EVOLVING METHODS FOR THE CALIBRATION OF FLOW CONTROLS FOR STORMWATER AND WASTEWATER MANAGEMENT

LeCornu, J.P. and Faram, M.G.

Hydro International

ABSTRACT

The ability to accurately and reliably control flows in drainage and sewerage systems is critical for the effective operation of such systems. The use of inaccurate or unreliable flow controls can lead to adverse effects including flooding.

Conventional methods for the calibration of flow controls are time consuming and can suffer from poor repeatability. This paper describes work carried out with the aim of developing new, improved methods, to both enhance accuracy and improve repeatability, while also reducing test times. In order to achieve the objectives, a PROFIBUS based instrumentation and control system was fitted to existing hydraulic test facilities, operated by Hydro International.

The new methods, applied to the calibration of vortex flow controls and orifice plates, show potential to reduce test times by a factor of more than ten, while also increasing the accuracy and repeatability of results.

KEY WORDS

Flooding; instrumentation; laboratory methods; PROFIBUS; sewer network modelling; vortex flow controls

INTRODUCTION

Since 1980, Hydro International has been supplying vortex flow controls under the trade name of the “Hydro-Brake® Flow Control” in the UK and Europe, and later as the “Reg-U-Flo® Vortex Valve” in North America. To date, over 15,000 units have been supplied.

Flow controls are used frequently in urban drainage systems, including combined sewer networks, to regulate flows, thereby preventing problems, such as flooding, from occurring downstream. This flooding can result from the indiscriminate addition of new connections to existing sewer networks, including those from new developments, and illegal connections. The extra flow produced, particularly during storm conditions, can exceed the original system capacity, leading to flooding and the operation of combined sewer overflows. Discharges to watercourses from surface water drainage systems can also lead to flooding problems if not adequately controlled.

Flow controls can be installed at carefully chosen points in a drainage network so that in-pipe or off-line storage can be used to attenuate excess flows. Thus the discharge into the overloaded part of the network, or in the case of surface water drainage systems the receiving watercourse, is reduced.

Several types of flow control device have been used within sewer or drainage networks, including penstocks, orifice plates, float controlled valves, and vortex flow controls. Vortex flow controls have several advantages over the other types. One major advantage is that vortex flow controls have a clear opening of around 300% to 600% larger than the equivalent orifice. This results in them being less prone to blockage. This reduced susceptibility to blockage is particularly important in drainage networks. Another important parameter is the ability to transfer flows at low heads i.e. not to prematurely restrict flows. This allows available storage volumes to be used most efficiently. In comparison to other devices, orifice plates tend to over-restrict flows at low heads when flow regulation is perhaps not needed, also tending to have smallest clearances under these circumstances. Float controlled valves and vortex flow controls on the other hand have the ability to ‘switch’ into action when regulation is most required, so not over-restricting flows at low heads. Float valves achieve this ‘switching’ effect through physical reduction in clearance areas as head levels increase and as such at their operating heads have clearances that are similar to that of orifice plates. Vortex flow controls achieve this through hydrodynamic, vortex induced restriction, retaining open clearances throughout, and are therefore less prone to blocking. The operation and resulting discharge characteristic of a vortex flow control compared to different sizes of orifice plate, is shown in Figure 1.

Vortex flow controls have been extensively applied in practice, and have been the subject of numerous studies (Smisson, 1980; Lamb, 1983; Parsian & Butler, 1993; Velon et al., 1994; Andoh & Smisson, 1995; Andoh & Declerk, 1999; Boakes et al., 2004; Faram & Kane, 2006).

