Paper 12:

Experience with Installation of Ultrasonic Gas Flow Meters under severe conditions

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SUMMARY:

Ultrasonic gas flow meters, primarily of the multipath kind, have gained a large portion of the world market for custody transfer metering since the technology was introduced in the early 1990s. Over the last 4-6 years numerous papers have described the features of ultrasonic meters, highlighted their advantages over more traditional metering technologies such as orifice and turbines, and presented operational experiences.

This paper will discuss experiences from one permanent installation and two test installations where the FMC Kongsberg Metering's FMU 700/MPU 1200 technology has been subjected to severe conditions. At the Statoil operated Åsgard B platform in the North Sea two 20" FMU 700s were installed in 2000 and were faced with such levels of ultrasonic noise that they would not function properly. Through cooperation with the technical people in Statoil and the ultrasonic group at FMC Kongsberg Metering this situation was solved by installing analogue filters in the FMU 700s. Varying operational conditions such as pressure and temperature has also proved to be items which need to be considered when setting up and commissioning ultrasonic meters.

Installation effects caused by upstream piping configurations have always been an important part of the discussion of ultrasonic technology. This paper will show and discuss results from tests performed at the Verbundnetz Gas and Ruhrgas, Lintorf facilities in Germany where an 8" MPU 1200 were exposed to a number of piping arrangements. Some of which pushed the MPU beyond its capabilities.

As is showed here, the ultrasonic technology has a very bright future in gas metering when used right. USMs have limitations and it is important to know what they are and to take these into account when designing metering stations where USMs are the source of measurement.

ABBREVIATIONS AND SYMBOL LIST:

VNG	Verbundnetz Gas AG
FMU	Fiscal Meter Ultrasonic
MPU	MultiPath Ultrasonic
USM	UltraSonic Meter
FMU 700	FMC Kongsberg Metering's first generation ultrasonic gas flow meter
MPU 1200	FMC Kongsberg Metering's second generation ultrasonic gas flow meter
RTR parameters	Reference Transient Response parameters
LL	Low Level
HL	High Level
ISO	International Organization for Standardization
IPU	ISO Perturbation Unit

1. INTRODUCTION

The operational experience from the above mentioned sites will be described as four different situations.

2. SITUATION 1: SET–UP

2.1. INSTALLATION

As can be seen in figure 1 below, the two FMU 700s on Åsgard B are installed in series with 9D straight upstream pipe to the flow conditioner and an additional 7D between the flow conditioner and the upstream 90º bend. Downstream meter 1 is a 5D section before meter 2 and then a 13D section containing dual pressure and temperature outlets as well as an annubar check meter.

The closest control valve, and possible ultrasonic noise source is more than 50 meters (110 D) upstream and more than 25 meters (55 D) downstream.

The installation is done according to normal specifications for an ultrasonic based application and the upstream lengths and use of a flow conditioner prevents the meters from being affected by any special secondary flow profile effects.

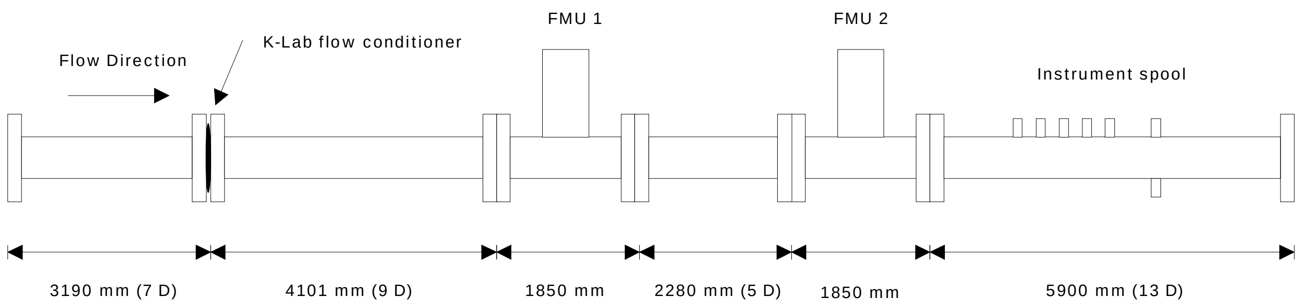

Figure 1: Åsgard B metering section

Prior to installation the entire metering skid, as shown in figure 1 including flow computers, pressure transmitters, temperature transmitters and the annubar, was tested at K-Lab with different pressure and temperature combinations. And it was after that sent to Advantica, the former BG Technology calibration facility in Bishop Auckland, England, for flow calibration.

No noise or other problems were observed during the flow calibrations. The results from the flow calibrations with calibration factors implemented is shown in figure 2 below.

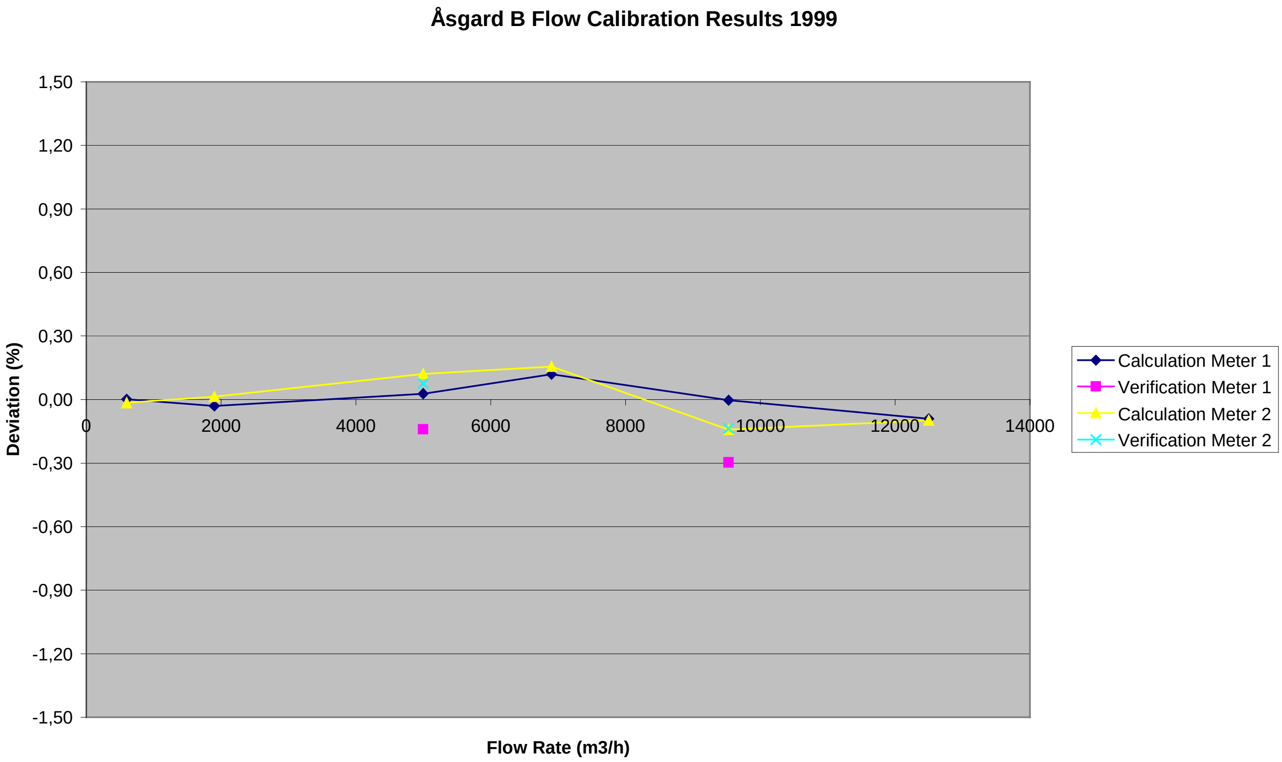

Figure 2: Åsgard B Flow Calibration

2.2. OBSERVATIONS

Calibration of Ultrasonic Meters

Statoil has two offshore installations in the area Halten – Nordland, Åsgard B and Heidrun, which both have gas metering stations based on two serial mounted ultrasonic meters from two different suppliers. The main supplier at Heidrun is Daniel Europe while Åsgard B's station is delivered by FMC. Both stations deliver gas to the same gas pipeline and experiences more or less the same operational conditions:

Mean gas velocity:	5 – 15 m/s
Temperature:	40 – 60 ^{o}C
Pressure:	150 – 200 bar

Calibrations of both stations were very similar. The FMC metering skid was tested in two steps; first at Statoil's K-lab facility at Kårstø and finally at the BG Technology, now Advantica, test facility in Bishop Auckland, England. The Heidrun metering skid was shipped from factory directly to Bishop Auckland.

