An Investigation into the realistic accuracy that can be achieved using clamp-on ultrasonic meters for meter verification in the Water Industry.

Public Domain Version

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It is assumed the reader of this paper has a basic understanding of Clamp-on transit time flow measurement.

Background

Population growth, climate change, economic growth can all play their part in putting water resources under stress. The UN 2019 Global Water Report noted "Global water demand is expected to continue increasing… until 2050, accounting for an increase of 20 to 30% above the current level of water use." (UN, 2019)

By 2050 it is expected that almost a third of the world's population will live in high or extremely high water stressed areas.

Speaking in 2019, Sir James Bevan the Chief Executive of England's Environment Agency (EA) noted that "by 2050 [in the UK], the amount of water available could be reduced by 10-15%, with some rivers seeing 50%-80% less water during the summer months" if no action was taken. This would lead to significant water deficits and have an adverse effect on the Environment. (Bevan, 2019)

Action is being taken, new reservoirs are being planned and built, as are additional cross-company transfers, and water utilities are reducing water loss and planning to halve leakage by 2050. (Water UK, 2022). In all these areas, flow measurement is key to achieving and monitoring progress. It is an essential enabler. Because metering is so essential, the EA insist Abstraction meters are verified and Ofwat require that Distribution Input[1] meters are verified. As more UK water utilities move towards calculating trunk main[2] leakage via flow balances, there is a growing desire by water utilities to validate their meters in the trunk main network.

The Need for a Study

Regulatory guidance states that for a permanent meter to be considered working "within specification" then when it is tested against a verification meter the difference must be no greater than five percent (EA,2016). For almost all utilities in the UK, clamp-on ultrasonic flow meters are used as the verification meter.

[1] Also known as System Input Volume (SIV) meters.
[2] Also known as Transmission main.

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It has been over 20 years since the regulatory guidance was originally published. Since then, there has been research that has indicated that it might not be possible for clamp-on meters to always be within 5% of permanently installed meters. For instance, there is evidence that different pipe configurations and velocities affect the accuracies of clamp-on ultrasonic meters. (Thomas 2015, Doyle, et al. 2017, Durham, et al. 2019, Durham, et al. 2020).

To understand the realistic accuracy that can be achieved using clamp-on ultrasonic meters for flow verification in the water industry, a project funded by eight British and Irish water utilities and lead by I&P Services (a flow measurement specialist consultancy) was created where Verification Service Providers (VSPs) would carry out tests on a specially configured flow loop within a United Kingdom Accreditation Service (UKAS) accredited laboratory, chosen for its high accuracy and traceability. The rigs reference meter had an uncertainty of 0.25%.

Methodology

Four UK based VSP's were chosen to be part of this project. Three of the VSPs were highly experienced in the field of verification and one VSP a relative newcomer to flow verification.

The VSP's were asked to test on four different parts of the specially configured flow loop. Four test points were incorporated into the test line (See Figure 1). The first test point was on the DN500 ductile pipe section had more than 10 diameters of straight upstream pipework and was 2 diameters before a bend; the second test point was three diameters after the same ductile iron bend. Test point 3 was on a 300mm PVC section and three diameters downstream of the 500mm x 300mm reducer. Test point 4 was on old 300mm section of carbon steel pipework, with a corroded and variable inner surface, five diameters downstream of a bend combined with a swirl generator. These positions were chosen to present the VSPs with a variety of pipe materials and hydraulic conditions and mimic real-world conditions.

