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ON -LINE QUALITY CONTROL OF ULTRASONIC GAS FLOW METERS

Authors:
R. Sakariassen, Statoil/K-Lab, Norway

Organiser:
Norwegian Society of Chartered Engineers
Norwegian Society for Oil and Gas Measurement
Co-organiser:
National Engineering Laboratory, UK

On-line quality control of ultrasonic gas flow meters

by

Reidar Sakariassen

Statoil/K-Lab

ABSTRACT

An ultrasonic gas flow meter (USM) offers a great deal of information about the performance of the meter and the conditions in the gas flow. Some of the information is used by the computer of the meter itself to perform self diagnostics while other part of the available information is not yet fully utilised.

This paper will give principles and show examples of how information of the measured flow velocities, the measured velocities of sound and density could be utilised to perform an on-line quality control. Performing such quality control may in the end result in maintenance based on condition monitoring rather than the resource consuming concept of preventive maintenance. Even for single run meter stations with limited number of parallel measurements to compare this principle seems to be possible.

Our experience is built on the follow-up of a total number of 12 USM with diameter from 12" to 30" in operation offshore together with a number laboratory tests.
Examples of data collected, presentation of data and interpretation of the results will be presented and the paper will conclude with a proposed procedure for on-line quality control of the USM.

INTRODUCTION

Since 1997 the ultrasonic gas flow meters have been introduced into the Norwegian Regulation relating to fiscal measurement of oil and gas etc. (ref. 1). Among others it requires that "during the operational phase "the parameters relevant to verify the condition of the meter shall be checked". In the guidelines to the Regulations it is said that "the ultrasonic flowmeter should..monitor the velocity of flow and the velocity of sound for each ultrasonic path" and that it would be reasonable that those parameters "are used for further follow up".
In a recently developed American Draft Standard (ref. 2) it is said that the "the manufacturer should provide the following and other diagnostic measurements". Among the measurements listed are:

- average axial flow velocity through the meter
- flow velocity for each acoustic path (or equivalent for evaluation of the flowing velocity profile)
- speed of sound along each acoustic path
- average speed of sound.
- percentage of accepted acoustic pulses for each acoustic path

Those requirements have always been part of Statoil's specifications for ultrasonic gas flow meters. The utilisation of those parameters and the meters' own internal diagnostic tools has turned out to be of great value in verifying the performance of the meters. To know how the information should be treated and why it provides such good information, a good understanding of the meter's operating principle is necessary.

DESIGN OF ULTRASONIC METERING SYSTEMS

Figure 1 shows how most our ultrasonic gas flow metering systems are designed. The ultrasonic meter meters the actual or gross volume flow rate. To convert to mass flow rate, density is required. The densitometer is installed in a pocket in the main pipe wall. Flow through the densitometer loop is forced by the differential pressure across a doublesided pitot probe protruding into the pipe. (The probe inside the pipe is not shown on the sketch).

Figure 2 shows typical what type of information the metering systems reports.
In addition to the parameters listed above, this meter also reports standard deviation (Std.dev.) of the individual flow velocities. This number expresses how stable the velocity or velocity measurement has been during the measurement cycle.

The calculated values for density and velocity of sound is in this case based on a gas composition, pressure and temperature. It is most usual to see the figure for calculated density, for instance based on the method described in AGA report no. 8 (ref. 3). A calculated value for velocity of sound is more unusual. Different methods exist for this calculation. The best method seems to be based on AGA report no. 8 version 1994. This item will be treated later in the paper. It should be mentioned that a relation exists between velocity of sound and density although it is complicated.

