Innovations in step testing using sluice valve metering

A Arscott, arscotta@rpsgroup.com

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Overview

One of the main challenges in leakage control is obtaining accurate information on the location of leaks across the pipeline network. Performing step tests has provided the best way to locate areas of high leakage of demonstrating the results following the repair of leaks. However, to date, this has required the setting up of monitoring areas and expensive installation of metering points across the distribution network.

This paper describes work that led to the development of a new portable valve flow meter that enables a conventional sluice valve to be converted into a temporary metering point. The Accuflow™ valve flow meter has opened up new step testing techniques which provide a cheaper and more effective way to pinpoint leaks. With a sluice valve on nearly every corner, metering flows across the network has at last become a realistic option for the Leakage Engineer. These new techniques will be of particular benefit in countries where high set-up costs have previous prevented the use of conventional step testing.

What improvements in step testing are needed?

The history of system monitoring for leakage control has long relied on meter installations at fixed locations across the water distribution system. These are set up so that all flow entering or leaving a defined District Meter Area (DMA), normally covering around 1,500 properties, is metered. This approach has the major advantage of quantifying the leakage, coupled with the ability to pinpoint the leak location using a step test procedure. The meters used are normally helical vane meters in fixed chamber installations. In some cases temporary insertion flow meter are used, which require a fixed insertion point and chamber to be installed on the water main.

However, the conventional approach to step testing using fixed metering points has a number of disadvantages. These include:

- The cost and effort required to installing meter points, and the lack of flexibility in changing these once established.
- The need for temporary shut off of customers' supplies for periods of an hour or more. This can cause problems for some customers and result in discoloured water.
- Where shut off steps are monitored by a meter (or meters) sited at the DMA boundary, it can often be hard to separate legitimate use from leakage.

In recent years, as an alternative approach, acoustic flow logging has been used. A number of loggers are normally deployed for a period across a defined area of the network. The analysis of the pattern of persistent noise generated by leaks provides an indication of the location of leakage. This approach has the advantage that it does not require any permanent installation, so is cheaper to operate, as the equipment can be moved from area to area. However, the level of noise recorded does not always have a strong relation to the size of the leak; for example, a large volume of leakage from a complete pipe break is likely to generate far less noise than small volume of leakage through a small crack. The level of noise detected is also dependent on the distance from the sensor and the type of pipe material.

The conclusions from the above considerations shows that the desirable approach would combine the flexibility and cost advantages of acoustic logging, with the kind of leak flow information provided by conventional step testing. Any such improvements would need to:

- Measure actual flows in the distribution network, rather than noise levels.
- Avoid expensive fixed installations.
- Eliminate the need for temporary shut off of customers' supplies, or at least reduce them to very short periods.
- Provide metering as close as possible to each step, reducing the impact of customer usage on leakage measurements.

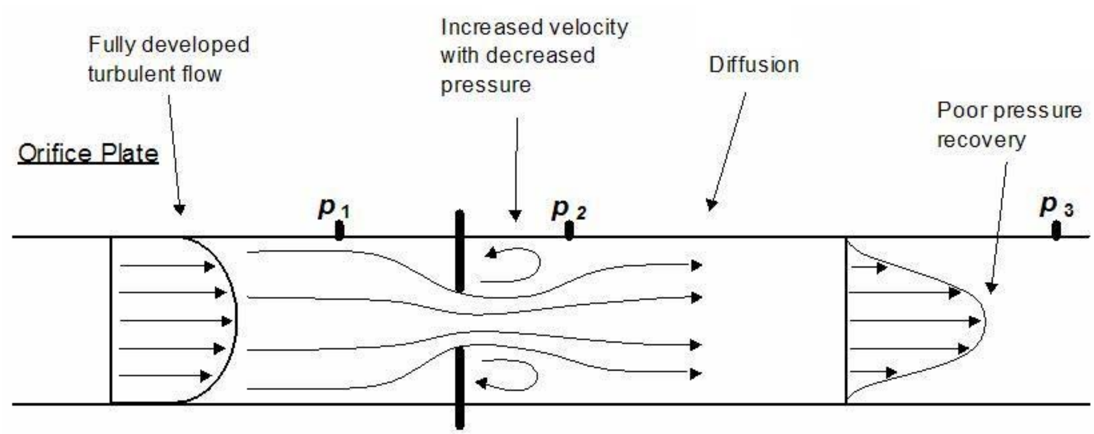
Developing new alternatives to conventional step testing

