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WHY WE USE ULTRASONIC GAS FLOW METERS

1.5

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WHY WE USE ULTRASONIC GAS FLOW METER

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SUMMARY

Statoil has more than six years experience with multipath ultrasonic gas flow meters and has been using such gas flow meters for fiscal purposes offshore for past two years.

This paper will present those projects where fiscal ultrasonic meters are installed and give reason for the selection.

Further, experiences from the operation of meters from 12" to 24" are reported, highlighting the utilisation of the information which is unique for ultrasonic flowmeters: Information about velocity distribution in the pipe and velocity sound.

Some test and calibration results are also presented.

1 INTRODUCTION

Statoil decided back in 1988 to investigate the possibilities of introducing simpler fiscal metering equipment than the conventional multirun orifice systems on a riser platforms to be tie-in points for new pipelines. Up till now it has been a request to fiscally meter all streams into, out of and between the different parts of the pipeline system. In some cases this also require bi-directional metering systems.
Ultrasonic flow meters turned up to be the solution with the best potential for the future.

Currently eight ultrasonic meters are installed and running offshore. Two of them are part of the Sleipner/Zeepipe project and six of them are part of the 16/11-S/Europipe project. They are all accepted by Norwegian Petroleum Directorate (NPD) as fiscal meters.

We plan and expect more meters of this type to be installed offshore, in the near future.

Over the passed 6 years Statoil has therefore gained a lot of experience from laboratory testing, from monitoring of meters in operation and from research and development.

2 WHY ULTRASONIC FLOW METERS

2.1 General

2.1.1 Size and money

The main driving force behind our search for simpler metering system was saving of money.
With the information we had six years ago, the potential was an enormous reduction in size and weight when using ultrasonic meters instead of conventional orifice plates.
The reason is that for our operational conditions, the measuring range for a single meter run with ultrasonic meters was three times that of the orice meter run of the same diameter and the requirement for the length of straight pipe.
Figure 1 illustrates this point for a bidirectional system.

The cost savings on offshore platforms by reduced weight is estimated to 300 - 800 kNOK pr.ton depending on type of platform.

2.1.2 Accuracy

From the meter specification the accuracy seemed to match that of orifice meters.
We think we can conclude that through our tests this is confirmed for the meters that we have put in operation provided the meters are flow calibrated and eventually corrected.
We have however performed a number of investigations on installation details and are aware of the result from the Ultraflow Project [1]. There are indications that more work need to be done in order to obtaine the correlation between design of meter, type of flow and pipe disturbancies and meter error.

2.1.3 Information and diagnostics

The ultrasonic meters can offer valuable additional information about the flow velocity and velocity of sound. This information can partly be used for diagnosis of the condition of the meter and partly as valuable information about what is going on inside the pipe.
In addition, the meters themselves have built-in diagnostics which can tell the operators when and why the condition of the meter is deteriorated.
Our experience is that such additional information is of high importance and enables the operator to evaluate the condition of the meter at any time.

2.1.4 Redundancy in one meter

The multipath design can, in addition to improve accuracy, also be ragarded as a redundant meter provided the meters are so designed that it continue to meter with one or more pair (up to maximum all except one pair) fails and there is possibility to replace a malfunctioning pair during normal flow conditions.
Our experience is that this is the case.

2.2 Sleipner/Zeepipe project

Sleipner is in addition to being a production platform also a tie-in point between the Statpipe and Zeepipe transportation system.
Sleipner's own production is metered by a conventional orifice metering system. The requirement to also fiscally meter the flow between the two transportation systems required bi-directional metering systems.
After thoroughly evaluation and testing including a test period of 6 month with a 24" meter temporarily installed at 16/11-S [2] it was decided to go for an ultrasonic solution.

The concept consists of one single bi-directional 12" meter run and uni-directional 24" meter run in parallel. The ultrasonic meters fitted into the piping that anyway was required.

The reason why a single run concept for one direction was selected and accepted was partly because of space limitation, partly because of the built in redundancy in the meter and partly because of the possibility to estimate the the quantity by means of other meters in the transportation network.

The 12" meter has been in operation since September 1993 after being accepted by NPD. The 24" will probably be in operation from summer 1996 when Troll start production.

The investment cost saving by using this ultrasonic system compared to conventional bidirectional orifice station was found to be between 100 and 150 MNOK.

2.3 16/11-S/Europipe project

The excisting riser platform 16/11-S was appointed to be the tie-in point between the Zeepipe, Statpipe and Europipe transportation system.
This required the installation of six new fiscal metering sytems at a small excisting riser platform: The flow in each of three incoming pipelines could be splitted in two outgoing pipeline simultaneously.See figure 2.
Installation of six conventional orifice stations each having a capacity of approximately 40 MSm^3/d and a required turndown of 1:30 for a design pressure of 172 bar would be almost impossible to install concerning the space required and the additional weight.
Based on experience from previous tests and the Sleipner/Zeepipe project it was decided to install six 20" single meter run systems with ultrasonic flow meters.

