Figure 2. Flow conditioner of adapted Spearman design (NEL), tested in combination with the ultrasonic meter

The pressure drop across the flow conditioner can be characterised using the pressure loss coefficient K. The pressure loss coefficient is defined using equation (1).

$$\Delta P = K \cdot r \cdot (V_{gas})^2 \qquad (1)$$

The pressure loss coefficient, K of the plate was measured to be:

$$K = 0.0137 \frac{mbar \cdot m \cdot s}{kg} \qquad (2)$$

6 Test facilities.

From June to October 2002 a test program has been performed at the Ruhrgas high pressure test facility (HDV) in Lintorf. The HDV Lintorf is equipped with 5 orifice runs as reference meters and a turbine meter to check the consistency of the test results. The installation has a pressure range of 10 to 45 bar and flow range of 100 – 8.000 m^3/h, while installation uncertainty is ±0.26% to ±0.4%, depending on flow rate.

Pigsar is the German national standard for measuring high pressure natural gas and employs turbine meters as reference meters. Using turbine meters as working standards and the way the traceability to primary national standards is accomplished, give the Pigsar installation a better uncertainty. This uncertainty (also based on the harmonisation of standards with the NMi of the Netherlands) is nowadays stated to be 0.15%.

7 Test program

In the initial stage of the test program several tests were performed to determine the optimal distance between the flow conditioning perforated plate and the ultrasonic meter.

From previous experience it could be inferred that the resettling of the gas velocity profile while it moves to the meter is not completely described by the distance expressed in the number of diameters. The amount of variation in flow profile also seems to be a function of the travel time from the flow conditioner to the meter. At a certain distance downstream of the flow conditioner, this results in a flow profile that varies, dependant of the gas velocity. To avoid this effect, either a long settling distance or the shortest possible distance between conditioner and meter is required.

At very short distances downstream of some types of flow conditioners, a jetting effect is known to occur. As gas passes through a hole in the flow conditioner, it forms a beam of gas flowing at a high velocity. The increased turbulence tends to flatten this irregularity in the flow profile but it will require a certain minimum distance or time. Therefore, the minimal distance at which a flow conditioner can be installed upstream of an ultrasonic meter is limited by the settling distance of this jetting effect.

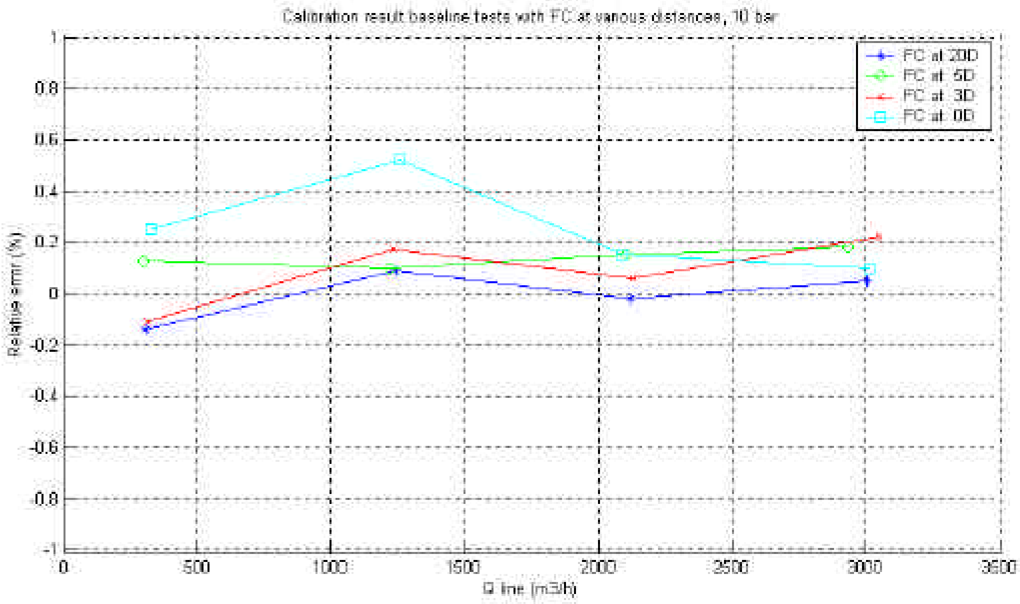

Figure 3. Baseline curves of the ultrasonic mete r at 10 bar with the flow conditioner at different distances upstream of the meter.