As described above, neither conventional step testing nor acoustic logging provides a completely satisfactory solution to leakage control, with each approach having its advantages and disadvantages. Extensive experience of using both techniques led RPS Water to review options for a completely new approach to leakage monitoring. Research carried out by Dŵr Cymru Welsh Water indicates that a third of repaired leaks had no noticeable impact on reducing measured leakage levels. This being the case, methods that provided a quantifiable assessment of leakage were seen as the most fruitful approach, so new options for system metering were investigated. The practical experience of the team at RPS made a major contribution to the development process by recalling that skilled leakage inspectors could estimate the size of a leak by closing down a stop valve and listening to the volume of the noise. Generally, the louder the noise, the greater the volume of leakage that was found. This empirical observation lead to questions as to whether this principle could be enhanced by the use of electronic acoustic measurement and the identification of a relationship between the flow rate and the acoustic profile.

These ideas started an initial investigation by RPS into possible links between flow rate and the acoustic signature. A variety of existing meter sites with sluice valves provided ideal locations for testing the theory. By logging the meter readings, and carrying out acoustic measurements as the sluice valve was slowly closed, RPS established that there is a positive correlation between the acoustic noise level and the full bore flow volume. The establishment of this principle justified the setting up of a Research and Development programme on valve flow metering. To help deliver this, RPS agreed a joint development project with Dŵr Cymru Welsh Water and Technolog. Dŵr Cymru Welsh Water contributed operational testing and support for the development of procedures which make effective use of the new technology. Technolog provided a wealth of experience in developing "state of the art" electronic devices for logging and measurement which are robust enough for field use.

Initial R&D – Defining the basic principles of valve flow metering

Valve flow metering is a new technique, although its principles are founded on traditional engineering hydraulics. The measurement method used is generally based on Bernoulli's equation of fluid flow, as applied to orifice flow meters. Here there is a relationship between the flow rate, the size of the pipe, the size of the orifice, the upstream pressure and the downstream pressure immediately after the constriction. In summary, by measuring the upstream and down stream pressures for a given pipe and orifice, the equation can be used to calculate the flow rate. A diagram illustrating the orifice flow meter is shown below



The normal sluice valve provides a means of varying the size of the orifice, although the orifice itself is at the bottom of the pipe, rather than in the centre, as in a traditional orifice plate. This tends to introduce additional factors in the measuring process, including difficulties in measuring the pressure immediately downstream of the constriction. However, as a sluice valve is closed, this also causes increased noise due to the turbulence generated as flow passes through the constriction. The greater the flow, for a given input pressure, pipe and valve combination, the larger the acoustic profile. This principle formed the basis for the development of the valve flow meter. In developing this technology, considerable research and testing was carried out to establish the relationships between flow rate and the resulting acoustic noise profile generated as a valve is closed, for different pipe size and pressure regimes.

The initial research started in 2004 and was based on over 300 individual field tests across Dŵr Cymru, rather than on laboratory based pipe configurations. This empirical approach means that the relationships developed apply to real life situations, not artificial ones. Flow measurement algorithms developed from the research activities opened up the way for development of an electronic control unit. Currently the valve flow meter has been calibrated for use on pipes of 200 mm and below, as this size range includes the majority of local distribution mains.

Developing the prototype valve flow meter

Once the principles, accuracy and algorithms had been established, project activities focussed on the development of the valve flow meter device itself. The challenges were provide a robust device which will fulfil the variety of functions required; operation as a conventional valve key, acoustic measurement, rotational measurement, input of data, output of operational instructions, together with processing, presentation and logging of results. This complex set of requirements necessitated an extended iterative approach, utilising practical field trials to ensure the device was robust and accurate. A number of prototypes were developed and extensively field tested; a picture of one of the early prototypes is given below.

The development of the prototype device and field trials was carried out during 2005 and patents were successfully obtained for the valve flow meter. The patent application process confirmed the unique nature of the device. More advanced field trials and the development of and manufacture of the first production model, called the Accuflow™, was completed during 2006. Development to date has involved over 1000 field tests which have has shown that the Accuflow delivers overall accuracy levels of +/-10% at flow rates ranging from 0.3 litres/sec to 3 litres/sec. In relation to leakage control work, accuracy at low flows is an important characteristic of the Accuflow. By comparison, the minimum flow specified for a typical 100 mm helical vane meter used for DMA monitoring is 0.5 litres/sec.

The Accuflow device utilises leading edge technology for sensors, electronic control, graphical user interfaces and data logging and is pictured below. It delivers a unique combination of technologies integrated into one device, providing, for the first time, a way to measure flow using existing sluice valves. It incorporates the following functions:

- A traditional valve key, to open and close standard distribution sluice valves.