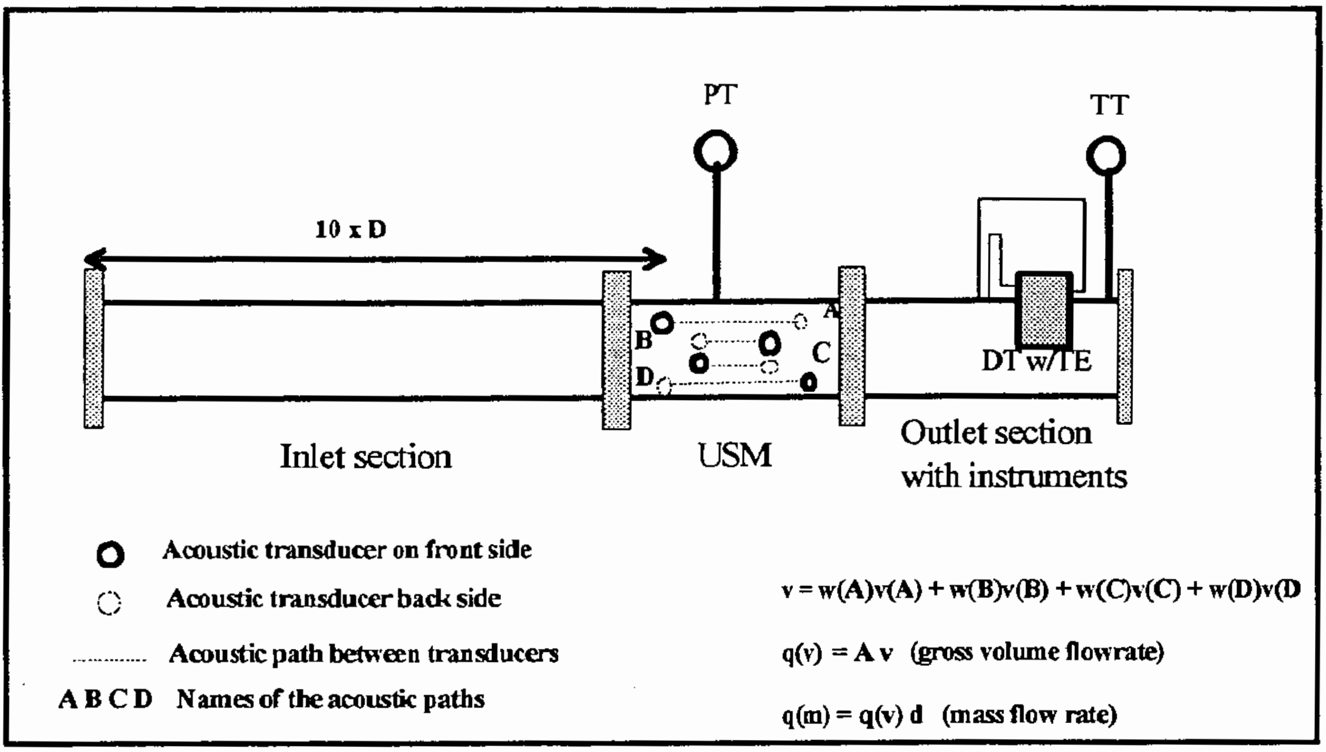


Figure 1 Typical layout for a meter run with a four paths ultrasonic meter. Included in the sketch is also the secondary instrumentation: pressure transmitter (PT), temperature transmitter (TT) and densitometer with internal temperature element (DT and TE respectively).

Transducer no.	Measurements % used
0	100
1	100
2	100
3	100
4	100
5	100
6	99
7	100
8	100
9	100
10	100
11	100

Pressure: 125.44 barg
Temperature: 12.36 degC
Density measured: 124.76 kg/m³
Density calculated 124.37 kg/m³

	FLOW VELOCITIES (m/s)		SOUND VELOCITIES (m/s)	
Path. no.	Measured	Std. dev.	Measured	Calculated
Tot,	**7.7839**	0.0139	**416,63**	**417,11**
0 - 11	7.1178	0.0188	416,58	
1 - 10	7.3468	0.0201	416,55	
2 - 9	8.1592	0.0117	417,05	
3 - 8	8.1736	0.0150	416,73	
4 - 7	8.0758	0.0116	416,49	
5 - 6	7.2234	0.0211	416,36	

Figure 2 Typical information from a system like fig. 1

BASIC TECHNICAL BACKGROUND

To understand how an on-line quality control could be performed, it is essential to understand the function of the ultrasonic meter and how physical parameters are related to each other.

Working principle of the ultrasonic meter

The fundamental principle is that the propagation velocity for sound (which is a pressure wave) in a fluid will be the sum of the velocity of sound and the fluid velocity long the path of the pressure wave. In an ultrasonic meter (ref. figure 1) the transit time is measured for a sound pulse travelling between two transducer mounted in meter section of the pipe. The transit time is measured both with the pulse travelling with and against the fluid flow direction.

The average fluid flow axial velocity along the acoustic path, v, can is calculated by the ultrasonic meter by equation (1):

$$v = \frac{L^2}{2 \cdot X} \cdot \frac{(t_2 - t_1)}{t_2 \cdot t_1} \qquad (1)$$

where

L	is the length of the acoustic path between the transducers in a pair
X	is the axial distance between a pair of transducers
t_1 and t_2	is the transit time in downstream and upstream direction respectively between the transducer fronts

To a good approximation the velocity of sound, c, is also determined by equation (2)

$$c = \frac{L^2 \cdot (t_1 + t_2)}{2 \cdot t_1 \cdot t_2} \qquad (2)$$

Transit time measurement

The principle of measuring the transit time for an acoustic pulse is shown in figure 3. The acoustic pulse is detected by the receiving transducer. The pulse consists of a number of pressure pulsations or periods. The pulsation frequency is normally between 100 kHz and 200 kHz for gas meters.

The timer for transit time measurement is triggered at the exact right period in the pulse.

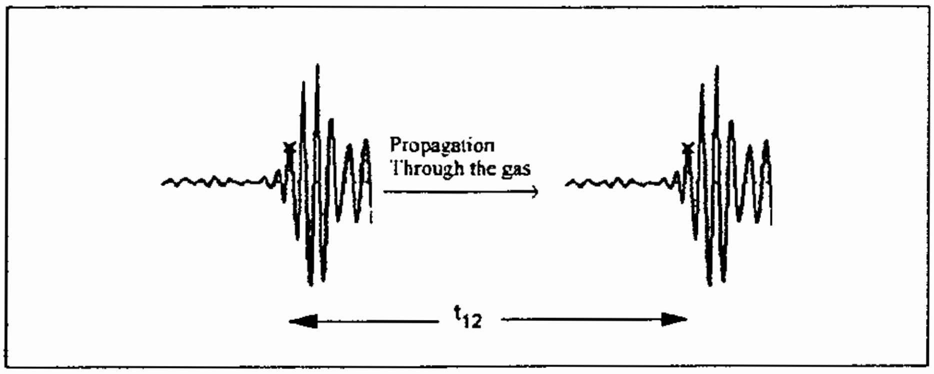


Figure 3 Propagation of acoustic pulse from emitting transducer to receiving transducer

t_1 and t_2 are determined from measured times between electronically transmission of the acoustic signal till electronically detecting received signal. Delay times in the transducers and electronics and delays caused by detection method must be taken into account.

$$t_1 = t_1' - \Delta t_1 \tag{3}$$

$$t_2 = t_2' - \Delta t_2 \tag{4}$$

where

t_1 and t_2	is the transit times as detected by the electronics
Δt_1 and Δt_2	is delay times

Internal diagnosis system

Most meters have a built in check and diagnosis system. This system checks for example for stability in transit time measurement, stability in the acoustic pulse, signal to noise ratio. During a measurement cycle the transit time is normally measured several times and then an average value is calculated. The number for "measurement used" tells how many (percentage) of the pulses are used to form the average value have passed the internal quality check.