The reasons for selecting and accepting single run systems was partly because of space limitations,the built in redundancy in a single meter, the excisting possibility of by-pass piping in case of need for repair requiring no flow through the meter and the possibility for estimating the quantity in case of meter malfunctioning or by-pass flow for other reason.

The meters was put in operation summer 1995 after being accepted for fiscal metering by NPD.

No detailed estimate of cost savings by using the ultrasonic concept instead of orifice system was done. It was uncertain how many and how big additional moduls were required on the platform to create sufficient space for conventional meter systems. However, a brief estimate was a cost saving 150-300 MNOK compare to installation of conventional orifice system.

3 EXPERIENCE

3.1 Accuracy and calibration

All meters installed up til now have been individually calibrated in flow laboratory.
Examples of results from such flow calibrations are shown in figure 3 for a number of 20" meters.

Additional tests have been performed to study the accuracy under varying conditions like pressure and temperature and also under different installation conditions.
Figure 4 shows example of calibration results obtained at different pressures for a 12" meter.

Smaller meter like 6" meters turns out be be less linear than bigger meters. The reason might be that the flow pattern inside the meter body is not as ideal as assumed. Example of calibration result of a 6" meter at different installation condition is shown in figure 5.

Calibration results are used to determine correction factors for the individual meter.

Also, after the meters are installed, they are continuously monitored and compared with other meters.

It is a goal for the manufacturer and the user to rely on dry calibration. Our experience from our calibration program is that individual flow calibration before installation is necessary to obtain and verify sufficient accuracy in volume flow measurement to obtain an uncertainty of less than 1 % on mass flow.

3.2 Information and diagnostics

To understand the possibility that a ultrasonic flowmeter offers concerning checking, monitoring and utilisation of if information, it is worthwile to briefly describe some basic elements of the principle. The basic equation which relates the transit times measurement to the velocity,v, for a chord is:

$$v = \frac{L^2}{2X} \cdot \frac{t_2 - t_1}{t_1 \cdot t_2}$$

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 transducerfronts

t_1 and t_2 are determined from measured times between electronically transmission of signal till electronically detecting received signal minus delay times in the transducers and electronics and delays caused by detection method. Typical delay time in the transducerpair and electronics is in the order of 10 μs and a difference in upstream and downstream direction of typically 0 - 200 ns. The delay caused by signal detection method is in the order of 10 - 20 μs.

The most critical term is (t_2-t_1), also denoted as Δt. Δt is very much affected by the small difference in the transducers' delay times in the two directions. Errors in Δt results in zero error.

Typical velocity of sound (or the equivalent terms L/t_1 and L/t_2 in the above equation) in natural gas is between 350 - 420 m/s depending on composition, pressure and temperature.
For a 12" meter with chord design the transit time are in the order of 2000 µs and the Dt at 1 m/s approximately 2.2 µs.

Reporting of the individual gas flow velocity and velocity of sound (see figure 6), useful information is available for monitoring, check and verification of the stability and condition of the meter.

3.2.1 Monitoring of gas flow velocity for check purposes

In a mulipath meter more individual flow velocity are measured.
For a meter installed in a fixed geometry, the relation between the individual velocities are constant over time and velocity range.

Under this assumption, monitoring the individual velocities chronologically and also plotted as function of average flow velocity will indicate the stability of factors affecting the time measurement. Error in the most sensitive term, Δt, will result in a zero error for the actual chord.

Figure 7 shows an example of such a monitoring for a 12" meter installed offshore over a period of 7 months. In the same figure is also indicated what would be observed should a change in Δt of 200 ns occure in chord A: As the vlocity is approaching zero, the deviation in velocity from chord A relative to the average velocity will increase. The resulting change in the meter's flow readings is also indicated. As can be sen, this kind of monitoring will reveal drift in the meter caused by drift in the transducers' "delta delay times".
No other single flow meters offer similar possibility.

In some cases, however, the velocity distribution is not fixed even when the meter is installed in a fixed geometry. In such cases where there is a rather complexed relation between the velocity, the chronological monitoring or a monitoring of velocity distribution with flow velocity rather difficult to interpretate. In the next section such an example is given. An example is given in the next paragraph.

3.2.2 Monitoring of gas flow velocity for investigation purposes

In addition of being a valuable verification method, the information of flow velocity distribution can also give valuable information about the effect from certain pipe elements.
An example of such a case is the results from one of the installation at 16/11-S:

One of the streams is split in a tee-connection. The flowrates in the two branches are controlled separately.
When observing the gas flow velocity distribution in one of the meters chronologically or as a function of flow velocity, the distribution pattern was rather random. See figure 8a and 8b.
However, when plotting the flow velocity distribution between the chords as a function of the ratio

of flow in the two branches, the trend became quite clear as shown in figure 8c. Given this velocity distribution relationship, it is possible to continue the monitoring for revealing zero offsets in the future.

