North Sea

FLOW

Measurement Workshop

1998

PAPER 27

FOCUS DISCUSSION GROUP D

GAS ULTRASONICS

Karen van Bloemendaal, Gasunie

ULTRASONIC METERS AND NOISE
A TASK OF THE '98 GERG PROJECT ON ULTRASONIC GAS FLOW METERS

K. van Bloemendaal, N.V. Nederlandse Gasunie, Groningen, The Netherlands.
G.H. Sloet, N.V. Nederlandse Gasunie, Groningen, The Netherlands.

1 INTRODUCTION

1.1 Background

In 1995, the status of multi-path ultrasonic gas flow metering was investigated by a GERG project group. This study not only established the state-of-the-art at that moment, but also identified gaps in the knowledge of such meters, which could be identified as topics for future research. The results were published in GERG Technical Monograph nr. 8 [1].

The most relevant of these "knowledge-gaps" were taken up in a second GERG project on ultrasonic gas flow meters (USM's). One of these items, the effects of (ultrasonic) noise on USM's, was investigated experimentally by Gasunie, and some results are presented in this paper. The other subjects of the GERG project, the effects of non-ideal flow, the development of a general uncertainty model, the development of procedures to evaluate transducers, and attenuation and propagation of noise in pipelines were or will be reported elsewhere [2, 3, 4, 5]. This GERG project ran in 1997 and 1998, and the project group involved 9 European gas companies: BG Technology, UK; Distrigaz, Belgium; ENAGAS, Spain; Gasunie, the Netherlands; Gaz de France, France; NAM, the Netherlands; Ruhrgas, Germany; SNAM, Italy, and Statoil, Norway.

1.2 Previous Work on USM's and Noise

The research of (ultrasonic) noise and the effects of it on USM's is induced by problems with USM's in the neighbourhood of valves and regulators encountered by users of these meters. A few times these problems in field locations were published [for example 6, 7, 8], but more often the problems are tackled in a practical way. Solutions to the problems are often sought in replacing the (silent) regulator with one of a different type, usually a non-silent one, or by increasing the distance between the regulator and the USM. The 1996 AGA Technical Note on USM's [9] also advises not to install USM's in close proximity to throttling devices, and suggests manufacturers to improve signal handling by techniques as for example stacking, and to increase the transducer power in order to increase the signal to noise ratio. In [8] it was possible to increase the transmission output to the sensors, but this is not usually the case. [10] presents a noise suppression algorithm for a USM.
In field situations, varying of flow and pressure difference is often difficult, and noise, if measured at all, can only be measured at one or two locations. In some publications [11, 12] an attempt is made to investigate the effect of noise on a given meter more systematically. However, the scheduled tests in these cases were curtailed, because the USM's would not operate correctly with substantial pressure reduction, and no noise measurements were performed. In [13] many sound spectra were recorded and compared with the signal level of a USM, but this investigation was performed at low pressures. [14] presents sound measurements of one regulator and signal to noise ratios of a USM .

1.3 Aim of the Present Work

The aim of the present work is to investigate whether it is, in principle, possible to measure gas flows with USM's in the vicinity of ultrasonic noise sources such as regulators, and if so, how reliable the USM output is. This is done by observation of the performance of as much as possible USM's of different makes in the vicinity of a pressure reducer and simultaneous registration of the noise disturbance in a more systematic way than has been done up till now. It has not been the intention to perform a competitive test, in other words to identify "the best meter".

2 EXPERIMENTAL SET-UP

2.1 Test Facility

The experiments described in this paper were performed in a test section at the Gasunie laboratory in Groningen. The gas flows first through the test section and then through the reference meters, before it is delivered into the distribution network of Groningen city. Pressure is reduced near the inlet from the supply pressure of 40 bar(a) to the desired test pressure and in case the test pressure is higher than 9 bar(a), between the test section and the reference meters, who always operate at the outlet pressure of 9 bar(a). Flow rate is controlled at the outlet of the facility, and it is limited by the gas demand of the city.

2.2 Pipe Configurations

The test section was about 18 m long. A large part of this section was of 200 mm diameter pipe. The inlet and the outlet of the test section are defined by 150 mm plug valves, which are a fixed part of the test facility. In the following figures, gas flow is from left to right.

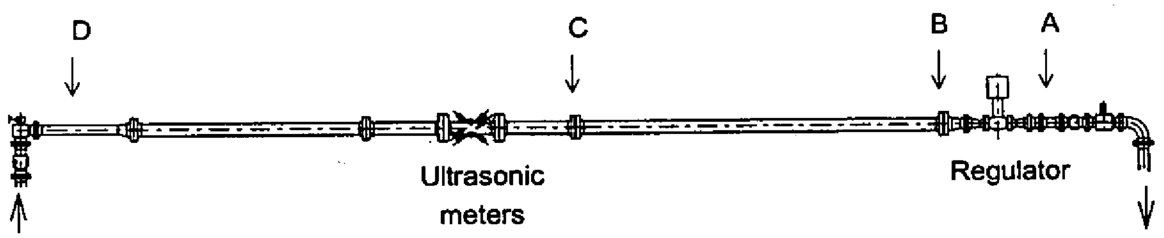

Figure 1: Test Set-up With Regulator Downstream (DN)

Figure 1 shows the set-up with the regulator (see 2.3) close to the downstream end of the test section (DN). Downstream of the 150 mm angular plug valve, the piping expands to 200 mm. Ca. 1.5 m upstream of the end of the test section, the pipe diameter is reduced back to 150 mm. The 100 mm regulator is mounted between two 100-150 mm reducers and is located about 1 m upstream of the outlet valve. The USM's spool piece (see 2.5) is located about 6 m downstream of the inlet valve; the distance between the USM's and the regulator is about 9 m. Sound measurement sensors (see 2.4) are located upstream (D), close to the middle of the test section (C), further downstream (B) and downstream of the regulator (A).

