North Sea

FLOW

Measurement Workshop

1998

PAPER 7 - 2.3

ULTRASONIC NOISE CHARACTERISTICS OF VALVES WITH RESPECT TO ULTRASONIC GAS FLOW METERS

G de Boer, Instromet Ultrasonics B.V.
Dr P Stoll, Verbundnetz Gas AG

16th NORTH SEA FLOW MEASUREMENT WORKSHOP 1998

ULTRASONIC NOISE CHARACTERISTICS OF VALVES WITH RESPECT TO ULTRASONIC GAS FLOWMETERS

Dr. Peter Stoll, Verbundnetz Gas AG
Heiko Slawig, Verbundnetz Gas AG
Carsten Müller, PLEcon
Geeuwke de Boer, Instromet Ultrasonics B.V.
Marcel Vermeulen, Instromet Ultrasonics B.V.

ABSTRACT

The subject of this paper is a series of tests with an ultrasonic gasflow meter, control valves of three different designs and silencers of three different designs, operating under various conditions regarding pressure cut and flow rate.

The paper is split up into two sections, the first section, prepared by Verbundnetz Gas, deals with the issues of specific interest of Verbundnetz Gas, that is the design of a suitable solution and the verification of its functionality for the expansion of the measuring facilities at the location Sayda.

The second section, prepared by Instromet Ultrasonics, presents, based on the data acquired during the tests at Sayda, a more general approach for characterising the ultrasonic noise aspects of control valves and piping elements. Based on this characterisation a model is presented that can be used to predict whether an ultrasonic meter can function properly under specific conditions.

SECTION 1: ULTRASONIC NOSIE TESTS WITH VALVES, SILENCERS AND AN ULTRASONIC METERS AT SAYDA

1 WHO IS VERBUNDNETZ GAS (VNG) AG?

VNG AG is the second-largest gas importer in the Federal Republic of Germany. It operates in the new federal states and in Berlin, and has, in this supply area, a comprehensive network of around 8100 km of high-pressure gas pipelines with operating pressures ranges up to 25, 45 and 84 bar.

VNG operates 7 underground gas storage's with a storage capacity of approx. $2{,}4 \cdot 10^9$ m³ as well as 5 compressor stations with a total power of 60 MW.

This network is connected to the Western European and Eastern European gas transit systems at three points and thus makes it possible to obtain gas both from Western European sources and from Russia.

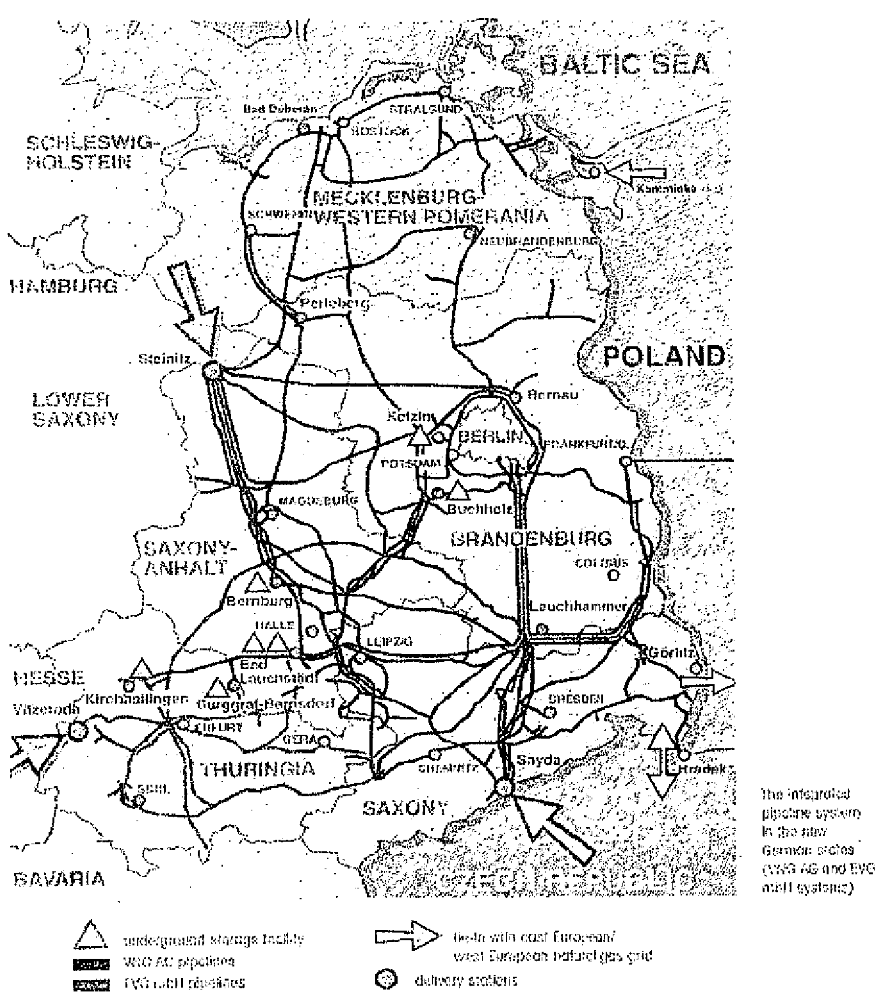


Figure 1 - VNG

2 WHAT WAS THE PROBLEM?

VNG AG had to reconstruct one of its main feed stations in Sayda. The purpose of the new plant was to measure and regulate the gas flows for all outgoing gas pipelines, and to ensure a flexible combination and switching between different flows.

In order to meet these requirements, the measuring and control devices must be used bi-directional. In order to avoid high cost of bypasses (this would have resulted in additional costs of approx. DM 1.5 mill.), the concept provided for using bi-directional ultrasonic measurement devices and operating some of the control valves in a reverse direction.

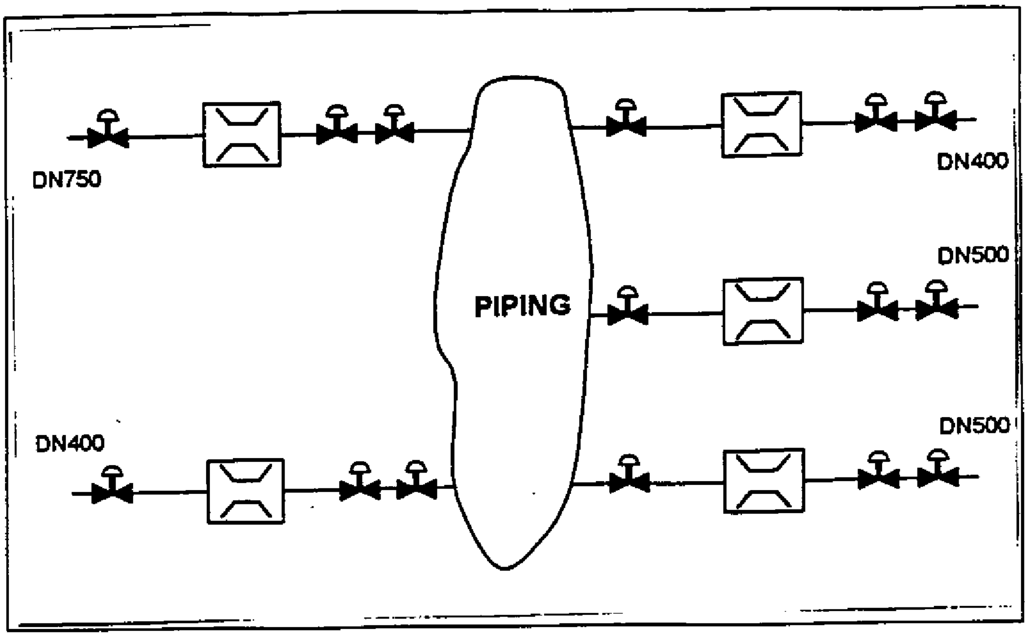


Figure 2 - Sayda

Our own experience, as well as discussions with partners from other gas supply companies, as well as the company Instromet, had shown that ultrasonic measuring devices which are located in close vicinity of control valves may suffer from interference from the ultrasonic noise generated in the control valves. This can lead to complete failure of the measurement.