With the increased interest in addressing urban drainage problems, combined with the emergence of software based

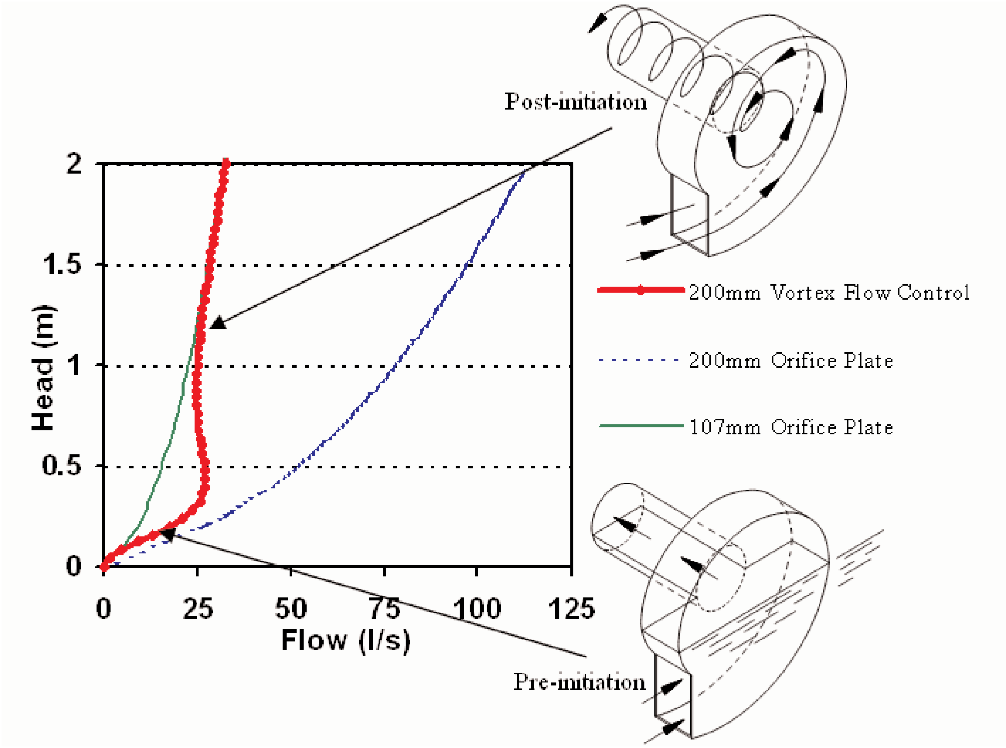

Figure 1: **Operation of a Vortex Flow Control Compared to Orifice Plates**

network modelling methods, it has become increasingly important that flow controls are accurately characterised. The paper describes work that has been carried out at Hydro International to enhance its vortex flow control test facilities. This has resulted in improvements in the accuracy and reliability of outputs, and has also significantly reduced test times. The improvements have major implications to new product development, and will also play a role in day to day quality control, ensuring that supplied units continue to deliver specified hydraulic discharge characteristics.

TEST FACILITY AND HISTORICAL TEST METHODS

The main test facility at Hydro International's offices in Clevedon was designed primarily with the testing of flow controls in mind. A schematic is provided in Figure 2. The test rig can also be used for testing other devices.

The facility comprises three on-line, basement sump tanks, with a further two off-line storage tanks that can be used for volumetric measurement (giving a sump volume of around 6.5 m^3). Water is pumped to the ground floor test area using a variable speed inverter controlled semi-submersible pump. The flow initially enters the test tank into which the flow control to be tested is installed. This has a lid which can be sealed allowing the tank to be pressurised, applying extra head to the flow control. After flowing out of the test tank through the flow control the water passes through an intermediate tank, which allows controlled surcharging to be applied, then finally into a V-notch weir tank before discharging back to the sump tanks.

For many years, the method of measuring the performance of a flow control was manual. An operator made pump speed, and hence, flow rate adjustments and measured water levels in manometers, producing a point by point, steady state, head-flow characteristic for the device in question. Flow rate was derived from a depth-flow calibration for the V-notch weir. This method was found to be subject to a number of possible errors and included those due to taking instantaneous (rather than time-averaged) readings of the various parameters, and operator error.