The example from 16/11-S indicates the possibilities that multipath ultrasonic flow meters offers in this respect. For example, 6" and 12" meters have been used at K-Lab to study the effect bends and flow control valves as well as the effect of installing flow conditioner behind bends and valves. Results from such studies will however not be presented here.

3.2.3 Monitoring of velocity of sound distribution for check purposes

In addition to the monitoring of the velocity and the velocity distribution which in essence is a monitoring of the stability of Δt measurements, the monitoring of the velocity of sound (VOS) is in essence a monitoring and verification of the absolute transit times measurements. It is two kinds of monitoring: Verification of the the closeness between the individual measured VOS and a comparison between measured VOS and a calculated VOS.

When gas is flowing through the meter the VOS from each chord normally is equal within certain limits. This indicate that the time measurement is correct. (No miss on the the period of received signal).
Figure 9 gives an example of such a monotoring indicating stable conditions over a long period of time.

The comparison between measured and calculated VOS is a bit more "tricky". We have based our calculated VOS, c_g, on the general thermodynamic relation:

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

The expression $(\frac{\delta p}{\delta \rho})_T$ can be calculated based on the method for density/compressibility calculation from gas composition described in AGA Report No.8 or other similar method. The problem is that the exact knowledge of the gas composition at any time is normally lacking. In our systems, however, we are continously measuring operating density.

Our method for calculating VOS, c_c, is as follows:

$$c_c = c_g + A(p, T, \rho_m - \rho_g)$$

where

- c_g is calculated VOS from a fixed, nominal gas composition
- A is an expression dependant on p.T and ρ_m-ρ_g
- ρ_m is measured operating density
- ρ_g is calculated density from a fixed nominal gas composition at operating pressure and temperature

It is important that ρ_g and c_g is based on the same equation of state.

Figure 10 shows measured results compared with theoretical results based on AGA 8 rev. 85 and 92. All data are reduced to data at 100 bar and 7 °C.
Figure 11 shows the agreement between our calculated VOS and measured VOS. A change of 1 m/s in VOS affects the flow velocity measurement by 0.5 %. The uncertainty in our way of calculating the VOS is estimated to less than 1 m/s.
Revision -85 and -92 of AGA 8 differs. The measured results is in between, but closer to the -85 version.. Our field measurement is very close to measurement performed by laboratory measurement [3].
We believe this a very good method to verify the transit time measurement. It does not only allow for a check of the VOS measurements. It also allow for a cross check between two independently measurement, density and VOS.

3.2.4 Monitoring of VOS for research purposes

For the compositions we are deling with, it seems like there is a theoretical unique relation between density and VOS.
This relation can and has been checked out in our metering systems where the density is measured together with VOS.
Our conclusion so far is that the VOS can be as reliable for density determination as the densitometer itself.

Another use of the VOS measurements and distribution is to study temperature gradients in the pipe. For our most common operating conditions, the VOS drops about 1 m/s per °C drop. Provided the measurements of VOS are reliable, such measurements can give interesting information about the hydrodynamic taking place inside the pipe.

Paper will be hopefully be presented at other events descibing such findings.

3.3 Redundancy

From experience at flow laboratory with missing pair(s) of transducers it is verified that for 20" four path meter the additional uncertainty when all but one chord is working, is less than 0.2 %. With all but two chords working the additional uncertainty is less than 0.4 %.

Operating experience from Sleipner with replacement of transducer under flowing condition is fully possibly. There was no noticeable effect on the flow readings during or after the replacement.

Future operators should however be aware of the retraction mechanism and check whether it is accepted from a safety point of view by their company.

3.4 Installation hints

Two impotant consideration should be mentioned:

1. Flow control valve installed in the proximity to the meter might create ultrasonic noise unacceptable to the meter. This is most expelled with low (audible) noise valves.

2. The meter spoolbody should be thermally insulated. This is especially important when gass temperature is far from ambient, smaller meters and meters with deep transducer cavities.

3.5 Standardisation

The status concerning standardisation is that a ISO TR Working Draft [4] has recently been issued. It is for comment until the end of 1995.

4 CONCLUSION

With the knowledge about the the multipath ultrasonic flowmeters that we have obtained over the past six years, we still consider this type of meter as a meter for the future.

Because of the good relation we have had with different manufacturer, the technoly has improved and relevant and good verification procedures have been developed.

There is however still a nedd for more work to be done, especially on installation effects including effects of flow control valves.

