18th NORTH SEA FLOW MEASUREMENT WORKSHOP 2000

BUILDING CONFIDENCE WITH MULTI-PATH ULTRASONIC METERS

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1 INTRODUCTION

BG has many years experience with high pressure Ultrasonic meters. We were involved with the original development of the meter including the verification of the technology using the BG Technology high pressure testing facility at Bishop Auckland. Experience included installing a number of mulipath meters at BG sites. The early versions of meters indicated problems with noise, reliability and transducer failure particularly at high flows

The 1990's saw a considerable improvement in the electronic and sensor/transducer technologies. This led to improvements in the flow measurement ability of the multipath ultrasonic meters. Tests have shown that now USMs perform as well as state of the art turbine meters, in some cases even better.

One problem remaining has been the generation of noise from control valves. Over the recent years the industry has made efforts to gain a better understanding of this problem [1]. For BG installations, upstream and downstream pipe configurations and the type of control valves vary considerably. For USMs to be readily accepted and used in the high pressure and high flow applications by BG, a better understanding of the effect of pipe configurations, valves and regulators on USMs was necessary. Since 1998, a programme of work was undertaken to look at the behaviours of multipath ultrasonic meters [2] in ideal and more complex pipework situations. This study was also extended to examine the effect of noise generation by three of the most popular valves/regulators used by the BG at metering stations (offtakes). This paper presents the results of this programme.

The paper also presents work comparing the USM against other metering systems as well as some of the issues that BG faced both during the calibration and commissioning of USMs such as correction methods and compatibility with the various flow computers currently available.

2 ASSESSMENT OF PIPE CONFIGURATION AND 'NOISE EFFECT'

Following a review of the configuration and equipment located at existing high pressure metering sites, a test programme was set up to examine the effect of three of the most widely used valves/regulators within BG. These tests were carried out at the BG Technology test facility at Bishop Auckland, located in the North of England.

2.1 Description of the Test Facility

The layout of the Bishop Auckland Test Facility is shown in Figure 1. BG Technology operates the site for flow test work both within BG and on commercial contracts. The site is UKAS accredited for volume flow measurement and utilises a series of 4", 6", 8" and 12" turbine meters as reference meters given a maximum accredited flow rate of 19,500 acmh.

The facility is connected to the UK National Transmission System (NTS), which constitutes a very large upstream reservoir of gas at a very stable pressure during calibration periods. The facility operates in two flow modes dependent upon the pressure and flow rates required. Normally, the site operates at the prevailing NTS pressure (typically in the range 50 to 60 bar), providing extremely good reliability and stability of flow. In this mode, gas is supplied to the test area at flow rates up to 1,400,000 m^3/hr at standard conditions before being discharged back into the National Transmission System. For lower pressure calibrations, gas is taken from the National Transmission System and discharged to the Regional Transmission System (RTS) providing controlled pressure in the range of 28 to 60 bar. In this mode of operation, flow rates in the range of 100 to 600,000 m^3/hr at standard conditions are available. During a calibration appropriate reference meters are used to match the flow rates required for the test meter. Smaller diameter meters, typically less than 300mm, are calibrated in a series of 100 to 300 diameter test lines located in the reference meter building. Larger meters are tested in either a 600 and one of two 300mm diameter test lines, enabling equipment up to 1050 mm in diameter to be accommodated.

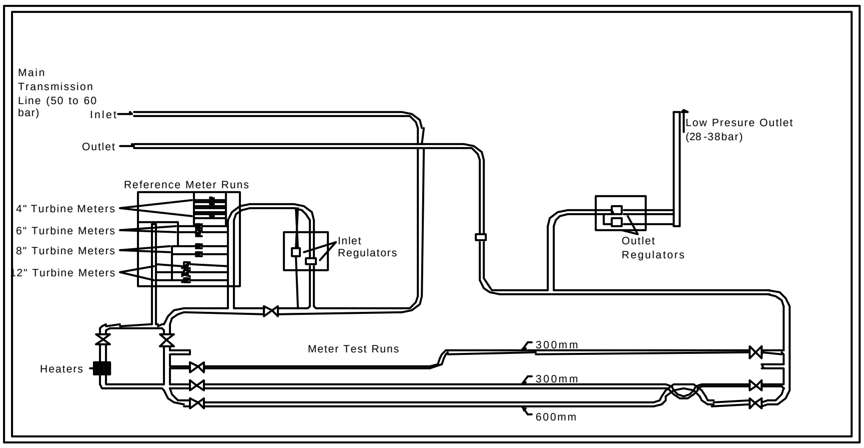


Figure 1 - Bishop Auckland Test Facility

2.2 Test Programme

The test programme consisted of three sets of pipe configuration tests as described below, (a) the standard configuration, (b) pressure regulators 20 metres downstream of 12" multipath ultrasonic meters, (c) pressure regulators 10 metres downstream of 12" multipath ultrasonic meters. The programme also included a 12" Mokveld valve with three different trims (RMGAX, RMGCX and RVX) and a 6" Jetstream regulator. At a later date, experiments were carried out on one of the multipath USM installed upstream of an IGA Axial valve. The test programme was supported by two meter manufacturers who provided meters, one manufacturer also provided microphones to enable noise measurements to be made at various points along the configuration. The names of the two meter manufacturers are excluded from the results. They are referred to as Meter 1 and Meter 2. The test programme consisted of:

- Calibration of both USMs in 'ideal' configuration – standard meter calibration configuration.
- Construction of a simulated BG offtake (comprising a filter, meter run, 2 tees, 2 bends and a pressure cut valve) and testing of each meter located approximately15 metres upstream of the pressure cut valve (a).
- Testing of each meter located approximately 10 metres upstream of the pressure cut valve (b).