In order to improve the accuracy of flow rate measurement, a vernier hook gauge was fitted to the weir tank in 1994. This allowed the water level over the V-notch weir to be measured to the nearest 0.1mm. This achieved the objective of improving accuracy. However, it was found that under certain circumstances, response times could be as high as two hours, resulting in complete calibration times of in excess of two weeks. As the system was totally manual in its control, and with no fail-safe mechanisms built into its operation, there had to be an operator present at all times while the test rig was in use.

REQUIREMENTS OF THE NEW SYSTEM

With a view to improving the accuracy and reliability of flow control testing, while also reducing test times, a decision was made to invest in a series of improvements. Following detailed consideration, the following base requirements were established:

- A facility was needed that could measure the head applied to a flow control, the flow rate being discharged, and the flow rate pumped from the sump tanks to an accuracy of within ±1%.
- The system should, ideally, not require any operator input once the test had been set up and initialised.
- The system should have fail-safe systems incorporated (for example, to prevent flooding in the event of a power cut or control system failure).
- The system should remain unaffected by electrical noise.
- The system should be readily expandable and also adaptable to allow different types of system to be tested.
- The system should allow flow controls to be tested in a much reduced time.

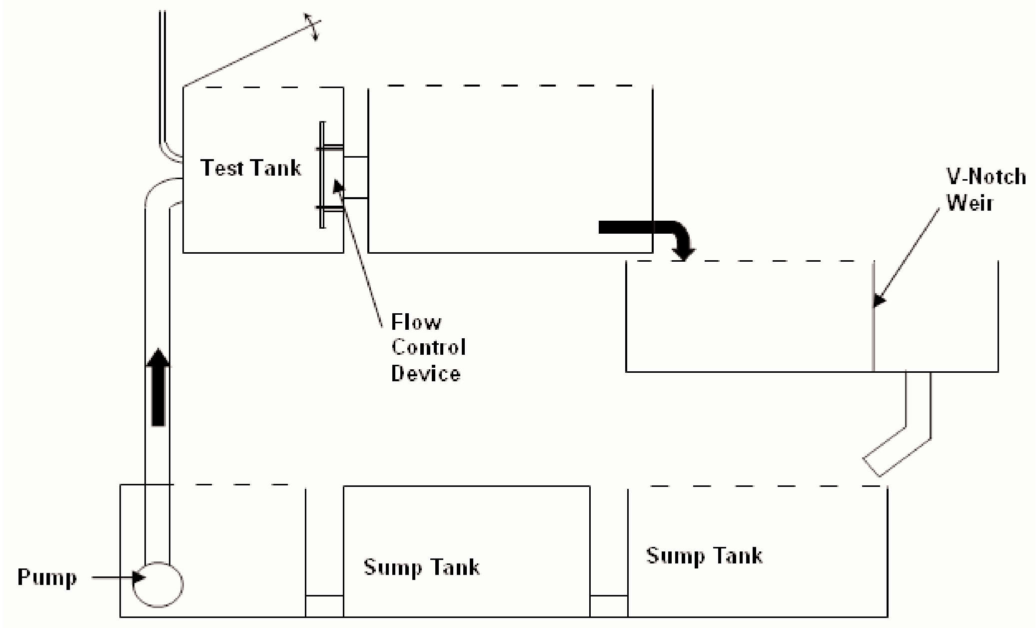

Figure 2: Schematic Diagram of Hydro International's Hydraulic Test Facility in Clevedon

The requirements of expandability, reliability, and safety suggested that a modern type of system would be required. Analogue (current or voltage) systems require a separate physical channel for each instrument, and are therefore less readily expandable. Analogue voltage systems are particularly prone to induced noise; on a previous occasion it was found that the variable speed inverter drive on the pump could induce sufficient mains-borne noise to completely mask a portable instrument's signal. Current based systems (e.g. 4-20mA) on the other hand are inherently better at handling noise.

Modern digital systems are better at handling noise than analogue systems. This is partly due to the fact that they are current based, but also due to the fact that the change in signal between transmission points (e.g. from zero to one) is relatively large compared to typical background noise, producing a more reliable system. A further benefit of digital systems is that there are reduced conversion errors as the actual readings are transmitted. They also allow greater flexibility, given the ability to handle multiple signals on a single wire pair.

