CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY

2021
OCTOBER
NOVEMBER
DECEMBER

Temperature Calibrations, Part 4

A Case Study on Interlaboratory Consensus Building

TAR Versus TUR: Why TAR Should RIP ASAP

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CAL LAB
THE INTERNATIONAL JOURNAL OF METROLOGY
www.callabmag.com

VOLUME 28, NUMBER 4

FEATURES

DEPARTMENTS

ON THE COVER: Graftel calibration laboratory's new automated high flow compressed air test stand named Jupiter. Staff setting up a venturi air flow meter to run a 13 lbm/sec mass flow audit prior to submitting data for ISO accreditation. The Jupiter stand was fully accredited on September 21, 2021.

UPCOMING CONFERENCES & MEETINGS

The following event dates and delivery methods are subject to change. Visit the event URL provided for the latest information.

Nov 15-18, 2021 MSC Training Symposium. Anaheim, CA. The MSC Training Symposium takes place annually in Orange County, California and is celebrating 50 years of educational training. The Symposium provides measurement professionals the opportunity to provide a training session of related subjects within the measurement industry and share the knowledge gained through education or on-the-job training. https://msc-conf.com/

Jan 17-18, 2022 98th ARFTG Microwave Measurement Symposium. Las Vegas, NV. Co-located with Radio & Wireless Week RWW-2022. The Automatic Radio Frequency Techniques Group (ARFTG) is a technical organization interested in all aspects of RF and microwave test and measurement. https://www.arftg.org/

Feb 21-23, 2022 NCSLI Technical Exchange. Houston, TX. The Technical Exchange training program is directed at beginner, intermediate and advanced users dedicated to training on prominent metrology topics. https://ncsli.org/page/tep

Apr 3-6, 2022 A2LA Tech Forum. Chantilly, VA. Be part of one of the accreditation industry's largest annual events! https://a2la.org/

Apr 7-8, 2022 METROMEET (Hybrid). Bilbao, Spain. METROMEET is a unique event and the most important conference in the sector of Industrial Dimensional Metrology. https://metromeet.org/

Apr 25-28, 2022. CAFMET. Casablanca, Morocco. CAFMET 2022 est la 8ème Conférence Internationale de Métrologie. CAFMET 2022 est programmée du 25 au 28 avril 2022 à Casablanca. De nombreuses conférences et plusieurs ateliers vous attendent. https://www.cafmet-conference.com/inscription-2/

Apr 25-28, 2022 FORUMESURE. Casablanca, Morocco. FORUMESURE est une exposition organisée annuellement. Celle-ci est libre d'accès et permet à des entreprises et à des laboratoires d'exposer leurs activités et leurs produits et services, ainsi que leurs dernières innovations. http://www.forumesure.com

May 10-12, 2022 SENSOR+TEST. Nürnberg, Germany. SENSOR+TEST is one of the major international scientific forums for sensors, measuring and testing technologies where researchers and other professionals from all over the world meet to discuss new technologies and the latest processes. https://www.sensor-test.de/

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CAL LAB
PO Box 111113
Aurora, CO 80042
TEL 303-317-6670 • FAX 303-317-5295
office@callabmag.com
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EDITOR'S DESK

Busy

Nobody ever told me that mid-life would be so busy. Instead, friends wonder when you plan on getting married, if you plan on going back to school, etc., while family nudges you as to when you plan on having a baby. In fact, any advice seems to center around the reproductive system, diseases associated with the reproductive system, and *the change*—I should have been born with a manual. While we are improved under the pressures of family and career, at the same time, the clock is ticking on this machine called the human body. Even after the reproductive pressures are off, the clock still ticks as though the mid-century mark is high noon and it's a rush to complete all the work before five o'clock.

This past year has been a push to work, to produce, to complete. It hasn't been boring. And it went by too fast. But I am not the only one who has been busy…

After arranging all of the articles for this issue, I realized that Henry Zumbrun of Morehouse Instruments has contributed as many great articles as years that I've been editing and putting together the magazine. Between 2011 and 2021, we have published 10 of Henry's articles. And since 1995, Christopher Grachanen has contributed 19 times! I THANK them, not for all they've contributed to the magazine, but to all they have contributed to their industry!

There are many other prolific metrologists who have contributed much during their working careers (and even after they've left the profession), who should feel proud about what they've done and are still doing.

For this issue, we have Sine Calibration School's fourth installment of "Temperature Calibrations."

Next, we have another contribution from Dr. Hening Huang on measurement uncertainties—this time, "A Case Study of Interlaboratory Consensus Building" using eight frequentist methods.

Finally, we have Henry Zumbrun's article on "TAR vs. TUR: Why TAR Should RIP ASAP." The title is fairly explanatory.

As the publisher and I traipse off to Orange County, California to attend the Measurement Science Conference Training Symposium, I wish readers a much deserved, recuperative holiday season. We all have a lot to do and precious time left to do so.

Happy Measuring,

Sita Schwartz

CALENDAR

May 16-19, 2022 MSC Training Symposium. Anaheim, CA. The annual symposium provides measurement professionals the opportunity to provide a training session of related subjects within the measurement industry and share the knowledge gained through education or on-the-job training. https://msc-conf.com/

May 16-19, 2022 I2MTC. Ottawa, Canada. The IEEE I2MTC – International Instrumentation and Measurement Technology Conference – is the flagship conference of the IEEE Instrumentation and Measurement Society and is dedicated to advances in measurement methodologies, measurement systems, instrumentation and sensors in all areas of science and technology. https://i2mtc2022.ieee-ims.org/

May 25-27, 2022 MetroLivEnv. Cosenza, Italy. The 2022 IEEE International Workshop on Metrology for Living Environment (IEEE MetroLivEnv 2022) aims to be a solid reference of the technical community to present and discuss the most recent results of scientific and technological research for the living environment, with particular emphasis on applications and new trends. https://www.metrolivenv.org/

Jun 7-9, 2022 MetroInd4.0&IoT. Trento, Italy. MetroInd4.0&IoT aims to discuss the contributions both of the metrology for the development of Industry 4.0 and IoT and the new opportunities offered by Industry 4.0 and IoT for the development of new measurement methods and instruments. https://www.metroind40iot.org/

Jun 15-17, 2022 CIVEMSA. Chemnitz, Germany. IEEE 9th International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications (CIVEMSA). https://conferences.ieee.org/conferences_events/conferences/conferencedetails/53371

Jun 19-24, 2022 International Microwave Symposium (IMS). Denver, CO. IMS is the flagship event in a week dedicated to all things microwaves and RF. The week also includes the IEEE MTT-S Radio Frequency Integrated Circuits Symposium (RFIC) and the Automatic Radio Frequency Techniques Group (ARFTG). https://ims-ieee.org/

Jun 24, 2022 99th ARFTG Microwave Measurement Conference. Denver, CO. The Automatic Radio Frequency Techniques Group (ARFTG) is a technical organization interested in all aspects of RF and microwave test and measurement. https://www.arftg.org/

Visit **www.callabmag.com** for upcoming metrology events & webinars!

SEMINARS & WEBINARS: Dimensional

Dec 1-2, 2021 "Hands-On" Precision Gage Calibration & Repair Training. Virtual Class. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. https://www.calibrationtraining.com/

Dec 9-10, 2021 "Hands-On" Precision Gage Calibration & Repair Training. Bloomington, MN. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. https://www.calibrationtraining.com/

Jan 11-12, 2022 "Hands-On" Precision Gage Calibration & Repair Training. Virtual Class. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. https://www.calibrationtraining.com/

Jan 11-13, 2022 Dimensional Gage Calibration. Aurora (Chicago), IL. Mitutoyo. Mitutoyo America's Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. https://www.mitutoyo.com/training-education/

Jan 26, 2022 Introduction to Dimensional Gage Calibration. Huntersville, NC. Mitutoyo. The course will thoroughly cover micrometer and caliper calibration, as well as touch on all types of indicators, and in addition, the course will build a base understanding of the principles in dimensional calibration such that the student can extend the concepts to other measuring equipment. https://www.mitutoyo.com/training-education/

Jan 27-28, 2022 "Hands-On" Precision Gage Calibration & Repair Training. Bloomington, MN. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. https://www.calibrationtraining.com/

CALENDAR

Feb 1-3, 2022 Dimensional Gage Calibration. Aurora (Chicago), IL. Mitutoyo. America's Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. https://www.mitutoyo.com/training-education/

