Minimizing Calibration Costs for Measuring and Test Equipment

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Inspection and testing are two of the most important activities performed by service centers. Additionally, it is critical that special processes such as vacuum pressure impregnation and oven cycles are controlled. When collecting measurement information, service center technicians obtain data consisting of two components – the actual value of the measured dimension and the error associated with the measurement. The service center should be focused on minimizing measurement error such that the measurement values are reasonably close to actual values. One necessary step in minimizing measurement error is calibration of measuring & test equipment (M&TE). As with any process, it is beneficial to ensure this activity is carried out in a cost effective manner.

ACCURACY & PRECISION

Measurement values determined by use of M&TE are a function of the true value as well as the M&TE accuracy and precision. The terms accuracy and precision are often demonstrated and differentiated graphically using an archery example as shown in FIGURE 1.

Precision refers to the degree of repeatability and reproducibility in the measurement system. M&TE repeatability is the ability of a single technician to obtain the same measurement value multiple times using the same M&TE on the same measured item. M&TE reproducibility is the ability of multiple technicians to obtain the same measurement value using the same M&TE on the same measured item. The precision of M&TE is commonly assessed using repeatability & reproducibility (R&R) studies which are outside the scope of this session.

Accuracy is the degree to which the measured value agrees with the true value. The accuracy of M&TE is assessed through calibration, which is the focus of this session.

CALIBRATION

Calibration is a term often misunderstood and misused. Simply put, calibration is nothing more than a comparison. Calibration quantifies the relationship between the readings of the M&TE (e.g. caliper, ammeter, thermometer, pressure gauge) and the relevant standard measurement units. The M&TE readings are compared to the values of a measurement standard under controlled and specified conditions. Properly establishing the necessary conditions and performing this comparison can be a simple or complex process, depending on the nature of the subject M&TE and the accuracy required.

Calibration is formally defined by the Joint Committee for Guides in Metrology (JCGM) in the document JCGM 200:2012, “International vocabulary of metrology – Basic and general concepts and associated terms (VIM).” The definition provided in JCGM 200:2012 §2.39 is included here for reference.

Calibration: operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with...
associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.

Note 1: A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

Note 2: Calibration should not be confused with adjustment of a measuring system, often mistakenly called “self-calibration”, nor with verification of calibration.

The definition tells us that if we have a standard and we know its uncertainty (e.g. gauge block of 1.00000+/-.00001 units) then under specified conditions we can compare an indication or reading from our M&TE to the gauge block. Using information gained from the comparison, we can determine whether our M&TE gives valid results and assign an associated uncertainty which is usually much larger than that of the standard.

Note 1 tells us that the comparison can be documented in several forms including curves or tables and that adjustment factors could be involved. For example, an M&TE might indicate a percentage of the value in question (e.g. current transformer).

Note 2 emphasizes that calibration is not adjustment or verification of calibration. Adjustments are used to bring the indicated value of M&TE closer to the standard value. Of course not all M&TE can be adjusted (e.g. ruler, thermometer) even though they can certainly be calibrated. When M&TE cannot be adjusted to provide adequate indications throughout their range of use, they are usually given limited calibration status or removed from service. Verification of calibration is more of an audit function such as reviewing an affixed calibration sticker, equipment calibration log or calibration certificate.

TAR VS. TUR

The terms Test Accuracy Ratio (TAR) and Test Uncertainty Ratio (TUR) are both used in calibration circles and are not clearly differentiated. While it is not important for personnel using M&TE in the service center to understand these topics in great depth, some familiarity should be present if in-house calibration is to be performed.

The Test Accuracy Ratio (TAR) is the ratio of the accuracy tolerance of the M&TE (also termed UUT for unit under test) to the measurement ensemble (ME). For simple calibrations, the measurement ensemble may consist only of the standard, but for more complex calibrations, several instruments and accessories may be required to complete the calibration. The TAR is calculated as TAR = UUT tolerance / ME tolerance. The idea is that the larger this ratio is, the less likely any error is to be attributed to the ME. Typically, a TAR of 4:1 is deemed acceptable and for most service center measurements, this would probably be sufficient for calibration without additional uncertainty analysis being performed. For example, if a lab calibrated voltage meter used as a service center standard has a 0.1% accuracy tolerance and the service center feels that measurements with 1% accuracy tolerance are acceptable, a TAR of 10:1 would exist. Similarly, temperature measurements with a standard having an accuracy tolerance of 1°C should be fine for an oven chart recorder providing an assigned accuracy tolerance of 4°C is acceptable. In the case that the assigned accuracy tolerance range is larger than the manufacturer’s tolerance range, this limitation should be clearly identifiable by anyone using the M&TE. By default, a standard at least 4 times as accurate as the manufacturer’s tolerance would be chosen.

