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OPERATIONAL EXPERIENCE OF MULTIPATH ULTRASONIC METERS FOR FISCAL GAS SERVICE

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Operational Experience of Multipath Ultrasonic Meters in Fiscal Gas Service

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1 INTRODUCTION

This paper has been written with the intent of sharing an operator's experience associated with the application of ultrasonic gas meters in fiscal service. The paper starts on general calibration issues and then focuses on the performance of a five-path meter, which has been in fiscal service for the last three years. Some further experience from the testing of three and four path ultrasonic devices will also be covered. Issues from initial testing, routine maintenance, in service operation and general observations will be discussed to increase awareness of the areas of concern and potential pitfalls.

The historical trends obtained from the progressive testing of the five-path meter demonstrates the suitability of this device for the demanding application of sales gas metering with the associated tight uncertainty requirements. Use of such meters will give operating companies many benefits and cost savings in project development and in day to day operations, while the customer can have confidence in the accuracy and repeatability of the instrument. With the increasing demands to reduce operating costs, the reduction of maintenance and recertification activities must be actively pursued.

As this technology is still in its infancy all associated parties need to communicate actively and work together to improve our common understanding and knowledge of this type of meter.

Areas that offer the largest potential gains are:

- Effects on the meter response to differing surface conditions of the meter internal pipe wall and the associated upstream and down stream meter tubes.
- Simple methods for insitu testing, removing the requirement for frequent testing at calibration facilities, (e.g. the possibility of a simple method for zero checking the meter).
- The effects of noise from external sources and system design to avoid such problems.

2 CALIBRATION

2.1 Selection of a suitable test facility

If the meter is new and under going acceptance trials the test venue will normally be selected by the manufacturer. This choice of venue should be discussed and agreed with the customer. The manufacturer may have built up an understanding with a particular test facility but it may not be the most cost-effective venue for the customer. To establish traceability, the meter will ideally be returned to the same facility a number of times. This will be an on going cost for the customer.

Before the initial tests a clear understanding of the program of events and procedures being used should be discussed and agreed, so all parties are aware of the deliverables required and the acceptance criteria.

The operator is then faced with a problem on subsequent tests, should he repeat the test at the same location or can he be more flexible and tender the recalibration, thereby obtaining a better deal elsewhere. The operator is required to build up a history of calibration data of a meter in Fiscal service. He must demonstrate to both customers and government bodies that the meter is reading without bias and accurately over the operating range and that it is being operated and maintained within the terms of the commercial agreements. This usually means that once a particular facility has been chosen, it will be used repeatedly (assuming testing meets the requirements) until historical evidence and an understanding of the instrument's performance has been built up.

2.2 OPERATOR EXPECTATIONS FOR THE CALIBRATION

The following three areas give the expectations of the operator, when interfacing with the test facilities and the meter vendor during calibration testing.

2.2.1 Actions to be considered and undertaken by the operator

- The test facility chosen must be traceable to a recognised International standards authority, with the primary calibration test records available for inspection at the facility.
- The facility should be accessible, both from testing availability (given reasonable notice) and location (transport and accommodation).
- Have the ability to reproduce the operators pipework configuration for the test i.e. Upstream & downstream lengths, inlet bend ('T', curve or 90^{o}) and pipework classification.
- The ability to meet the requirement to quickly change pipework configuration, giving the possibility of completing multiple tests on one day.
- Having the availability of suitable quality test gas to enable the full operating range of the instrument to be tested.
- Have access to all aspects of the testing facility for inspection during the test (if safe to do so).
- The meter should be ready to test (even if this requires the vendors to perform a pretest).

2.2.2 Information requirements of the calibration facility

- Prior knowledge of the instrument to be calibrated, both size & body rating and interface requirements for the electronics.
- Information on the required test configuration.
- What is the full range of flow, how many test points and repeats are required. Considerations for repeat tests as a mirror image.
- What type of factor adjustment is required i.e. linear interpolation or 'Nth' order curve fit.
- If repeat test points are required after factor adjustment has been applied as a check reference.
- If any extra testing will be required and for what purpose i.e. removing probes, altering surface conditions of the meter.
- The number of people attending and whether they require reports of the test results.
- Any preparation works prior to installation in the line i.e. surface cleaning.
- The format, including what language, of the test certificate.

2.2.3 Service provision from the vendor if requested to be present at the test

- Sufficient quality and quantity of equipment to allow testing to commence i.e. power supplies, interface boxes, diagnostic software.
- Ability to obtain parts at short notice so that calibrations can continue even if a component failure occurs.
- Offer full technical support, on operation of all associated equipment, the analysis of the results and possible suggestions from operational experience.
- Clearly written user manuals giving details of the meters build and operational calculations.

2.3 Actual calibration

2.3.1 Preparation

The preparation prior to testing determines the success of the exercise. If everyone associated with the activity is aware of the tasks, procedures and deliverables, the calibration can be completed in a reasonably short space of time and in a controlled manner.

Once the operator/vendor establishes the need for a calibration and has determined the type of testing required, a discussion with the test facility is recommended. This will produce availability dates of the facility for the test, an estimate on time required for the proposed testing required and highlight any need for procurement of new spools. Agreement on the upstream and downstream straight lengths is a must.