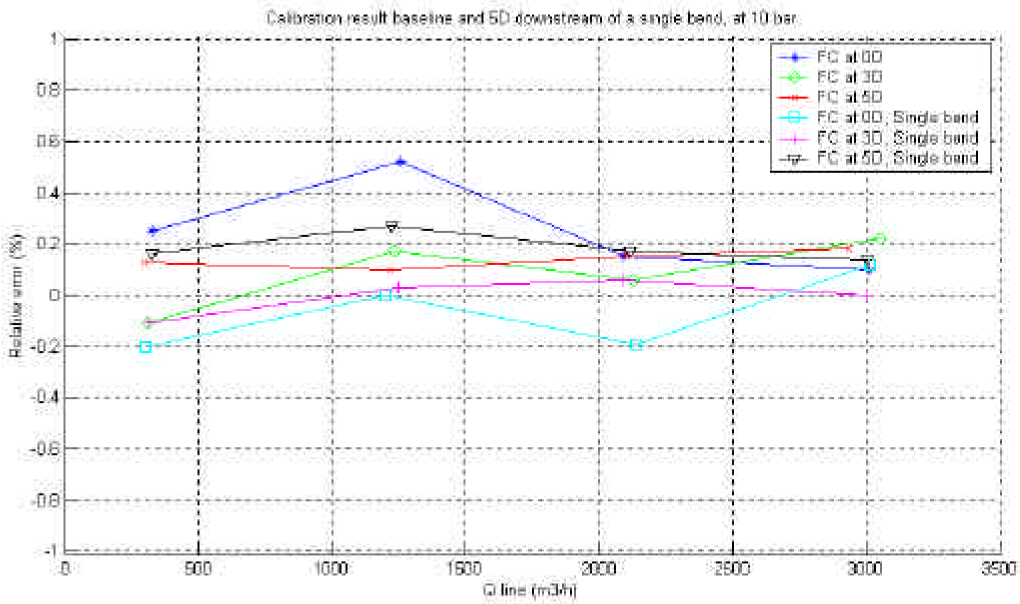

Figure 4. Baseline curves of the ultrasonic meter with the flow conditioner at 0, 3 and 5D upstream of the meter in a straight pipe set-up and 5D downstream of a single bend, at 10 bar.

The initial test (shown in Figure 3) showed a minimal variability in the meter error curve and an acceptable turbulence level when the flow conditioner was installed at 3D upstream of the ultrasonic meter. Figure 4 presents the results of the baseline tests with the flow conditioner at 5D, 3D and 0D (as already shown in Figure 3) and additionally the results of tests that were performed with a single bend installed 5D upstream of the meter and having the flow conditioner installed at

5D, 3D and 0D upstream of the meter, leaving the distance between flow conditioner and single bend as 0D, 2D and 5D.

With the flow conditioner installed at 0D, the data of the individual paths show a large shift in flow profile as a result of the perturbation, this is reflected in a shift in meter output of about 0.4%. When the flow conditioner is installed at 5D, the effect on the error curve is relatively small. However, from the data of the individual paths a large shift in flow profile was observed. When the flow conditioner was installed at 3D, the flow profile showed the smallest shift. From the stability of the flow profile, it could be seen that the effectiveness of the flow conditioner was optimal when the flow conditioner was installed at 3D upstream of the meter.

Based on this result, further tests were performed with a distance between flow conditioner and meter of 3D. During the next part of the test program in Lintorf the following arrangements of piping creating perturbations were installed upstream of the ultrasonic meter:

- a single bend
- a 10” to 8” contraction
- a double bend out of plane
- a double bend out of plane with a half-moon plate between the bends

The meter was tested at various distances downstream of these perturbations and was tested at angles of 0°, 30°, 60° and 90° rotated relative to the meter’s upright position. Test have been performed at pressures of 10 bar and 40 bar. Most tests have been performed both with and without flow conditioner. For most tests, the meter was tested at flow rates of 3000, 2100, 1250 and 300 m^3/h. Tests at 40 bar were limited to 1200 m^3/h due to the limited availability of gas flow in the transport system.

Additional to this program, tests at several pressures, with and without flow conditioner have been performed at Pigsar. The meter was tested at Pigsar to provide a reference point for the Lintorf tests.

8 Summary of test results

The meter was tested at the Pigsar installation with 30D straight piping upstream of the meter. The gas enters the test run from a header. At the upstream end of this test run a Zanker flow conditioner was installed to improve the flow profile entering the test run. It is expected that downstream of the flow Zanker flow conditioner, after 30D length of straight pipe, at the location of the meter, the gas flow has arrived at a fully developed turbulent state.

At Pigsar tests were performed with the ultrasonic meter both with and without the flow conditioner installed at 3D upstream of the meter, at pressures of 17 bar and 50 bar. Results of these tests are shown in Figure 5. Over a range of 10:1 the meter error was within a 0.19% band. Over the whole range the meter was within the error limits for custody transfer. The difference in meter output between the 50 bar and the 17 bar test is on average 0.07%. This influence of the gas pressure on the ultrasonic meter can not be considered as significant. Removal of the flow conditioner that was installed 3D upstream of the meter gave a 0.14% shift in the output of the meter.