The K-lab test was done to expose the USMs to temperature and pressure conditions close to the actual operating conditions. With K-Lab's capacity these tests were with low gas flow velocity. Because of compressor problems at K-Lab during the test the test was done with a pressure far below later operational pressure. No results will therefore be presented.

At Bishop Auckland the tests were performed with actual operational conditions for gas flow velocity but very low gas temperature and pressure compared to later normal operational conditions. The calibration was done with the two USMs in series with the instrument spool piece. That is, the whole metering stations were shipped to Bishop Auckland for calibration of the complete skids that were to be placed on Åsgard B and Heidrun.

The calibration was performed as an individual calibration of each meter against the reference gas flow velocity and a Certificate of Calibration were issued by BG Technology for both Åsgard B and Heidrun ultrasonic meters. Based on these certificates calibration factors/curves were calculated for all USMs. FMC use a calibration curve equation of 1st degree polynomial. Daniel Senior Sonic use a calibration curve equation of 3rd order polynomial.

Both metering skids with serial mounted ultrasonic meters were calibrated against reference on an individual basis. Deviation between the two serial mounted meters was not taken into consideration during calibration.

Ultrasonic meters in operation

Åsgard B

Gas export from Åsgard B was started in October 2000. Early in operation strange behavior was detected. Logging of signals from the FMU 700s showed results which indicated that problems were due to ultrasonic noise disturbing the signals, this is discussed further in chapter 3.

Before implementation of analogue filters there was an internal deviation between the two meters varying between 0.3 % to up to 2 %. For Åsgard B this was not an acceptable situation and FMC was asked to do something about it.

Before implementation of filters Åsgard B also experienced sudden trips in the meters. This was due to a rise in export pressure in the meters. Initially the meters had been set up to switch between different RTR parameters dependent of temperature level only. It was believed that the pressure would not influence the operation to the same degree and that RTR parameters were mostly dependent on temperature. Trips in the meters made the meters indicate zero flow through the station even if there was a considerable export rate.

FMC reconfigured their software so that the meters switched between different RTR parameters depending on both temperature and pressure. Initially the pressure was about 130 bar when the first set of RTR parameters were found. The meters tripped at about 175 bar. It was then concluded that an interval of about 30 bar was maximum of what could be accepted as range before using a new set of RTR parameters. The new software, therefore, includes a table of RTR parameters dependent of both temperature and pressure, that is a 4 x 2 matrix of RTR parameters as shown below.

	ΔT1	ΔT2	ΔT3	ΔT4
ΔP1	RTR1	RTR2	RTR3	RTR4
ΔP2	RTR5	RTR6	RTR7	RTR8

Matrix 1.

The influence of noise seemed to be more damaging to the measurement to one of the meters than to the other. Therefore, Åsgard B had to disqualify one of the meters in the time between startup and date for implementation of filters (see chapter 3 below) and new software with RTRs for different pressure levels. The last job with the meters was done in June 2001. This means that the Åsgard B gas export metering station did not behave to Statoil's satisfaction for a period of 8 months of operation.

The succeeding 2 months from mid June to mid August the meters were in operation with no problems and with an average internal deviation of about 0.22 %.

Figure 3 shows the deviation between the two FMU 700s in the period from June to August 2001.

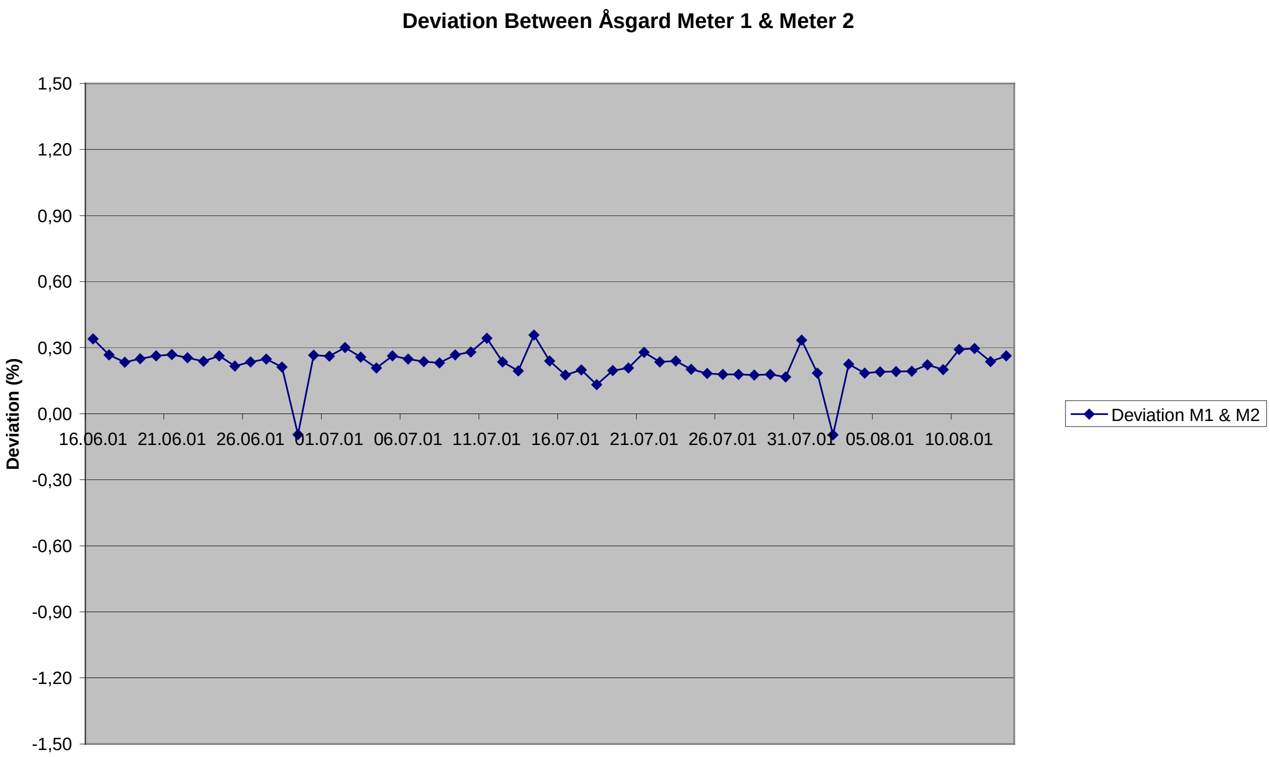

Figure 3: Deviation between Åsgard B meter 1 and meter 2

<u>Heidrun:</u>

Gas export from Heidrun was started in February 2001. Early in operation strange behavior was detected on this installation as well. Previous experiences from Åsgard B made us investigate if there was ultrasonic noise present that disturbed the signals. It was quickly concluded that this was not the problem. The problem was finally found to be faulty transducers. After less than two months of operation two sets of transducers had to be dismounted and shipped back to factory for repair and calibration.

