FLOW MEASUREMENT GUIDANCE NOTE NO. 37

Electromagnetic Flowmeters

for the water industry

September 2003

1 *Introduction*

Electromagnetic (E.M.) flowmeters are used extensively to measure the quantity, or flowrate, of water being transported in water networks. They are wide ranging, accurate and reliable and are now widely accepted as the first-choice meter to replace traditional methods such as nozzles or positive displacement meters. Although the technology has become very reliable, E.M. meters are still not perfect, and require to be specified, installed and used correctly to achieve the expected performance.

This Guidance Note summarises the methods which should be employed to specify, install and use an E.M. meter as part of a water metering application. It does not cover calibration and verification. This summary draws extensively on experience gained through contact with both manufacturers and users as well as the the results of a comprehensive test programme that was undertaken by NEL under the 1999-2002 Flow Programme.

2 *Vocabulary*

Turndown (ratio) - the ratio of the maximum flow specified for the meter to the minimum flow being described.

Accuracy - A qualitative term to express a measure of the expected uncertainty which may be achieved from a measuring system.

Full bore - the common design of electromagnetic flowmeter whereby the internal diameter of the meter is the same as the connecting pipework.

Reduced bore - a more recent design of electromagnetic flowmeter which has a convergent/divergent section within the meter, reducing the bore to less than that of the connecting pipe diameter.

3 *Principle of operation*

E.M. meters operate by applying Faraday's laws of electromagnetic induction. A conductor (flowing water) moving at right angles to a magnetic field induces a potential difference (voltage) at right angles to both the direction of movement and the field. The magnitude of the voltage is proportional to the velocity of the moving conductor.

E.M. meters generally take the form of a circular pipe with an elastomer lining, insulating the stainless steel meter tube from the conducting fluid. The field coils are encapsulated in fixings outside the pipe. Most meters for water duty utilise pulsed DC techniques to induce the magnetic field. Varying the size and frequency of the pulses allows the power requirement to be minimised or the accuracy to be maximised. This allows battery-powered (or low-power) versions to be available in addition to the normal mains-powered versions.

The induced voltage is developed between electrodes flush with the meter internal bore but protruding through the lining. The voltage is then transmitted to the secondary electronics for measurement and processing. The secondary electronics may be integral with the meter or mounted remotely.

In all current meters, the secondary electronics are based on a microprocessor control system which provides the user's interface with the sensor in addition to control and measuring functions.

The generation of the DC pulses to the coils, and the subsequent detection and measurement of the voltage are controlled by the processor. This covers the timing of the pulses and the voltage amplification, filtering and measurement. As the voltages measured are very small, repeated measurements (normally not seen by the user) are averaged to give a mean value for conversion to the output value. The processor controls the sample rate and averaging functions to produce this result. The processor converts the mean voltage reading to a velocity and then a volumetric flowrate. The resultant values are output to the user in the form of a display, a 4-20 mA current, a pulsed signal, or a digital (serial) output based on a separate time base from that used for averaging the voltage. Totalised volume is also calculated and made available.

All these outputs are generated by the microprocessor and can be scaled based on chosen units, time factors, and selected meter range.

4 Choosing an E.M. Meter

There are many manufacturers offering E.M. flowmeters designed to measure potable, abstraction or waste water. In many cases the choice of meter will be commercial as well as technical. The choice of supplier must be made based on the stated performance for the duty as well as an assessment of the veracity of the claims. Of course there will be other considerations in the case of water network installations such as the price, compatablity with existing equipment and a knowledge of the track record of previous installations. Long-term reliability, ease of setup and compatibility with the remote data transmission will be other factors to be taken into account along with the extent of maintainance diagnostics and availability of verification hardware.

5 Sizing

A critical issue in the choice of flowmeter is the sizing of the meter.

As discussed earlier an E.M. meter measures velocity. The maximum velocity measurable is theoretically very high but most manufacturers limit this to 10 m/s in the meter. Turn-down ratio will be based on this figure. As most water network applications operate at pipe velocities significantly below 10 m/s and probably closer to 1 or 2 m/s, any meter selected based on pipe size alone will be expected to perform with the maximum expected flow at the lower end of a 10:1 turn-down ratio based on the maximum capability. E.M. meters can only be expected to perform well down to 200 : 1, (although the best will measure down to 1000:1), sizing the meter based on velocity rather than pipe size will bring significant advantages. This applies especially where the meter may be used for leakage determination studies taken at times of low consumption.