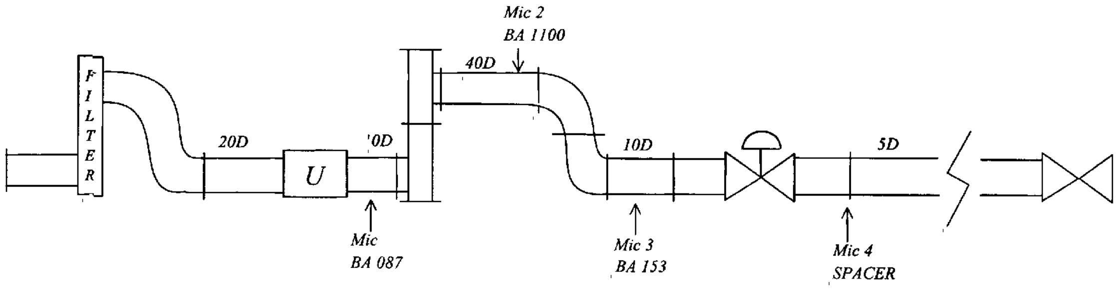
In configurations a & b, each meter was calibrated with a combination of the following variables:

10%, 25%, 40%, 70%, 100% of max. flow

4 different valves, 3 Mokveld trims (cages) and Jetstream

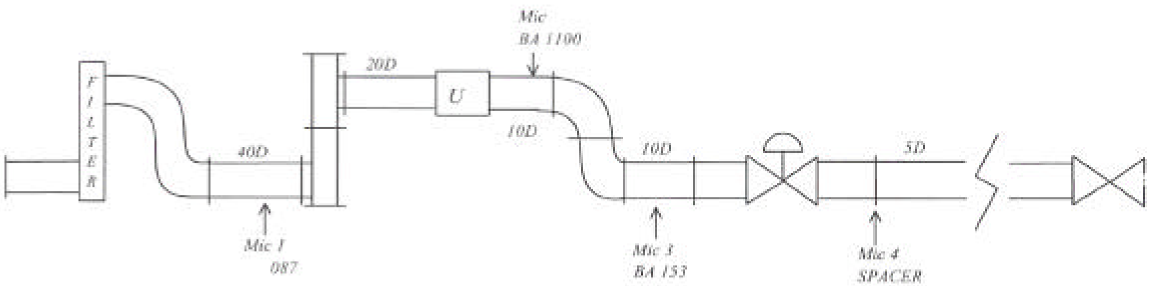
3 pressure cuts, 55/35, 55/45, 45/35 bars

Configuration (a): An upstream filter and a double in plane bend installed between the USM and the header. 10D downstream of the USM, 2 Tees to act as buffers, together with a 40D straight length and two in plane double bends between the Tees and the pressure cut regulator were installed as shown below (USM is indicated by 'U').



Configuration (b):

USM moved between 10 metres upstream of the pressure regulator and the 2 Tees as shown below.

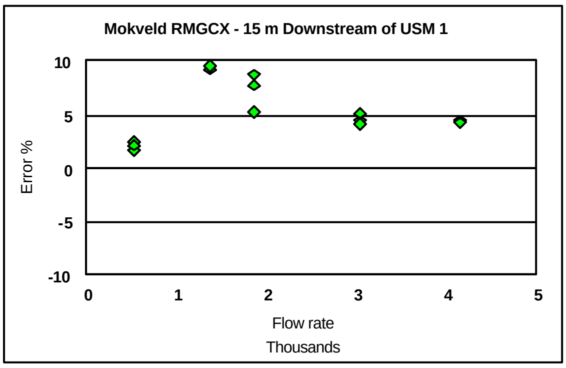


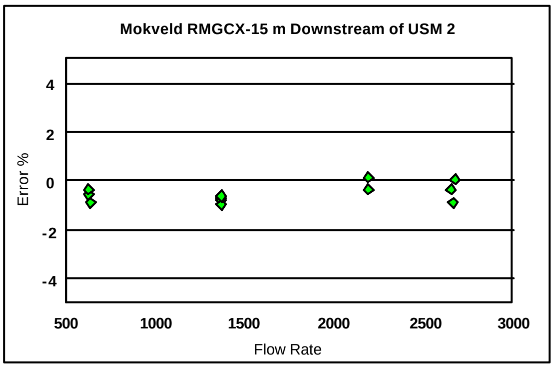
2.3 Test Results

Both meter's accuracy were better than +/- 0.4% when tested under 'ideal calibration' conditions which is not untypical for multipath USMs tested this way.