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Reidar Sakariassen, Statoil (N)
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3. Thermophysical properties of fluids for the gas industry: Speed of sound of natural gases.
Annual Report 1987
Gas Research Institute 1988

4. ISO/TC 30/WG 20 N 103 E:
9th Working draft "Measurement of fluid flow in closed conduits: Methods using transit time ultrasonic flowmeters"

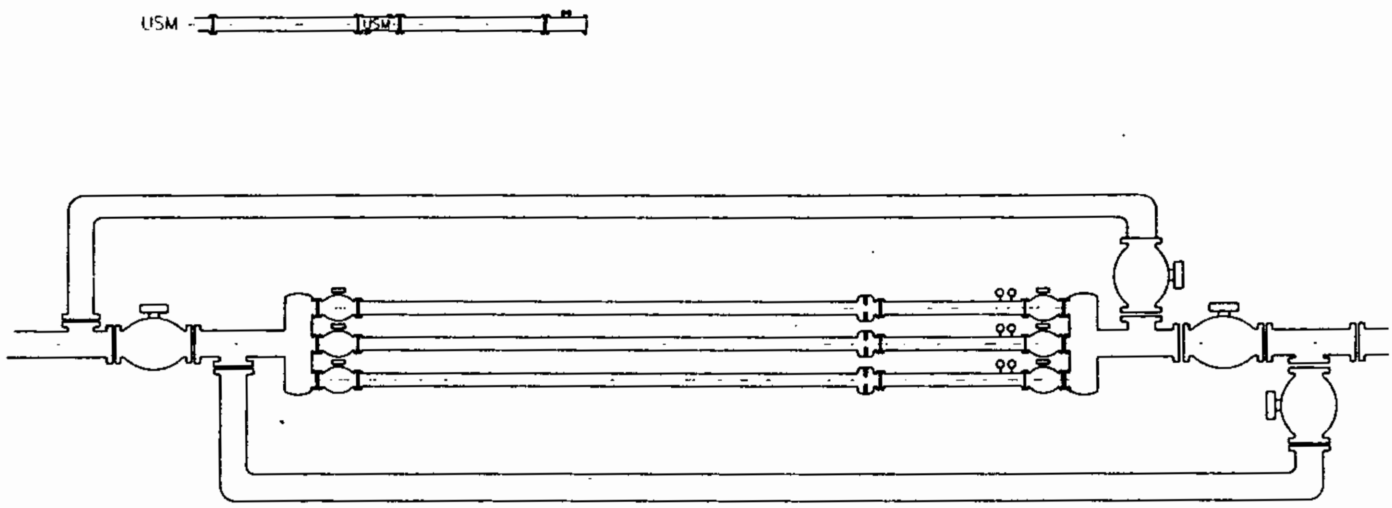


Fig. 1 Sketch showing potential difference in size between bi-directional USM and orifice system

