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PRACTICAL EXPERIENCE WITH GAS ULTRASONIC FLOW METERS

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1. SUMMARY

Two very different situations are reported: type approval testing of a small 6" meter; and calibration of a large 30" meter. The small meter was chosen for its sensitivity to dimensional and timing errors, whereas the large meter (5 times larger) should be immune to such influences. However when calibrating the 30" meter some unexpected effects were experienced: at one extreme, due to the difficulty in obtaining large flows in the calibration facility and maintaining them long enough to reach thermal equilibrium; and at the other, due to solar radiation, stratification and convection currents distorting the low flows.
Type testing showed that: the meter functioned equally well in both the forward and reverse flow direction; and that it is possible to exchange transducers with little loss in accuracy.
The 30" meter calibration showed that: the diagnostic ability of the ultrasonic meter can recognise unusual conditions; that more care must be taken to reach thermal equilibrium during calibration; and that the meter design could be refined.

2. NOTATION

NMI	Netherlands Measurement Institute
VOS	Velocity of sound in the gas
D	Pipe internal diameter
t_1	Transit time against flow component
t_2	Transit time with flow component
$\Delta\tau$	Transit time difference (t_1 - t_2)
Tamb	Ambient temperature
Tult	Temperature in the ultrasonic meter
ChdVel	Chord velocity
AveVel	Average velocity

3. INTRODUCTION

The multipath meter was developed by British Gas in the early 1980's and licensed to Daniel Industries in 1986. The first commercial production meters were sold in 1989, thus there is 7 years of field experience and many publications (Ref. 1,2,3,4,5) describing meter theory, performance, application and special features. Despite this, ultrasonic technology for gas flow measurement is relatively new, especially compared with the orifice plate, and not yet well established. There is no recognised standard at present although there is a draft ISO technical report (Ref. 2). The information given here is presented with the intention of advancing the acceptance and standardisation of Ultrasonic gas flow measurement.

4. TYPE APPROVAL TESTING OF A 6" METER

As part of the NMI type approval process for the ultrasonic meter the following tests were performed:

- Calibration of the meter with flow in the normal forward direction
- Calibration with the flow in the reverse direction (meter rotated 180 degrees)
- Re-calibration after exchanging one pair of transducers (one chord)
- Re-calibration after exchanging two pair of transducers (two chords)

A 6" meter was chosen for these tests because it is the smallest in the range and hence the most sensitive to dimensional (D = 150 mm) and timing (t = 600 μs) errors.

The results are shown in Figs 1, 2, 3 & 4, as % Error from the reference meter against Velocity, with the open points showing all the repeated tests and the closed points showing the average error. To help comparison of these results, all four average errors are plotted on the same graph in Fig 5.

The scattering of the results increases at the lower velocity flows, which is to be expected as the transit time difference $\Delta\tau$ decreases. In fact at 1 m/s velocity in the 6" meter, $\Delta\tau$ = 1 μs for chords A & D (outside) and $\Delta\tau$ = 2 μs for chords B & C (inside) , giving a weighted average of $\Delta\tau$ = 1.7 μs. Thus a timing error of just 17 ns is sufficient to give a 1% error in velocity and is in line with the Daniel claimed timing accuracy of 20 ns. At higher flows the typical scatter, or repeatability, is 0.2%, coming from both the meter and test facility.

The results from Fig 1 & 2 show that the meter is reversible without the need to change any meter factor for the different flow directions. The results from Fig 3 & 4 show that transducers can be exchanged using the factory "dry" calibration procedure, with negligible deterioration in performance. Fig. 5 shows that all four tests give basically the same result within the scatter and repeatability of any individual test.

4.1 Comments

The dry calibration determines the physical size of the transducer and the delay times associated with the transducers and electronics. The average delay time for a pair of transducers (AveDly = $[t_1 + t_2]/2$) is typically 24 μs, is known to about 1% or 0.24 μs, and thus should contribute 0.48/600 = 0.08% to the velocity measurement error (VOS**2). The delta delay (DltDly = t_1 - t_2 at zero flow) can only be determined to 0.02 μs and is the cause of any zero offset error and the scatter at low flows.
The exchangeability of the transducers suggests that the AveDly and DltDly are basically associated with the transducers and not the electronics. This is in line with the design of the new and improved MK II electronics.

With these transducer exchange tests only the factory dimensions and delays were entered into the software. In practice these can be further verified in the field by checking the VOS and velocity profile before and after the exchange.

5. CALIBRATION OF A 30" ULTRASONIC METER

The 30" meter with D = 670 mm, t = 4000 μs and $\Delta\tau$ = 10 μs at 1 m/s was expected to give a good calibration, but that was not found to be the case, as shown in Fig 6. One immediate pointer to a possible reason was the temperature difference between ambient and the gas (Tamb - Tult), also shown in Fig 6. When the temperatures are not the same it gives rise to two potential problems:
- what temperature should be used to correct the reference meter flow to the actual flow through the ultrasonic meter ?
- what effect does the temperature gradient over the acoustic path have on the operation of the ultrasonic meter ?

The calibration was performed on a relatively rare warm and sunny day (Tamb = 16 C) and at high flow the gas temperature dropped to Tult = 4 C, as a result of expansion due to the pressure drop required to achieve the large flow. The maximum flow of 11 m/s (not 15 m/s velocity) could only be held for 15 min, both limited by the test facility, and hence thermal equilibrium was never reached. Furthermore the max flow was the first flow of the day, due to the test facility being part of the national grid, it would have been better to increase the flow slowly up to the max, to try to cool down all the pipework and meter body to the gas temperature, but then there would be no guarantee of still being able to reach the max flow.