The required flow range must be determined, the number of points across the range should be checked and the number of repeats at each point agreed. This decision depends on the service the meter has seen. At present for a new meter a full comprehensive check is almost essential, whereas repeat calibrations can be less ownerous depending on previous calibration history. For a new meter, a minimum of six flow rates at equidistant points across the flow range are required, with three repeats at the four higher flow rates and five repeats at the two lowest flow rates. Using the high flow rates first gives better temperature stabilisation. After a factor adjustment has been applied, two spot checks within the range shall be made. In principle, as our understanding increases, it should be possible to use the manufacturer's factory calibration, derived from metrology of the meter, for the initial settings.

The cost of testing can vary from facility to facility, charges can be against the number of required flow ranges, or the number of repeats per flow range (the total amount of runs required), or even based solely on the time period for which the facility is being utilised by the customer. The costs can normally be adjusted during discussion with the facility personnel.

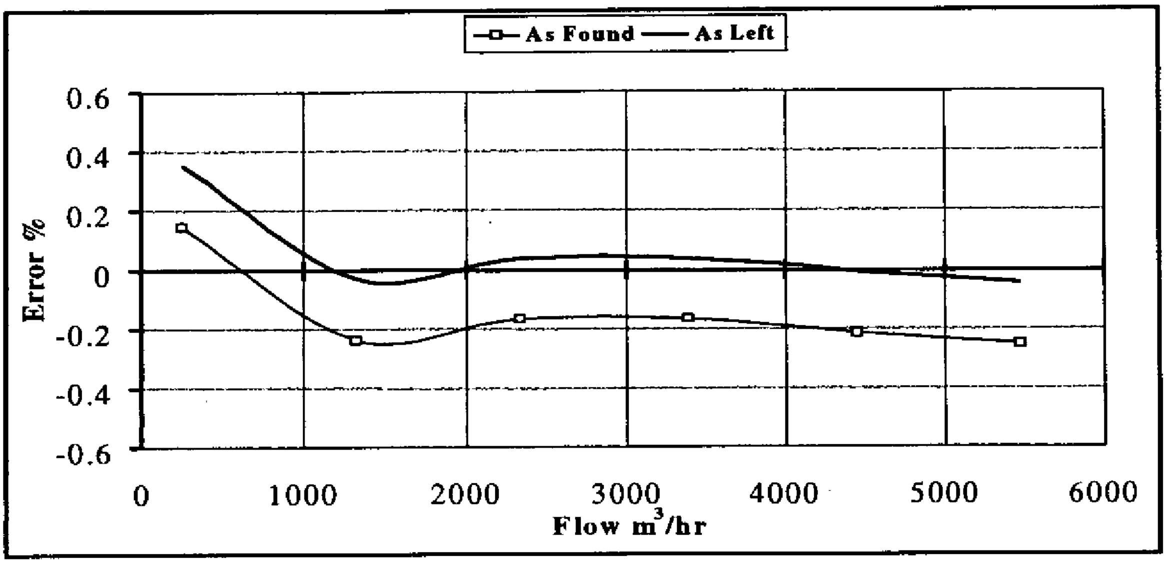
As each test run is completed a resultant performance curve will become evident. The method of factor adjustment should be considered. This may depend on the software available in the meter's electronics or the associated flow computer being used. Also different manufacturers meters produce different shaped curves, so another method of adjustment may be required. The required test certificate / report information should also be defined with inclusion of test temperature and pressure.

2.3.2 Flow factor adjustment techniques

This section aims to explain and demonstrate the current techniques and philosophies used to adjust the meter to read without bias and accurately. For all the correction demonstrations, actual calibration data has been used.