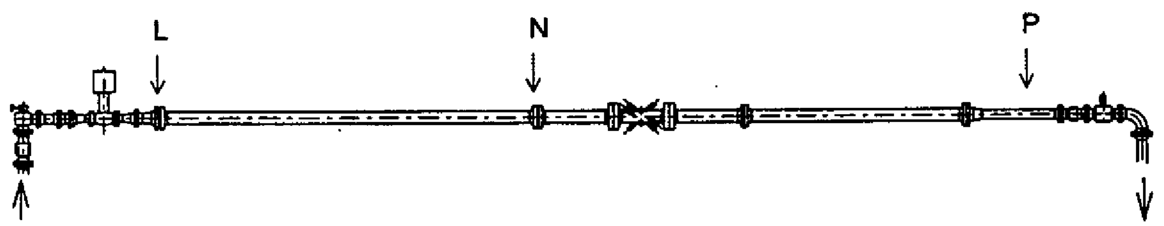

Figure 2: Test Set-up With Regulator Upstream and USM's in Middle of Test Section (UP-M)

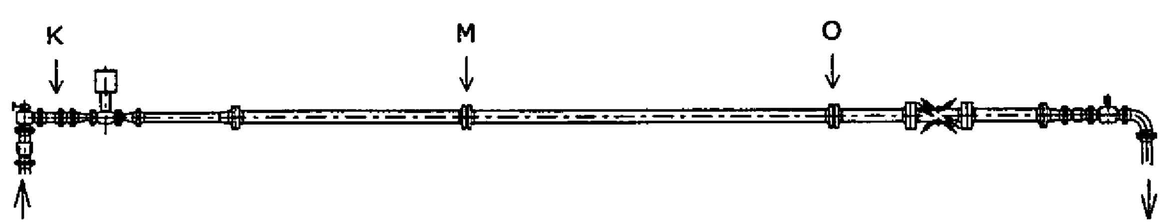

Figure 3: Test Set-up With Regulator Upstream and USM's at Long Distance (UP-L)

Figures 2 and 3 show the set-up with the regulator close to the upstream end of the test section, and the USM's spool piece located respectively near the middle of the test section (UP-M), or at longer distance, about 13 m, from the regulator (UP-L). In the UP-M case, the distance between regulator and USM's was about 9 m, the same as in the DN case. Sound measurement sensors were located at 3 positions downstream of the regulator: close to the regulator (L), near the middle of the test section (N) and near the end of the test section (P). In the UP-L case sound measurement sensors were located upstream of the regulator (K), between locations L and N (M), and between locations N and P (O).

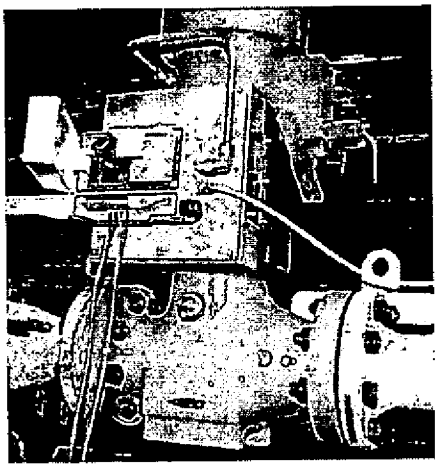

Figure 4: Mokveld Regulator.

2.3 Regulator

The regulator, a 4" axial flow valve see figure 4, is a product of and made available to the project by Mokveld Valves [15]. Bodies of such regulators are standard, the internal cages, the parts where actual pressure reduction takes place, are sized on specification. For this project the maximum pressure difference was set at 27 bar, and maximum flow rate at 30000 m3/h(s). The regulator was equipped with a pneumatic actuator so that it could be moved into position from the control room. Its position output could be read by the data acquisition system. The regulator was mounted both on the downstream and upstream ends of the test section.

Two cage designs were selected in order to investigate the influence of these constructions on the spectrum, see figure 5. The RVX cage is a "standard" cage with 7 slots, which produces a lot of audible noise. Noise levels of more than 100 dB(A) were recorded in the test room. The RQX cage is a low noise design with 228 holes, producing considerably less audible noise.

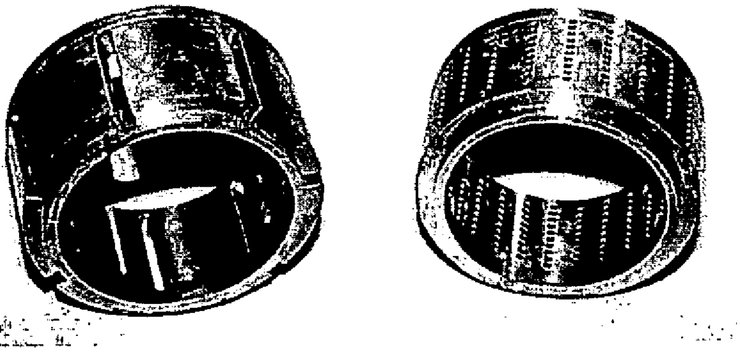

Figure 5: RVX (left) and RQX Cages.

2.4 Sound Measurements

Under all test conditions, the noise levels and spectra were measured inside the pipe at several locations, both upstream and downstream of the regulator (see figures 1 to 3 in section 2.2). For the sound measurements, PCB sensors type 132 A 41 [16] were selected. These piezoelectric sensors are very small, 3 mm diameter, and may be used in high pressure surroundings. Response is claimed to be accurate within ½ dB in the range up to 500 kHz. Calibration results of the sensitivity, in the order of 3000 mV/psi, are supplied with each sensor.

The signal of the sensor was recorded on a digital storage oscilloscope. Every sound measurement consists of 60000 data points, sampled at 1 μs, which were stored on file and processed off-line in a Matlab-environment. Every measurement was transformed into a spectrum by a FFT procedure, from which sound pressures in 1/3 -octave frequency bands were calculated. Mean sound pressure values over the frequency range of 50-500 kHz were calculated from these.

2.5 Ultrasonic Meters

Six major ultrasonic gas flow meter manufacturers were all willing to make available their equipment for the measurements. These were: Daniel; Instromet Ultrasonics; Kongsberg Offshore; Krohne Altometer; Panametrics and Ultraflux. Each manufacturer supplied one set of transducers and the necessary cabling, electronics and flow computers, to complete a 1-path meter. A pulse output frequency could be read by the data acquisition system of the installation for the calibrations (see chapter 4).