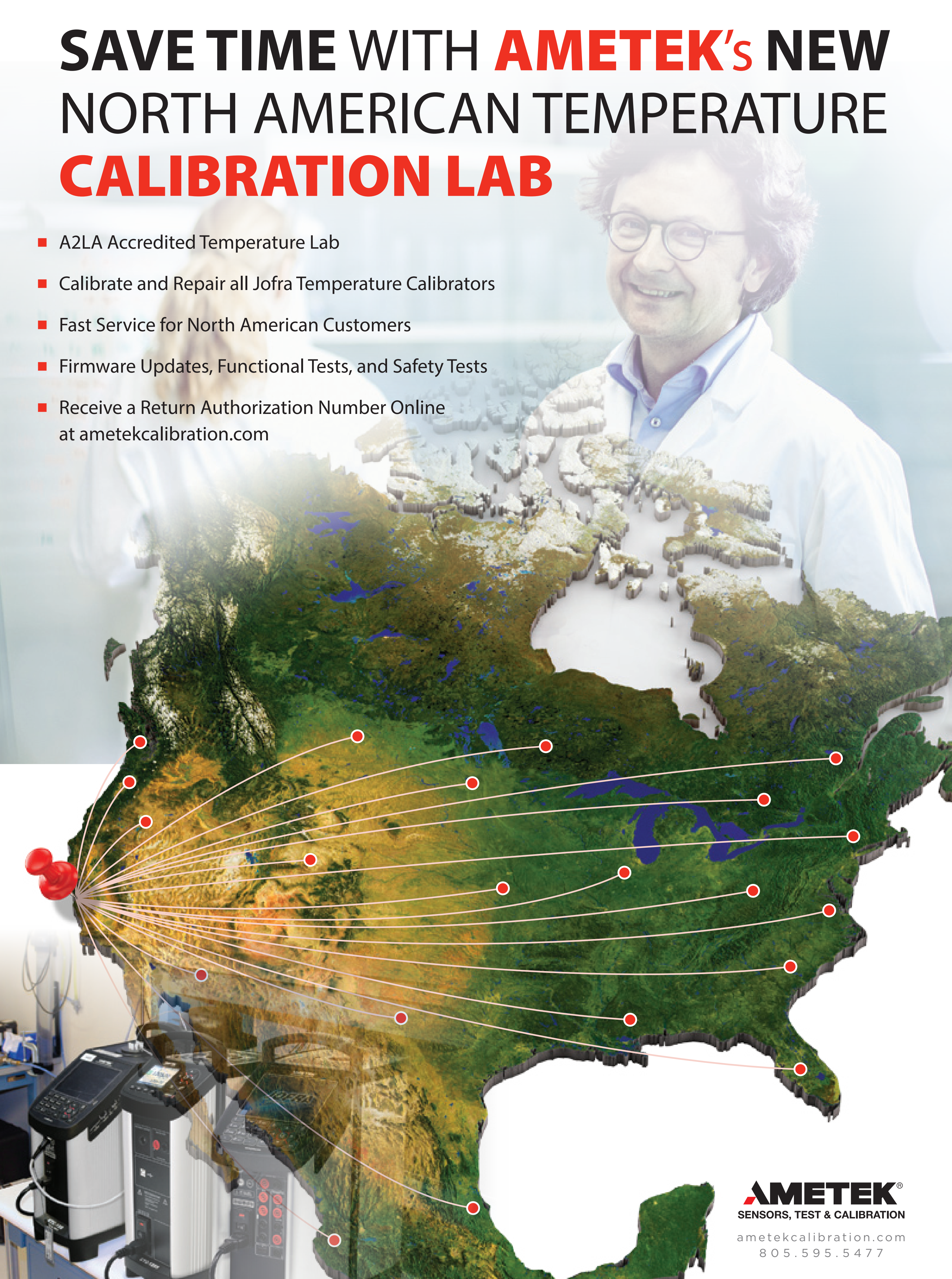
Feb 8-9, 2022 "Hands-On" Precision Gage Calibration & Repair Training. Virtual Class. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. https://www.calibrationtraining.com/

Feb 9, 2022 Introduction to Dimensional Gage Calibration. City of Industry, CA. Mitutoyo. The course will thoroughly cover micrometer and caliper calibration, as well as touch on all types of indicators, and in addition, the course will build a base understanding of the principles in dimensional calibration such that the student can extend the concepts to other measuring equipment. https://www.mitutoyo.com/training-education/

Feb 23-24, 2022 "Hands-On" Precision Gage Calibration & Repair Training. Madison, WI. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. https://www.calibrationtraining.com/

Mar 8-9, 2022 "Hands-On" Precision Gage Calibration & Repair Training. Virtual Class. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. https://www.calibrationtraining.com/

Mar 22-23, 2022 "Hands-On" Precision Gage Calibration & Repair Training. Bloomington, MN. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. https://www.calibrationtraining.com/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Mar 22-24, 2022 Dimensional Gage Calibration. Aurora (Chicago), IL. Mitutoyo. America's Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. https://www.mitutoyo.com/training-education/

Apr 6, 2022 Introduction to Dimensional Gage Calibration. Renton, WA. Mitutoyo. The course will thoroughly cover micrometer and caliper calibration, as well as touch on all types of indicators, and in addition, the course will build a base understanding of the principles in dimensional calibration such that the student can extend the concepts to other measuring equipment. https://www.mitutoyo.com/training-education/

Apr 12-13, 2022 "Hands-On" Precision Gage Calibration & Repair Training. Virtual Class. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. https://www.calibrationtraining.com/

April 27-28, 2022 "Hands-On" Precision Gage Calibration & Repair Training. Las Vegas, NV. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. https://www.calibrationtraining.com/

SEMINARS & WEBINARS: Electrical

Nov 24-25, 2021 Electrical Measurement. Lindfield NSW, Australia. NMI. This two day (9am-5pm) course covers essential knowledge of the theory and practice of electrical measurement using digital multimeters and calibrators; special attention is given to important practical issues such as grounding, interference and thermal effects. https://shop.measurement.gov.au/collections/physical-metrology-training

SEMINARS & WEBINARS: Flow

Apr 6-7, 2022 Calibration of Liquid Hydrocarbon Flow Meters. Online Delivery. National Measurement Institute (NMI, Australia. This two-day course provides training on the calibration of liquid-hydrocarbon LPG and petroleum flow meters. It is aimed at manufacturers, technicians and laboratory managers involved in the calibration and use of flowmeters. https://shop.measurement.gov.au/collections/physical-metrology-training

SEMINARS & WEBINARS: General

Dec 15, 2021 Calibration and Measurement Fundamentals – Online Delivery. National Measurement Institute (NMI), Australia. This course covers general metrological terms, definitions and explains practical concept applications involved in calibration and measurements. The course is recommended for technical officers and laboratory technicians working in all industry sectors who are involved in making measurements and calibration process. https://shop.measurement.gov.au/collections/physical-metrology-training

Mar 2, 2022 Calibration and Measurement Fundamentals – Online Delivery. National Measurement Institute (NMI), Australia. This course covers general metrological terms, definitions and explains practical concept applications involved in calibration and measurements. The course is recommended for technical officers and laboratory technicians working in all industry sectors who are involved in making measurements and calibration process. https://shop.measurement.gov.au/collections/physical-metrology-training

SEMINARS & WEBINARS: Industry Standards

Nov 30-Dec 1, 2021 Validation and Verification of Analytical Methods. Live Online. ANAB. This course provides an introduction to validation and verification of analytical methods. The common elements of a validation/verification plan and a general approach to performing a validation or verification are presented. https://anab.ansi.org/training

Dec 6-7, 2021 Understanding ISO/IEC 17025 for Testing and Calibration Labs. Webinar timed for ME and South Asia. IAS. To learn about ISO/IEC 17025 from one of its original authors. To learn its Principles and what it requires of laboratory staff. https://www.iasonline.org/training/ias-training-schedule/

Dec 6-9, 2021 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories. Virtual. A2LA WPT. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/training

Dec 13-14, 2021 Laboratories: Understanding the Requirements and Concepts of ISO/IEC 17025:2017. Live Online. This introductory course is specifically designed for those individuals who want to understand the requirements of ISO/IEC 17025:2017 and how those requirements apply to laboratories. The course covers all requirements of the standard with a focus on what laboratory personnel need to know to understand and apply the requirements of the standard. https://anab.ansi.org/training

CALENDAR

Dec 13-15, 2021 Internal Auditing to ISO/IEC 17025:2017 (Non-Forensic). Live Online. ISO/IEC 17025 training course prepares the internal auditor to clearly understand technical issues relating to an audit. Attendees of Auditing to ISO/IEC 17025 training course will learn how to coordinate a quality management system audit to ISO/IEC 17025:2017 and collect audit evidence and document observations, including techniques for effective questioning and listening. https://anab.ansi.org/training

Dec 13-16, 2021 Auditing Your Laboratory to ISO/IEC 17025:2017. Virtual. A2LA WPT. This ISO/IEC 17025 auditor training course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. The participant will learn about auditing principles and develop skills for performing higher-value internal audits. https://www.a2lawpt.org/events

Feb 1-2, 2022 Laboratories: Understanding the Requirements and Concepts of ISO/IEC 17025:2017. Live Online. This introductory course is specifically designed for those individuals who want to understand the requirements of ISO/IEC 17025:2017 and how those requirements apply to laboratories. The course covers all requirements of the standard with a focus on what laboratory personnel need to know to understand and apply the requirements of the standard. https://anab.ansi.org/training

Feb 1-3, 2022 Internal Auditing to ISO/IEC 17025:2017 (Non-Forensic). Live Online. ISO/IEC 17025 training course prepares the internal auditor to clearly understand technical issues relating to an audit. Attendees of Auditing to ISO/IEC 17025 training course will learn how to coordinate a quality management system audit to ISO/IEC 17025:2017 and collect audit evidence and document observations, including techniques for effective questioning and listening. https://anab.ansi.org/training

Feb 15-16, 2022 Validation and Verification of Analytical Methods. Live Online. ANAB. This course provides an introduction to validation and verification of analytical methods. The common elements of a validation/verification plan and a general approach to performing a validation or verification are presented. https://anab.ansi.org/training

Mar 22-23, 2022 Laboratories: Understanding the Requirements and Concepts of ISO/IEC 17025:2017. Live Online. This introductory course is specifically designed for those individuals who want to understand the requirements of ISO/IEC 17025:2017 and how those requirements apply to laboratories. The course covers all requirements of the standard with a focus on what laboratory personnel need to know to understand and apply the requirements of the standard. https://anab.ansi.org/training

Mar 22-24, 2022 Internal Auditing to ISO/IEC 17025:2017 (Non-Forensic). Live Online. ISO/IEC 17025 training course prepares the internal auditor to clearly understand technical issues relating to an audit. Attendees of Auditing to ISO/IEC 17025 training course will learn how to coordinate a quality management system audit to ISO/IEC 17025:2017 and collect audit evidence and document observations, including techniques for effective questioning and listening. https://anab.ansi.org/training

May 5-6, 2022 Laboratories: Understanding the Requirements and Concepts of ISO/IEC 17025:2017. Live Online. This introductory course is specifically designed for those individuals who want to understand the requirements of ISO/IEC 17025:2017 and how those requirements apply to laboratories. The course covers all requirements of the standard with a focus on what laboratory personnel need to know to understand and apply the requirements of the standard. https://anab.ansi.org/training