Before a decision to install a reduced bore or a meter smaller than the main pipe bore is made, a number of factors should be taken into consideration:

- Increased pressure drop influences pumping costs. Typical head loss is >75 mbars for reduced bore meters and less for full bore meters.There is an increased likelihood of blockage, or silting of the upstream pipe.

- Pigging, scouring or lining operations of existing pipes may be difficult, especially if records do not show the bore reduction.

- Extra cost for reducers and associated pipe.

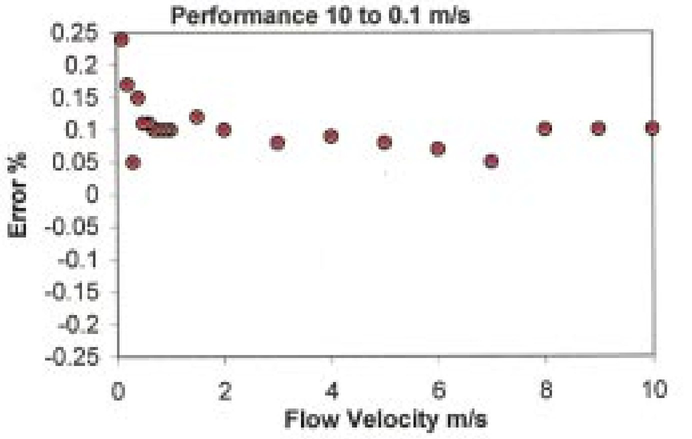
- Reduced-bore meters can be significantly less affected by upstream flow disturbances.

Some manufacturers supply reduced-bore meters to match the pipe size but have a reduced internal bore. These theoretically have the same advantages and disadvantages as installing a smaller bore pipe section and a full-bore meter with a reduced pipe size. Reduced-bore meters are characterised to reduce the effect of flow profile due to the bore reduction. It is important that installation records state clearly that a reduced- bore meter is used, and not just the nominal size of meter.

6 Performance of E.M. Meters.

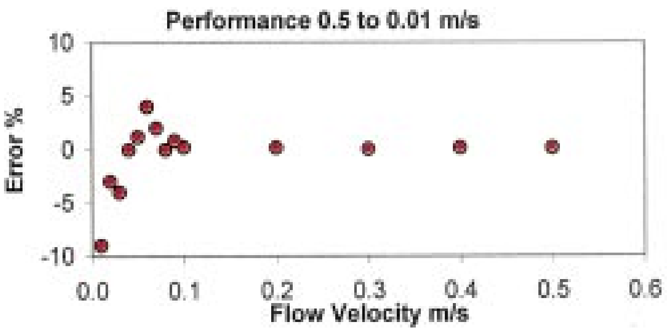
E.M. meters have a performance curve that is quite different from that of conventional mechanical meters. With the latter a distinctive curve is formed showing performance with flowrate as the balance between fluid slippage and meter friction is maintained. This error curve may be expected to change in both shape and magnitude with age and wear. With an E.M. meter, the induced voltage is directly proportional to the velocity and the meter gives a flat performance characteristic, only starting to show changes in performance as the flow profile changes from the turbulent to transitional, to laminar flow regime at low velocities. The characteristic depends primarily on the design of the magnetic field.

Three figures are used to show what the typical performance curve and accuracy expectation may be for a well installed and correctly set E.M. meter



Note: The specified performance will probably be well within +/- 0.25% across a 100:1 turndown.

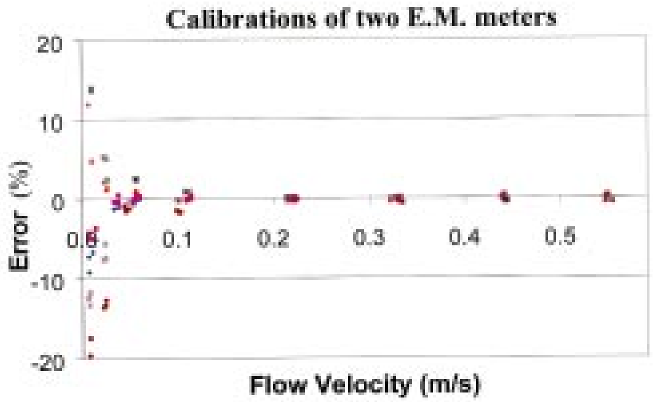
This first figure shows that the meter would be expected to give an error within 0.1 per cent across most of a 100:1 turndown based on a maximum velocity of 10 m/s. The error would increase in magnitude only towards the lower velocities. This will be accompanied by a deterioration in repeatability. In the range of velocities expected from a water installation at the lower flowrate end of the application, the performance is shown below.