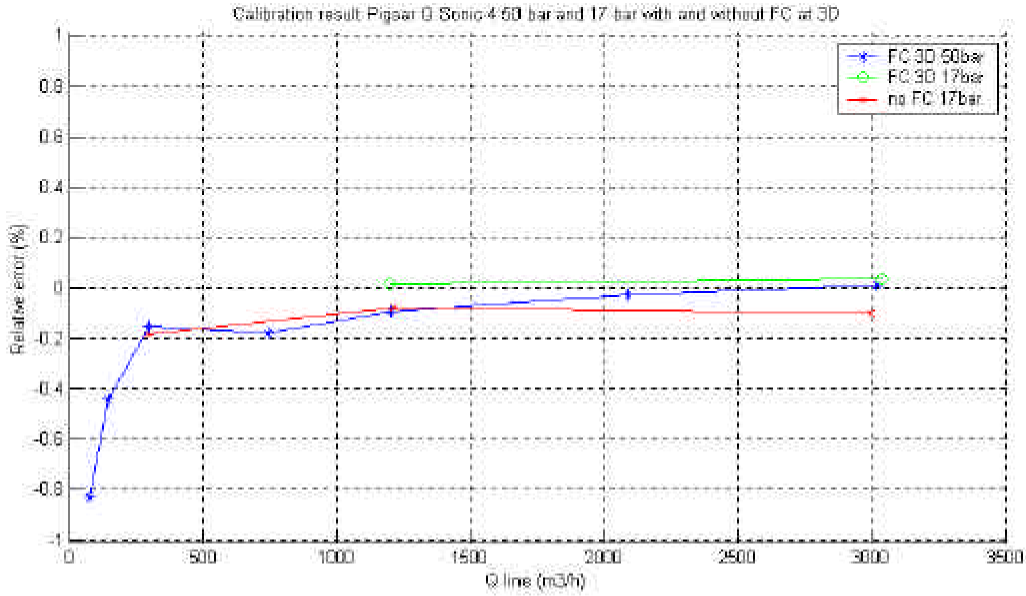

Figure 5. Baseline curve of the ultrasonic meter at Pigsar, at 50 bar and 17 bar, with and without flow conditioner.

At the HDV Lintorf, the baseline tests were performed with the meter installed with 70D of straight upstream piping. Results of these test are shown in Figure 6. These baseline tests were performed at the start of the test program and repeated at the end of the program. The results of these initial and final tests show that both the installation and the meter have been consistent throughout the duration of the test program. The “dip” in the Lintorf curves (which is absent in the test results of Pigsar) is caused by the switching between the reference orifice runs.

As shown in Figure 6, the baseline error curves as found at the HDV Lintorf, on an average, reproduce the error curves as found in Pigsar fairly well. Compared to the baseline error curves as found in Pigsar, individual error curves show shifts within the uncertainty and reproducibility of the HDV Lintorf. The difference between the base line tests with and without flow conditioner therefore appears to be larger, about 0.3% instead of 0.14%.

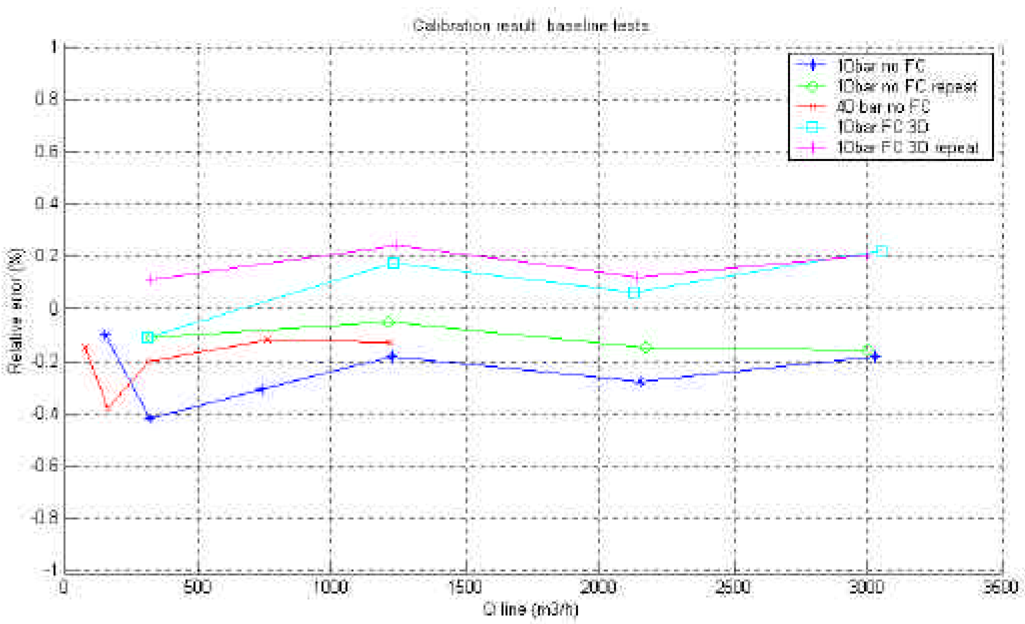

Figure 6. Baseline curves of the ultrasonic meter at the HDV Lintorf, at 40 bar and at 10 bar with and without flow conditioner