The ultrasonic meters used by VNG AG so far were either located at sufficient distance from the control valves, or acoustically de-coupled by installing heat exchangers between the control valve and the ultrasonic meter. Noise produced at pressure differentials of 30 bar across the control valve and flow rates of 30 m/s did not interfere with the measurement.

3 WHAT HAS BEEN DONE?

In order to make sure that the planned plant design would function well we decided to:

... Test several control valves with regard to their noise emission in the ultrasonic range at different flow rates (also reverse)

... Develop and test silencing devices which can be installed between the control valve and the ultrasonic meter and provide high attenuation in the relevant ultrasonic range (100-200 kHz)

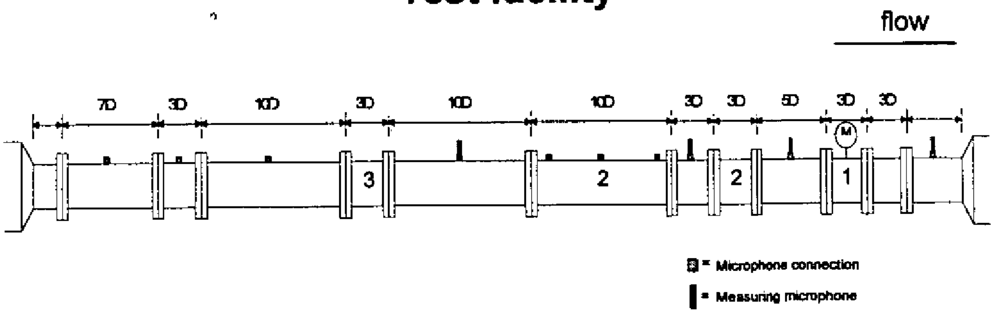
... Determine limits for the noise level up to which ultrasonic meters are able to work reliably.

For this purpose, a test run was built at Sayda in DN 300, PN 84, the basic design of which is presented in Figure 3. In the direction of the flow, the control unit (1), the silencer (2) and the ultrasonic meter (3) with inlet and outlet piping were flanged to each other via spool pieces.

The spool pieces between the units were equipped with appropriate connections for measuring microphones so that it was possible to measure the sound pressure before and after the control valve and directly at the meter.

The sound level was simultaneously measured in the frequency range from 1 kHz to 1000 kHz at 4 measuring connections using a storage oscilloscope.

Test facility



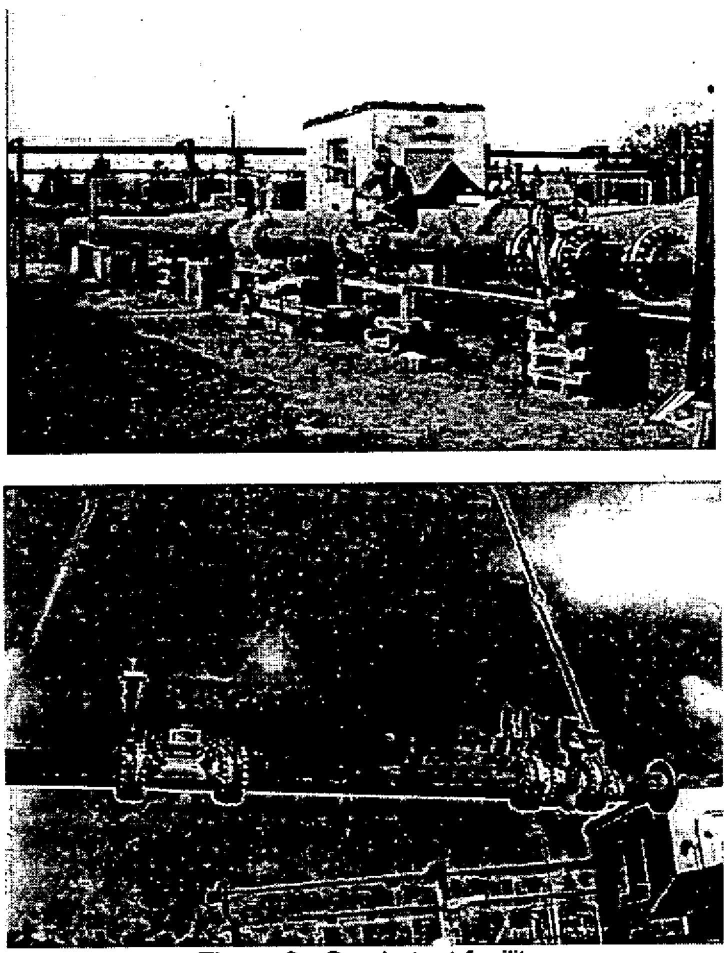


Figure 3 - Sayda test facility

In addition, suitable software was used to record the difference between the actual gain as set, and the maximum allowable gain as calculated, for the automatic gain control function, that controls the signal levels of the individual paths. Indirectly, these measured parameters supplied information about the signal-to-noise ratio.

The measuring arrangement was changed several times during the tests. The following devices were used:

1)	Ultrasonic meter	5-path US meter
2)	Control unit A	Control valve with multiple cage
	Control unit B	Ball valve type control valve

3) Silencer S1 — 10 D spoolpiece with 2 internal pipe bundles
Silencer S2 — 3 D adapter with perforated plates parallel to the flow direction
Silencer S3 — 13 D adapter consisting of pipe fittings

