Process measurement calibration:

Why? What? When? How? Who?

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It is a truth, universally acknowledged, that a process in possession of a measurement must be in want of calibration. (With apologies to Jane Austen). Calibration is widely understood to be a good thing, but contrary to the above sentiment, it is not in fact universally good. Calibration, even when correctly performed, can be a bad thing if it expends time and resources to no good purpose. This paper explores the underlying rationale of measurement system calibration to help identify the Why? What? When? How? and Who? of effective calibration.

There is perhaps a greater general concern with calibration than formerly, with the development of the disciplines required for certification of Quality Assurance. Unfortunately this has led some to fall in the 'some is good, more is better' trap. There are many circumstances where routine calibration is simply redundant. Whilst not immediately damaging, it does represent a waste of resources and a distraction from real business concerns.

I distinguish here between, 'routine calibration', i.e. calibration performed at intervals during equipment service, and 'non-routine calibration'; such as pre-commissioning, or post overhaul checks.These non-routine calibration checks are a usual requirement during pre-commissioning to detect gross errors arising from procurement or set up.

Why?

A measurement will suffer two component types of error:
1. An error component - which will vary between repeated measurements of the same variable made under the same circumstances; sometimes referred to as 'random error' or 'precision'.
2. A systematic error component - which is fixed for repeated measurements of the same variable made under the same circumstances; sometimes referred to as 'bias'.

The random error is essentially determined by the measurement device/system design and its intrinsic capability, and will remain unaffected by calibration. It will, however, tend to worsen as a measurement system deteriorates through damage, wear or ageing.

Although calibration cannot itself correct random errors, it can be used to detect them and identify a deteriorating system. This can be a useful diagnostic provision.

Systematic errors will arise from a host of causes, including variations in operating/environmental conditions, physical installation effects, configuration errors, ageing and drift.

Drift may be generally defined as "an undesired change in the (measurement system) output-input relationship over a period of time". In practice it is recognised as a non-random (systematic) change in a measurement of the same value of a variable made under the same circumstances over a period of time.

If a measurement system reports the temperature of boiling water at atmospheric pressure as 100°C initially and then as 99°C a month later, the measurement may be said to have suffered drift of 1°C.

The point of routine calibration is that:
a) It can reveal degradation of a measurement system in increased random error components.
b) It can reveal and correct drift in the measurement system.

What is the cost of drift? For many measurements, such as those associated with supply contracts, the drift may favour either party and it is conceivable that it may actually be profitable for you until it is recognised by the other contractual party. Calibration is used here to reduce the uncertainty in the contractual sums payable.

For other measurements, there is only a downside to drift, since it will mean your process will operate away from optimal conditions. If a measurement relates to a process constraint, the implication of drift is that you will operate further from the constraint than necessary or that you unknowingly violate the constraint.

In simple terms:
Profit=Product Revenue–Raw Material Costs–Fuel/Energy Costs-Fixed Costs.

Figure.1: Well planned calibration ensures that you achieve the optimum balance.

Figure 2: Endress+Hauser's water-based flow calibration facility in Manchester.

It is therefore possible to consider the uncertainty in profit due to uncertainties in product, feedstock and energy measurement.

The smaller the profit margin, the more significant (in proportional terms) the uncertainty in these measurements will be. Discounting fixed costs for the moment to simplify the point, a 10% profit margin would mean that ±2% uncertainty in product volume would represent ±20% uncertainty in profit.

One can argue that 'profit' is known without uncertainty which, in accounting terms, is true. However, the uncertainty relates to the range in which the profit figure could move with no change other than drift in the stream measurements.

In practice, it may well be the hidden cost of sub-optimal operation that will be the more significant loss. Consider what 1% reduction in yield or efficiency represents in terms of business performance. How much influence a given measurement will have on such performance is, of course, entirely dependent on the specific configuration of the process.

What?

