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TESTING OF NOISE SUPPRESSION SYSTEM FOR MULTIPATH ULTRASONIC GAS FLOW METERS

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TESTING OF NOISE SUPPRESSION SYSTEM FOR MULTIPATH ULTRASONIC GAS FLOW METERS

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SUMMARY

The use of ultrasonic meters for custody transfer metering is gaining acceptance within the oil companies as well as by the authorities. There is an ongoing effort to improve these meters to make them a competitive alternative to orifice plates and gas turbine meters. Operational experience has shown that ultrasonic meters are sensitive to noise generated by flow control valves. KOS has, in cooperation with CMR, developed an ultrasonic noise suppression system.

In the summer of 1997 KOS tested a 12" FMU-700 multipath ultrasonic gas flow meter at Statoil's K-Lab in Norway. The tests quantified the performance of the ultrasonic noise suppression method developed by KOS and CMR. The ultrasonic noise was generated by a 6" control valve with silencer trim manufactured by Mokveld. This valve is known to radiate noise in the ultrasonic frequency range [1]. The meter was tested for velocities from 0.5 m/s to 9 m/s giving a wide range of noise levels at the meter and signal to noise ratios from approximately 126 (42 dB) to 0.7 (-3 dB). The results show that the FMU-700 is capable of measuring accurately even in cases where there is more noise than signal.

ABBREVATION AND SYMBOL LIST

CMR	Christian Michelsen Research AS
FMU	Flow Metering Unit
KOS	Kongsberg Offshore AS
NFR	Norges Forskningsråd (Norwegian Research Council)
SNR	Signal to Noise Ratio (for the transducer receiving most noise)
USM	Ultrasonic Meter
P	Hydrostatic pressure at the USM [bar]
ΔP	Hydrostatic differential pressure (pressure drop) across the valve [bar]
v	Average axial flow velocity at line conditions [m/s]
D	Inner pipe diameter [m]

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1. INTRODUCTION

Most ultrasonic meters are based upon an accurate measurement of the transit time of an ultrasonic signal traversing the gas flow in the pipe. When a USM is situated close to other sources of ultrasonic sound, this sound will interfere with the original signal and make the latter hard to detect. It is known that some flow control valves generate noise in the ultrasonic frequency range. To save space it may be desirable to place such valves in the vicinity of the metering device. This will, however, move the source of ultrasonic noise close to the USM. To avoid a conflict between the space requirements and the functionality of the USM, an ultrasonic noise suppression method has been developed. The noise immunity project has been a cooperation between KOS, CMR, NFR and Statoil. This paper is a follow-up of the paper presented by CMR at the NSFMW in 1996 [1]. The test results presented here are based on the test matrix used for the paper presented last year [1]. The meter used in this year's tests is the same as the one used in 1996. The electronics and software have been changed to implement the noise suppression method and to comply with the KOS product line for fiscal metering.

2. TEST PREPARATIONS

With basis in the tests performed in 1996, a theoretical method for suppressing noise in the received ultrasonic signal was developed by KOS and CMR. The object of the tests was to quantify the performance of this method for signal processing with the meter operating in a noisy environment. The problem with noise suppression basically consists in recognizing the arrival of the transmitted signal in cases where the transducers receive a lot of noise. This is done by a correlation and averaging technique.

Prior to the noise suppression tests at K-Lab, the meter was zero calibrated at KOS. The 6 transducer pairs were zero calibrated by mounting them in a pressure- and temperature-controlled zero calibration chamber. Nitrogen was used as the calibration gas. The distances between the transducers in the spool piece were measured to an accuracy of one tenth of a millimetre.

3. TESTING AT K-LAB

The tests were performed at Statoil's K-Lab gas research facility between the 23rd of June and the 10th of July 1997.

3.1 Test installation

The 12" USM was installed in the gas test loop at K-Lab in series with a 6" Mokveld control valve with silencer trim. Thus the gas flow velocity through the valve was approximately four times higher than the gas flow velocity through the USM due to the difference in cross-sectional area.

It is known that some flow control valves will produce noise in the ultrasonic frequency range. Different types of valves will probably produce noise of different frequency and intensity. This has, however, not been investigated in this project.

