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Practical experiences with multipath ultrasonic gas flowmeters

by

Reidar Sakariassen
Statoil

Norway

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ABSTRACT

This paper will concentrate on experience gathered from laboratory tests and offshore field test of a 24" four-path ultrasonic gas flowmeter system. Experience with other dimensions and different marks will be mentioned when necessary to verify the general validity of the findings from the tests with the 24" system.

The paper will also describe basics of the measurement method, what could influence on the meter, how the meter behave, check possibilities and proposed check procedures.

Through the projects Statoil has learned a lot about this technology. Through this paper we wish to share our knowledge about a metering principle which we believe is a technique which will be widely used in the future.

CONTENTS

1 INTRODUCTION

Statoil is constantly searching for costeffective solutions offshore. This include also metering systems. Traditionally, metering systems based on orifice plates are bulky and heavy. Accordingly, the platform costs are considerable. The cost can be significantly reduced if the size of the metering systems is reduced [1,2].

Statoil has recently experienced that due to the increasing number of pipeline to come (Fig. 1), a large number of metering systems at one single riser platform could be required. The cost for large conventional metering systems with capacity up to 50 MSm^3/d installed at an existing riser platforms would be enormous.

In cross-overs between transportation systems bi-directional flow occurs and bi-directional measurement is required.

Those examples indicate Statoil's interest for compact metering systems. Statoil has seen the potential of compact metering stations based on ultrasonic gas flow meters. Fig. 2 indicates the difference in size between a convential metering station based on orifice plates and a system based on multipath ultrasonic flowmeter for bi-directional flow. The main reasons for the reduction in size is the increased flow capacity for a given dimension and reduced requirement for length of straight pipes.
For some more reflection concerning size,ref. is made to [3].

However, it is mandatory with high accuracy and reliability. To verify accuracy and reliability, Statoil has initiated and been actively involved in a number of projects aiming to verify the feasibility of ultrasonic flowmeters. Among those can be mentioned:

- tests at K-Lab of 6" meters of different marks and design
- development and tests at different laboratories of a 12" meter in cooperation with Fluenta/CMR [4]
- laboratory tests at K-Lab and six months field tests at riser platform 16/11-S (Statpipe) of a 24" system
- laboratory test at K-Lab and offshore installations of a 12" system

From these activities it has been possible for Statoil to learn how these meters behave, which precautions should be taken to obtain and maintain accuracy and which checks to be performed. Also, we have been aware of what could cause problems for such meters and what should be looked further into in the future. In close cooperation with the manufacturers, it has been possible to improve the equipment and propose modifications.

Through this paper it is our intention to share with other potential users of such technique the knowledge necessarry to improve the probality for successful use of ultrasonic gas flow meters.

2 BASICS OF THE MEASUREMENT METHOD

The description in this chapter is partly based on fundamental theory and partly on findings and observations during our projects.

2.1 Basic principles for the velocity measurement

The basic principle of the meters is based on the well established transit time difference. It utilize the fact that the propagation velocity of an acoustic pulse is modified by the flowing gas. An acoustic pulse will propagate faster with the flow than against the flow.
The basic principle is described in Fig. 3.
Ideally, the transit time is the time between the acoustic pulse is passing the imagary points where the intertransducer line is crossing the flush with the inner pipewall.
The formulas used in Fig. 3 is a practical formula which takes into the consideration the fact that in practice the transducers are set back a certain distance from the pipewall. Another practical solution is described in [4].
It must be underlined that with the practical solutions described above, it is the transit times between the transducers' outer fronts that is the transit time to consider.

Based on the transit times, the **velocity of sound** is measured as $(t_{AB} + t_{BA})/(2L)$. As will be seen later, the velocity of sound can be used as check parameter.

2.2 Volume flow measurement

To determine the the volume flow, the average velocity over the cross sectional area of the pipe, more pair of transducers is mounted. The principle is described in Fig. 4.

2.3 The ultrasonic transducers

Before proceeding to the various aspects of the ultrasonic meters, I think it is worthwile to describe and explain the functions of the ultrasonic transducers.

An example of a design of a transducer is shown in Fig. 5 [5]. The active part of a transducer is the piezoelectric crystal. By applying a voltage to the crystal at a certain frequency, the crystal itself will start to oscillate at the same frequency resulting in pressure wave (acoustic wave) radiations from the crystal. Also, a short voltage "kick" to the crystal start an oscillation of the crystal at a frequency given by the type, size and form of the crystal. The normal frequency range for high pressure gas meters is 100 - 200 kHz. The crystal works also opposite: Applying a pressure change results in the generation of a voltage change across the crystal picked up by the electrodes.

The tricky things with such transducers is to have radiation patterns (lobes) so the radiation hits the receiving transducer and enough acoustic energy is transferred into the gas from the generating transducer and from the gas into the receiving transducer. This latter requirement is the difficult part. The combinatination of mechanical protection and matching of the acouştic impedances between gas and tranducer material is hard to achieve.

As can be seen from Fig. 5, there is a distance between the transducer front and the active crystal. The time of interest is from when the acoustic signal pass the front end of the emitting transducer till it pass thr front end of the receiving transmitter. The direct measured time is from the voltage is applied to the generating crystal till a voltage is generated by the receiving crystal. Therefor the measured transit time needs to be corrected to arrive at the time of interest. This time correction is often referred to as **the transducer's delay time**. Normally, the delay time, with the symbol τ, is in the order of 10 μs.
It is a fact that this delay time is not the same for a transducer when it is acting as a transmitter and as a receiver. For a pair of transducers the total delay time will therefor not be the same for both directions,
The time delay also differs slightly between transducers. For different pairs of transducers, the total delay time will therefor not be the same.

Determination of the transmitters' acoustical behaviour, the delay times and the length of the transmitters are the most important parameters the manufacturer should determine.

