

Rethinking Dry Calibration

Roger C BAKER, Pamela I MOORE & Tao WANG,
(Institute for Manufacturing, University of Cambridge, UK)

Abstract The use of dry calibration for modern flowmeter technologies may offer a way to reduce the frequency and cost of wet calibrations. This paper contrasts the acceptability of dry calibration for the orifice plate with the use of dry calibration for modern flowmeters. Some background to dry calibration is reviewed, in particular for the electromagnetic flowmeter (EMFM). Suggestions have been made to achieve dry calibration in modern flowmeters, and the paper explores how this might be achieved in various designs. Some new strategies are discussed for dry and *in situ* calibration. It is concluded that dry calibration techniques should be reconsidered and incorporated within the design and manufacture of meters, and combined with e-calibration.

Keywords Flowmeter, dry calibration, *in situ* calibration, e-calibration

1. Introduction

1.1 Working definitions

In the context of dry-calibration we imply^[1] by:

Calibration: the installation and testing of a flowmeter in an accredited flow calibration facility resulting in a certificate traceable to a national or an international standard.

Dry calibration: the physical measurement of the flowmeter to confirm that dimensions, amplification, magnetic field etc. have not changed in the course of its use, so that the uncertainty at manufacture is retained (e.g. ISO5167^[2] and Al-Rabeh and Baker^[3]). Perversely, this could require the meter to be full of liquid although the flow rate of the liquid is not a factor in the measurements.

Verification: means of measurement which only partially confirm the integrity of the meter, for example by:

- a flow test in which the flow rate is from a traverse of the flow profile in a pipe;
- the checking of electrical and magnetic quantities in an electromagnetic flowmeter, but not the integrity of the flow tube^[4].

For the electromagnetic flowmeter (EMFM) verification may check electrical and magnetic values plus security of earths, cables and insulation. Dry calibration requires that the wetted geometry is checked to ensure that it is unchanged. It is worth noting that, whereas the extraction of an orifice plate for inspection and measuring may not be too difficult a task, particularly where special designs of carrier allow such removal, the removal of, say, an electromagnetic flowmeter for inspection is a major task, and may gain little over removal for wet calibration.

There is the further matter of the installation and the constancy of the relationship between generated signal and flow rate. Even when a meter is removed for re-calibration, the nature of the flow profile which it measures when installed is not checked. The

correct installation is a matter for the customer. It is interesting to consider, therefore, that future analysis of the flow signals may provide a check on the suitability of the installation. Such ideas have been proposed in the past, for instance by using a second rotor in a gas turbine meter^[5].

1.2 History

In discussion of dry calibration, it is important to recall that the coefficient of discharge of the standard orifice plate has been documented for over 100 years^[6] and, in normal use, is never calibrated today.

The idea of dry calibration was considered for the EMFM, possibly in part due to the simple relationship which it appeared to obey:

$$\Delta U = SBDV_m \quad (1)$$

where ΔU is the voltage generated between the electrodes, V_m is the mean velocity in the pipe, S is the flowmeter sensitivity, B is the magnetic flux density and D is the internal diameter of the pipe. Using a more complete equation for its behaviour it appeared possible to predict the relationship between the flow and the output signal, but in practice it proved hard to achieve. Both Murgatroyd and Shercliff^[7] suggested the need for standardised designs of meter. Haacke^[8] described a flow simulator which he used for 'dry calibration' and for which he claimed an uncertainty of 1.75% or better. Al-Rabeh and Baker^[3] undertook careful construction and measurement of an experimental electromagnetic flowmeter and concluded that "dry calibration of flowmeters using magnetic field measurements is attainable to accuracy levels dependent on the precision of the magnetic field measurements".

Dry calibration for standardised instruments has continued, alongside a lack of acceptance of the possibility of dry calibration for modern instruments. It is only recently that the cost of calibration, both in manufacture and in maintenance, has reawakened interest in the possibility of dry calibration.

2. Standardised devices

Dry calibration of the orifice plate should include measurement of the plate, measurement of the tappings etc., visual inspection of the impulse tubes, calibration of the pressure transducer and integrity of the sensing circuits. In addition the upstream and downstream installation should meet the requirements of ISO5167, which assumes that there are no deposits etc.