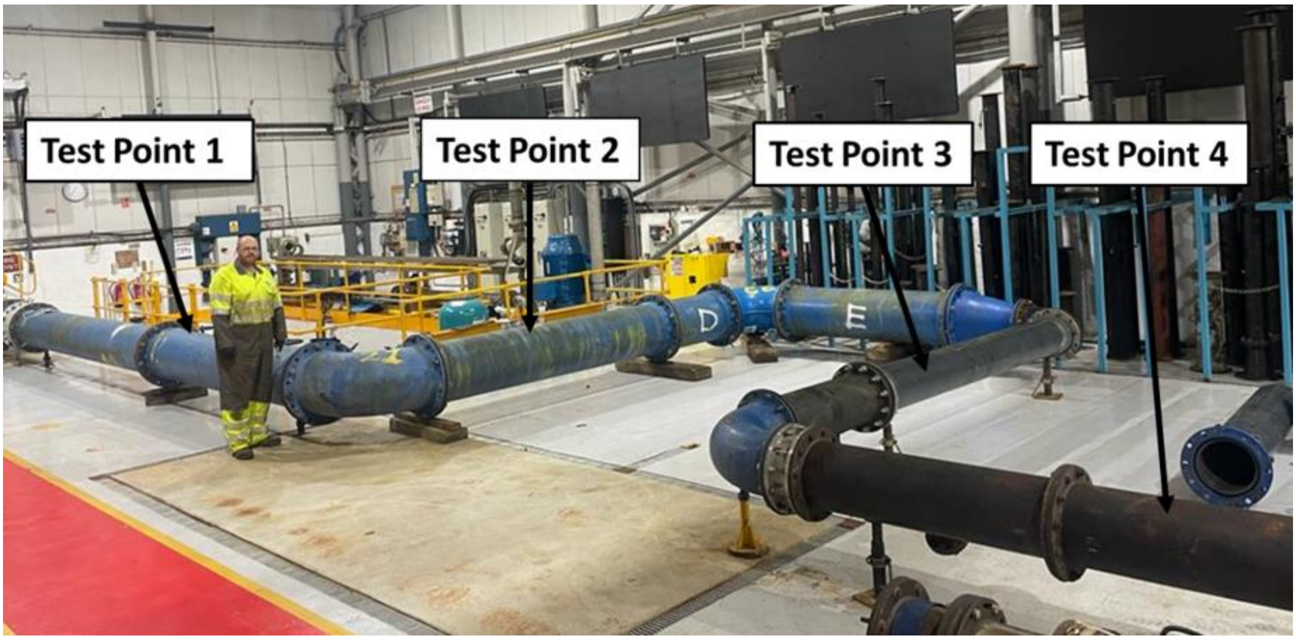

Figure 1: The UKAS Accredited Flow Rig

Each test lasted one hour. Within each one-hour test there were three mini-tests. This was made possible by recording the volume in the following time periods:

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Minute 5 to minute 20

Minute 25 to minute 40

Minute 45 to minute 60

Each test saw a range of flow rates. Flow rates ranged from around 50l/s to 300l/s for the 500mm pipework – this covers a velocity range of around 0.25m/s to 1.5 m/s. In the 300mm pipework a range of 20l/s to 180l/s was used which covered a velocity range of around 0.3m/s to 2.5 m/s.

All tests were witnessed by I&P services.

Overall Results

From the 16 one-hour tests the average absolute errors, ranged from 0.1% to 13.0% with an average absolute error of 4.9%. As can be seen in Figure 2 a quarter of tests had an error of less than 3%, a bit more than half the tests (62.5%) had errors that were under 5%. Meaning almost 40% of results had an error of greater than 5%. And one in five results had an error greater than 10%.

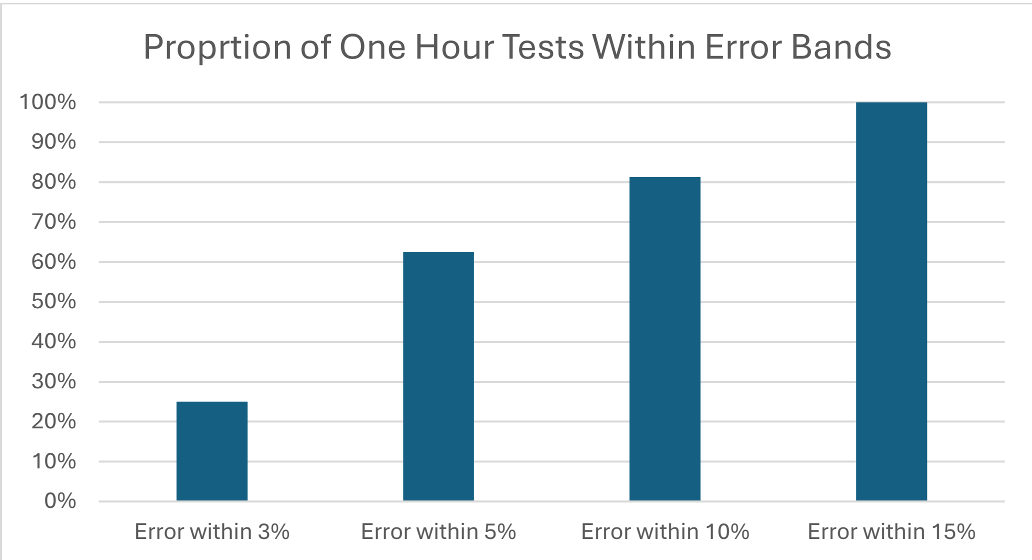

Figure 2: Proportion of 1 Hour Tests within Error Bands.

