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# FOCUS DISCUSSION GROUP E

## LIQUID ULTRASONICS

G Brown, National Engineering Laboratory

# ULTRASONIC METERING OF LIQUID HYDROCARBON FLOWS

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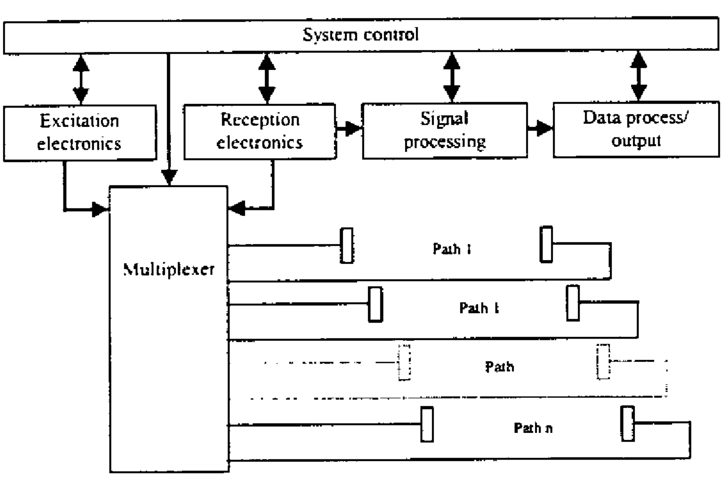
## 1 INTRODUCTION

Use of transit time ultrasonic meters for high accuracy demand applications in the North Sea is on the increase. This is obviously due to the economic and operational benefits related to the technology. It is however a relatively complex technology area and one in which there is great scope for variation in meter design and manufacturing quality. This paper is intended to promote discussion of the developments required to enable successful deployment of ultrasonic meters for liquid metering duties.

## 2 METER SELECTION

Meter selection would appear to be a good place to start discussion but it is not a trivial matter. As anyone who has looked through the manufacturers product literature knows, there is no such thing as a standard ultrasonic meter. Variations that influence performance and behaviour can exist in all the elements that make up the flowmeter as illustrated schematically in Figure 1. The function and behaviour of each of these elements is by no means transparent.

**FIGURE 1**
**A schematic diagram of a transit time ultrasonic flowmeter system**




In addition to the excitation, reception and signal processing elements of Figure 1, there are variations in the way that the transducers can be configured. These configurations (single path, multiple paths, crossed paths, bounced paths etc.) are at least apparent, if somewhat confusing at times. Although the transducer configuration constrains the information available to the data processing stage it does not dictate how the data is processed.

Selection of an appropriate meter requires that all the important requirements and considerations for a given application are identified. These can then be ranked in order of significance and a score given for each selection option in turn. For this approach to be successful, detailed information is required. Such information can generally be classified as one of three types.

- Vendor information
- User experience
- Independent information

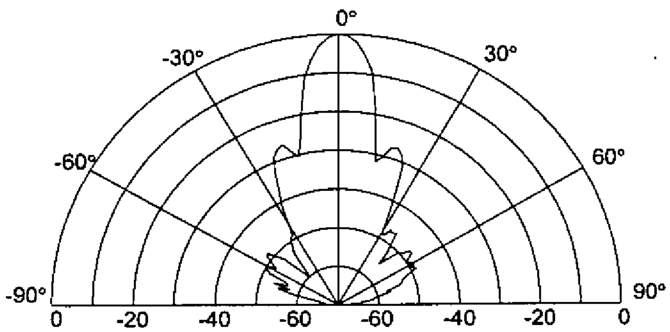
Each of these types of information has its uses and limitations. On balance at present it would appear that independent data is particularly scarce.

## 3 PRODUCTION CONTROL

Testing of specific designs and models, manufacturing quality control and factory calibration are factors which determine the potential performance of individual units that are delivered to the end user.

Type testing should be undertaken for all new designs and any significant alterations to components or systems. Both a representative sample and range of units should be tested over the full range of acceptable operating conditions. Extrapolation of test results to other configurations or application conditions must have a sound basis to be acceptable.

FIGURE 2
The directional response (in dB) of an ultrasonic transducer




Manufacturing quality control is important in order that the performance of units sold conforms to the results of type testing. An area of quality control that is critical is transducer manufacture, from production of the piezoelectric element to final assembly. Variability in characteristics of assembled transducers is well known (if not yet fully understood) and can affect the ultrasonic waveform and the radiation pattern significantly.