It is seen that the level of ultrasonic noise received by the ultrasonic meter is depending on the distance between the valve and the meter, the differential pressure across the valve, the static pressure in the pipe and the gas flow velocity in the pipe. Whether the valve is placed up- or downstream of the meter is also influencing the noise level. The noise experienced by the individual transducers will vary with the length, angle and lateral position of the path, and whether the receiving transducer is facing the source of the noise or facing away from it [1]. The SNR values in the following are values for the transducer receiving most ultrasonic noise.

K-Lab offers a maximum flow velocity of 9 m/s for 12" pipes. The meter has therefore not been tested at higher velocities. The outdoor temperature at K-Lab in the test period was 20-25°C, and the typical composition of the test gas was: 82.8% methane, 14.2% ethane, 0.9% propane, 0.04% iso-butane, 0.05% normal-butane, 0.01% iso-pentane, 1.1% nitrogen and 0.9% carbon dioxide. The composition is given in molar-%.

The gas temperature and pressure were measured both upstream and downstream of the valve. The gas temperature at the USM was in the range 35-38.5°C. The valve was installed respectively 10D (≈3.4 m) downstream, 5D (≈2.1 m) downstream and 5D upstream of the ultrasonic meter, see Figure 1. The downstream installations correspond to the test installations that were used last year. In addition, the upstream installation (which this year was 5D from the USM instead of last year's 10D) was chosen in order to create sufficient levels of noise at the USM to investigate the limits of the noise suppression method.

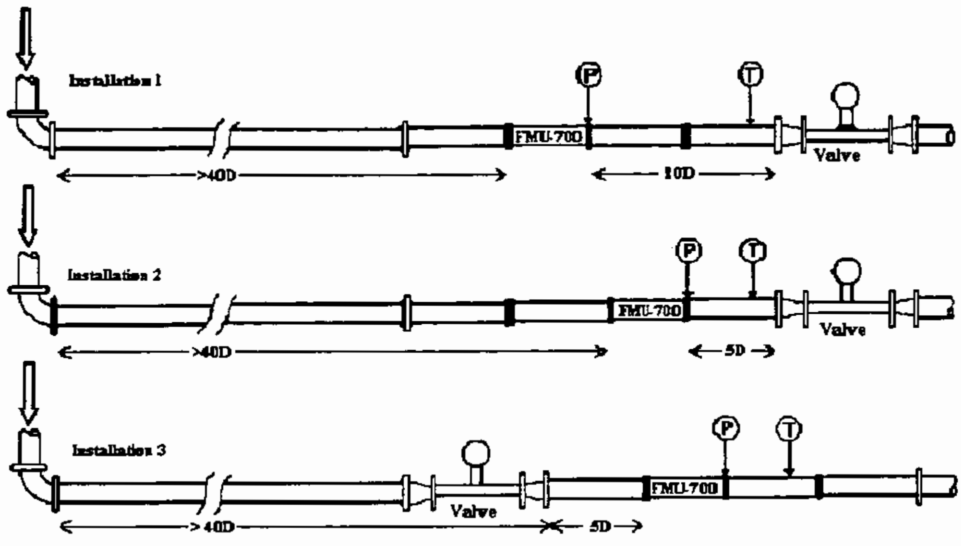

Figure 1: The three test installations at K-Lab. Installation 1; valve placed 10D downstream, installation 2; valve placed 5D downstream and installation 3; valve placed 5D upstream of the USM. The differential pressure across the valve is the calculated difference between the pressure measured up- and downstream of the valve. D is in this case the inner diameter of a 12" pipe, i.e. D=0.26 m.

The gas flow velocity, the static pressure in the pipe, the differential pressure across the valve and the position of the valve have been varied to investigate the behaviour of the ultrasonic meter at various levels of noise. See Table 1 for the complete test matrix.

3.2 Test matrix

Table 1: Test matrix for the USM valve noise testing at K-Lab 1997.