If the number of pulses used to form the average transit times is higher than 10, normally 40 % of pulses should be accepted to make a reliable measurement.

Most meter also provide the reason why the quality of the pulse is rejected. Figure 4 shows an example of a pulse rejected because of low signal to noise ratio (SNR).
This example also shows how vital it is that the timer for transit time measurement is triggered at the exact right period in the pulse.

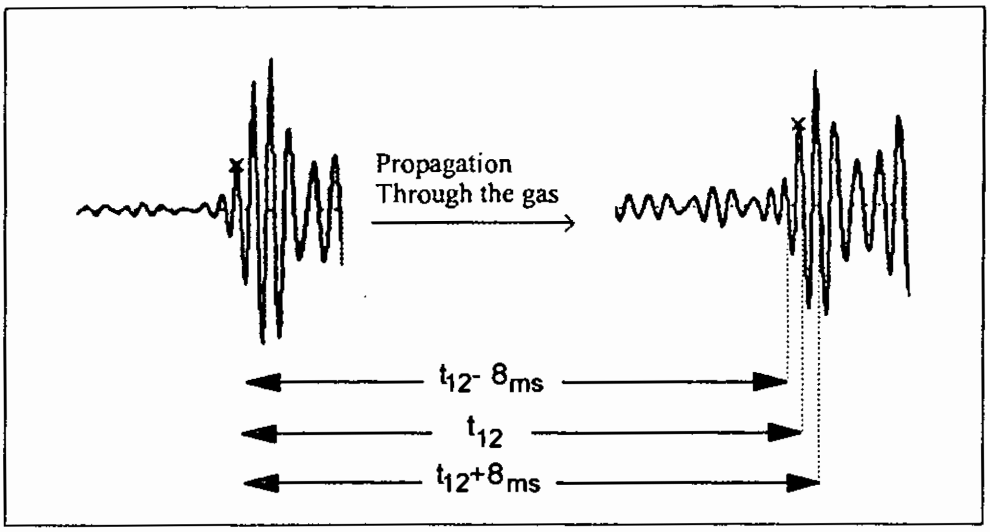


Figure 4 Propagations of the acoustic pulse. The received pulse is "polluted" with noise, making it impossible or difficult to determine exact arrival time of the pulse.

Effect of possible malfunctions of the meter

For an ultrasonic meter with all dimension correctly measured and flow calibrated, the main source of malfunctions is the transit time measurement.

Missing correct period in the received pulse

As indicated in figure 4, the error in transit time measurement will be approximate 8 µs if the timer is triggered one period away from the correct pulse. The effect of such a miss could be calculated by equation (1) and (2).
Table 1 gives examples of what effect it has on meters of different dimension.

Error in delay time

Error in the delay times defined in equation (3) and (4) affects in principle the end result in the same way as a miss of the correct pulse described in the previous section. However, the effect is much smaller. The delay times are normally in the order of 10 µs - 30 µs. The error in delay times caused either from the calibration of the transducer or by drift is normally maximum 1 µs. The effect is therefor normally less than 1/10 of the effect of missing the correct period in the pulse.

Table 1 Effect of error in transit times. Path notation refers to figure 1.

Dim. (inch)	Path	L (m)	X (m)	Parameter	$t_1$and t_2 correct	t_1 error chord A and D 8 µs*	t_1 error chord B and C 8 µs*	t_1 and t_2 error all chords 8 µs*
6	A,D	0.205	0.0838	VOS (m/s)	400	396,9	400	393,85
				v (m/s)	9	1,34	9	8,72
	B,C	0.230	0.133	VOS (m/s)	400	400	397,24	394,51
				v (m/s)	10	10	5,11	9,72
	Total			VOS (m/s)	400	398,45	398,62	394,18
				v (m/s)	9,72	7,61	6,19	9,44
12	A,D	0.762	0.165	VOS (m/s)	400	399,16	400	398,33
				v (m/s)	9	5,1	9	8,92
	B,C	0.794	0.267	VOS (m/s)	400	400	399,2	398,39
				v (m/s)	10	10	7,58	9,92
	Total			VOS (m/s)	400	399,58	399,6	398,36
				v (m/s)	9,72	8,65	7,97	9,64
20	A,D	0.950	0.275	VOS (m/s)	400	399,33	400	398,66
				v (m/s)	9	6,65	9	8,94
	B,C	1.03	0.445	VOS (m/s)	400	400	399,38	398,76
				v (m/s)	10	10	8,53	9,94
	Total			VOS (m/s)	400	399,67	399,69	398,71
				v (m/s)	9,72	9,07	8,66	9,66

* 8 µs reflects a frequency of the ultrasonic signal of 125 kHz.