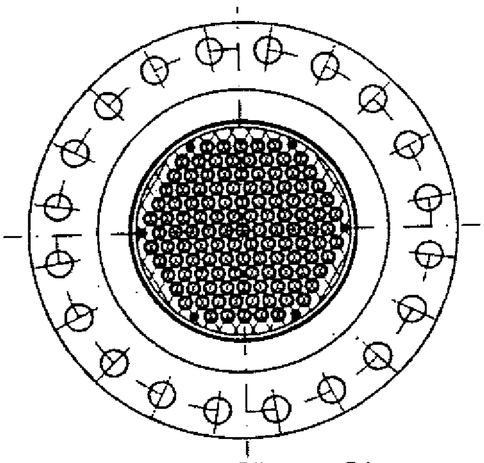


Figure 4 - Silencer S1

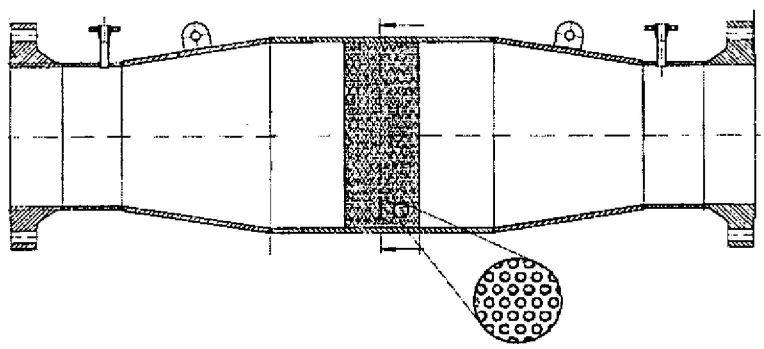


Figure 5 - Silencer S2

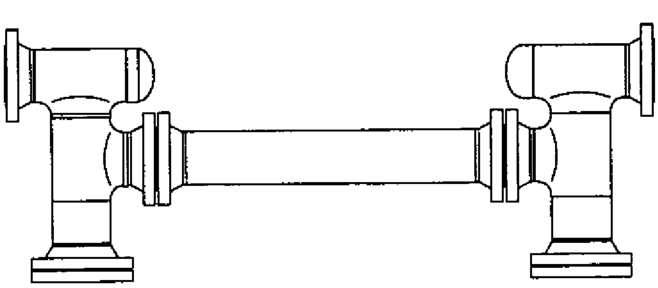


Figure 6 - Silencer S3

4 WHAT ARE THE RESULTS?

The results described below are examples from a series of measurements where sound spectra were recorded at various measuring points in the test section. At the same time the function of the US meter was monitored. The configuration of the test section was changed several times, and flow and pressure conditions were varied as much as possible.

4.1 Normal Operation of Control Devices

Figures 7 and 8 show the sound spectra of 2 control devices at different pressure differentials ΔP. The flow rate for all tests was in the range of 7 to 9 m/s. It becomes obvious that the control device B, due to its design and the associated higher K_v value, generates a smaller pressure loss in the fully opened state. Thus noise generation in the US range is lower than with control device A. For a partially opened valve where ΔP is of equal magnitude for both units, the noise generation in this example is comparable, independent of valve design.

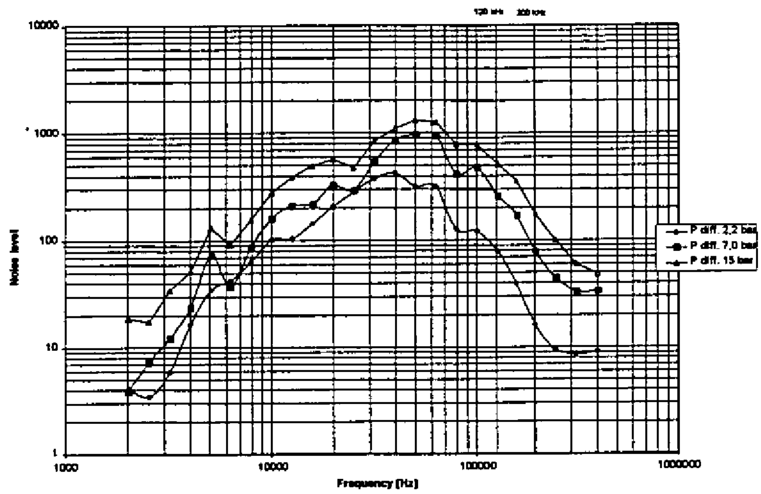


Figure 7 - Sound spectra for control device A

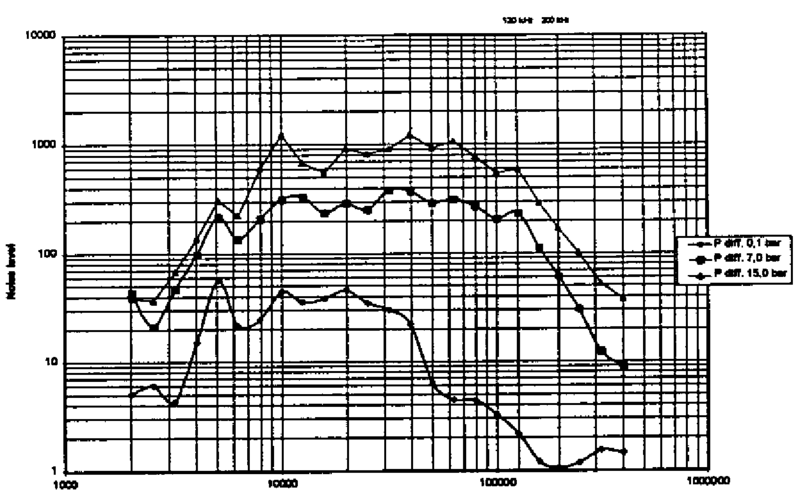


Figure 8 - Sound spectra for control device B

4.2 Reverse Operation of Control Devices

Figure 9 shows the sound spectra obtained when the units are installed in the gas flow direction (normal) as envisaged by the manufacturer compared with the results obtained for reverse installation. In both modes of operation, the ultrasonic sound emission levels differ only slightly between the units. For both units, they are lower by the factor 2 - 3 in the case of reverse installation. This means that the envisaged bi-directional use of the control devices will not bring any additional risks for meter interference.

SECTION 2: VALVE CHARACTERISATION AND NOISE MODEL

1 INTRODUCTION

As outlined in the previous section Verbundnetz Gas performed an extensive series of test in order to assess the performance of the Q-Sonic Ultrasonic flow meter when subject to ultrasonic noise as generated by control valves. The tests included a variety of

- operating conditions (pressure cut and flowrate)
- equipment arrangements and flow directions
- pressure or flow control valves

The operation of the Q-Sonic was judged by comparing the measured flow rate to another flow meter (turbine meter) and by observing the performance indicators presented by the meter's internal diagnostics.

Instromet supported the test program by providing flow meters, instrumentation for measuring acoustic noise levels and assistance in the processing and analysing of the acquired data. The data from this test program was of great value in the framework of Instromet's research on ultrasonic noise affecting ultrasonic flow meters.

2 HISTORY

Since the successful introduction of Instromet's ultrasonic flow meters for measuring gas flow (late eighties: single path meters; early nineties: multipath meters) such flow meters are operating satisfactorily in an increasing number of applications.

However, with the increase in numbers, some applications were encountered where ultrasonic noise created by pressure or flow regulators caused problems. When Instromet started to investigate this problem area it became apparent that hardly any information on noise was available, especially in the ultrasonic range and in high-pressure pipelines. Although models were available describing the ultrasonic noise generation for the audible range, extensions of these models to the ultrasonic range were hardly supported by any experimental data.

For this reason Instromet started a research program to measure and investigate the ultrasonic noise generated and perceived in high-pressure gas pipelines, where pressure regulators appear to be the most prominent sources for such noise.

3 OBJECTIVE

The objective of measuring and analysing the ultrasonic noise was:

- to obtain basic data and information needed for designing ultrasonic flow meters with improved noise immunity, and
- to obtain data for building a model that can be used to predict, in the first place, the noise levels generated and, secondly, the performance of an ultrasonic flow meter subject to the ultrasonic noise levels thus predicted.