If we consider the philosophy of a conventional feedback control loop (regardless of actual application), the following observations can be made:

• Any drift in the output circuit or final element calibration will be corrected by the feedback loop without exerting influence on the process.
• Only drift in the set point or measurement will result in a corresponding error in the process. There is, therefore, no point in routinely calibrating analogue outputs, I/P converters or valve positioners to eliminate drift. (There may, however, be other reasons e.g., diagnostic function checks.)

If you consider the common cascade control configuration, it is apparent that any drift in the secondary (slave) loop set point, measurement or output will be corrected by the action of the primary controller. Routine calibration of secondary loop systems is therefore redundant.

For example, if a temperature controller manipulates a coolant or steam flow controller set point, any error in the flow control loop will be compensated for by the action of the temperature controller. The accuracy of the flow loop is not important; it is the calibration of the temperature measurement that is critical.

Sometimes it maybe that the operator effectively takes the place of the master loop and makes a set point adjustment based on some other process measurement. Typically this might involve an off-line laboratory measurement. In these circumstances it is the calibration of the laboratory measurement that becomes critical.

Because of the off-line, intermittent nature of these laboratory measurements, they become vulnerable to systematic (predominantly human) errors arising from sampling techniques, sample handling and laboratory procedures. It is important to remain aware of these potential problems as it is all too easy to inadvertently distort process operations due to compromised sample measurements.

Any loop that acts as an intermediate means to a given process end (that is measured by some other provision), is unlikely to require absolute accuracy. It will be sufficient that it offers stable, consistent performance in the short term. This is known as reproducibility, which is like repeatability, but considers additional factors such as the approach to a measurement from both up- and downscale and thereby includes hysteresis effects that are not included in specifications of repeatability.

If an intermediate measurement is consistently wrong, i.e. it suffers a constant systematic error, that is of no particular significance. (If it could not offer consistent performance, then the variations might compromise the corrections applied from the critical measurement.)

Measurements that are likely to require routine calibration include those relating to:

• Product quality.
• Product quantity.
• Feedstock quality.
• Feedstock quantity.
• Energy/fuel quantity purchased or supplied.
• Process operating point.

Note that it is not necessary to formally calibrate all such measurements, the accuracy requirements of some may be quite modest and a simple cross-check against other indications may be sufficient.

Although most of this discussion relates to continuous measurements, remember that some point switching devices will also require calibration to ensure that the switching point has not drifted significantly. For the most part these are likely to relate to protection systems and their correct operation will be subject to proof testing procedures which are often separate from routine calibration provisions. Nevertheless, many of the issues pertaining to calibration will also be relevant to proof testing provisions.

To establish the true calibration needs, a comprehensive survey of the plant measurements is needed to identify:

• Where drift will impact on business performance.
• Their likely or established drift characteristics.
• The acceptable tolerance on measurement and corresponding calibration interval.
• The appropriate calibration procedures.

When?

The frequency with which calibration should be undertaken is dependent on several factors:

• Measurement stability.
• Potential cost of systematic errors.
• Overall cost of calibration.
• Practicability.

Calibration of temperature, pressure, and composition tends to be, in the main, relatively practicable. Isolation and access are usually straightforward and reference standards are commonly available in workshops or plant laboratories. Calibration of flow measurements, however, can be more problematical; it is usually necessary to take a flow meter out of line and transport it to a purpose-built calibration facility. Sometimes a portable proving rig can be used to provide *in-situ* calibration. This has the advantages of minimising disruption and providing a rigorous calibration that will include any installation effects. *In-situ* 'dry' calibration of some flow meter amplifier/converters is possible but this does not, of course, offer the same rigour as a full 'wet' calibration. It may, however, form a useful interim check between full wet calibrations.

Sometimes dedicated proving facilities are engineered into systems at the design stage (typically in petroleum custody transfer applications), but these are exceptional circumstances that justify the additional expense.

Too little calibration will incur process costs, too much will incur excessive overhead costs to the business. An optimum exists that represents minimum overall cost to the business. A formal review of requirements will help identify this optimum. This should consider not only the potential cost of progressive drift, but also that of spurious but unrevealed shifts in calibration.