Alarms have also been detected from the flow computers, which indicated problems with transducers. After a lot of investigation both from Heidrun personnel and Daniel personnel, this problem was found to be caused by a software bug in the flow computer.

After 8 months of operation the Heidrun gas export metering skid has, therefore, not behaved to Statoil's satisfaction.

3. SITUATION 2: ULTRASONIC NOISE

3.1. OBSERVATIONS

There have been several issues with the FMU 700 ultrasonic meters on Åsgard B. Apart from the issues discussed above, FMC could see from measurement data logged with the FMU 700 meters, that additional issues were due to noise disturbing the ultrasonic signals. To verify this, and to try to localize the source of noise, FMC procured two ultrasonic clamp-on transducers that had a sensitivity well suited for such type of external measurements.

From the measurements done 17.10.00 with one of these clamp-on transducers at Åsgard B, it was found that the strongest noise was at 9 kHz and that it was propagating through the construction which the pipe with the two FMU 700 meters was resting on. Noise with this frequency can propagate over very long distances, especially in steel.

Figure 4 below show the frequency spectrum measured with the external clamp-on transducers. The Frequency scale is 0 – 200 kHz.

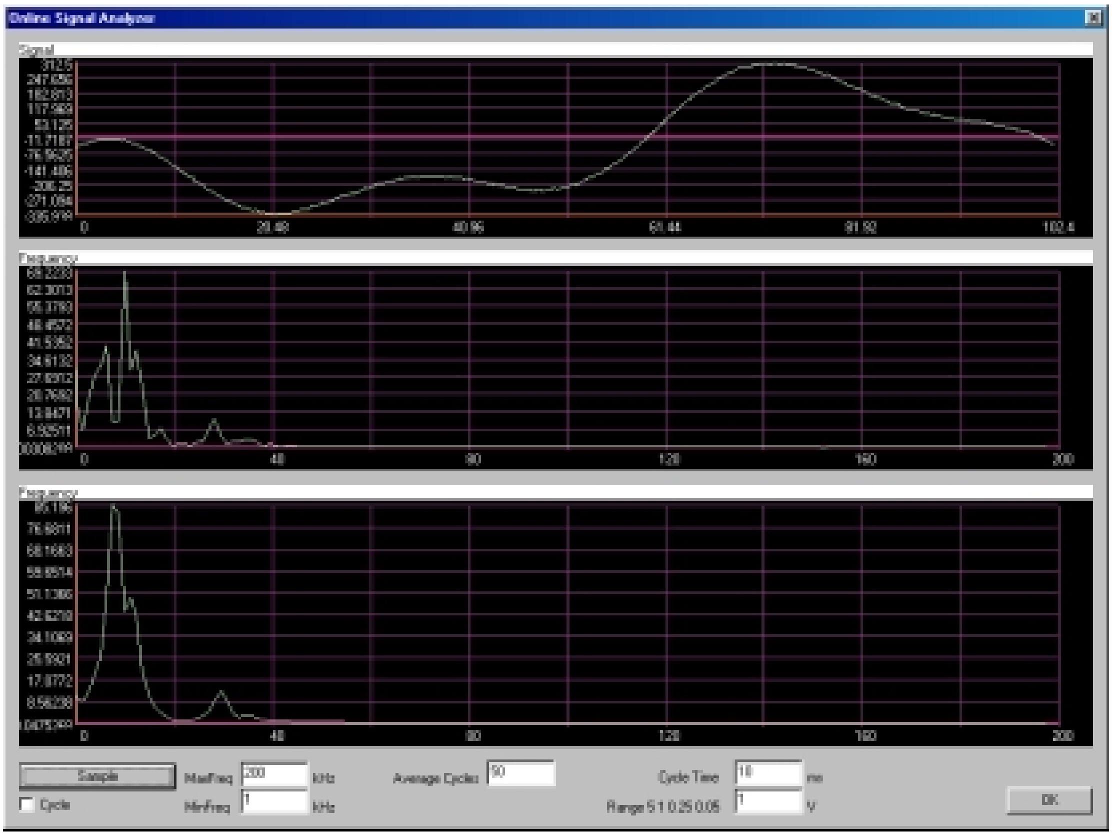

Figure 4: Frequency spectrum with external clamp-on transducers, 0-200 kHz.

Figure 5 below show the frequency spectrum measured with the external clamp-on transducers. Now with a frequency scale of 0 – 20 kHz.

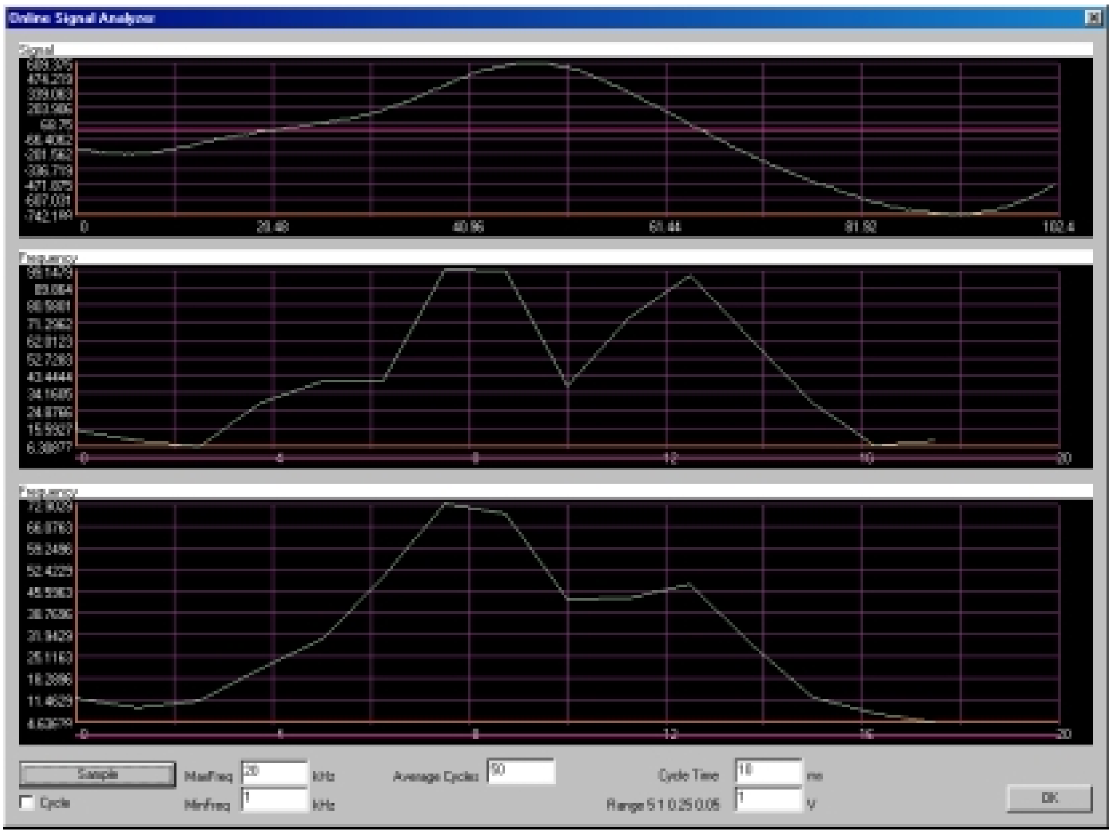

Figure 5: Frequency spectrum with external clamp-on transducers, 0-20 kHz.

Measurements were also done with the transducers on the FMU 700 meters. From these measurements it became evident that there was considerable noise at about 70 kHz as well. This noise was very difficult to detect with the clamp-on transducers due to the extremely high amplitude of the noise at 9 kHz. The noise at 9 kHz were several hundred times higher in amplitude than the signal from the transducers.

