Principles of Metrology

Application Note

Imagine a world with no regard for accuracy. What would happen if no one could agree on terms of time, length, weight, or the amount of electrical energy in a volt? It would be impossible to know for sure that a pound of meat really was a pound, or a gallon of gasoline really a gallon.

Advances in electricity and electronics this past century have made accurate measurement of many different properties essential. We wake up to electrical alarm clocks, cook in microwave ovens, and regulate the heat in our homes with thermostats. All of these devices depend on accurate voltages, currents and resistances to function properly.

Metrology is the science that provides us with the accuracy we need to get on with business and our personal lives. It is within metrology that international definitions for measurements are agreed upon. Calibration is the action of metrology. Through calibration, the actual accuracy and integrity of a measurement is established. Calibration, then, is the process that provides the confidence that our measurement results are accurate.

The Fluke Josephson Voltage System in Everett, Washington USA. Fluke laboratories in the United States and Germany house 2 of only 35 Josephson dc voltage arrays in the world found outside a national laboratory.

SI UNITS

A measurement uses an instrument as a physical means of determining a quantity or variable. Measurement correlates numbers to quantities: a pound of meat, a gallon of gasoline, 10 volts, or 1,800 miles. A quantity is assigned a number and a unit that people readily understand.

So, how are the numbers and units assigned? Someone had to be the first to say, "This is what is meant when I say kilogram/meter/liter/volt/Ampere." This is where unit definitions come in to play. A standard unit is merely the agreed upon *definition of a unit of measure*. A unit might be mass (kilogram), length (meter), time (second), electric current (ampere), volt and so on. The "caretaker" for these internationally agreed upon *defined* units is the International Committee of Weights and Measures [Bureau International des Poids et Mesures (BIPM)] located in France. Units are agreed upon between countries via treaty.

The abbreviation SI is taken from its French name, Système International d'Unités. It was established in 1960 by the General Conference of Weights and Measures. The United States and most other nations subscribe to this conference and use the SI for most legal, scientific, and technical purposes.

10 V working standards of voltage in the Fluke standards laboratory in Everett, Washington USA.

A simple example:

A car will not start. A voltmeter is used to read the voltage of the car's battery. The voltmeter says that the battery reads 12 volts. But how is it possible to know that it's really 12 volts? What if the actual value is really ten volts? Then there may not be enough power in the battery to crank the engine. What if it is really 14 volts? If it is, the battery is probably good and the problem is elsewhere in the car's starting system. If the meter had recently been calibrated, the user could be confident that the reading was accurate.

By complying with international standards such as ANSI/ISO/IEC 17025 and using internationally agreed upon definitions of units, measurements are assured to be compatible and traceable anywhere on earth. Companies that comply with metrological standards and practices reduce their rework costs and the number of faulty units shipped, both of which translate to lower production costs.

Each country has some process for deriving measurement units from the definitions. This may be accomplished in one of three ways. In the U.S., the National Institute of Standards and Technology (NIST) determines, maintains and disseminates measurement standards. In Germany the Physikalish-Techniche Bundesanstalt (PTB) is the official standards organization. Some countries rely on the organizations in other countries. Still others use a combination of sources. Keep in mind that differences do exist between the standards of various countries. These differences are measured and recognized so that there is little confusion.

Why calibrate?

The strongest force driving the development and practice of metrology and calibration is the need for accurate information in trade and industry. Some of the oldest laws in existence deal with the need for dependable honest measurements of grains, oils, and metals, which were among the principle items of early commerce. These laws were aimed at answering the question, "Am I getting what I paid for?" This category of measurements is part of *legal metrology*. *Legal metrology* concentrates on protecting the unwary from the unscrupulous. An example of this is the legal requirement to have gasoline pumps calibrated at regular intervals.

Technical metrology, on the other hand, deals with questions of "fitness" for intended use and compatibility.

Modern industry relies heavily on measurements for standardizing components. In industry, calibration makes it possible to achieve the accuracy, precision, and interchangeability that make mass production feasible. Calibration is the provider of confidence that components manufactured all over the world can come together in a single location and fit.

Calibration is the highly refined measurement process that compares test and measurement instruments of unknown accuracy with well-defined standards of greater accuracy. The purpose is to detect, eliminate by adjustment and report any variation in an instrument's accuracy. The accuracy of an electrical measurement, for example, is an expression of the closeness of its result to the true value. High accuracy indicates a close approach to the true value of the item being measured.

Where does the confidence come from?

To answer this question, we'll look at an example that will help illustrate what calibration means and introduce some basic metrological terms.

This example features a pressure meter used by a manufacturer to set up a production process. To insure that their instruments measure accurately, this company periodically sends all of its test and measurement equipment to a calibration laboratory.

When the calibration lab receives the meter, a technician starts by using a calibrator to check or verify its performance. The calibrator is essentially a very accurate source that produces stimuli in the various units needed for the calibration—a device whose accuracy is known to be within a tightly specified tolerance. The technician connects the test leads of the meter to the calibrator's output terminals. The calibrator then produces a signal that is read by the meter. Since the technician knows how accurate the calibrator is, he considers the meter to be "in calibration" if its reading agrees with the calibrator's. It may not have to read precisely the same as the calibrator; it may only need to read within ± 1 % of the calibrator setting. For example, if the calibrator were producing a signal that emulates 100 pounds per square inch (PSI) of pressure, the meter would be within its specification if it reads between 99 and 101 PSI. This portion of calibration is considered *verification*.