- A patented sensor system to log the rotation of the device when opening or closing a valve to take a flow measurement.
- An acoustic transducer, located in the bottom of the Accuflow, which rests on the valve head to accurately record changes in the acoustic profile.
- A LCD display unit and keypad for the user input of key data which provides visual and audible signals giving step-by-step instructions on how to close the valve in a controlled fashion to take the measurements.
- A microprocessor unit which records and processes the input and sensor derived data to provide an estimation of flow.

Development to date has identified the following requirement for the Valve Flow Meter to operate effectively:

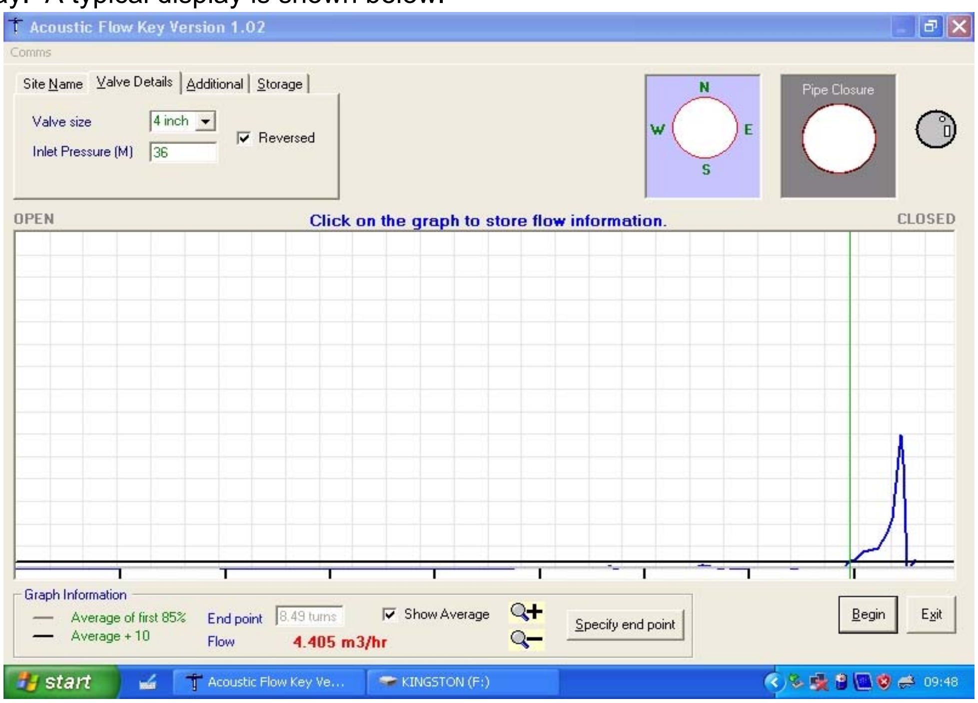
- A pipeline diameter of between 50mm and 200mm, with a sluice valve the same diameter as the pipe
- A sluice valve in reasonably good condition, with leak proof closure
- A clean valve head to provide a good contact with the acoustic sensor
- The facility to take a pressure reading upstream of the valve (normally within 10 m)
- The ability to completely close the valve for a short period, although this is only normally required for 10 seconds or so.
- Flow rate and inlet pressure during the period of the measurement should be fairly constant.

How to take a flow measurement using the Accuflow

The Accuflow valve flow meter can be easily operated by one technician, having been designed for ease of use. However, the situations where it is likely to be of most use, such as measuring night flow across the distribution system, will required staff with a high standard of training and experience to get the best results out of the device.
The basic steps in using the Accuflow valve flow meter are outlined below. They assume that the valve has been exercised and checked prior to arrival on site, as have any valves necessary to isolate the flow to the valve being used as the metering point.