During the initial specification process, the type of control software required was also considered. To allow for the flexibility of the physical system, this would have to be easily programmable by existing test operators.

It was decided that a digital bus type system, with a generic software control interface and sufficiently accurate digital instruments, would be the best solution.

COMPONENTS AND INSTALLATION

There are several different digital bus based protocols that can be used for instrumentation control and monitoring, including PROFIBUS, CAN and FIELDBUS. These operate at low voltages and are therefore relatively safe in terms of electrical shock risk. The protocol chosen was PROFIBUS, this appearing to be the most frequently used for this type of system in Europe.

The new system utilises four instruments, two sensors, and a pump controller. These are connected to a dedicated computer via a common bus type network (which contains a segment coupler) through a PCI interface card. The user accesses the data through software which connects to the PCI card using an OPC (OLE (Object Linking and Embedding) for Process Control) server. The user can also perform configuration tasks on the PROFIBUS network with dedicated software supplied with the PCI card. A simplified diagram of the system communication structure is shown in Figure 3.

The instruments chosen were as follows: three Smar LD303 pressure transducers, accurate to within ±0.04% of the calibrated range, and an Endress and Hauser Promag 50 electromagnetic flow meter, accurate to better than ±0.2% of reading. Two sensors, including a float switch for level detection in the sump, and a microswitch to detect the status of the head tank lid (i.e. whether open or closed), are connected to the PROFIBUS system using a Pepperl and Fuchs (P&F) sensor interface. The pump is powered with a