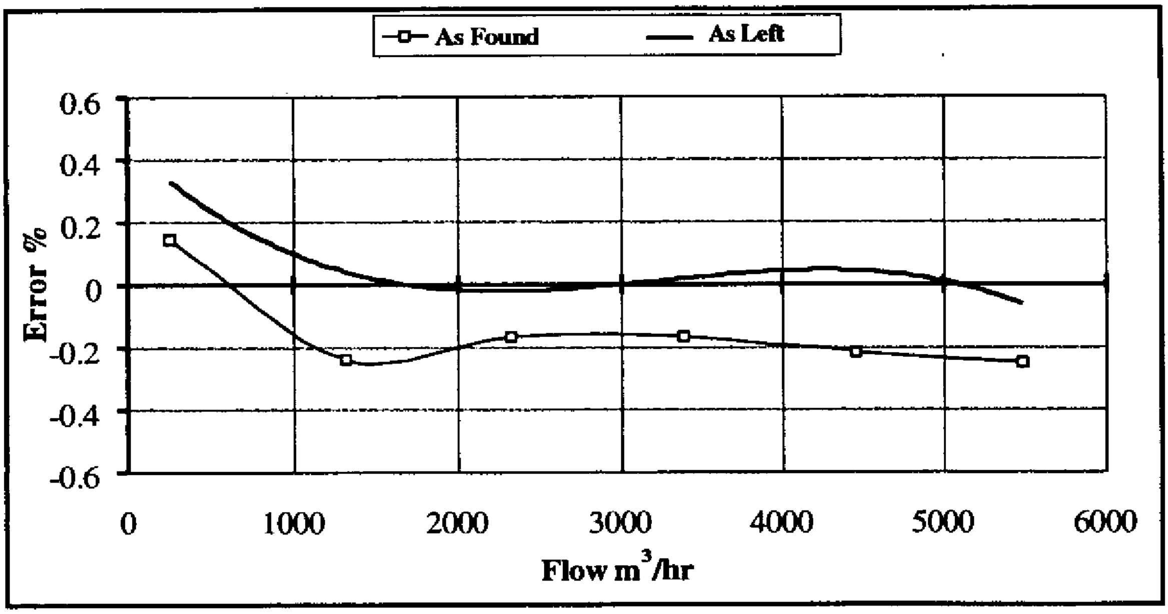
Average flow factor

The average offset over a selected range is calculated arithmetically and applied as a one-off correction.



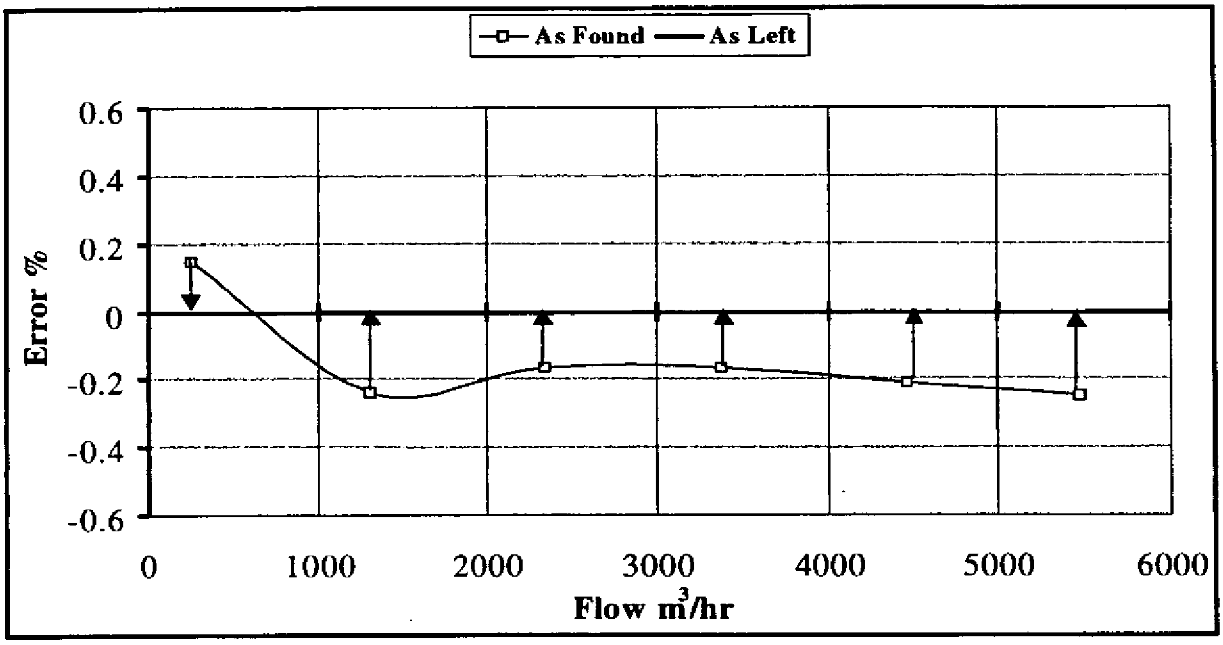
Third order polynomial

A third order polynomial is fitted to the data and the flow coefficients determined.



Linear interpolation

Each calibration point is adjusted to give zero offset. From a look up table containing the flow rate against offset, a value can be predicted over the whole flow range by using linear interpolation.



As an operator we have selected linear interpolation because:

- The method is already in use on turbine meters.
- The method is easily demonstrated to auditors.
- The resultant curve lies exactly along the datum line.

The reasons we don't like the second option of 3rd (or indeed Nth order) curve fit:

- A decision has to be made as to which order the curve is corrected.
- It's difficult for auditors to check the curve fit calculation easily.

The operator, government authorities and customers must agree the method of adjustment used. Whilst details of any adjustment must be recorded, provision of these details may not necessarily form part of the scope of work of the calibration facility.

2.3.3 Testing

The meter and pipework associated with the calibration activity must be inspected prior to insertion into the test configuration.

Meter:

Pay particular attention to the internal surface condition and make a sketch for the record (taking photographs of the internals is very difficult). The manufacturers often apply corrosion inhibitor to the inner surfaces. This must be removed prior to testing, as any residue discovered after the event will mean the calibration test is null and void. The surface conditions will change in use dependent on operational parameters. Surface corrosion, erosion or component deposits may be evident – other than for a new meter no attempt should be made to clean or wipe the internal surface as this will have direct effect on the calibration result.

Pipework:

It is important that no steps are evident, no protruding welds are present and the correct flange types are being used (ISO5167 is a useful guide). This is to obtain the required flow profile at the meter. Records should be kept of the test spools used for future reference.