At low flows temperature effect become very pronounced, both on the velocity profile and the VOS profile across the chords.

Figs 7 & 8 show the same non-dimensional chord velocity ratio data in two different ways:
- Fig 7 plots the individual chord velocity ratio against the flow velocity
- Fig 8 plots the velocity profile across the pipe diameter for different flow velocities

At high flows the profile is normal, but at low flows the velocity at the top of the pipe (Chord-A) decreases while the velocity at the bottom of the pipe (Chord-D) increases.

Figs 9 & 10 show the same velocity of sound (VOS) data in two different ways:
- Fig 9 plots the individual chord VOS against the flow velocity
- Fig 10 plots the VOS profile across the pipe diameter for different flow velocities

At high flows the VOS becomes uniform across the pipe, but at low flows the VOS increases, with the greatest effect noticeable at the top of the pipe (Chord-A), next on Chord-B and so on.

It was observed that at flows below 1 m/s the temperature in the pipe rose to 22 C (measured near the top) as a result of solar radiation on the un-insulated steel pipes. VOS is a measure of temperature for constant gas composition, a 1% change in VOS (4/400) corresponds to a 2% change in temperature (6/300) as VOS = T**0.5. Thus the 10 m/s VOS gradient corresponds to a 15 Deg C temperature gradient from 7 to 22 Deg C and seems reasonable.

The max VOS (and temperature) occurs at 1 m/s and not at Zero flow, presumably this is because the heat transfer with the pipe wall is better.

It is most likely that the VOS and velocity profiles are related via convection effects. One can postulate that cold gas (from the mains) enters a hot meter (from solar radiation) and tends to fall towards the bottom of the meter giving the observed higher velocity on the D-Chord.

A crude estimate of the convection current magnitude, based on a density difference of 3% and a 600 mm fall, gives a velocity of (20*3%*0.6)**0.5 = 0.6 m/s (where 20 = 2g m/s/s). The calculation shows that the large size (30") contributes as much as the temperature difference (density difference) to the problem of convection. Thus the large meter size magnifies any problems due to a lack of thermal equilibrium.

Apart from this vertical VOS and temperature gradient, there is a horizontal VOS gradient because the gas in the transducer ports and isolating valves will be closer to Tamb than to Tult. The effects of these gradients on the meter performance are difficult to estimate. Simple theory assumes that the VOS is the same throughout the meter, not only does the gradient upset this, but it also produces other effects due to refraction and distortion of the ultrasonic signal.

5.1 Comments

The problems described above are associated with calibration and will not occur in the actual 30" meter application. In use the meter and pipework will be insulated and the flow will be continuous such that thermal equilibrium will be achieved and maintained. The diagnostic ability of the meter will recognise any peculiarities in velocity profile or VOS distribution and confirm that the meter is functioning correctly

There is a need to improve the calibration facility for these large meters, but this is not straightforward. The 30" meter can easily handle the total national grid flow at the British Gas, Bishop Auckland facility. Insulating all the pipework would considerably reduce the flexibility of the test site. Covering the pipework, to shied it from direct sunlight, would reduce access with cranes and equipment. Increasing the flow rate and holding it for a longer time would require another mode of operation, with the cooperation of Transco and require three reference 12" turbine flow meters, instead of the two used at present.

Alternatively it can be argued that there is no need to calibrate large meters, as their performance could be predicted, with sufficient accuracy, based on theory and model testing of smaller meters. It is the ultimate goal to produce an ultrasonic meter that does not require flow calibration.

Another approach is to modify the ultrasonic meter design. The 6" meter is too small to fit transducer isolation valves, but the 30" meter has 1500# double block & bleed isolation valves fitted to all eight transducer ports, making a very much longer acoustic path, 4000 μs compared with 2680 μs (= 600*670/150) for a scaled up 6" meter, with much of the path outside of the flow and hence influenced more by the ambient temperature.

The idea of isolating valves is attractive, to be able to change transducers without shutting down the flow, but can increase potential temperature gradient effects and act as a moisture trap. The present tendency is to place the transducer close to the pipe bore (not in a cavity) to eliminate temperature gradients in the ultrasonic path and avoid liquid traps thus making wet gas measurement possible. An extractor mechanism is being designed to remove transducers from the meter under pressure one at a time, with the added advantage that only one extractor is necessary, not eight isolation valves.

6. CONCLUSIONS

It has been demonstrated that the ultrasonic meter is reversible, with the same performance in both directions.

It is possible to change transducers, without the need for re-calibration, with negligible (0.1%) loss of accuracy.

It proved to be quite difficult to calibrate the large 30" meter, mainly because it was impossible to reach thermal equilibrium in the flow facility

The calibration did reveal that the diagnostic ability of the meter was able to recognise this unusual situation and would be able to confirm correct operation in actual practice.

The calibration did suggest that some modifications to meter design could partly alleviate these difficulties.

The strange effects are a result of the calibration process and would not occur in actual use.

It might be both more expedient and more accurate to accept "dry" calibration of large meters.

The small meter magnifies the effects of dimensional and timing errors, where as the large meter magnifies any effects due to temperature differences.