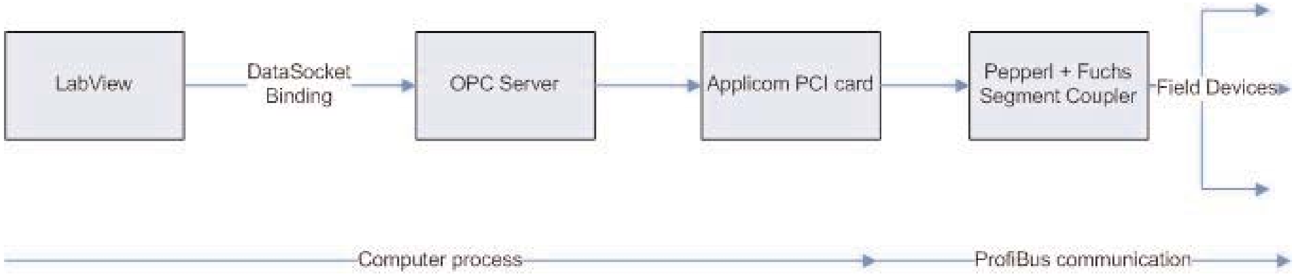

Figure 3: Communication Structure of the Installed Control System

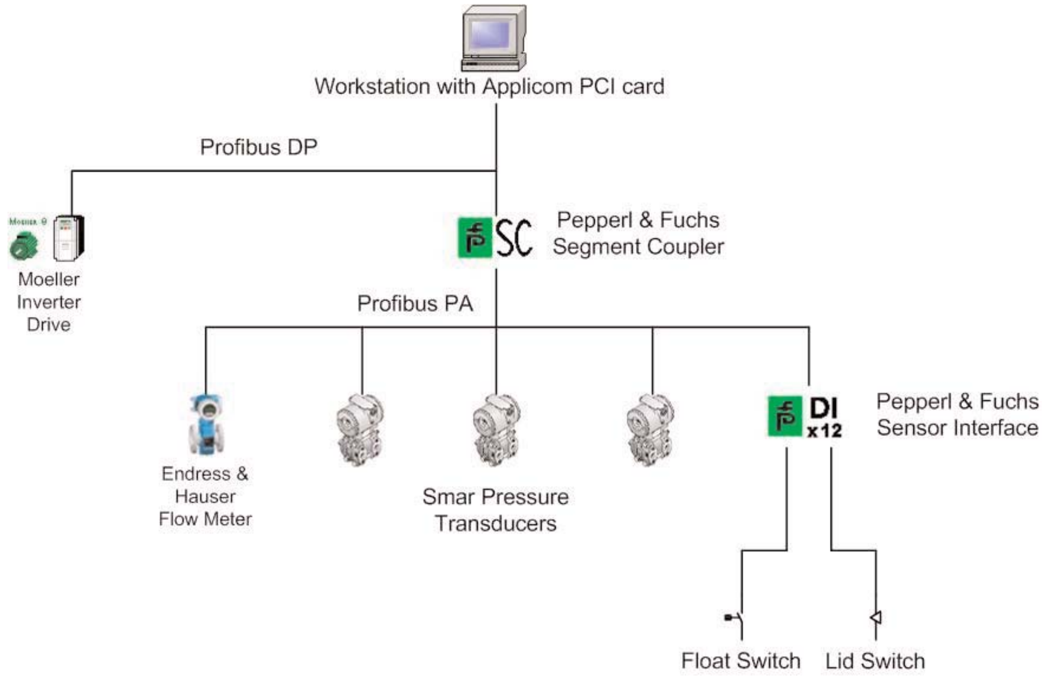

Figure 4: **Schematic of the Instrumentation and Control System Layout**

Moeller inverter, a variable speed drive, which is also connected to the network. The control software chosen for the system was National Instruments' Labview. There is also a Pepperl and Fuchs segment coupler which connects the bus-powered (PA) segment to the non-bus-powered (DP) segment of the PROFIBUS system. Two P&F junction boxes are also used to allow flexibility with regard to the mounting position of one of the pressure transducers. The instruments are connected with cables specifically designed for the PROFIBUS protocol. A schematic of the process layout is shown in Figure 4.

Flow rate measurements are carried out both upstream and downstream of the test tank. The electromagnetic flow meter is installed upstream of the test tank. The V-notch weir tank situated downstream of the test tank is fitted with a pressure transducer. As a result, there are two independent methods of flow rate measurement.

This provides a number of benefits. Electromagnetic flow meters suffer a reduction in accuracy below a flow velocity of 0.5 m/s. This is not the case with a V-notch weir. The accuracy of a V-notch increases with reducing flow rate, assuming that the accuracy of the level measurement is not diminished with reducing head over the weir. Another advantage is that the flow rates both into and out of the test tank can be measured. This provides scope to test flow controls under dynamic conditions; for example to assess the discharge response to a simulated input storm profile. It also presents the opportunity to cross-check the calibration of each flow measurement device with the other, and also to assess during a test whether steady state conditions have been reached. This is established as being the situation when the inlet and outlet flow rates are the same.

The water level over the V-notch weir is measured with one of the pressure transducers. This was factory calibrated for the head level range required (0 to 500 mm of water) such that its output reading is accurate to within ±0.2 mm. This resolution when the weir equation is applied produces a flow rate accurate to within ±0.1 l/s. Head level in the test tank is measured with one of the remaining two pressure transducers, factory calibrated for the range of levels that the transducer will experience. The calibration allows a reading to be taken that is accurate to within ±1 mm. The third pressure transducer is fitted with a flying lead. This allows it to be plugged into one of two junction boxes. The boxes are installed on opposite sides of the test rig and are fitted with suitable sockets to allow the transducer to be quickly connected or disconnected. The PROFIBUS system automatically recognises the instrument when connected, and works without fault when it is not connected. The transducer has also been factory calibrated to produce readings accurate to within ±1 mm. This allows measurement of pressure in other points in the system, for example, surcharge levels on flow controls being tested.