Needless to say that Instromet's first objective is to improve the noise immunity of its ultrasonic flow meter family. Data characterising the ultrasonic noise is essential information for that purpose. We expect that the application of advanced signal processing techniques will introduce improvements, but will still not resolve every problem. For a limited number of applications it may remain inevitable to use additional noise abating equipment such as a silencer. This requires tools to asses a particular application in terms of expected ultrasonic noise levels and to calculate - if necessary - the amount of attenuation of the ultrasonic noise required and that has to be implemented by means of a silencer or other measures. In addition to this the effectiveness of silencing devices has to be addressed.

4 THE MODEL

4.1 Theory on Noise Generation

Pressure regulators are seen as the main source of ultrasonic noise. Therefore pressure regulators should be characterised in terms of noise generation, dependent of operational conditions such as pressure drop and flow rate.

For this characterisation a good starting point is the model described by Reethof and Ward. The acoustic power produced by a control valve can, according to Reethof and Ward, be described as:

$$W_a \propto \Phi_m \cdot c_1^{\,2} \cdot \left[\frac{2}{\gamma - 1} \left\{ \left(\frac{P_1}{P_{vc}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right\} \right]^{5/2} \left(\frac{P_1}{P_{vc}} \right)^{\gamma + \frac{1}{\gamma} - 1} \tag{1}$$

Where W_a is acoustic power, Φ_m is massflow, c_1 is velocity of sound upstream, $\gamma = C_p/C_v$, P_1 is pressure upstream and P_{vc} is the pressure in the vena contracta. P_{vc} is related to the valve characteristics and can be described by the pressure recovery coefficient F_L:

Figure 1 - Pressure change

$$F_L = \frac{P_1 - P_2}{P_1 - P_{vc}} \tag{2}$$

Remarks:

- When $P_1 = P_2$ (high recovery) than $F_L = 0$,
- When $P_2 = P_{vc}$ (no recovery) than $F_L = 1$, and
- F_L can be related to the opening of one type of valve (α_v). Example: $F_L = 1 - 0.45\alpha_v$.

The acoustic power can be calculated acording to expression 1 To determine the functionality of an ultrasonic analyzer we do not use acoustic power but acoustic pressure. According to Morse and Ingard the acoustic pressure is:

$$p_a = 2 \cdot \sqrt{\frac{W_a \cdot \rho \cdot c}{A}} \tag{3}$$

Here p_a is the acoustic pressure, ρ is the gas density, c is the velocity of sound and A is the surface of the cross area of the pipe.

4.2 A Practical Indicator

Expressions (1), (2) and (3) indicate that important parameters for estimating the ultrasonic noise levels are the massflow and pressure ratios. However these expressions are not very practical for direct use and the validity in the ultrasonic range needs further investigation as well. Additionally we are in fact not interested in the noise level but looking for a method of calculation for an indicative value, predicting whether the meter can perform satisfactory under given conditions or not.

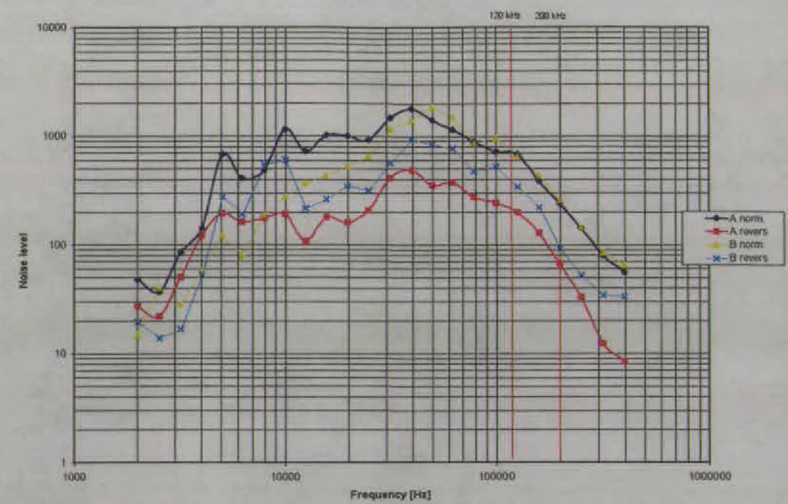


Figure 9 - Sound spectra for control devices A / B normal and reverse

4.3 Silencers

Another test was carried out to study the attenuation characteristics of the 3 silencer designs. Figure 10 shows this for a flow rate of approx. 6 m/s. In the frequency range relevant for the transducer, the sound absorbers S2 and S3 show an attenuation of more than 20 dB. Silencer S1 requires further optimisation for this range, as an attenuation of more than 20 dB is only reached in the range of 65 - 110 kHz.

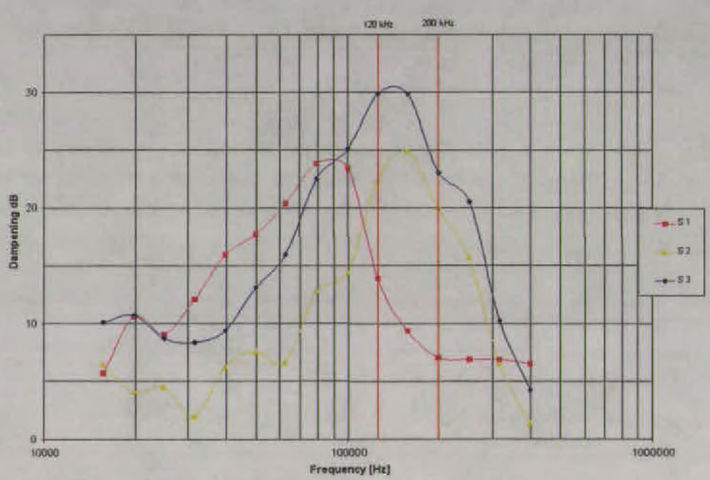


Figure 10 - Attenuation curve of the 3 silencers

4.4 Meters

The log file from the meter electronics was recorded as long as the ultrasonic meter was fully operational. This file contains, among other data, the values of automatic gain control levels and automatic gain control limits of the individual paths. The ratio reflects the actual signal to noise ratio and can be seen as a gain margin.

Previous tests showed that a reliable function of the US meter is ensured up to a gain margin of > 10 dB.

The Figures below show the flow rates at definite points of time together with the associated gain margin of the critical path (in general path 2b).

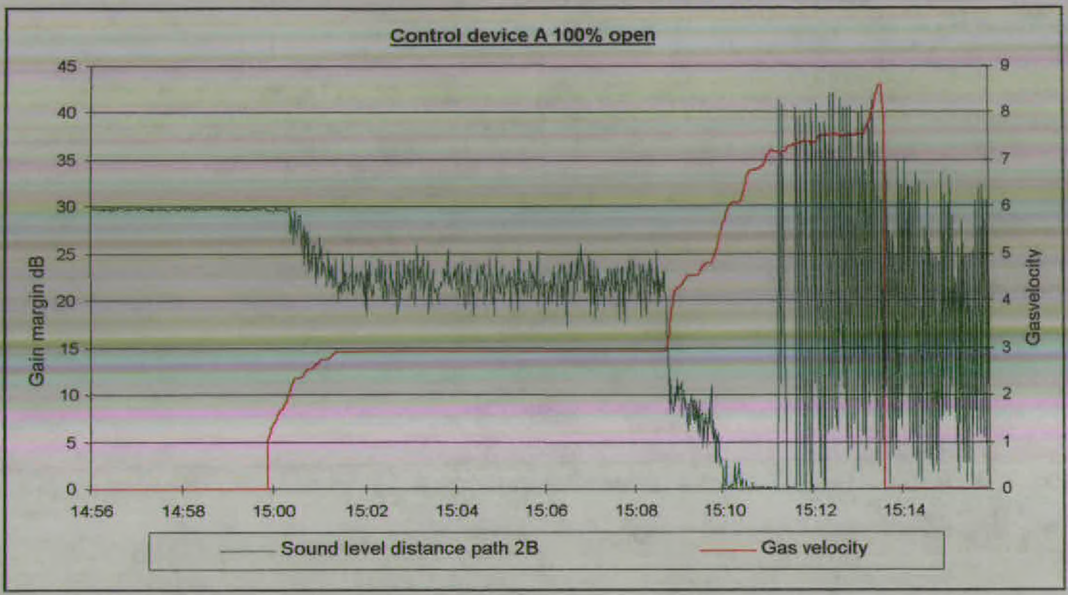


Figure 11 - Functionality of flowmeter w.r.t. gasflow (control valve A)