If the meter is within the tolerance specified, it has passed its verification and needs no further calibration at this time. (Remember this is a simplified example. A meter may be verified at a several different levels, and on different functions.) It's usually given a sticker that shows the date it was calibrated and that it passed.

If the meter did not pass the verification tests it is then *adjusted.* (Note that some devices cannot be adjusted. In this case various actions might be taken such as the development of correction tables.) This is the second part of calibration. Adjustment involves repairing the instrument or adjusting specific circuit components until the instrument passes another "verification test." When it passes, it's given a calibration sticker and sent back to the end user.

As an instrument is being calibrated, each step is thoroughly documented, with records of the tests that were performed and at what points, the tolerances, and the noted results. These records are required in order to make the calibration *traceable*.

Traceability

The act of calibration did not end when the meter was sent back to the production department. To keep the calibrator accurate, it too is periodically compared to a standard of higher accuracy. Likewise, that upper level standard is compared to another and perhaps another, until eventually a comparison is made to a legally established national standards laboratory such NIST. These inter-comparisons are referred to as a chain of *traceability*.

To make this concept clearer, we will modify the example slightly. The meter might be used to test pressure on some process affecting airplanes. The company that manufactures and tests the airplane is legally required by the government (FAA) to prove that the measuring instruments used in the process were calibrated, just as described previously, and that the calibrations are traceable. This means that the measuring instruments can be traced, via a chain of documented calibrations, back to a legally defined national standard for that measurement.

To sum up this simplified traceability chain, the steps were:

1. The meter was sent to a cal lab and compared to a calibrator.
2. The calibrator was sent to a standards lab and compared to a working standard.
3. The working standard was compared to a reference standard that always stays in the standards lab.
4. The reference standard is compared to a transfer standard.
5. The transfer standard is sent to the National Measurement Institute where it is compared to the legal parameter.

Think of traceability as the pedigree of a measurement, much like the bloodline of champion animals. From a particular calibration job, it should be possible to trace each measurement all the way back to national standards. This trail of calibration is carefully recorded along with the parameters of the procedure including the conditions of the test, instruments used and the time between calibrations.

Some basic terms explained

When discussing metrology, it is necessary to have a common understanding of the meaning of certain terms. They are words used every day, but in the context of calibration they take on a very exact meaning.

Common terms defined:

Accuracy is a *qualitative* expression of the closeness of a measurement's result to the true value.

Precision is a measure of repeatability. A high precision indicates the ability to repeat measurements within narrow limits.

Resolution is the smallest change that can be detected. With today's digital instruments resolution can be thought of as significant digits. It is the smallest increment that can be measured, generated, or displayed.

An example of these concepts involves measuring a resistor whose true value is 1,234,567 Ω. The multimeter used to measure this resistor consistently reads 1.235 MΩ. Without the additional resolution required, it does not conform to the measurement requirements of the resistor. Even though the meter conforms up to a certain point in reading the true value, a greater degree of resolution is required in order to make a precise determination of the true value of the resistor.

Uncertainty is a *quantitative* term that represents a range of values wherein the true value may lie and how confident the cal lab is that it is so. Uncertainty and confidence is determined using statistical tools. Although it is common to refer to instrument specifications as "Accuracy Specs", for the most part instrumentation specifications are specified terms of uncertainty rather than accuracy.

The Fluke 8508A Reference Multimeter is an 8.5 digit multimeter designed specifically for calibration and metrology applications.

Measurement errors

A measurement is subject to many sources of error, some of which may make the measurements too high, others too low. While the goal is to keep these errors as small as possible, they cannot be reduced to zero. Thus, in any measurement process the task remains to try to find out what errors exist and how large they may be. For this reason, information about the sources of measurement error is indispensable.

Measurements are impacted by three types of errors; Random, Systematic, and Gross. **Random** errors are due to generally unknown causes and are only detectable when repeated measurements are made with a seemingly constant setup and consistent technique. It is often noted that when measurements are repeated the result is not always the same. If the reason for these variations is not obvious, then it falls into the category of random errors. Think of them as the gremlins of metrology. **Systematic** errors relate to the instruments being used or external influences on the instruments. These may also be called offset errors, as they cause the measured value to be offset by a fixed amount. Examples of these are loading, thermals, drift-rate, leakage currents, and external noise.

The third type of error in measurement is *gross* errors. **Gross** errors are those which can be strictly controlled, and are caused by the metrologist. Examples of these might include misreading the instrument, making incorrect adjustments, using the wrong instrument, computational errors, or making errors in recording calibration data. These are errors that can be avoided by care and attention.

Summary

Metrology is the science of measurement. In the context used here, it is that portion of measurement science used to maintain and disseminate a consistent set of measurement standards. It is used to provide support for the enforcement of equity in trade by weights and measurement laws and to provide data for quality control in manufacturing.

Calibration is the portion of metrology that verifies our measurements are in accordance with established standards. More specifically, calibration is a highly refined measurement process in which measurement and test equipment instruments of unknown accuracy are compared with well-defined standards of greater accuracy. Its purpose is to verify the operational integrity of measurement and test equipment.

Traceability means that there is a link that can be documented between the accuracy of an instrument and the highest level of standards as maintained by a national or international laboratory. The highest-level of standards are referred to as legal standards, meaning that they are recognized among several nations as being a standard of reference.

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