AC 2008-2865: METROLOGY: WHY ENGINEERS SHOULD CARE

Helga Alexander, Keithley Instruments Inc

Helga Alexander is Manager of Metrology Services at Keithley Instruments, Inc. Keithley Instruments, Inc. designs, develops, manufactures and markets complex electronic instruments and systems geared to the specialized needs of electronics manufacturers for high-performance production testing, process monitoring, product development and research.

Metrology: Why Engineers Should Care

Abstract

Many engineering graduates are hired by manufacturing companies whose end products are designed to measure some physical quantity, whether it is chemical, electrical, or mechanical in nature. The graduates' college engineering training prepares them for careers in all kinds of engineering areas, whether it be manufacturing processes, new product design, or testing. As part of their undergraduate or graduate work, they are taught sound engineering principles and receive a thorough foundation in their chosen fields to become the designers of tomorrow's products. However, although many end up designing measuring and test equipment, their college training never introduced them to metrology, the science of measurement. They are unaware of the importance of traceability to the international system of units or the existence of international standards on the computation of measurement uncertainty. When asked to produce error budgets for their designs, which form the basis for final product specifications and warranty agreements, many of them are inadequately prepared. Furthermore, many will be involved in determining a calibration method for their products, yet they are unaware of the metrology requirements. This paper examines how awareness of metrology principles and their application in early product design of measuring and test equipment will lead to a superior product. Measuring or testing products designed using sound metrological principles can more easily be shown to be traceable to the international system of units (SI) and comply with international standards.

Introduction

Large numbers of science and engineering graduates are involved in the design, manufacture, and test of products that perform measurements. These products may range from high precision test and measurement equipment to handheld meters, calipers, gauges, and scales used in repair and inspection in various industries. All these products require calibration before they leave the manufacturing facility and, depending on their type and use, will probably require recalibration at certain time intervals. Yet, most engineers graduate from college without ever having been introduced to basic metrology concepts.

What is metrology?

Metrology, the science of measurement, deals with making accurate, repeatable measurements with a known level of uncertainty. Metrology regulations form the basis for national and international trade—we trust that a gallon of gas sold at gas station A is the same quantity as a gallon of gas obtained down the road at gas station B, mainly because we know that legal metrological requirements have to be enforced by the state by law. The same applies to international trade. How else can we be sure that a volt measured with a voltmeter produced in the United States is the same quantity measured by a voltmeter produced in Germany (taking into account the two instruments' specifications, of course)? The lack of such assurance would be a large obstacle to global trade.

The need for international agreements on measurement units and standards as the basis for effective trade between nations prompted the formation of the Mètre Convention in 1875.

Governments of 17 nations signed a treaty to establish and finance the Bureau International des Poids et Mesures (BIPM), which is responsible for the coordination of measurements performed worldwide. This institution, located just outside Paris, France, is overseen by the Comité International des Poids and Mesures (CIPM). Today, there are 51 member states of the Mètre Convention and many associate members. Each member state has a national metrology institute (NMI), which is responsible for the state's national standards for measurements. The national metrology institute of the United States is the National Institute for Standards and Technology (NIST).

The next milestone in metrology was set in 1960 with the establishment of the International System of Units (SI). But even though most countries used the same units, there were still obstacles to trade. For example, even if the measurement of a volt in the United States was traceable back to NIST by an uninterrupted chain of comparisons, and the accuracy of a German voltmeter was traceable back to the Physikalisch-Technische Bundesanstalt (PTB), the "German NIST," there was still no guarantee that the NIST volt and the PTB volt were the same. German customers may require that an American-built voltmeter be traceable to the SI through the national metrological institute of their own country and not recognize traceability through NIST. The CIPM Mutual Recognition Arrangement (MRA) of 1999 solved this problem by providing for the mutual recognition of calibration and measurement certificates issued by national metrology institutes participating in the agreement, thus establishing the degree of equivalence of national measurement standards maintained by national metrology institutes. All these successive metrological agreements allow international trade to flourish to the degree it does today.

Metrology, thus, does not only deal with the actual act of making a physical measurement, but also with the rules and international regulations associated with measurements. By ensuring that a measurement is traceable to the SI, we can have confidence that a volt measured in Germany is the same quantity as a volt measured in the United States. The same principles apply to other physical quantities such as length, time, mass, etc.

Absence of metrology concepts from engineering curricula

The NCSLI (National Conference of Standards Laboratories International) web page lists 13 educational institutions with metrology content in the programs they offer, most of them at the 2-year associate degree or diploma level. Due to the current shortage of qualified metrology technicians and engineers, we know that these graduates have no trouble finding employment as metrology professionals. However, while the lack of qualified metrology practitioners is a serious problem, I would like to draw attention to a somewhat different problem, namely the lack of any type of metrology education in today's engineering curricula.

Most engineers do not work in the metrology field as such, but all use and many design instruments that measure a physical parameter. At a large test and measurement company, there usually is a metrology department or chief metrologist responsible for ensuring that the company's products comply with today's metrology requirements. However, smaller engineering companies often do not have a metrology department or even a single metrologist on staff. The engineers of such a company may simply be unaware of the metrological requirements of today's global economy, until they find out that their product does not sell because of the difficulty of obtaining a traceable calibration for it.