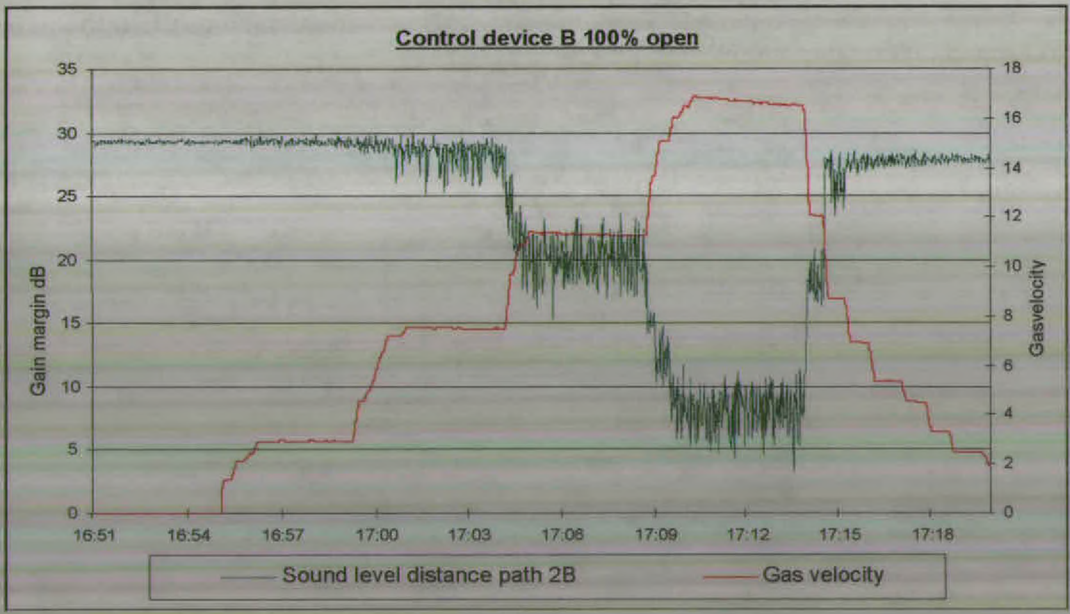


Figure 12 - Functionality of flowmeter w.r.t. gasflow (control valve B)

Figures 11 and 12 show that the US meter fails despite the 100% opening of control device A at a gas velocity of approx. 7 m/s. With control device B (high K_V value), reliable operation is possible up to about 16 m/s. Meter failure is characterised by oscillation of the gain control. As long as other, less critical paths are still operational, the meter will still indicate a flow rate, eventually with reduced accuracy. This behaviour is in agreement with the measuring results from the sound spectra.

For the next tests, a silencer with an attenuation of approx. 20 dB was installed between the control device B and the US meter (version S3).

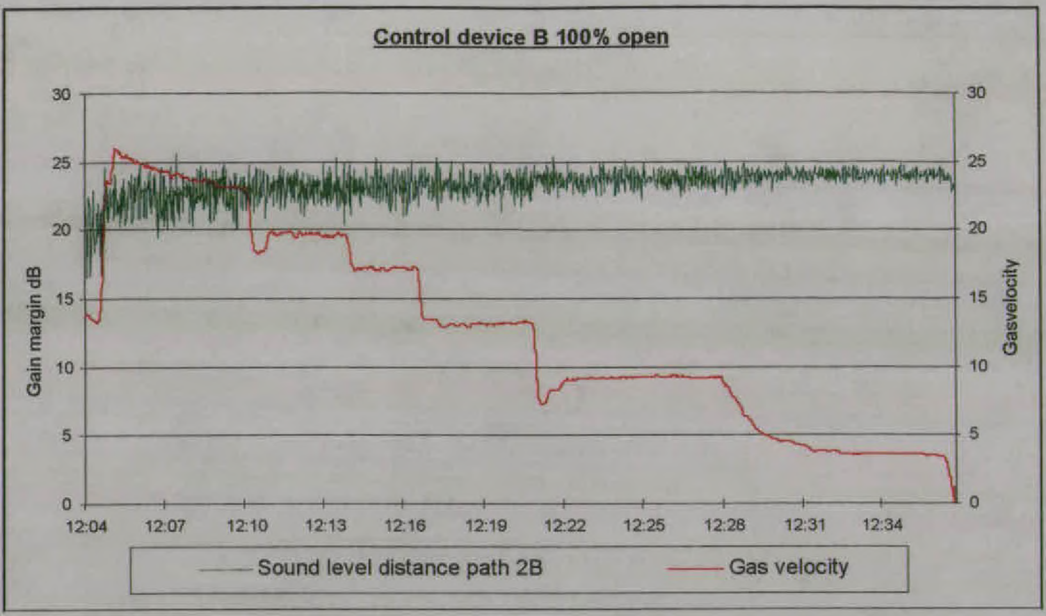


Figure13 - Functionality of flowmeter w.r.t. gasflow (silencer S3, control valve B)

Figure 13 shows clearly that in this case even flow rates of 25 m/s (100 % opening) do not result in any significant reduction in the gain margin.

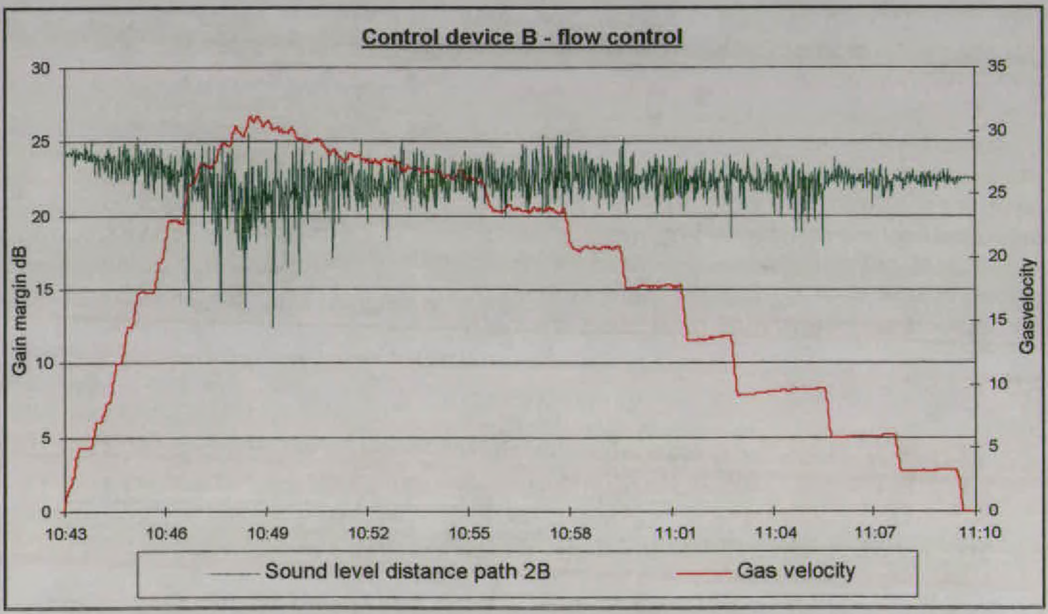


Figure 14 - Functionality of flowmeter w.r.t. gasflow (silencer S3, control valve B)

Figure 14 shows the result of a flow using control unit B between

full load 34 m/s = 8,000 m^3/h and
partial load 0.4 m/s = 100 m^3/h.