In turn this can influence meter behaviour. If, for example, variations in the radiation pattern are apparent, the effective path of the ultrasound through the fluid could be affected. It is likely that transducer characterisation will be an integral part of production and quality control for high accuracy meters.

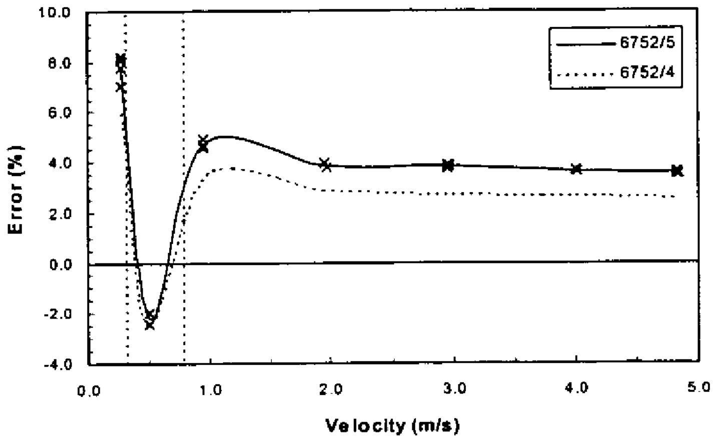
## 4 CALIBRATION

Calibration is normally undertaken in the factory prior to delivery. 'Dry calibration' involves measurement of the meter body and path geometry in order to determine a theoretical calibration factor. The dry calibration process may also involve determination of offsets in transit time measurements by filling the meter body with static fluid (usually of known acoustic properties.

'Wet calibration' involves a comparison with results from a test rig in the factory or an independent laboratory. Normally the results are then used to adjust the factor determined by dry calibration. Wet calibration is preferable until improvements in the accuracy of dry calibration can be achieved and confidence in the approach can be established. The uncertainty and traceability of measurements made in a calibration facility are of utmost importance if the results are to be used in computation of the volume passed through the meter.

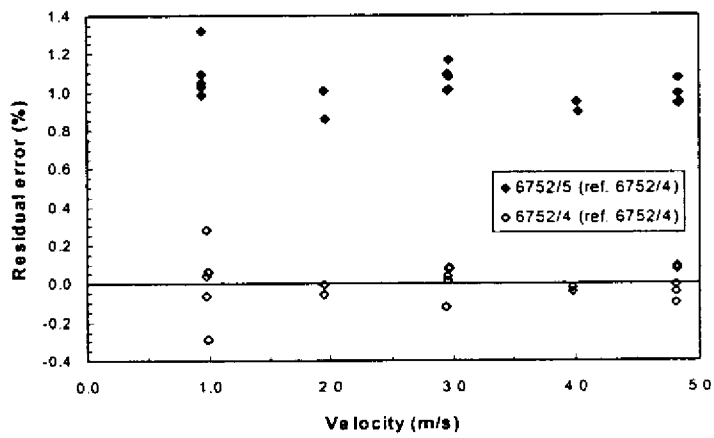
In the case of clamp-on meters, the results of wet calibration are only truly applicable if the transducers and pipe are treated as a complete assembly and installed as such. Even when the pipe in the field is the same as that used in the calibration facility, removal and replacement of the transducers will contribute to the uncertainty of measurement once the meter is installed.

FIGURE 3
Recalibration of a clamp-on meter following removal and replacement of transducers




This is illustrated in Figure 3 which shows the results of laboratory calibration of a clamp-on meter on 6-inch carbon steel pipe. Between the initial calibration (shown by the dotted line) and the repeat calibration (shown by the solid line) the transducers and mounting fixtures were removed from the pipe and replaced. Figure 4 shows the residual errors with respect to a second order polynomial curve fit to the initial calibration points above 1 m/s.

