ADVANCES IN ON-SITE VERIFICATION OF WATER FLOW METERS. THE INTELLIGENT APPLICATION OF ELECTROMAGNETIC INSERTION PROBES

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Abstract The aim of this paper is to present recent advances which have been made in applying electromagnetic insertion probes to the verification of bulk supply water flowmeters.

Building on laboratory work undertaken to define the baseline calibration of this type of insertion probe the authors illustrate how Traceability, Performance and Productivity have been dramatically improved through the use of intelligent software. Key elements that are discussed relate to the increasing demands of Water Industry Regulators for the introduction of Quality Management principles at the Site and Data level and how this has crucially influenced development of the applied technology. The on-site verification of bulk supply meters in the range 150mm and above is illustrated in detail and the current technique is contrasted with existing methods to show how major improvements have been achieved; delivering improved Traceability, uncertainty, performance and productivity. The authors will conclude by suggesting that through the use of the improved methods described the case for wider use of the electromagnetic insertion flowmeter, not only as the primary tool for verifying bulk water supply meters but also as a valid technique which can be applied in situations with poor hydraulics, can be made.

Keywords: insertion probe; verification; water industry; velocity profiling

1 Introduction

Insertion flowmeters are highly useful, flexible flow measurement devices that have for many years been used in a variety of Industry applications.
However, the majority of users have been from the Water Industry (WI) with the technique being generally applied to pipes of 200mm or more. As many WI applications are such that stopping the flow or cutting the pipeline is impossible, hot tap methods are commonly required, for which insertion probes are ideal.
Whilst the use of insertion meters as a cheaper alternative to full bore metering has increased over recent years, their application for modeling survey work and most recently in verification programmes designed to benchmark the ongoing performance of existing fixed flowmeters has become widespread. However, all of the applications mentioned rely on the insertion flowmeter returning good, accurate and repeatable measurements. Regrettably, whilst the WI believes for the most part that this is what is being delivered, the evidence for such is, in the authors opinions, presently lacking. This opinion is based upon evidence from a number of extant verification programmes dating to the 1990's from which data became available that showed the true difficulties of point velocity measurement under real water industry conditions.
Errors as large as 60% were observed, but more importantly, it was impossible to assess the quality of the insertion meter data being presented due to the lack of suitable on-site analysis tools. Therefore, this was the area that Information+Performance Services chose to address.

2 Generic Verification Methodology

2.1 Standard Procedure.

The standard procedure used in applying insertion technology to the verification of an existing bulk source or supply meter is to install an insertion flowmeter in a location close to the meter in question, such that the flow through the meter is the same as that past the insertion flowmeter. No pipe junctions must be between the two. Once the location is decided, then the User must be sure that the point velocity measurement taken by the insertion flowmeter can be reliably converted into the mean pipeline flow as read by the station meter or meter under test (MUT).

It is normally possible to convert velocity into flow rate as follows:

$$Q = V \text{ x } A \qquad \text{Equation 1}$$

Where Q= Flowrate in m^3/sec

V= Mean Velocity in m/s

A= Cross Sectional Area in m^2

However, this depends critically on the mean velocity being known. An insertion meter is a point measuring device by definition and therefore measures the velocity at a point, not the average. Fortunately, point velocity can be converted into the mean velocity *if* the relationship between the two is known. Given that the flow profile within the pipe is fully developed and turbulent, then the relationship between point velocity and mean velocity (Profile Factor F_p) is known. Particularly, given that the point velocity is measured on the centre line of the pipe, then the relationship is defined by the following equation.

Equation 2

where

Equation 3

and

Equation 4

What is essential is that the flow profile is fully turbulent and developed, for which there are two necessary conditions, namely: (a) condition one that the Reynold's number R_e is greater than 4000 and (b) condition two that the insertion point has at least 100 times the diameter of straight pipe upstream of it, and at least 5 times the diameter downstream – to ensure full development of the profile.