The ultrasonic meter was extensively tested in Lintorf with the flow conditioner installed at 3D upstream of the meter. This combination was installed at various distances downstream of perturbations with the smallest distance between the meter and the disturbance being 5D, leaving about 2D between the disturbance and the flow conditioner. The results of these test are summarised in Figure 7, Figure 8, Figure 9 and Figure 10. These results are not shown relative to the baseline, they are shown as they were tested.

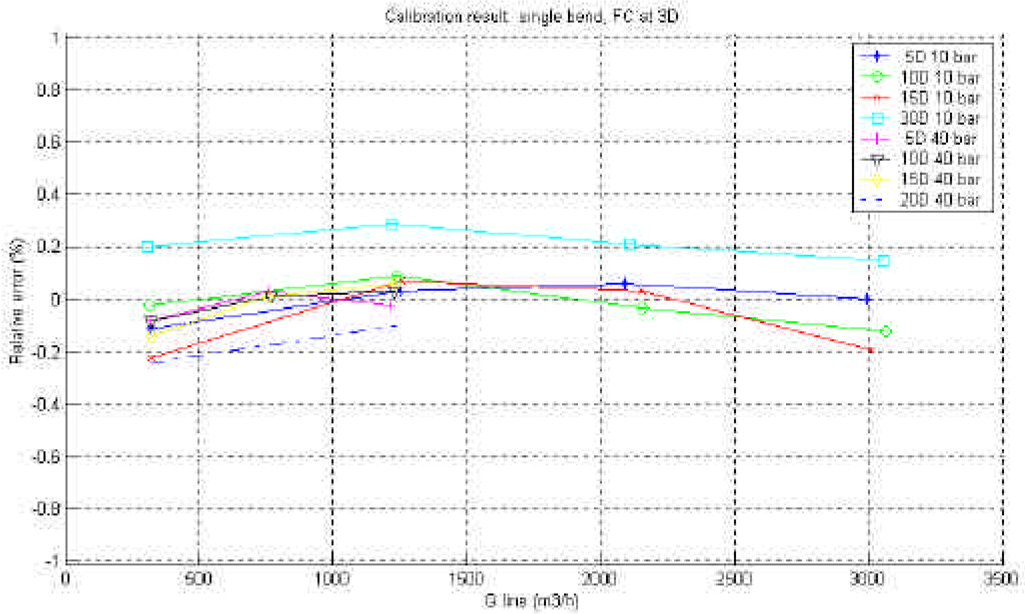

Figure 7. Test results of the ultrasonic meter with flow conditioner at 3D at various distances downstream of a single bend, at 10 bar and at 40 bar.

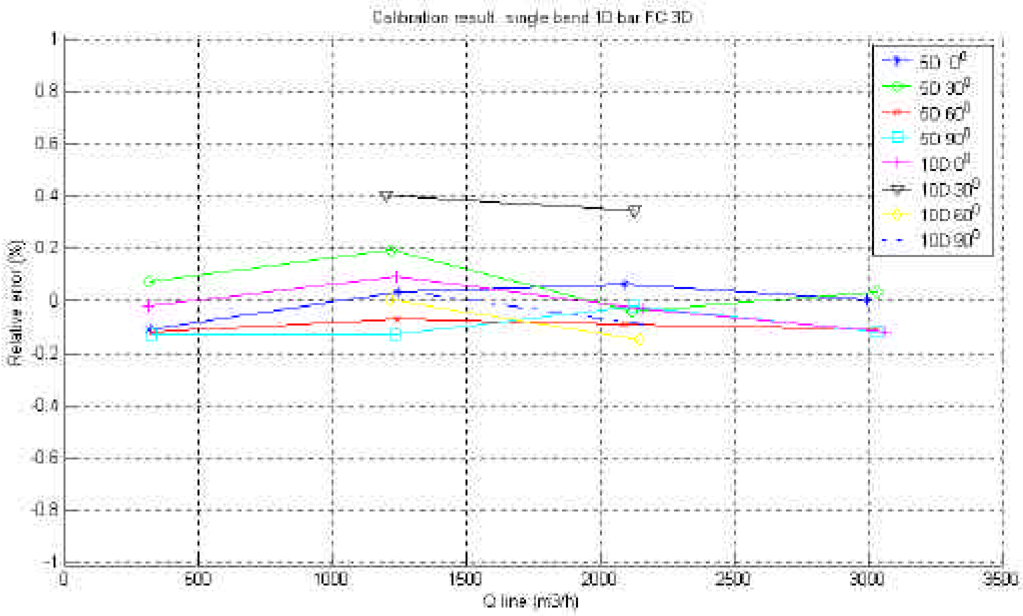

Figure 8. Test results of the ultrasonic meter with flow conditioner at 3D installed at different angles, at 5D and 10D downstream of a single bend