May 10-12, 2022 Internal Auditing to ISO/IEC 17025:2017 (Non-Forensic). Live Online. ISO/IEC 17025 training course prepares the internal auditor to clearly understand technical issues relating to an audit. Attendees of Auditing to ISO/IEC 17025 training course will learn how to coordinate a quality management system audit to ISO/IEC 17025:2017 and collect audit evidence and document observations, including techniques for effective questioning and listening. https://anab.ansi.org/training

May 24-25, 2022 Validation and Verification of Analytical Methods. Live Online. ANAB. This course provides an introduction to validation and verification of analytical methods. The common elements of a validation/verification plan and a general approach to performing a validation or verification are presented. https://anab.ansi.org/training

SEMINARS & WEBINARS: Measurement Uncertainty

Dec 6-7, 2021 Measurement Confidence: Fundamentals. Live online. ANAB. This Measurement Confidence course introduces the foundational concepts of measurement traceability, measurement assurance and measurement uncertainty as well as provides a detailed review of applicable requirements from ISO/IEC 17025 and ISO/IEC 17020. https://anab.ansi.org/training

Dec 8-10, 2021 Measurement Uncertainty: Practical Applications. Live Online. ANAB. This course is designed for individual interested to further their understanding of measurement uncertainty to identifying uncertainty components, specifying the measurement process and calculating and combining standard uncertainties, as well as expanding uncertainties. https://anab.ansi.org/training/

Dec 8-10, 2021 Introduction to Estimating Measurement Uncertainty. Online Delivery. NMI, Australia. This course will give you a clear step-by-step approach to uncertainty estimation with practical examples; you will learn techniques covering the whole process from identifying the sources of uncertainty in your measurements right through to completing the uncertainty budget. https://shop.measurement.gov.au/collections/physical-metrology-training

Feb 9, 2022 Measurement, Uncertainty and Calibration Workshop. Auckland, NZ. Measurement Standards Laboratory of New Zealand. This course gives a broad high-level overview of measurement and calibration principles, and calculation of uncertainty. https://www.measurement.govt.nz/training/

Feb 9-11, 2022 Introduction to Estimating Measurement Uncertainty. Online Delivery. NMI, Australia. This course will give you a clear step-by-step approach to uncertainty estimation with practical examples; you will learn techniques covering the whole process from identifying the sources of uncertainty in your measurements right through to completing the uncertainty budget. https://shop.measurement.gov.au/collections/physical-metrology-training

SEMINARS & WEBINARS: Photometry & Radiometry

Feb 23-24, 2022 Photometry and Radiometry. Lindfield NSW, Australia. NMI, Australia. This two-day course (9 am to 5 pm) covers the broad range of equipment and techniques used to measure colour and light output, the basic operating principles involved in radiometry, working techniques, potential problems and their solutions. https://shop.measurement.gov.au/collections/physical-metrology-training

SEMINARS & WEBINARS: Pressure

Dec 1-2, 2021 Pressure Measurement. Port Melbourne VIC, Australia. NMI, Australia. This two-day course (9 am to 5 pm each day) covers essential knowledge of the calibration and use of a wide range of pressure measuring instruments, their principles of operation and potential sources of error — it incorporates extensive hands-on practical exercises.https://shop.measurement.gov.au/collections/physical-metrology-training

SEMINARS & WEBINARS: Software

Mar 15-17, 2022 VNA Tools Training Course. Beaverton, OR. Federal Institute of Metrology METAS. VNA Tools is a free software developed by METAS for measurements with the Vector Network Analyzer (VNA). The software facilitates the tasks of evaluating measurement uncertainty in compliance with the ISO-GUM and vindicating metrological traceability. The software is available for download at www.metas.ch/vnatools. The three day course provides a practical and hands-on lesson with this superior and versatile software. https://www.metas.ch/metas/en/home/dl/kurse---seminare.html

May 3-5, 2022 VNA Tools Training Course. Berne-Wabern, Switzerland. Federal Institute of Metrology METAS. VNA Tools is a free software developed by METAS for measurements with the Vector Network Analyzer (VNA). The software facilitates the tasks of evaluating measurement uncertainty in compliance with the ISO-GUM and vindicating metrological traceability. The software is available for download at www.metas.ch/vnatools. The three day course provides a practical and hands-on lesson with this superior and versatile software. https://www.metas.ch/metas/en/home/dl/kurse---seminare.html

SEMINARS & WEBINARS: Temperature & Humidity

Feb 10, 2022 Temperature Measurement and Calibration Workshop. Auckland, NZ. Measurement Standards Laboratory of New Zealand. This course covers the use, care, and calibration of liquid-in-glass, platinum resistance, thermocouple, and radiation thermometers. https://www.measurement.govt.nz/training/

Mar 10, 2022 Humidity Measurement. Lindfield NSW, Australia. NMI. This course (9am-5pm) provides information about the main concepts and practical techniques involved in measuring humidity in air and explains how to make such measurements accurately and consistently. https://shop.measurement.gov.au/collections/physical-metrology-training

Mar 22-24, 2022 Temperature Measurement. Lindfield NSW, Australia. NMI. This three-day course (9 am to 5 pm) covers the measurement of temperature and the calibration of temperature measuring instruments. It incorporates extensive hands-on practical exercises. https://shop.measurement.gov.au/collections/physical-metrology-training

Jun 8, 2022 Testing Temperature Controlled Enclosures. Online Delivery. National Metrology Institute (NMI), Australia. This one day course is for people involved in routine performance testing of temperature-controlled enclosures (oven, furnace, refrigerator and fluid bath). It incorporates an extensive overview and comparison of AS2853 and IEC 60068-3-5 requirements, and it also includes an overview of the medical refrigeration equipment temperature mapping requirement to AS3864.2. https://shop.measurement.gov.au/collections/physical-metrology-training

SEMINARS & WEBINARS: Vibration

Apr 5-7, 2022 Fundamentals of Random Vibration and Shock Testing. San Jose, CA. This three-day Training in Fundamentals of Random Vibration and Shock Testing covers all the information required to plan, perform, and interpret the results of all types of dynamic testing. Some of the additional areas covered are fixture design, field data measurement and interpretation, evolution of test standards and HALT/HASS processes. https://equipment-reliability.com/open-courses/

SEMINARS & WEBINARS: Weight

Sep 8, 2022 Calibration of Weights and Balances. Lindfield NSW, Australia. National Measurement Institute (NMI), Australia. This course covers the theory and practice of the calibration of weights and balances. It incorporates hands-on practical exercises to demonstrate adjustment features and the effects of static, magnetism, vibration and draughts on balance performance. https://shop.measurement.gov.au/collections/physical-metrology-training

Let us know what we've missed, so we can include it here!
Email **office@callabmag.com**.

Testing 1-2: New Laser-Based Microphone Calibration Measures Up

NIST News, September 02, 2021 — Researchers at the National Institute of Standards and Technology (NIST) have conducted the first demonstration of a faster and more accurate way to calibrate certain kinds of microphones.

The technique, which uses lasers to measure the velocity at which a microphone's diaphragm vibrates, performs well enough to overtake one of the main calibration methods used at NIST and throughout industry. Someday, a laser-based method could be commercialized to become a completely new way to do extremely sensitive, low-uncertainty calibrations of microphones in the field, in places such as factories and power plants. Potential users of such a commercial system could include organizations that monitor workplace or community noise levels or the condition of machinery via sound.

"There's nothing like this on the market now, not that I'm aware of," said NIST scientist Randall Wagner. "It would be far in the future — a pie-in-the-sky kind of thing — but I see this work as opening the door to commercial applications."

Their work was published online this week* in JASA Express Letters.

Traditional "comparison calibrations" involve comparing a customer's microphone to a laboratory standard microphone that has already been calibrated by other means. The new laser method demonstrated by NIST has lower uncertainties and is roughly 30% faster than the traditional comparison method currently used at NIST to calibrate customers' microphones.

"People have been looking for a highly accurate calibration method that uses lasers, and they haven't found an approach that is competitive with the most accurate existing method," said NIST scientist Richard Allen. "But now we've found a comparison calibration that is better than the ones used in common practice."

The 'Standard' Standard

Sound is pressure waves traveling through a medium such as air. A microphone is a device that takes those pressure waves and turns them into an electrical signal.

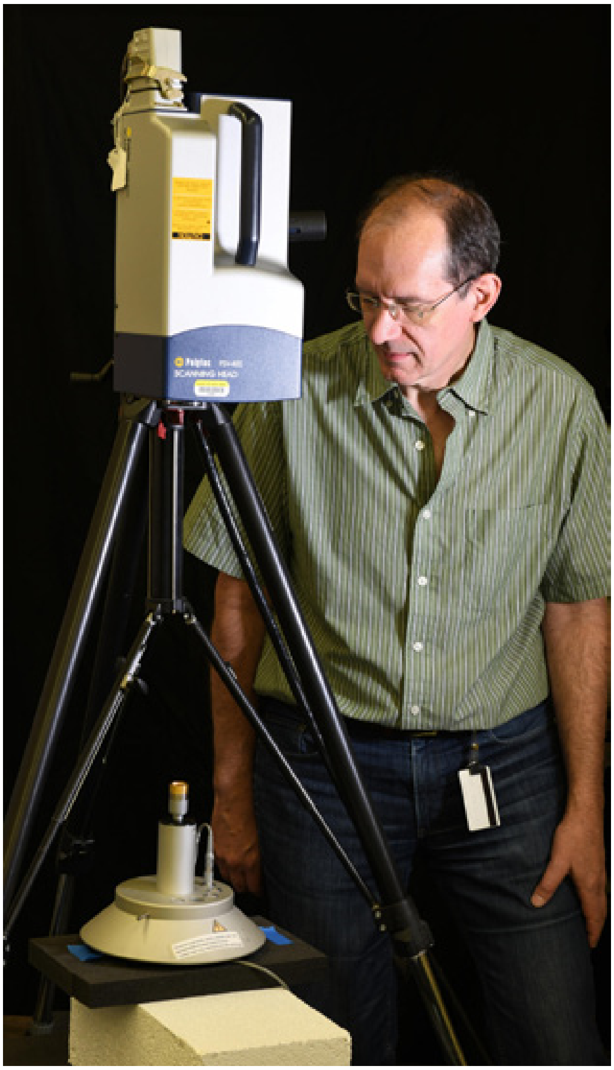
To calibrate a microphone, researchers need to measure how sensitive it is to pressure waves. They start by calibrating a set of laboratory standard microphones using a technique called the "reciprocity method" — the gold standard for microphone calibrations.