Condition 1 is almost always met with the flowrates normal in water industry pipes but condition 2 is far more problematic, as in practical circumstances it is often difficult to know the pipeline layout especially over large distances. Generally, it is therefore not prudent to assume that the condition for full profile development is met. In turn this necessitates that all assumptions of textbook velocity profile values are disregarded, requiring the User to accurately determine the true on-site profile factor Fp. This is done by a process known as 'Profiling' the pipe.

2.2 Profiling Specifics

The fundamentals of 'Profiling' involve measuring the velocity at a given number of points across the diameter of the pipe, and from these using one of the accepted methods of calculating mean velocity. Once the mean velocity is known then the relationship between it and any given point, usually the centre point, can be found. (F_p)

The methods of calculation open to Users are varied with four general methods in use. (i) the equal annular area method, (ii) the Log-Log method, (iii) the Log Cherbichof method and (iv) the method of Cubics. These methods are fully described in British Standard BS 1042.

Having decided upon the number of measuring points to be undertaken and their locations, it would appear to be a relatively simple task to locate the measuring probe at these points and record the velocities measured. In a laboratory environment, this would indeed be the case, as in a laboratory it is normal to be able to accurately control and stabilise the mean flow such that the small differences in flow velocity measured at each of the successive points across the pipe can be distinguished. In the real world on-site, control of the flow does not exist and the User is faced with the difficulty of establishing whether the data he has collected is both correct and a true representation of the flow velocity distribution within the pipe, or just a record of the mean velocity changes due to completely unrelated influences

2.3 Refocus on Data Collection

2.3.1 Current Position.

Prior to this work, the method of collecting data has been by use of purpose designed but physically separate dataloggers connected to the output of the insertion flowmeter and station meter. The key point is that such data collection is 'blind', providing no feedback to the User during the progress of the on-site work . In particular there has been no visual representation of the live measurement and no collection of time series rate based data. The net result is a complete inability to apportion any value for Quality to the data collected.

The true quality of all past data has thus been completely unknown, and although it may have in some circumstances been good, experience suggests that this is unlikely. Hence the on-site investment of User resources has to date always been fundamentally undermined by an inability to assess data collection performance quality, due to a lack of appropriate on-site analysis tools.

2.3.2 The Way Forward adopted by I+P.

In response to the above, a strategy was developed which aimed to integrate all of the separate elements of the Profiling and Verification tasks into a single integrated, software driven Process. Underlying this Process were six principle themes:

(i) to collect Fast, Digital Time-Series data, direct from the insertion and station meters

(ii) to make the data collected available to the operator, in real time, for real time decision making.

(iii) to remove the need for post processing, and to store all data for audit purposes should this be required at a later data.

(iv) to provide the ability for the User to repeat and change the profile sequence on-site by being able to retest and re evaluate.

(v) to provide secure data archiving, including all the Instrument, Site and Operator details.

(vi) to open up the possibility of normalising data by use of the MUT as a normalising signal.

2.4 Outcome of the new Data collection approach

To the present time, uncertainty, whilst thought to be good, was in reality unknown because there was no means to observe the collection of the actual insertion probe time series data. Thus flow changes occurring during the measurement were unconsidered, a position which was allowed to continue due to the lack of pressure to demonstrate Traceability.

With the I+P approach, improvements in data performance, which have in turn improved quality and lowered the overall result uncertainty, have been achieved because of increased

Precision:	the base data is in true time series
Visibility	the Uncertainty can be 'seen' visually on screen and estimated on site where it counts
Rigour	through applying proven calculation methods linked to an algorithm that can estimate the data quality in real time and
Quality	achieved by eliminating the need for User expertise in the process and by standardising the procedure, but mostly due to the quality measurements taken by the software working in real time.

3 Overview of Verification Software Package

I+P's specialist insertion probe software is a significant advance in the use of insertion probes for both profile measurement and meter verification and in the manner in which these separated activities can be combined. It is the result of many years of experience in this field, allied with 4 years development and testing and has resulted in a package which can cope with the vagaries of trying to measure a velocity profile whilst the flow is unstable, a measurement previously thought impossible.