The performance at very low velocities becomes more unpredictable. Down to velocities of around 0.1 m/s, errors may have increased to around 0.5 per cent; this will be accompanied by poorer repeatability. Below 0.1 per cent the error may be expected to increase in magnitude to anything up to 10 per cent or more. The classical performance would be as indicated with the error going positive first before dropping exponentially in a negative direction. This may be accompanied by a large deterioration in repeatability, which may mask any particular trend.

Such behaviour is not unexpected. The output is generated from very small voltages, modified by correction algorithms and subject to amplifier performance. To improve performance, a number of measures may be taken. The meter must be installed correctly. The meter's parameters must then be set up with no flow present and the meter full of water. The sample times and integration times must be set to long intervals. It is not uncommon for readings of flowrate to fluctuate widely, showing both positive and negative values at the lowest velocities, but, when averaged over a significant time, the quantity measured is within the specified error. Reducing the meter size chosen or using a reduced-bore meter will increase velocity hence giving improved performance.

The following shows actual results from the testing of two different E.M. meters showing results from calibrations.



The performance at the lowest flowrates indicates the performance that may be expected in the field across short integration times, as may be used in leakage testing. Many users in fact report fluctuating readings which may even indicate positive and negative flowrates when the meters are used in this manner. Integration of quantity over longer times is reported to yield lower errors. Installation where pump noise or fluctuations flows are present will give large errors at the lowest flowrates.

As a guide the expected performance will be as follows based on a velocity turndown from 10 m/s.

- 10 to 0.5 m/s +/- 0.15%
- 0.5 to 0.05 m/s +/- 0.5%
- 0.05 to 0.01 m/s +/- 1 to 20%

This is based on the expectation from a new good quality meter which has been correctly installed and supplied by a reputable manufacturer.

7 Installation

E.M. meters will only perform correctly and have a long life if they are installed correctly. The environment, the electrical installation, and the mechanical installation all contribute to the performance over the longer term.

Meters must be installed in such a manner that the environment does not impinge on the long-term performance. Most meter sensors are designed to be water resistant and suitable for 'in-ground' (buried) installation. Always install meters in a manner where they will be well supported and the ground is well drained. Install on a deep layer of gravel and coarse sand and pack the ground around the meter in a similar way to protect the meter from damage and from water saturation.

Mark the position of the meter at ground level.

Before back filling, test for leakage. Also ensure all the advised earth wiring or cathodic protection is in place, the connections secure, and the connectors protected from corrosion. Install the cables to the secondary electronics to avoid running in parallel with mains cabling in the ground.

For a meter installed above ground, ensure it is installed so that the pipework must always remain full. Fit the meter well away from any source of heavy electrical power or any pumps and sheltered from direct heat sources or wind chill. Ensure the meter is well supported.

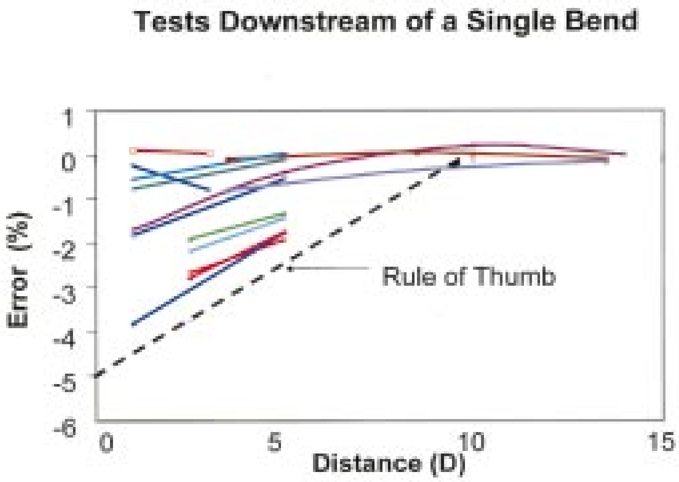
Always install the meter to avoid build up of silt or sediment and orient the meter to avoid the electrodes from becoming covered should silting occur.