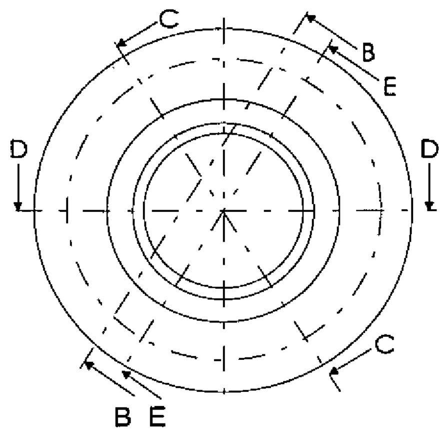

Figure 6 Spool Piece Cross Section

These 6 USM's were all to be exposed to the same test conditions and disturbances such as gas pressure, gas velocity, noise levels and distance to the source of the noise. For this purpose, a special spool piece was designed in which each manufacturer could install one pair of transducers. This spool piece basically consists of a 200 mm ANSI 1500 pipe of 1 m length (see figures 6 and 7). Each meter is (part of) a commercially available product of the manufacturer, each with its own transducer holder design.

The transducer holders are located in the planes B-B, C-C, D-D and E-E. The planes B-B and E-E each contain one straight path (i.e. no reflection on the pipe wall). The path in B-B makes an angle of 55° to the centre line, and is located at half- radius; the path in E-E crosses the centre line at an angle of 60°.Plane C-C contains two straight paths, both through the centre line at an angle of 45°. Plane D-D contains two reflection paths (both transducers of one path are located at the same side of the pipe, and the ultrasonic beam reflects on the opposite pipe wall). Both paths have angles of 60°.

Using this spool piece, and operating the ultrasonic meters one by one, the results of the meters and the effects of the noise could be compared

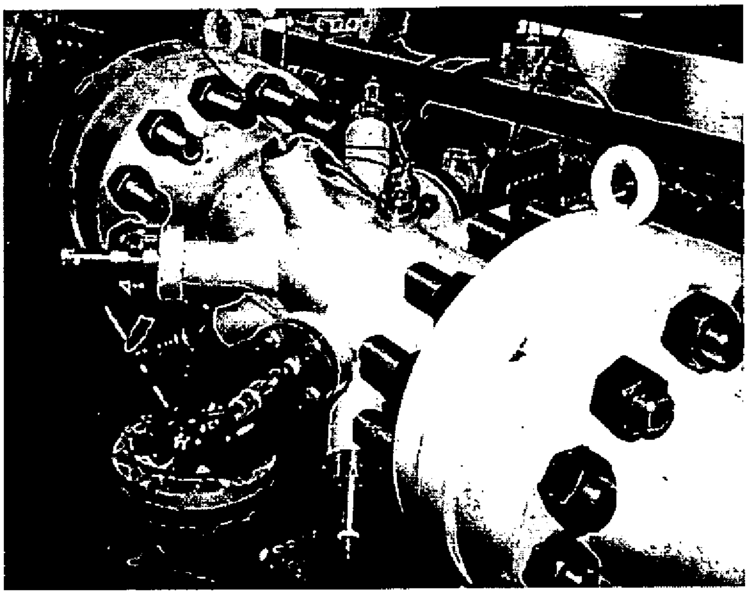

Figure 7: USM's Spool Piece

2.6 Test Procedure

For each test set-up at three fixed upstream pressures, 15, 24 and 36 bar(a), the flow rate was varied; and at two fixed flow rates, 6800 and 17000 m3/h(s), the pressure difference was varied. At every test condition sound measurements were performed and all USM's calibrated. During the sound measurements all USM's were switched OFF. The USM's were tested one by one, i.e. when one meter is switched ON, all other meters are switched OFF. This way, the meters are never influenced by (reflections of) signals from other meters.
As flow rates are given in standard cubic meters per hour, the actual gas velocity at the USM's is dependent on the local pressure, which is different when the meter is upstream or downstream of the regulator. Appendix A gives an indication of gas velocities at each flow rate.

3 RESULTS SOUND MEASUREMENTS

The sound measurements consist of sampling the signals from the piezoelectric sensors (see 2.4). The calculated mean sound pressures in 1/3-octave frequency bands are plotted against the central frequencies in every band in the range of 30 to 500 kHz. The y-axis is given in the sound pressure unit Pa, on a logarithmical scale, ranging from 1.e-1 to 1.e+4 Pa [1].
In every situation the mean sound pressure in the frequency range 50-500 kHz was calculated also, and plotted against three main variables: the valve position in percentage of maximum valve opening, the product of flow rate and pressure difference and the distance to the regulator.

3.1 Non-silent regulator RVX

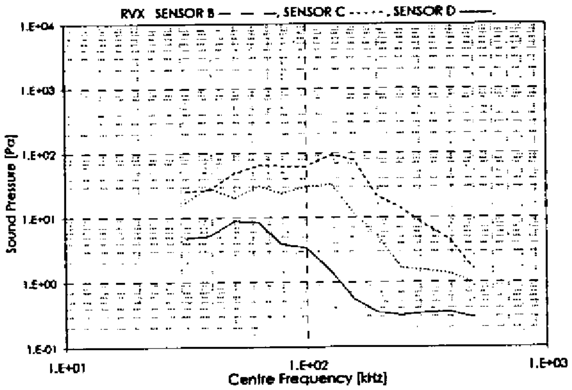

Figure 8: Results Sound Measurements Upstream of Non-Silent Regulator RVX

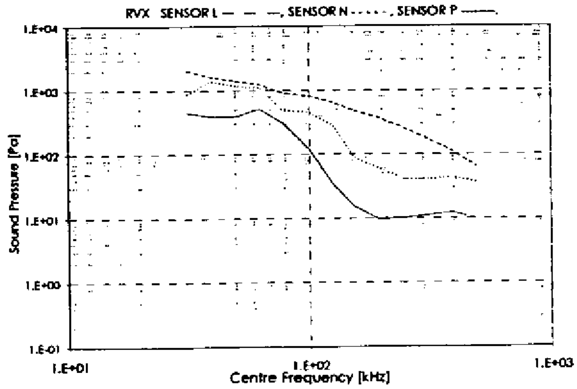

Figure 9: Results Sound Measurements Downstream of Non-Silent Regulator RVX

Figure 8 shows some results with the non-silent regulator RVX. The regulator was mounted at the downstream end of the test section, and the sensors (B, C and D) were located upstream of the regulator. The pressure upstream of the regulator was 36 bar(a), downstream 9 bar(a), the flow rate was 12000 m3/h(s). The valve position was 41% open. Figure 9 shows similar results, obtained in similar conditions, from sensor L, N and P, located downstream of the RVX regulator which was mounted at the upstream end of the test section.
These figures show clearly more noise downstream of the regulator than upstream, and also relatively more low frequency noise. With distance the noise decays, and this decay is stronger for higher frequencies.