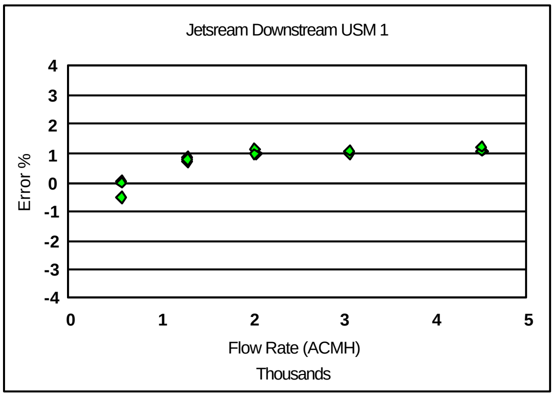
Tests results from both USMs indicated that downstream valves or pressure regulators have an impact on the operation of the meter performance at certain flow rates, pipe configurations and pressure cuts. Installing T joints and double bends between the USMs and valves as in configuration (a) certainly dampens the noise effect to a certain level, but when the meters were installed downstream of the T joints with smaller distance between the valves and the meters, a complete failure of the USM output was observed at selected flow velocities and pressure cuts. Figures 2 – 5 are some of the examples of test results showing the effect of Mokveld valve fitted with the RMGCX cage and Jetstream regulator on the two USMs when tested with a maximum pressure cut of 20 bar in configuration (a).

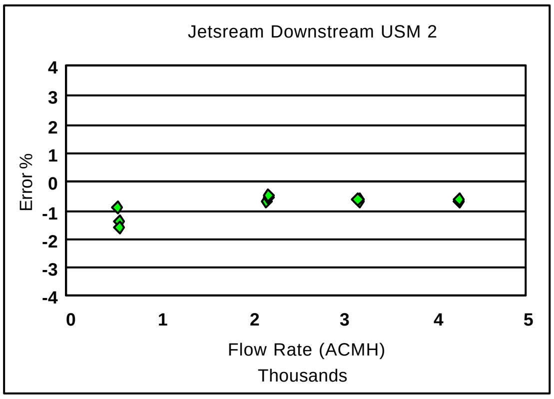
Although not too significant changes can be seen on USM2, USM1 was recording errors of up to 9.6% with one of the Mokveld cages (RMCGX). When tested with the Jestream regulator, maximum errors observed from both USMs did not exceed +/- 1.2% at the maximum pressure cut of 20 bar and the maximum flow rate in configuration (a).





Figures 2 & 3 - USM 1 & USM 2 errors, positioned 15 m Upstream Mokveld RMGCX (configuration 'a') With 20 bar pressure cut

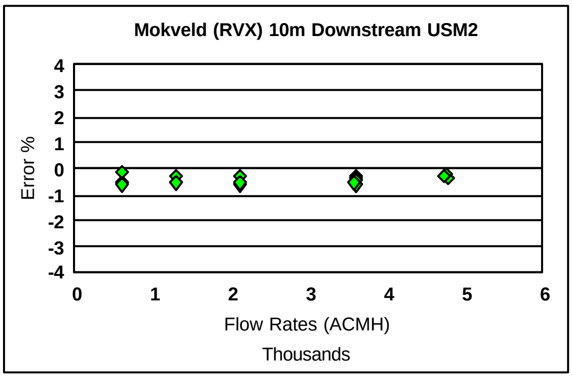


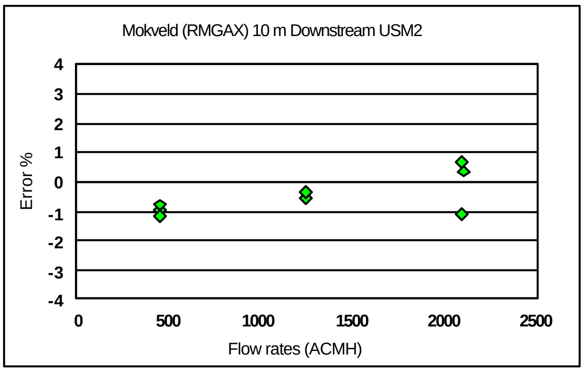


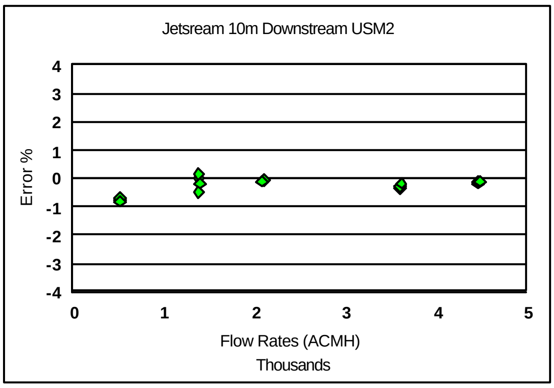
Figures 4 & 5 - USM 1 & USM 2 errors, positioned 15 m Upstream Jetsream (configuration 'a') With 20 bar pressure cut

Due to large errors observed with the USM1 during configuration (a), no further tests were carried out on the meter in configuration (b).

During configuration (b), USM2 errors remained around +/- 1% when tested with the Jetsream and the Mokveld cages RMGAX and RVX as shown below (Figures 5 – 7). When tested with Mokveld, RMGCX trim, the meter stopped functioning altogether.







Figures 5, 6 & 7 - USM 2 errors, positioned 10 m Upstream Jetsream, Mokveld RVX & Mokveld RMGAX (configuration ‘b’) With 20 bar pressure cut.