The test result shown in figure 8 where the meter is installed at 10D downstream of a single bend with a rotation angle of 30°, deviates from the other results. This seems to be an exception, however the planning of the test program did not allow to check the reproducibility of this measurement. For reasons of completeness, this test result is included in this paper despite the uncertainty.

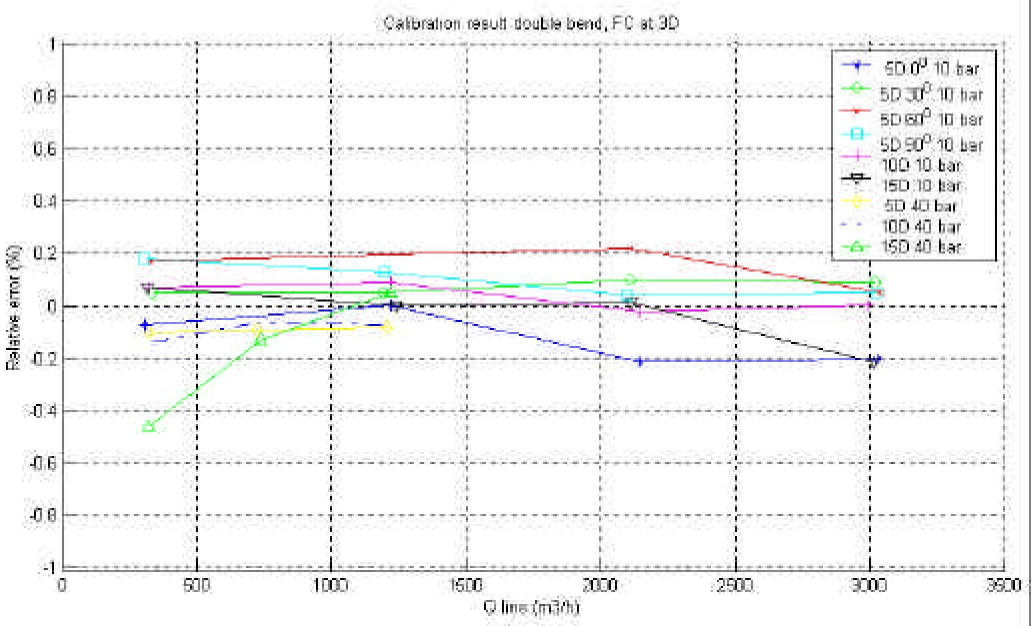

Figure 9. Test results of the ultrasonic meter with flow conditioner at 3D installed at different angles and at various distances downstream of a single bend, at 10 bar and at 40 bar.