Test parameters according to plan				Actual parameters at K-Lab		
Valve position relative to meter, see Figure 1	**P**	**v**	**ΔP/P**	**P**	**v**†	**ΔP/P**
10D DOWN	20 bar	0.5 m/s	≈ 0%	22.27 bar	0.49 m/s	0.2%
			10%	22.63 bar	0.45 m/s	8.6%
			20%	22.83 bar	0.41 m/s	17.4%
		3 m/s	≈ 0%	22.42 bar	3.10 m/s	0.8%
			10%	22.65 bar	2.83 m/s	9.0%
			20%	22.98 bar	2.43 m/s	17.4%
		9 m/s	≈ 0%	22.44 bar	8.74 m/s	5.5%
			10%	22.54 bar	8.39 m/s	9.3%
			20%	23.16 bar	7.40 m/s	17.1%
	100 bar	0.5 m/s	≈ 0%	100.35 bar	0.46 m/s	0.1%
			10%	103.04 bar	0.41 m/s	10.4%
			20%	103.77 bar	0.38 m/s	16.8%
		3 m/s	≈ 0%	100.44 bar	2.92 m/s	0.8%
			10%	102.98 bar	2.64 m/s	10.2%
			20%	104.81 bar	2.36 m/s	20.1%
		9 m/s	≈ 0%	101.80 bar	8.20 m/s	5.9%
			10%	102.36 bar	7.84 m/s	9.9%
			20%	105.27 bar	6.89 m/s	19.0%
5D DOWN	100 bar	0.5 m/s	≈ 0%	100.42 bar	0.46 m/s	0.1%
			10%	103.00 bar	0.41 m/s	10.2%
			20%	102.96 bar	0.38 m/s	16.5%
		3 m/s	≈ 0%	100.88 bar	2.92 m/s	0.8%
			10%	101.85 bar	2.63 m/s	9.9%
			20%	103.50 bar	2.43 m/s	16.9%
		9 m/s	≈ 0%	101.42 bar	8.19 m/s	5.9%
			10%	101.78 bar	7.84 m/s	9.9%
			20%	103.50 bar	5.99 m/s	19.0%
5D UP	100 bar	0.5 m/s	≈ 0%	101.95 bar	0.46 m/s	0.2%
			3%	87.81 bar	0.47 m/s	3.5%
		3 m/s	≈ 0%	101.07 bar	2.93 m/s	0.4%
			10%	92.77 bar	2.91 m/s	10.8%
			15%	90.02 bar	2.91 m/s	16.1%
		9 m/s	≈ 0%	96.93 bar	8.54 m/s	4.6%
			10%	91.90 bar	8.50 m/s	10.8%

† The average axial gas flow velocity given in the table was calculated from the reference volume flow rates, and is the flow velocity through the USM. The flow velocity through the valve is approximately 4 times higher.

3.3 Reference measurement system

K-Lab uses sonic nozzles as the main reference flow meter. An 8" Instromet turbine meter was used as reference when the flow through the nozzles was subsonic. Subsonic flow through the sonic nozzle bank occurred when the control valve consumed too much of the total pressure drop in the loop. The total uncertainty in the reference volume flow rate at K-Lab is ±0.35%. In the setups with 20 bar pipe pressure and 0.5 m/s flow velocity, and when the valve is placed upstream of the USM, the uncertainty in the reference volume flow rate is increased to ±0.5%. At these conditions, temperature gradients in the gas will become significant, making it difficult to obtain representative values for the gas temperature[3]. This will influence the density calculation and the calculated volume flow rate will be less accurate.

3.4 Problem description

Figure 2 and Figure 3 visualize the effect of ultrasonic noise generated by valves on the signals transmitted and received by the USM for determining the transit times.