Noise measurements made during the tests, it was found that although the downstream noise levels for Jetsream and the Mokveld valve with its three trims are similar, upstream noise generated by the Mokveld valve with RMGCX trim was much higher than the others. This particular valve with the RMGCX trim generates a peak spectral distribution in the region of between 50 to 60 KHz.

3 FIELD EXPERIENCE WITH MULTIPATH ULTRASONIC METERS

3.1 USM Vs Orifice Plate Comparison, Calibration, Installation and Configuration

After calibration at the Bishop Auckland Test Facility, an 18” multipath USM was installed at an operational site upstream of an existing orifice plate metering system to monitor its long term operation and compare its performance with the orifice plate system. A photograph capturing the installation details is shown below (Figure 8). A flow straightener - 18” * 600 RTJ NEL flow conditioner, stainless steel perforated plate type fitted between two flanges - has been included in the pipe configuration upstream of the U/S flow meter. The two metering systems used flow computers which were kept independent from each other when carrying out the necessary flow computations. Each flow computer was connected to a remote data collection and storage system, via two independent data logging systems especially designed for this site. Both flow computers received information from two separate pressure transmitters, using the same pressure tapping and impulse lines. Line gas temperature for both flow computers were provided by the orifice plate temperature transmitter.

Figure 8 - USM and Orifice Plate Installation

3.2 USM Vs Orifice Plate Comparison Results

The USM was calibrated at Bishop Auckland before installation, the initial calibration curve can be seen in Figure 9. This calibration is normally carried out with a meter factor set to 1.0. Following the 'approved' calibration of the meter, a new meter factor (new adjust factor) is calculated and entered into the meter. Using this new adjust factor, new adjusted error figures are calculated which are plotted on the same graph for comparison. Figure 9 also shows the last calibration details of the USM after approximately two years of service.

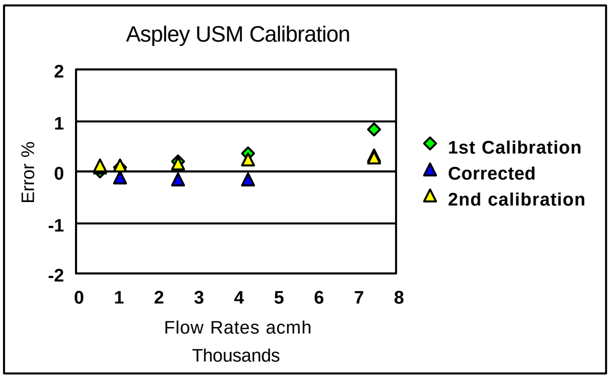


Figure 9 - 18 " USM calibrated at Bishop Auckland Test Facility

The claimed accuracy of this particular meter is approximately +/- 1.0% for a flow velocity range of 0.9 to 21 m/s. The meter however was initially calibrated over a range of 0.9 to 14 m/s (as this was the range available at the test facility at the time). This was sufficient to cover the flow range experienced at the operational site. As shown in the above graph, the meter's performance was well within +/- 1% and by applying the error adjustment technique, these errors were improved to less than +/- 0.5%. The meter was finally calibrated (2^{nd} calibration) over a range of 1 to 21 m/s. The meter's performance was within +/-0.28%.

During the comparison exercise, the performance of the USM transducers as well as their associated timing circuitry and metrology was assessed by comparing the speed of sounds on each chord and secondly by comparing the measured speeds of sound with a theoretical value calculated from the gas composition, temperature and pressure.

For example:

Data recorded on 14/03/1999 at 00:30 hours.

The four speeds are:

Chord A	383.856	m/s		
Chord B	384.0446	m/s		
Chord C	384.0222	ms		
Chord D	383.9474	m/s		
Average	383.9676	m/s		
Spread	0.1662	m/s	i.e.	0.043%

Using the gas composition data from the gas chromatograph recorded in the first scan of 14/03/1999 together with the measured pressure and temperature, a theoretical value of the speed of sound can be calculated, using the BG Technology programme GasVLE (Ref 3)

Theoretical speed of sound	383.64	m/s		
Average measured value	383.9676	m/s		
Difference	0.3276	m/s	i.e.	0.085%.

This comparison confirms that there are no obvious errors in the operation of the timing or in the dimensional data in the USM. This technique was used through out the trial to confirm the validity of the speed of sound readings from the USM.

In order to compare the performance of the U/S flow meter against that of the official O/P flow meter, data is collected and stored in self-powered loggers, one for each flow metering system. The two loggers collect and store data from the flow computers at 30 minute intervals which can be accessed and downloaded over the public telephone system, from BG Technology. This is done as required using a computer with a modem connected to a telephone line. The data collection time interval of 30 minutes can be changed as required. This interval was chosen as it provided sufficient resolution to give a good indication of what the metering systems were doing throughout a 24 hour period, at the same time enable the loggers to have sufficient capacity to hold several days data in between downloads.

Using this system it is possible to collect the diagnostic data from the Ultrasonic Meter such as individual chord velocity of sound, chord ratios and percentage of readings rejected on each chord. This information cam in very useful when investigating the performance of the meter.

For the comparison between the Orifice plate and the Ultrasonic meter “actual cubic metres” were used as the main unit for comparison. This was easily obtained from the ultrasonic meter but had to be “back calculated” from the orifice plate, as the primary output from the orifice plate is mass flow. By using this comparison the number of uncertainties were reduced and the results were easily understandable.