In a reciprocity calibration, two microphones are connected to each other via a small hollow cylinder called an acoustic coupler. One microphone produces a sound that the other microphone picks up. After a measurement has been taken, the microphones' functional positions can be swapped, with the transmitter acting as receiver and vice versa.

(And yes, the microphones are sometimes used to produce sounds rather than just receive them. Unlike the microphones you might use for a conference call or karaoke night, laboratory standard microphones are able to perform as either a receiver or as a transmitter — essentially a loudspeaker.)

This process is repeated several times using a total of three laboratory standard microphones. By exchanging the microphones' roles between measurements, researchers can be sure of the sensitivity of each of the three microphones without the need for a previously calibrated microphone.

Once this master set of microphones has been calibrated, it can be used to directly calibrate customers' microphones. Different laboratories use different methods to accomplish this goal, but at NIST the technique commonly used for high-accuracy calibration of customers' microphones is a reciprocity-based "comparison" calibration. It's called



NIST's Richard Allen with the laser-based microphone calibration setup. The laser system points down at the microphone being measured. Credit: NIST "reciprocity-based" because it uses the same setup as the reciprocity method, except that the newly calibrated microphone acts exclusively as the transmitter and the microphone being calibrated acts exclusively as the receiver.

It is this second type of calibration, the "comparison" calibration, that NIST scientists set out to test against the new laser-based method.

New Method: Less Is More

Traditional microphone calibration methods are acoustical — they rely on transmission of sound through a medium. In contrast, the new laser-based calibration method measures the physical vibrations of the diaphragm itself.

For their recent experiment, NIST researchers used a laser Doppler vibrometer, a commercial instrument that shines a laser beam onto the surface of a microphone whose diaphragm is vibrating at a set frequency. (See animation.)

The beam bounces off the surface of the diaphragm and is recombined with a reference laser beam. In this way, subtle shifts in frequency are measured. (These shifts in frequency work along the same principle as the Doppler effect, which causes that ambulance outside your window to sound higher-pitched as it approaches and lower-pitched as it moves away.) Researchers convert the signal from the vibrometer into a velocity, which tells them how fast the diaphragm was vibrating at that point on its surface.

To conduct the new test, NIST scientists used nine nominally identical laboratory standard microphones, each with an 18.6 millimeter diameter diaphragm, about the width of a postage stamp. All were tested at two frequencies, 250 hertz (for piano players, roughly the B note below middle C) and 1,000 hertz (two octaves higher than 250 hertz).

They began by measuring over the whole surface area of the diaphragms. They found that the velocity in the center of the diaphragms was significantly higher than near the edges, where there was practically no motion.

Ultimately, they discovered that the best approach was to use data from just a small section at the center of the diaphragms taking up only 3% of the total surface area. The idea of using just the central section came from a recent paper [https://tohoku.pure.elsevier.com/en/publications/sensitivity-measurement-of-a-laboratory-standard-microphone-by-me] by a team of researchers from the Republic of Korea and Japan.

"The key to making the velocity measurements nice and repeatable is measuring in the center of the diaphragm," Wagner said. "As you go further and further toward the edges, our measurements just weren't very repeatable."

As a final step, Wagner and Allen compared the microphone sensitivities they measured with the laser-based calibrations to measurements they had previously taken using the gold-standard reciprocity calibrations with the same set of microphones. The verdict?

"The numbers agreed very well," Wagner said. "They were statistically indistinguishable from each other."

Moreover, the uncertainties for the new laser method were impressive. For comparison: While the gold-standard reciprocity method has the lowest uncertainty at 0.03 decibels (dB), and the traditional reciprocity-based comparison method has an uncertainty of 0.08 dB, the laser-based comparison method has an uncertainty of just 0.05 dB.

Wagner and Allen say that the laser comparison method saves "significant time" primarily because it is performed in open air. In contrast, the traditional NIST way of doing a comparison at higher frequencies requires connecting two microphones with an acoustic coupler and then filling the coupler with hydrogen, which takes up to 20 minutes per test.

Next Steps

Wagner hopes that scientists will find a way to develop the laser-based system into a highly accurate primary calibration method that rivals or even outperforms the gold-standard reciprocity method. If successful, a primary laser-based method would be significantly faster, since the reciprocity method requires researchers to repeat the measurements multiple times with different combinations of microphones and acoustic couplers.

Meanwhile, Wagner thinks the laser method could someday be standardized by a standards organization.

"That would be a consensus stamp of acceptance," Wagner said. Until then, he continued, "we have a lot of work left to do."

In the coming months, he and Allen will be upgrading to a more sensitive laser Doppler vibrometer system and will begin expanding the types of microphones calibrated as well as the range of frequencies. They have applied for a provisional patent, and they will also try to turn the method into a suitable primary calibration technique.

"This first attempt was sort of an example of walking past the trees and seeing the really low-hanging fruit, and grabbing it," Allen said.

Wagner says that this experiment is unusual in his experience. Vibrations are usually considered "problematic" when making acoustic measurements since they can lead to increased noise levels. But in this experiment, the vibration and acoustic measurements are connected by design.

"I've been at NIST 30 years, and I don't recall a project that brought vibration and acoustics so closely together," Wagner said.

— Reported and written by Jennifer Lauren Lee

* R.P. Wagner, R.A. Allen and Q. Dong. Laser-based comparison calibration of laboratory standard microphones. JASA Express Letters. Published online Aug. 30, 2021. DOI: https://asa.scitation.org/doi/10.1121/10.0005919

Source: *https://www.nist.gov/news-events/news/2021/09/testing-1-2-new-laser-based-microphone-calibration-measures*

Diode Lasers for Optical Metrology

PTBnews 3.2021—In collaboration with an industrial partner, PTB has developed and assessed a very compact wavelength standard. This standard is based on a diode laser whose frequency is stabilized to transitions of the iodine molecule. In the future, this type of lasers could replace power-intensive and bulky helium-neon lasers as a wavelength standard for interferometric length measurement.

Helium-neon lasers with a wavelength of 633 nm have been used for a long time as wavelength references for industrial interferometric length measurements. With comparatively little effort, they can achieve a relative accuracy of 10^{-8}, which corresponds to an uncertainty of 10 nm per meter and is absolutely sufficient for most applications. This technology is, however, obsolete, and the number of manufacturers has been constantly decreasing. Moreover, compared to modern diode lasers, these gas lasers are bulky, they need high voltage, and they exhibit rather poor efficiency as well as a low output power.

Alternative solutions must keep the wavelength of 633 nm to make it possible to continue using the large number of existing interferometers for length measurement seamlessly. For this reason, diode lasers are a suitable solution, although their inherent wavelength accuracy is not sufficient. This is where stabilization with iodine comes into play: Iodine molecules have numerous absorption lines in the relevant wavelength range. These absorption lines can serve as a wavelength reference.

A special laser diode chip (with internal optical wavelength selection at 633 nm) has been combined with an iodine cell of only 3.3 cm in length in a housing of 27 cm × 15 cm. This has been undertaken by Toptica Photonics AG, a laser manufacturer, within the scope of a project funded by the German Federal Ministry of Education and Research. The laser frequency is automatically stabilized at a defined Doppler-broadened iodine absorption line. A comparatively high power of approx. 5 mW is available at the output of an optical fiber. The device was evaluated with an optical frequency comb against atomic clocks of PTB. This evaluation yielded a relative instability of less than 10^{-10} for averaging times of more than 10 s. This is considerably less than the values provided by commercially available helium-neon lasers with simple stabilization. The absolute frequency obtained was in agreement with expected values. The line shape and the stabilization were modelled to be able to easily predict the absolute frequency and stability when other iodine lines are selected.

Integrated with micro-optical elements into a small housing (only a few centimeters in size), the prototype has the potential to enable very compact and accurate interferometers in the future.

Contact

Uwe Sterr,Department 4.3, Quantum Optics and Unit of Length, Phone: +49 531 592-4310, uwe.sterr(at)ptb.de.

Scientific publication

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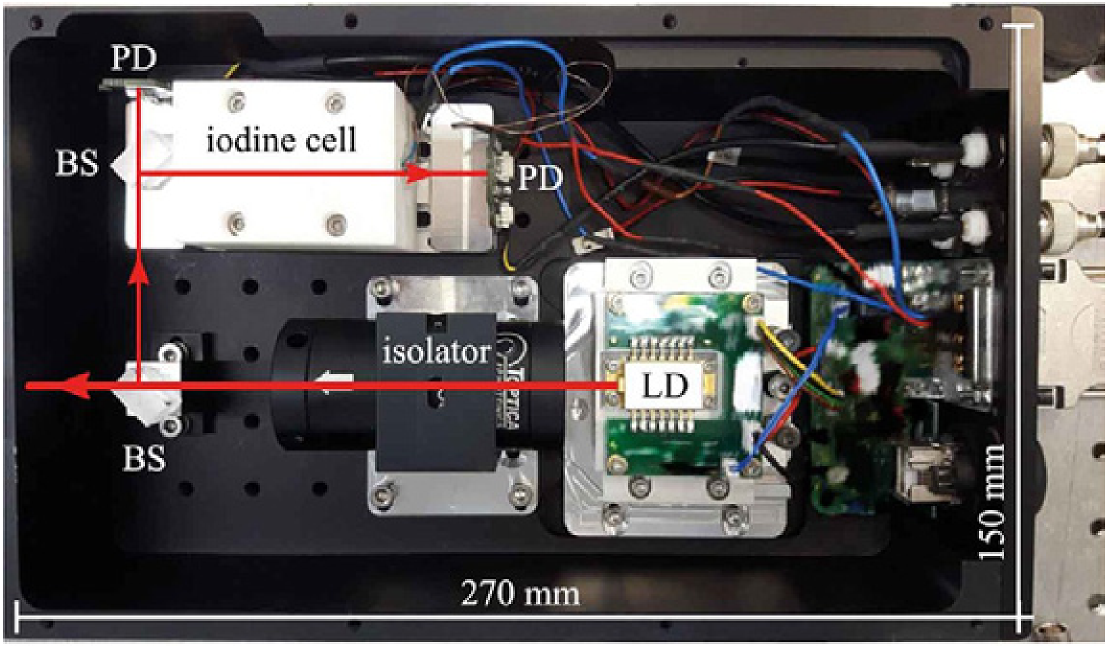
Source: *https://www.ptb.de/cms/en/presseaktuelles/journals-magazines/ptb-news.html*



Top view of the prototype – the optical path is indicated by the red arrows with the laser diode (LD), the beam splitter (BS) and the photodetectors (PD). Credit: PTB

Gauge block made of single-crystal silicon. Dimensions: 197 mm × 35 mm × 9 mm. Credit: PTB

On the Path to a "Nanometer Standard"

PTBnews 3.2021 — At PTB, absolute length measurements on a single-crystal silicon gauge block have been performed using imaging interferometry. These measurements have a smaller measurement uncertainty than all previous measurements. They provide more accurate values for the CODATA reference data and are valuable for a new secondary realization of the meter.