Relations between physical properties

As shown in figure 1 and figure 2 our metering systems determines velocity of sound and density as well as pressure and temperature. Both velocity of sound and density varies with variations in pressure and temperature. In addition, both velocity and density depends on gas composition.

For a given gas composition, the velocity of sound and density varies with pressure as shown in figure 5 and figure 6.

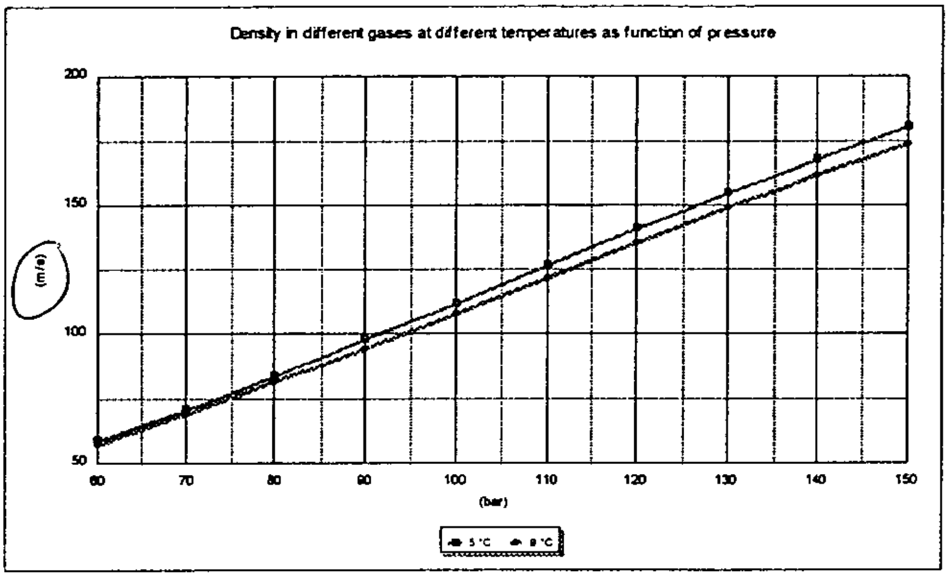


Figure 5 Density as a function of pressure at different temperature.
Gas composition in mole % ; C1 84.6, C2 11.4, C3 1.35, iC4 0.1, nC4 0.2, iC5 0.02, nC5 0.02, C6+ 0.03, N_2 1.3, CO_2 1

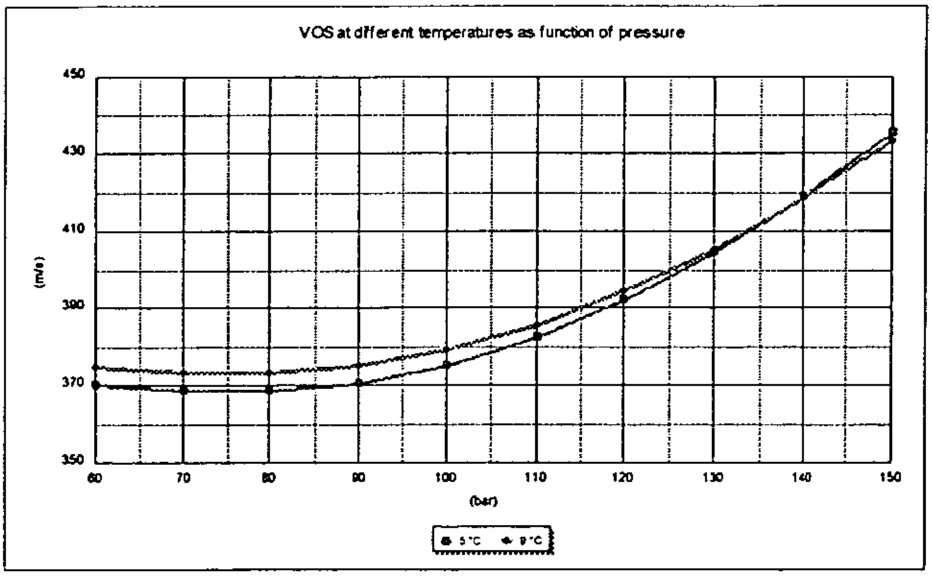


Figure 6 Velocity of sound as a function of pressure at different temperature. Gas composition as in figure 5

The relation between density and velocity of sound is described in the thermodynamic relation (5)

$$c = \sqrt{\gamma\left(\frac{\delta p}{\delta \rho}\right)_T} \qquad (5)$$

where

γ is heat capacity ratio

Both ρ and $(\delta p/\delta \rho)$ can be calculated from a density model, for example AGA Report No. 8. It should be mentioned that to derive an expression for $(\delta p/\delta \rho)$ is a complex task.

Figure 7 shows an example of how density and velocity of sound is related to each other.