The first step was to produce a monthly overview of the comparison between the two meters. A typical example can be seen in Figure 10. This is the overview for February 1999. It shows the comparison of the daily volume passed by the two meters in actual cubic metres for each 24 hour period for the whole month.

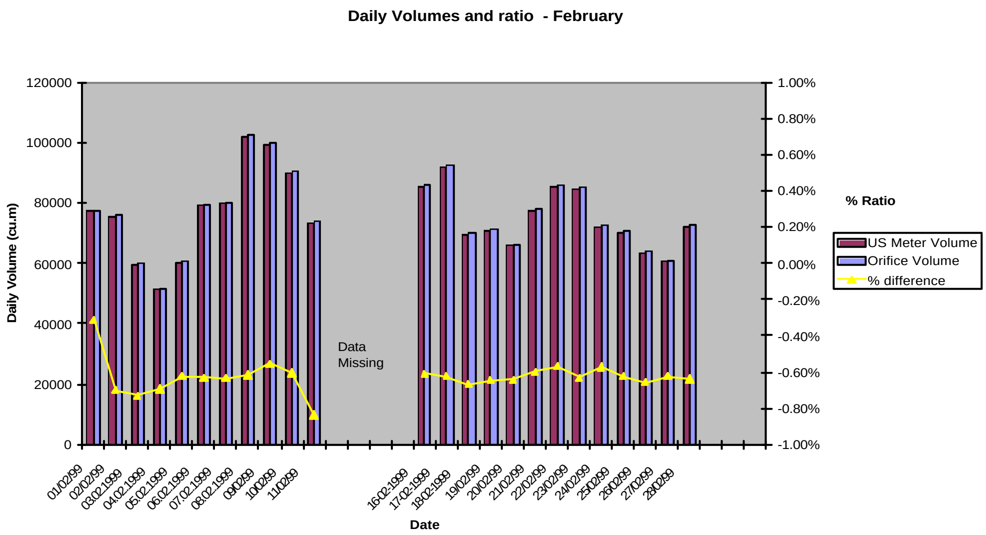


Figure 10 - Comparison of daily volumes passed through USM and O/P systems in 24 hour period

This is a typical example where the two meters agree with each other to an accuracy of +/- 0.1%, but with an offset of 0.7%. This trend was found through out the trial.

Figure 11 below shows the behaviour of the two metering systems in May 1999, the site experienced lower flow rates passing through. Both meters are showing perfect agreement when zero gas flowing through the system. Here the dependency tends towards –0.8% indicating there might be a slight flow dependency.

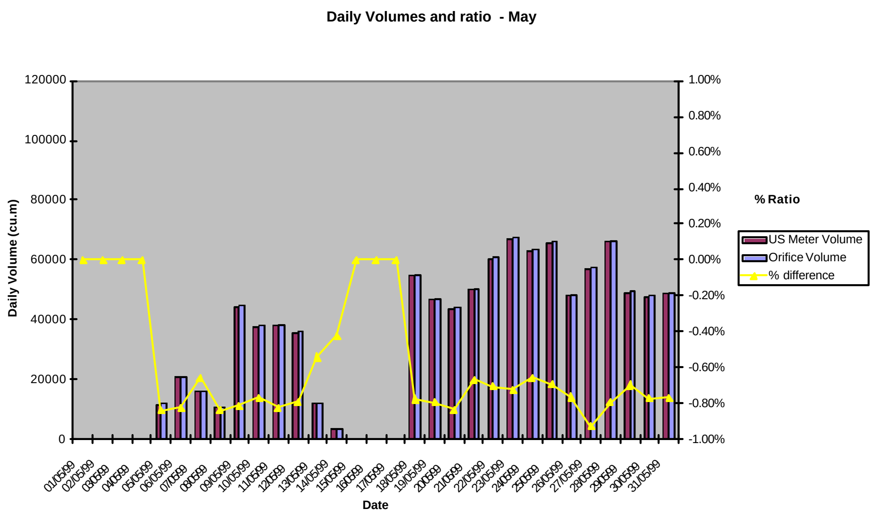


Figure 11 - May 1999 data

With very small flows it was found that the measuring cut off point (i.e. zero flow indication) for the orifice plate system reaches the point where no further measurements take place. The USM system however continues to register flows down to approximately 70 acmh as shown in the following two graphs (Figures 12 & 13). These readings were confirmed by studying the USM diagnostics and establishing that velocity of sound, chord ratios etc. were sensible numbers and no failures were identified.