The frequency spectrum as recorded by the FMU 700 prior to installing any filters can be seen in figure 6a below. Figure 6b shows the actual signal recorded.

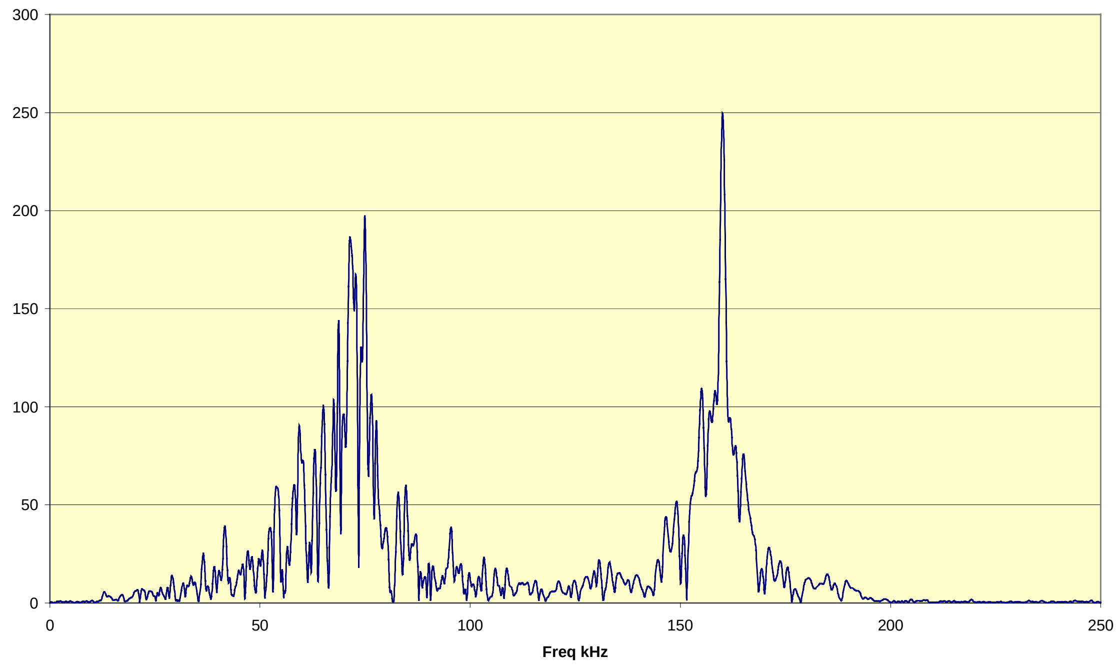

Figure 6a: Frequency spectrum recorded by the FMU 700 before installing filter

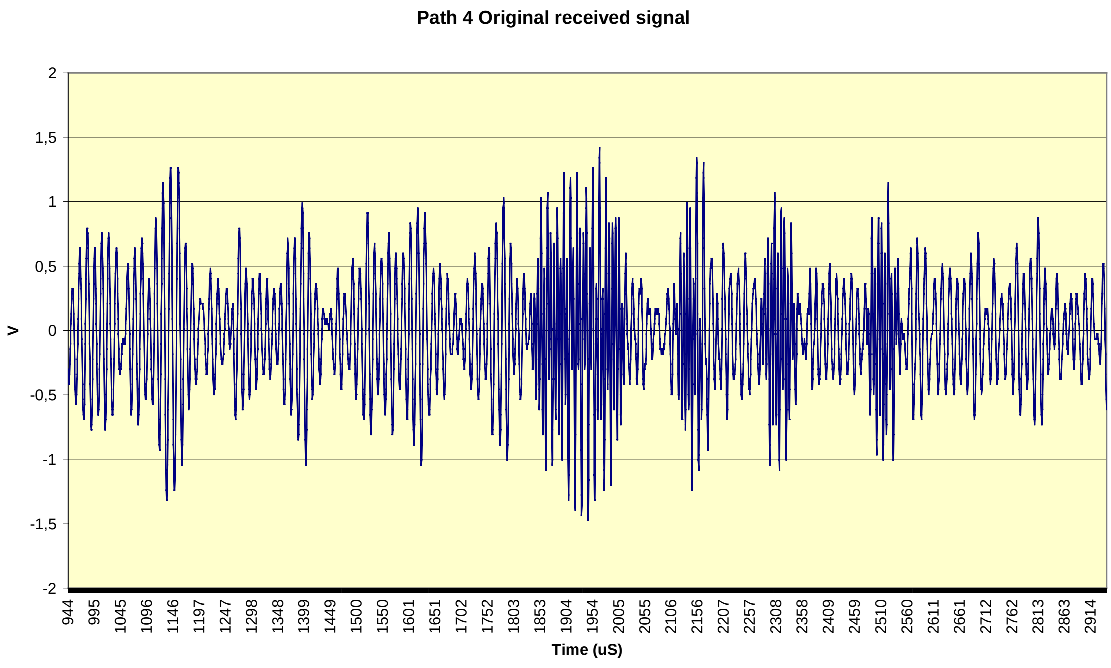

Figure 6b: Received signal on path 4 by the FMU 700 before installing filter

Measurements of noise on the gas pipe at different levels of mean gas velocity showed that the source of noise and the noise frequency were not dependent on export rate.

From all the measurement results, it was decided to solve the problems by using analogue filters. To decide which parameters the final filters were going to have, an adjustable filter was to be tested at Åsgard B.

Testing was started at Kongsberg before being installed at Åsgard B. The aspects of how the installation of a filter like this was going to affect the performance of the meter was checked. From theoretical evaluations it was shown that the performance was going to be unaffected. The preliminary tests at Kongsberg confirmed this.

From simulations and testing at Kongsberg, it was found that the best solution would be to use an 8. order Butterworth high pass filter. The corner frequency was found to be optimal at 110/120 kHz. At Åsgard it was found that the most optimal frequency would be 110 kHz.

The frequency spectrum as recorded by the FMU 700 after installing analogue filters is shown in figure 7a below. Figure 7b shows the actual signal recorded.