FIGURE 4
A plot showing residual errors with respect to the baseline calibration



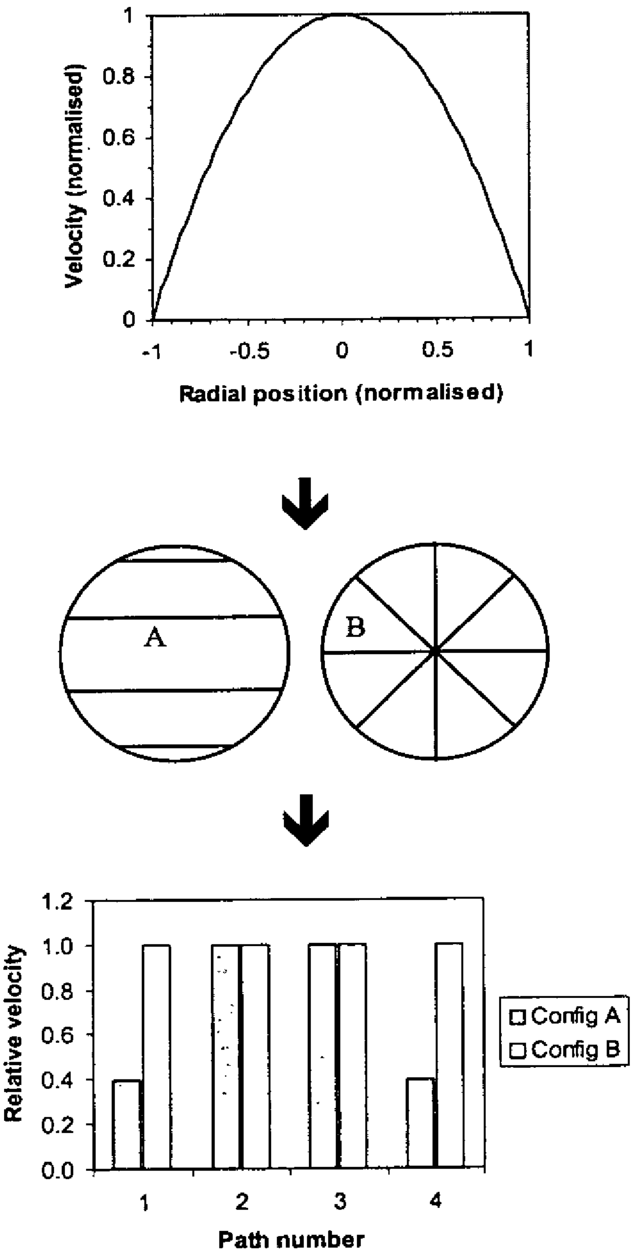

For high accuracy demand applications calibration conditions should match application conditions as closely as possible. In terms of flow conditions this is normally taken to mean that either velocity or Reynolds number should be matched. In some cases (e.g. low velocity and low Reynolds number) it may be necessary to match both, as either may have a significant influence on performance.

Wet calibration of large meters can present a problem when attempting to match both Reynolds number and velocity ranges as few facilities have high capacity, the ability to vary viscosity, and an accurate and traceable reference. In this situation it may be that use of a water calibration facility is an option, in which case it is more appropriate to match the velocity range. Dry calibration may also be an option as relative uncertainty in dimensional measurement is reduced. In ether case the applicability of the approach should be demonstrated by experimental results which demonstrate the accuracy of the alternative calibration procedure in practice under similar conditions.

## 5 INSTALLATION

Installation requirements will vary from meter to meter and with application conditions and performance requirements. In this discussion the term 'installation effect' is taken to mean the error in reading due to the presence of transverse velocity components (cross-flow and swirl) and distortions of the axial velocity profile. In general, the greater the number of paths, the less sensitive to the meter will be to velocity distribution. However, this being said, it is important to realise that the arrangement of the paths and the scheme employed to combine the measurements is generally more important than the number of paths employed.

FIGURE 5
An illustration of the relationship between velocity distribution and transducer configuration




To illustrate the importance of path configuration, consider two different flowmeter configurations applied to the same flow which has an axisymmetric velocity distribution. In configuration B all paths exhibit symmetry with rotation about the axis and therefore all measure the same value of velocity. Configuration B has paths on two chords with respect to the symmetry of the profile and therefore provides additional information that can be utilised in estimating the mean velocity.

Quantification of installation effects is a difficult area to address properly due to the wide variation in configurations and orientations. Sweeping statements on the subject should not be accepted as credible. For example, it has been suggested that ultrasonic meters are insensitive to small steps in bore upstream and downstream. This may be the case for configurations which are inherently less sensitive to variations in velocity profile (such as configuration A) but is almost certainly untrue for the likes of configuration B as the meter would have no ability to sense an axisymmteric distortion of the flow.

Installation effects are also likely to vary with meter size. As meter size increases, the disturbing effects of the transducer recesses and effects due to the finite size of the transducers will reduce. This does not necessarily mean that larger meters will perform better, these effects may increase or decrease the magnitude of an installation effect, depending on the pipework and transducer configuration.