Since it was necessary to have a reference material for high-accuracy measurements of thermal expansion, a large number of measurements used to be performed on silicon over a wide temperature range. Due to its diamond-like crystalline structure, single-crystal silicon expands uniformly in all spatial directions, meaning that it is isotropic with regard to thermal expansion. In addition, high-grade silicon is readily available at an industrial scale.

As early as six years ago, PTB had already presented results of thermal expansion measurements between 7 K and 293 K obtained by means of imaging interferometry. A systematic deviation from the CODATA reference values was, however, noticed in this temperature range. In contrast to dilatometric measurements obtained by others, PTB's results were derived from absolute length measurements. The present thermal expansion study is based on this work. In this study, the temperature range has been extended to 320 K and the measurement uncertainty reduced. In addition, the study includes the simultaneous determination of the compressibility of silicon.

The measured data were analyzed by means of a new method that provides for the fact that the thermal expansion coefficient (calculated by derivation) is a quantity that is sensitive to the data evaluation model chosen. The approach is based on Bayesian model averaging (BMA) and allows different models to be dealt with at the same time and also to be taken into account when calculating model probabilities.

The results have shown that in the temperature and pressure ranges covered, the thermal expansion coefficient hardly depends on the ambient pressure. The new measurements provide more accurate values than the previous reference values. Furthermore, the measurement uncertainty is smaller than that of previously obtained results by up to one order of magnitude.

Since the latest revision of the mise en pratique for the definition of the meter in the SI refers to the lattice spacing of silicon as a basis for nanoscale secondary realization methods for the meter, these findings can also be used in this context.

Contact

Guido Bartl, Department 5.4,Interferometry on Material Measures, Phone: +49 531 592-5430 guido.bartl(at)ptb.de

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Source: *https://www.ptb.de/cms/en/presseaktuelles/journals-magazines/ptb-news.html*

New Purdue Research Building Will Offer a World's First in Hypersonic Testing, Materials Development

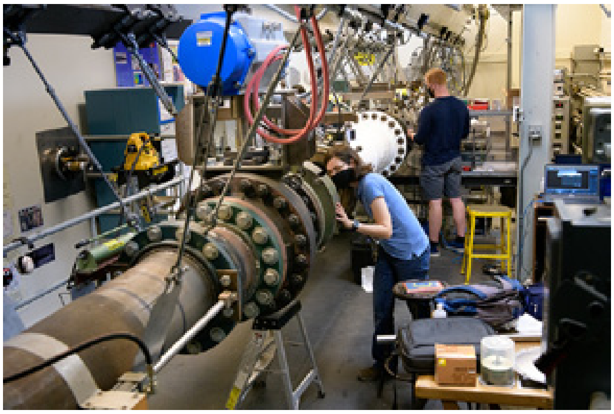
July 27, 2021, WEST LAFAYETTE, Ind. — Imagine an aircraft flying 2,800 miles across the United States in only 15 minutes. A state-of-the-art building ready for construction at Purdue University will provide the facilities to explore that idea through advanced hypersonic research.

The planned 65,000-square-foot Hypersonics and Applied Research Facility (HARF) will house two cutting-edge wind tunnels, enhancing Purdue's world-leading capabilities in hypersonics evaluation and testing. The $41 million facility will house the only Mach 8 quiet wind tunnel in the world as well as a hypersonic pulse (HYPULSE) shock tunnel. The tunnels recreate different scenarios such as spacecraft re-entry or missile flight through the atmosphere as well as replicating unique engine conditions for extremely high-speed propulsion.

"Purdue's rich hypersonics program includes both a broad bench of more than 40 experts and unique capabilities that allow the university to play an important role in the security of our nation," said Theresa Mayer, Purdue's executive vice president for research and partnerships. "This first-of-its-kind facility will further Purdue's capacity to conduct research including tests and evaluations under real-world conditions for faculty, industry partners, federal agencies and other stakeholders."

The Mach 8 quiet wind tunnel and the HYPULSE tunnel offer controlled environments to research several facets of high-speed flight. The new Mach 8 quiet wind tunnel more closely simulates flight and provides more accurate data than conventional hypersonic wind tunnels.

The HYPULSE tunnel uses a shock wave of high-temperature air to recreate specific hypersonic flight conditions. It will allow flight simulations at speeds ranging from Mach 5 to as high as Mach 40. Purdue will be only the second university in the U.S. to offer HYPULSE test capabilities. The university currently offers one of only two working Mach 6 quiet tunnels in the country.



Students work during the summer with Purdue's Mach 6 quiet wind tunnel. A more advanced Mach 8 quiet wind tunnel will be part of the new hypersonics research building to be constructed at Purdue. Credit: Purdue University/John Underwood

Supporting a national defense strategy

National pursuit of hypersonics systems by government and industry has intensified during the last few years. Hypersonic vehicles can travel more than five times the speed of sound and fly in the upper reaches of the atmosphere, significantly challenging an adversary's ability to detect, track, target and engage. These systems are a top Department of Defense priority to ensure U.S. battlefield dominance, as competitors continue to advance similar programs. Hypersonics-related research is included in the FY22 President's budget request at $3.8 billion, up by 20% from a $3.2 billion request in FY21.

This potential increase in funding would build on previous investments by federal agencies and industry to help better integrate hypersonic systems with the U.S national security strategy. The new HYPULSE tunnel is a donation from Northrop Grumman Corp. In 2019, Purdue received a contract from the Air Force Research Laboratory to support the development of the first quiet Mach 8 tunnel in the world, the first facility of its kind capable of collecting data at speeds greater than Mach 6. Collecting data at higher Mach numbers is critical to extending the understanding of flow physics, especially heat transfer and flight control effectiveness, as Department of Defense programs continue working to fly faster and farther.

Purdue's own recent investments in hypersonics help to position the university as a compelling partner for national defense projects from industry and government. Hypersonics is a critical topic under two of Purdue's Next Moves, recently announced strategic initiatives that will advance the university's competitive advantage. Hypersonics research is a key component of Purdue's National Security and Technology initiative. The Purdue Applied Research Institute, the new nonprofit applied research arm of the university, will leverage the university's unique hypersonics capabilities to deliver innovative defense solutions for industry and government partners.

"This investment by Purdue University demonstrates our commitment to advancing national security technology, one of the pillars of Purdue's Next Moves," said Mung Chiang, Purdue's executive vice president for strategic initiatives and the John A. Edwardson Dean of the College of Engineering. "Building the world's fastest quiet wind tunnel and innovating manufacturing represent two more steps in creating America's hypersonic engineering epicenter here at Purdue Aerospace District."

Construction on the hypersonic building is scheduled to begin in September. The building is located in Purdue's Aerospace District, a university-affiliated aerospace business hub for public and private research collaborations on research and commerce. Tenants in the district already include Rolls-Royce, Saab Defense and Security and SEL Purdue (Schweitzer Engineering Labs).

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In addition to the HYPULSE and the quiet wind tunnel, the building also will feature advanced facilities that will enable the study of high-temperature materials applications. Hypersonic flight can create air friction above 1,000 degrees Celsius, requiring unique processes and materials to withstand such conditions. The research facility offers the chance to design and test these new materials. It also will create space for Purdue researchers to further capabilities to design, build and test hypersonic systems.