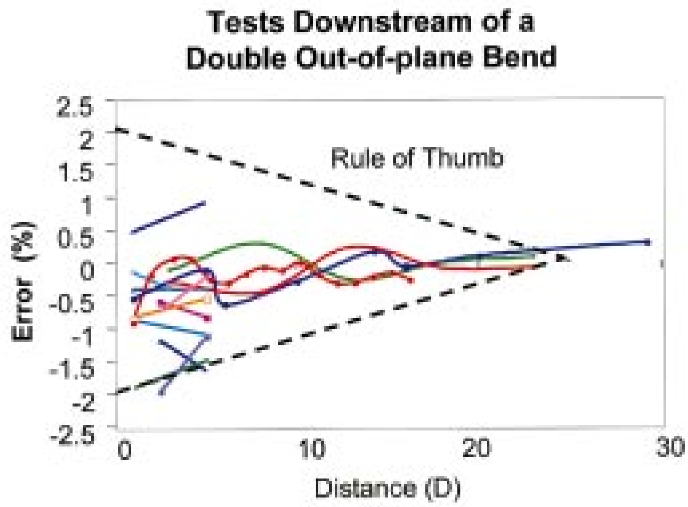
8 The Pipework Design

As the generation of the voltage in the sensor assumes the moving conductor is uniform and has a velocity vector in line with the direction of flow, any departures from this will create an error in the measurement. Disturbances to the flow due to bends, valves, reducers etc will therefore have a direct effect on the performance of the meter. Defining the exact effect from any disturbance on all meter designs is a huge task, and so some examples of the effects measured are given below along with suggested guides for avoiding problems.

Bends

A bend in the pipework causes asymetry in the flow profile to occur upstream of a meter. Double out-of-plane bends create swirl in the flow. The figures below show errors determined experimentally with a meter located downstream of bend(s). The distances are expressed as pipe diameters.

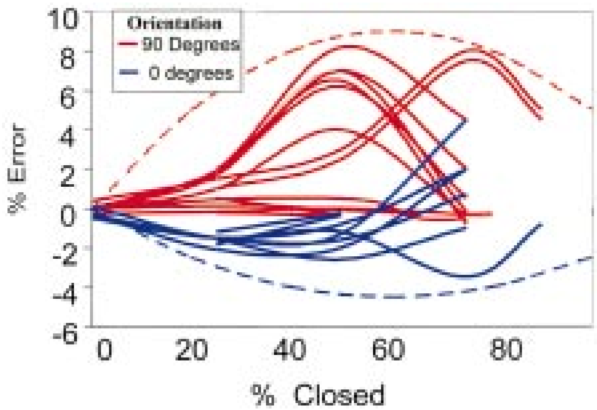




As can be seen, errors of 2.5 per cent, or greater, can be introduced by bends upstream of a meter. It requires the installation of 10 to 20 pipe diameters of straight pipe between the meter and the disturbance to reduce this error to acceptable levels.

Valves

Valves will also provide disturbances to the flow even when fully open. When partially closed these disturbances can be particularly severe. The figure below shows the effect of a gate valve at different distances from a meter, with different closing settings and two orientations relative to the meter's electrodes.

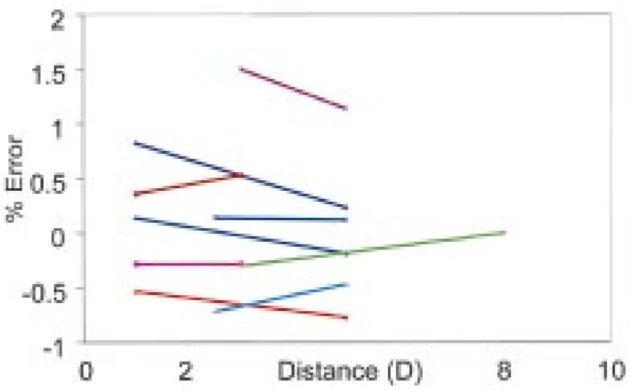


Metering error downstream of a gate valve

Other valve types, such as pressure reducing valves or flow control valves, will have similar effects.

Contractions and Expansions

Contractions and expansions also disturb the flow but introduce a smaller error than other disturbances. The figure below shows data taken from meters with different contractions and expansions located upstream of the meter.