The Test Uncertainty Ratio (TUR) is the ratio of the accuracy tolerance of the M&TE (or UUT) to the measurement ensemble (ME) uncertainty. The TUR is calculated as TUR = UUT tolerance / ME uncertainty. A 10:1 or 4:1 TUR is strived for by many calibration laboratories but with some technology, this just is not possible because the M&TE (UUT) has such a high required accuracy tolerance that the standard is not much better. The ME uncertainty is different than the ME accuracy tolerance. It is a statistical calculation (standard deviation) and is usually calculated for a specific confidence level by multiplying by a factor “k” which represents the number of standard deviations that would envelope the desired confidence level. Using a 95% (k=2) confidence level is typical. For very large sample sizes, roughly 68% (k=1) of readings will fall within one standard deviation and roughly 95% (k=2) will fall within two standard deviations. Again, for most service center or shop calibrations, having a TAR of 4:1 is usually acceptable and the TUR would not be...
calculated. Reporting the TUR is standard for accredited labs though and for that reason, there is less risk in accepting the results of their calibration services than services without a known TUR.

**TRACEABILITY**

Traceability in metrology requires a calibration hierarchy such that there is a sequence of calibrations from a reference (standard) to the final measurement where the outcome of each calibration depends on the outcome of the previous calibration. This requires that the measurement uncertainty increases along the sequence of calibrations. An example of this type of chain is as follows.

- National Standard ±0.001 units
- Reference Standard ±0.01 units
- Working Standard ±0.1 units
- Service Center M&TE ±0.5 units

**CALIBRATION PROGRAMS**

Specific calibration program requirements will vary by service center and could come from several sources such as customers, regulatory bodies or accreditation. Customer requirements should always be evaluated first before any business process decision is made. A service center whose most stringent customer is a local car wash may have a much different calibration program than one who repairs safety-related motors for a nuclear generating station. However, all service centers should implement a calibration program sufficient for giving them reasonable assurance in the process monitoring, test & inspection activities they perform.

**Getting Started**

**What types of M&TE should be calibrated?**

All M&TE used for activities affecting quality should be controlled, calibrated at a specified frequency, and adjusted where necessary to maintain required accuracy limits. Typically, the most reliable measurements are made by qualified technicians using calibrated M&TE in accordance with standard work instructions.

For service centers interested in the EASA Accreditation Program, a list of calibrated equipment required for repairs can be found in Annex A of the EASA Accreditation Checklist. Note however that this program is limited in scope to three-phase, squirrel cage motors so the equipment list does not necessarily envelope all M&TE used by the service center.

**What info should be compiled to get started?**

It is beneficial to gather and store some general information about all M&TE in an indexed manner. Most often, this is done in a database but it is certainly possible to have an effective paper-based system. For each M&TE item, a typical index may contain the following types of information.

- Unique identifier – assigned by the service center for use on labels, test forms (e.g. MTE-001, 002)
- Manufacturer, model number, serial number
- Category – assigned by service center (e.g. tachometer, micrometer, pressure gauge)
- Calibration interval – assigned by the service center (e.g. 3 months, 12 months, before use)
- Calibration due date (e.g. 14 JUN 2015)
- Maintenance interval – useful to combine any required preventive maintenance with calibration and synch where possible (e.g. 3 months, 12 months, before use)
- Maintenance due date (e.g. 14 JUN 2015), if applicable
- Location – simplifies equipment recall (e.g. machine shop, test center, winding area)

Compiling this information through a comprehensive inventory process is strongly recommended before beginning any calibration activities. A simple analysis of this information can help the service center make the right decisions about which M&TE to calibrate, which calibrations should be done in-house and which
should be subcontracted, and what M&TE are in shortage or excess.