If colleges and universities included some basic metrology training in their general engineering curriculum, engineers would be better prepared for the workplace, regardless of whether it was in industry, academia, or a government agency.

If it can't be adjusted, it can't be calibrated—true or false?

Many engineers suffer from the misconception that calibration equals adjustment of an instrument to make it agree with a reference standard. So, when asked whether a resistor can be calibrated, the answer is "no," it cannot be calibrated, it can only be "characterized." No wonder they are confused when a customer demands a calibration report for a resistor or a measurement device that cannot actually be tweaked or adjusted. Calibration does not necessarily have anything to do with adjustment. Calibration, as defined by ANSI/NCSL Z540.3, the American National Standard for Calibration, is "the set of operations that establish, under specific conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or reference material, and the corresponding values realized by standards." In other words, calibration is the act of establishing a relationship between a unit under test and a standard. Sometimes, calibration may establish that an instrument adjustment is needed, but the act of performing the adjustment is not necessarily a calibration in itself. After the adjustment has been performed, the relationship between the adjusted instrument and the standard must be reestablished. The process of reestablishing this relationship is the act of calibration.

Importance of meeting international calibration requirements

The international standard for calibration is ISO/IEC 17025:2005, "General requirements for the competence of testing and calibration laboratories." This international standard defines what constitutes a competent laboratory capable of performing certain calibrations. The standard establishes the requirement for a sound management system based on the principles of ISO 9001:2000 and specifies the requirements for technical competence for the types of tests or calibrations the laboratory undertakes.

Many industries have to comply with their own industry-specific national or international standards. Many of these industry standards require that the measurement and test equipment used to produce a product be calibrated at regular intervals in accordance with ISO 17025. If the product's design and test engineers were unaware of the requirements of this standard during the design phase, additional costs may be incurred after the product is released to ensure that it can be given a 17025 accredited calibration. For example, part of the requirement of an ISO 17025 calibration is that the calibration report contain certain information, such as the environmental conditions under which the calibration took place, proof of traceability to the international system of units through NIST or other national metrological institutes, the measurement data with measurement uncertainty, etc.

Usually the calibration software is developed during the design and test phase of a new product, so awareness of international calibration requirements can help avoid the need for expensive revisions later. This is particularly true with regard to the requirement of providing the measurement uncertainty for each parameter measured during the product calibration. Most engineers have a basic idea of how to come up with an error budget, but they probably won't have encountered the ISO Guide to the Expression of Uncertainty in Measurement (GUM for short). ISO 17025 requires calculating measurement uncertainties in accordance with the GUM, so familiarity with the GUM methods will be useful for design and test engineers alike when faced with determining calibration methods. In addition, when setting product specifications for test and measurement instruments, product designers and test engineers need to know how their customers will use the specifications. If the product is part of a customer's test system, the customer will most likely use the product specifications for their measurement uncertainty calculation. Providing additional information, such as specification confidence levels, as part of the product specifications could simplify uncertainty calculations and avoid the need for "worst-case" assumptions on the customer's part.

In today's global economy, it is important that a product designed and manufactured in one country meets the requirements of customers all over the world. Calibration in accordance with international standards is one such requirement. A company may have designed and produced a piece of state-of-the-art equipment, only to find that sales are suffering because they cannot offer their customers the type of calibration and associated documentation that will satisfy a particular industry's quality requirements. Customers will be reluctant to invest in equipment that requires them to jump through extra hoops every time the equipment is scheduled for calibration. Design and test engineers who have a good grasp of metrology and know where they can go to obtain more information will be able to design a product that meets international calibration requirements. This will be a competitive advantage for any new product.

Suggested metrology content for engineering/science curricula

All engineers will work with test and measurement equipment during the course of their careers, even if they are not involved in the design and testing of this type of equipment. Therefore, an introduction to metrology concepts would be a useful addition to any engineering curriculum. It could take the form of a separate metrology course or it could be taught as part of an instrumentation class. The following topics should be included:

- Historical background and purpose of metrology
- Definition of calibration
- Statistical concepts
- Measurement uncertainty calculations based on the ISO Guide to the Expression of Uncertainty in Measurement (GUM)
- International metrology standards
- Concept of traceability
- Common calibration methods
- Metrology careers

Conclusion

Engineers deal with quantitative concepts and are invariably involved in measurements. Introducing them to the basic concepts of metrology as part of the engineering curriculum will make them more effective engineers, whatever engineering discipline they choose. This is particularly important in today's technology-driven global economy.

Engineers with a background in metrology will perform better in their chosen careers as designers of tomorrow's measurement equipment because they know the needs of their customers, maybe better than the customers themselves. Unfortunately, many test equipment purchasers do not know what type of calibration they need until the day they get audited and find that they do not comply with their industry's standards. By understanding international metrology requirements, engineers will choose calibration methods that are accepted internationally, and they will save their companies money by saving redesign, rework, or recalibration costs. These knowledgeable engineers add value for which their companies will undoubtedly reward them.