3.2 Silent Regulator RQX

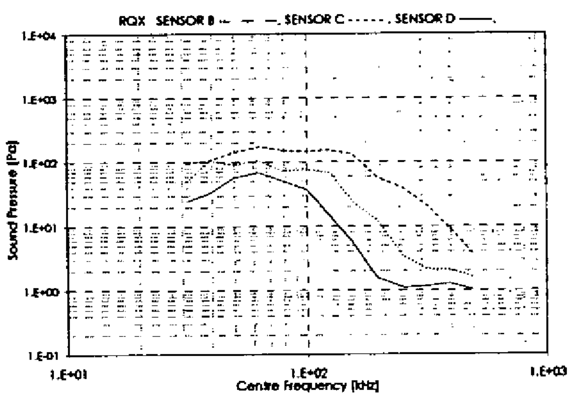

Figure 10: Results Sound Measurements Upstream of Silent Regulator RQX

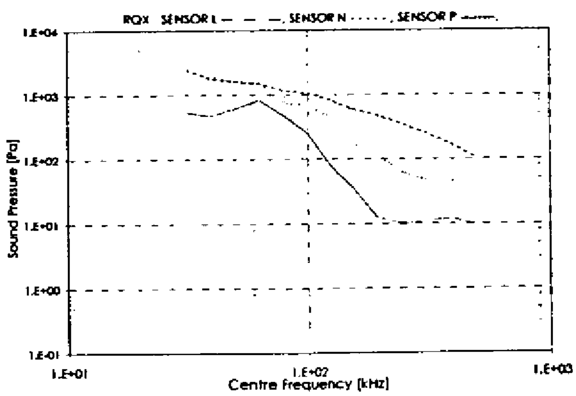

Figure 11: Results Sound Measurements Downstream of Silent Regulator RQX

[1] For readers who prefer decibel scales: this scale is equivalent to a linear scale ranging from 74 to 174 dB, relative to the internationally accepted value for reference pressure of 20 µPa [17].

Figures 10 and 11 show results of the silent regulator RQX, under test conditions corresponding to those of figures 8 and 9. Although this regulator is a low-noise one, designed for low noise in the audible range and outside the pipe, this regulator produces more noise inside the pipe in the frequency range of interest 30-500 kHz.

3.3 Mean Sound Pressure in Relation to Q*dP, Valve Position and Distance

Analysis of all (more than 500) obtained spectra revealed that the spectrum depends on regulator type, pressure difference across the regulator and flow rate, valve position, and distance to the regulator. In order to show these dependencies, the mean sound pressure (MSP) in the frequency range from 50 to 500 kHz is calculated for every test condition. Similar calculations were performed with two or more smaller ranges, to see the effect of frequency range.
Presented here is MSP(50-500 kHz) as a function of the valve position V, as a function of the product of flow and pressure difference Q*dP which are important parameters in the generation of noise inside the regulator, and as a function of distance to the regulator x as noise is known to decay with distance. Because of the large similarity, only results of non-silent regulator RVX are presented graphically.

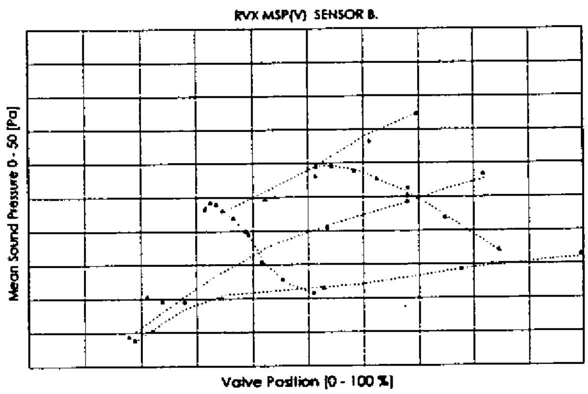

Figure 12: MSP as function of Valve Position Upstream of Non-Silent Regulator RVX

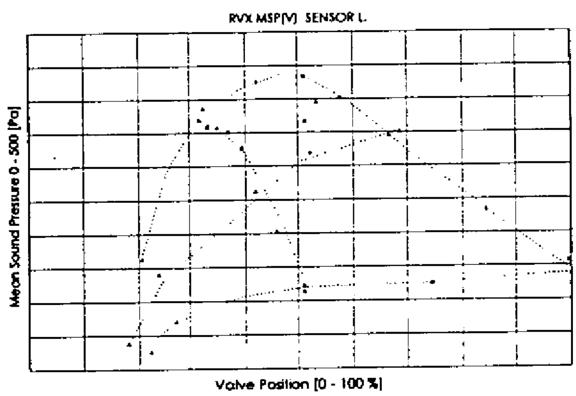

Figure 13: MSP as function of Valve Position Downstream of Non-Silent Regulator RVX

Figures 12 and 13 show mean sound pressures MSP for regulator RVX, upstream and downstream of the regulator, as a function of the valve position. Only data points from the sensors closest to the regulator, B and L respectively, are given in the figures. The other sensors show similar patterns, but at lower values.
The 5 different experiment series are clearly recognisable: three lines with fixed pressures and variable flow rates, and two lines with fixed flow rate and variable pressures. At a given flow rate, increasing valve opening means decreasing pressure difference, and accordingly decreasing sound pressure. At a given pressure difference, with increasing valve opening, flow rate and sound pressure increase.
With regulator RQX similar results were obtained.