2.4 Detection of received acoustic signal

The acoustic pulse signal consist of a number of periods. The piezoelectric crystal in the reciever needs to "see" a certain signal amplitudes of the periods to correctly detect the exact point of time when the signal is received. Fig. 6 indicates ways of detecting the pulse: Either based on pulse amplitude or on priod pattern recognation.

It is necessary to always detect the received signal at the same period as when the delay times were determined or when the laboratory calibration of the meter took place. This needs to be regular checked by use of oscilloscope.

If the detection systems hits the wrong period, the result will be an error. To illustrate the magnitude of the error the following example is given for the 24 " meter investigated:

Missing detection by one period in both direction the resulting error is 0.5% of velocity.
Missing detection by one period in only one direction, the resulting error is ~1.5 m/s.

Reason for not detecting the correct period is that either the acoustic signal is too weak because of:

- bad transducers (loose crystal)
- too much deposit on the transducers
- signal damping along the acoustic path because of temperature gradient

or there is too much noise because of

- too much noise from external sources compared to signal strength
- too much signal left from the previous acoustic "shot"
- electrical noise

2.5 Time delay in tranducers

As mentioned in 2.3, it is necessary to know the tranducers time delay.

For a pair of transducers this is determined by the manufacturer and given in certificate for the transducers. See example of a transducer certificate in Fig.7.

The delay times could however be influenced by the way the transducers are installed and possibly also by the temperature. It is therefore recommended to check the time delays after the meter is installed.

To understand the way the ultrasonic flowmeters could be checked, it is absolutely necessary to understand the importance of the delay times.
Based on measured "transit times" (which are not the true transit times as explained in 2.3) the expression for the gas velocity is as follows:

$$v = \frac{L^2}{2x} \frac{(t_2' - \tau_2) - (t_1' - \tau_1)}{(t_2' - \tau_1)\,(t_1' - \tau_1)} = \frac{L^2}{2x} \frac{(t_2' - t_1') - (\tau_2 - \tau_1)}{(t_2' - \tau_2)\,(t_1' - \tau_1)}$$

where
- t' is measured "transit times"
- τ is delay times
- subscript 1 is for upstream direction
- subscript 2 is for downstream direction

The delay times are entered into the flow computer.

Knowing that a transit time difference of 3 µs means approximately 1 m/s one can understand that the delay time difference ($\tau_2 - \tau_1$) needs to be determined by an accuracy of 0.03 µs to have an uncertainty of 0.01 m/s which means 1% at 1 m/s.

It is assumed that the absolute delay times are determined by an uncertainty of 0.5 µs. For the 24" meter investigated this means an uncertainty of approximately 0.05%.

To have a precise determination of the difference in the time delays, the meter is zero checked. When the flow is definitely zero, it is possible to **adjust the delay times** to obtain a reading of gas velocity on all pairs (or chords) to be exact zero. This is the socalled **zero flow check.**

This zero check should be done at a temperature close to normal operating temperature. From the testing of the 24" meter there are indications that there is a temperature effect on the zero reading of approximately +0.0003 m/s pr. °C. This corresponds to a temperature effect on the delay time difference of 0.001 µs.

2.6 Velocity of sound along the acoustic path

The description given in 2.1 and the formula in Fig. 3 is only correct if the velocity of sound in the cavity between the pipewall and the transducer front is the same as witin the cross section of the pipe.
If this cavity is deep, care should be taken to ensure that this is the case. For the four-path 24" meter extensivly investigated, the conditions can be illustrated as in Fig. 8. The main practical problem arises when the gas gas is much warmer than the ambient. This could cause a temperature gradient in the cavity and consequently also a gradient in the velocity of sound.

If the temperture gradient causes the average velocity of sound along the acoustic path to be changed by 1 m/s, the effect on measured velocity is affected by 0.5% for our 24" meter.

Velocity of sound decreases by approximately 1 m/s as temperature decreases with 1 °C at our normal conditions.

A way of checking the effect of the temperature gradient on the velocity of sound is to compare the measured velocity of sound with calculated velocity of sound. As mention in 2.1, velocity of sound is measured by an ultrasonic flowmeter. A program SONFLOW [6] makes it possible to calculate the velocity of sound very accurate.

The way to minimize this problem is to insulate the meter very carefully.

3 CONTENT OF THE TESTS

A complete 24" metering systems consisting of the ultrasonic flowmeter itself, inlet and outlet pipe sections, pressure transmitter, temperature sensors, density sensor and flowcomputers was tested at K-Lab before and after a test periode of 6 months at the riser platform 16/11-S in the Statpipe system.

At K-Lab it was very long straight pipe upstream the meter. At 16/11-S the meter was installed 10 D downstream a single horizontal bend.

The flow capacity of K-Lab limits the gas flow velocity tomaximum 2.2 m/s which is only approximately 10% of the meter's total range. The temperature was 37 °C.

At 16/11-S the gas flow velocity was normally between 2 and 5 m/s. Maximum velocity during the test was 12 m/s for a short while. The pressure varied between 72 and 100 bar and temperature 4 - 7 °C.

Fig. 9 shows the complete system. Its weight is about 15000 kg. It capacity with the conditions at 16/11-S is 45 MSm^3/day.

Fig. 10 shows its position in the transportation system.

The systems generates local reports at the platform. Data were also transferred to the Transportation Control Center, Bygnes. We were especially interested in how reliable the system would operate. Besides, it was also possible to check its measurement results against other orifice metering systems.

4 TEST RESULTS

4.1 K-Lab results

Fig. 11 shows the result from the K-Lab tests as deviation against K-Lab references before and after the test period at 16/11-S.

It seems to be a shift in calibration after the meter has been at 16/11-S. The shift can, however, be explained by the effect described in 2.6:
The first test was done in December -92 and the second was done in July -93. The difference in ambient temperature has affected the velocity of sound in the cavity. This is verified by an analysis of the velocity of sound logged during the tests. See Fig. 12. The conclusion is that the meter was not sufficient insulated in December resulting in an 0.5% error. The meter were adjusted by modifying the delay times corresponding to 0.5% as described in 2.5.