In the short-term experimental testing is the preferred method of determining installation effects on ultrasonic flowmeters. However, with further development it is likely that computational fluid dynamics will provide a useful means of assessing potential installation effects.

## 6 OPERATION AND VERIFICATION

Once a meter has been selected, properly calibrated and installed, some means of verifying that the meter continues to operate properly is required. Ultrasonic meters have an advantage here in that being non-intrusive and having no moving parts they are not so susceptible to wear and tear as turbine meters for example. It could be presumed that if you install one of these meters and continue to get a credible output then there is nothing more that need be done. Unfortunately in real world things can go wrong with the meter and process conditions can change.

Generally ultrasonic meters have self-checking and fault diagnosis capabilities within electronics modules and processors. In more sophisticated models the capability extends to signal analysis in the transit time electronics and analysis of data time series. This can be very useful in indicating a problem due to, for example, entrained gas attenuating the ultrasonic signals.

There are some fairly common approaches to measurement and reporting of signal parameters. For example, most modern meters will report the automatic gain control (AGC) level being used to amplify the input to reception electronics. What is lacking however, is adequate description of how these parameters are used to actuate fault conditions. More important than this even, is the lack of information or data that demonstrates a correlation between the measured parameters and meter performance.

Some parameters measured in a given meter, such as the computed velocity of sound (VOS), obviously have no direct relationship with performance. This being said velocity of sound is used to determine changes in the fluid and can be cross-checked with VOS determined from external information. Others, such as a measure of signal-to-noise ratio, may have a more direct relationship to performance. This is demonstrated by the results of a series of oil/gas tests on a clamp-on meter installed on 4-inch pipework. As shown in Table 1, for all flowrates greater than 10 l/s repeatability is seriously degraded when the meters signal strength parameter falls below 5 % at conditions of increased gas volume fraction (%).

TABLE 1
Minimum observed signal strength at each flow condition

| Nominal flowrate | GVF | Signal strength (%) | Repeatability (%) |
|---|---|---|---|
| 10 l/s | 2.5 % | 100 | 5.12 |
| | 7.5 % | 100 | 8.91 |
| | 22.5 % | 4.8 | 8.15 |
| 30 l/s | 0.75 % | 80 | 3.53 |
| | 1.5 % | 26 | 3.51 |
| | 4 % | 3.4 | 22.19 |
| 50 l/s | 0.35 % | 17 | 2.02 |
| | 0.7 % | 6 | 5.46 |
| | 1.5 % | 1.9 | 101.14 |
| 70 l/s | 0.4 % | 15 | 4.46 |
| | 0.8 % | 1 | 23.26 |

What an ultrasonic meter can not do at present is monitor the condition of the meter body and adjoining pipework. If degradation is serious enough, it may be possible to detect a change via velocity profile by analysis of relative velocities in multipath meters. It is also likely that deposits on transducers can be detected. However, it is less likely that a thin deposit on the interior of the meter body could be detected.

Changes to the internal bore are of great importance as any reduction in cross section will produce an equivalent error in volumetric flowrate. It would appear then, that until more progress is made it will be necessary to perform routine checks, either by inspection or by periodic calibration. Alternatively, appropriate material selection or regular cleaning may minimise the potential problem.

## 7 REDUNDANCY AND FAILURE

Failure of components or systems can occur for a variety of reasons. For example, it could be that a transducer cable is inadvertently damaged during work on an adjacent item of equipment or that an electronic component on a board fails. In any case, reasonable allowance for these sort of 'random' failures should be made within any metering system. With respect to ultrasonic meters, where multiple transducers and modular designs are common, it is possible to incorporate redundancy into a single meter design. Where in-built redundancy involves a change to the system function (e.g. computing flowrate based on a three-path rather than a four-path scheme) the effect of the (potential) failure on performance should be properly evaluated.

Some modes of failure (such as 'fatal' signal attenuation due to entrained gas) may render the meter inoperable in the short-term but permit unassisted recovery after the event. This type of failure may be inconsequential if it is of relatively short duration or may have significant consequences. If the later is the case, it may be that an alternative technology is required to guarantee continuous measurement.