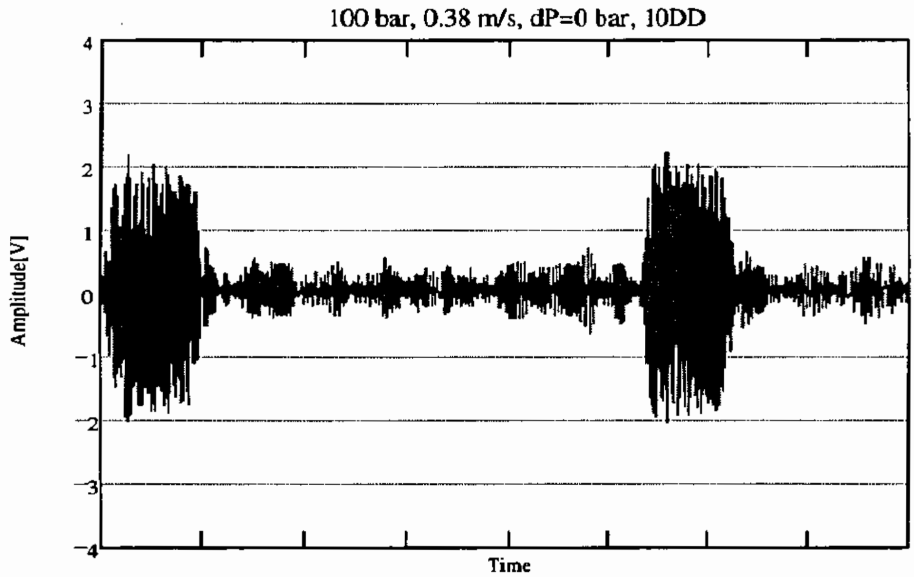

Figure 2: The signal used to measure transit times superimposed on ultrasonic noise generated by the valve, as received by the transducer. The valve is placed 10D downstream of the USM. The flow velocity is 0.38 m/s, the pressure is approx. 100 bar and the valve is open, i.e. the differential pressure across the valve is close to zero. The SNR is in this case 126 (42 dB).

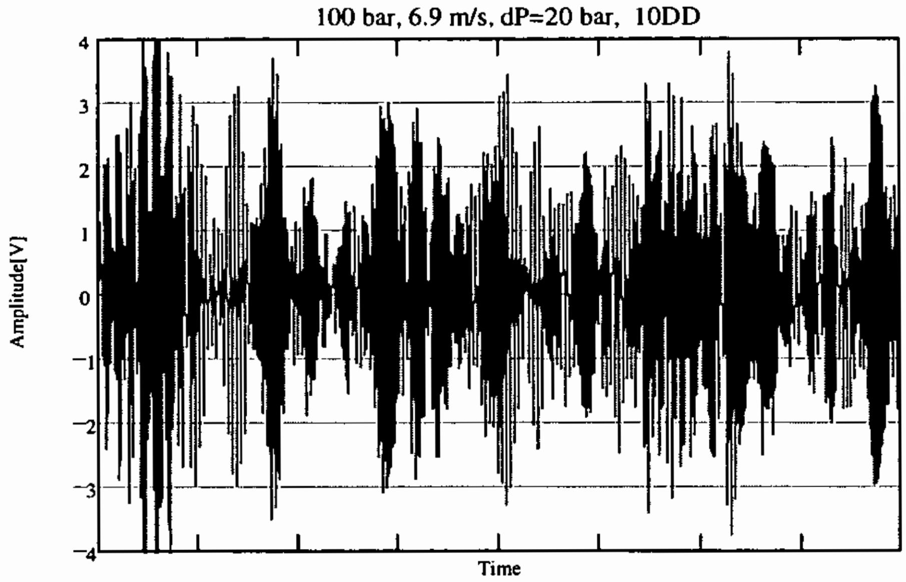

Figure 3: The signal used to measure transit times superimposed on ultrasonic noise generated by the valve, as received by the transducer. The valve is placed 10D downstream of the USM. The flow velocity is 6.9 m/s, the pressure is approx. 100 bar and the differential pressure across the valve is 18 bar. The SNR is in this case 1.25 (2 dB).

Figure 2 shows a setup with low gas flow velocity and open valve, a virtually noiseless operating environment. The signal is in this case easily detected. In Figure 3 the valve has been tightened and the gas flow velocity has been increased, the result of this being that the valve radiates much more noise. The SNR is in this case 1.25 (2 dB), and the signal is literally drowned in noise and impossible to detect visually.

The correlation and averaging method used by the USM is capable of removing the influence of the noise and detect the signal correctly in situations similar to this.

4. TEST RESULTS AND DISCUSSION

The evaluation of the test results is done by recording the deviation in percent between the USM and the reference meters. The repeatability, as defined by [2], is calculated and the SNR is estimated. Information from [1] put together with information extracted from sampling data recorded at K-Lab in the test period are used to find the SNR in the following. All values for the SNR should therefore be taken as estimates only.

The parameter that best indicates the meter's insensitivity to ultrasonic valve noise, is the repeatability. If the meter is able to measure constant over a period of time, this implies that the random signal disturbances introduced by valve noise are well suppressed. The repeatability should not exceed 0.2% [4].