The conclusion from the K-Lab tests is that the meter was in reality adjusted to read 0.5% too high prior to the test at 16/11-S

4.2 Analysis of the velocity of sound

As mention in 4.1, an analysis of the speed of sound indicated a problem with the insulation.

A further analysis of the velocity of sound can be done by comparing velocity of sound in the individual chords. This is shown in Fig. 13 and 14. It can be seen that in December it was very large differences between the chords. It can also be compared with results from 16/11-S as shown in Fig. 15 where there is almost no difference among the chords.

To indicate that this problem is related to the deep transducer cavities, results from a five-path meters with almost no cavities at all, is shown in Fig. 16.

The conclusion is that comparison of measured velocity of sound against calculated is a good day-to-day check. So is also an intercomparison between the chords.

4.3 Results from 16/11-S

When adjusting for the wrong adjustment of the meter at K-Lab in December, the comparison between the ultrasonic meter and orifice meter system showed a steady deviation of 0.3-0.5 % through the whole test period from February till June 1993. No dependance of flowrate or pressure was observed.

One significant shut-down of the meter occurred: At one occasion the pressure drop across a control valve 10 m from the meter created noise estimated to more than 105 dBA. This generated too much noise for the meter. When the noise decreased below 105 dBA, the meter started functioning again. The shut-down lasted for 20 minutes.

The meter was exposed to foreign matters in the gas. When the transducers were taken out of the meter after the tests at 16/11-S, it was observed that the cavity had been almost filled up with oily liquid. It was however no indications that this had caused problem during the offshore tests.

Conclusion from this tests is: The meter had function satisfactory. If high pressure drop is expected across control valve near the meter, use valves that generate little noise.

4.4 Velocity profile

With multipath ultrasonic flowmeter one can also get information about the velocity profile in the pipe.

Fig. 17 shows normalized velocity profile at 16/11-S for different flowrates. These indicate normal situations.

Fig. 18 shows simular results at K-Lab. Results with 12", 24", five- and four-path are consistent and indicates assymetric profile at low flowrates.

The velocity profile should also be used as day-to-day check.

5 CONCLUSIONS FROM THE TESTS

Through this project - and other similar projects - it has been shown that ultrasonic flowmeters can be accurate and reliable also in offshore situations.
As for other methods, some precautions have to be taken, such as:

- good insulation of meter with deep transducer cavities
- avoid noise generated from control valves close to the meter above 105 dBA

Before the meters are installed at the site of application, a complete flowcalibration should be performed.

By controlling the acoustic signal level, checking gas velocity profiles, velocity of sound measuremets and on-line zero checks it is fully possible to avoid later recalibration in flow laboratories.

6 FURTHER INVESTIGATIONS

Like with all other types of flowmeters, it is interesting and useful to know more about the meters.

The items that Statoil would study further in the near future is

a) to quantify more precisely the amount and type of deposit on the transducer the meter can cope with

b) to quantify more precise what level of noise from control valves it can withstand and if the type of valve is of any importance

c) to study more the temperature effect on the transducers.

Statoil would like to cooperate with other companies in such studies.

7 ACKNOWLEDGEMENTS

The author would like to thank the Statpipe Joint Venture Partners for allowing the tests to be run at 16/11-S and the Zeepipe Joint Venture Partners for the use of their meters in the tests. Further, the personell at K-Lab and 16/11-S for their good cooperation, efforts and enthusiasm that made the tests possible.

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[6] SONFLOW. A computer model for determination of thermodynamic properties developed by IFE .