Apart from software control, two other sensors help monitor the state of the test rig. These are the sump tank float switch and the test tank lid switch, and they are connected to the network using the sensor interface. Their purpose is to tell the control system that there may be a fault and that the control system should stop the pump. The lid switch will only cause the pump to stop if the water level in the test tank is close to the top, and the lid is open. The float switch warns of a very low water level in the sump tanks. This stops the pump before damage occurs. The pump is also tolerant of dry running for short periods. The condition of the pump itself is monitored internally by the inverter drive unit. The inverter will refuse to run the pump if it has detected an electrical fault within the pump. The inverter can also detect if the pump is becoming blocked or is running dry and overheating.

The Labview software allows in-house configuration of the system to meet specific test requirements. The software is designed such that a block diagram of the required program is developed on the screen. The software will then complete the data acquisition and processing tasks as shown in the block diagram, including collection of data from the instruments, checking for certain conditions, issuing commands to the pump, and saving data to files.

It was found that considerably more effort was required in developing the software control aspects, than in establishing the physical installation. To accelerate this process, control software consultants were utilised.

OPERATION AND VERIFICATION

The operation of the test facility was initially verified using a 100 mm diameter orifice plate that had previously been tested using the pre-instrumented facility, and also at an independent facility at the University of Bristol. These previous tests had involved the manual, point by point collection of steady state head-flow data.

Two types of test approach were verified using the new set-up:

- **Automated steady-state testing**. This is an automatic version of the manual method used previously. The method involves software monitoring of the system to check for steady state conditions, based on flow rates and head levels. Once steady state conditions have been reached head and flow readings are taken. Following this, the flow rate is adjusted, and the next reading taken, until a full characteristic has been produced. This method presents potential to reduce test times, through monitoring for stabilisation, rather than assuming a 'worst case' stabilisation time, as had been previously applied. It also eliminates the requirement for an operator to remain in attendance throughout a test.
- **Automated dynamic testing.** This involves monitoring and recording head and flow data while the pump speed is steadily ramped up over a period of time. The data collected, representing the variation of the test tank inlet flow rate and water level over time, is processed and integrated with the depth-cross sectional area profile of the test tank to give the characteristic discharge curve. This method has great potential to reduce test times, in that a test can be completed in the time that it takes for the test tank to fill. As with automated steady state testing, it also eliminates the requirement for operator attendance.

While steady state testing can be carried out as a manual process, dynamic testing can not, this only becoming practical with the support of automated logging facilities. This method provides additional opportunities, including scope to evaluate the response of a flow control to a time-varying flow profile, for example, a simulated storm profile.

Figure 5 shows data collected using these different methods, along with manual steady state data collected using both the facilities of Hydro International and of the University of Bristol. There are about 3500 data points plotted for the automated dynamic test, compared to around 50 for the automated steady state and manual tests. The dynamic data is smoothed using a five point moving average at the time of calculating the discharge flow rates in a spreadsheet.

The high levels of correspondence observed between the different data sets confirm the validity of the new test methods.

The produced characteristic is representative of the expected profile for the vortex flow control in question, exhibiting the characteristic 'kickback' as the device passes through from the pre-initiation to post-initiation phases of operation. The relatively high levels of noise shown during this transition correlate with previous experience of this operational phase as being relatively unstable. The brief data spike at a head of 750 mm corresponds to the instant at which the water level in the test tank reaches the lid, reflecting a brief pulse in the readings, rather than a performance attribute of the device.

Of particular significance is the fact that automated dynamic tests can be completed within a period of less than 8 hours. Previously, a good quality manual test, involving the collection of perhaps 50 data points, would have taken around two to three weeks to perform. This huge improvement shows that a full calibration may be performed in as little as 7 % of the time required to complete a manual test. Further to this, the requirement for operator attendance during a test is eliminated.