7. REFERENCES

1. BLOEMENDAAL K. van and KAM P.M.A. van der " Installation Effects on Multi-Path Ultrasonic Flowmeters: The Ultraflow Project" North Sea Flow Metering Workshop 1994

2. ISO/TR 12765, Draft Standard, " Measurement of Fluid Flow in Closed Conduits - Methods using Transit Time Ultrasonic Flowmeters" May 1996

3. ZANKER K.J. and FREUND W. R. "Developments of Multipath Transit Time Ultrasonic Gas Flow Meters" North Sea Flow Metering Workshop 1994

4. FREUND W.R. and WARNER K.L. "Performance Characteristics of Transit Time Ultrasonic Flow Meters" 3RD Int. Symp. on Fluid Flow Measurement, San Antonio, 19-22 Mar 1995

5. ZANKER K.J. "Ultrasonic Transit Time Gas Flow Meters" I M & C, May 1995

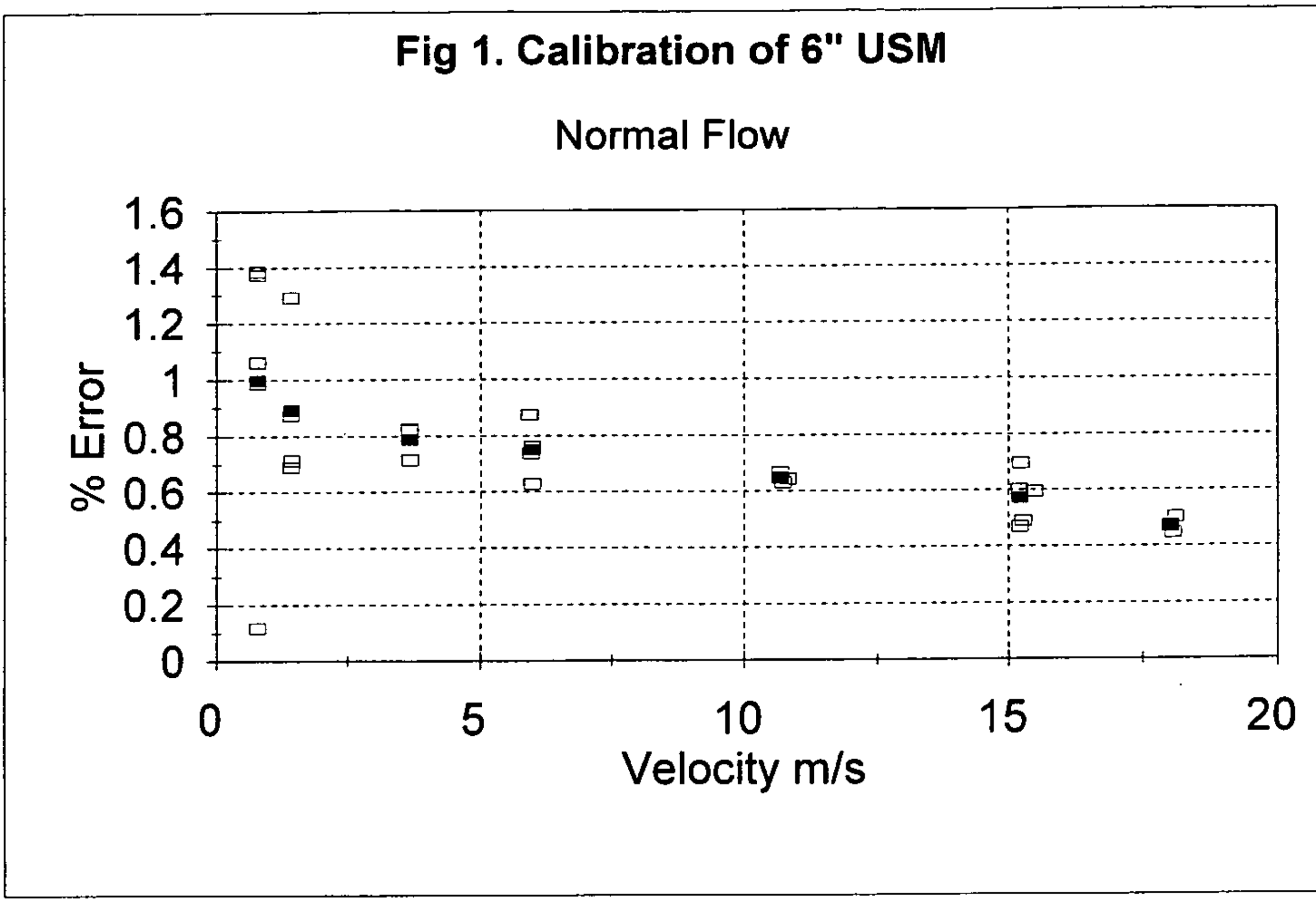
Fig 1. Calibration of 6" USM
Normal Flow
% Error
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
Velocity m/s