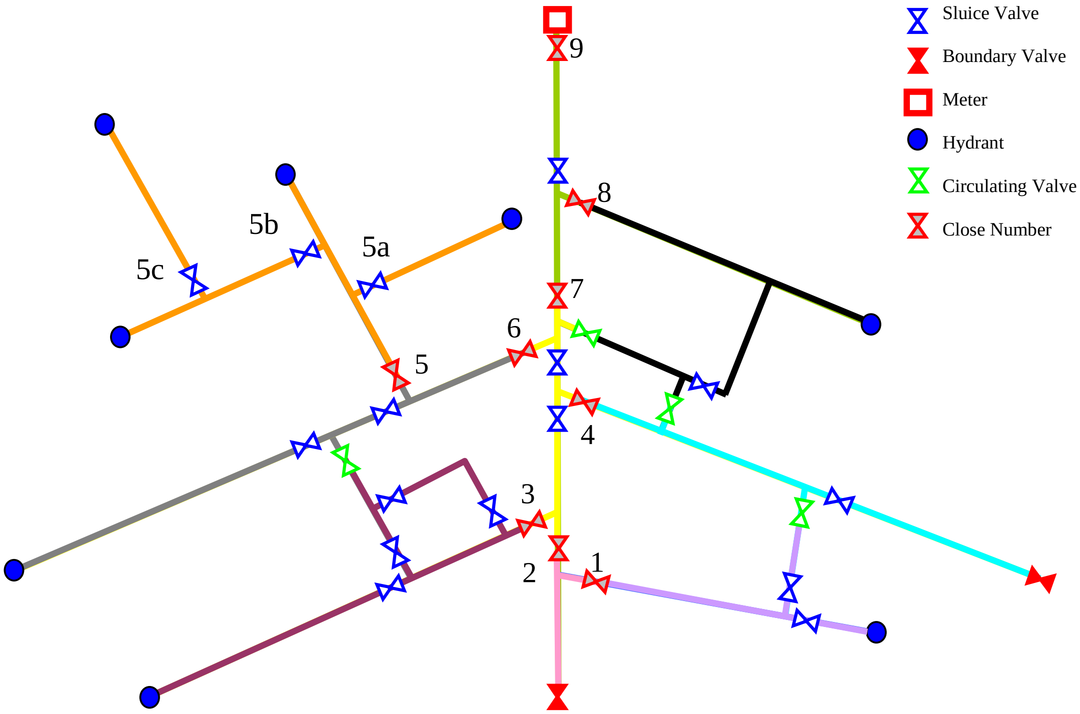
1. Carry out any isolation needed to ensure all flow passes through the valve selected to act as the meter point.
2. Place the Accuflow on the sluice valve to be used as the metering point.
3. Check that the valve is fully open.
4. Measure the upstream pressure.
5. Switch on the Accuflow and input the site location, upstream pressure, pipe diameter and direction of close for the valve.
6. Press start and close the valve as instructed by the display and audible prompts, stopping and restarting closing of the valve as instructed.
7. Complete closure of the valve and wait the flow is displayed before staring to reopen the valve.
8. Reopen the valve in accordance with normal operational procedures (note that once the Accuflow has indicated that valve is ready to be reopened, the Accuflow can be switched off and removed for use at another location, and the valve can be reopened using a conventional valve key if desired).

The time required for the flow measuring operation will depend on the valve size. The valve can be closed in larger steps at first, but then in much smaller stages from 75% closed, as instructed by the Accuflow display. The total operation will take about ten minutes for a 100mm pipe. If an incorrect valve pipe size has been input the device will identify this and will indicate whether a retest is necessary. Any major fluctuation in flow during the measuring operation will also trigger an unsuccessful test indication on the display. A typical display is shown below.



Developing new step testing methods using the Accuflow

Since November 2006 a number of RPS Water leakage control teams trained in using the Accuflow™ have been working with five water industry clients across the UK. This approach has allowed the device to be used in a wide range of operational situations. The step testing procedure is normally carried out at night and is similar to that conventionally used for step testing, but with some important differences. These can be explained by reference to the schematic diagram below.



The first step is to isolate the DMA by closing the boundary valves and to close all the circulating valves to ensure that each step has a single feed. Testing is then carried out by using the Accuflow to measure the flow at point 1, as explained under "How to take a flow measurement using the Accuflow". As soon as the Accuflow has calculated a flow value, the valve at point 1 can to be reopened with a conventional valve key, while the Accuflow is moved to point 2 to start taking the next flow reading. The process continues at the remaining step points, 3 through to 9. Where a DMA inlet meter is fitted, it is recommended that the flow is logged during the step testing exercise to provide an additional cross check of the flows into the DMA. Once the all steps 1 through 9 have been metered using the Accuflow, it is possible to review the results to see if any additional readings within the DMA are beneficial. For example, if there were an unexplained high flow at step 5, it would help pinpoint the location of leakage if further Accuflow readings were taken at the three sluice valves downstream of step point 5 (shown as 5A, 5B and 5C).

Cost and performance comparison of conventional step testing against the Accuflow

The varied conditions experienced across the water companies involved in the trials have providing valuable experience in refining the principles of step testing to maximise the advantages of using the Accuflow. The costs of carrying out step testing using the Accuflow in an existing DMA is similar to conventional step testing using radio linked equipment. Where a DMA is not already set-up, step testing can be implemented using the Accuflow without incurring the capital set-up costs associated with a DMA.