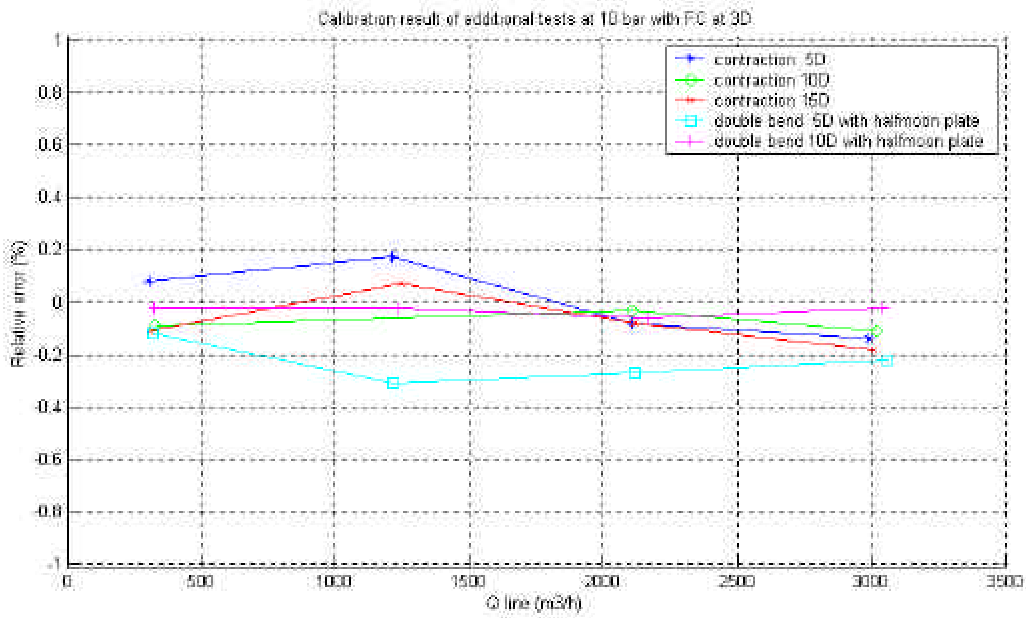

Figure 10. Test results of the ultrasonic meter with flow conditioner at 3D installed at different distances downstream of a 10" to 8" contraction and downstream of a double bend with a half-moon plate installed between the bends.

In order to compare meter performance with and without flow conditioner, a number of tests was performed without a flow conditioner. The results of these tests are shown in figure 11.

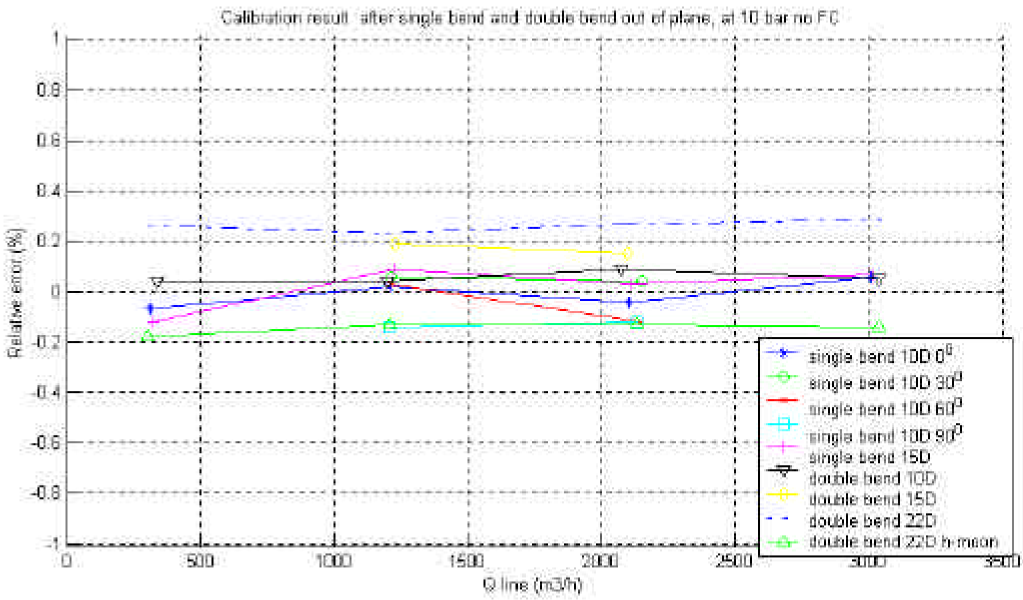

Figure 11. Test results of the ultrasonic meter without flow conditioner, installed at different distances and different angles downstream of a single bend and downstream of a double bend out of plane (in one test with a half moon plate between the bends).

9 Discussion of test results

The flow profile, as measured by the ultrasonic meter can be characterised in terms of several variables. Typically these variables include: swirl level, asymmetry level and flatness of the flow profile. The two variables used here for characterising the flow profile are the average gas velocity as perceived by the ultrasonic meter both on the single reflection paths and on the double reflection paths, both relative to the value of the reference gas velocity provided by the test installation. As the reference velocity is only available when a meter is being tested, the relative gas velocities on individual paths are not available in a practical application. However, the data is presented here in this format for ease of explaining the effect the flow conditioner has on the flow profile.

In Figure 12 and Figure 13, the gas velocities of the single reflection paths relative to the reference velocity of the test installation is shown on the X-axis. The Y-axis shows the gas velocities of the double reflection paths relative to the reference velocity of the test installation. Both figures are presented with equal axis properties. For every test, the flow weighted average of the relative gas velocity is shown. In Figure 12 the tests without flow conditioner are shown and in Figure 13 the tests with a flow conditioner 3D upstream of the ultrasonic meter are shown. Additionally, in Figure 12 the test result of the baseline test with flow conditioner at 20D upstream of the ultrasonic meter is shown.