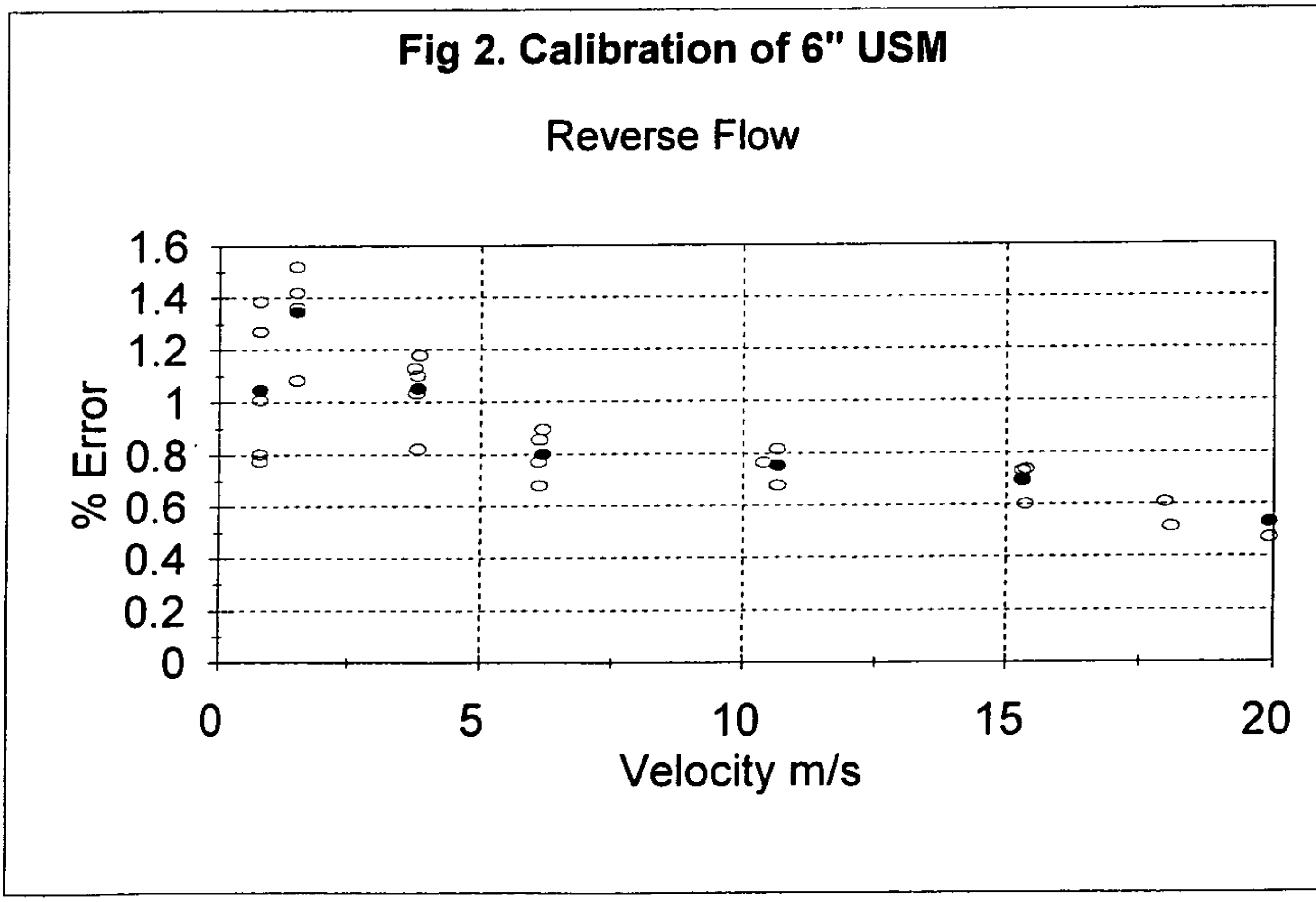
Fig 2. Calibration of 6" USM
Reverse Flow
% Error
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
Velocity m/s