There are two modes of operation, standalone and precision. The standalone mode utilises special algorithms to evaluate nuances in the flow signal to establish its acceptability and communicate this to the operator to advise him or her on the quality of the measurement.
The precision method utilises the output from the station meter, or the meter under test, to normalise the real time insertion probe readings. All readings taken are stored in a time series mode whether good or bad quality, and are subject to acceptance or rejection by the operator. Where data is rejected it is emphatically *not* expunged from the record but forms a part of the archive, being highlighted for easy recognition. Thus, for an external auditor there is no question of the Operator hiding or deleting "bad" data. As a key element in traceable and accountable information this feature of the I+P software is not always appreciated.

Once the profile has been established, in a form that allows the quality of the measurement to be established and recorded, the I+P software offers the opportunity to seamlessly proceed to verification of the station meter. In a similar way to the above, the package allows the meter that is to be verified to be recorded in parallel with the insertion flowmeter for a predetermined period of time. Again, all time series insertion meter and station meter data is visible to the operator and real time results are stored in the database for subsequent post processing.

Inbuilt to the I+P software are serial communications that automatically interrogate the respective flow meter transmitters. Different modes of operation may be selected depending on the exact set-up to be verified. All this is done through automatic record keeping that ensures that the quality, visibility and most importantly the Traceability of meter data and transmitter parameter configurations are maintained.

4 Examples of the I+P Advanced Techniques

4.1 General Approach.
The technique is a software-controlled operation and like all systems requires the User to input the 'base' data. This consists of the location, the operator's name, the reason for the work and any comments required. The operator must next enter the size of the pipeline (exact not estimate), either from previously measured data or from a measurement just taken. He must then enter the number of points to be taken; this must be an odd number, between 7 and 29, and then the time to measure at each point, (minimum 20 seconds). When all data is entered a window will open which will allow the selection of a name for the data file and a location to store it in. When the name has been accepted, a number of information boxes are displayed indicating the tasks being performed by the software until finally the main measurement screen is displayed.

4.2 Profiling Prompts.
When being instructed to move the probe, the information box gives two measurements, the distance to retract this time, and the total retraction distance. In the first movement these two measurements will always be the same, but in subsequent movements, the total retraction distance will be incremented by the retraction distance of that point. Under certain conditions it is difficult to position the probe at the exact point requested by the software. In case this happens, when the 'OK' button is clicked, a further window opens asking for the exact location retraction distance actually

achieved to be entered.

4.3 Normalisation of data.

The main profile measurement screen as displayed in the Master Meter Mode shows three graphs, one for the instantaneous probe data, one for the Instantaneous Master Meter data and the third to display the profile as it develops.

4.4 Data collection.

As the measurement is being taken, the readings from the insertion probe and the master normalising meter (if used) are displayed, simultaneously, the graph headed Raw Data will start to be drawn; this is the velocity being collected from the Insertion probe. Ideally it will be a straight horizontal line, but this is unlikely in practice. The variation from a straight line and the slope of the line will enable the user to make a judgment as to the validity of the series of point measurements.

4.5 Operator Acceptance of Quality.

Simultaneously, the master meter velocity measurement will also be displayed graphically. Finally a tick or cross will appear against the two data assessment values, noise and stability, and the software will make a recommendation as to whether the measurement is within limits or not and as such should be accepted or rejected. The recommendation "accept" or "reject" is a recommendation and can be overridden by the operator. If the measurement is rejected then it will be necessary to take the measurement again until the measurement is acceptable. When the measurement is accepted, there will be an instruction to move the probe again, and again there will be an opportunity to input the actual location achieved. When the centre point is reached, the software needs this to be accurate; there is no option to correct the requested value; it has to be the correct location in order to ensure that calculation symmetry is maintained.

When all points have been completed and accepted, the software will show the results screen.

4.6 Examples of Applying the I+P Techniques.

4.6.1 The Effect of Measurement Mode.

The results screens shown in figures 1 and 2 are for the same site taken under two different measurement modes. As can be seen the lower profile is taken with the 'normal' mode of operation, whilst the upper profile is the same site at a slightly earlier time with the measuring mode enhanced through software means. With the enhanced mode it can be seen that the results are much more detailed and give a value of Fp of 0.8274 compared with the higher and incorrect value of Fp obtained by the more normal measuring mode of 0.9062.