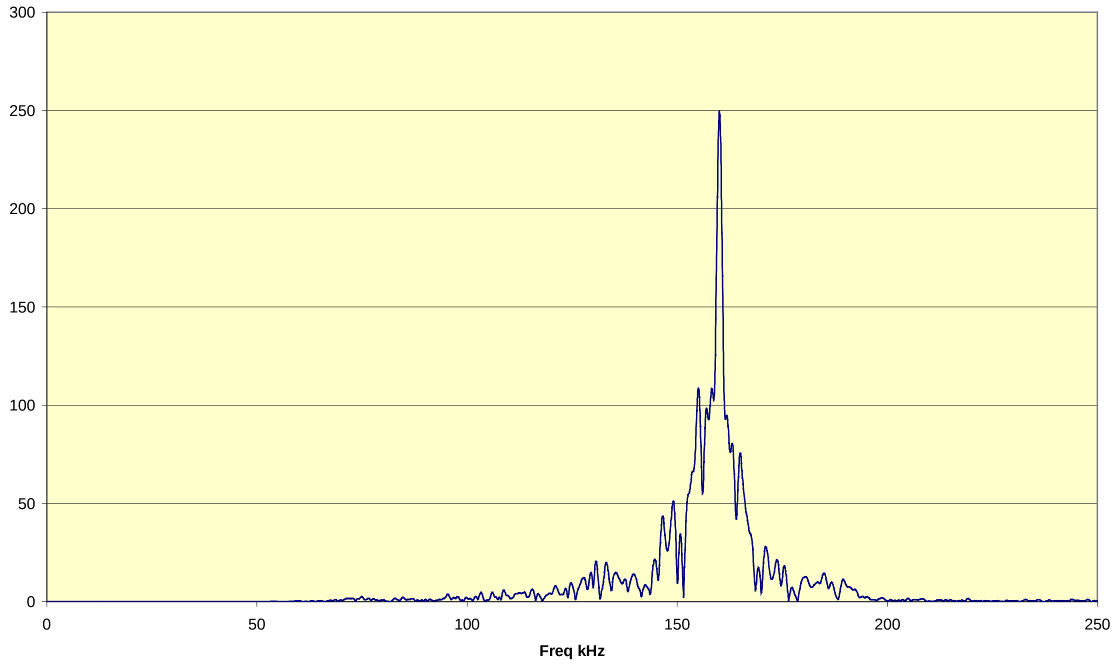

Figure 7a: Frequency spectrum recorded by the FMU 700 after installing filters

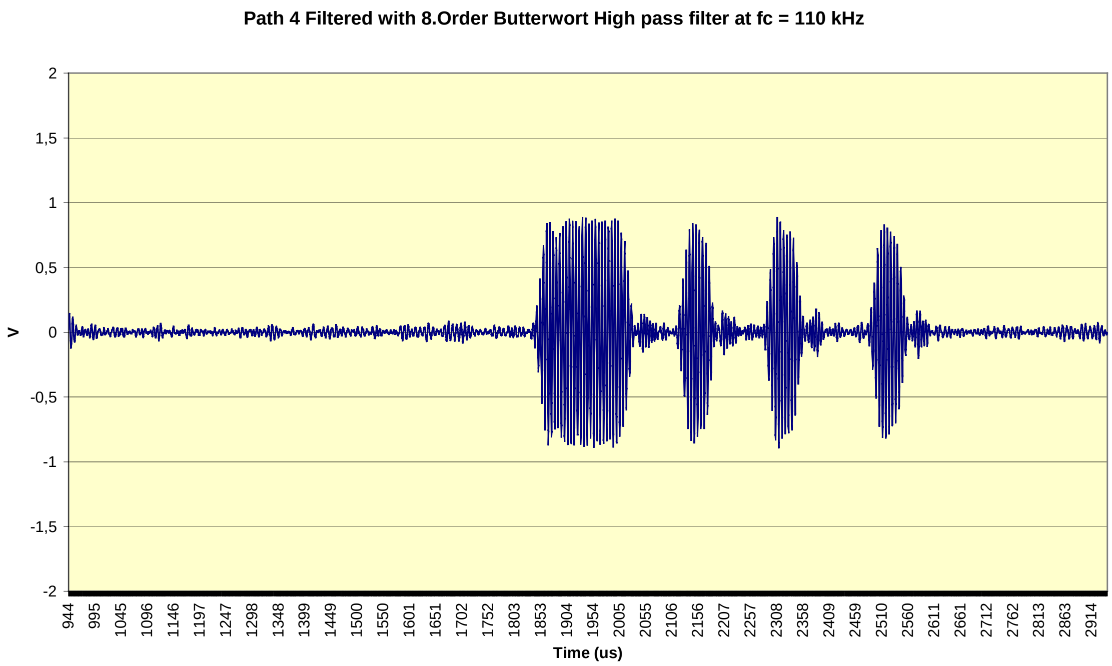

Figure 7b: Received signal on path 4 by the FMU 700 after installing filter

As can be seen in figures 7a and 7b the amplitude of the noise level recorded by the FMU transducers is actually higher than the ultrasonic signal transmitted by the FMU itself.

To get an impression of how the sensitivity of the clamp-on transducers affects the result seen in the snapshots if figures 4 and 5, one must look at the calibration curve of these transducers. At 30 kHz the sensitivity of the clamp-on transducer is –60 dB. At 70 kHz this value is –48 dB and at 160 kHz the value is –22 dB. So when the nose at 70 kHz and the signal at 160 kHz are not evident, this tells us how strong the noise at 9 kHz is.

3.2. CONCLUSIONS

Conclusion after nearly one year of operation:

Fiscal ultrasonic metering of gas under severe condition is still an area where there seems to be a need for more knowledge for both manufacturers and customers. To get a satisfactory operation, there has to be a high degree of cooperation between the two parts and a will from both sides to make it work satisfactory and to increase the knowledge about the details in the metering principles of USMs. Without a thorough knowledge it seems to be difficult to maintain a high quality of wanted results. Mounting two USMs in series may be extra challenging if you do not have a basic understanding of the principles.

Up until today the source of noise has not been discovered, but the problem was solved effectively by installing analog filters on the receiver electronics.
When the next generation USM electronics was developed by FMC such conditions were taken into account and provisions were made to be able to solve it in software in the MPU 1200. This would be done by software filtering.

4. SITUATION 3: FLOW PROFILES – LOW VELOCITY

4.1. INSTALLATION

An 8" MPU 1200 was tested at the Verbundnetz Gas AG (VNG) facility in Kircheilingen, Germany during the fall of 2000. VNG's primary purpose was to test the MPU in a situation which would be typical for many of their locations. As a secondary purpose they also wanted to see the meter's performance under even more adverse conditions. The reference used was turbine meters previously calibrated at Pigsar.

The MPU was installed downstream an above ground header as can be seen in figure 8 below. The piping goes vertically from the header, through two 90º large radius bends in the vertical plane, one 90º normal bend in the horizontal plane, and then the two bends out of plane immediately upstream the MPU.

Figure 8: Installation at VNG

4.2. OBSERVATIONS

During the installation the following tests were carried out:

1. A basis or reference test, where the meter was placed with more than 100D straight upstream length. This is the curve marked "Basis-vergleich" in figure 11 and "BASIS" in figure 13.
2. The meter placed 7D downstream of the second of the two out of plane bends. This is the curve marked "RK" in figure11.

3. The meter placed 7D downstream of the second of the two out of plane bends with a high perturbation device or a "swirl-amplifier" installed between the two out of plane bends. This is the curve marked "RK+HB" in figure 11. The "half-moon plate" can be seen in figure 9.
4. The meter placed 7D downstream of the second of the two out of plane bends with a high perturbation device or a "swirl-amplifier" installed between the two out of plane bends, and a flow conditioner immediately downstream the second bend. This is the curve marked "RK+HB+GR" in figure 2. The flow conditioner used can be seen in figure 10.

Figure 9: "Half-Moon-Plate"

Figure 10: Flow Conditioner

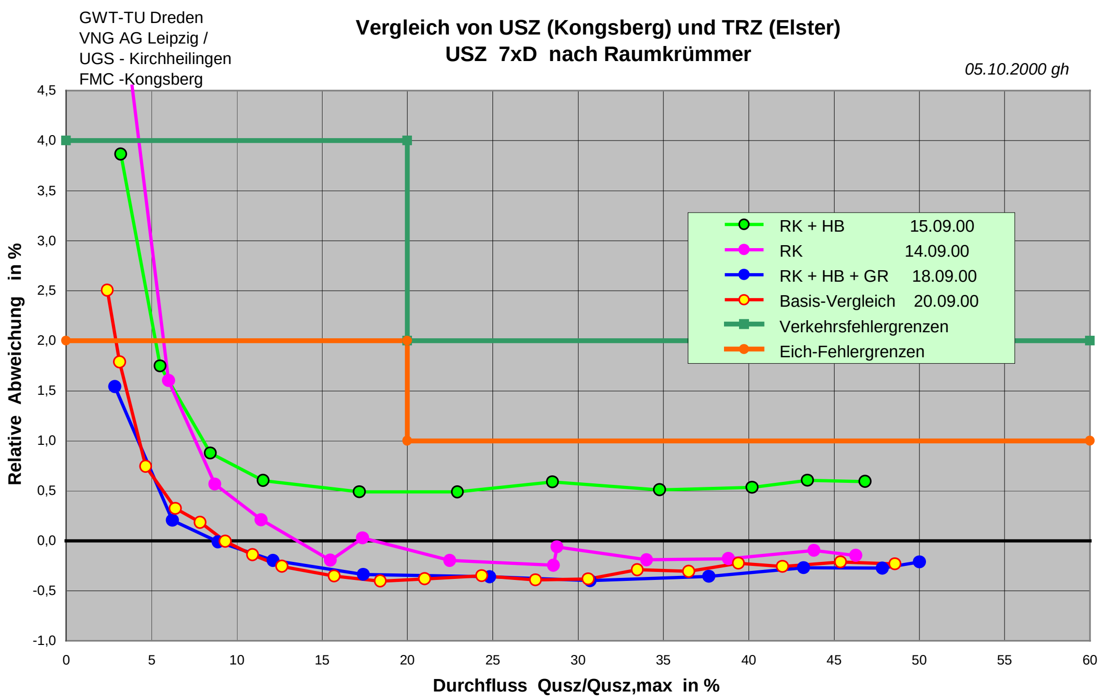

Figure 11: VNG 7D results

The y-axis in figure 11 above and figure 13 below is the percent difference from the reference. The x-axis is the actual flowrate in percent of the maximum flowrate. This