In addition to cost advantages, the Accuflow step testing procedure outlined above has major performance advantages over conventional step testing. Firstly, the ability to use the sluice valve at each shut off step as the actual metering point, rather than the remote meter at the inlet to the DMA. The effect of taking measurements at local street level eliminates the effect of any legitimate night use upstream of the step test point. Secondly, the approach is far more flexible, as extra measurements can easily be taken at any sluice valve to help better pinpoint leakage for further investigation. Any improvement in the measurement and pinpointing of leaks has significant potential to reduce the number of non-productive leaks that are identified for repair.

In relation to performance in quantifying and pinpointing leaks, all experience to date has indicated that step testing using the Accuflow produces significantly better results than conventional step testing. This is of particular importance given the high cost of leak repairs. Research carried out by Dŵr Cymru Welsh Water indicates that over a third of repaired leaks have no noticeable impact on reducing measured leakage levels. The cost of repair of these non-productive leaks to the UK Water Industry has been estimated to be in excess of £100 million per year. Trials so far have indicated that it is not unrealistic to expect that the number of non-productive leaks could be reduced by a third by using improved Accuflow based step testing. This would provide a potential saving of over £11 million each year across the UK.

Options for replacing DMAs with Accuflow monitored areas

The cost of setting-up, monitoring and maintaining a DMA has a high ongoing cost and typical values are given in Table 1 below. The Accuflow offers the possibility of carrying out area monitoring at far lower cost, which may prove to be a satisfactory and cost effective approach to leakage monitoring for many situations. The cost of using the Accuflow to valve in a discreet area at night four times a year to provide leakage monitoring information is given in Table 2 below

Table 1 - Cost of setting-up, monitoring and maintaining a DMA

Activity	Cost per year		Cost over 10 years	
	£	€	£	€
Initial DMA set-up costs (typically £5k to £50k, assume £15k)	1,500	2,175	15,000	21,500
Maintaining boundary integrity	400	580	4,000	5,800
Logging and data transfer	300	435	3,000	4,350
Flushing dead end mains	400	580	4,000	5,800
Replacing boundary meters	300	435	3,000	4,350
Total cost per DMA (average 1,500 properties)	2,900	4,205	29,000	42,050
Cost for a utility with 300,000 properties	580,000	841,000	5,800,000	8,410,000

Table 2 - Cost of monitoring an area of 1,500 properties using Accuflow testing, assuming four monitoring visits per year

Activity	Cost per year		Cost over 10 years	
	£	€	£	€
Capital cost of equipment (five year life,	40	58	400	580

assuming 200 areas monitored each year)				
Labour costs for testing (4 visit per year for 3 hours at £50/hour)	600	870	6,000	8,700
Total cost per 1,500 properties	640	928	6400	9280
Cost for a utility with 300,000 properties	128,000	185,600	1,280,000	1,856,000

These cost figures indicate that using the Accuflow can be expected to cost well under three quarters of the cost of an approach using conventional DMA monitoring. Even if Accuflow monitoring was necessary every month, it would still work out cheaper than continuous DMA monitoring. For utilities without the regulatory requirement for continuous leakage monitoring, establishing leakage monitoring areas using the Accuflow provides a new cost effective way to identifying areas with greatest levels of leakage.

In summary …….

The innovative technology of the Accuflow and valve flow metering offers significant cost and performance benefits when compared with other established techniques such as acoustic logging, DMA monitoring and conventional step testing. The use of enhanced step testing using valve flow meters has been shown to improve identification of those leaks worth repairing and so significantly improve the efficiency of leakage detection and repair activities. The advantages include:

- It requires no fixed installations and so reduces capital costs.
- The flow into any zone can be seen as soon as the valve is closed, rather than relying on logging or additional staff at a remote input meter.
- It provides high quality quantitative data on the levels of leakage and enables better targeting of leaks worth repairing.
- Unlike acoustic logging, it does not relay on noise to indicate the size of a leak, which can sometime give misleading results leading to unnecessary repairs.
- The metering points can be close to the area being monitored, reducing the impact of customer usage on leakage measurements.
- The controlled nature of the valve operation reduces the likelihood of causing small bursts on weak mains or of discoloured supplies.
- The short period of complete valve closure required means minimal disruption to customers' supplies.
- It allows follow-up monitoring to determine the effect of leak repairs.

The “Holy Grail” of leakage control has always been the ability to accurately pinpoint the location and volume of leaks, without the cost of expensive fixed asset installations. The Accuflow™ provides a significant step forward towards this goal.

Further information on the techniques described in the technical paper can be obtained by contacting Arthur Arscott at RPS Water:
via email: arscotta@rpsgroup.com
or phone: +44 (0) 1392 680 712