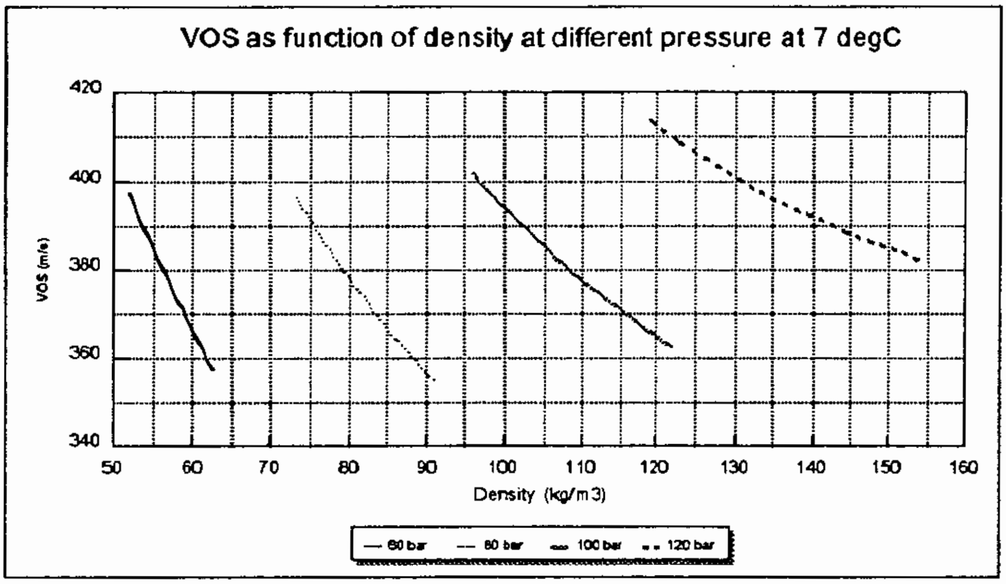


Figure 7 Velocity of sound as a function of density at different pressure. The variation in density and VOS for a given pressure and temperature is caused by variation in gas composition.

This relation can be utilised as a cross check between two independent measured values. From the measured density at a given pressure and temperature, velocity of sound can be calculated. This calculated velocity of sound can then be checked against measured velocity of sound for discrepancy. Vice versa can density be calculated from velocity of sound and checked against measured density for discrepancy. Action can be taken in case of discrepancies.

It should be mentioned a nice and simple relation is disturbed by variation in CO_2 and N_2 concentrations.

RECORDINGS OF DATA

Flow velocities

The reported flow velocities (ref. fig 2) can be recorded chronologically. The best way to get an overview is to set the readings in diagram.
From a flow meter in service such a diagram is shown in figure 8.

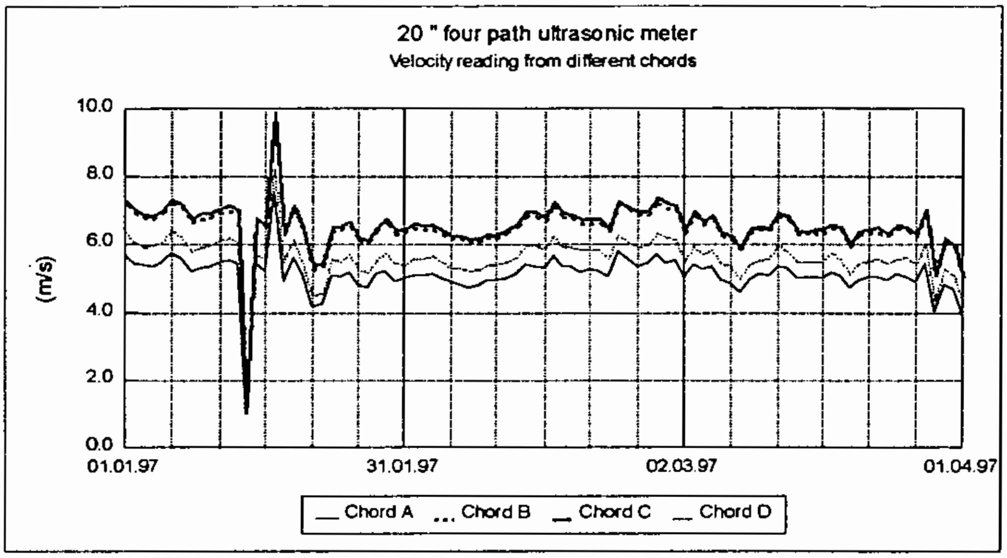


Figure 8 Recordings of flow velocity readings from all chords

A still better way of showing any effects on the individual measurement of velocity is to calculate the relative velocity for each chord. This means that the velocity for each acoustic path is divided by the average flow velocity. The data in fig. 8 then became as in figure 9.