Once the inventory is complete, the M&TE index can be sorted by equipment category. Based on subcontract calibration pricing, complexity of the calibration and quantity of M&TE needed, the service center can decide whether there is a cost benefit in developing an internal calibration procedure or that it makes more sense to subcontract the service.

This is also an opportunity to develop a more efficient, visual workplace by bringing shop tools and M&TE out of the tool box and utilizing concepts such as shadow boards (see FIGURE 3). Using shadow boards or similar visual storage clears floor space, makes it easier to locate and retrieve tools and can significantly reduce the quantity of tools needed. For example, one digital multi-meter and clamp-on ammeter on a shadow board with universal employee access may replace 2 or 3 in tool boxes. This can significantly reduce calibration costs.

![FIGURE 3: SHADOW BOARD](https://youtu.be/PyUwWkjn-0w)

Additionally, a service center may identify that they have 10 each, 0-1 inch micrometers but would never need more than 6 at one time. A decision might be to calibrate 0-1 inch micrometers internally based on cost estimates and to place 4 of them in storage identified as "calibrate before use" (CBU). Alternatively, the service center may find it cost prohibitive to calibrate other types of tools internally or discover a shortage based on availability versus need.

**Subcontract Calibration**

Many service centers subcontract calibration of their M&TE to firms specializing in such services. When choosing subcontract calibration providers, it is worthwhile to consider laboratories accredited to ISO/IEC 17025 whose scope of accreditation is appropriate for the service center M&TE requiring calibration. These labs have been audited by an accreditation body to ensure that they are competent within the scope of their accreditation. For example, a lab may be accredited for temperature but not for voltage. This may not be a practical approach for all motor repair equipment, but in exception cases, the equipment manufacturer may have an adequate calibration service offering.

Many accredited labs also include with their calibration service tools for making calibration program management much easier. For example, many labs will index your equipment and store all associated records in a web accessible database with recall functionality. This means they will absorb the vast majority of the administrative work required and the service center would be notified when equipment is due for calibration and be able to retrieve items such as calibration history, calibration certificates and repair information easily.

**In-house Calibration**

When the determination is made to perform certain calibrations in-house, the service center must maintain traceability and have the necessary environment, laboratory equipment and personnel skills. This can be a feasible and cost effective approach for certain types of M&TE depending on the available standards and skills of existing service center personnel.

A good starting point for in-house calibration might be micrometers if the service center has a machine shop. Many machinists learn how to calibrate these types of tools in trade school or perhaps the military. Additionally, service center technicians with a strong electronics background may have already had experience calibrating digital multi-meters. Another approach may be to shadow a subcontract calibration supplier for M&TE done on-site to get an idea of the complexity, necessary standards, etc. The calibration certificate will also identify the standards used. The best approach will likely be different for each service center depending on the quantity of M&TE to be calibrated, the necessary capital investment required for standards and program development and the skills of existing personnel.

Development of the calibration program typically involves the following activities:
• Evaluation of equipment capability
• Identification of calibration requirements
• Selection of standards
• Selection of calibration frequency and rules for adjusting the frequency
• Establishment of a recall system
• Implementation of a documentation and reporting system
• Evaluation of the calibration program through audit

Calibration procedures should be used that contain adequate information for the calibration of the M&TE. Calibration procedures can be developed by the service center, the M&TE manufacturer or a third party. They can also be developed using material compiled from any of these sources. Additionally, calibration procedures should be approved and controlled in accordance with service center document control procedure.

So, when the service center decides to perform calibration in-house, there is some development work required that will hopefully be offset by long-term savings. This is why an evaluation is critical when making this decision. Typical contents of calibration procedures are listed below.

• Equipment description (e.g. type, model, specifications)
• Measurement standards and auxiliary equipment required (e.g. gage blocks, power supplies)
• Preliminary operations required (e.g. safety, handling, cleaning, operational checks)
• Calibration process (e.g. detailed set of instructions, tolerance limits)
• Calibration results (e.g. records of calibration including control, retention)
• Closing operations (e.g. labeling, tamper prevention)
• Storage & handling (e.g. requirements for maintaining fitness for use)

It is common practice for many calibration procedures to require Test Accuracy Ratios (TAR) of 4:1 or better between the standard used and the M&TE being calibrated. That is, M&TE with an accuracy of 4% would be calibrated by using a standard whose accuracy is 1% or better.