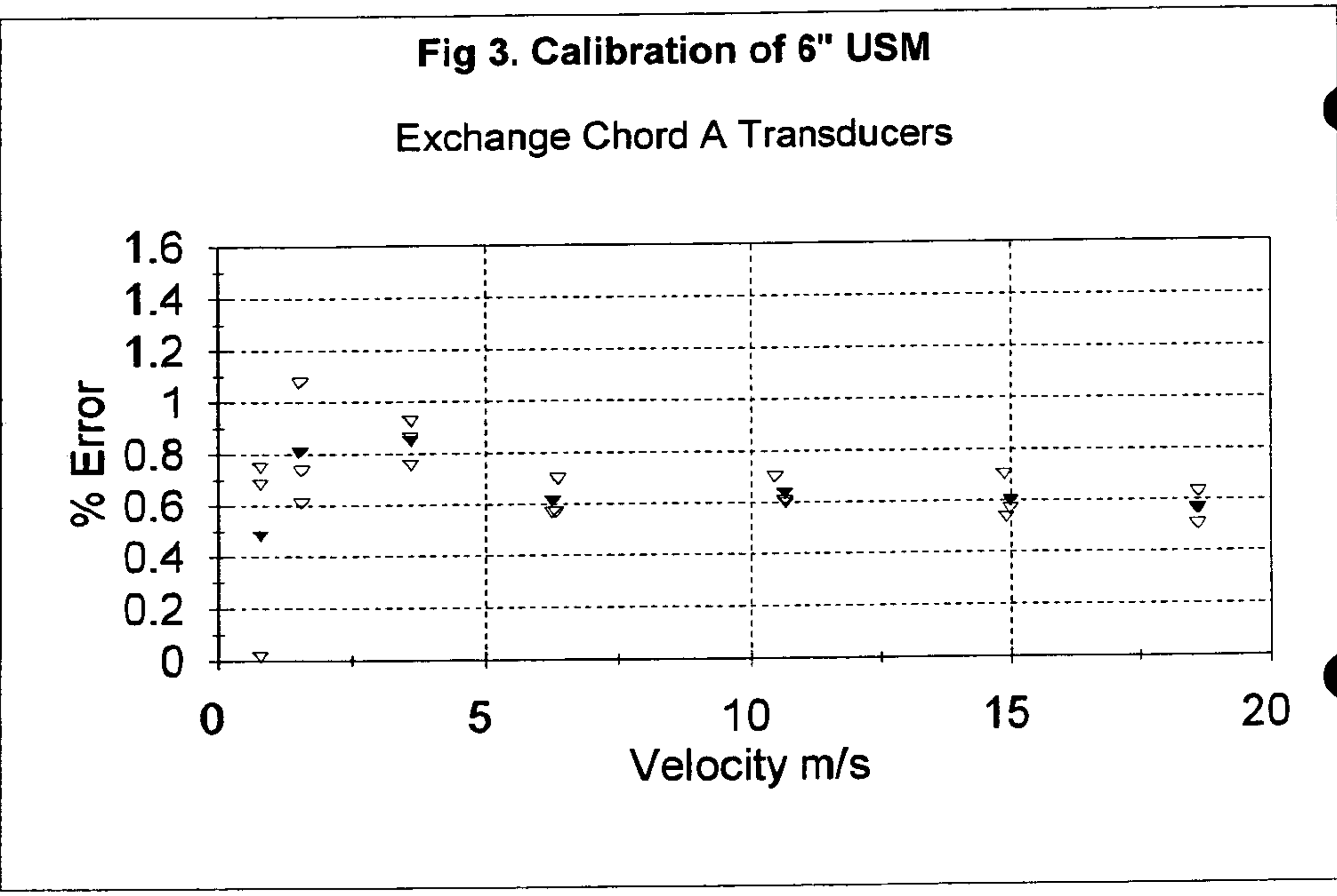

Fig 3. Calibration of 6" USM
Exchange Chord A Transducers
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
% Error
0
5
10
15
20
Velocity m/s

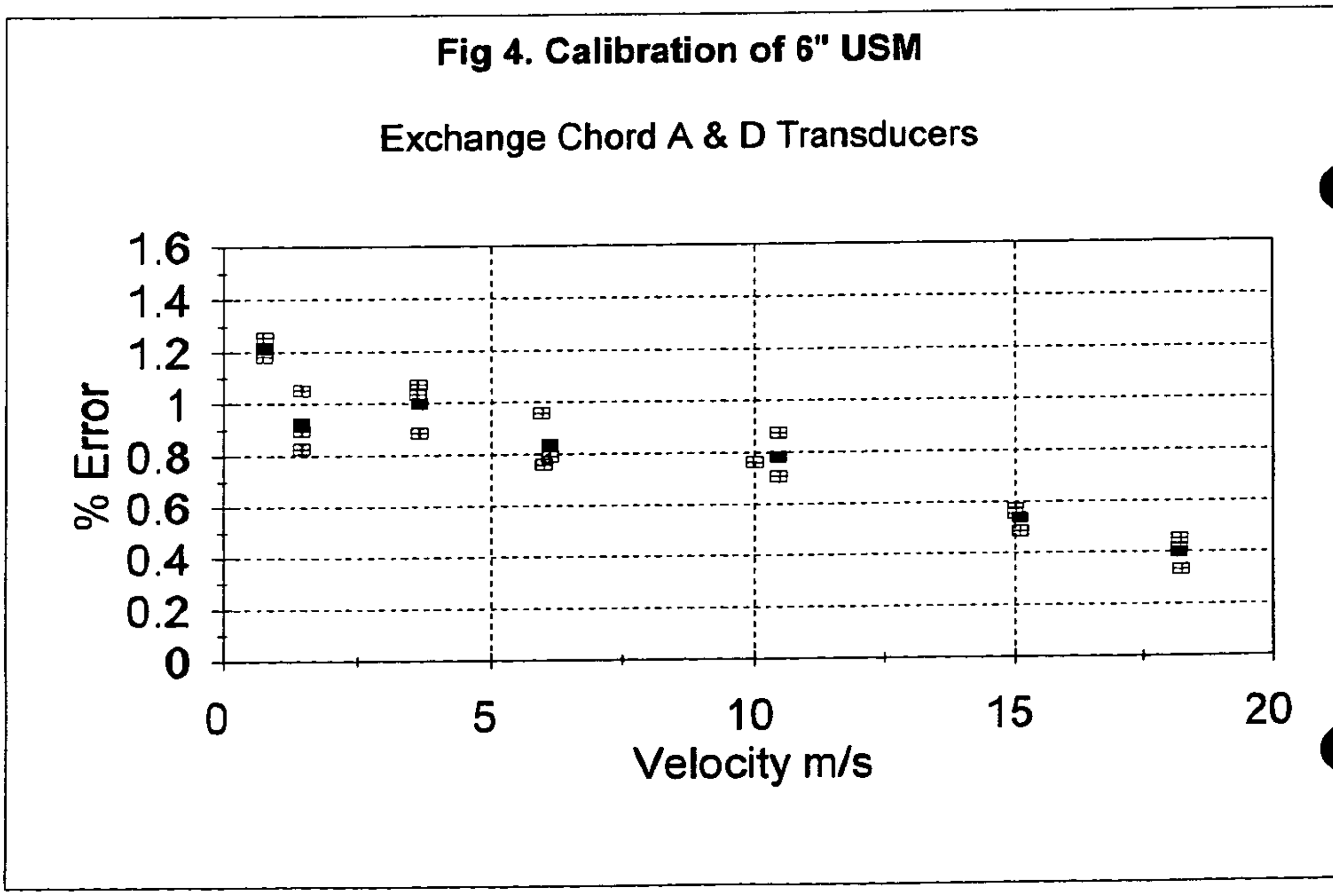

Fig 4. Calibration of 6" USM
Exchange Chord A & D Transducers
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
% Error
0
5
10
15
20
Velocity m/s