Figures 14 and 15 show mean sound pressures for regulator RVX, upstream and downstream of the regulator. With some scatter, the mean sound pressure fits logarithmically with the product of flow rate and pressure difference Q*dP. Curve fits in the form $MSP = A * \ln(Q*dP) - B$ are drawn in the figures. Factor A decreases with increasing distance to the regulator.
A has larger values with silent regulator RQX than with non-silent regulator RVX. The difference between RQX and RVX increases with increasing distance, and is larger upstream than downstream of the regulator.

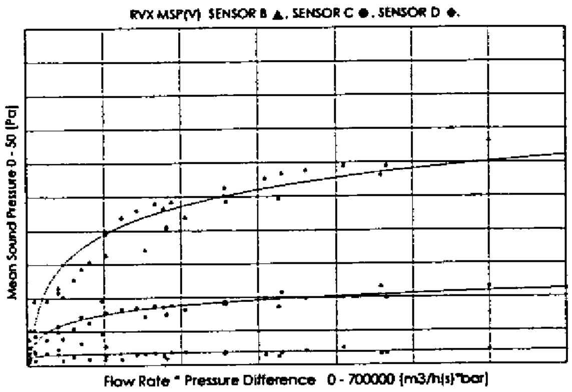

Figure 14: MSP as function of Q*dP
Upstream of Non-Silent Regulator RVX

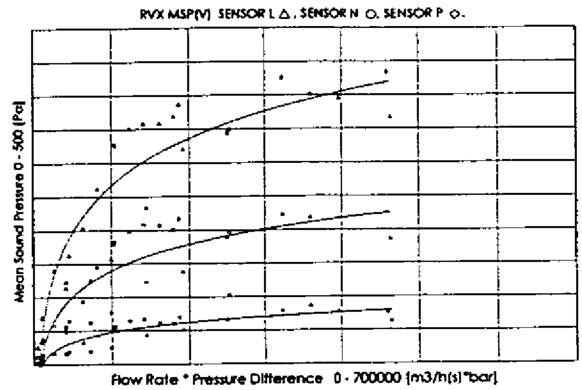

Figure 15: MSP as function of Q*dP
Downstream of Non-Silent Regulator RVX

Figure 16 gives MSP as a function of distance to the regulator. All results of regulator RVX (in the different set-ups, see 2.2) are drawn in the same figure. The sensors A and K are located in the short part of the test section, that is between the regulator outlet flange and the nearby downstream valve (sensor A, RVX-DN) or between the regulator inlet flange and the nearby upstream valve (sensor K, RVX-UP). The results of these sensors are given in open markers, in contrast to the results of all other sensors, given in black markers.

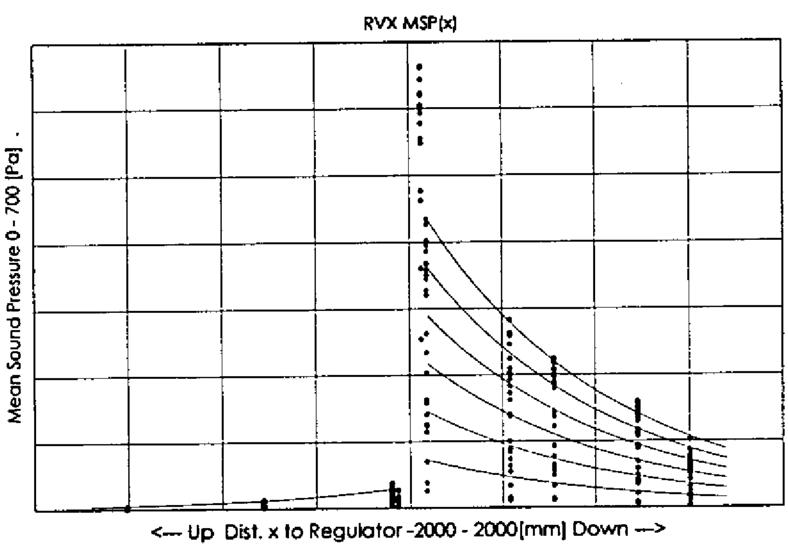

Figure 16: Mean Sound Power in the Range 50-500 kHz as a Function of Distance x for Non-Silent Regulator RVX

The results of sensors A and K are clearly very different from all other results. This shows that not only the source of the noise, the regulator is important, but also the up- and downstream pipe work and fittings. In this case, the up- and downstream valves may act as reflectors for the sound inside the pipe. When disregarding these results, the results of sensors B-D and L-P show an exponential decay with distance.
For illustration, a grid of exponential lines in the form $MSP(x) = MSP_0 * e^{-C*x}$ is drawn in the figure. The value x = 0 represents the middle of the regulator; the values of C and (maximum) MSP_0 are given in table 1.

Table 1 - Exponential Decay of Mean Sound Pressure with Distance

	Upstream of regulator		Downstream of regulator	
	RVX (non-silent)	RQX (silent)	RVX (non-silent)	RQX (silent)
C	-0.00012		-0.00010	
MSP_0 (max)	32	70	480	540

The exponent C gives the decay rate. In the frequency range 50-500 kHz, the upstream noise decays faster (C = -0.00012) than downstream noise (C = -0.00010). From the calculations with divided frequency ranges it follows that exponent C is larger for higher frequencies than for lower frequencies: the decay goes faster for higher frequencies

The base MSP_0, both upstream and downstream, is larger for the silent regulator RQX than for the non-silent regulator RVX. The "silent" regulator is producing more noise inside the pipe in the range of 50-500 kHz, than the "noisy" one. The ratio of noise for the two regulators RVX and RQX is not the same at the different sides of the regulator: upstream it is 0.5, downstream 0.9. These ratios change slightly with frequency.
Also, the base MSP_0 is much larger downstream than upstream for both regulators. This means that more noise is measured downstream of the regulator than upstream. The ratio downstream-upstream noise is not the same for these two regulators: 15 for regulator RVX and 7.7 for regulator RQX. These values are lower for higher frequencies, and higher for lower frequencies. Noise at lower frequencies is thus better "separated" by the regulator than noise at higher frequencies.