If the meter is new, consideration should be given to testing additional aspects before the final calibration run. This will mean slightly higher calibration costs but may save on operational cost – possibly saving on a retest after equipment or component failure. As an example, we consider sensor failure and replacement. First establish the basic meter curve, with two repeats at each flow rate across the whole range. Then assess relative probe failures on each individual path, and various combinations of failures (easily achievable by disconnecting the relevant cable) recording resultant meter performance after each test. Finally remove a pair of probes from the meter (observing all operational and safety implications), replacing them in the opposing locations (swapping the relative positions). Recheck the meter at two points on the curve to determine whether shifts have occurred, again keeping appropriate records of the test.

The test runs can now start in earnest following the agreed procedures. The application of an automatic data acquisition system speeds up processing and enhances confidence in the results.

When recalibrating the meter an 'as found' curve must be produced first. Then the factor adjustment can be applied. All data associated with the test should be captured in electronic and paper format. The configuration list of parameters, the temperature and pressure must be included with the calibration certification and report.

3 ROUTINE MAINTENANCE

3.1 Periodic checks

The following section details the maintenance carried out on the ultrasonic meters:

Daily checks

Visual checks performed on each of the stream flow computers.

- Ensure that no alarms are standing that would indicate poor meter performance.
- Ensure flow rate information is being received and is updating. Confirm updates are not displaying large step changes, indicative of poor meter performance or bad process conditions.
- If more than one stream online, ensure flow rates are comparable taking into account any known flow bias.
- On off line streams ensure that flow has not been accumulated. If so, confirm that it has not been recorded on the station daily report.

Weekly checks

Take a data log from each of the meters, review the logs as follows:

- Check the health state of each of the five flow paths. This is determined by the quantity of good flow signals processed for each flow path.
- Compare flow velocities of online meters, taking into account any known flow bias.
- Monitor the automatic gain control (AGC) level for each of the transducer pairs. This indicates how strong the signal level needs to be in order to transmit the ultrasonic signals through the process medium.
- Carry out a physical inspection of the meters, including all cabling and probes for any signs of damage.

An example of the meter data log is shown below:

Samples /sec	Performance Per Path %					Sound Velocity	Corrected Gas Vel	Gross Vol Flowrate	Stb
	Path 1	Path 2	Path 3	Path 4	Path 5				
13	100	100	100	100	100	421.68	2.71	7.2E+02	3
14	85	100	100	100	100	421.69	2.691	7.2E+02	3
13	100	100	100	100	100	421.71	2.734	7.3E+02	3
14	100	100	100	100	100	421.71	2.711	7.2E+02	3
14	100	100	100	100	100	421.71	2.695	7.2E+02	3
13	100	100	100	100	100	421.7	2.741	7.3E+02	3
14	100	100	100	100	100	421.7	2.704	7.2E+02	3
13	100	100	100	100	100	421.69	2.721	7.3E+02	3
14	85	100	100	100	100	421.67	2.715	7.2E+02	3
13	92	100	100	100	100	421.67	2.689	7.2E+02	3

AGC Level of transducer pair path A/B										Maximum AGC Level
1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	
5475	5600	8415	8415	5125	5400	8160	8160	5325	5325	65025
5350	5650	8925	8415	5300	5300	8160	8160	5275	5275	65025
5525	5525	8415	8415	5325	5325	8415	8415	5325	5325	65025
5600	5600	8160	8160	5175	5500	8160	8160	5325	5325	65025
5450	5575	8925	8160	5125	5250	8415	8415	5225	5225	65025
5500	5500	8415	8415	5025	5350	8160	8160	5300	5300	65025
5450	5775	8670	8670	5350	5350	8415	7905	5225	5225	65025
5350	5850	8160	8160	5100	5425	8670	7905	5225	5225	65025
5350	5475	8415	8415	5325	5325	8160	8415	5025	5150	65025
5425	5550	8670	8670	5100	5450	7905	7905	5350	5350	65025

Note: On the system that we were monitoring, after one year, detailed data logging was terminated. It was felt that sufficient confidence had been gained in the meters self-diagnostic mechanism.

Monthly checks

Validate the ultrasonic meter configuration, ensuring all constants are as per the calibration certificate.

Annual checks

Remove the meter from service and return it for re-calibration and certification.

3.2 Calibration frequency

One of the main drivers behind the use of this technology is the potential to reduce the testing regime required, saving possible production deferment and maintenance costs. To this end the testing performed so far has been focused on performance between calibrations. It should also be noted that if a system has two or more meters, only one of the meters should be used to determine the performance between calibrations and then the resultant agreed frequency applied across all the meters in the system.

Meter	New							
		3 Months		**3 Months**		**12 Months**		**As Agreed**
1	Test1	——▷	Test2	——▷	Test3	——▷	Test4	——▷
		3 Months		**As Agreed**				
2	Test1	——▷	Test2	——▷				
		3 Months		**As Agreed**				
3	Test1	——▷	Test2	——▷				

Note: The calibration interval given above is actual service period, not time period.