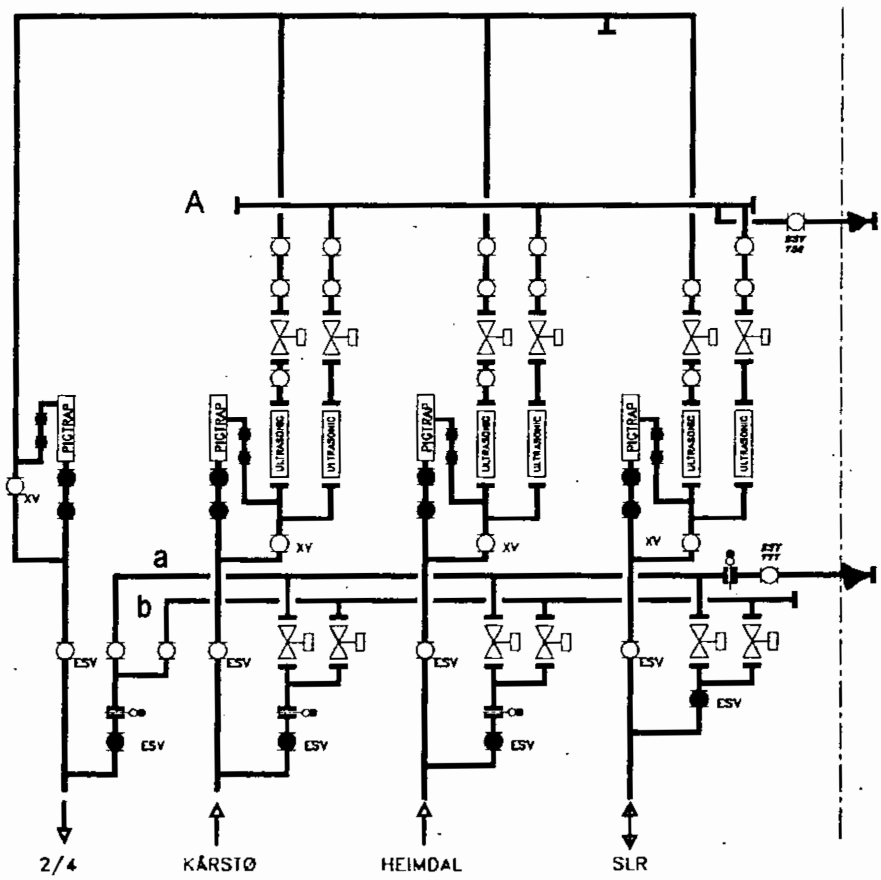


Fig. 2 Lay-out of metering concept at 16/11-S

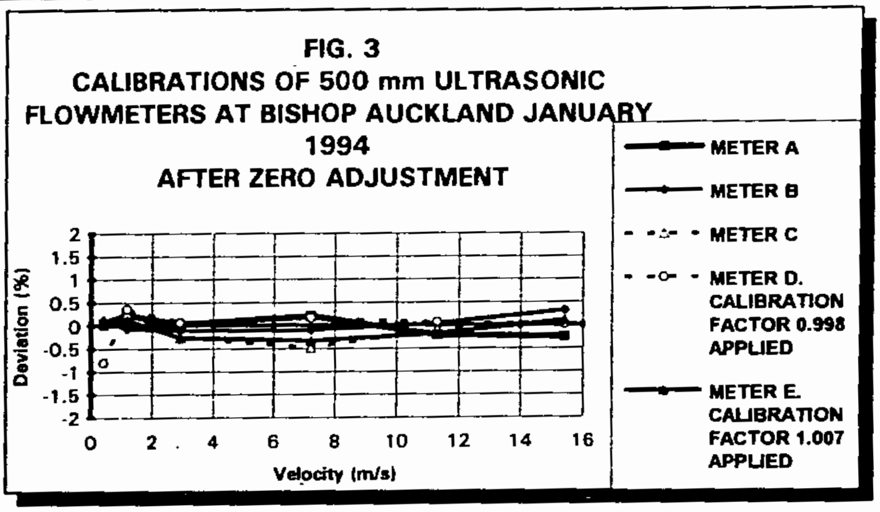


FIG. 3
CALIBRATIONS OF 500 mm ULTRASONIC FLOWMETERS AT BISHOP AUCKLAND JANUARY 1994
AFTER ZERO ADJUSTMENT
Deviation (%)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
2
4
6
8
10
12
14
16
Velocity (m/s)
METER A
METER B
METER C
METER D. CALIBRATION FACTOR 0.998 APPLIED
METER E. CALIBRATION FACTOR 1.007 APPLIED

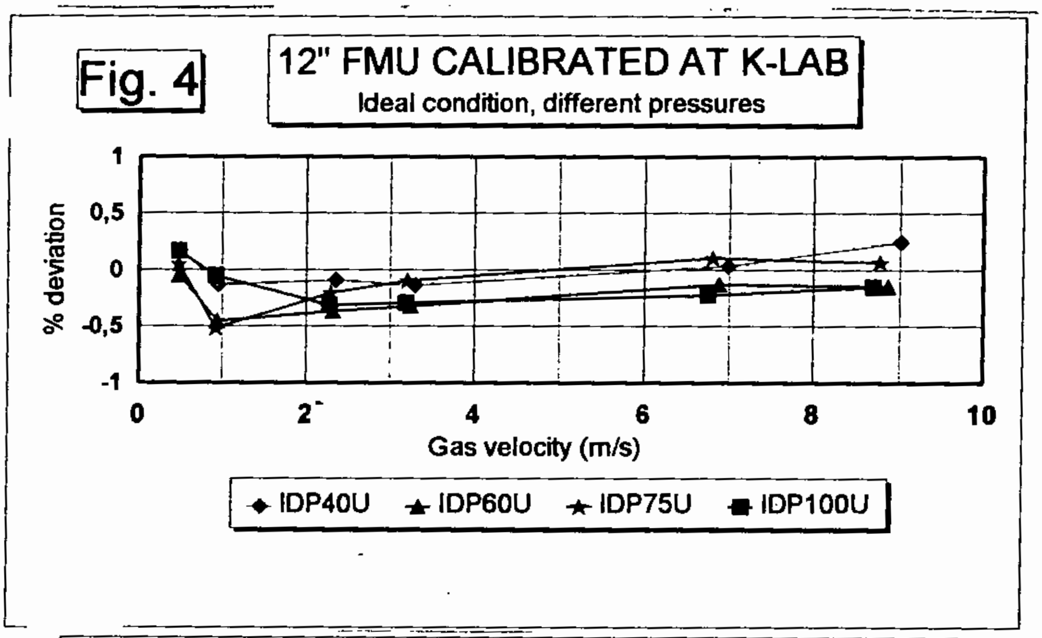


Fig. 4
12" FMU CALIBRATED AT K-LAB
Ideal condition, different pressures
% deviation
1
0,5
0
-0,5
-1
0
2
4
6
8
10
Gas velocity (m/s)
IDP40U
IDP60U
IDP75U
IDP100U