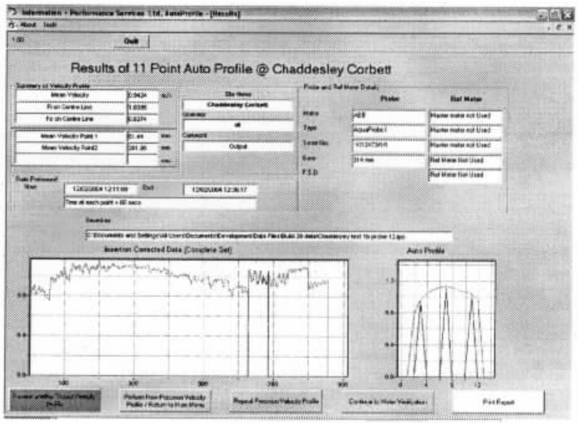

Fig 1: Profile results, probe in S1 mode

In addition, observe on the results screen shown in figure 1, that there is part of the insertion Corrected Data Set that is highlighted in red. This indicates that the data was collected and rejected by the User for a reason, and, although the data is not used in the calculation, for reasons of quality it is retained in the database and displayed as an integral part of the results archive.

4.6.2 Probe Applications under difficult conditions.

Figure 4 gives an example of a site where measurement using insertion probes was not considered possible prior to these developments. (Figure 3 shows the pipework on this site measured only 8 pipe diameters after a very complex series of flow disturbances). With the new approach, the profile was able to be accurately measured, with confidence and an insertion probe used where it would not have been possible before.

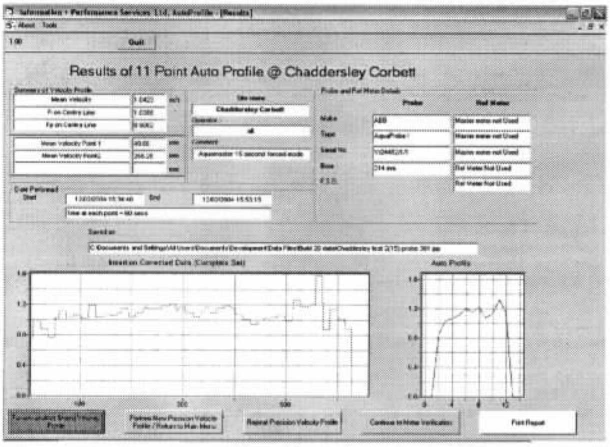

Fig 2: Profile results, probe in S2 mode

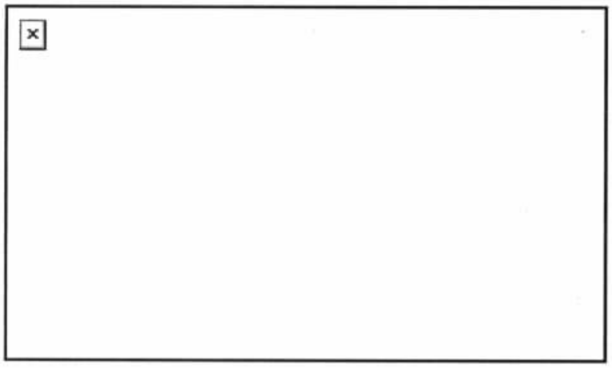

Figure 3: Schematic of Complex Pipework Upstream of very Difficult Probe Location

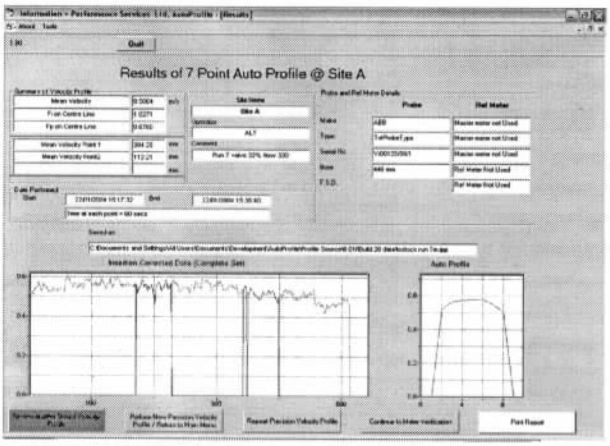

Fig 4:Excellent profile results from very difficult site

Valve opening	330m3 /hr	800m3 /hr	1150m3/ hr
32	0.878	0.8943	
48	0.8783	0.8978	0.8626
90	0.8806	0.8923	0.902