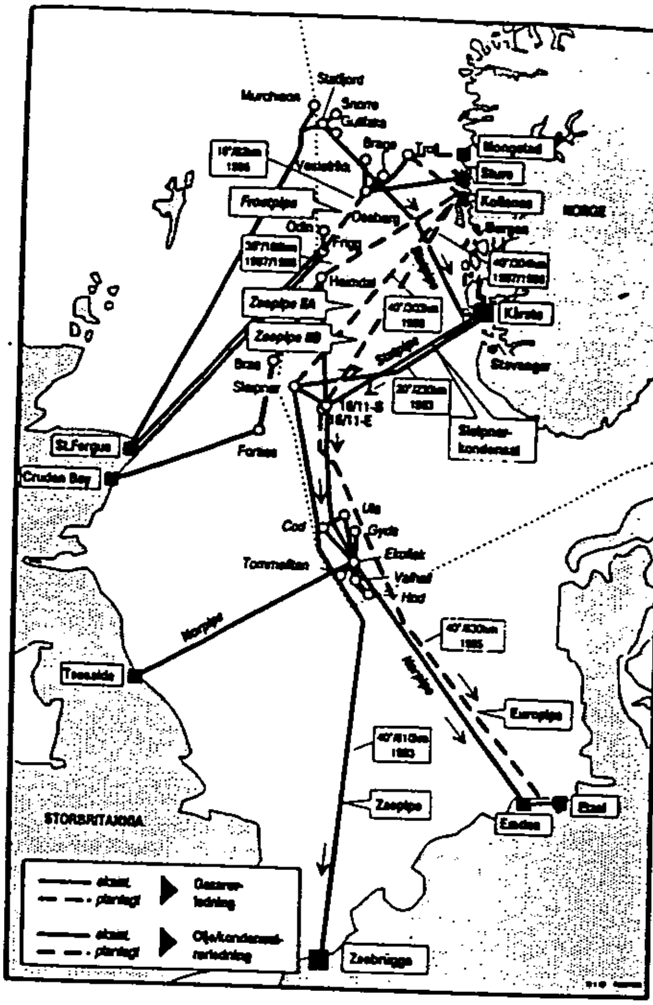


Fig.1 Existing and coming pipelines in the Norwegian sector

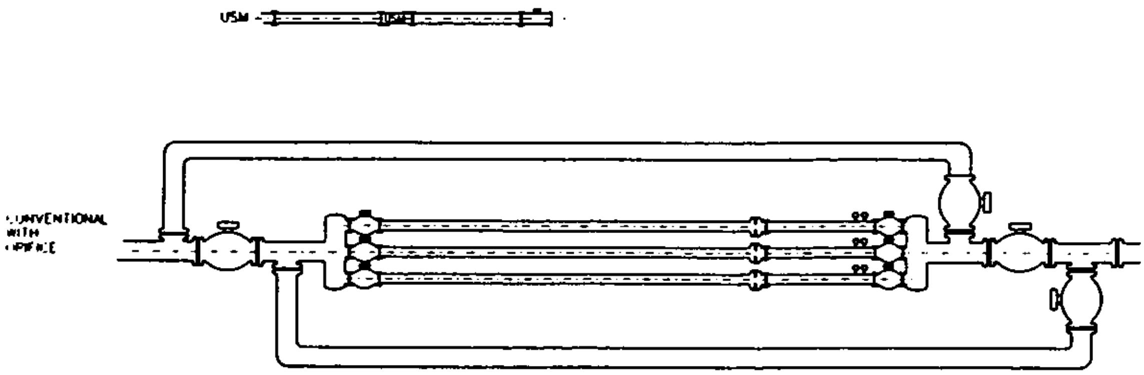
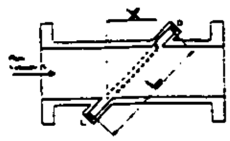


Fig.2 Possible difference in size between bidirectional meter based on ultrasonic flowmeter (USM) and orifice plates

Single-path meter



c = velocity of sound in the gas

$t_{AB} = L/(c + v \cdot (X/L))$; $t_{BA} = L/(c - v \cdot (X/L))$

Subtracting the reciprocals of these times and re-arranging gives:

$v = ((t_{BA} - t_{AB}) / (t_{AB} \cdot t_{BA})) \cdot L^2/(2 \cdot X)$

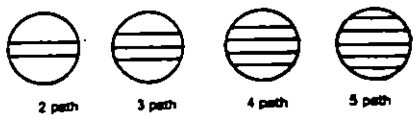
$q_v = A \cdot v$

A being the cross sectional area of meter spool piece

Fig.3 Basic principle for transit time difference flowmeters

Multi-path meter

By increasing the number of path improved performance is obtained.



Integration methods will combine the individual measured velocities to obtain the average velocity over the cross sectional area:

$$\bar{v} = \sum_{i=1} W_i \cdot v_i$$

where W is the weighing factor.

Fig. 4 Multi-path ultrasonic flowmeter

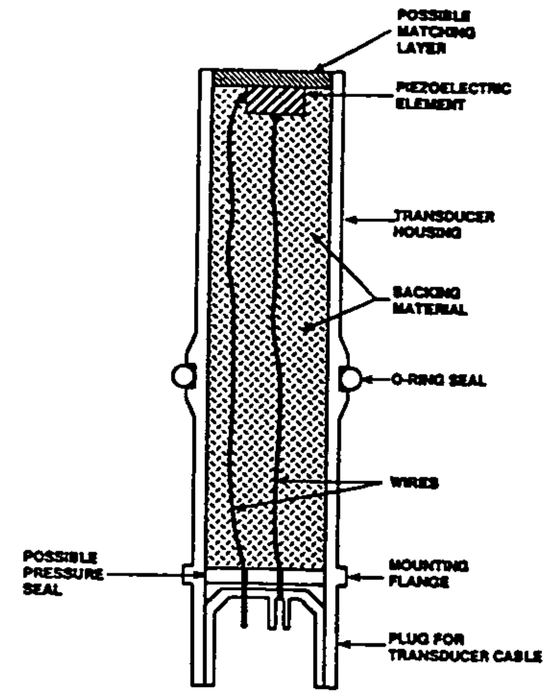
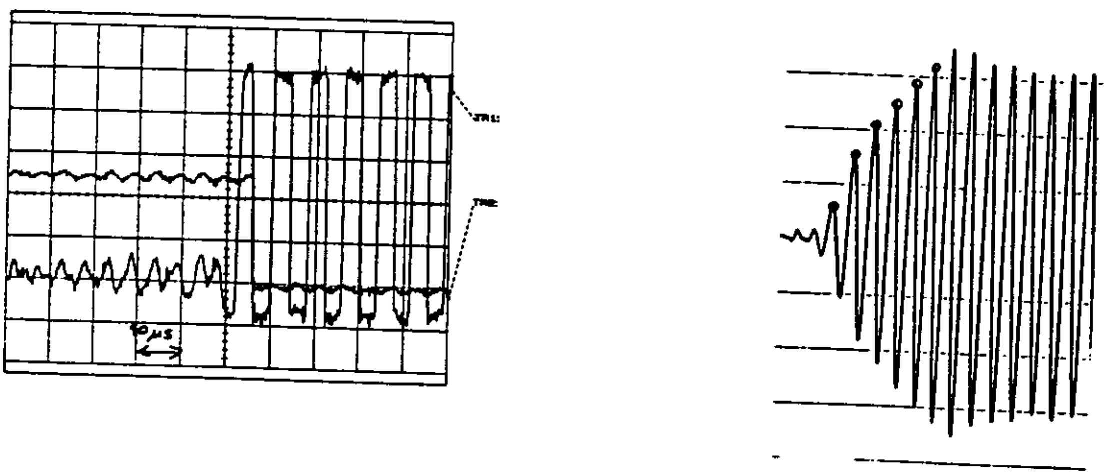


Fig.5 A possible design of a ultrasonic transducer



a

b

Fig.6 Detected received pulses
a) Pulse amplitude detection
b) Pulse pattern recognisition

TITLE

ULTRASONIC TRANSDUCERS
TEST CERTIFICATE

Meter Serial No. N/A Pipe Area N/A ft^2

Chord No.	N/A	
Basic Transducer Distance L (inch)	N/A	
Transducer length Side 1 (inch)	1.9265"	
Transducer Length Side 2 (inch)	1.9305"	
Corrected Transducer Distance "L" (inch)	N/A	
Corrected Transducer Distance "L" (feet)	N/A	
Component Path In Flow X (feet)	N/A	

$$"L" \text{ (feet)} = \frac{"L" \text{ (inch)}}{12}$$

Transducer Distance "L" = Basic Transducer Distance L - (Length Side 1 + Side 2)