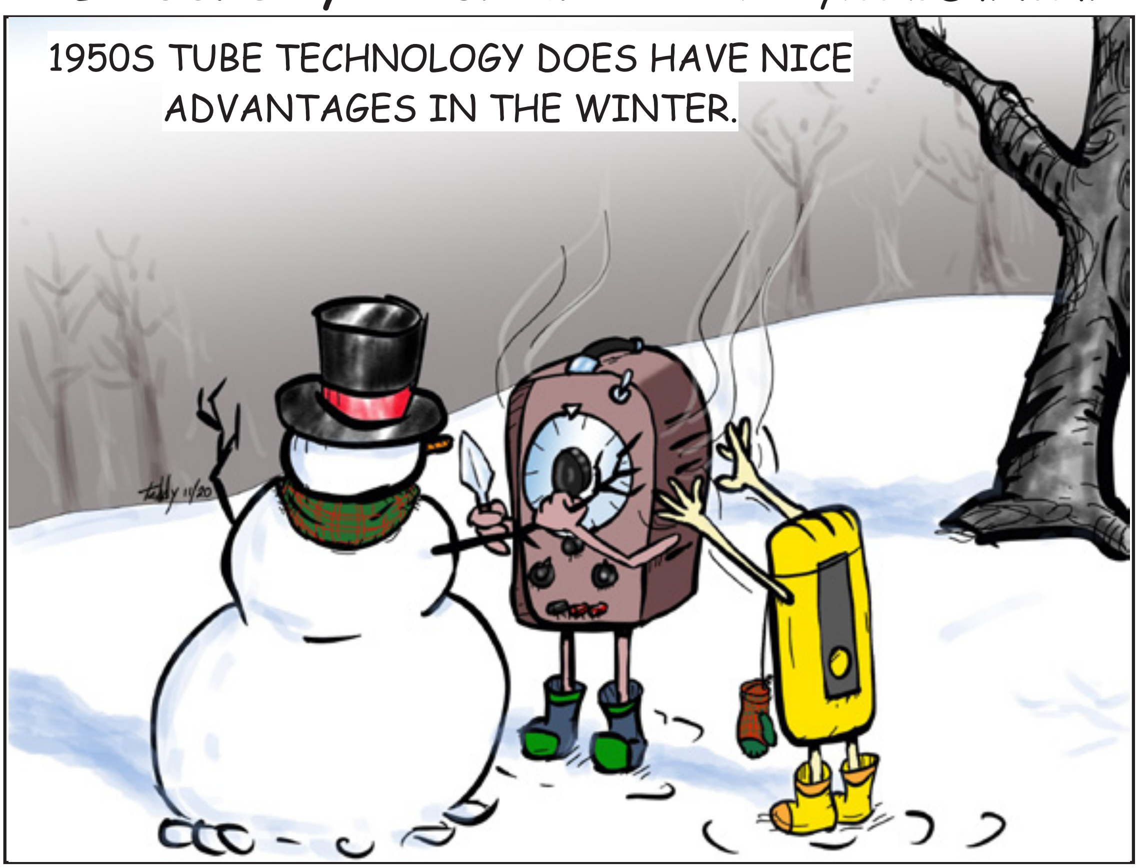
Scott Meyer, managing director of Purdue's Maurice J. Zucrow Laboratories, said the facility would enable faculty to use advanced laser-based optical diagnostic measurement techniques as part of the quiet wind tunnel and HYPULSE testing. The diagnostic techniques are able to make quantitative measurements at a million times per second, slowing testing observations to take in specific details such as what the air flow field direction is and what chemical reactions are occurring.

"The diagnostic measurement techniques are almost going to make the Mach 8 quiet wind tunnel and HYPULSE like brand new tools to investigate the physics of what is happening in these conditions," Meyer said. "Researchers will be applying the techniques at the same conditions that would occur on real systems in flight and enable measurements that have never been made before under these extreme testing conditions."

A better understanding of when and how airflow over a surface changes from smooth to turbulent is essential in the successful design of expendable and reusable hypersonic vehicles.

Source: *https://www.purdue.edu/newsroom/releases/2021/Q3/new-purdue-research-building-will-offer-a-worlds-first,-and-hypersonic-testing,-materials-development.html*

CAL-TOONS by Ted Green teddytoons@me.com



Temperature Calibrations, Part 4

Ryan Egbert and Joseph Rindone
Sine Calibration School

The following article is the last of a four-part Metrology 101 series focusing on temperature. The written content provided here is also intended to be combined with demonstration videos that we will provide through our school, Sine Calibration School. If you follow this series and complete the training online, you will be awarded our temperature badge credential for free! But, for this to happen, you must complete all of the content provided this year and complete the final quiz in our school in December 2021. Register today at www.sinecalibration.com, you will see a link at the top of the screen. Thank you to all that have participated in this event, it has been a great time!

Introduction

The content we have discussed up to this point will take most beginners to temperature measurements fairly far in their career. The majority of calibration work at a "typical" calibration laboratory will fall under one of the categories we covered in the three articles leading up to this one: **Thermocouples, Resistance Temperature Detectors,** and **Thermistors**. Even though these three sensors make up the "state-of-the-art" of the industry's temperature devices, there are a couple others that need to make their appearance here in our course. We at the school have been seeing a growing demand for information surrounding Infrared Radiation (IR) thermometers, as well as the classic liquid in glass (LiG) thermometers. This is due to the growing demand of these measurements in today's biomedical manufacturing environment and also with the emergence of the COVID-19 virus. Anecdotally, we have heard from numerous managers at different calibration laboratories around the United States that have been seeing an increase in IR thermometer calibrations on the scale of 300% to 5,000%!

Blackbody Radiation

To teach about infrared radiation, or electromagnetic radiation, on a basic level is not an easy task. However, when you break down the tasks that most beginning calibrators are asked to do, the picture of what you need to know to reduce errors becomes clearer. From our experience, the majority of calibrations that a new technician will encounter will be them sitting down in their lab with an IR thermometer "gun," a blackbody standard, and a procedure or datasheet. Little is discussed about what a blackbody standard is or what errors are involved in the measurement.

In physics, an ideal blackbody is something that absorbs all incident electromagnetic radiation falling upon it with no reflection. It is given the name "black" body because it absorbs all colors of light. This ideal blackbody will radiate a temperature based on its absolute temperature alone, not affected by the composition or size of the object being measured [1]. Note that I said *ideal*, as we all know this world is anything but ideal, and the same can be said for blackbodies.

Emissivity

Materials in our real world are considered to be more of a ***greybody*** and emit this thermal energy at a fraction of the perfect blackbody. This is because a greybody does not absorb all incident electromagnetic radiation, meaning some of the radiation from the surrounding environment will also reflect off the surface and back to the sensor taking a reading (the device under test). This fractional energy is called ***emissivity*** and is denoted by the Greek letter epsilon, or **ε**. This applies to the measurements we do in a calibration lab because none of our measurements will be in the ideal range.

An ideal blackbody will have a perfect emissivity of 1.0, whereas the typical single setting IR thermometer is set at an emissivity of 0.95 or 0.97. For reference, our skin typically has an ε of around 0.98 [2], and a perfect reflector (or ***whitebody***) would be an ε of zero (ε = 0.0). It is important to note, however, that a perfect ε = 1.0 blackbody is only theoretical. There are many high-level labs around the globe that have elaborate setups to achieve around ε = 0.999, usually using a deep well with specialized paint designed for maximum light absorption, but a 1.0 currently does not exist.

The importance of knowing the emissivity settings of both your device under test (DUT) and your standard cannot be overstated, if they do not match, the difference must be compensated for. Another way of looking at the emissivity of an object is: An ε of 1.0 means that all of the temperature being sensed off an object is from the object itself. In contrast, an ε of 0.98 means that 98% of the temperature being sensed is from the intended target, but 0.02 or 2% is either reflected from the surroundings or transmitted from behind and through the object. There

are many different makes and models of IR calibrators, some with fixed emissivity others with variables. We will show the difference between proper and improper emissivity settings and take a look at the differences between emitters and reflectors in the video portion of this block. The visual of this type of measurement can be helpful in understanding it.

Angle and Distance

With the basics of emissivity discussed, the last calibration error contributor we will discuss in this article is the angle and distance from the target you are measuring. As you can see from the image above, most IR thermometers will provide a distance scale that applies to that particular thermometer. This is something very specific to each device. It will usually be displayed in a ratio, like seen above as 12:1. For this particular device, it means that at 12 inches away from the target the size of the sensing circle area will be 1.5 inches. To take this further, this area is extremely important because the sensor will collect the electromagnetic radiation from that entire area. If the circle is larger than the intended target, you will get temperature measurement errors that include the temperatures of the area surrounding the target.

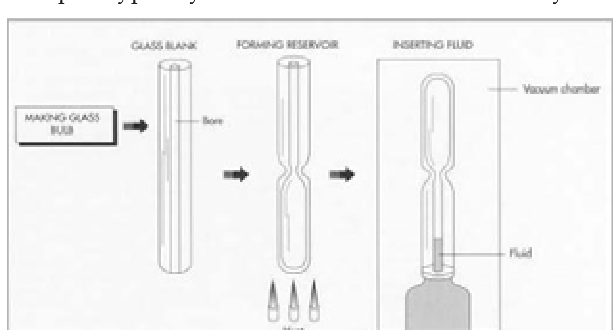
What is important here is that there is not just a sensing element inside an IR thermometer, but also a lens that helps focus the radiated energy onto the sensor. The majority of IR thermometers in the industry will have a circular area that can be measured, but rectangle and square sensors also exist. You must understand this distance to size ratio before using the device, but the other consideration here is to also keep the device at a 90° angle toward the surface being measured. This is for similar reasons as remembering the size of the circle. If you are angled, the sensor is taking in radiation outside of the intended target. This is another factor we will show in the video portions of this training.

Liquid In Glass Thermometers

In ending this article, a quick discussion on the devices that started it all, Liquid in Glass (LiG) thermometers. Thermometry as a science has existed for over half a millennium. We have already discussed the inventor of the first accurate thermometer, who made it out of glass and a liquid. Yes, there were prior thermometers, however, the previous models were called "thermoscopes" as was the one Galileo did in 1593. These thermoscopes were inaccurate and the glass was open ended, which was not very practical for movement. We are not going to review Fahrenheit or his scales, but what we are going to discuss is a temperature device that is still very prevalent in metrology. So much so that NIST devotes great attention to these items. We have seen glass thermometers our whole lives. Professionally known as "Liquid in Glass" thermometers, or just LiG thermometers in the field, the glass thermometers your mom or doctor used to check your temperature is a simple example. In this discussion, we are going to examine laboratory grade LiG thermometers used in metrology and the concerns both in the use and maintenance of these very fragile glassware items. You will learn all of the descriptive parts of LiG thermometers. We will describe what they look like, how they are constructed, and how to use and calibrate them.