Additionally, it is reasonable to adjust the required accuracy of M&TE to meet the needs of the application. For example, if 10% accuracy is sufficient for an application, the standard used for calibration may have 2.5% or better accuracy. This can result in a direct cost savings. Whether manufacturer specified accuracy or an alternative accuracy is used, the conditions of the calibration will be documented through a label on the M&TE that is linked to a calibration certificate (or equivalent record) on file at the service center that references the applicable calibration procedure.

As previously mentioned, when accuracy tolerance used for acceptance exceeds that of the manufacturer, the M&TE should be identified as having limited calibration. This is to ensure that it is not used for tests, inspections or process measurements where a false assumption of accuracy nullifies the measurements. This can be done using a special calibration label simply marked as limited that directs the user to research the M&TE limitation before use or a more detailed label could be used that actually lists the limitations. In either case, it should be marked differently than standard calibrated M&TE.

For example, if a pressure gauge used on a VPI system where processing is at 80±5 psi is to be calibrated and the gauge has a range of 0-200 psi, it is reasonable to have a limited calibration performed, maybe from 70-90 psi. FIGURE 4 shows an example of how this pressure gauge might be labeled.
Calibration Checks
In-house calibration checks are not considered calibrations and do not need to be treated as such. There are many checks for different types of M&TE that provide the operator with some added assurance that the M&TE is acceptable for use. These optional checks are performed in-between required calibrations at a frequency suitable to the service center. However, calibration is required any time an adjustment is necessary.

For example, an organization may have a calibration check in place such that 1-inch micrometers are checked for a zero indication when closed and a 1-inch indication using a working standard before use. This gives the operator a certain level of confidence that measurements taken between 0 and 1 inch will be accurate. Another example would be the use of ice-melting points and steam points with thermometers.

Impact analysis for out-of-tolerance conditions
If there is one important aspect of a calibration program that organizations most often fail to implement, it is impact analysis for out-of-tolerance conditions. As previously mentioned, adjustments are used to bring the indicated value of M&TE closer to the standard value. If an indicated value is actually out of tolerance, the validity of previous measurements should be evaluated and the evaluation should cover measurements made at least back to the last acceptable calibration.

The evaluation performed and resulting actions taken by the organization should be commensurate with the significance of the condition. The actions could vary from documenting that no additional action is required to notification of customer and/or recalling work product. Again, knowing the application is important here – remember the car wash versus nuclear generating station example?

CALIBRATION COSTS
Excellent organizations rarely incur intentional expenses that do not lead to increased business performance. That is, if it is not going to make the organization more successful, do not do it. Calibration

![FIGURE 5: RELATIVE ESTIMATED COST OF TYPICAL SHOP M&TE](image)
is no different than any other business expense and it is entirely optional for any service center depending on the customer base and opportunities they wish to pursue.

Based on the discussion thus far, some key steps that may help the organization to minimize costs associated with the development, implementation and maintenance of a calibration program can be summarized as follows.

1. Determine the types of M&TE needed to execute the scope of work pursued by your service center.
2. Determine what M&TE you have and what M&TE you need by organizing and allocating properly.
3. Determine by analysis which M&TE calibration activities will be subcontracted and which will be done in-house.
4. Develop and implement any necessary documentation for the calibration program.
5. Periodically reassess the program for improvement and to meet your current business needs.

**Typical costs for M&TE calibration**

Calibration costs may vary greatly depending on whether the calibration is performed internally or subcontracted and will also depend on volume, location and scheduling considerations. For these reasons, it is difficult to provide meaningful estimates for calibrating a typical list of service center M&TE. However, based on some historical information, a rough estimate of relative costs subcontracted calibration of typical service center M&TE is given in FIGURE 5. For example, a high potential tester calibration would cost roughly $5/1 = 5$ times as much as a micrometer calibration and about $5/2 = 2.5$ times as much as a turn counter in the winding department. You can also see the relative cost in calibrating three surge testers every year when perhaps you only use two of them on a regular basis – it may be worthwhile to store one and label it CBU (calibrate before use).

Proper planning of a calibration program is a worthwhile endeavor and can provide a significant cost savings to a service center. And again, the extent of your calibration program should be based on sound business decisions dependent on the implicit and explicit requirements of the customers and industries you serve.

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