THE
CERTIFIED CALIBRATION
TECHNICIAN PRIMER

WITH A LITTLE HELP FROM MY FRIENDS.

JOHN LENNON/PAUL McCARTNEY

Acknowledgments

In a professional career spanning forty years, one is influenced by many sources. Greatest among these is always ones colleagues, and there is no possible way to express enough gratitude to them for the mentoring, the collegial relationships, and all the fun of working together. Still, a few people stand out among the hundreds with whom I've enjoyed working and from whom I've learned so much (listed in no particular order).

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CCT Primer Contents

NOTHING IS GOOD OR BAD, BUT BY COMPARISON

THOMAS FULLER

Calibration Systems

Calibration Systems is presented in the following major topic areas:

- **Calibration Procedures**
- **Standardization and Adjustment Methods**
- **Industry Practices and Regulations**
- **Environmental Control**
- **Calibration Processes for IM&TE**
- **Validation Processes**
- **Records Management**
- **Official Reports**

Calibration Procedures

ISO/IEC 17025:2005[7] (5.4.1) states:

"*The laboratory shall use appropriate methods and procedures for all tests and/or calibrations within its scope.*"

In fact, this requirement doesn't state that the method must be documented, although nearly everyone uses written procedures. The United States military, in particular, has operated a highly successful calibration program for many years that depends on having good documented procedures and ensuring that they are followed. This produces a high degree of uniformity in the resulting work and also makes it possible to develop a corps of trained technicians. Most military calibration procedures are available to any organization that performs work for a military contractor. See GIDEP (2010)[5] for more information.

In its simplest form, a calibration procedure is a step-by-step description of what must be done in order to carry out a proper calibration. It should be possible, following the instructions, to come out with repeatable results when the procedure is conducted many times.

This requirement is not difficult if the unit being calibrated (often called the TI for test instrument) is always the same and if the reference standard and other test equipment, being used, is always the same. When this is true, the instructions can be very specific – referring to each control and display and accompanied by pictures – so that little uncertainty remains in exactly how to carry out the work repeatably.

Calibration Procedures (Continued)

In fact, there are many different test instruments (TIs) and so many possible configurations of calibration standards and instruments that it would be practically impossible to write detailed instructions for every combination. Procedures are often written in a more general fashion so they will apply properly to a range of possible equipment. Most of the effort that goes into writing calibration procedures is concentrated on designing methods that can be described accurately and still cover a wide range of circumstances.

A calibration procedure should be a controlled quality document of either internal or external origin. As such, it should be dated, should have a revision level and revision history, and should have a means of determining if it is the current version.

This latter requirement is often satisfied by active document control, in which all copies are inventoried so that obsolete ones may be removed from all intended points of use. It's also possible to accomplish this with a master list, in which the current revision of each procedure is listed. When a technician goes to use a procedure, he or she must check the master list to make sure the copy in hand is the most recent.

In the case of external documents such as manufacturer's manuals, the organization is required to have a process whereby the source of the information is periodically checked for updates. Commercial services are available that will monitor this information for a company. A particularly sticky point exists here. Updated manuals and procedures may not be the proper ones for specific older equipment. Often, newer manuals refer to newer revisions of the hardware. Sometimes, though, revisions will apply to older equipment as well. Proper application of this control process requires keeping track of the current (revised) documents for particular equipment.

ANSI/NCSL Z540.3 (2006)[2], the U.S. National standard for calibration labs, states the following requirements for the content of calibration procedures:

"*Calibration procedures shall contain the required range and tolerance or uncertainty of each item or unit parameter being calibrated or verified. In addition, the procedures shall contain the generic description of the measurement standards and equipment needed with the required parameter, range, tolerances or uncertainties, and specifications for performing the measurement of the calibration or verification, and/or representative types (manufacturer, model, option) that are capable of meeting the generic description for the measurement standards. The procedures shall be consistent with the accuracy required, and with any standard specifications relevant to the calibrations/verifications concerned.*"

Calibration Procedures (Continued)

Let's look at these requirements in detail:

"*Calibration procedures shall contain the required range and tolerance or uncertainty of each item or unit parameter being calibrated or verified.*"

This requirement refers to the test instrument (TI). The procedure must describe in detail the items covered – what can and what can't be calibrated using this method. In addition, the range and uncertainty (or accuracy, or tolerance) of the TI covered by the procedure must be listed.

For example, consider a procedure for calibration of liquid-in-glass thermometers:

- **Covers total-immersion and partial-immersion thermometers of all listed ASTM types**
- **Temperature range –40 to +150 °C (-40 to 302 °F)**
- **Tolerance ± 0.1 °C**

Or, if the procedure cannot be made general in nature, it should still contain a statement like:

- **Procedure for calibration of ACME model 9816 thermometer**
- **This procedure does not apply to calibration of any other instrument**

Also sometimes acceptable, but less useful:

- **Procedure for calibration of ACME model 9816 thermometer or equivalent**

This last example leaves it up to the user to determine if the TI being calibrated is equivalent to the 9816 or not. Since it is the purpose of a procedure to describe in detail everything the technician needs to know in order to perform the work, this limited information may not be adequate for that purpose.