The standards claim 0.5 to 0.75% uncertainty for the discharge coefficient. Baker^[9] showed the result of combining this with typical (good) uncertainties for the other parameters in the flow equation. With great care this can result in an uncertainty as low as 0.57% for water and 0.64% for air.

To retain the initial uncertainties will require considerable care in the dry calibration, and a not-insignificant amount of time spent. A larger uncertainty on differential pressure and a larger uncertainty on the ID of the pipe can result in a total uncertainty exceeding 1%.

The paper of Reader-Harris *et al* on venturi manufacturing uncertainty^[10] indicated the problem of eliminating unidentified variational effects.

It may be useful to identify the figure of 1% as a target for dry calibration. The object, clearly, must be to achieve this, and then better it.

3. Modern flowmeters

Meters for which dry calibration is likely to be relevant and for which verification is currently being introduced are: vortex; electromagnetic; ultrasonic; Coriolis.

3.1 Vortex flowmeters

The vortex flowmeter is included because of similarities to the orifice, although the signal analysis may be less precise than for the other designs. A recent paper by Takamoto & Terao^[11] looked at the possibility of dry calibration for vortex meters

It is useful to consider what would cause changes in calibration from the predicted value. This might be:

- changes in the surface finish of the tube, or deposits after a period of use;
- changes in the bluff body, again due to deposits or due to wear;
- changes in the sensor which cause it to change its sensitivity to pressure fluctuations;
- changes in the electronics or design problems which result in spurious pulse counts.

Takamoto and Terao^[11] commented that "it is very important for the dry calibration (of vortex flowmeters) to minimise the manufacturing error or measurement error of the dimensions of the

flowmeter". They discussed the predictive uncertainty of their design which uses a trapezium cross-section bluff body. They appear to have achieved results within about 0.2%. However, they identified a clearance gap between the bluff body and the meter body which causes significant changes in the linearity of the vortex meter. It is in the region of a horseshoe vortex which is shed by the root of the bluff body. It appears, therefore, that if this type of detail can be controlled, there is good reason to expect that a dry calibration of the vortex meter is as possible as of the orifice meter.

The use of signal analysis may allow a further step towards checking the flow. Rossberg *et al*^[12] demonstrated a method for detecting inappropriate installations of vortex meters. Using a model of the signal they expected to be able to detect erosion, deposition or inhomogeneity of the flow. They claimed that their experiments detected installation effects that led to more than 0.5% error. The work appears to be at an early stage, but it is likely that advanced signal analysis combined with a satisfactory model of the flowmeter and signal could, indeed, yield such data. Thus Rossberg *et al*^[12] may be able to identify wear. The problem of incorrectly registered and transmitted pulses may need other considerations, but this is, in a sense, similar to problems with pressure transducers etc. for orifice plate meters.

3.2 Electromagnetic flowmeters (EMFM)

Shercliff^[7] commented: "For most purposes a much more useful type of meter (than one whose calibration is predictable to high accuracy) would be one whose calibration, though not predictable from theory, was accurately reproducible, and which was cheap and simple. Empirical calibration laws could be established for it to cover a wide range of conditions in the manner that has long been done for orthodox flowmeters. ... Though Murgatroyd several years ago suggested that one or more standard designs of transverse-field flowmeter should be agreed upon and tested exhaustively to yield standardised calibration data, no progress towards this desirable goal can be reported." Shercliff's comments are still essentially true with each manufacturer producing their own design. However, a new direction has been developing with the move from "simulation" which was the injection of signals into the electrode circuit to check the operation of the flowmeter secondary circuit, to "verification" which attempts to check more of the operation of the meter.

Two of the authors recently undertook some work on verification^[13,14]. Several manufacturers^[4] offer verification of electrical circuits. One or more offer verification including checking the magnetic field size, and verification claims for these may be

between 1 and 2%. Excluded from this uncertainty calculation are:

- liner condition;
- deposits;
- flow profile changes.

There is a valid question, therefore, as to the extent to which these could be checked. This intriguing question is under consideration at Cambridge University and is the subject of a patent application.