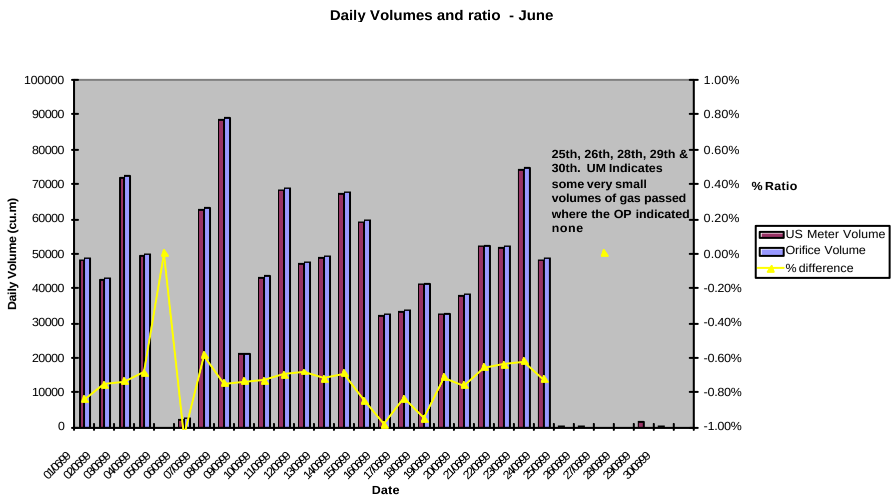


Figure 12 - June 1999 data

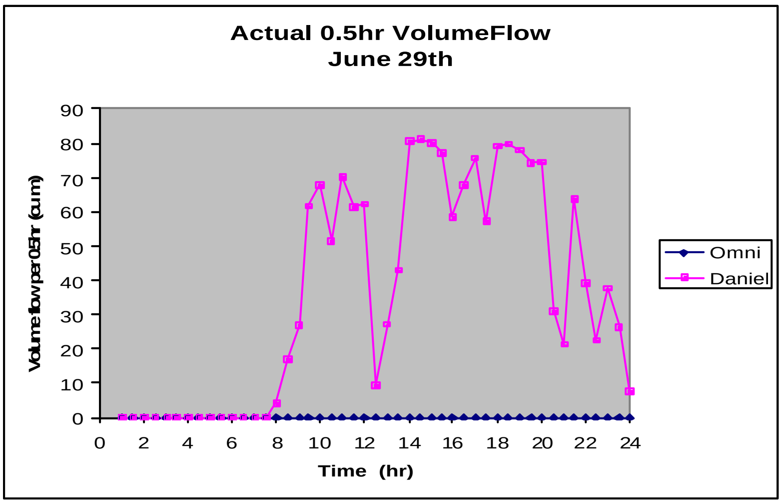


Figure 13 - Low flow data for June 1999

A more extreme example of this phenomena occurred on the 2nd September (Figure 14). Here the site is experiencing relatively high flow rates up to 12.00 hours and both meters agree. Then the flow decreases, at this point the Orifice Plate is measuring a differential pressure of 0.5 mb (0.5% of range) which is in fact below its cut off point and therefore not registering any flow, however the Ultrasonic Meter continuous to register a flow of around 160 actual cubic meters hour. Later in the day (20.00) the flow rate decreases further, the orifice plate DP drops to 0.1 mb

(0.1% of range), at this point the flow rate is too small for the Orifice Plate or the Ultrasonic Meter to register and both indicate zero flow. However, between 12.00 and 20.00 1280 ACM of gas has passed through the site which the orifice plate will not have registered.

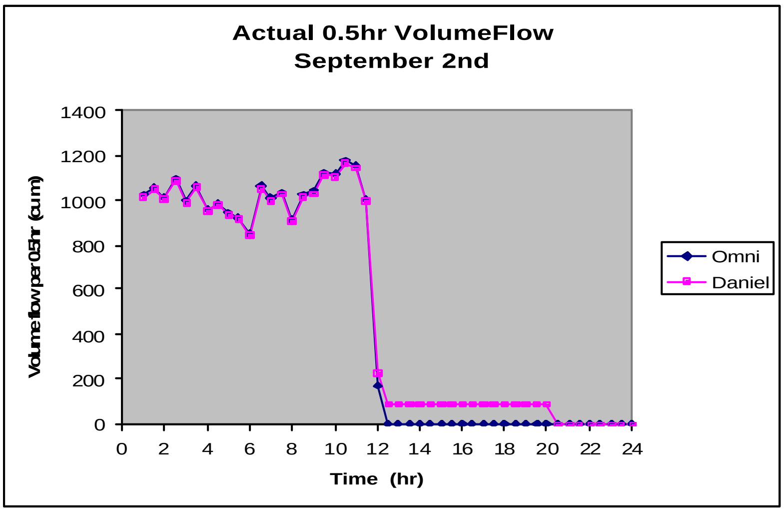


Figure 14 - Low flow data for September 1999

During winter months, unusual behavior between the two metering systems was observed. Differences greater than 9% were recorded between the two metering system during 20th and 21st December 1999 as shown in Figure 15 below.

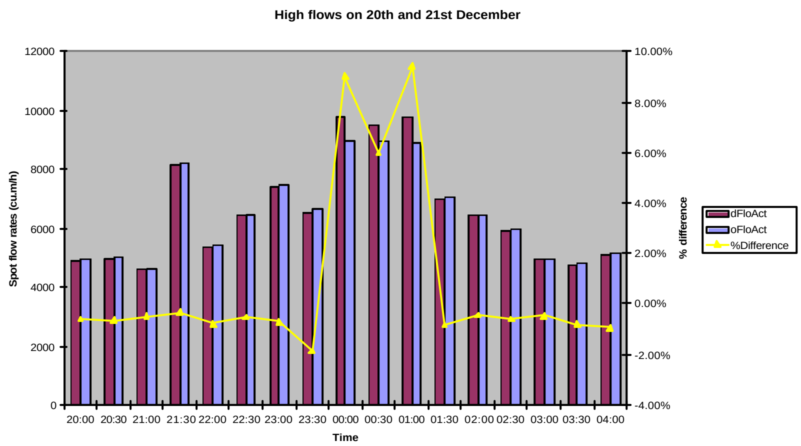


Figure 15 - High flow % errors between two metering systems for 20th & 21st December 1999.