Fig 5: Summarised Fp's from very difficult site

The profile factors, achieved for each profile with differing openings of the upstream butterfly valve, are given in figure 5 and show an overall spread of 2.2%.

4.6.3 Normalisation Demonstration.

A key feature of the I+P approach has been the use of normalisation of velocity data, as referenced to a defined Master Meter, usually that of the permanently installed bulk supply or source meter. An illustration of the power of this technique is shown in figure 6 below. The dark blue line shows the uncorrected profile that has been distorted by severe changes in the flow. The light blue line shows the normalised profile as created in real time during the test. The difference is quite remarkable.

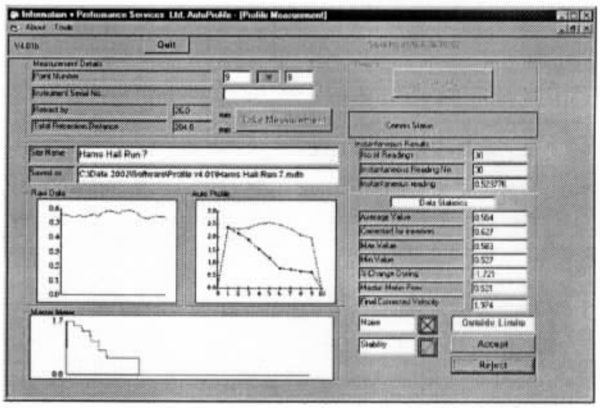

Fig 6: Eliminating profile distortion using normalisation techniques

4.6.4 Capturing the Reality and the Quality of Data.

One of the advances that has had most impact as a result of using the I+P approach is that brought about by the ability to observe and review real-time data. During the measuring process the information referred to previously, and as displayed on the main profile measurement screen, can prove invaluable in assessing the quality of the profile measurement. Examine figure 7 below, a screen that demonstrates the power of providing real time feedback to the on-site User.

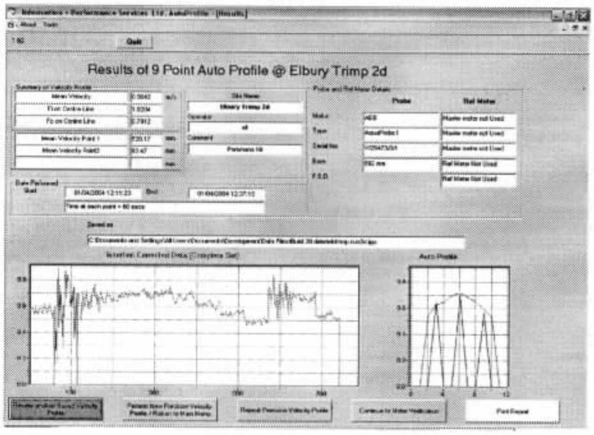

Fig 7: Feedback to Operator delivers Quality Data

As can be seen, the initial periods of measurement were quiet with little noise in the flow, whilst the time from 60 to 120 seconds shows a really significant increase in the noise to such a level as to render impossible the measurement of small differences between the points in the profile. The section of poor data is in red, indicating that the User quite rightly rejected the data and re-measured when the flow had quietened down.

What caused this flow noise is not known by the authors, but it is sufficient to simply show that it had occurred and that the User, for the first time ever, had been made aware of it and had taken the requisite action. In point of fact, careful observation of the trace shows that it would have probably been even more beneficial if the User has also rejected the next reading and taken a third, given that the noise quietened again after 180 seconds.