Depending on the results of the tests, the frequency can be adjusted to suit the interested parties. The table above is only a suggestion, but it is supported by our test results to date. Agreement must always be reached between all parties prior to changing any frequencies.

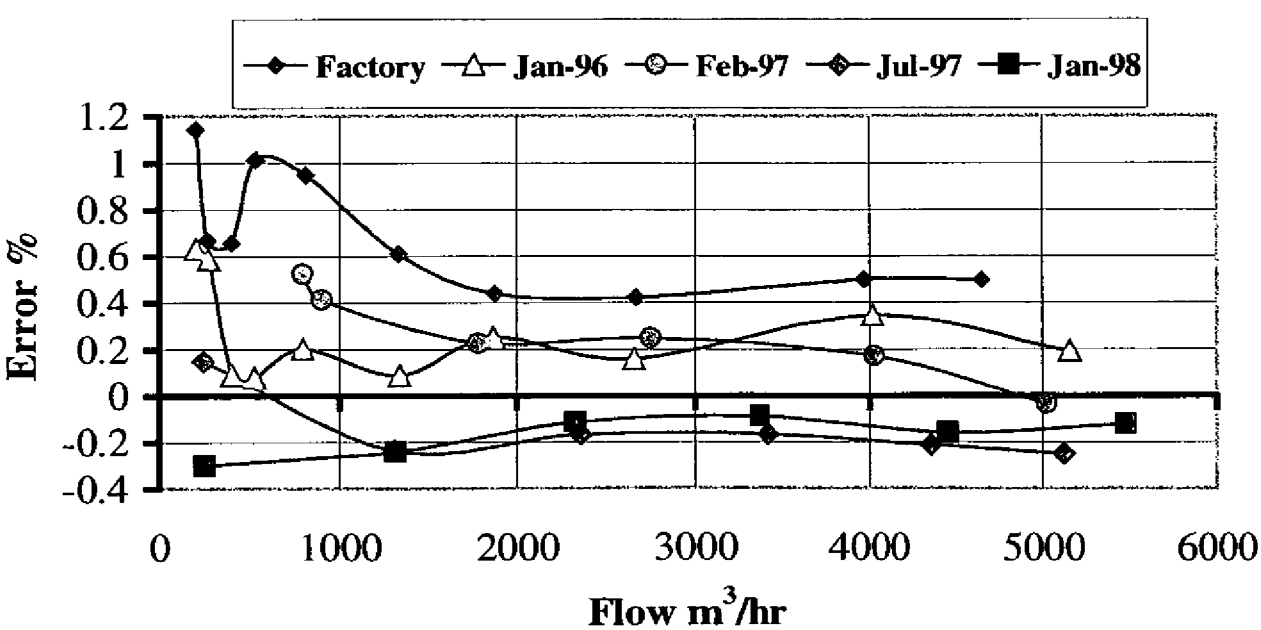
4 OPERATIONAL EXPERIENCE OF ULTRASONIC METERS

4.1 Five-path meters

4.1.1 Performance over a three year period

The following graph shows the calibration performance of a 5-path meter, which has been in fiscal measurement service at an onshore facility over a 3-year period.

Meter 2026 "As Found"