Liquid	Temperature Range (Celsius)		
Mercury	-35	to	+510
Alcohol	-80	to	+70
Pentane	-200	to	+30
Toluene	-80	to	+100
Creosote	-5	to	+200

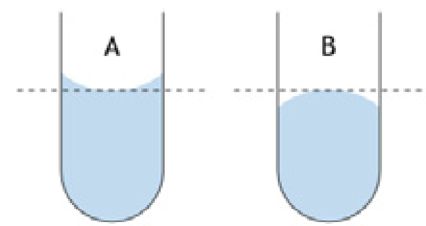
We are mentioning LiG thermometers as measurement devices lastly because they are not as widespread as other devices such as TC's and RTD's. This is mostly due to their limitations and fragile construction, but they are still used in limited applications in military, scientific, and medical process control. The table above lists the different types of liquid typically found in these devices. Mercury LiG

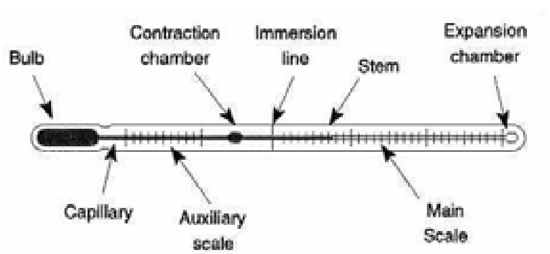


Credit: NIST [3]

thermometers have been on the out for some time now and NIST no longer calibrates these devices due to the hazard of mercury itself.

Glass thermometers are made from glass tubes that have small inner chambers called capillary tubes. LiG thermometers have 3 basic sections incorporated into them, not including the liquid itself. Along the length of the stem is the scale. The scale is determined by the particular liquid being used. In this case, since mercury is no longer a prevalent liquid in the industry, alcohol is found to be within the range of -80 to +70 degree Celsius. There are important items found on and within the thermometer itself. At this point we want to discuss a major component of the LiG thermometer. This is because this is where you take the measurement from, known as the **meniscus**. Let's take a moment to talk about this. When measuring a liquid by sighting the meniscus it is important to take the line of sight, or parallax, into consideration as well as the "center of the meniscus." With liquids, such as water and alcohol, it is measured at the bottom of the meniscus (Fig. A). For mercury, it is referenced at the top of the meniscus (Fig. B).





From the bottom up, you will find the "**bulb**" which contains the liquid. The "**stem**" is a thick glass rod with the capillary tube inside. The stem itself is very thick in comparison to the bulb, which is thin, in order to pass the thermal change rapidly to the liquid. There are sometimes "**auxiliary scales**" (aux) found below the main scale. This aux scale provides for the Ice Point reference for calibration. Not all thermometers have these, as the main scale may contain the zero reference. The next part is the "**contraction chamber**" which allows for a shorter stem overall. The "**immersion line**" shows the depth at which the thermometer should be inserted into the measurement medium [3]. Using this immersion line is called "**partial immersion**" and is designed to be used as implied. This type of immersion gives the greatest uncertainties due to the stem being exposed to the surrounding environment. "**Total immersion**" thermometers are designed to be immersed to the same level as the fluid you are reading. For example, if the temperature was 75 °F the LiG would be immersed to the point on the thermometer where 75 °F would be. This is more accurate because of the amount of thermometer exposed. There is a 3rd immersion method called "**complete immersion**" where the entire length of the LiG is held in the measurement medium or chamber. In a bath, the complete LiG item would be immersed entirely with no part of the stem showing. In a chamber, the DUT would be placed in a holder in the center of the chamber. Once we have established the correct measurement technique, we can read the value directly off the main scale. These scales which we discussed are determined by the liquid characteristics and the length of the thermometer.

Lastly, the thermometer has an expansion chamber on the very top to reduce pressure as the temperature rises. We know the physical action of materials when heat is applied or withdrawn from it. Thermal expansion occurs when heat reacts with liquids. We apply calculations involving the coefficient of linear expansion for the specific fluid used in the thermometer. We know these coefficients from the scientist who discovered the laws of fluid dynamics earlier in history. It is important to make a statement about thermal expansion now. All fluids conform to this process except one: water does not behave in the manner all other material does. Water expands when frozen because ice crystals form. This crates space, allowing air to be captured within. Without this anomaly ice would sink and the oceans of the Earth would be frozen from the bottom up allowing no liquid water to exist anywhere.

This concludes the written portion of this last section of our temperature training. We are very thankful for the opportunity to train all of you and appreciate your participation! If you have any questions throughout any of our training, please reach out to us at support@sinecalibration.com.

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A Case Study on Interlaboratory Consensus Building

Hening Huang
Teledyne RD Instruments (Retired)

This technical note reports a case study that addresses a challenge of interlaboratory consensus building called for by Possolo (2020). The consensus value is estimated as a weighted-average (WA) and the associated standard uncertainty (SU) is estimated with a formula that is applicable to any type of weight. In addition to the traditionally used "degree of equivalence," the performance of a participating laboratory is also evaluated with the root mean square percentage error (RMSPE) of its measured value with respect to the consensus value.

1. Introduction

Possolo (2020) called for an interlaboratory consensus building challenge. The data used in this challenge are the selected measurement results of eleven laboratories for the activity of iron-59 obtained in the key comparison BIPM.RI(II)-K1.Fe-59. Let y denote the measured value A_e (^{59}Fe) of a laboratory and σ denote the associated standard uncertainty (SU) $u[A_e(^{59}\text{Fe})]$. Table 1 shows the data for y and σ of the eleven participating laboratories.

This challenge comprises four tasks (Possolo 2020):

- deriving a consensus value from these results;
- evaluating the associated standard uncertainty;
- producing a coverage interval that, with 95% confidence, is believed to include the true value of which the consensus value is an estimate; and
- suggesting how the measurement result from NIST may be compared with the consensus value.

In this case study, we address this challenge using eight frequentist methods. These eight methods have one thing in common: the consensus value is estimated as a weighted-average (WA). However, different weights are used by each method, so the estimated consensus values by these eight methods are different. On the other hand, the associated SU is estimated with a formula that is applicable to any type of weight. The results of this case study are compared with those obtained from the Bayesian method of Possolo (2021) and Mana (2021).

In addition to the traditional use of "degree of equivalence," we also use the root mean square percentage error (RMSPE) to evaluate the performance of participating laboratories. We believe that RMSPE is a more appropriate measure of laboratory's performance.

Laboratory	$y = A_e(^{59}\text{Fe})$ (kBq)	$\sigma = u[A_e(^{59}\text{Fe})]$ (kBq)
BKFH	14,685	32
IAEA/RCC	14,663	24
PTB	14,609	25
NIST	14,641	60
NPL	14,668	55
ANSTO	14,548	54
CMI-IIR	14,709	36
LNE-LNHB	14,603	36
NMIJ	14,576	23
BARC	14,511	28
KRISS	14,728	50

Table 1. Data for y and σ used in the challenge of interlaboratory consensus building called for by Possolo (2020).

2. Calculation of Consensus Value, Standard Uncertainty, and Coverage Interval

2.1 Statistical Methods

Frequentist statistics gives weighted-average (WA), denoted by $\hat{\mu}$, as an estimator of the true consensus value μ. The general form of WA is written as

$$\hat{\mu} = \frac{\sum_{i=1}^{m} w_i y_i}{\sum_{i=1}^{m} w_i} \quad (1)$$

where y_i is the measured value of the i-th laboratory, w_i is the weight, and m is the number of participating laboratories.

There are five different weights: equal-weight, inverse-σ, inverse-σ^2, inverse-ω^2, and inverse-RMSE (RMSE stands for root mean squared error), where σ^2 is the within-laboratory variance and ω^2 is the total variance. Equal-weight corresponds to the arithmetic average. The other four types of weights correspond to inverse-σ WA, inverse-σ^2 WA, inverse-ω^2 WA, and inverse-RMSE WA, respectively. The inverse-ω^2 WA includes four different methods: DerSimonian–Laird (DL) (DerSimonian and Laird 1986), maximum likelihood (ML), restricted maximum likelihood (REML), and Paule-Mandel (PM) (Paule and Mandel 1982). For descriptions of the ML and REML methods, readers can refer to, for example, Huang (2018). The inverse-RMSE WA is also known as the ZSNR estimator (Huang 2018), where ZSNR stands for "zero sum of the normalized residual." Therefore, we consider a total of eight frequentist methods for estimating the consensus value. It is important to note that, because $E(y_i)=\mu$, $\hat{\mu}$ is an unbiased estimator of μ, regardless of the type of weights (Shahar 2017).

We use the following formula to estimate the SU of $\hat{\mu}$ (Huang 2019)

$$u = \frac{1}{c_4\sqrt{m-1}} \sqrt{\frac{\sum_{i=1}^{m} w_i (y_i - \hat{\mu})^2}{\sum_{i=1}^{m} w_i}} \quad (2)$$

where $c_4 = \sqrt{\frac{2}{m-1}}\Gamma\left(\frac{m}{2}\right) \Big/ \Gamma\left(\frac{m-1}{2}\right)$ and $\Gamma(.)$ stands for Gamma function. The factor c_4 depends on m. It is 0.7979 for m=2, 0.9400 for m=5, and 0.9727 for m=10.

Equation (2) is an approximately unbiased estimate of the unconditional SU of $\hat{\mu}$; it accounts for both the within- and between-laboratory variability (Huang 2019).

Table 2 shows the five WA-type consensus value estimators (correspond to eight frequentist methods) and the associated SU expressions. In the special case where all within-laboratory variances are the same, i.e. $\sigma_i^2 \equiv \sigma^2$, the inverse-$\sigma$ WA, inverse-σ^2 WA, or inverse-ω^2 WA reduces to the arithmetic average. Consequently, Eq. (2) reduces to $u = \hat{\omega} / (c_4 \sqrt{m})$, where $\hat{\omega}$ is the sample standard deviation.