Transducer Serial No. Side 1		
Transducer Serial No. Side 2		
Transducer Delay Side 1 (μsec)	25.66009562	
Transducer Delay Side 2 (μsec)	25.60176228	
Date	12.2.93	
Signature	[signature]	

Fig.7 Example of a transducer certificate

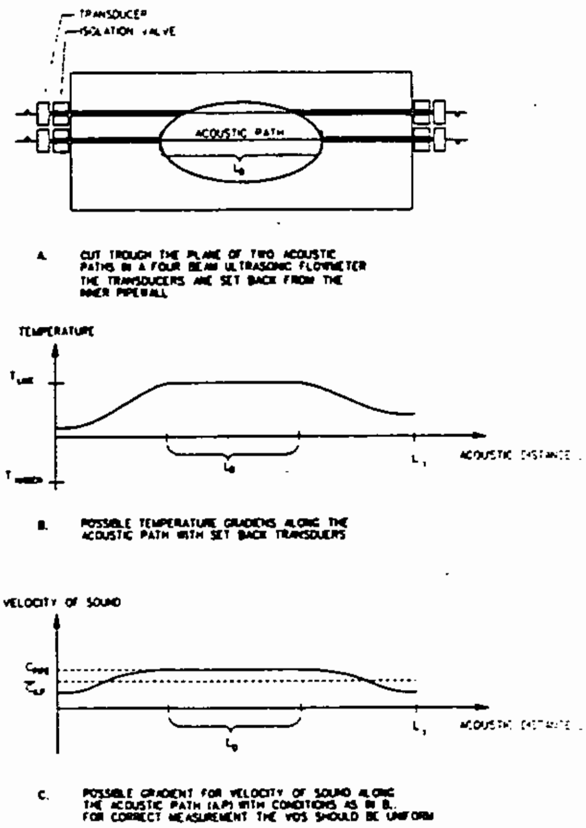


Fig. 8 Condition with deep transducer cavities

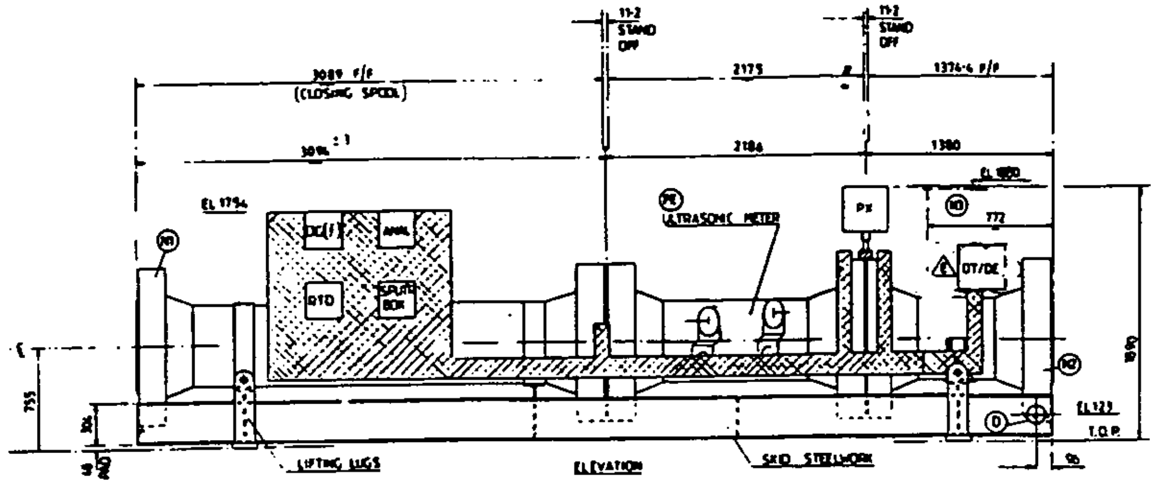


Fig. 9 The 24" ultrasonic metering skid