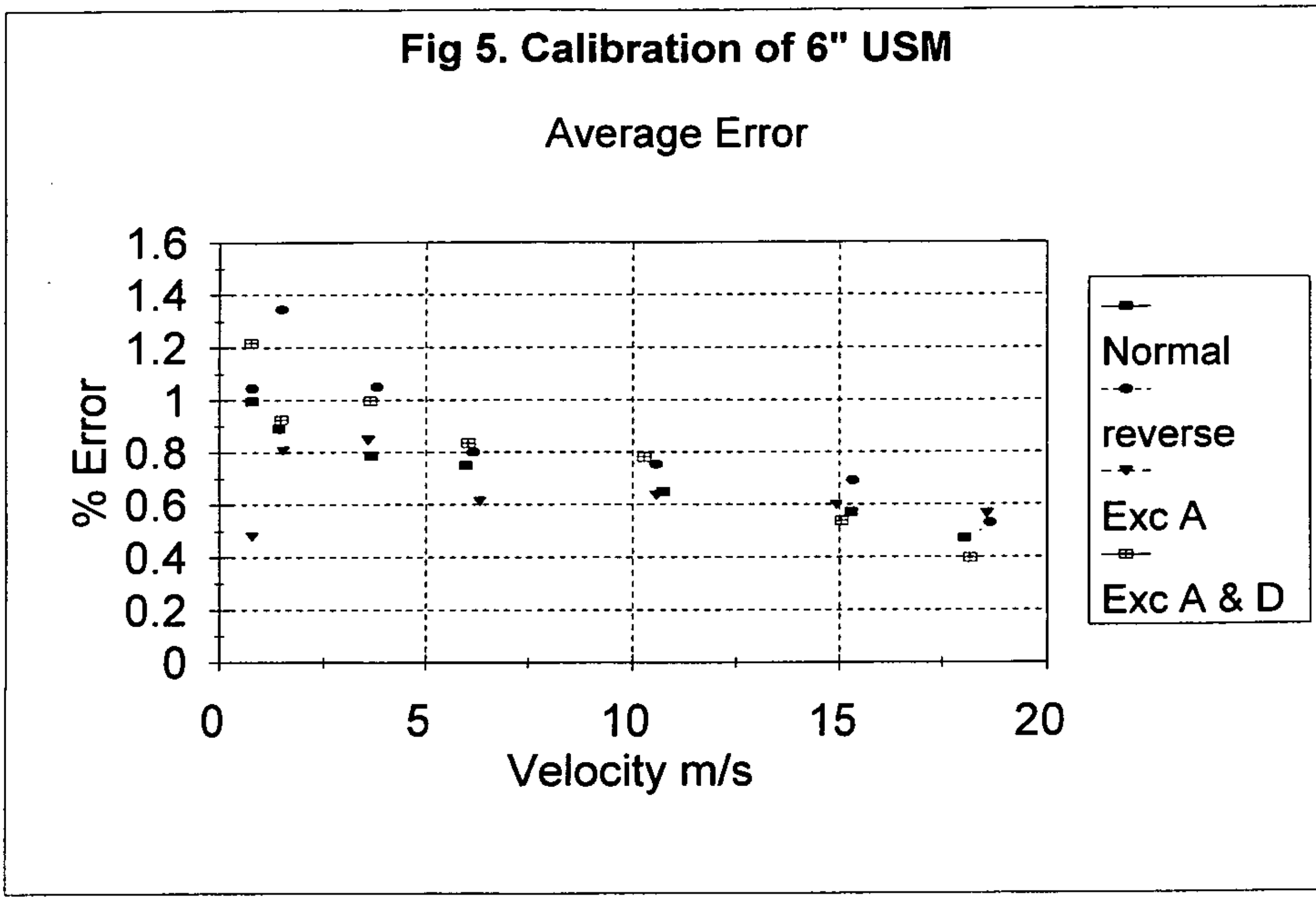

Fig 6. Calibration of 30" USM

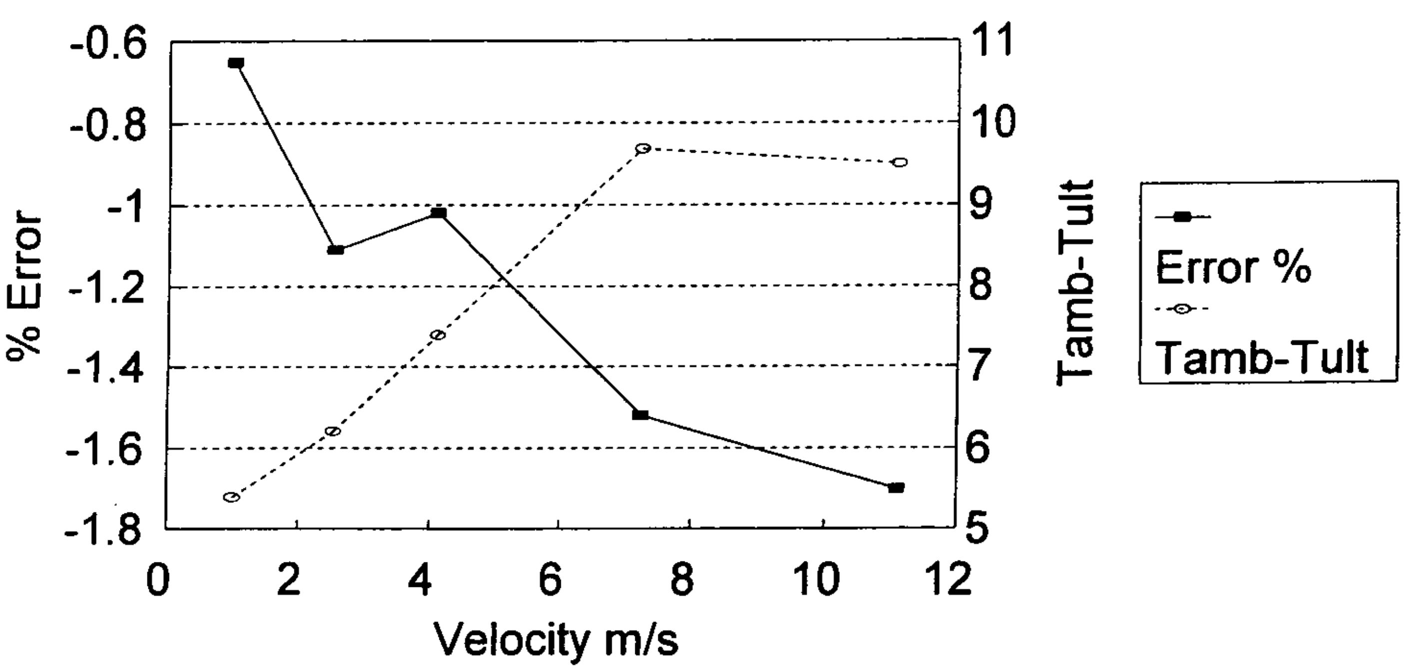