3.3 Ultrasonic flowmeters (USFM)

Ultrasonic transit time flowmeters are generally available in three design configurations: clamp-on, weld-on and spool-piece. In all three configurations the geometry and flow profile are the two main parameters which influence the calibration factor. Associated with each of these parameters is a range of possible sources of uncertainty including:

- transit time calculation;
- wall thickness;
- pipe roughness;
- turbulence intensity;
- Reynolds number;
- time delay;
- transducer location.

It is useful to consider the different forms of ultrasonic flowmeter separately.

Spool piece transit-time flowmeters

The possibility of dry-calibration exists where the effect of geometry and profile factor can be minimised or eliminated. Drenthen and de Boer^[15] have demonstrated that geometry and profile factor combined uncertainty is of the order of 0.36 % in the case of their ultrasonic gas flowmeter design.

These low values of uncertainty for dry-calibrated instruments, and the possibility of reducing them further, are promising for the future. Although the problems of measurement in a *weld-on design* are greater, possibilities for dry calibration also exist.

An example of extending the use of sampled data from a multi-path gas meter to estimate the turbulence intensity distribution in the pipe is given by Zanker^[16].

It is, also, possible that measurement of path lengths could be achieved by geometrical measurement with a special tool^[15], or independent electronic means of path length measurement, while the meter is in line. Such a probe could also provide information on pipe deposits and pipe dimensions.

Clamp-on transit-time flowmeter

The use of the large amount of data available from the ultrasonic signals has been suggested^[1], but not

completely used to date. This could give indication of operating changes or problems. It was suggested^[1] that ultrasonic technology might develop a clamp-on meter (possibly a master meter) that senses:

- wall thickness,
- the quality of the inside of the tube,
- beam steering and focussing;
- the turbulence level,
- flow profile from a range gated doppler system,
- flow measurement from a transit-time system,
- correlation to provide information about a second phase,
- density from the impedance and sound speed,
- condition (self) monitoring.

These possibilities take us beyond dry calibration to pose the question: "Could a clamp-on system achieve an accuracy to be accepted as a transfer standard master meter?" This possibility has been foreseen for some time^[1].

3.4 Coriolis flowmeters

Checking the Coriolis flowmeter will require that it is highly stable, and that any shift in its structure can be sensed. Wang and Baker^[17] have discussed the effect of very small variations in manufacture on the signal, and have looked at the effect of prestress. This suggests that checks on resonant frequency might provide useful information, as appears to be used by at least one manufacturer.

In theory the sensitivity factor of mass flow rate for a Coriolis meter is determined by its equivalent stiffness. It is well known that the resonant frequency is used for density measurement. Since the stiffness of a structure can be characterised by its resonant frequency, changes of stiffness or mass (resulting from creeping of the measuring tube material or erosion), may result in a change of frequency and provide a means of *in situ* calibration with a fluid of known density. Small adjustment might be provided *in situ* or, as has been suggested^[18], an inspection might be recommended.

This can be shown by a numerical simulation. By using the numerical model described by Wang and Baker^[17], the effects of axial stress change and wall thickness change were evaluated. In the former case, stress relaxation of 10MPa was simulated and gave 0.3% increase of mass flow sensitivity corresponding to 0.9 Hz decrease of drive frequency. In the latter case, 5µm wall thickness reduction was modelled and gave 0.6% increase of mass flow sensitivity corresponding to 1.0 Hz decrease of drive frequency. It appears that these small changes to mass flow measurement can be indicated by changes in the drive frequency. Therefore, a check of the frequency may provide an efficient means for determining a calibration error condition^[18].

4. Discussion of possibilities

The benefits of dry or *in situ* calibration are many. However, this paper has highlighted differences in approach which are significant:

Removal for measurement

It should be remembered that the orifice plate requires removal for checking (dry calibration), and as a result commercial systems have been developed to allow this^[1]. If dry calibration is to be a satisfactory option for modern flowmeters, then ways will be needed to avoid spool piece removal from the line. This may require that, for instance in the case of the vortex flowmeter, the bluff body is removable. However, inspection or checking of the inside of the tube will still be important.