Figure 4 shows the results when the valve is placed 10D downstream of the USM, see Figure 1, installation 1. The pressure at the USM is approximately 20 bar. Each curve represents a different pressure drop across the valve. Each point on the curve is a calculated average of measurements taken over a period of approximately ½ hour. The repeatability is indicated at each point. The SNR varied from 126 (42 dB) to 1.25 (2 dB), decreasing with the differential pressure across the valve and the flow velocity.

The figure shows that

- the deviation is within ±0.5% for all points.
- the repeatability is of the order of 0.2% for $v \leq 0.5$ m/s.
- the repeatability is of the order of 0.04% for $v > 0.5$ m/s.

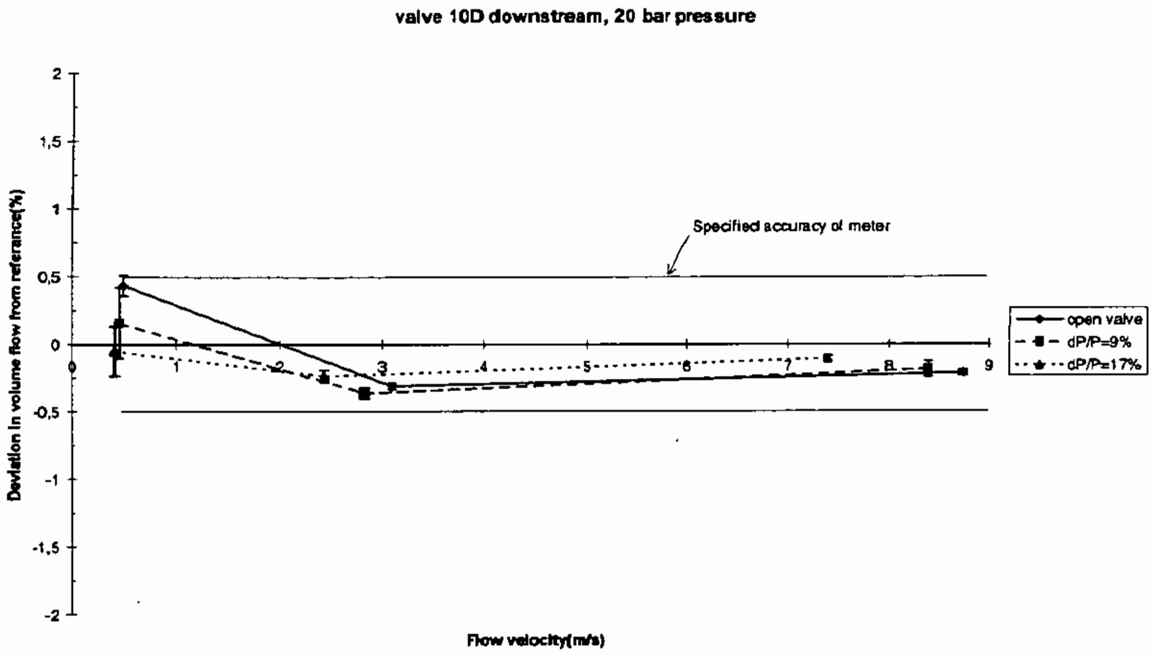

Figure 4: The deviation from the reference. The different curves represent various differential pressure across the valve. The repeatability for each point is indicated by error bars. For installation conditions, see figure legends.

As can be seen from Figure 4 the repeatability is very good for all points, indicating that the noise generated from the valve represents no source of error when the valve is placed 10D downstream of the USM. At the low flow, low pressure setups, the repeatability is poorer. This is due to the fact that the flow in the test loop at K-Lab is fluctuating somewhat on short term basis under these circumstances[3]. The SNR for the setups with this installation may be as low as 1.25 (2 dB). This constitutes no difficulties for the noise suppressing algorithm implemented in the USM.

Figure 5 shows the results from the same installation as Figure 4. The pressure at the USM is increased to approximately 100 bar. The SNR varied from 126 (42 dB) to 1.25 (2 dB), as above. This is due to the fact that the SNR is pressure dependent mostly through the ratio between the differential pressure across the valve and the pressure in the pipe.