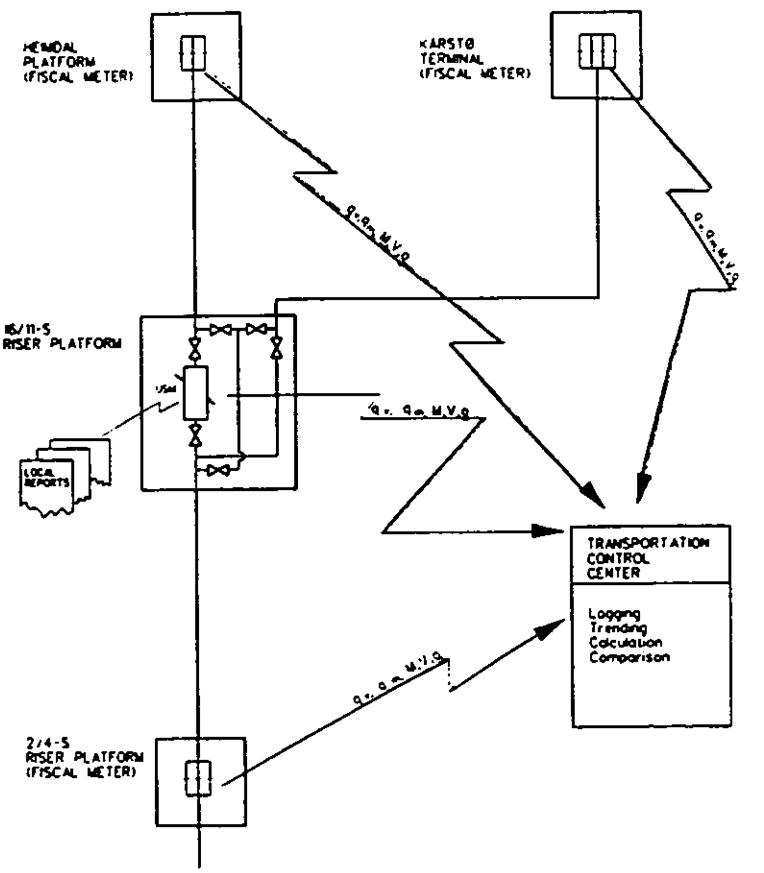


Fig. 10 Position of the meter's location in the transportation system

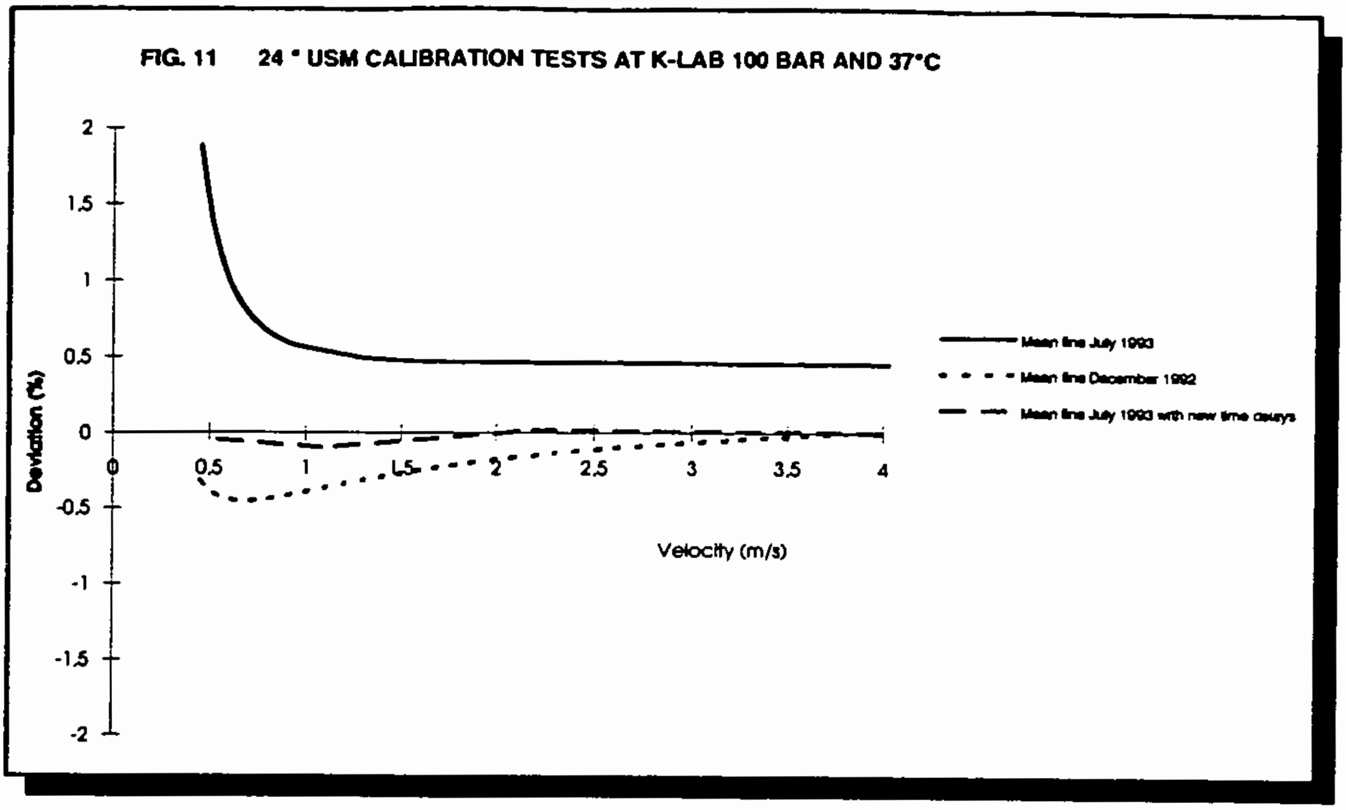


FIG. 11 24 " USM CALIBRATION TESTS AT K-LAB 100 BAR AND 37°C
2
1,5
1
0,5
0
-0,5
-1
-1,5
-2
Deviation (%)
0
0,5
1
1,5
2
2,5
3
3,5
4
Velocity (m/s)
Mean line July 1993
Mean line December 1992
Mean line July 1993 with new time delays