This corresponds to the future application (flow control). Again, the gain margin stays in the safe functional range so that there is no risk of meter interference.

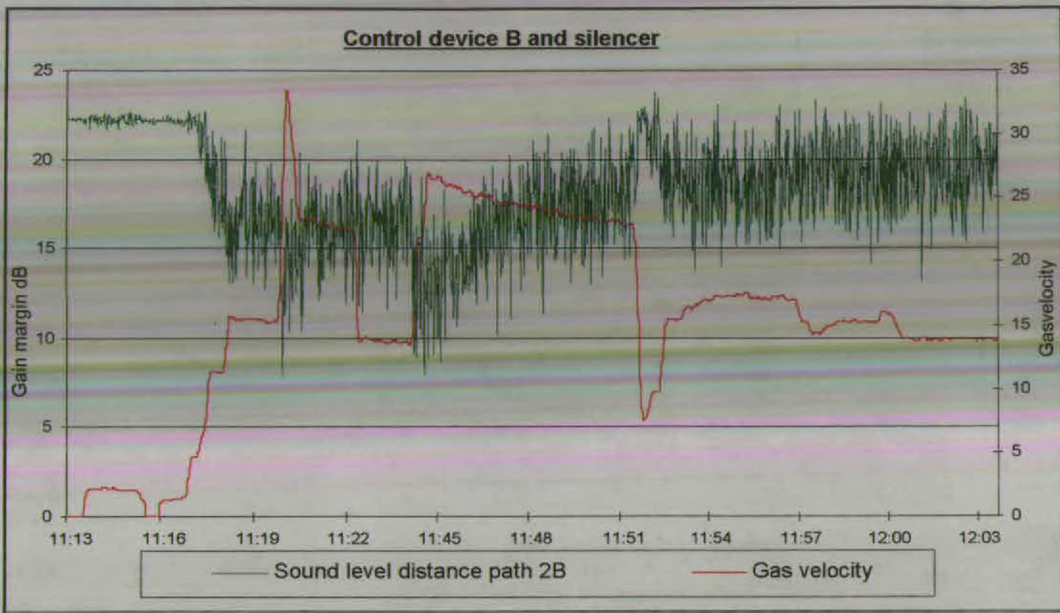


Figure 15 - Functionality of flowmeter w.r.t. gasflow (control valve B, silencer S3)

The last figure (15) shows the conditions at a high differential pressure across the control device and different flow rates. It can be seen clearly that even for the most critical operating case (V = 26 m/s, ΔP = 8.9 bar, opening degree 67%) which can be reached during the test, the installation of the silencer will ensure a gain margin > 10 dB and thus the reliable function of the meter.

5 SUMMARY

The examples shown demonstrate that because of a possible interference in US meters caused by control valves, some important aspects have to be taken into account during plant design. If it is not possible to acoustically de-couple the meter and the control device by existing elements such as bends, tees, heat exchangers etc, the installation of specifically designed sound absorbers may be a good alternative.

ACKNOWLEDGEMENT

The authors wish to thank the companies INSTROMET, RMG, ARTEC and MOKVELD which were involved in the tests, for their commitment and help. Without the many years of close co-operation with the gentlemen Drenthen, de Boer and Kurth from INSTROMET such a comprehensive test program would not have been possible.

Thanks also to Dr. Dane and Mr. Vermeulen for the processing of the comprehensive test material.

Therefore not only the noise level (acoustic pressure) generated by the valve should be taken into account but ultrasonic flow meter characteristics and properties of piping, such as elbows and tee's, and silencers (if applicable) should be represented as well. The indicative value looked for can be seen as reflecting the signal to noise ratio as perceived by the ultrasonic flowmeter. By convention we will use a value proportional to the inverse (noise to signal ratio). Hence, a large number will represent severe conditions whereas a smaller number will represent more relaxed conditions.

4.3 Piping Elements

Based on linear systems theory we assume that effects from piping elements can be represented by a number indicating the attenuation of ultrasonic sound in the relevant frequency band. The effect of several piping elements is represented by a number N_d, which is the multiplication of the contributions of all separate elements.

4.4 Valve Representation

Instead of using complex expressions modelling specific valve design details, a more simple and general model based on the energy dissipation in the valve was adopted. A specific valve is characterised with a number N_v, which is proportional to the noise emission of that design in comparison to other valves, when operated at identical conditions. We defined N_v to be 1 for an "average" type of valve. Valves generating higher or lower noise levels, compared to the "average valve", will have a value N_v higher respectively lower than 1 (range of N_v between 0.2 and 4). As it is found that valves do exhibit different noise emission levels in upstream and downstream direction, two different numbers, one for the upstream emission and one for the downstream emission may be needed.

4.5 Practical Model

Based on the assumptions made above, a simple and practical model predicting the performance of an ultrasonic meter subject to noise can be written as:

$$\delta = k \cdot F(..) \cdot N_v \cdot N_d \tag{4}$$

In this expression F(..) reflects the noise to signal ratio due to the valve and the ultrasonic meter characteristics under the given operating conditions and k is a constant in order to make the result dimensionless.

In order to represent the noise level generated by the valve and with reference to expressions (1), (2) and (3). Variables that may appear in the expression for F(..) are P1, P2 or ΔP, Φ, ρ, c and D.

Parameters relevant for the ultrasonic meter's signal strength are P or ρ or c and D.

A reasonable and acceptable fit with empirical data was found when the expression for F(..) reads as:

$$F(..) = F(P, \Delta P, \Phi, T, D) = \frac{\Delta P}{P}\sqrt{\frac{\Phi \cdot D^2}{T}} \tag{5}$$

Here P [bar] is the pressure at the ultrasonic flowmeter, ΔP [bar] is the pressure difference across the control valve, Φ [Nm^3/h] is the normalised flow, D [m] is the diameter of the pipeline and T [s] is the integration time.

5 NOISE EMISSION DATA OF VALVES

At the test site in Sayda the parameters relevant to the ultrasonic meter's signal strength such as size and static operating pressure can be supposed to be constant. The expression F(..) should then be proportional to the strength of the ultrasonic noise generated by the valve. In the test configuration the acoustic noise up- and downstream of the valve are measured at different flow rates and pressure drops accross the control valve.