The figure shows that

- the deviation is within ±0.5% for all points.
- the repeatability is of the order of 0.1% for $v \leq 0.5$ m/s.
- the repeatability is of the order of 0.03% for $v > 0.5$ m/s.

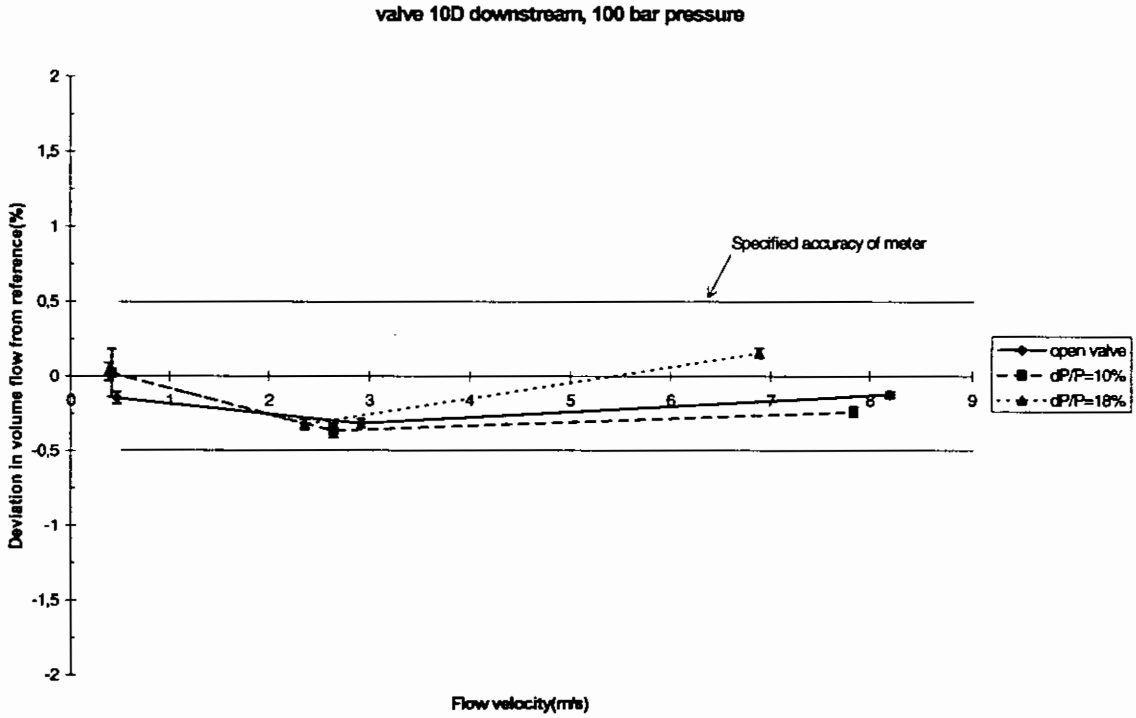

Figure 5: The deviation from the reference. The different curves represent various differential pressure across the valve. The repeatability for each point is indicated by error bars. For installation conditions, see figure legends.

As can be seen in Figure 5 the repeatability is very good for all points, indicating that the noise generated from the valve represents no source of error when the valve is placed 10D downstream of the USM. The SNR for these setups can be as low as 1.25 (2 dB). This constitutes no difficulties for the noise suppressing algorithm implemented in the USM.

Figure 6 shows the results when the valve is placed 5D downstream of the USM, see Figure 1, installation 2. The pressure at the USM is approximately 100 bar. The SNR varied from 126 (42 dB) to 1 (0 dB) at this installation.

The figure shows that

– the deviation is within ±0.5% for all points but one.

– the repeatability is of the order of 0.3% for the point with highest differential pressure and highest velocity.

– the repeatability is of the order of 0.05% for all other points.