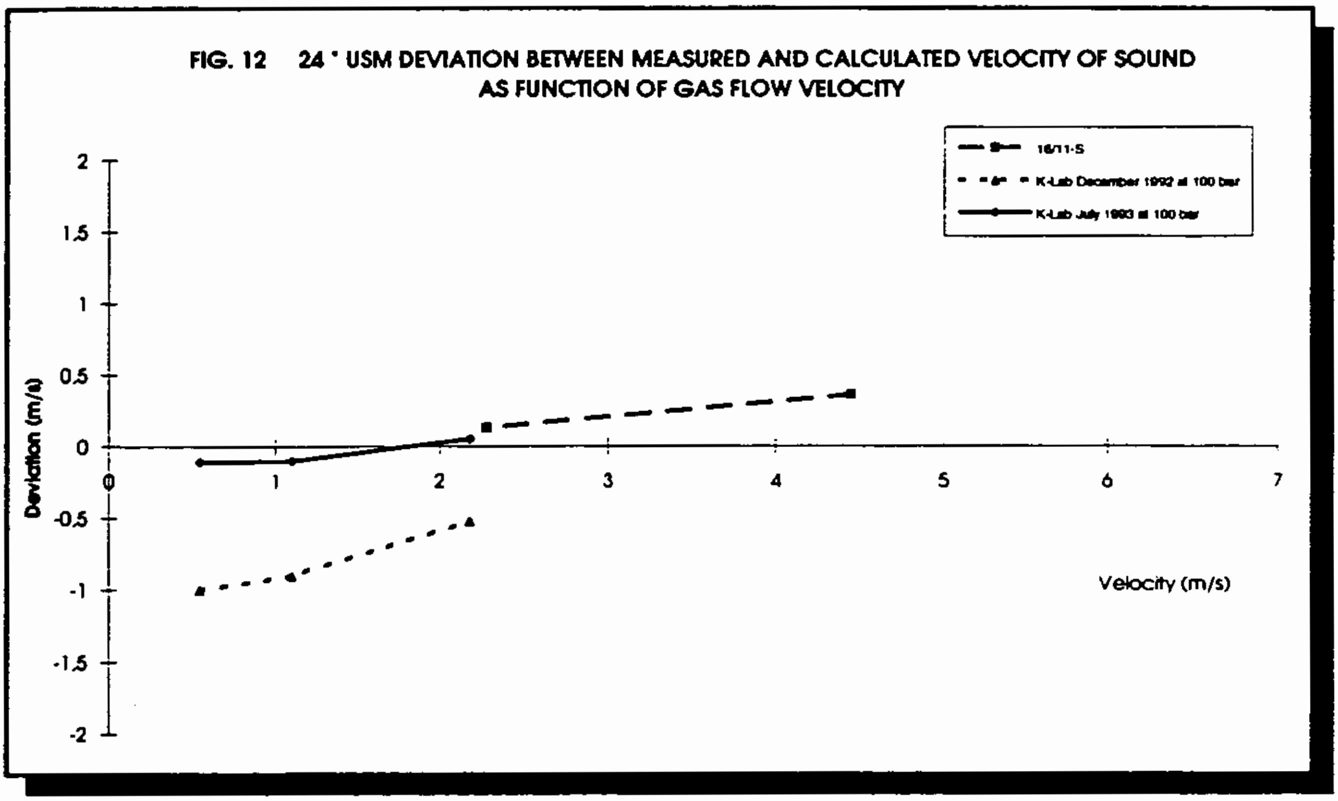


FIG. 12 24 " USM DEVIATION BETWEEN MEASURED AND CALCULATED VELOCITY OF SOUND AS FUNCTION OF GAS FLOW VELOCITY
16/11-S
K-Lab December 1992 at 100 bar
K-Lab July 1993 at 100 bar
2
1,5
1
0,5
0
-0,5
-1
-1,5
-2
Deviation (m/s)
0
1
2
3
4
5
6
7
Velocity (m/s)