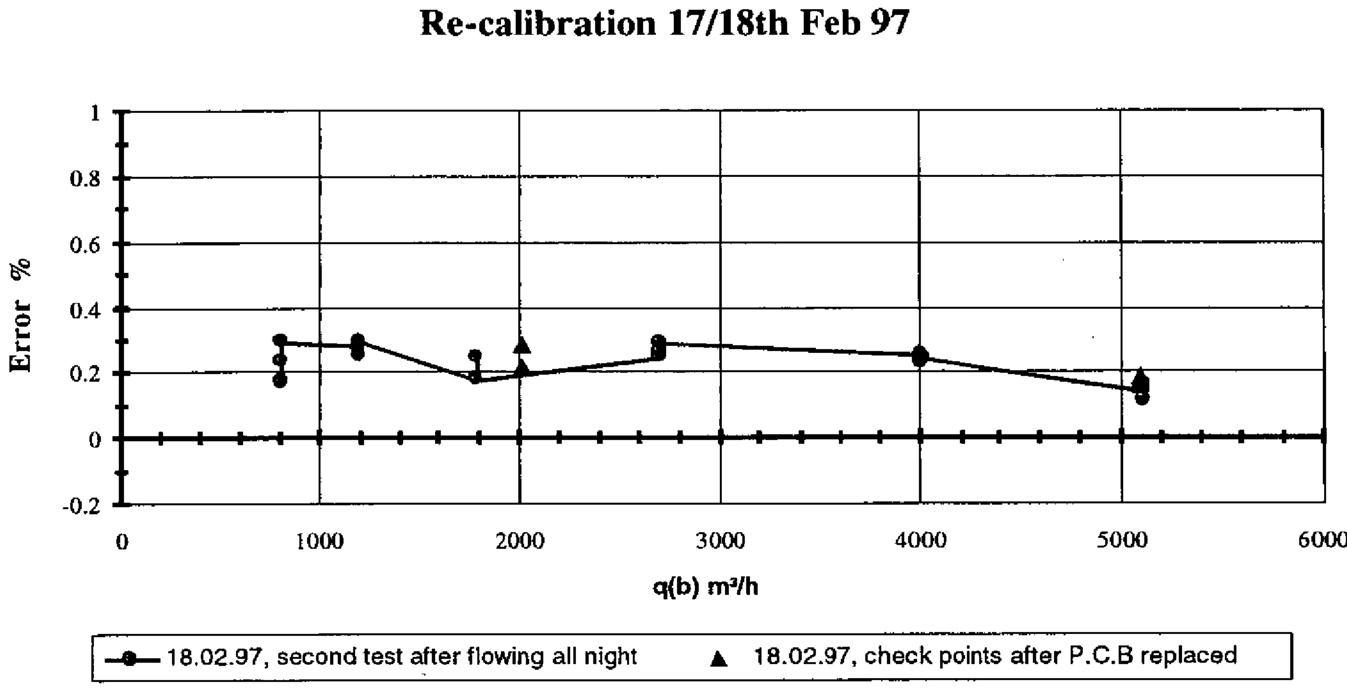


The first curve was produced at the factory acceptance tests. The internal meter surfaces were clean and had a smooth, machined finish. After four months of service, the meter was returned for calibration at the same test site. The internal surface condition had changed, some fine dust / metal oxide coated the whole surface area.

From the graph it can be seen that after initial adjustment subsequent recalibrations have stayed within a tolerance of +/- 0.25%, between 1000 and 6000 m3/hr. Allowing for the fact that the calibration house has a measurement uncertainty of 0.25%, the performance of the meter over time has been excellent. It should be noted that after adjustment the curves shown were moved to the datum line, reading with out bias and accurately.

It is very important not to interfere with the surface coating, because this layer on the internal surface has built up in operational service and is the best representation of normal in line conditions. A calibration in the 'as found' condition allows for the best operational adjustment. Experience has shown, any cleaning of the surface, even a wipe with a rag, will affect the calibration adjustment and may lead to bias offsets when returned to service conditions.

4.1.2 Changing electronics



During one of our tests, we took the opportunity to upgrade our equipment with new electronics. Having completed an 'as found' run with the original equipment, the electronic boards were replaced and four spot checks were subsequently carried out. The points were superimposed on the 'as found' curve. They fell perfectly in line with the curve.

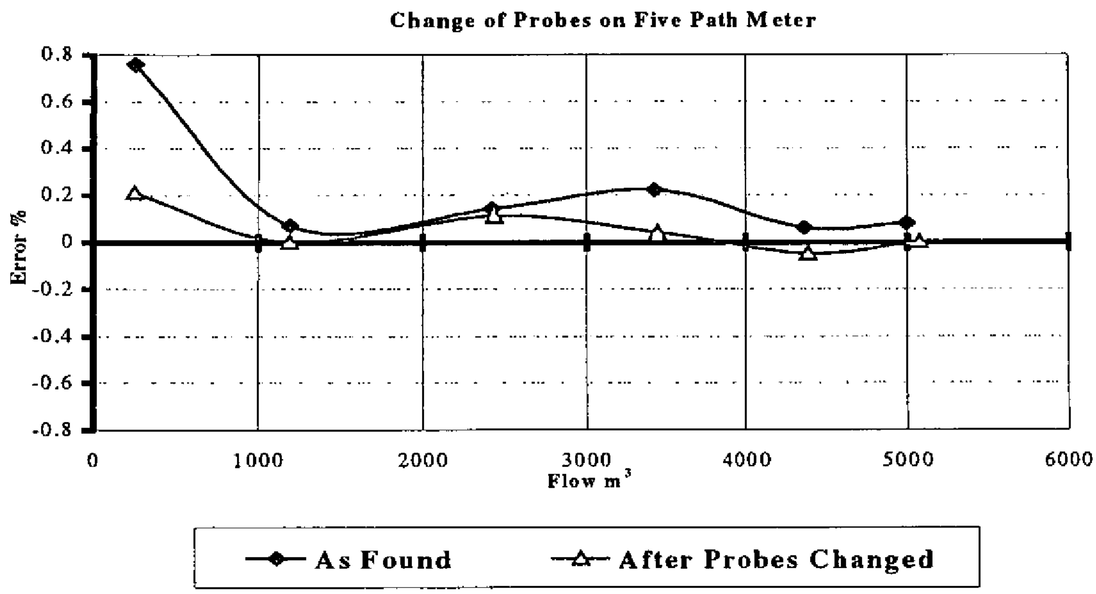
This test shows that it is possible to change the electronic boards without unduly affecting the calibration. Thus in the case of an electronic failure in the field, the need to replace the board would not necessitate an immediate return of the unit for calibration.

4.1.3 Noise problem and probe replacement.

During periods of operational use deterioration in the meter performance was detected. This was traced to an upstream regulation valve and a slightly heavier mix of gas. As the volume flow increased the meter performance dropped off. This coincided with an increase in pressure drop across the valve. Noise was being generated at the valve and was masking the signals being produced at the meter.

After discussions with the meter manufacturer, the remedial action was the replacement of the meter probes. The new probes operate at a frequency outside of the noise produced by the valve.