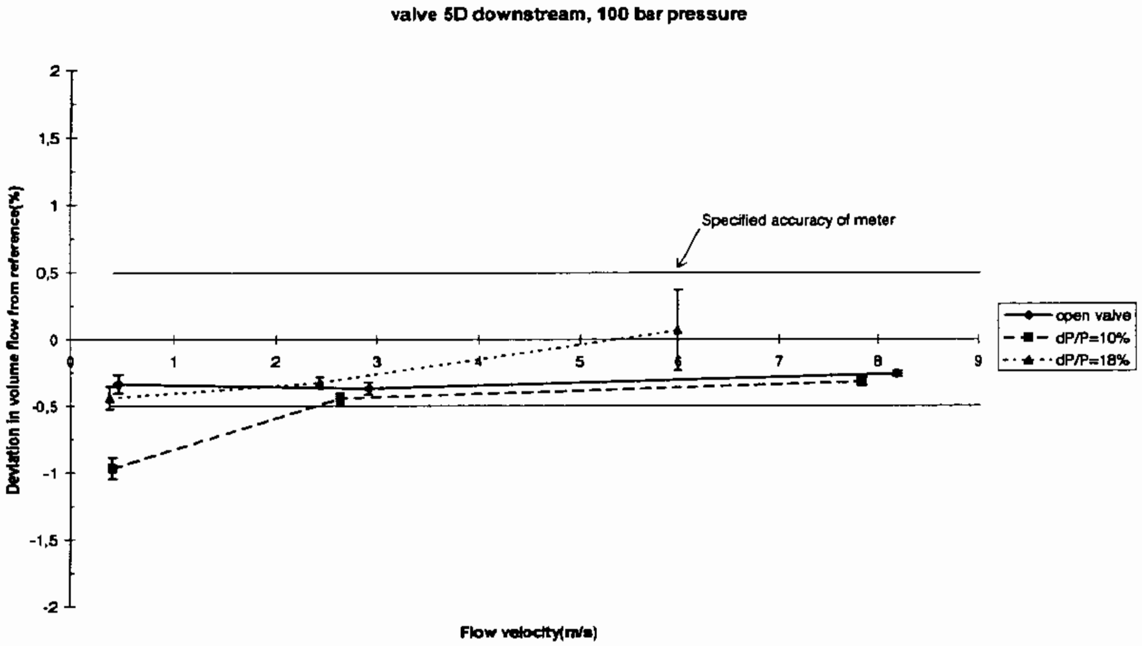

Figure 6: The deviation from the reference. The different curves represent various differential pressure across the valve. The repeatability for each point is indicated by error bars. For installation conditions, see figure legends..

When the valve is moved closer to the USM, it is seen, by inspection of the repeatability in Figure 6, that the meter still performs well with respect to noise immunity. At the highest flow velocity combined with the highest differential pressure across the valve, however, the repeatability is increased to 0.3%. Even though the meter measures the volume flow rate well within the specified 0.5% from the reference, this indicates that the noise generated by the valve is beginning to deteriorate the repeatability of the meter.

To fully test the noise suppressing algorithm, the USM was also tested with the valve placed upstream. At this installation the SNR will decrease significantly compared to all other installations in the test. In addition to generating noise, the valve is setting up strong secondary motion (swirl) in the gas, making it difficult to measure the volume flow rate accurately. Installations like this are not recommended due to both flow profile disturbances and generation of ultrasonic noise.

Figure 7 shows the results from the installation where the valve is placed 5D upstream of the USM, see Figure 1, installation 3. The pressure at the USM is approximately 100 bar. The SNR for the worst cases in this installation is as low as 0.7 (-3 dB). At this installation the volume flow rate measured deviated more from the reference than what is seen at the other installations. Setups described in the test matrix, where valve noise and secondary flow have made the meter unable to measure correctly, are not included in the figure.

The figure shows that

- the deviation is within ±0.5% for all points included.
- the repeatability is of the order of 0.25% for the point with highest velocity.
- the repeatability is of the order of 0.1% for all other points.