Fig 7. 30" USM Chord Velocities

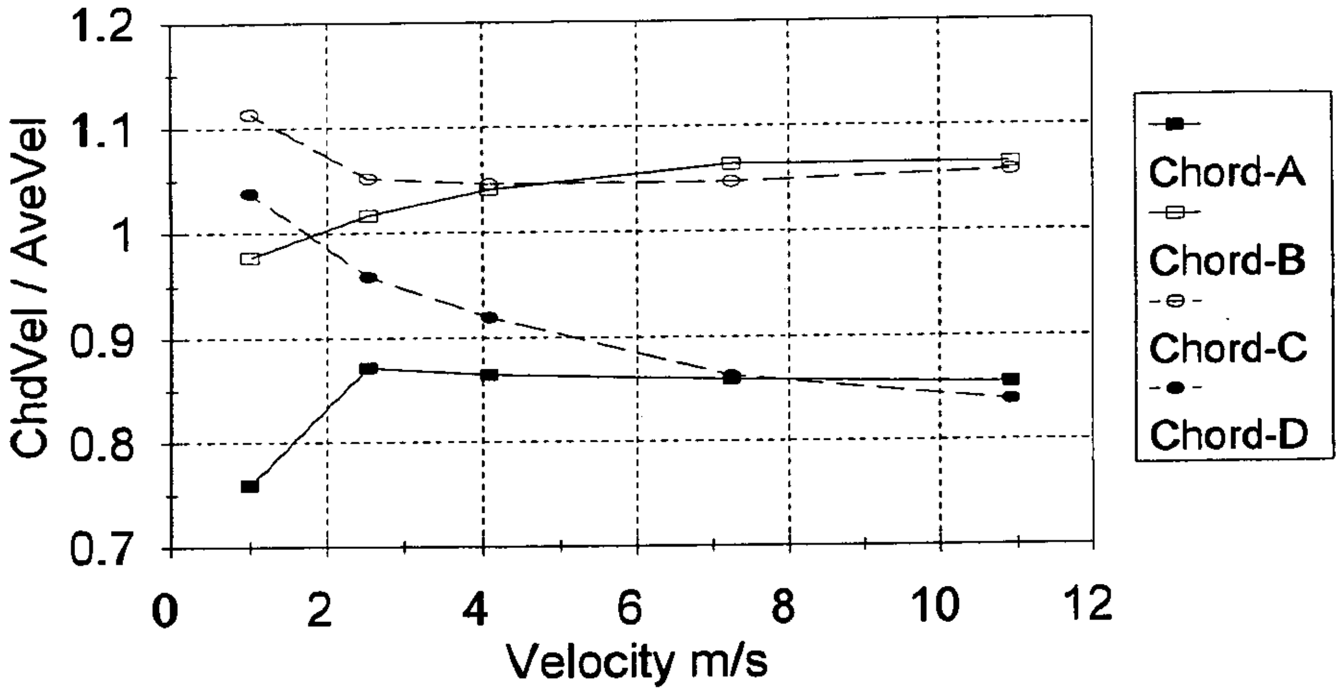

Fig 8. 30" USM Velocity Profile