"*…procedures shall contain the generic description of the measurement standards and equipment needed with the required parameter, range, tolerances or uncertainties...*"

This requirement refers to the measurement system – the equipment and reference standards to be used in the calibration. Each procedure must have a listing of all the equipment required to perform the method. The procedure must contain a detailed *generic* description. It should specify the test equipment, fixturing, and reference standards, (all) in terms of the properties required. This will enable a technician to properly select equipment from among those assets available.

Calibration Procedures (Continued)

Specifying the equipment to be used, for example, by brand and model number leaves the technician unsure whether the equipment on hand will be adequate for the job unless it is exactly what is called out in the procedure. For example a procedure for calibration of 3-1/2 digit multimeter:

- Requires electronic calibrator capable of the following outputs:
  0 – 1000 VDC @ 10 mA, uncertainty < 100 ppm
  0 – 350 VAC @ 10 mA, uncertainty < 1000 ppm
  0 – 100 MΩ, uncertainty < 100 ppm, etc.

If the procedure cannot be made general, it should still contain a statement like:

Procedure for calibration of 3-1/2 digit multimeter:
- This procedure applies only when using the Fluke model 5700A calibrator.

Also sometimes acceptable, but less useful:

Procedure for calibration of 3-1/2 digit multimeter:
- This procedure applies when using the Fluke model 5700A calibrator or equivalent.

The last example leaves it up to the user to determine if the test instrument being used is equivalent to the 5700A or not. Since it is the purpose of a procedure to describe in detail everything the technician needs to know in order to perform the work, this limited information may not be adequate for that purpose.

"*…specifications for performing the measurement of the calibration or verification*,"

These are the step-by-step instructions to be carried out, including the use of fixtures or test connections, preparation of the TI such as cleaning and warm-up, data recording, and calculations necessary to generate the final result.

"*…representative types (manufacturer, model, option) that are capable of meeting the generic description for the measurement standards.*"

For example: Procedure for calibration of 3-1/2 digit multimeter:
- Requires electronic calibrator such as the Fluke 5700A
- Capable of the following outputs:
  0 – 1000 VDC @ 10 mA, uncertainty < 100 ppm
  0 – 350 VAC @ 10 mA, uncertainty < 1000 ppm
  0 – 100 MΩ, uncertainty < 100 ppm, etc.

Calibration Procedures (Continued)

Note that while this last procedure is similar to the statement "Fluke 5700A or equivalent," it tells one the specific requirements for this test. The 5700A may have capabilities, such as AC current generation, that are not needed for this calibration, and if only "5700A or equivalent is specified," the technician is limited to using something with all the functions of a 5700A – some of which may not be necessary.

A procedure must specify the calibration environment. Most of the time we think of temperature, and then humidity, and indeed these variables affect a large proportion of our measurements. However, ISO/IEC 17025:2005[7] (5.3.2) lists many potential environmental influences: "*Due attention shall be paid, for example, to biological sterility, dust, electromagnetic disturbances, radiation, humidity, electrical supply, temperature, and sound and vibration levels, as appropriate to the technical activities concerned.*"

The environment will affect the obtained answers in two ways. One effect is that changes in environmental factors may need to be corrected in the final calculations, when reporting data. For example, changes in the density of the ambient air will make small changes in the wavelength of a length-measuring laser interferometer. Air pressure, temperature, and humidity must be measured and a density correction calculated.

The second effect is that the environment may be unsuitable for carrying out calibrations at all. Large temperature swings will adversely affect precision dimensional measurements, while large power line swings will make electrical measurements impossible. These effects are most pronounced, and must be considered most carefully, when working in the field.

Each procedure, and also a general laboratory policy, must state the environmental limits within which the area must remain in order to continue work, and that work shall be stopped when these limits are exceeded.

Calibration Procedures Summary

Common elements of calibration procedures include: 1) required equipment, 2) revisions and document control, 3) equipment listing, 4) environmental considerations and restraints, 5) range and uncertainty or tolerance, and 6) reference standards to be used in the calibration. There must be documented evidence that the person performing the calibration has been trained on the procedure.

Standardization and Adjustment Methods

A calibration process always involves a comparison between an unknown (unit under test, UUT, or TI) and a reference standard. The value of the reference standard is known through the calibration pyramid (with uncertainty, of course), and the comparison is made using some sort of sensor or test instrument.

Many times, the reference standard is built into the test instrument, so it appears as though there is only one part to the measuring apparatus, but the standard is always somewhere inside.

Nulling

If the nominal value of the UUT and the reference are the same, the comparison may be made by a nulling process. A sensitive indicator is used to display the difference between the UUT and the reference. This indicator can have a very small range because, even though the actual value of the reference and UUT may be quite large, the difference is small.