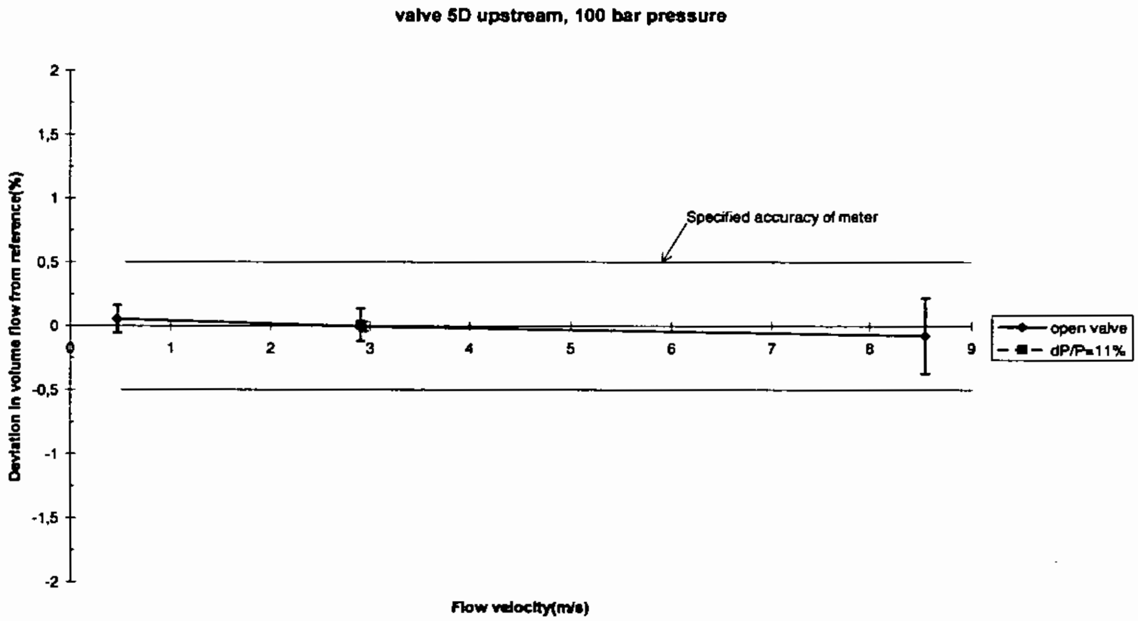

Figure 7: The deviation from the reference. The different curves represent various differential pressure across the valve. The repeatability for each point is indicated by error bars. For installation conditions, see figure legends.

As can be seen in Figure 7, the repeatability is getting worse as the differential pressure across the valve and the flow velocity increases. If the flow velocity is kept constant and the differential pressure is increased, the value of the repeatability will increase. If the differential pressure is kept constant and the flow velocity increased, the same phenomenon is observed. The algorithm is clearly stretched to its limit in this case. The SNR limit for the algorithm seems to be about 0.9 (-1 dB).

It is important to notice that the gas flow velocity through the 6" valve is 4 times higher than the gas flow velocity through the USM. This is due to the reduced cross section in the valve. The gas flow velocity through a 12" valve will be significantly lower, compared to a 6" valve, at the same gas volume flow. A 12" valve will therefore probably generate less ultrasonic noise at the same volume flow. This may make it possible to increase the volume flow through the USM further, before the SNR limit of the meter is reached.

Table 2 sums up the results from the tests at K-Lab, and shows at which setups the USM measures satisfactorily.

Table 2: Schematic result matrix for the USM valve noise testing at K-Lab 1997.

Valve position relative to meter, see Figure 1	P	v	ΔP/P	Deviation	Repeatability
10D DOWN	20 bar	All setups		OK	OK
	100 bar	All setups		OK	OK
5D DOWN	100 bar	0.5 m/s	10%	> 0.5%	OK
		9 m/s	20%	OK	> 0.2%
		All other setups		OK	OK
5D UP	100 bar	0.5 m/s	≈ 0%	OK	OK
			3%	> 0.5%	>0.2%
		3 m/s	≈ 0%	OK	OK
			10%	OK	OK
			15%	> 0.5%	OK
		9 m/s	≈ 0%	OK	> 0.2%
			10%	> 0.5%	> 0.2%

5. CONCLUSION

Based on the foregoing discussion it is concluded that the new noise suppressing algorithm implemented in the FMU-700 ultrasonic meter is able to separate the signal from the noise for SNR as low as 0.9 (-1 dB). This gives accurate measurements of the signal transit times and thus accurate calculations of volume flow even when ultrasonic noise generators such as flow control valves are present in the vicinity of the meter.

Other valves will most likely have other characteristics with respect to noise level and frequency content of the noise. The results obtained in this test is therefore not directly applicable to other valves.

ACKNOWLEDGEMENTS

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