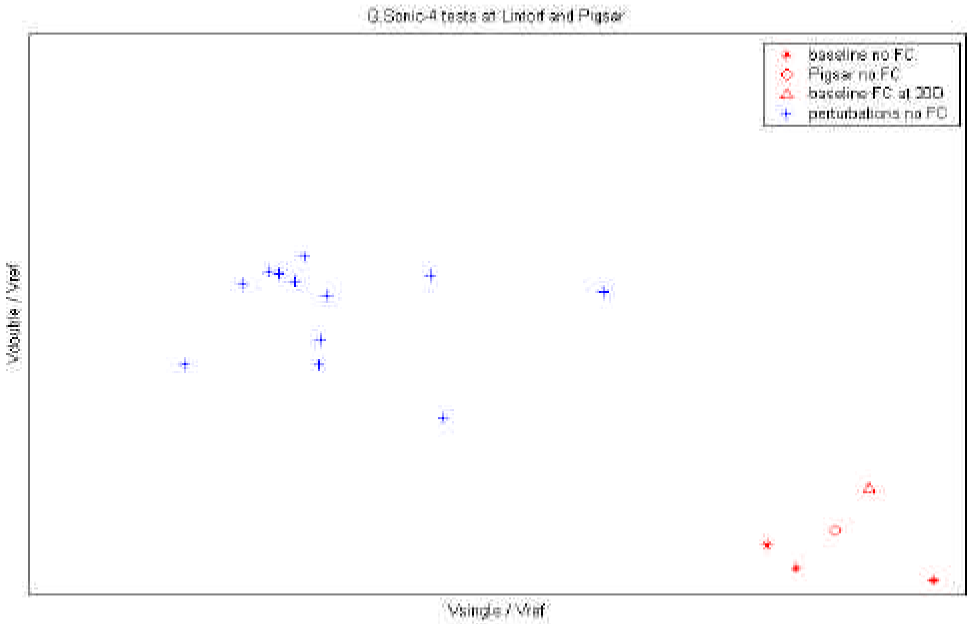

Figure 12. Path velocities of the double - and single reflection paths of the tests without a flow conditioner installed

When an ultrasonic meter is installed downstream of various perturbations, it will see a different flow profile compared to a fully developed flow profile. As can be seen in Figure 12, the baseline tests are represented by points clustering at the right bottom corner of the figure and the flow profiles in perturbed situations are represented by points in a different cluster (middle left).

When the flow conditioner is installed at 20D upstream of the ultrasonic meter (as can be seen in Figure 12), the flow profile in the meter is similar to a flow profile at baseline conditions. This implies that after 20D of straight piping, the flow profile has resettled to a fully developed state, however this is not a suitable approach for designing compact meter runs.

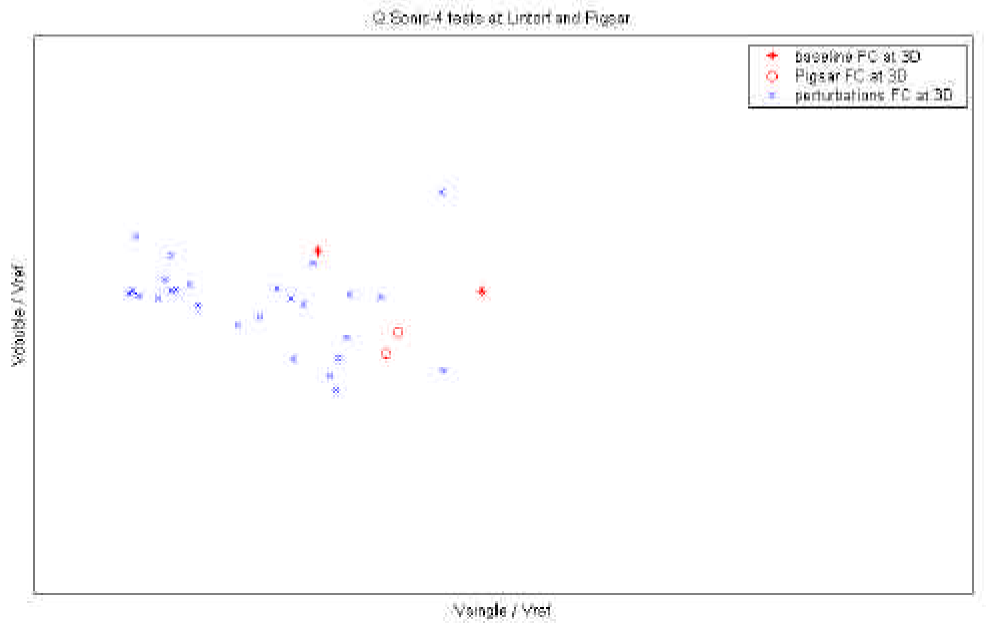

Figure 13. Path velocities of the double - and single reflection paths of the tests with a flow conditioner installed 3D upstream of the ultrasonic meter

In Figure 13, it can be seen that all tests with a flow conditioner at 3D upstream of the ultrasonic meter form a single cluster. The baseline curves (with flow conditioner) are part of the same cluster as the perturbation test results. This means that the flow conditioner is the dominant factor for characterising the flow profile in the ultrasonic meter.