The graphs below show two stages of testing, an 'as found' calibration with the old probes and an 'as left' calibration with the new probes. The meter factor shift of 0.09% across the operating range indicates that changes can be made between probes without large shifts taking place.



4.1.4 Surface condition effects

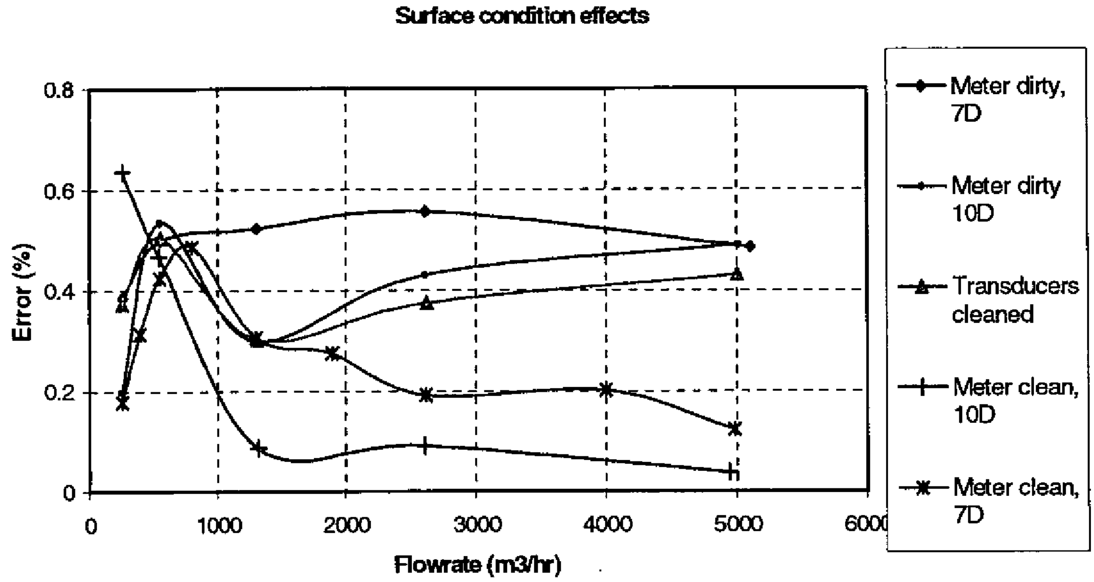
In the course of our recalibration of the St Fergus meters we were surprised to discover that a very fine layer of dust (probably of the order of a few tens of microns) can affect the calibration. When the first of the three meters was recalibrated there was a shift of +0.3% from the initial manufacturer's calibration. We considered at that time that this was within the range of variation that could be expected from a station with a stated uncertainty of 0.25%.

When the second meter was recalibrated a few months later it showed a shift of +0.45%, well outwith what could be attributed to the calibration station. We removed the meter for examination, decided to clean off the coating of dust, and retested the meter. The shift was reduced to 0.28%. We also examined the traceability of the calibration station and concluded that although it had a claimed uncertainty of 0.25% in absolute terms, for repeat calibrations the repeatability of the station from year to year was probably nearer to 0.1%, making the residual 0.28% well outwith what could be attributed to the calibration station. Possible causes could be movement of the transducers (unlikely as all five pairs would have to move in a similar way to give path length changes of several millimetres), or variations in the master clock frequency (again unlikely as this would have to be wrong by the equivalent of several minutes in a day).

The meter was then left with the manufacturer who carried out a series of tests and concluded that the shift might be explained by the use of shorter upstream straight lengths (7D) on the initial calibration compared to the 10D used for the second.

We decided to use the third meter to establish whether this explanation was valid, and whether the dust layer did have a significant effect. Accordingly the dirty meter was tested with 7D and 10D upstream straight lengths. Our customer was also concerned that dust on the transducer faces might have an effect, so a third test was done with the transducer faces cleaned, but not the inside of the meter body. For the fourth test the inside of the meter was cleaned and tested with 10D upstream straight lengths. Finally the clean meter was tested with 7D upstream straight lengths.

The results of the five tests are shown in the graph below. There may be a small effect from the difference in upstream straight lengths (compare the top two and bottom two traces). The effect of cleaning the transducer faces is within the scatter of the measurements (compare the second and third traces from the top). There is however, a very marked effect from cleaning the meter body of the order of 0.4% (compare the first and fourth traces for 7D, and the second and fifth traces for 10D). Thus there was clear evidence that the dust layer was responsible for most of the shift in calibration.