Further investigation looked at the DP readings from the Orifice Plate Differential Pressures. This provided further information. (See Figure 16).

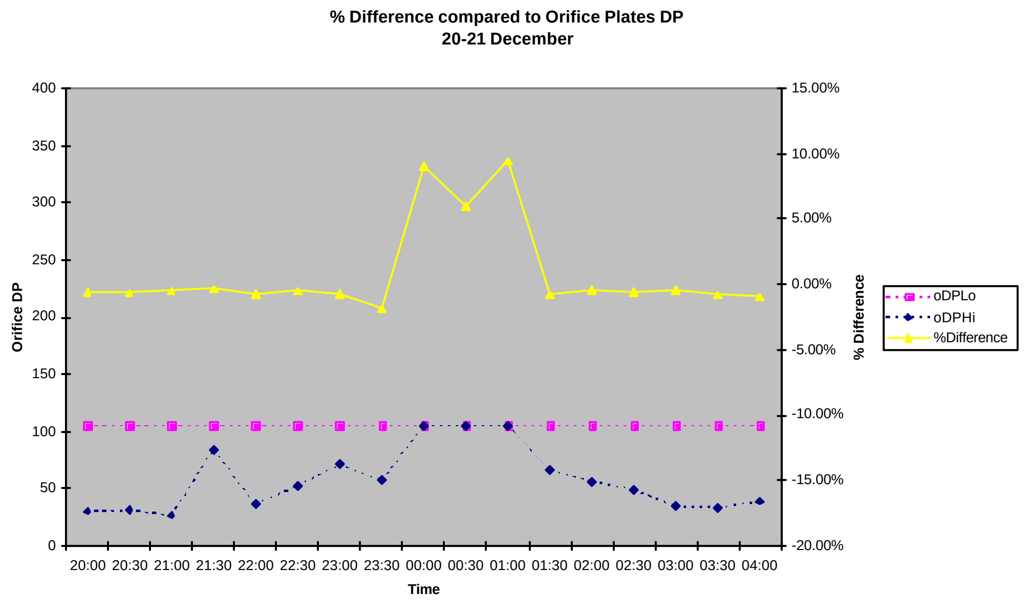


Figure 16 - Orifice DP readings at high flows

As the flow increases the differential pressure increases until eventually the DP "tops out" (i.e. reaches the top of its range) at about 105% of its range. This means that once the orifice plate has "topped out" it will then under read. Flow rates measured by the USM indicated flows of up to 10,300 acmh were experienced. Some chords failures were observed at these rates, but chord substitution technique used by the meter diagnostics enabled the meter to continue measuring accurately.

It can be concluded from this study that the two metering systems are in general agreement with each other, albeit with a consistent offset of 0.7%. There is evidence that during 'low flows' of below 200 acmh, the orifice plate system installed at this site stopped registering flows well before the USM system. At very high flows, the orifice plate DP reached the top of its range resulting in very large measurement errors, while the USM system continued to operate satisfactorily despite some of the chord failures.

4 CALIBRATION AND TRACEABILITY OF ERROR ADJUSTMENT

When an USM is calibrated at an accredited test facility, a calibration/error curve is produced (Figure 16 below), normally from the 'frequency' output of the meter. During the first calibration, the manufacturer of the relevant USM is normally present and they may request to carry out software corrections within the USM, in order to reduce the calibration curve error as seen with the meter used in long term monitoring mentioned in the previous section. This correction may be carried out using various methods, which are acceptable to AGA-9 [4]. One example (Figure 16) is the Linear Correction/Interpolation method shown below, which is employed by most USM manufacturers (this is an actual calibration data from a 12" class 600 USM).

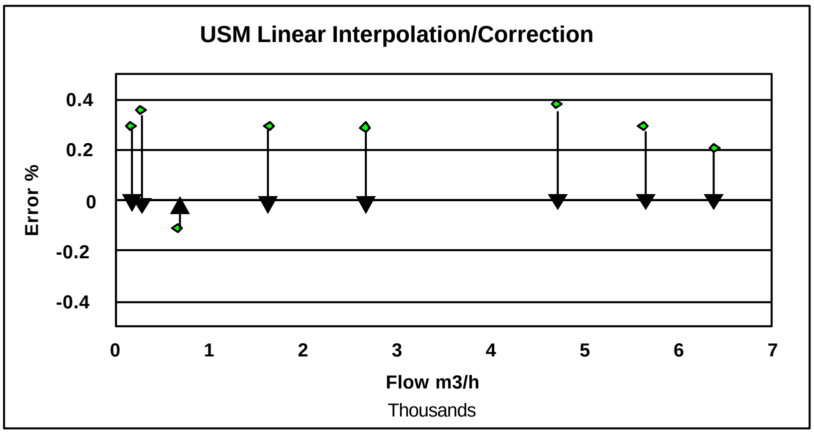


Figure 16 - USM Calibration and Linear Correction

This method is an accepted way of correcting for turbine meters. It is easily demonstrated to auditors and the curve fitting is accurate. This is true for turbine meters and USMs, if the necessary correction is carried out in the flow computer. However, carrying out this correction within the USM electronics causes concern as below:

- The ‘official’ calibration certificate, supplied by the ‘test’ facility, only has the record of the ‘true’ calibration curve and NOT the corrected curve.
- The meter is NOT recalibrated after the software corrections/changes are carried out on the USM! There potentially could be an additional uncertainty introduced by this change.
- A corrected curve (if the meter’s software is altered) may be issued by the manufacturer (NOT by the calibration facility), which may or may not be attached to the certificate of calibration.
- Re-calibration of the meter at a later date and comparison with the original calibration may be complicated if the addendum to the calibration certificate is misplaced or lost by the operator (calibration facilities only keep record of the ‘official’ calibration certificates). Here is an example :-

The following ‘official’ calibration results are issued by a test facility for an USM:

Flowrate acmh	Error (%)
611.4	0.03
1108.6	0.1
2580.7	0.2
4308.2	0.36
7476.5	0.85

Following this calibration, the manufacturer of the USM carries out a ‘least mean square’ correction and produces the following results. These results are then issued to the operator on a separate document!

Flowrate acmh	Error (%)	Corrected Error (%)
611.4	0.03	0.11
1108.6	0.1	-0.08
2580.7	0.2	-0.15
4308.2	0.36	-0.12
7476.5	0.85	0.34

This is the correction used for the meter in Figure 9.

Tracing and keeping records of this in our experience is difficult and our preference is to carry out corrections outside the USM (i.e. in the flow computer) as it is currently done for the turbine meters. This however is not as straight forward as it seems.

5 FLOW COMPUTERS AND USMS

Most operators are now moving towards multiple 'K' Factor corrections for turbine meters, where the calibration points are individually adjusted to achieve zero offset over the whole range of the flow rates (linear interpolation as explained above). For USMs this should also be possible during the calibration and within the supervisory systems, e.g. flow computers.

Unlike turbine meters, the most accurate way of transmitting the USM flow measurement to a supervisory system (e.g. flow computer) is via a serial link. The serial mode is also necessary to provide diagnostic information. Pulses are normally derived from the calculated flow rate, over a long period of time, the accuracy of the flow measurement using this method is as good as the serial link, however over a short period of time these pulses may not be equal to the flow rate calculated by the meter.

Experience has shown that until now, there are no flow computers in the market which can be successfully connected serially to USMs, unless the flow computer is produced by the same manufacturer e.g. Instromet Q.Sonic-5 link to FC2000, Daniel Senior Sonic link to Spectra 600.

Most of the high pressure metering sites operated by BG are fitted with approved (by the regulator) flow computers. These flow computers are capable of operating with Instromet, Daniel and Kongsberg USMs in the frequency mode. However, only one of these meters can operate successfully with the flow computer in the serial mode. To carry out corrections within the flow computer, only the pulse mode correction is possible.

Points to consider:

The operator must specify what optional comms outputs the USM should provide. Most USMs are supplied with a choice of comms, e.g.

Daniel SeniorSonic can have:

Digital interface:	RS485 Modbus
Frequency:	0-5k Hz
Analogue outputs:	4-20 ma

Instromet Q.Sonic5 has:

Digital interface:	RS485 Modbus
Frequency:	0-3k Hz
Analogue:	4-20 ma

Kongsberg MPU 1200 has:

Digital interface	RS485 Modbus
Frequency	Available but not specified
Analogue	4-20 ma

The operator should be aware that not all ‘flow computers’ are compatible with all USMs both in serial or pulse/frequency options.

If corrections are carried out in the flow computer (as with the turbine meters), the operator should be aware of the capability of the flow computer. Some correction methods (e.g. polynomial correction) acceptable to AGA 9 may not be possible due to the extra demand on the processing power of the flow computer.

The serial mode is necessary to provide diagnostic information and more accurate measurement. The Operator must specify that the flow computer should be capable of carrying out the necessary corrections from the serial data and not from the frequency output.

6 CONCLUSIONS

Typical pressure reduction valves/regulators used at the UK offtakes, especially those which are fitted with external noise suppression trims, can, depending on operational conditions such as pressure cut and flow rate, generate sufficient internal noise to cause adverse operation of multipath ultrasonic flow meters.

Field experience has shown that the USM has compared favourably with an Orifice Plate Metering system. At times, particularly at high and low (but not zero) flow rates, the USM has continued measuring accurately whereas the orifice plate was in error. Investigation indicated that chord substitution at high flows worked well.

Linear correction/interpolation method is an accepted correction method used for turbines and USMs. For the USMs, this correction is normally carried out during the first calibration. This procedure must be documented and the operator must be made aware so that double correction can be avoided later on.

Supervisory systems (e.g. flow computers) must be specified correctly to achieve communication compatibility with USMs.

7 REFERENCES

[1] GERG Collaborative Group: Multipath Ultrasonic Gas Flow Meters.

[2] MARSHALL, D., NIAZI, A., and BURROWS, M. Multipath Ultrasonic Meter Performance. Effect of Ultrasonic Noise Generated by Control Valves, August 1998.

[3] LAUGHTON, A. Gas VLE (Version 4.1).

[4] American Gas Association Transmission Measurement Committee Report No 9: Measurement of Gas by Multipath Ultrasonic Meters, June 1998.