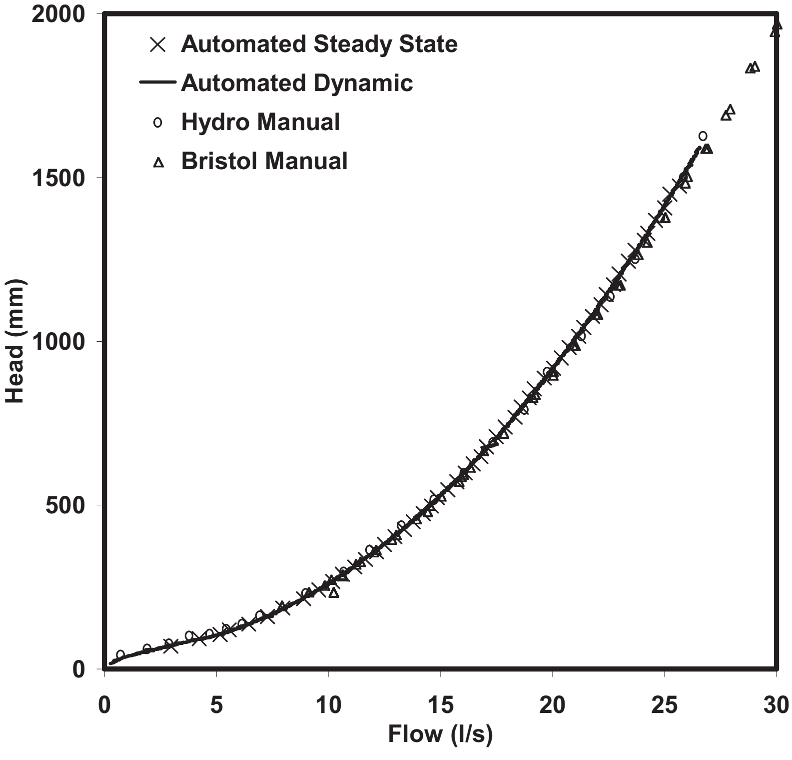

Figure 5.: **Comparison of Automated Dynamic and Automated Steady State Test Results with Manually Obtained Test Data for an Orifice Plate**

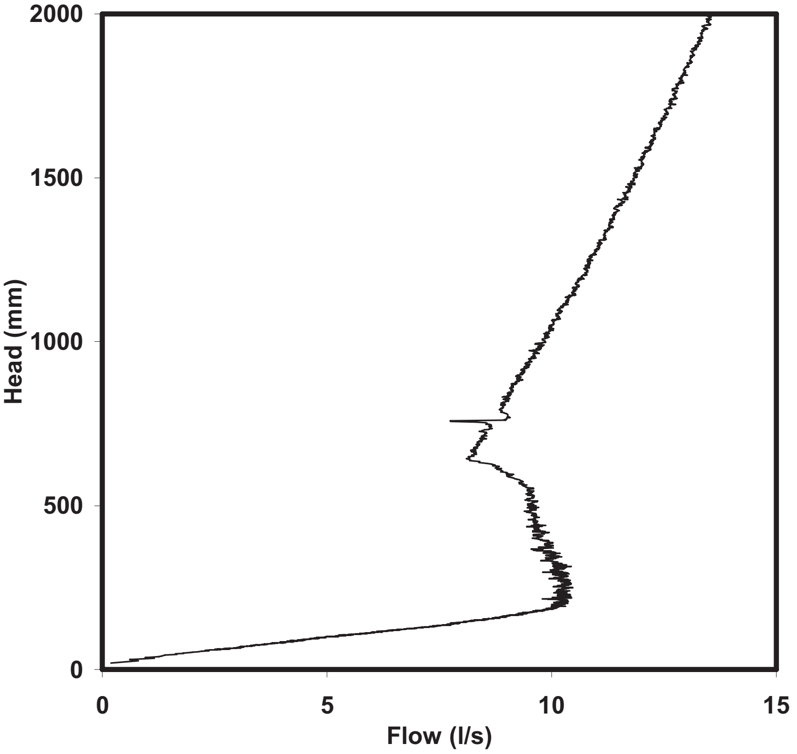

Figure 6. Hydraulic Characteristic of a Vortex Flow Control Produced using the Automated Dynamic Method

FURTHER WORK

Further work on the system and the investigation of new calibration methods is ongoing. The system will benefit from having the control software refined further. It is anticipated that these refinements will include better memory usage in the computer, as at present the software uses most of the available processing power. There will also be the implementation of smoothing regimes which will reduce the noise on the signals. These will require careful evaluation to ensure that the smoothing does not affect the calibration of the flow control being evaluated.