A two-pan balance is an excellent example of this type of nulling measurement. With the UUT on one pan, a range of reference standards may be created by addition and subtraction of weights, from a general-purpose set, until the indicator needle rests in the center of the scale, indicating that the force applied to the two pans is equal. The value of the UUT is, therefore, equal to the total of the weights on the reference pan.

Note that the indicator needle didn't have to be calibrated at all. Its main job is to show zero deflection or equality of the pans. Its only other job is to show the operator which pan is heavier during the balancing process – which it does by swinging left or right.

A similar operation is carried out by a galvanometer or electronic null detector when using a nulling process in electrical measurements.

Note that this method only works when one has a reference standard that can take on any desired value, such as a set of weights or a set of gage blocks.

Nulling is used for the most accurate measurements, since the null process can be quite sensitive to minute differences between reference and UUT.

Standardization and Adjustment Methods (Continued)

Reference Dividers

Often, the available reference standard has a single value or a small selection of values – but the UUT can take on any value within a practical range. The nulling method cannot be used by itself, since most of the time there will not be a UUT and a reference of the same value.

Many times, in this case, one can use a reference divider. This is a device that takes as input the value of the reference standard and outputs a precise, known, adjustable fraction of that value. While the reference standard is fixed, the fraction is known (intrinsically or by calibration) so that a local reference equal to the nominal value of any UUT can be had. At this point, the nulling method is used to compare the divided reference with the UUT.

A typical example of this approach is with electrical calibrations – where the reference is usually a ten-volt Zener standard. A divider – either a dial-type or slide wire – is used to produce an adjustable fraction of the reference. A separate circuit or galvanometer compares the divided reference with the UUT, and the ratio or fraction of the divider, multiplied by the value of the reference, gives the value of the UUT when adjusted for null.

Input Dividers (Attenuators)

The reference divider method only works when the value of the UUT is smaller than the value of the reference standard. When the UUT value is larger, the adjustable divider may be used to generate a known fraction of the UUT. Again, this may be nulled against the reference.

Measurements on a Scale

An alternative to nulling, where the reference and the unknown must be the same value, is to have the measuring instrument read the measured value on a scale. Simple weighing or force measurement immediately comes to mind, where the elongation of a spring is proportional to the applied force (weight or other force). Many instruments that display results on a scale, in fact, use the nulling principle inside, but to the user they appear as a scale device.

Calibration of a scale device is usually done by adjusting one end of the scale to zero (with zero applied force or other signal), then adjusting the other end of the scale at a maximum reading. Often, the linearity of the scale is then checked by looking at one or more values at or near the mid-point.

Standardization and Adjustment Methods (Continued)

Measurements on a Scale (Continued)

In many cases, no linearity adjustment is possible but the measurement must be verified anyway. This process is sometimes called "spanning." If the scale ranges between negative and positive values, with zero somewhere in the middle, one should adjust one end at the most negative value and the other end at the most positive value. The technician should then be sure to check that zero is in the right place.

This process often needs to be repeated a few times before it converges on a setting. The zero and maximum (span) adjustments interact with each other, and changing one may affect the setting of the other.

Linearization

Many sensors give an indication that has a linear relationship with the applied signal. These devices are ideal measuring tools, since they can be directly calibrated to a simple linear display scale.

Many others, though, respond according to a non-linear curve. These can still be useful tools. In many cases, such as at very low and very high temperatures, linear sensors are not available at all.

A non-linear sensor can still be displayed on a linear scale. Electronics, embedded computers, or occasionally mechanical devices can be used to convert the non-linear sensor signal to a linear display. Calibration of these displays requires choosing and testing several points on the scale, including but not limited to the top and bottom. This action verifies that the linearization function is working. If the particulars of the non-linear behavior are known, the test points can be chosen to explicitly check the more "difficult" values.

Industry Practices and Regulations

ISO/IEC 17025:2005[7] specifies several possible sources for test and calibration methods. It is quite clear that there is an order of preference when choosing a source. This list is expanded here to include other possibilities, in descending order of precedence. That is, items nearest the top of the list must be chosen first if they are available.

The following order is correct for United States laws and practices only. Each country will have a different priority.

From a legal perspective, the order is:

- **OIML standards if adopted by law (OIML is the International Organization of Legal Metrology. It writes standards mostly for weights and measures.)**
- **NIST standards if adopted by law**
- **ASTM standards if adopted by law, etc.**
- **Individual State laws**
- **Methods required by a regulatory agency**

In many cases, harmonization among these various requirements is at least being attempted.

From a technical perspective, the order is:

- **Methods required by treaty, law, or regulation**
- **Methods specified by the client purchasing the services**
- **Methods specified by a National Measurement Institute (e.g. NIST)**
- **Methods that have been published either in international, regional or national standards**
- **Methods published by reputable technical organizations**
- **Methods published in relevant scientific texts or journals**
- **Methods specified by the manufacturer of the equipment**