5 Data Quality and Traceability Issues

At the present there are no formal Quality regulations governing the way in which key meter verification data is to be acquired, processed, presented or archived. Nevertheless, a system of individual, formal audits by independent assessors is already in place in which the output of meter tests, along with other data pertaining to the specific area of regulatory interest, typically the Water Company's assessed level of leakage, is examined.

Nevertheless formal systems are beginning to be created and within the UK the Environment Agency (EA), which is charged with regulating and licensing water abstraction, is actively developing guidelines for the verification of all buried electromagnetic meters. These will be published during 2004-5. From discussions it is probable that Users shall be required to demonstrate:

1 Provide Traceable evidence;
which is
2 Accurately collected;
by
3 Competent, Trained Personnel;
using
4 Independently, Calibrated kit;
to create a
5 Verification record Database;
which can be
6 Objectively analysed;
and
7 Categorised using Uncertainty techniques;
that can be
8 Securely Archived;
to achieve a single
9 Metering Installation Uncertainty;
which can be subject to
10 Periodic Independent Review.

For the purpose of meter verification using insertion meters, it was therefore clear to the authors that past practice that involved a series of separate, mixed paper and electronic records, plus additional data analysis and comparison of the probe and meter under test figures, would no longer be acceptable. An integrated software design was therefore embarqued upon in which both the fundamental time series recorded data and the data analysis and database archive were integrated. The operation of which is described elsewhere in the paper.

Creation of such an integrated design has enabled Operators not only to provide clear evidence of the state of the flows being measured and assessed, but has allowed the earlier two part verification process to be concatenated into a single site operation. Thus, instead of having to determine the velocity profile in one operation, followed by setting the probe on the centreline and running a 20 hour comparative test, it is now possible to combine the actions and profile the test location; to be followed seamlessly by assessment of the meter under test. A procedure that is possible only because all of the profile and pipe information is held in the software database archive, ready for immediate and automatic look-up during the follow-on verification stage.

The I+P software also brings much improved confidence in the insertion probe and meter verification results as a consequence of dispensing with the mix of various pieces of paper, datalogger files and file transfers. This eliminates the ever present possibility that location and pipework details could be mixed-up at the analysis stage. In terms of Quality, Traceability and Productivity, but especially in regard to external audit of the meter verification records, the overall process is at once both simplified and formalised. What was once a matter of skilled and conscientious personnel attempting to make the best of a task where they were neither asked for nor provided with information, insertion meter verification has been refined to the status of a formal, staged Process where Operators are both asked for information that is key to subsequently establishing Traceability but are also provided with continuous and visual information concerning the Quality of the ongoing task. Finally, what once demanded the skills of a trained auditor can now become the tabling of secure archive files capable of retrospective analysis using the real time series data measured on site. In short, a quiet revolution.

7 Conclusions

The increased use of insertion meters for the purpose of verifying bulk water supply meters has demanded significant improvements in the overall approach to the process. This has demanded significant attention to and improvements in probe Traceability, instrument performance, on-site data collection, operator methodology, quality, productivity and data analysis and archiving.

Work by Information+Performance Services, to formalise the process of velocity profiling and meter verification within a single bespoke software package, operable by semi skilled personnel, has delivered many of these demanded changes.

In particular, through the use of digital logging of true time series probe velocity data, backed by an integrated database archive one is now able to demonstrate the scope of meter performance in an unambiguous manner. Normalisation of measured velocities, implemented within the I+P software package, has been shown to substantially eliminate errors caused by flow changes and general instability of the flow, both when calibrating in the laboratory and when measuring on-site.

Moreover, in the critical area of data Quality, the Operator both can view statistical flow information during testing and post test, where all values and results are open to independent traceable audit.

Such are the improvements that measurements in locations that were previously outside the scope of the insertion technique are now possible. Finally, integration of the two elements comprising meter verification, namely determination of the velocity profile and the checking of recorded volumes from the meter under test and the insertion probe meter, has been achieved.

References

[1] Thomas, A.L., Kobryn, P., Franklin, B. Electromagnetic Insertion Probe Calibration. Advances Towards a Standard. FLOMEKO 2004 12th International Conference on Flow Measurement, September 14-17, 2004, Guilin, China.