FIG.13 24" USM VELOCITY OF SOUND PROFILE AT K-LAB JULY 1993 FOR DIFFERENT GAS VELOCITIES

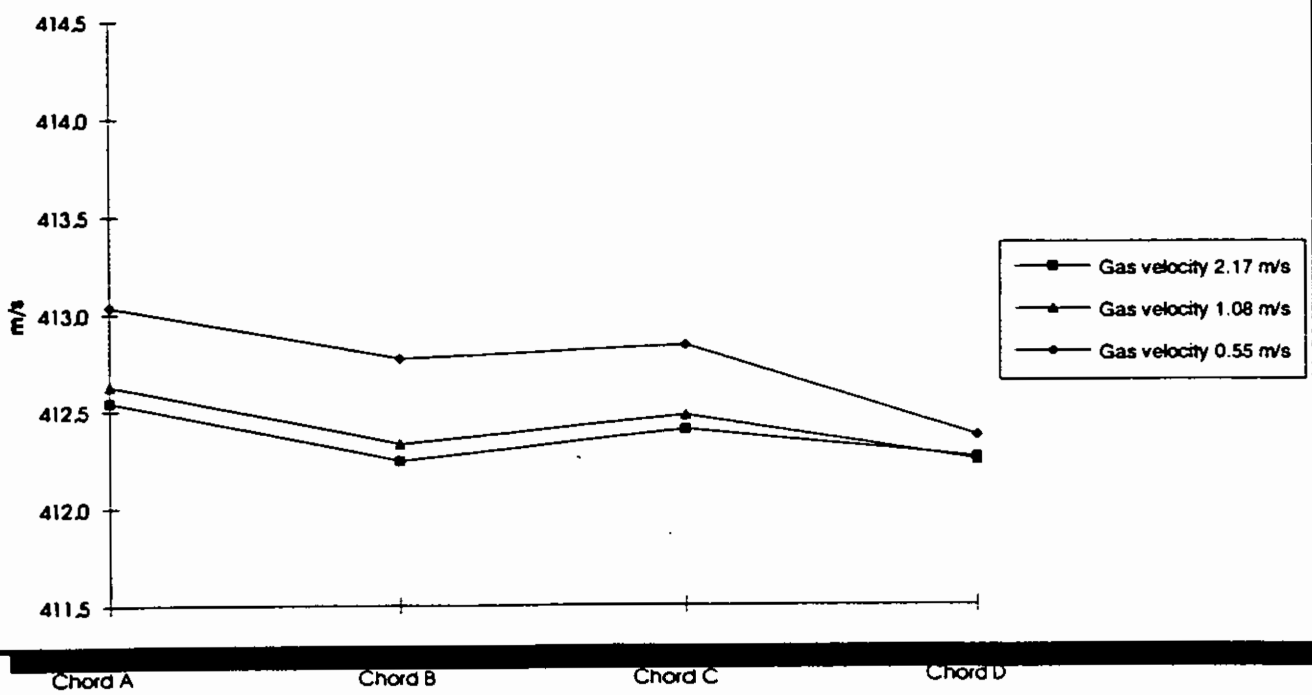


FIG. 14 24" USM VELOCITY OF SOUND PROFILE AT K-LAB DECEMBER 1992 FOR DIFFERENT GAS VELOCITIES

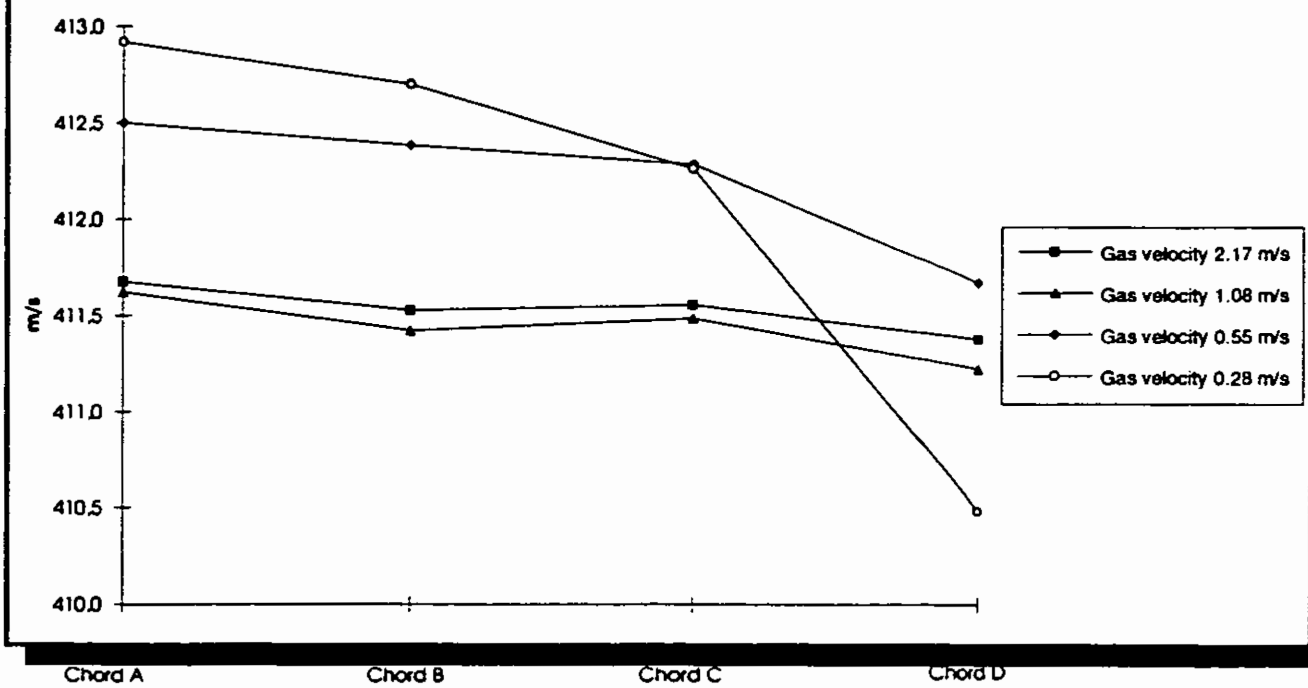


FIG 15 24" USM VELOCITY OF SOUND PROFILE AT 16/11-S FOR DIFFERENT AMBIENT TEMPERATURE

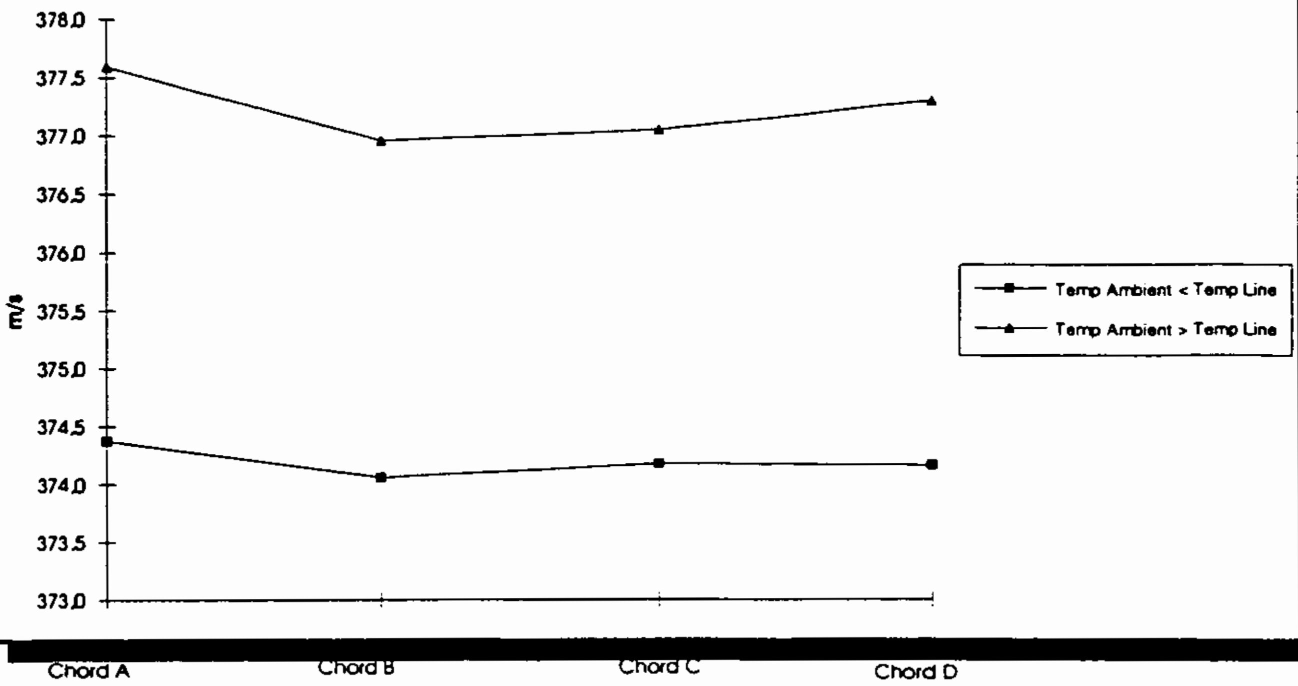


FIG. 16
12" USM FIVE PATH WITH TRANSDUCERS AT THE PIPEWALL. VELOCITY OF SOUND (VOS) AT K-LAB AT 20 DEGC