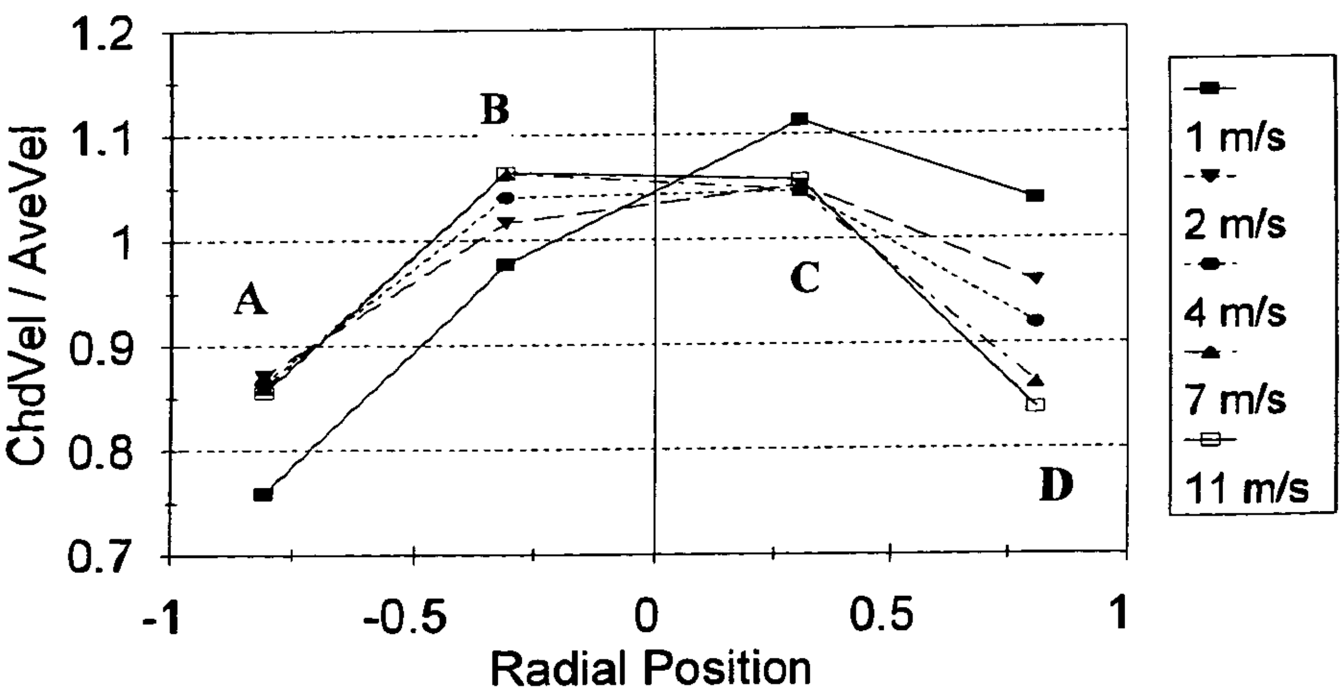

Fig 9. 30" USM Chord VOS

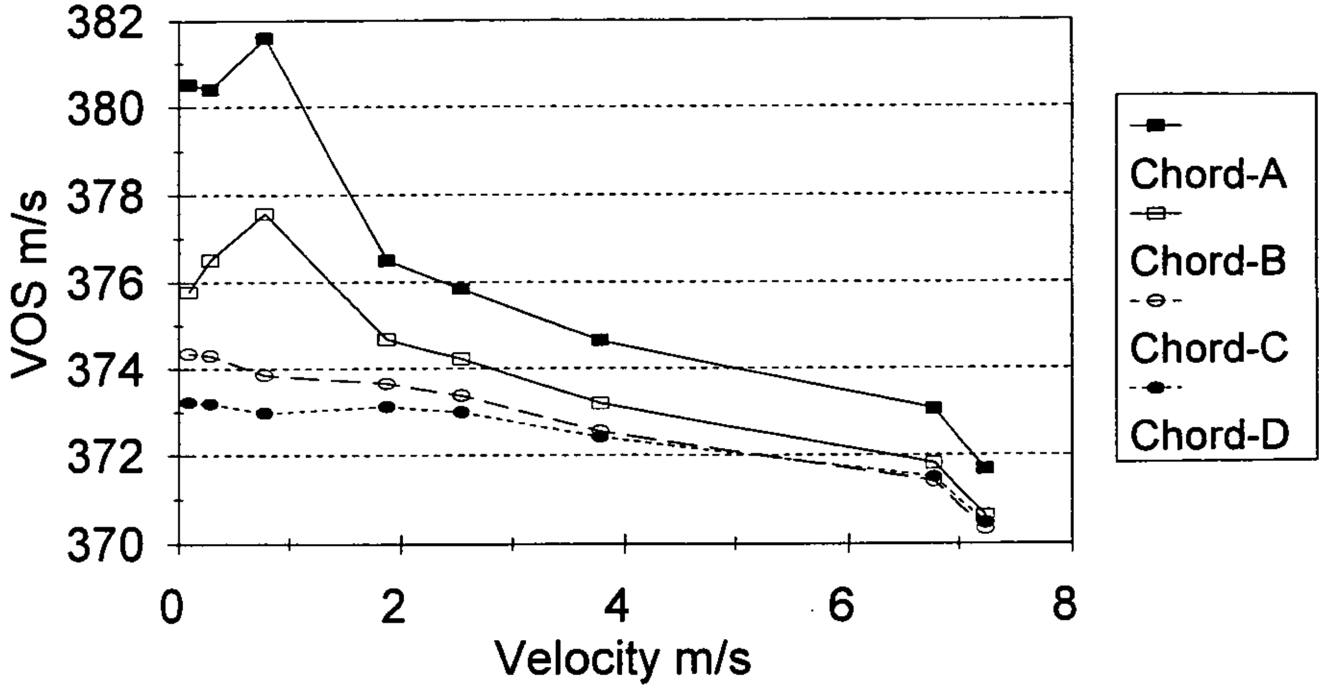

Fig 10. 30" USM VOS Profile