resulted in that 25% was approximately 3,5 m/s and 50% was approximately 7,0 m/s gas flow velocity.
The screen below shows a typical picture from the MPU WinScreen program when the MPU 1200 is subjected to similar swirl conditions as on VNG.

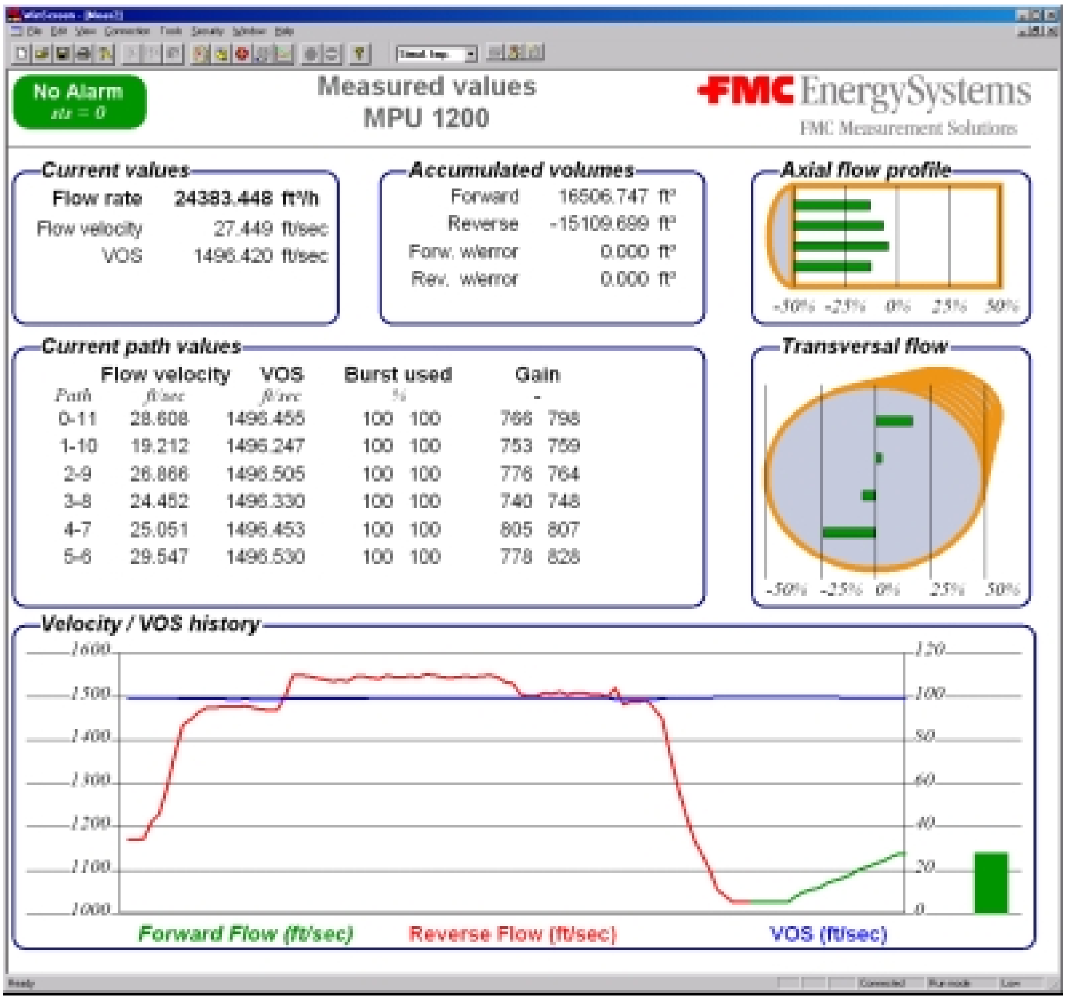

Figure 12: MPU WinScreen showing typical swirl conditions

After the first series of tests with the meter installed 7D downstream of the double bend were completed, the MPU was moved to a position 3D downstream of the double bend and the following tests were carried out:

5. The meter placed 3D downstream of the second of the two out of plane bends. This is the curve marked "RK" in figure 13.
6. The meter placed 3D downstream of the second of the two out of plane bends with a high perturbation device or a "swirl-amplifier" installed between the two out of plane bends. This is the curve marked "RK+HB" in figure 13. The "half-moon plate" can be seen in figure 9.
7. The meter placed 3D downstream of the second of the two out of plane bends with a high perturbation device or a "swirl-amplifier" installed between the two out of plane bends, and a flow conditioner immediately downstream the second bend.. This is the curve marked "RK+HB+GR" in figure 13. The flow conditioner used can be seen in figure 10.

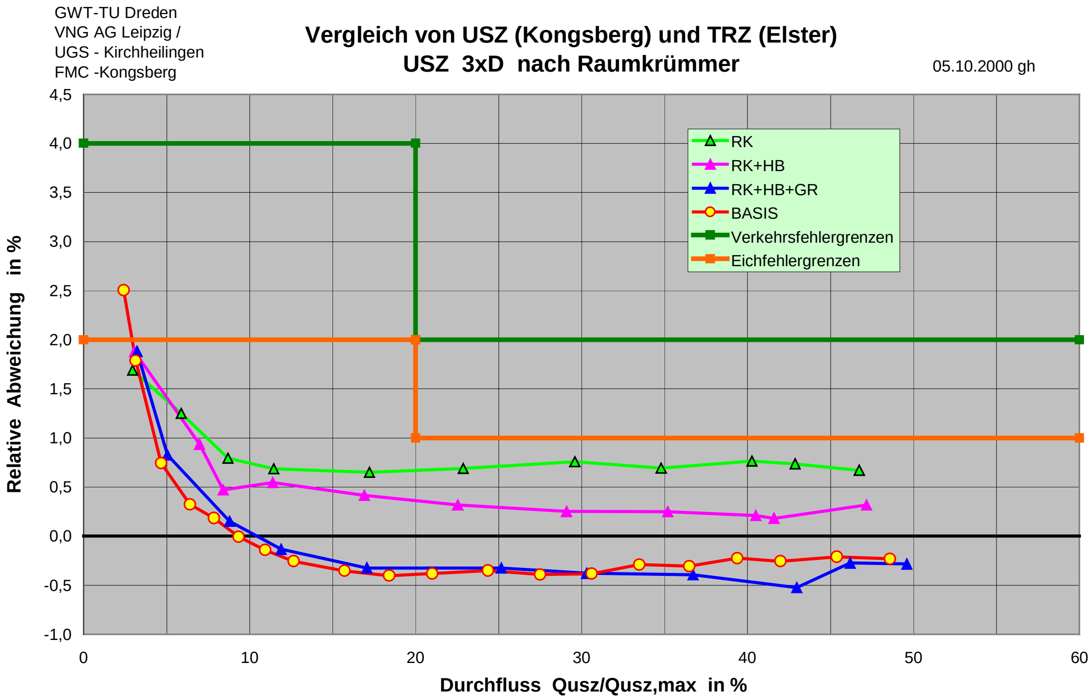

Figure 13: VNG 3D results

4.3. CONCLUSIONS

The meter had previously been flow calibrated at the Ruhrgas Pigsar facility and the linear correction factors A and B, in the form Q = A*Qo + B, had been implemented. The base test results from test 1 show that the offset of the meter is less than 0,5% from the reference.