Other features could be added to the control software that present further potential to reduce test times. This could include modules to perform the aspects of the data processing that are currently carried out in a spreadsheet.

Added engineering features such as a more in depth view of the pump performance for maintenance issues could also be included. The PROFIBUS protocol also allows data to be written to the instruments. Implementing this feature would allow the calibration profiles of the instruments to be changed, and the status of each instrument queried. These changes would require further development of the control program, and are more desired rather than required features.

CONCLUSIONS

From the work carried out so far on evolving the calibration methods of flow controls it is possible to draw several conclusions:

1. The increased interest in addressing urban drainage problems, combined with the emergence of software based network modelling methods has reinforced the need for accurate calibration of flow controls for storm and wastewater management.
2. Vortex flow controls have been widely used in sewer/drainage systems. They are more resistant to blockage and hence more reliable than many of the other types of flow control available to the drainage engineer. They also allow storage volumes to be utilised efficiently.
3. Modern instrumentation and control methods present the opportunity to allow flow controls to be tested to a greater degree of accuracy, and more efficiently, than conventional manual methods.
4. The instrumentation system installed on Hydro International's flow control test facility has improved the accuracy and repeatability of results. With system errors estimated at ±0.5 % of reading, correspondence with previous, manually collected data has been shown to be very good.
5. The new methods show potential to reduce flow control calibration times by a factor of more than ten, while also minimising the need for human intervention.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contribution of Mr Mark Bowditch and Miss Elizabeth Hill in developing and assessing the described system, and also the inputs of Develop-ING Solutions (consultants). Foundation work, carried out by Mr Andrew Deamer in the 1990's, looking at improved methods of flow control testing, is also acknowledged.

REFERENCES

Andoh, R.Y.G., and Smisson, R.P.M (1995) Alternative Urban Drainage Strategy Utilising the Single Pipe System. NOVATECH 95: 2nd *Int. Conf. On Innovative Technologies in Urban Storm Drainage*, Lyon, France, pp 189 – 196.

Andoh, R. Y. G, and Declerk, C. (1999) Source Control and Distributed Storage – A Cost Effective Approach to Urban Drainage for the New Millennium ? *8th International Conference on Urban Storm Drainage*, Sydney, Australia, August-September, pp 1997-2005.

Boakes, G. P., Stephenson, A., Lowes, J. B., Morison, A. C. and Osborne, A. T. (2004) Weedon Flood Storage Scheme – the Biggest Hydro-Brake in the World. *British Dam Society 13th Biennial Conference*, University of Kent, Canterbury, UK, 22-26 June.

Faram, M.G. and Kane, A.S. (2006) Innovative 'Hard Engineered' Approaches to Urban Stormwater Management. Emerging Environmental Issues and Future Challenges: *4th CIWEM Annual Conference*, Newcastle upon Tyne, 12-14 September.

Lamb, T. J. (1983) Practical Use of Hydro-Brake Flow Controls to Alleviate Flooding at Low Cost. *The Public Health Engineer*, 11, **3**, pp 19 – 23.

Parsian, H. and Butler, D. (1993) Investigation into the Performance of an In-Sewer Vortex Flow Regulator. J. *IWEM,* 7 April, pp 182 – 189.

Smisson, R.P.M. (1980) The Single Pipe System For Stormwater Management. Prog. *Wat. Tech.*, Vol. **13**, pp. 203 – 214.

Velon, J., Barber, D., Persaud, R., and Stonebac, D. (1994) Real World Evaluation of Inlet Control Effectiveness in Solving Combined Sewer Problems. WEFTEC '94: *Water Environment Federation 67th Annual Conference & Exposition*, Chicago, Illinois, pp 241 – 251.