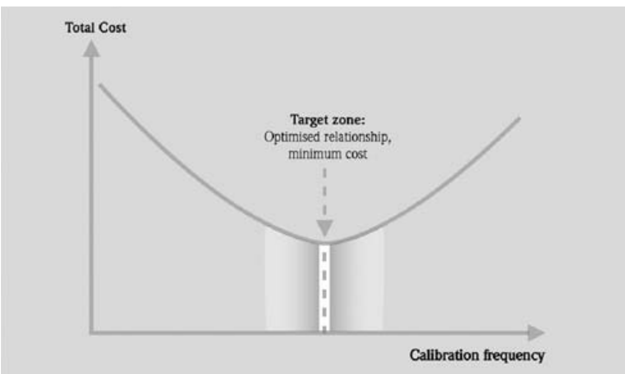

Figure 3: Finding the optimum balance.

How?

Calibration references should be traceable back to national standards. If there is no such traceability, the calibration is of questionable value and could conceivably degrade your measurement. You do not need to identify the full traceability chain, but you do need to have appropriate assurances from reputable suppliers or calibration houses. In this respect UKAS (formerly NAMAS) certification is not essential, but may enhance confidence that proper calibration QA procedures have been adopted.

It is necessary that the calibration standards should be more accurate than the device being calibrated or the calibration may degrade performance. A rigorous calibration will declare the uncertainty of the calibration with a statement of the tolerances of the calibration for a nominated confidence level. [Usually 95%; this relates to the assumed or identified probability distribution of the calibration measurements.]

On critical measurements, adjustment should be made (upon installation) for differences between calibration conditions and actual operating conditions. If, for example, offsets due to changes in operating temperature or line pressure can be quantified from the known characteristics of an instrument, an appropriate correction should be made. More sophisticated installations, such as those typically used on custody transfer duties, will normally include continuous correction for secondary influences such as these.

Calibration should not be confined to end points only (zero/span), but should include a mid-span point to identify non-linearities. A minimum 5 point calibration would be considered good practice. (3 points are satisfactory for functional checks, but are less likely to be adequate for proper calibration of a critical measurement unless you have substantiated confidence in the linear performance of the device.)

It may be useful to have the 'as found' calibration reported as well as the 'as left' (i.e. after adjustment) in order to allow evaluation of drift in performance. This information may be used to refine calibration intervals on the basis of actual in-service drift.

Specific calibration procedures for critical measurements should be written into your QA manual system. These should identify the acceptable tolerances and actions to be taken when they are breached. I suggest you include all measurements that impact on your business performance, not just the narrow subset of those that impact on 'quality'. It may be appropriate to have multiple thresholds with different actions.

An intelligently written calibration manual that effectively discriminates between measurement duties and their specific calibration needs can do much to eliminate wasted effort and provide effective support to your business.

Who?

End-users have a decision to make here. Whether to tackle calibration in-house or whether to outsource? As long as the appropriate disciplines are maintained there is no particular virtue of one over the other, except in custody transfer applications where an outside company can offer a degree of independence that can enhance confidence for the contractual parties.

The critical question is the resource allocation required to maintain the appropriate disciplines. Proper management and execution of calibration routines is not a trivial matter. If you do not have the personnel and equipment to undertake calibration with appropriate rigour, it is more appropriate to consider outsourcing. We all know what the road to hell is paved with! If other demands mean that the calibration routines are likely to be continually displaced or overlooked, there is little point in denying this reality.

Calibration is a QA critical activity of course; appropriate methods, disciplines and competencies are required. Any failure in this will compromise the calibration and may do more harm than good. In many service activities, an indifferent performance would be immediately apparent to the user who could take appropriate steps. This is not necessarily true of calibration, where indifferent performance may remain hidden together with the associated costs. End-users need to have full confidence that any service provided will be effectively performed with appropriate rigour.

A combination of internal and external resources is the likely optimum. The key requirement is to identify the scope of the real calibration requirements as they relate to your business. It is a truth, almost universally unacknowledged, that much of the time and money spent on calibration is expended to no good purpose.