***in situ* dry calibration**

To measure the internals and the physical features of a modern flowmeter while remaining in line, and possibly full of liquid, will not be easy even where dimensional measurement gives promise of low uncertainty. To achieve this there is a need to develop:

- designs allowing the extraction of key items of flowmeters for measurement without removing the flowmeter;
- measurement systems dependent on electrical signals only;

However, one meter which may offer *in situ* dry calibration is the ultrasonic meter:

Special measurements

As indicated earlier we are developing some ideas to achieve the measurement of the continued integrity of the EMFM.

Certain measurements may provide an initial fingerprint for the Coriolis meter.

Within the output signals of modern meters, there may be information which we fail adequately to interrogate, and which may provide significant confirmation of continued operational integrity.

Permanently installed weld points for ultrasonic transducers

Lynnworth^[19] has suggested a clamp-on off-axis meter using cut-outs in the internal bore of the tube. Thus the transducers can be removed and replaced when required. The idea of installing welded-on insertion points for the ultrasonic transducers has been considered by us for other types of modern meter. For instance, the vortex meter might be so equipped to allow a set of transducers to be inserted

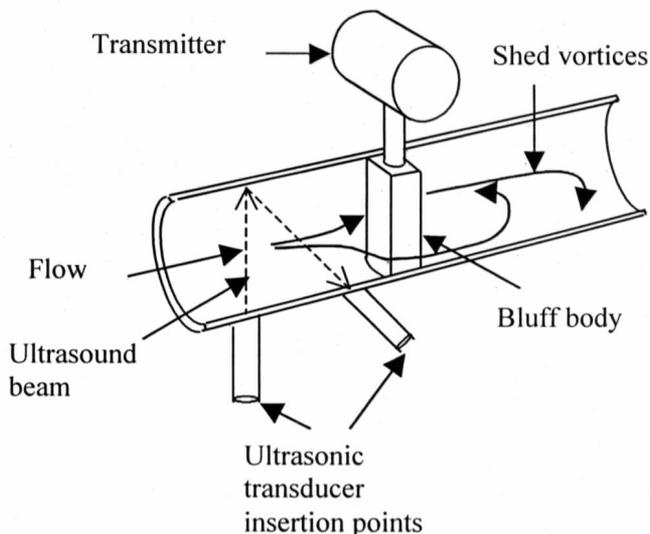


Figure 1 Non-ultrasonic flowmeter with welded-on receptacles to provide ultrasonic transducer insertion points

from time to time to check the measurement signal (Figure 1). Such an approach would need to be tested for industrial acceptance of weld-on ultrasonic transducer insertion points on other (non-ultrasonic) flowmeters, and to convince the certification authorities of their validity.

Hybrid concepts

This method approaches Medlock's^[20] concept of hybrid meters. One such hybrid could be a bluff body in an EMFM such that the frequency shedding and the EMFM flow signal would be continually compared to ensure that neither had drifted and to infer from this that the meter was operating within calibration uncertainty.

Clamp-on ultrasonic master meter

A clamp-on ultrasonic master meter would:

- avoid removal of flowmeters from lines, with the resultant cost and the inconvenience;
- greatly reduce the labour commitment required;
- bring the calibration to the site of the flowmeter installation and avoid damage to meters during removal and shipping;
- possibly allow development of e-calibration methods, the calibration of flowmeters with national accreditation by use of signals transmitted through the internet. The whole of this procedure could simplify to a drag and drop procedure on a remote desktop computer.

At present the accepted uncertainty for clamp-on meters is up to 5%. The aim should be to reduce this significantly in order for the meter to approach master meter performance.

5. Conclusions

There is further work to do before we can be sure that either *in situ* dry calibration or the use of a clamp-on ultrasonic meter as a master meter would achieve sufficiently small uncertainty.

It is likely that much research effort is being put into ways of avoiding flowmeter removal for calibration, and there are major implications for manufacture relating to low variation, good housekeeping and documentation, and resultant high quality.

The realisation of e-calibration could bring major benefits.

Bodies which administer national calibration standards for flow measurement, will need to be open to the developments of the next few years.

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