Figure 2 shows the correlation between the measured noise level and the calculated value of the function F(..). The results of three types of valves are referenced as A, B and C. The valves are tested in the normal way (Figure 2) and in reverse direction (not presented in this paper). Also the noise is measured downstream (D, Figure 2) and upstream (not presented) of the valve. Upstream and downstream is always referenced relative to the gasflow direction.

The graph shows the actual measured data by means of the symbols. There is a more or less linear relation between the measured acoustic noise and the calculated value of the function F(..) which is represented by the regression lines shown as well. The slope (tangent) of the regression line is proportional to N_v in the expression (5). N_v is dependent of the type of valve and as well dependent of the flow direction in the valve (normal or reversed).

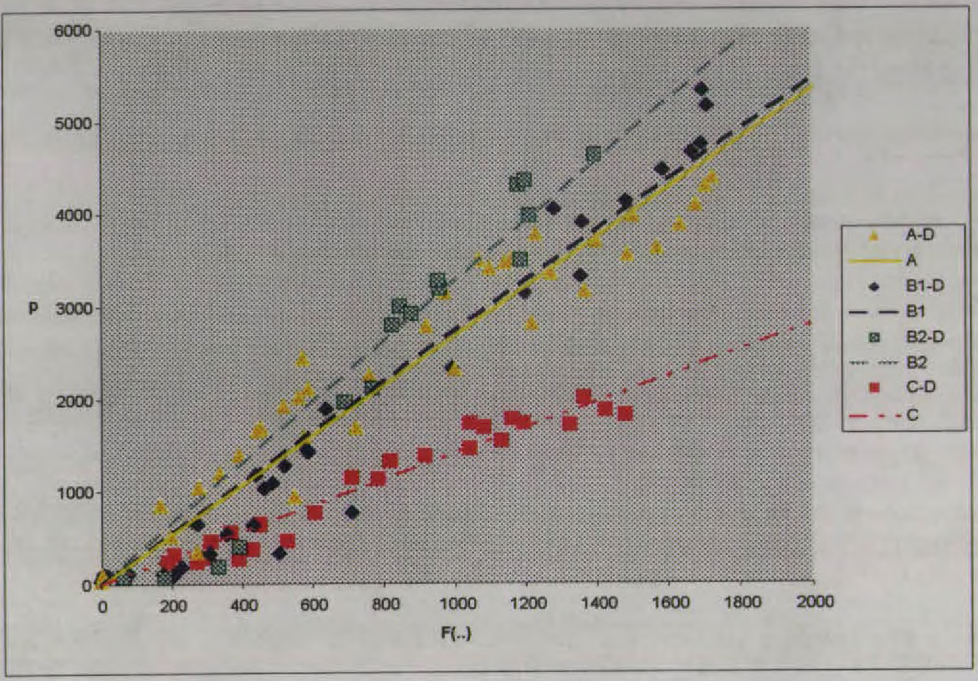


Figure 2 - Relation between F(..) and p_a (estimation of N_v)

6 EFFECT OF PIPING ELEMENTS E.G. SILENCERS.

All elements present in an installation generate or attenuate acoustic noise. The attenuation is frequency dependent and can also be flow dependent. The attenuation of a piping element can be estimated by comparison of the noise levels up- and downstream of that element. Table 1 shows the attenuation due to different piping elements.

Analyzing the frequency spectrum of the noise (see Figure 3 for one example of valve C it can be concluded that the spectra are broad banded with a maximum somewher between the 30 and 90 kHz.

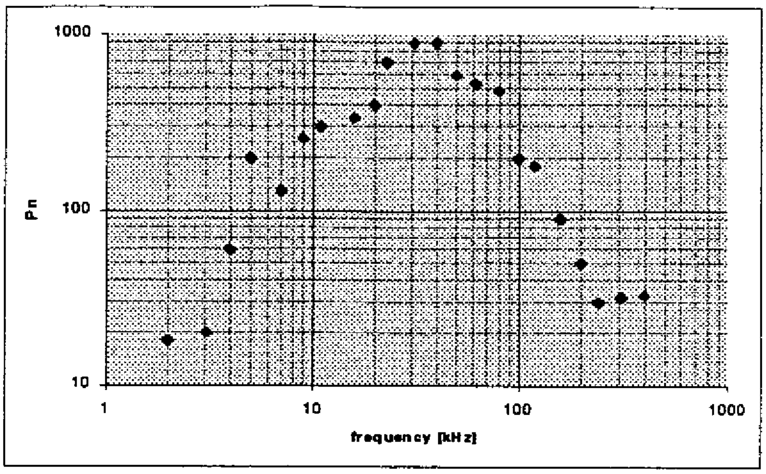


Figure 3 - Spectra of the acoustic noise of valve C, P: 51.4>39 bar, F=180.000 Nm^3/h

Previously it was supposed that designs for so called "low noise" valves ("low noise" in this case stands for low energy levels in the audible frequency range) shifted the noise emission to the higher frequency range. Comparing the frequency spectra and noise levels of different valves shows that this is not necessarily true.

Whereas bends and tee's show significant attenuation of ultrasonic noise, straight pipe has little to almost no effect. In case the noise level exeeds acceptable limits, additional bends or tee's can be installed to act as silencer or silencers specifically designed for this purpose can be used. Such a silencer has to be engineered for a specific kind of application (e.g. dependent of frequency). At Sayda three types of silencers (S_1, S_2 and S_3) were tested by measuring the attenuation of the ultrasonic noise.

The results of the acoustic measurements are shown in Figure 4^{a-c}. This Figure shows the relation between the acoustic noise level entering the silencer (p_{in}) and the acoustic noise level leaving the silencer (p_{out}). The ratio represents the degree of attenuation.

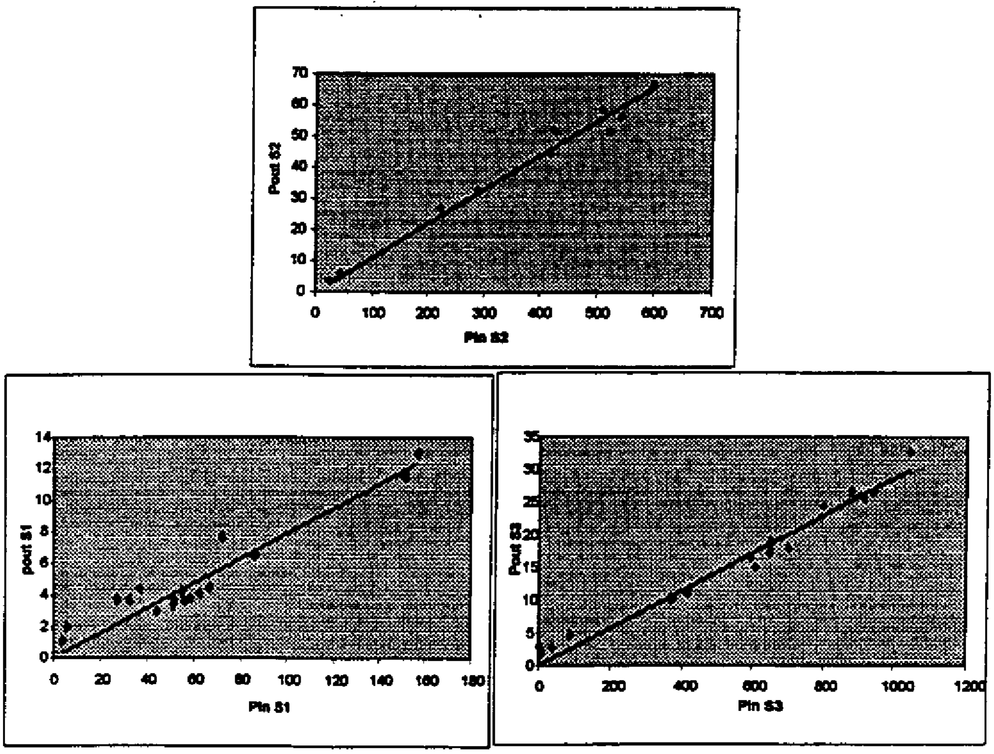


Figure 4^{a-c} - Attenuation of ultrasonic noise in the frequency band of a standard transducer