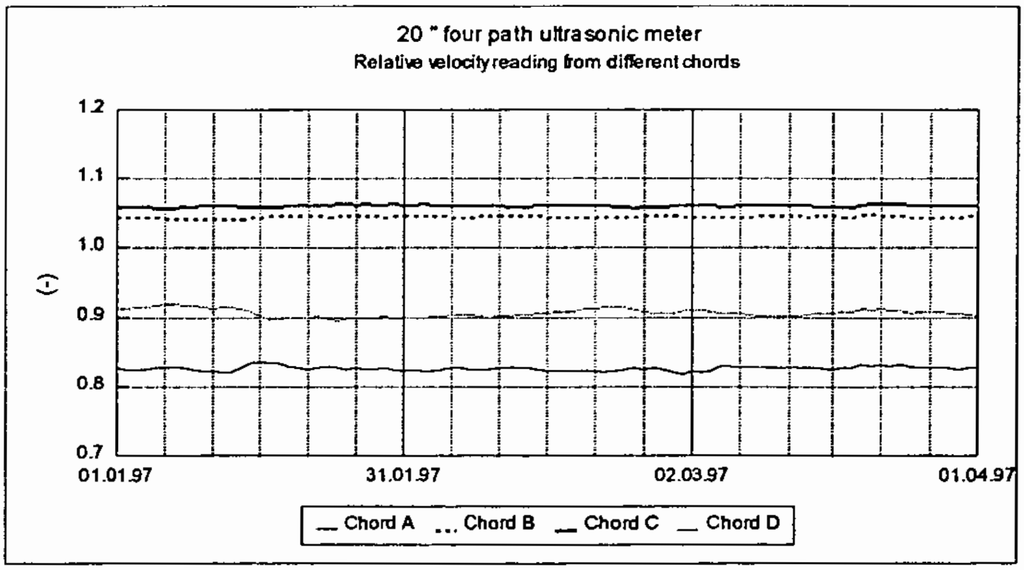


Figure 9 Recordings of velocities relative to average flow velocity for all chords The database is the same as in figure 8

Still another way of setting up the data is to set up the relative velocities as a function of flow velocities. The data set in figure 8 and figure 9 will then look like in figure 10:

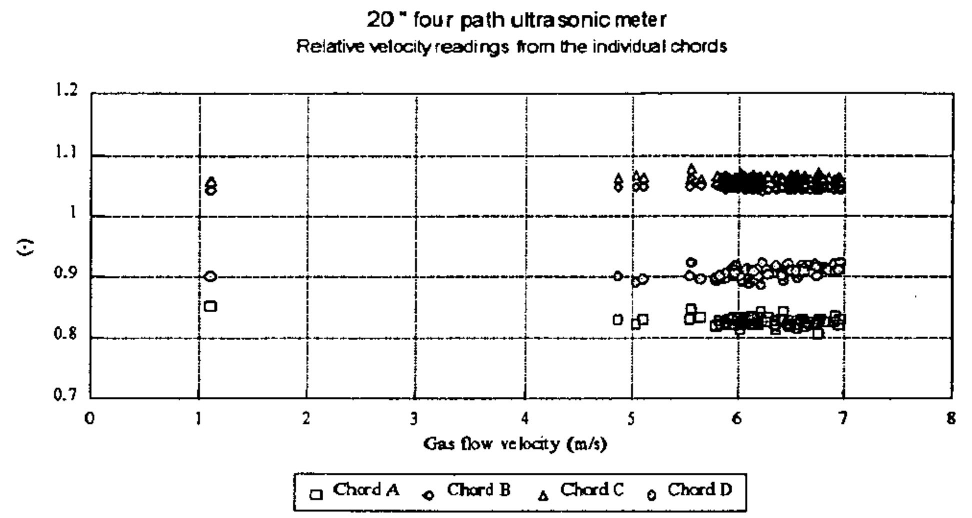


Fig. 4 a

Figure 10 Relative velocity as a function of average flow velocity. The database is the same as in figure 9

Figure 8 to 10 indicate a stable meter function. Any miss in period triggering for any chord would result in large jumps in velocity and relative velocity for that chord. A miss in period triggering on all chords would have resulted in smaller jumps in relative velocity, but much in the velocity of sound checks.

The set up like in figure 10 can reveal even small errors in velocity. This is illustrated in figure 11 where the effect of a change in delay time (caused by calibration error or drift) of 1 μs in chord D is shown in a data set up like in figure 10.

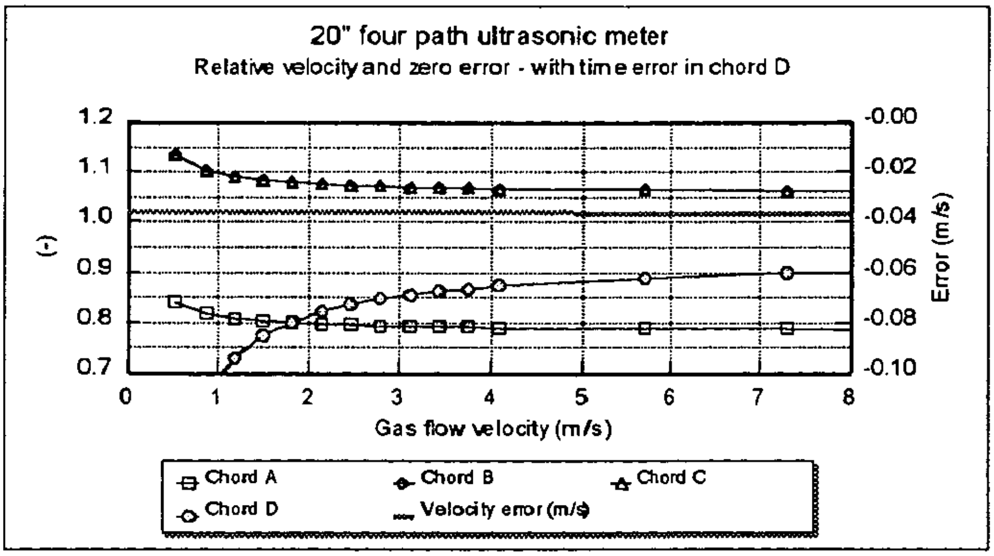


Figure 11 Calculated effect of an error in transit time for chord D of 1 μs in a 20" 4 path USM. The effect is a zero effect in average velocity of - 0.036 m/s

Velocity of sound data

The information about velocity of sound (ref. figure 2) can be treated in different ways.
One way is to intercompare the velocity of sound measured by the individual acoustic paths. This check in combination with the check of the velocity measurement can reveal whether there is an error in transit time in one direction or the other (t_1 or t_2), in both (t_1 and t_2) or not.