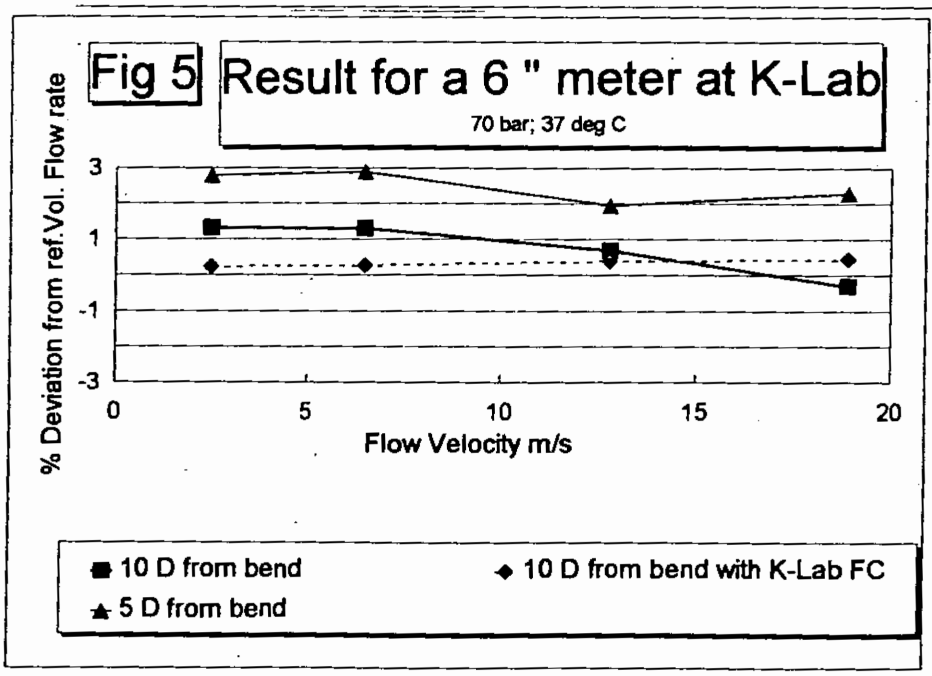


Fig 5
Result for a 6 " meter at K-Lab
70 bar; 37 deg C
% Deviation from ref.Vol. Flow rate
3
1
-1
-3
0
5
10
15
20
Flow Velocity m/s
10 D from bend
10 D from bend with K-Lab FC
5 D from bend

Fig. 7
12" USM at Sleipner.
Normalised gasflow velocities from each acoustic path logged daily over a period November 1994 till June 1995