## 8 MAINTENANCE, REPAIR AND UPGRADE

FIGURE 6
Recalibration of an ultrasonic meter following exchange of the electronics

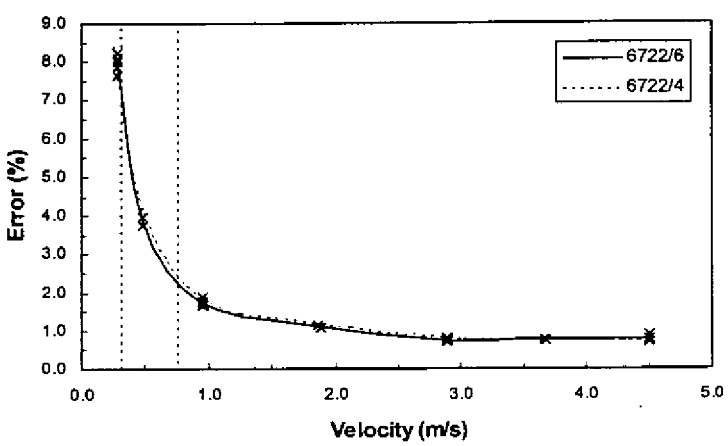
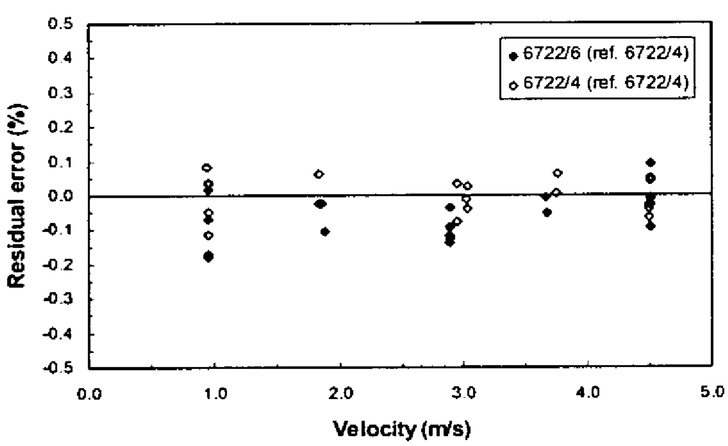



FIGURE 8
A plot showing residual errors with respect to the baseline calibration




As mentioned earlier, in an ideal world the ultrasonic meter should not require user intervention once properly installed and set-up. However, it may be necessary in the long run to perform some maintenance or repairs, or it may be beneficial to upgrade hardware or software. In any case caution should be exercised to ensure that calibration is not compromised.

Recent tests at NEL have shown the exchange of the electronics to have minimal effect on the calibration of a selection of 6-inch ultrasonic meters. One such result is shown in Figures 6 and 7. Figure 6 shows the baseline calibration as a dotted line and the calibration following the exchange as a solid line. Figure 7 shows the residual errors with respect to a second order polynomial curve fit to the initial calibration points above 1 m/s. Following the exchange of the electronics, the residual errors are less than ± 0.2 % and have a mean value of -0.072 %.

These results indicate that electronics can be exchanged without significantly affecting calibration. However, it should be noted that both sets of electronics were supplied at the same time by the manufacturers. As such it is advised that spare electronics be obtained at the time of purchase, otherwise good practice would dictated that the meters be recalibrated.

## 9 CONCLUSIONS

Ultrasonic meters based on the transit time principle can appear to be both deceptively simple and confusingly complex. For example, the theory of operation presented in most technical papers makes little reference to assumptions that have been made. At the same time, a higher degree of 'intelligence' than is generally feasible is often implied (especially with respect to signal detection and sensitivity to velocity distribution). At present the only rigorous way to determine the validity of manufacturers claims is by undertaking experimental evaluation. This will normally necessitate laboratory tests as performance evaluation in the field tends to be limited in terms of the range of conditions that can be obtained and the availability of an accurate and traceable reference. As such field trials very often do little more than demonstrate the reproducibility and reliability of a device rather than producing data to allow quantification of uncertainty in measurement.

In order to employ the technology more effectively and with greater confidence, operators will require a detailed knowledge of ultrasonic meter performance in relation to high accuracy demand applications. To meet this need NEL are initiating a Joint Industry Project (JIP) *The Evaluation of Ultrasonic Meters for Oil Flow Duties*. The mainstay of the JIP will be laboratory evaluation of the most commercially advanced devices across a range of flow conditions. For example, temperature, viscosity and two-phase flow effects will be determined. It is envisaged that this project will focus development in the technology area and lead to the development of testing and certification guidelines for custody transfer and fiscal applications.

### ACKNOLEDGEMENT

Aspects of this paper are based on work carried out as part of the Flow Programme, under the sponsorship of the DTI's National Measurement System Policy Unit.

## References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.