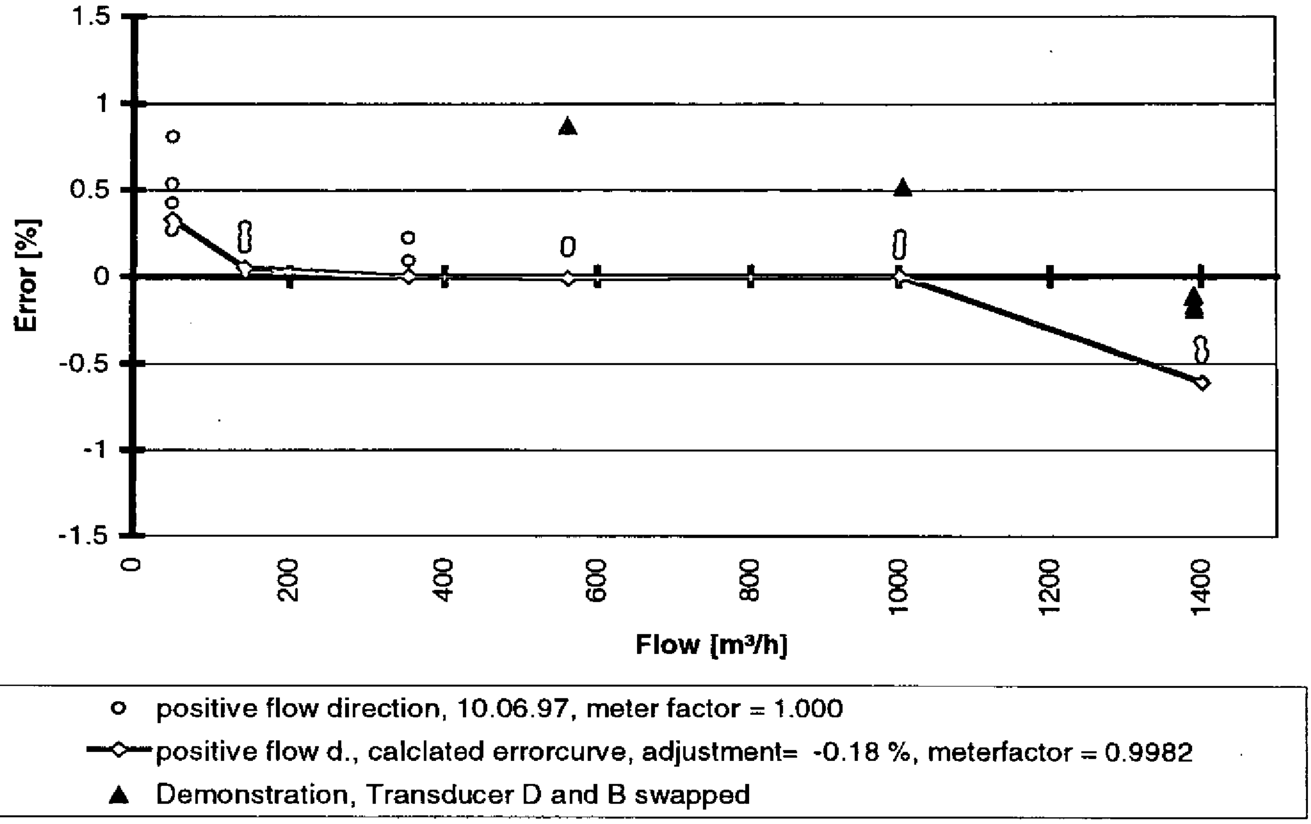
This was a startling conclusion, as there is no obvious reason that it should only apply to ultrasonic meters. We speculate that changes in the meter body surface lead to changes in the thickness of the boundary layer on the pipe wall. This is the thin layer of gas that is stationary. For a given volume flow rate this has the effect of varying the gas velocity. Nevertheless we are also convinced that in practice we may not be too inconvenienced. Provided the surface of the meter body does not change, the calibration will not change. Our recommendation, therefore, is not to clean ultrasonic meters before recalibrating them. Furthermore all the changes in calibration shown are contained in a band 0.5% wide, which can be compared of the basic uncertainty of the discharge coefficient of an orifice plate of +/- 0.6%.

Points of note

- The meters output curve is affected by micro surface conditions.
- The meters inner surface of a meter should not be tampered with prior to, during or after calibration.
- If the meter is being used on a slightly wet gas, the resultant output will be offset from the dry gas calibration.
- Any advantage gained from the material used for manufacture of the meter body or the application of an inner surface coating will be offset by operational environment in which the meter operates.
- The internal surfaces of the upstream & down stream pipework was not touched (so any attributable effects from pipework could be discounted)
- When the meter was removed from the test line, it was found to be dry.
- If any moisture is present on the internal surface, the resultant curve will be skewed. We have seen this effect repeated at other calibrations. Results should not be accepted if moisture or liquids are found on the internal surfaces of the meter or spools pre or post the calibration run. This is due to the fact that it will not be representative of the process conditions for which it is to be used.

- As only the internals of the meter were affected, an understanding of the cause of this phenomenon is still to be found. We speculate that boundary layer changes are altering velocity profiles, variable with flow rates

4.2 Four path meters



The shape of the curve can be variable on this type of meter, but the points have proven to be repeatable. With the implementation of a curve fit it has proven to be suitable for this specific type of application.

It should be noted that the operating philosophy of this meter is different to the three and five path meters, having only direct paths and different calculation algorithms.

The calibration test undertaken included the exchange of probes from transducer D and B. As can be seen from the results a large shift was experienced. This raises the question that whether probes failing in service can be replaced without the need for recalibration. At present the answer for meters in fiscal service is no.

Depending on the adjustment techniques used on the curve, care is required with the slope at the higher flow rates. A large bias is introduced and would be unacceptable if this was within the normal operating range of the instrument.

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.