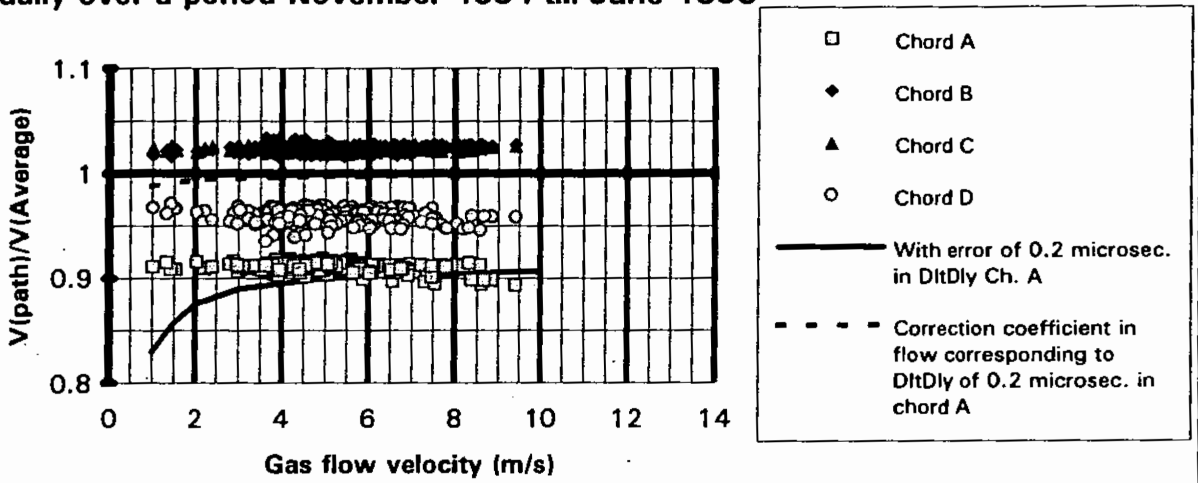


Fig 8 a

Normalised velocity v(chord i)/v(average) in A-meter chronologically monitored

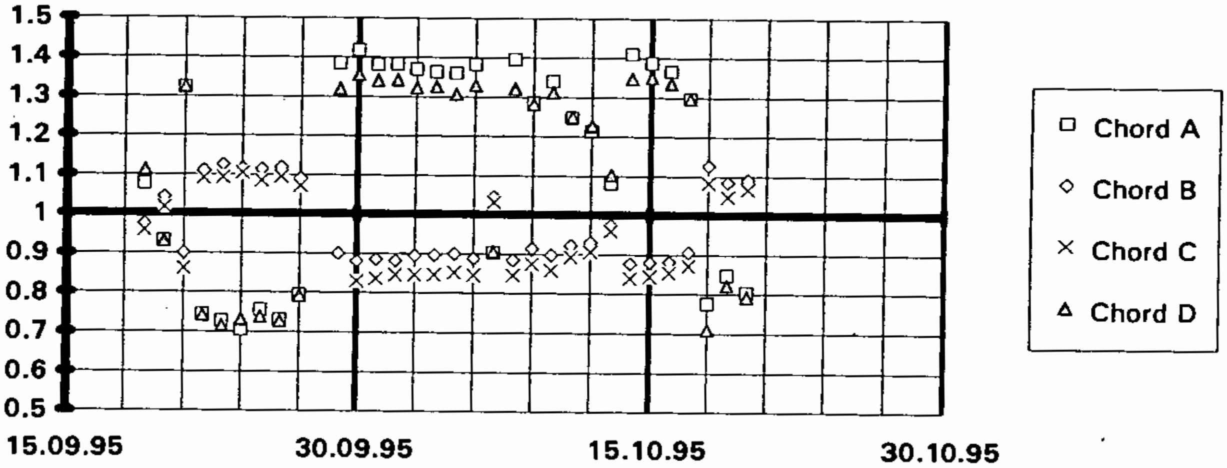


Fig 8 b

Normalised velocity v(chord i)/v(average) in A-meter as function of flow velocity

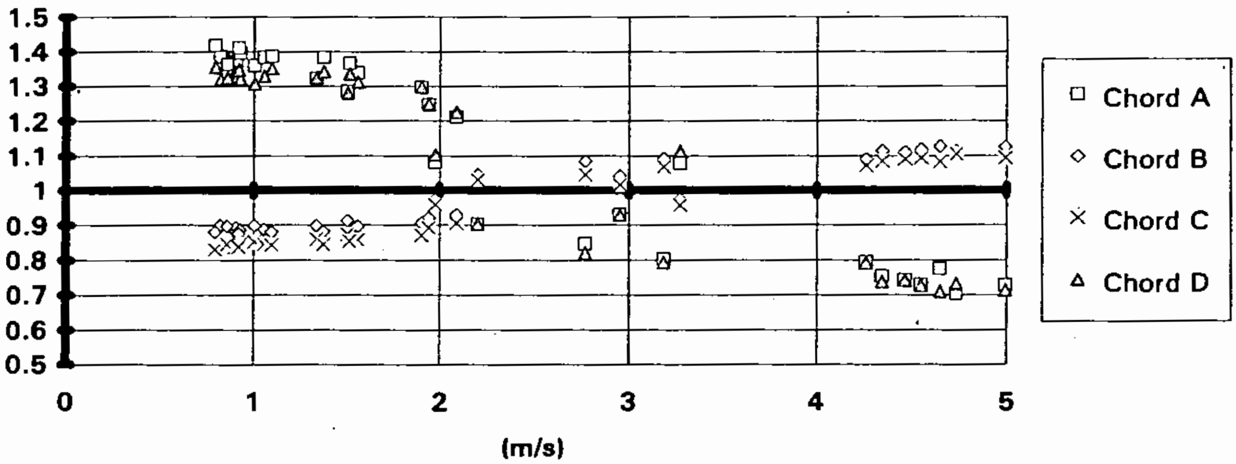
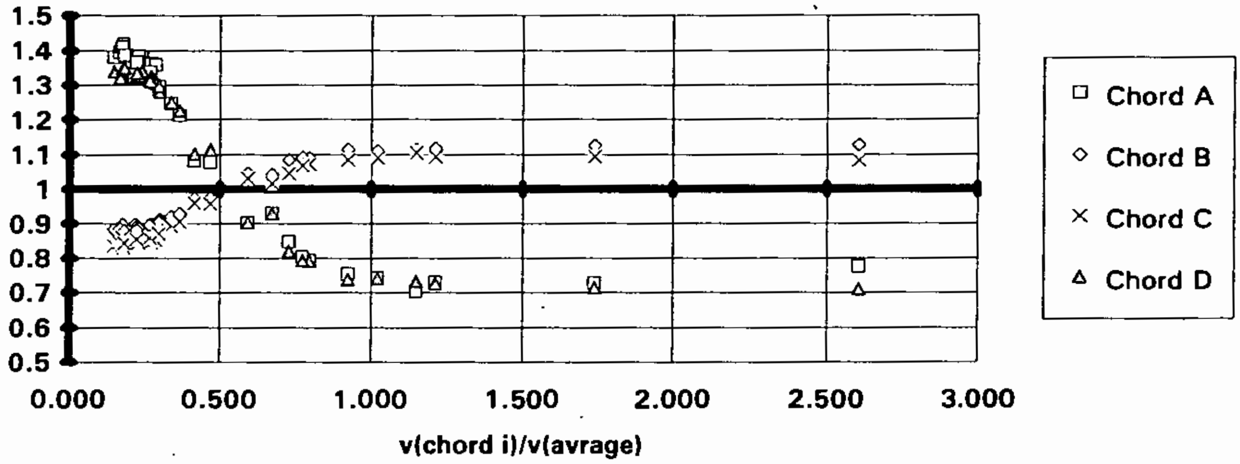