4 RESULTS ULTRASONIC METERS

4.1 Presentation of calibration results

The USM's are calibrated against the Gasunie reference flow meters during 3 times 100 s. For confidentiality reasons, the results of the calibrations of each USM in test situations with regulator are only presented as error shifts compared to the mean error of the same meter in "ideal flow": the calibration of the meter at the same pressure, when no regulator is mounted in the line. The results of these "ideal" calibrations are not presented in this paper.
A calibration of a USM under noise disturbed conditions is only sensible if the meter is functioning continuously. If one or more USM's are partially failing, one should assess its performance in another way, for example with a performance comparison method as described below.

4.2 A Performance Comparison Method

As ultrasonic meters are based on a measuring principle using a beam of sound, it is likely to expect that they may be disturbed by sound in the right frequency range and/or of sufficient power. Field experience learns that this is indeed the case. When both the ultrasonic beam and noise reach the receiving sensor of the USM, it will be more difficult or even impossible to detect the right signal out of it and from that, calculate a correct gas flow velocity. The output that is shown to the user, in this case the frequency of the pulse output, depends on signal strength, signal detection, analysis techniques and often also on user-set parameters.
The following four types of behaviour and the effect on the error curves of the meter, were observed in the experiments. In brackets the number of meters that showed this behaviour is given; one meter may be in different categories.

1 The meter fails, and the pulse output frequency is set to zero Hz. If the failure is complete, a meter error E of -100% will be found. If the meter only part of the time is failing, the error will be smaller. (4 meters).
2 The meter fails, and the pulse output frequency is set to a user specified "error-frequency", usually a frequency much higher than the maximum flow rate frequency. If the failure is complete, a high error E will be found. The value of E is dependent of the error-frequency, the frequency factor and the actual flow rate. If the meter is only partially failing, then the more it fails, the higher the meter error is. (1 meter).
3 The meter continues working but with a larger output variation. In the error curve more scatter will be observed. If the variation is on a relatively small time base, it is filtered out during the measurement time of in this case 100 s. (2 meters).
4 The meter continues working but with erroneous output. The resulting error shift is usually of several percents. The wrong output may be steady or switching between distinct values (2 meters).

For every test condition, each USM is given a "performance number" according to the scheme below. From all these performance numbers for each test set-up (USM's upstream or down-stream of the regulator, the latter at two distances), a mean performance number P_i is calculated for each individual USM and P_m for all USM's together[2].

100 %	IF	USM functions correctly all the time	AND meter error E is smaller than 1 %
90 %	IF	USM functions correctly all the time	AND E lies between 1 and 5 %,
	OR	USM functions but shows some alarms	AND E is smaller than 1 %
75%	IF	USM functions all the time	AND E lies between 5 and 20 %,
	OR	USM functions but gives regular alarms	AND E lies between 1 and 5 %
	OR	USM fails sometimes	AND E is smaller than 1 %
50 %	IF	USM fails sometimes	AND E lies between 1 and 5 %
	OR	USM functions only half of the time	AND E is smaller than 1 %
25 %	IF	USM functions only sometimes	AND E is smaller than 1 %
	OR	USM functions half of the time	AND E lies between 1 and 5 %
	OR	USM functions (almost) all the time	AND E is larger than 20 %
10 %	IF	USM functions only a few times shortly	
0 %	IF	USM is not functioning at all	

4.3 Results with USM's Upstream of the Regulator

Figure 17 and 18 show meter error shift curves for all six USM's located near the middle of the test section, upstream of the regulator which is mounted at the downstream end of the test section (RVX-DN and RQX-DN). These are the results of the experiments with fixed upstream pressure, 15, 24 or 36 bar(a), and varying flow rate. The curves are given as error shifts relative to the meter error $E_{mean,\,Base}$ from the calibration of the same USM at the same pressure but in absence of the regulator (see 2.6 and 4.1).

Except for the lowest flow rates, almost all error shifts are well within ±2 %. Although the noise is at relatively low level in these situations, at the lowest flow rates of less than 1.5 m/s, the shifts of some USM's are much larger: within ±15%. As almost all USM's kept on functioning almost all the time, the mean performance numbers P_m are 94% with the non-silent RVX regulator, and 93% with the silent RQX regulator. All meters were in one way or another affected by the noise, the maximum P_i was not 100% but 98%. For some USM's the noise from silent regulator RQX was more severe than the noise from non-silent regulator RVX: the lowest individual performance numbers P_i were 81% (RQX) vs. 91% (RVX).

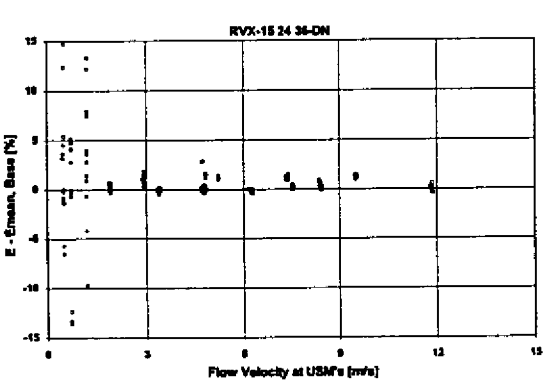

Figure 17: USM's Meter Error Shifts Upstream of Non-Silent Regulator RVX

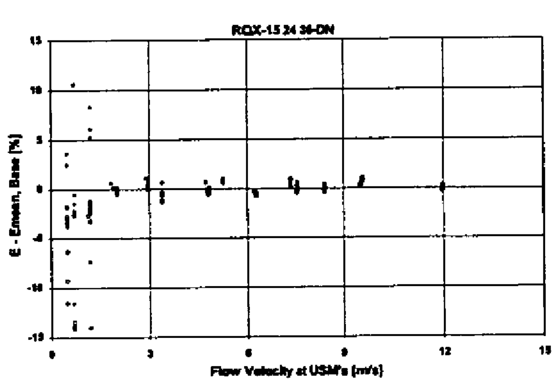

Figure 18: USM's Meter Error Shifts Upstream of Silent Regulator RQX

[2] Note that this is a selection scheme, in which error deviation and failing time are rated as good as equal. If one would appoint more value to the reliability of the answer or to the amount of time it is failing, this scheme and the mean performance numbers P_i and P_m could be quite different.