The perturbed cluster in Figure 12 and the results in Figure 13 show that the flow profile produced by the flow conditioner at 3D distance (as observed by the ultrasonic meter's paths) is similar to the flow profile that is produced by several perturbations but different from the fully developed turbulent flow profile. As the algorithms in the meter software are designed to correct for both distorted and undistorted flow profiles, this should not have a significant effect in terms of bias. However some bias may be observed between the meter error with and without flow conditioner (for undistorted flow profiles). This can easily be accounted for by having a meter calibrated with the flow conditioner as planned for the installation, which is already common practice. However this has a significance regarding the flow conditioner’s effectiveness. As in practical applications flow profiles with some degree of distortion are much more likely to occur than the “ideal” fully developed flow profile, it seems a more logical approach to use a flow conditioner that transfers any kind of incoming flow profile (including “ideal” or fully developed turbulent flow) to a kind of “standard” or “average” distorted flow profile, instead of the other way around.

The effectiveness of a flow conditioner is determined by the reduction of variability of the flow profile at the position of the meter downstream of the flow conditioner. This is reflected in the size of the cluster shown in Figure 13. The size of this cluster is mainly determined by the uncertainty of the installation and the level of isolation between the flow profile upstream and downstream of the flow conditioner. As can be seen in Figure 13, the cluster of flow profiles downstream of the flow conditioner still has non-zero dimensions. This cluster is however less scattered than the cluster of perturbed flow profiles shown in Figure 12.

The effect of using the flow conditioner can be assessed by looking at the flow weighted mean error (FWME) of the meter as observed in various test configurations and comparing this to the same value when measuring in undistorted flow.

The reduction of meter errors both in terms of minimum and maximum errors (FWME) as well as the average of the absolute values of the errors (FWME) for a number of test conditions is presented in Table 1 and Table 2. These values are relative to the FWME for undistorted flow. The numbers clearly demonstrate the effectiveness of the approach as explained above.

10 Simulation of other meter types

The logged data of the individual acoustic paths of the multi-path meter was used for a simulation of a meter with one single reflection path. The output of the simulated meter type is calculated by ignoring data from the paths that are not relevant for generating the simulated meter's output. This allows a direct comparison of the single path meter subject to the same tests, at exactly the same test conditions. The meter was simulated using the current default factory setting of parameters. The simulated meter output is compared with the flow of the reference meters during the actual test. The flow weighted mean error of the single path meter for each test, is then compared to the flow weighted mean error of the baseline test for the single path meter.

This exercise is performed with all tests that have been performed both with and without a flow conditioner (in total 10 tests). The resulting minimum and maximum deviations from the baseline test are shown in Table 1. The mean absolute deviation from the baseline test is shown in Table 2.

	Q.Sonic-4 (min / max)	CheckSonic-1 (min / max)
no FC	0.00% / 0.39%	-3.71% / 1.05%
FC at 3D	-0.24% / 0.22%	-0.94% / 1.34%

Table 1. Flow weighted minimum and maximum error of the multi- and single path meter

	Q.Sonic-4 (mean abs error)	CheckSonic-1 (mean abs error)
no FC	0.19 %	2.47 %
FC at 3D	0.16 %	0.54 %

Table 2. Flow weighted mean absolu te error the multi- and single path meter

As can be seen from Table 2, using the flow conditioner in combination with an ultrasonic multi-path meter gave an average improvement in accuracy of about 15%. The other meter type with only one single reflection path shows an even greater improvement. Nevertheless, such a meter does not reach the accuracy of multi-path meters by far.

11 Conclusions

In this paper, test results are presented regarding the performance of a combination of an ultrasonic gas flow meter and a flow conditioner installed at 3D upstream of the ultrasonic meter.

The flow conditioner proved to be a dominant factor influencing the flow profile presented to the ultrasonic meter. The effectiveness of a flow conditioner is mainly determined by the level of isolation between the flow profile upstream and downstream of the flow conditioner. Using a flow conditioner will certainly not completely isolate the effects of distorted flow due to installation elements upstream of the flow meter.

These test results have demonstrated that combining an ultrasonic meter with a flow conditioner reduces the required length of straight piping upstream of the meter from 10D to 5D.
At the same time, the level of uncertainty due to installation effects is reduced by 15%.

Typically there is a wide gap in accuracy between multi-path ultrasonic meters and single path ultrasonic flow meters having only one single reflection path.

Using a flow conditioner may improve the accuracy of a single path ultrasonic flow meters, and therefore narrow the gap between the single path meters and multi-path meters. It will certainly not upgrade the performance of a single path meter to a level of accuracy comparable to multi-path meters.

12 Acknowledgements

Instromet Ultrasonics wishes to thank Ruhrgas Research for their contribution to this project. Especially the effort of Dr. D. Vieth in organising and supervising the experimental work is highly valued.

13 References:

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