From the meter referred to in figure 8, 9 and 10, a chronological presentation of the difference between the individual measured velocity of sound and the average value is shown in figure 12.

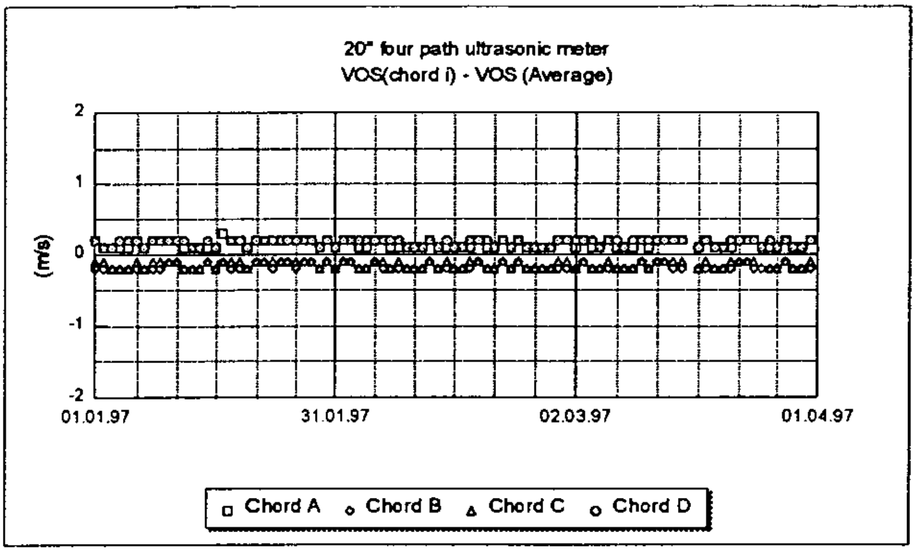


Figure 12 Velocity of sound measurement from the individual chords

Another way of checking the velocity of sound measurement is to compare the measured value with that calculated from measured density. Such a comparison is shown in figure 12 and 13.

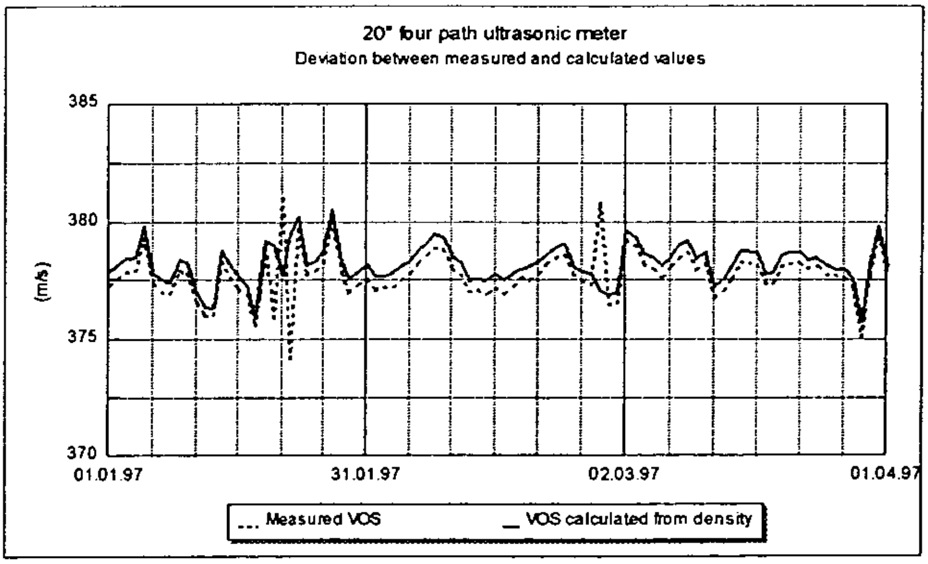


Figure 13 Comparison of measured VOS and VOS calculated from density, pressure and temperature. The database is as for figure 12. The occasional discrepancies is due to not simultaneously measured parameters. There is a delay in the densitometer loop.

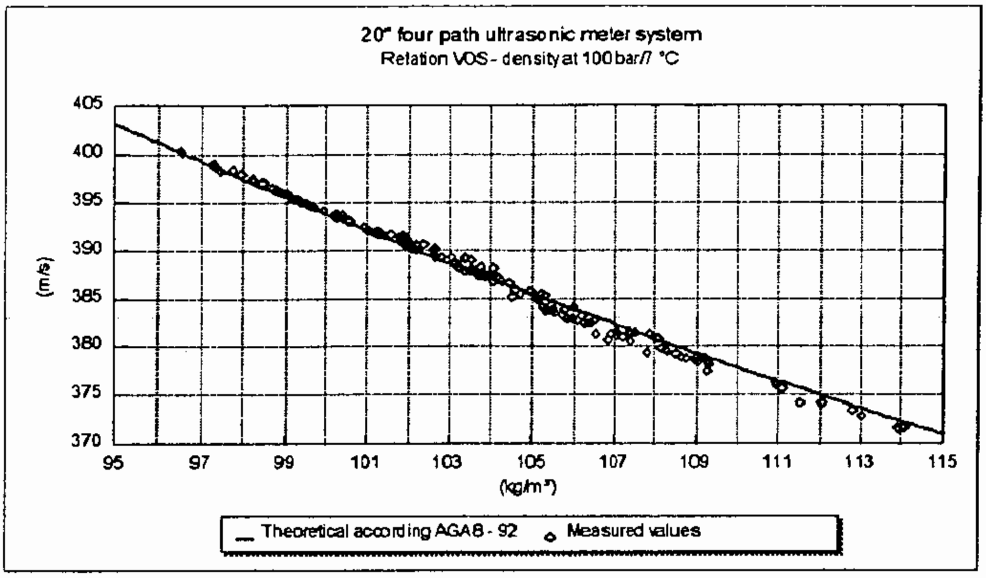


Figure 14 Measured velocity of sound reduced to 100 bar and 7°C. Each point of measured values is data from a period with varying gas composition. Ref. figure 7.