4.4 Results with USM's Downstream of the Regulator

Figures 19 and 20 show meter error shifts for all six USM's located at the end of the test section, as far as possible downstream of the at the upstream end mounted regulator (RVX-UP-L and RQX-UP-L). These situations are in two ways worse than with the USM's upstream of the regulator: downstream of the regulator the noise is considerably more than upstream, and the USM's operate at a lower pressure. The performance of the USM's is in these cases clearly much less than described above.

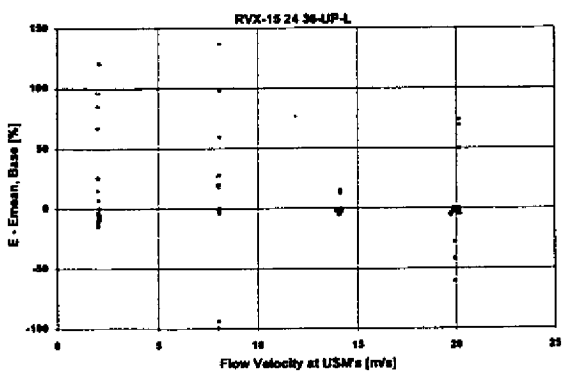

Figure 19: USM's Meter Error Shifts Downstream of Non-Silent Regulator RVX

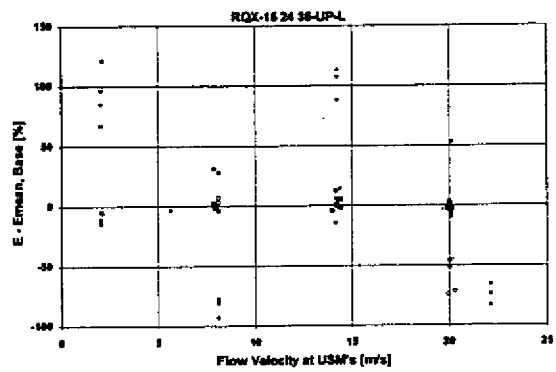

Figure 20: USM's Meter Error Shifts Downstream of Silent Regulator RQX

The figures show the 4 different meter behaviours, see 4.2:

1. USM's partially failing and, when failing, giving zero Hz output: error shifts of -50 to -100 %
2. USM's partially failing and, when failing, giving a (high) error frequency: error shifts of more than +50% (these may also be even more than +100%)
3. USM's that continue working, but output shows more fluctuation: the variation in data points around the x-axis is about twice as much as in figures 17 and 18.
4. USM's that "jump" between modes: mean error shift gives more variation, and may become very high (open circles).

With the non-silent RVX regulator the individual performance number P_i ranges from 34 to 87, and mean performance number P_m is 64 with a standard deviation of 22, and with the silent RQX regulator P_i ranges from 25 to 83; P_m is 58 with a standard deviation of 24.

When the USM's are located near the middle of the test section, which is closer to the regulator, more meters stop functioning, or are functioning less. Mean performance numbers P_m in these cases are: 53 with the non-silent RVX regulator and 49 with the silent regulator.

5 DISCUSSION

Before drawing conclusions, one should bear in mind the following:

- The situations tested here will always differ from field situations, and not only by the type and size of the regulator. For example the pipe work near the regulator (bends, valves, reducers etc.) has great influence on the noise that is measured in a certain position, due to reflection and/or absorption of noise. The pressure and flow control in the test installation (see 2.1) may influence the measured noise too. This work bears no illusion of being complete, but is more intended to make a step forward towards understanding USM's in noisy conditions.
- Immunity from noise is a subject for new developments for many meter manufacturers. In the past years, a great deal of work has been spent on this. Although this target has not been attained yet, many improvements have already been made.
- All experiments were performed with single path meters. For observing meter behaviour in noisy conditions only this is sufficient. However, for example when meter failure is not complete, the performance of a multi-path USM may be better than described in this paper.

- There is no "best meter". All meter characteristics, such as performance in pulsating flow, response times, maximum flows, error handling, and not to forget immunity from noise are a result of the specific combination of mechanical construction, path dimensions, techniques of sending and detecting of signals, signal analysis, filtering, etc. Many of these characteristics may also be influenced by a number of user-set parameters. For example: during the experiments, one meter kept on operating in almost all test conditions, albeit at the expense of large output variations; another meter was clearly indicating when it was failing, but if it was operating the output was highly reliable (no significant error shift nor variations). This makes it difficult to compare USM's, and select a "best one". A user should identify his specific conditions and needs, and select a meter accordingly.

6 CONCLUSIONS

- In-duct sound measurements near a Mokveld regulator were performed in which a "non-silent" RVX and a "silent" RQX internal cage were used. The regulator with RQX cage produces indeed considerable less audible noise outside the pipe, but more ultrasonic noise inside the pipe than with the RVX cage.
- The measured mean sound pressures of the noise fit logarithmically with the product of flow rate through and pressure difference across the regulator.
- Downstream of the regulator more noise was measured than upstream, and also relatively more low frequency noise.
- With distance the noise decays exponentially, and this decay is stronger for higher frequencies. The exponent C is larger upstream than downstream, which is a result of the frequency distribution: upstream relatively more higher frequency noise was registered.
- USM's may behave differently when subjected to noise: 4 different categories of behaviour were described. Many factors, including user-set parameters, influence the type of behaviour a meter adopts in a given situation.
- In general, a USM functions better when it is mounted upstream from the regulator, where the sound pressure is considerably less, and the operational pressure is higher. Furthermore because of the frequency distribution, the noise decays a bit faster than downstream, thus the effect of shifting the meter away from the regulator is larger.
- The mean performance of all USM's with the non-silent regulator cage RVX is better than with the silent cage RQX.
- The worst case (USM's at close distance to RQX regulator) still resulted in a mean performance number of 49%. The best case resulted in a mean performance number of 94%. This indicates that it is indeed possible to measure gas flows with USM's in the vicinity of a regulator. However, at this moment not with all meters and not under all circumstances.
- The work described in this paper is far from complete. In order to get a full picture of noise generated by regulators, future research could perform similar experiments under different circumstances: other pressure reducing devices, different flow and pressure regimes, varying distances to the regulator, and studying the effect of other devices such as bends and diffusers in the flow.
- Manufacturers of USM's have done a great deal of work on immunity from noise, and have already reached a number of successes. Although several meters have shown very good performances, no meter is perfect under every condition. Further development will be necessary. From the users point of view, more co-operation between the manufacturers could be a good idea.