With the meter placed 7D downstream of the double bends in test 2, the offset is approximately within 0,2% of the base results which also is within the repeatability of the meter.
Test 3 however, where the "half-moon-plate" is also placed upstream, the MPU performance shifts about 1% from the base test.
Test 4 shows that a flow conditioner is able to bring the extreme conditions in test 3 to conditions easily measured by the MPU.

Similar results can be seen in tests 5-7 with the meter 3D from the out of plane bends, with the difference that test 5 also shifts the MPU results to approximately 0,6% above the base results. Again, with the flow conditioner the results are practically the same as for the base test.

One interesting observation was made during the extreme tests with the "half-moon-plate". The turbine meter placed immediately downstream of the MPU (yellow spool in picture 1) showed more than 3% offset from the reference when the MPU was less than 1% offset.

These tests were all done at fairly low flow velocities and the next chapter shows that the performance at low velocities is not necessarily reflected at higher velocities.

5. SITUATION 4: FLOW PROFILES – HIGH VELOCITY

5.1. INSTALLATION

The same 8" MPU 1200 that was tested at VNG was also tested by Ruhrgas at their Lintorf test facility during the summer of 2000. Ruhrgas got the meter flow calibrated at their Pigsar facility before the meter was shipped to Lintorf. Here they exposed the meter to a large number of different tests, two of which were similar to the ones performed by VNG.

The MPU 1200 was installed downstream of two double bends out of plane with and without an ISO HL High Level perturbation device placed between the two bends. The installation at Lintorf can be seen in figure 14 below.

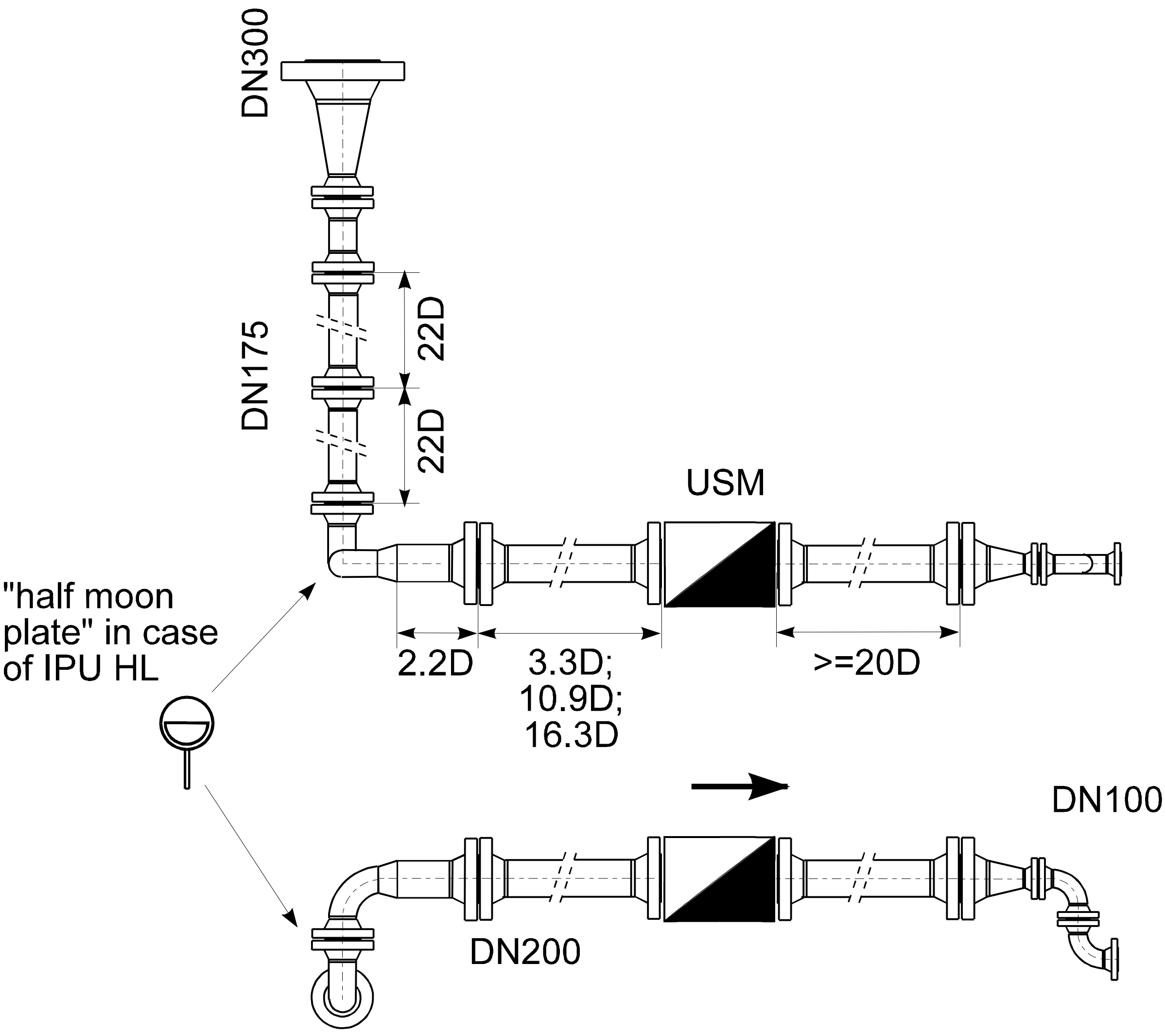

Figure 14: Installation for ISO LL and HL perturbation tests, top and side view

The ISO perturbation units (IPU) were initially designed to test turbine meters under disturbed conditions, see e.g. ISO 9951 and CEN prEN 12261. The so called low

level (LL) version consists of two elbows out of plane with a downstream diffuser in the form of an enlargement in pipe diameter, in this case from 175 mm to 200 mm, as defined in e.g. ISO 9951. High swirl and axial profile deformations are produced by the IPU LL. The high level version (HL) consists additionally of a half-moon-plate installed between the two bends. The axial profile deformations are higher and also instationary effects are higher due to flow separation. The IPU HL simulates flow perturbations produced by regulators and valves.
Below is a picture from Lintorf with the USM in the 18.5D position.

Figure 15: Lintorf installation

5.2. OBSERVATIONS

Included here are results from two of the tests performed by Ruhrgas. These tests were all completed with an operational pressure of approximately 10 bar and temperature of approximately 10ºC. During the test period a number of tests were completed with different setups of the meter. All the results shown below are with a setup done by FMC personnel.

The x-axis in all graphs is the volume flow Qv through the meter as percent of a maximum Q of 3470 m^3/h. This volume flow gave a maximum gas flow velocity of 30 m/s through the 8" MPU 1200, which is the maximum velocity the meter is specified to.

1. IPU Low Level perturbation at 18.5D.
   The MPU was installed 18.5D downstream of the two out of plane bends and the diffuser. The results can be seen below in figure 16.