The sensitivity in velocity of sound calculation to change in density can be seen from figure 7. In most cases, change of 1% in density results in a change in VOS of 1 - 2 m/s.

Statoil is supporting further development of methods to calculate density from VOS and vice versa.

Investigation of flowing condition

The information from a multipath ultrasonic meter with chordial acoustic path can also to a certain degree be used to check the quality of the flowpattern inside the pipe.
In this paper only one example will be given.
At K-Lab a six inch FMU 700 from KOS was tested downstream a double bend out of plane with and without flowconditioner. Figure 15 shows the installation.

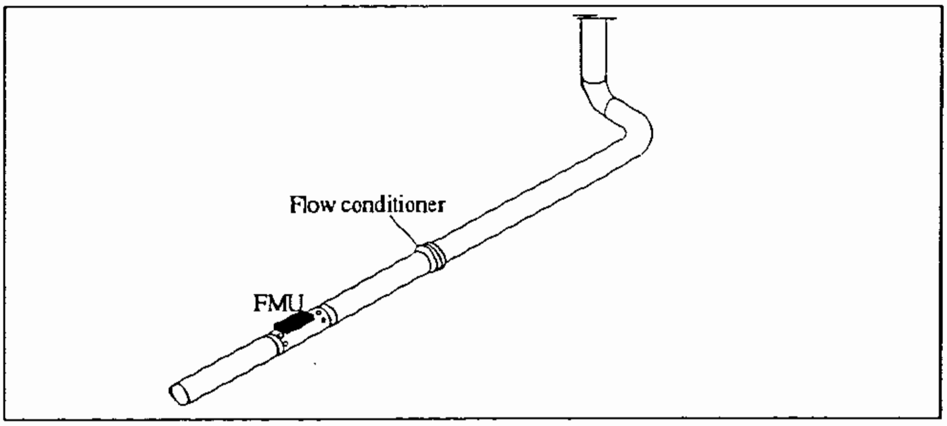
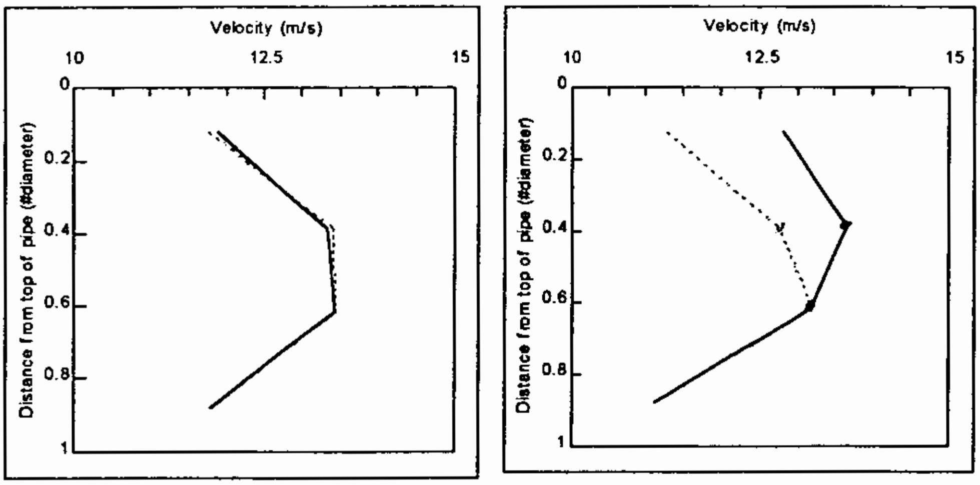


Figure 15 Installation of a 6" USM at K-lab

The FMU 700 has a path configuration that reveals very clear swirl condition. Figure 14 shows the velocity profiles as indicated by the meter in the two cases.



a

b

Figure 16 Results from velocity readings installed as shown in figure 15. a) is with flow conditioner and b) is without the flow conditioner. There are two acoustic paths at the two top chords at different angles relative to the pipe axes. Deviation between dotted line and full line indicates swirl. The effect of flow conditioner is clearly indicated.

CONCLUSION

It is demonstrated that information provided by an ultrasonic meter enables the operator to check and verify stability of the meter.

In a system providing information about density, pressure and temperature it is possible to cross check. Discrepancies could indicate problem with any of the measured values and action should be taken.

It is also demonstrated the multipath ultrasonic meters can provide valuable information about flow pattern inside the pipe.

List of references

1. NPD, Regulations relating to fiscal measurement of oil and gas etc. 1997.

2. A.G.A. Report No. 9, Measurement of Gas by Ultrasonic Meters, 1997.

3. A.G.A. Report No. 8, Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gases, 1992.