Hydraulics

Pipe hydraulics clearly play an important role in the accuracy of the clamp-on meter. Test point 1, which in the judgment of the authors had the most benign and stable hydraulics due to the long length of straight pipe upstream of the testing point, had an average error under 2.5%. While test point 2 which in the judgment of the authors is likely to have had the most turbulence (i.e. poorest hydraulics) due to the 90-degree bend (see Figure 3) immediately upstream had an average error over 8%.

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Results at Test Point 3, although after a bend were significantly better than at Test Point 2. In this case the upstream reducing cone flattens the flow profile, stabilising the hydraulics, resulting in reasonable test results (see Figure 4).

Figure 3: Test Point 2

Figure 4: Test Point 3

Table 1 provides a summary of the errors found at different test points, based on the one-hour tests.

Test Point	Average Absolute Error	Lowest Absolute Error	Highest Absolute Error
Test Point 1	2.4%	0.8%	4.2%
Test Point 2	8.3%	3.2%	13.0%
Test Point 3	2.8%	0.1%	5.9%
Test Point 4	6.1%	3.5%	11.0%

Table1: Summary of Errors at each Test Point for one Hour Tests

Length of Tests

Within each one-hour test, there were three 15-minute mini-tests. The 15-minute tests gave more variable results. Indeed, the standard deviation for 15 minutes tests were about 30% higher than it was for 1-hour tests. When comparing Table 1 (summary of one hour data) with Table 2 (summary of 15-minute data) we can see that in Table 2, the lowest and highest absolute errors were more substantial than the 1-hour data, demonstrating the greater variability of the shorter tests.

Test Point	Average Absolute Error	Lowest Absolute Error	Highest Absolute Error
Test Point 1	2.2%	0.4%	4.3%
Test Point 2	9.5%	3.1%	18.6%
Test Point 3	2.6%	<0.1%	6.2%
Test Point 4	6.5%	0.3%	12.2%

Table 2: Summary of Errors at each Test Point for 15-minute Tests

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Velocity

Ultrasonic flow meters measure the velocity of the flow, and it would be reasonable to suggest that accuracy might improve as velocity increases. In the mini-tests there was no statistically significant overall relationship between clamp-on accuracy and velocity. However, if the velocity was grouped into categories there was a general decrease in error as the flow velocity increased, although this was not statistically significant (See Table 3).

	Average velocity (m/sec)	Average Abs. Error (%)	Standard Deviation
Low (0.3-0.4m/sec)	0.33	6.42%	4.76%
Medium (0.6-0.9m/sec)	0.71	5.16%	5.01%
High (1.2-2.5m/sec)	1.79	4.58%	4.01%

Table 3: Accuracy of clamp-on meter results at low, medium and high flow velocities

Pipe Sizing and Potential Effect on Accuracy

As part of their test processes the VSPs need to estimate the internal diameter of the pipe.

	Pre-Measured	VSP 1	VSP2	VSP3	VSP4
DN500 Ductile					
Outside diameter	530	531	531	530	531
Wall	9	9	8	8	8
Lining	6.2	6	6	6.5	7.5
Inside Diameter	499.6	501	503	501	500
300mmm PVC					
Outside diameter	316	316	316	313	316
Wall	13.25	13	13	13	14
Lining	0	0	0	0	0
Inside Diameter	289.3	290	290	287	288
300mm Steel					
Outside diameter	326	326	326	330	326
Wall	7.75	9.5	8	11	7.5
Lining	0	0	0	0	0
Inside Diameter	310.5	307	310	308	311

Table 4: Pipe Internal and external diameter and thickness

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To assess the accuracy of these estimates I+P measured all of the test pipes using internal and external callipers to confirm their dimensions. It is estimated that the mechanical measurement method used by I+P had an uncertainty of 0.3%, the uncertainty of the method used by the VSPs was unknown but probably higher. The results of these measurements are compared with the estimates made by the VSPs in Table 4.

As can be seen there were some differences between the measurements made by I+P and the VSPs. Given that flow calculations include the diameter squared, small errors in diameter estimation can have a significant impact on calculated flow.

In the worst case the errors in pipe dimensions could have accounted for approximately 2.2% of meter error.

Number of paths and correction factors

The VSPs were able to select their own preferred equipment and process. They were free to use as many or as few paths as they wished. Only one VSP used four paths. From the limited range of equipment used in this study the four-path clamp-on instrument produced more accurate results (average 2.0% on 1-hours tests) than the single or two channel instruments (3.7% to 8.5% overall) used by the other VSPs. This improvement from deploying additional paths is in line with many published reports describing fiscal metering applications. Moreover, we observed that the use of appropriate manufacturer supplied correction factors had the effect of improving the overall accuracy of the results, compared to similar clamp-on units when this facility was not deployed.