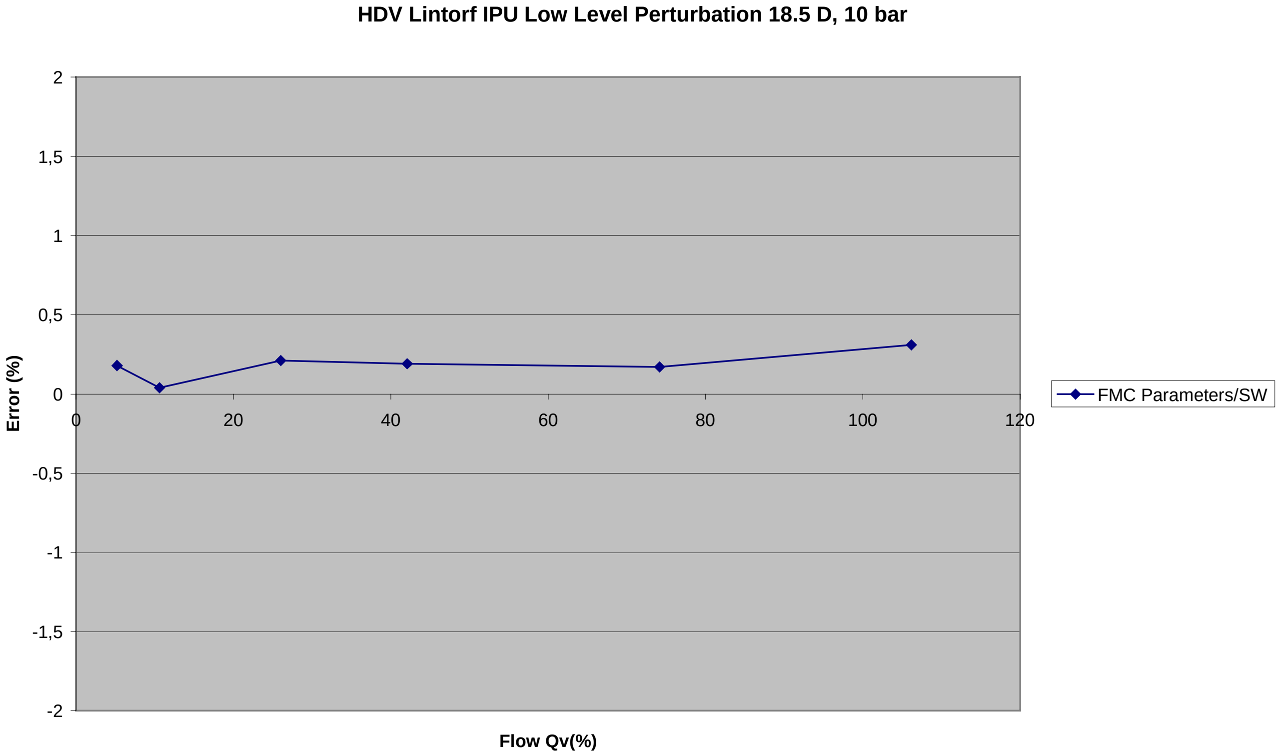

Figure 16: Lintorf LL results

2. IPU High Level perturbation at 18.5D.
   The MPU was installed 18.5D downstream of the two out of plane bends and the diffuser. During this test the "half-moon-plate" was installed between the two upstream out of plane bends as shown in figure 14. The results can be seen below in figure 17.

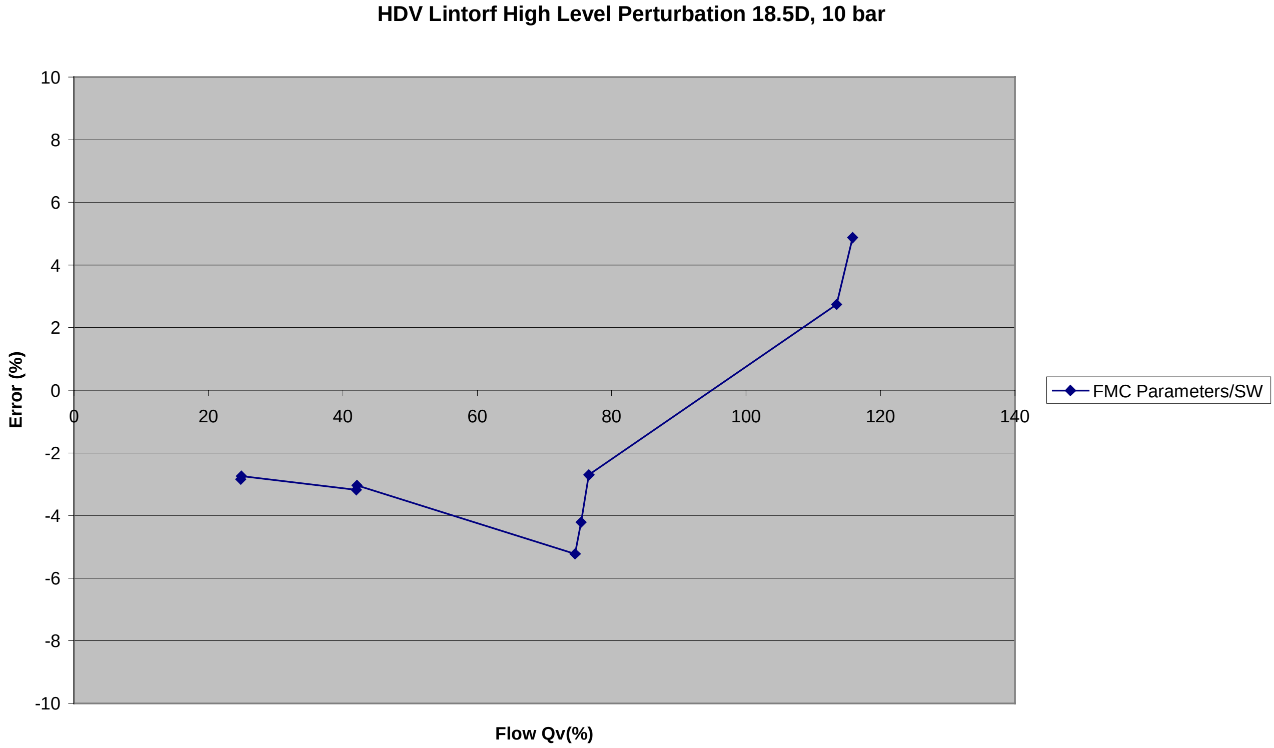

Figure 17: Lintorf HL results

5.3. CONCLUSIONS

The results in figure 16 show solid performance of the USM when placed 18.5D downstream of the two bends out of plane, as was also shown in the VNG tests above.

The results in figure 17 however, show that placing the MPU 18.5D downstream of a double out of plane bend with a high level perturbation device, or any other part producing similar disturbances, is pushing the MPU beyond its limits.

When comparing the Lintorf results in figure 17 with the ones from the VNG figures 11 and 13 above they give us reason to conclude that the secondary flow patterns created by the high level perturbation device increase with the flow velocity. The MPU is able to compensate for the effects up to the approximate 7 m/s velocity at VNG but not with the higher velocities at Lintorf.

Individual path data from the MPU shows that the transverse velocity components are higher than 100% of the actual mean flow velocity and this is really an extreme swirl condition. The MPU has simply not been designed to cope with such special conditions.

It can also be noted that the MPU actually measures even though the velocities go up to more than 115% of the maximum specified range of the meter.

6. CONCLUSIONS

The ultrasonic technology is excellent and provides the users with a lot of valuable information. It is a cost-effective technology with easy and superior performance in a large number of areas to other technologies.
However, USMs do have limitations, and it is important that users know them and use the USMs right.

It is also important that manufacturers, contractors and users work together. By doing so most, if not all, limitations can be overcome either during the design and manufacturing stage or during the installation and operation stage.

The final conclusion is that although ultrasonics has come a long way since the beginning in the late 1980s and early 1990s, there are still challenges ahead. The technology will develop to further increase the performance in areas and one will also see that ultrasonics will continue to find new applications.

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