Fig 8 c

Normalised velocity v(chord i)/v(average) in A-meter as function of flow ratio between A and B meter



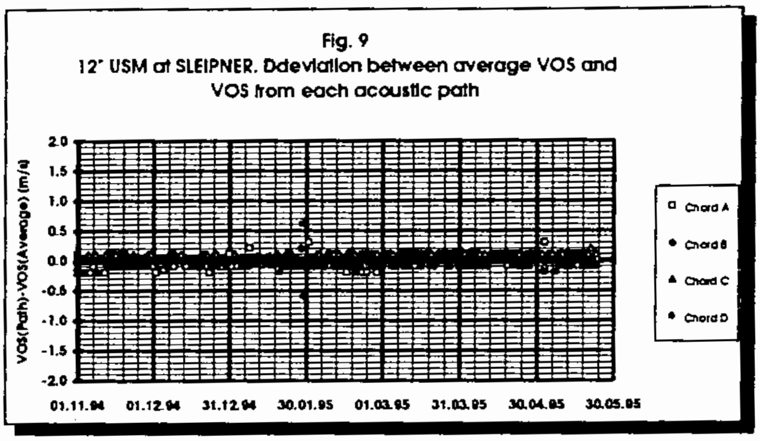


Fig. 9
12" USM at SLEIPNER. Ddeviation between average VOS and VOS from each acoustic path
VOS(Path)-VOS(Average) (m/s)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
01.11.94
01.12.94
31.12.94
30.01.95
01.03.95
31.03.95
30.04.95
30.05.95
Chord A
Chord B
Chord C
Chord D

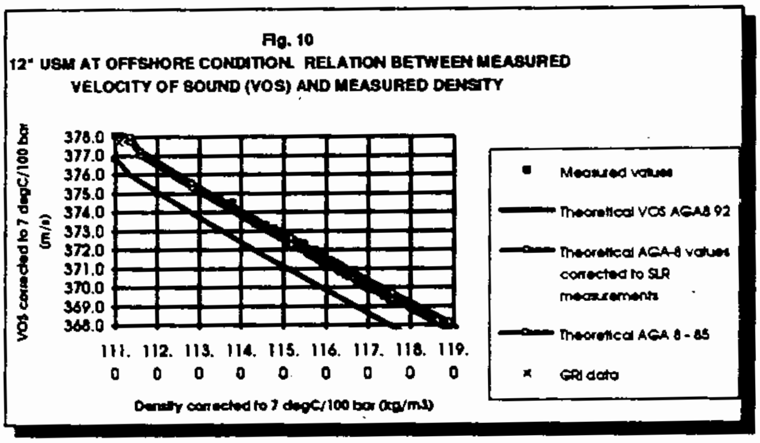


Fig. 10
12" USM AT OFFSHORE CONDITION. RELATION BETWEEN MEASURED VELOCITY OF SOUND (VOS) AND MEASURED DENSITY
VOS corrected to 7 degC/100 bar (m/s)
378.0
377.0
376.0
375.0
374.0
373.0
372.0
371.0
370.0
369.0
368.0
111.0
112.0
113.0
114.0
115.0
116.0
117.0
118.0
119.0
Density corrected to 7 degC/100 bar (kg/m3)
Measured values
Theoretical VOS AGA8 92
Theoretical AGA-8 values corrected to SLR measurements
Theoretical AGA 8 - 85
GRI data

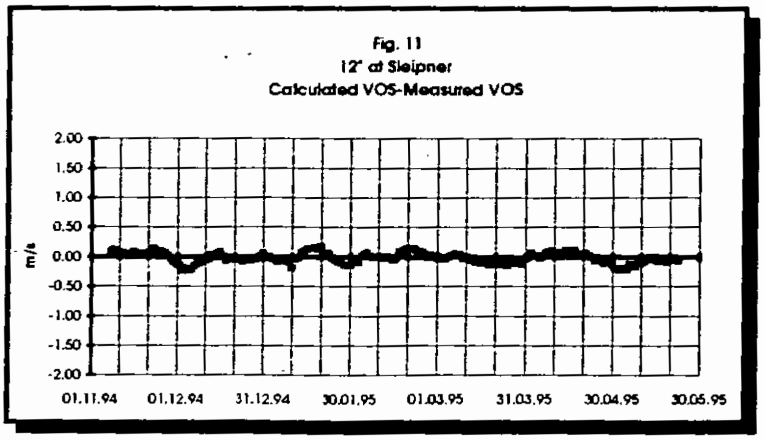


Fig. 11
12" at Sleipner
Calculated VOS-Measured VOS
m/s
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
01.11.94
01.12.94
31.12.94
30.01.95
01.03.95
31.03.95
30.04.95
30.05.95