It should be noted correction factors in this study refer to adjustments made to compensate for a distorted flow profile. These correction factors are based on research and studies carried out by meter manufacturers.

VSPs

All of the operators taking part in this study were competent, well equipped and followed a controlled verification procedure. There were varying results across the VSPs. For instance, two VSPs used the same equipment, but one VSP consistently got better results.

People, processes, and policies of the VSPs affect the overall accuracy of test results.

Review of Typical Verification Reports

As part of the project typical verification reports from all four VSPs were reviewed. These are verification reports that water utilities would typically get from their VSP suppliers. We found all VSPs would report more than one error calculation. For example, one VSP would report an average error calculated during the test period and an error based on what the totaliser recorded.

ISO4064 (*Water meters for cold potable water and hot water*) states that the error of a complete water meter under test should be calculated using the formula:

$$Em = \frac{Vi - Va}{Va} x100\%$$

Where: *Em* is the relative error expressed as a percentage

Va is the reference volume passed during the test period

Vi is the volume added to (or subtracted from) the indicating device during the test period

In the case of meter verification using a portable clamp-on meter this ISO4064 error calculation becomes:

Test Meter Error % = (Test Meter Reading m^3 - Clamp-on Reading m^3)/Clamp-On Reading m_3x 100%

Based on the verification reports shared by the VSPs, it was not clear that all of the VSPs would use this this method to calculate the reported errors. This is likely because following ISO4064 has not been requested by the water utility they are performing the verification for.

Conclusions

Only at Test point 1 did all tests achieve an accuracy of less than 5%. We therefore conclude a performance level of ±5%, often the accepted "norm" for in-situ clamp-on meter measurement uncertainty, was achievable ONLY on the straight pipe where the hydraulics were stable and the pipe condition and dimensions could be accurately evaluated.

Where the hydraulics are less than ideal, or the pipe size(s) and condition cannot be determined accurately, achieving an in-situ verification accuracy of better than ±8 to ±10% is statistically most unlikely.

The 15-minute tests were also far less reliable and less consistent than the 1-hour tests; arguably to the point of being unsuitable for verification testing.

By studying verification reports, we found the reporting of meter test errors was not always consistent.

Overall, we conclude that operators with well trained staff, well maintained, up to date equipment and a controlled operating procedure are able to achieve a result within 5% of the true value ONLY when conditions similar to test point 1 are measured, i.e. where the pipe size is well known, and hydraulic conditions are both stable and well controlled.

Recommendations

1. The method of calculating and reporting test meter error is standardised. We suggest that the primary error report should be based on the Test Reference volume passed in a minimum time period and expressed as a percentage relative to this same Test Reference volume as recommended by ISO4064 (water meters) and MCERTS i.e. :

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Error% = ((Test Meter m^3 - Clamp-on m^3)/Clamp-on m^3) x 100 ± Confidence limits

This error report may be supplemented with alternative descriptors at the VSP's discretion e.g. : 'Average Point Comparison', 'Instantaneous Error', etc, together with additional complementary uncertainty calculations by the VSP as required; but only provided that these are clearly and separately identified as supporting error reports and that the basis and method of calculation of all supplementary data is stated.

2. The verification test duration is a minimum of 1 hour, longer if the flow is changing or if the hydraulics are compromised. Additional testing and calibration should be carried out at each selected verification location to determine the minimum verification period for future tests.
3. All available measurement channels and correction factors are used, in accordance with manufacturer's instructions, to optimise equipment performance. For the application of correction factors, it is recommended that this too is standardised to eliminate confusion in application and use. Otherwise, the values used could differ between companies, VSPs and other users.

   The provenance for all applied Correction Factor values should be stated and should be allowable only if based on traceable data from test work, modelling or other known source, with a full audit path.
4. The requirement to achieve a verification standard of, for example, ±5% shall be applicable only where the hydraulics are known to be stable and the test location has been formally assessed and documented e.g. straight pipe with a minimum of 10-20D upstream and 3D downstream, of the test point. 2D may also be accepted.
5. We recommend that the industry produces a 'Verification Manual' to standardise the methods, calculations and reporting used to carry out and report meter verification testing on closed pipes.
6. To improve verification performance in applications where the hydraulics are not well characterised, new technology and methods should be researched to provide insight into the conditions applying to that particular location. Only through adequately characterising the hydraulics of each Test Point and then matching the chosen measurement technique to those specific conditions, can the measured accuracy and uncertainty associated with a particular meter verification be justified and ultimately improved.

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Pictures of various set ups

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