A usual way to present the ratios is in dB. Because we use here the acoustic pressure (instead of acoustic power) the ratio in dB is:

$$Ratio[dB] = 20 \cdot Log\left[\frac{p_{out}}{p_{in}}\right] \tag{6}$$

Table 1 - Attenuation of Piping Elements

	Factor Type 1	DB Type 1		factor	dB
S_1	0.079	22	Bend 90°	0.32-0.56	5-10
S_2	0.11	19	Bend 45°	0.79	2
S_3	0.029	31	Bend out of plane	0.10-0.20	14-20
			100 m pipeline	0.56	5

A typical phenomenon occurring with one type of silencer is that the attenuation is dependant of the gas velocity. It appears that at high gas velocities the silencer S_2 starts to generate noise. The explanation for this is the exitation of resonance frequencies of the cavities inside the silencer at high gas velocities. This phenomenon is only relevant when the meter is installed downstream of this type of silencer. For bidirectional applications the remedy is to keep the gas velocity inside the silencer below a certain value.

7 FUNCTIONALITY OF THE ULTRASONIC FLOWMETER

The equations and data presented so far show that an indicative value proportional to noise present at the ultrasonic flowmeters position can be calculated. The next step is to demonstrate the correlation between the performance of the ultrasonic flowmeter and the calculated value of the indicator (δ).

The performance of the meter can be assessed using the indicators calculated and showed by means of the diagnostic functions implemented in the software belonging to the meter. The meter can be classified as operational or not operational based on it's "valid data signal". When the meter is operational, the percentage of accepted signal pulses shows how well the meter operates. In ideal conditions this percentage should be close to 100%, say between 70 and 100 %. This percentage drops rapidly when the ultrasonic noise level pevents the meter to operate normally.

Another feature of the diagnostics of the ultrasonic gasflowmeter is that it calculates an AGC-limit value. This is based on the ultrasonic background noise level which is measured between succesive signal pulse transmissions. This values indicates the maximum gain that will keep the noise level below an acceptable value. The actual gain (AGC-level) needed to amplify the signal to the required normalized value should stay well below the value of the AGC-limit. A satisfactory margin can be expressed in terms of the ratio of AGC-limit/AGC-level, this indicates how much margin is left before there is a risk of the meter having problems due to noise.

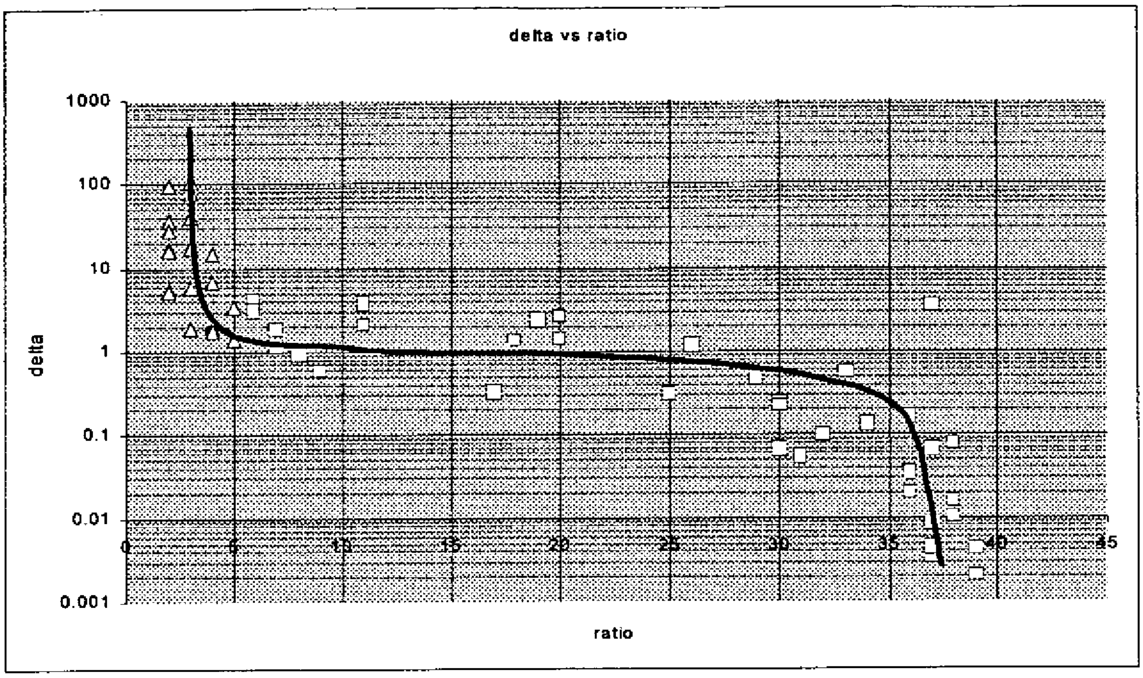


Figure 5 - Good functionality of the ultrasonic flowmeter

Figure 5 shows a typical graph of the AGC_ratio (Autmatic Gain Control_ratio) versus the δ-factor. As long as the AGC ratio is larger than 5 the instrument is functioning properly (level has not reached the limit). Figure 5 shows that a rapid decrease of the AGC ratio occurs starting from a δ-value of about 1.

8 CONCLUSION

The objective was to establish a model capable of predicting the performance of an ultrasonic flowmeter in a specific application.

This report shows that based on installation (piping) drawings, the control valve characteristics and relevant process parameters, it is possible to calculate a δ-factor value that predicts whether the ultrasonic flowmeter can function properly in a specific application. If not, it can be calculated to which extent additional measures are required to assure proper operation of an ultrasonic meter in the installation under study.

9 FINAL REMARK

For the calculation of the indicator (δ) a first approach can be made by using a valve characteristic value N_v of 1 as default value. For a more accurate assessment it is recommended to use the valve characteristic value. In case this value is not available Instromet has the equipment and capability to perform measurements on a site where a representative model of the particular valve is in operation as long as provisions can be made to install ultrasonic measuring microphones. In this way most applications can be analyzed for acoustic noise behavior and an advice can be given for the applicability of our ultrasonic gasflowmeters analyzers.

ACKNOWLEDGEMENT

Instromet wants to thank Verbundnetz Gas for organising and conducting this project. Especially the enthusiastic co-operations of Dr. Stoll, Mr. Slawig, as well as the support of Mr. Müller from PLE are greatly appreciated.

We also want to mention Dr. Dane who contributed in the processing and analysing of the ultrasonic sound measurement data.

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.