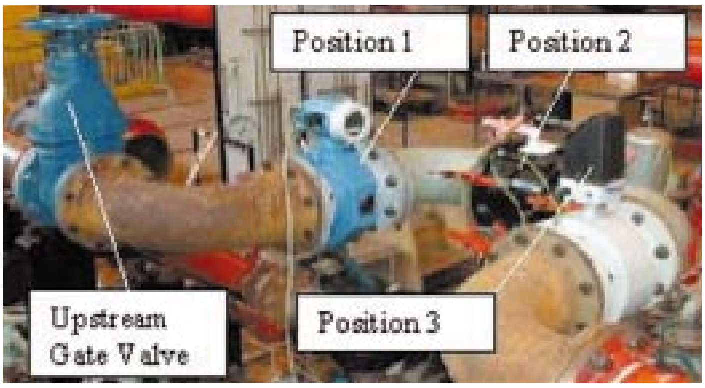


Metering Error Downstream of a Pipe Contraction

Reduced-bore meters are optimised and calibrated to allow for this effect within the meter.

Combination of disturbances.

A common combination found in water industry pipework, is a bend and valve combination as may be seen in a meter bypass type installation. Generally the additional error introduced by a combination of disturbances will not be much greater than the one with the largest effect. As this is a complex situation it would be prudent however to assume a combination would give a larger error than any one alone and assuming the largest plus half the next would not be far wrong.



Testing for bend and valve installation effects.

Guidance on pipework installation

The list below recognises the practicalities faced when installing meters in the field and is prioritised to recognise the compromise that may have to be made.

- Install the meter in a straight length of pipework of the same nominal diameter.
- Separate from sources of flow disturbance by the following lengths of upstream pipework:
  - ➢ Design for a minimum of 20 D.
  - ➢ Insist in having at least 10 D.
  - ➢ Do not install with less than 5 D.
- Downstream straight pipe should be a minimum of half that of the upstream length.
- Ensure any upstream valves are always fully open.
- Do not install close to pumps or control valves. The extreme flow disturbances and potential aeration, cavitation or pulsation may cause errors.
- Record location of upstream and downstream valves for maintenance.
- Fit tapping boss for insertion meter verification.
- It has been observed that reduced-bore meters produce lower levels of additional error when installed downstream of disturbances

9 Outputs, Readouts and Verification

No meter is much good unless the output of flowrate or quantity passed can be read and recorded. E.M. meters have a wide choice of both local display and remote transmission of the readings. Local displays are self-explanatory and can be configured to read in any units desired and at almost any resolution. The choice of remote reading is more of a concern.

The first choice must be to utilise the digital output capability. This may be implemented via serial (RS232 or RS485), HART type communication superimposed on a current loop, or full 'Fieldbus' type communication. For all these options, the meter can be interrogated to provide flowrate or total quantity readings, diagnostic information and the full resolution of the device utilised.

Experiment has shown that the pulsed, digital and current outputs replicate each other extremely well when using one of the main recognised makes of meter.

Where a 4-20 mA output or a pulsed output is used, the user has to consider resolution issues. The output of the meter does not generally suffer from any lack of resolution available. The user does, however, have to recognise the potential lack of resolution in the signal transmission or data logging installed to record the output. For pulsed outputs the resolution is chosen to suit the application; however, the resolution chosen for normal consumption metering may be inadequate for leak testing.

For current outputs a meter configured to give 20 mA at 2 m/s will be giving 4.16 mA at a low velocity (0.02 m/s). If leakage flow has to be measured, the data logger will require to resolve to better than 0.1 mA to be useful. Full 16-bit conversion is recommended when choosing the data logging and transmission.

10 CFD Flow Modelling

Computational Fluid Dynamics (CFD) is a computer-based simulation technique that can be used to model the disturbed flow through an electromagnetic meter and predict the error in the measurement. This method has been shown to give particularly good predictions when bends are modelled but comparisons are less good when a partially closed gate valve is introduced (> 25% closed).

CFD modelling is particularly advantageous in the following applications:

- Assessment of large meter installations (expensive to assess by any other method).
- Investigation of pipe blockage and material build up effects.
- Extrapolation of test data to field conditions.
- Sensitivity and design studies.

The full description of this work has been published as NEL report no 2003/123: 'C.F.D. Simulation of Installation Effects for Electromagnetic Flowmeters'

This is available from the Flow Programme web site: **www.flowprogramme.co.uk** or from NEL directly.

Contact for Further Information

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Guidance Notes

This series of Guidance Notes is designed to provide, in condensed form, information on flow measurement methods and equipment that has been generated as a result of Flow Programme work. In each case, the Guidance Note is based on the full project report, which is available from NEL
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