7 ACKNOWLEDGEMENTS

The authors wish to express their gratitude to all who contributed to this part of the GERG project, which are to many to be named here: colleagues from the gas companies participating in the project, representatives from the manufacturers who made available equipment and expertise to the project, and several colleagues from within Gasunie.

8 REFERENCES

[1] Lygre, A., Lunde, P., and Frøysa, K.-E.: *Present Status and Future Research on Multi-Path Ultrasonic Gas Flow Meters*. GERG Technical Monograph Nr. 8 (1995).

[2] Hilgenstock, A., Hüwener, Th., and Nath, B.: *Kalibra® - A Fast Numerical Method for Determining Installation Effects in Ultrasonic Flowmeters*. 9th International Conference on Flow Measurement FLOMEKO '98. Lund, Sweden.

[3] Lunde, P., Frøysa, K.-E., and Vestrheim, M.: *Garuso version 1.0. Uncertainty Model for Multipath Ultrasonic Transit Time Gas Flow Meters*. CMR report no. CMR-97-A10014.

[4] Development of procedures to evaluate transducers: to be published by Statoil in 1998.

[5] Brassier, P., Hosten, B., Castaings, M., and Vulovic, F.: *Study of Ultrasonic Disturbances in Gas Pipelines*. Université de Bordeaux and Gaz de France, December 1997.

[6] Rogi, M.J., Williamson, I.D., and McBrien, R.K.: *Single Path Ultrasonic Meters, Performance Evaluation and Operational Experience*. A.G.A. Op. Conf. 1996, Montreal.

[7] Smits, T.C.L.: *Acoustic Noise Investigation GASSONIC ® - 400 Ruhrgas Winterswijk*. Stork Servex report 014853.TST.001. August 1994.

[8] Agricola, J.B.: *Gas Well Flowline Measurement by Ultrasonic Flow Meter*. North Sea Flow Measurement Workshop 1997. Norway

[9] American Gas Association. *Ultrasonic Flow Measurement for Natural Gas Applications*. Engineering Technical Note M-96-2-3, March 1996. Darlington, Virginia.

[10] Kristensen, B.D., Lofsei, C., Frøysa, K.-E.: *Testing of Noise Suppression System for Multipath Ultrasonic Gas Flow Meters*. North Sea Flow Measurement Workshop 1997.

[11] Bloemendaal, K. van, and Kam, P.M.A. van der: *Installation Effects on Multi-Path Ultrasonic Flow Meters: the Ultraflow Project*. North Sea Flow Measurement Workshop 1994. Scotland, UK.

[12] Vulovic, F., Harbrink, B., and Bloemendaal, K. van: *Installation Effects on a Multipath Ultrasonic Flow Meter Designed for Profile disturbances*. North Sea Flow Measurement Workshop 1995, Norway.

[13] Bruggeman, J.C., Hopmans, L.J.M., Looijmnas, K.H.N.: *Sound Power Radiated into Pipes by Control Valves*. TNO report TPD-HAG-RPT-960041. April 1996.

[14] Frøysa, K.-E., Lunde, P., Sakariassen, R., Grendstad, J., and Norheim, R.: *Operations of Multipath Ultrasonic Gas Flow Meters in Noisy Environments*. North Sea Flow Measurement Workshop 1996. Scotland, UK.

[15] *Control Valves*. Commercial brochure Mokveld Valves B.V., Gouda, The Netherlands.

[16] *Series 132A30 & A40. ICP® Microsensor for High Frequency and Dynamic Pressure Measurement*. Commercial brochure PCB Piezotronics Inc., Depew, NY, USA.

[17] Norton, M.P.: *Fundamentals of Noise and Vibration Analysis for engineers*. Cambridge University Press, 1989.

9 NOTATION

dP	Pressure difference across regulator	[bar]
E	Meter Error $(Q_{meter} - Q_{reference})/Q_{reference} * 100$ %	[%]
$E_{mean, Base}$	Mean Meter Error in baseline calibration at the same pressure	[%]
MSP	Mean Sound Pressure	[Pa]
P_i	Performance number for individual USM, based on all test conditions	[%]
P_m	Mean performance number for all USM's, based on all test conditions	[%]
USM	UltraSonic (gas flow) Meter	[-]
Q	Flow rate	[m^3/h (s)]
V	Valve position in percentage of maximum (=open)	[%]
x	Distance to regulator	[mm]

Tests are indicated with codes in the form RRR-FF-PP-N, or parts of these., which stands for:

RRR =	RVX or RQX	Regulator with standard "non-silent" cage RVX or with "silent" cage RQX
FF =	9, 15, 24 or 36	Test pressure of 9, 15, 24 or 36 bar(a), and variable flow rate
FF =	LO or HI	Flow rate is LOw or High, 6800 or 17000 m3/h (s), pressure variable
PP =	UP or DN	Regulator at UPstream or DowNstream end of the test section
N =	M, L	USM's spool piece at Medium or Long distance from regulator

APPENDIX A

Table A1: Indication of local gas velocities in m/s at USM's for each flow rate as a function of pressure at USM's.

Flow rate in m3/h(s)	USM's donwstream of regulator 9 bar(a)	USM's upstream of regulator 15 bar(a)	USM's upstream of regulator 24 bar(a)	USM's upstream of regulator 26 bar(a)
27000	32	19	12	8
22000	26	15	10	6
17000	20	12	7	5
12000	14	8	5	3
6800	8	5	3	2
1700	2	1	1	1