Estimator $\hat{\mu}$	Weight	SU of $\hat{\mu}$
Arithmetic average (equal-weight)	$w = \frac{1}{m}$	$u = \frac{1}{c_4\sqrt{m}} \sqrt{\frac{1}{m-1}\sum_{i=1}^{m}(y_i - \overline{y})^2} = \frac{\hat{\omega}}{c_4\sqrt{m}}$
Inverse-σ WA	$w_i = \frac{1}{\sigma_i}$	$u = \frac{1}{c_4\sqrt{m-1}} \sqrt{\frac{\sum_{i=1}^{m} \frac{(y_i - \hat{\mu})^2}{\sigma_i}}{\sum_{i=1}^{m} \frac{1}{\sigma_i}}}$
Inverse-σ^2 WA	$w_i = \frac{1}{\sigma_i^2}$	$u = \frac{1}{c_4\sqrt{m-1}} \sqrt{\frac{\sum_{i=1}^{m} \frac{(y_i - \hat{\mu})^2}{\sigma_i^2}}{\sum_{i=1}^{m} \frac{1}{\sigma_i^2}}}$
Inverse-ω^2 WA (DL, ML, REML, and PM methods)	$w_i = \frac{1}{(\hat{\tau}^2 + \sigma_i^2)}$	$u = \frac{1}{c_4\sqrt{m-1}} \sqrt{\frac{\sum_{i=1}^{m} \frac{(y_i - \hat{\mu})^2}{(\hat{\tau}^2 + \sigma_i^2)}}{\sum_{i=1}^{m} \frac{1}{(\hat{\tau}^2 + \sigma_i^2)}}}$
Inverse-RMSE WA (ZSNR estimator)	$w_i = \frac{1}{\sqrt{d_i^2 + \sigma_i^2}}$	$u = \frac{1}{c_4\sqrt{m-1}} \sqrt{\frac{\sum_{i=1}^{m} \frac{(y_i - \hat{\mu})^2}{\sqrt{d_i^2 + \sigma_i^2}}}{\sum_{i=1}^{m} \frac{1}{\sqrt{d_i^2 + \sigma_i^2}}}}$

Table 2. Five WA-type consensus value estimators (eight frequentist methods) and the associated SU expressions

In Table 2, d_i is the sample residual: $d_i = y_i - \hat{\mu}$ (often known as the degree of equivalence), $\bar{y}$ is the sample mean (arithmetic average), and $\hat{\tau}^2$ is an estimator of the heterogeneity (i.e. between-laboratory) variance τ^2.

We employ a generalized method of moments (GMM) estimator, denoted by $\hat{\tau}^2_{\text{GMM}}$ (Veroniki et al. 2016), to estimate the heterogeneity variance τ^2

$$\hat{\tau}^2_{\text{GMM}} = \frac{\sum w_i (y_i - \hat{y})^2 - \left(\sum w_i \sigma_i^2 - \sum w_i^2 \sigma_i^2 / \sum w_i\right)}{\sum w_i - \sum w_i^2 / \sum w_i} \quad (3)$$

The GMM estimator is applicable to all five types of weight w_i shown in Table 2. As will be shown later, the results of $\hat{\tau}^2_{\text{GMM}}$ are slightly different from those of the $\hat{\tau}^2$ estimated with the DL, ML, REML, and PM methods. We employ $\hat{\tau}^2_{\text{GMM}}$ to achieve a unified estimation of the heterogeneity variance.

We also calculate the model-based SCI (signal content index) for $\hat{\tau}$ (Huang 2020)

$$\text{SCI}_{\text{model}} = \frac{\hat{\tau}^2}{\hat{\tau}^2 + \frac{1}{m}\sum \sigma_i^2} \quad (4)$$

$\text{SCI}_{\text{model}}$ coincides with the modified definition of the heterogeneity index I^2 proposed by Borenstein et al. (2017).

We assume that $\hat{\mu}$ is normally distributed based on the Central Limit Theorem. The coverage interval at the 95% coverage probability (confidence) is estimated as

$$[\hat{\mu} - 1.96u(\hat{\mu}), \hat{\mu} + 1.96u(\hat{\mu})] \quad (5)$$

2.2 Results

Table 3 shows the results for the consensus value $\hat{\mu}$, associated SU $u(\hat{\mu})$, and coverage interval, estimated with weight frequentist methods in this case study, and the results of the Bayesian method of Possolo (2021) and Mana (2021).

In Table 3, the SCI (or I^2) corresponding to the PM, ML, REML, and DL methods are calculated using their originally estimated heterogeneity variances: $\hat{\tau}_{\text{PM}}$=60.96, $\hat{\tau}_{\text{ML}}$=54.18, $\hat{\tau}_{\text{REML}}$=57.96, and $\hat{\tau}_{\text{DL}}$=57.47 kBq, which are slightly greater or smaller than their $\hat{\tau}_{\text{GMM}}$ counterparties. Since the SCI ranges between 51.10 to 69.23%, this dataset is considered to exhibit a moderate level of heterogeneity.

It can be seen from Table 3 that, among the eight frequentist methods, the ZSNR estimator gives the smallest value of $u(\hat{\mu})$. The other six frequentist methods give almost the same value of $u(\hat{\mu})$. The ZSNR estimator may be preferred because it is a robust estimator and has the smallest SU among the eight frequentist methods for this dataset.

We also note that the ZSNR estimator gives the smallest $\hat{\tau}_{\text{GMM}}$ value and smallest SCI (I^2) value among the eight frequentist methods. It seems that the ZSNR estimator minimizes the heterogeneity variance.

It can be seen from Table 3 that the Bayesian results of Possolo (2021), obtained using the *NIST Consensus Builder* (Koepke et al. 2017), are comparable to the frequentist results of this case study. The Bayesian results of Mana (2021), obtained using an objective Bayesian approach, are comparable to the frequentist results of this case study and the Bayesian results of Possolo (2021).

			95% interval			
Method	$\hat{\mu}$	$u(\hat{\mu})$	Low bound	Upper bound	$\hat{\tau}_{\text{GMM}}$	SCI (I^2) (%)
Arithmetic average	14631.0	21.1	14589.7	14672.3	54.74	64.46
ZSNR	14633.2	17.4	14599.1	14667.4	41.55	51.10
Inverse-σ^2 WA	14619.4	20.1	14580.0	14658.9	57.47	66.66
Inverse-σ WA	14625.1	20.8	14584.3	14665.8	56.82	66.15
PM	14628.2	21.1	14586.9	14669.5	56.55	69.23
ML	14627.7	21.1	14586.4	14669.0	56.77	63.99
REML	14628.0	21.1	14586.7	14669.3	56.65	67.04
DL	14628.0	21.1	14586.7	14669.3	56.66	66.66
Bayesian (Possolo 2021)	14,628	23	14,585	14,674	--	--
Bayesian (Mana 2021)	14,620	16	14,588	14,652	--	--

Table 3. Results for the consensus value of Fe-59, SU, and coverage interval (unit: kBq)

3. Evaluating the Performance of Participating Laboratories

The performance of a participating laboratory can be evaluated by the root mean square percentage error (RMSPE) of its measured value with respect to the consensus value. The RMSPE is defined as

$$\text{RMSPE}_i = \frac{\sqrt{d_i^2 + \text{Var}(d_i)}}{\widehat{\mu}} \quad (6)$$

The variance of the degree of equivalence d_i is written as

$$\text{Var}(d_i) = \text{Var}(y_i - \widehat{\mu}) = \sigma_i^2 + [u(\widehat{\mu})]^2 - 2\rho_i\sigma_i u(\widehat{\mu}) \quad (7)$$

where ρ_i is the correlation between y_i and $\widehat{\mu}$.

$$\rho_i = \frac{\text{COV}(y_i, \widehat{\mu})}{\sigma_i u(\widehat{\mu})} \quad (8)$$

where $\text{COV}(y_i, \widehat{\mu})$ is the covariance between y_i and $\widehat{\mu}$. Thus, Eq. (6) can be rewritten as

$$\text{RMSPE}_i = \frac{\sqrt{d_i^2 + \sigma_i^2 + [u\,(\widehat{\mu})]^2 - 2\rho_i\sigma_i u(\widehat{\mu})}}{\widehat{\mu}} \quad (9)$$

We propose using the normalized weight as ρ_i. That is

$$\rho_i = \frac{w_i}{\sum_{j=1}^{m} w_j} \quad (10)$$

The validity of Eq. (10) was demonstrated through Monte Carlo simulation using Excel spreadsheets, with the samples drawn from a normal distribution. In fact, it is intuitive that ρ_i measures the relative contribution of the i-th measurement to the consensus value. For the arithmetic average, all laboratories' contributions are equal, $\rho_i = \frac{1}{m}$.

In addition, the SU of the degree of equivalence d_i can be estimated as

$$u(d_i) = \sqrt{\sigma_i^2 + [u(\widehat{\mu})]^2 - 2\rho_i\,\sigma_i u(\widehat{\mu})} \quad (11)$$

Table 4 shows the results for ρ, d, $u(d)$, and RMSPE for the NIST measurement result, estimated with the eight frequentist methods.

It can be seen from Table 4 that, the value of d is smallest for the ZSNR estimator, and so is the RMSPE. The values of RMSPE for all eight frequentist methods are comparable because the within-laboratory SU σ_{NIST} = 60 kBq is significantly greater than $u(\widehat{\mu})$ that ranges between 17.4 to 21.1 kBq (refer to Table 3). Also note that the correlation is insignificant, ranging between 0.027 and 0.092. This is because there are eleven laboratories participated in the interlaboratory comparison.

Moreover, it is of great interest to compare the performance of all eleven laboratories. We therefore calculated the RMSPEs of all eleven laboratories for the consensus value estimated with the ZSNR estimator. The results are shown in Table 5.

It can be seen from Table 5 that, among the eleven laboratories, the measurement result of PTB has the smallest RMSPE: 0.254%, while the measurement result of BARC has the highest RMSPE: 0.864%. Although the measurement result of NIST has the smallest d value: 7.8 kBq, it has a high RMSPE: 0.420%, which is greater than that of PTB's result. This is because the NIST measurement result has a much higher within-laboratory SU, σ_{NIST} = 60 kBq. It is interesting to note that RMSPE is inversely correlated with ρ. That is, the larger the normalized weight (i.e. correlation ρ) associated with a measurement, the smaller the RMSPE of the measurement is, and vice versa. This observation is consistent with the concept of the weighted average.

4. Conclusion

Among the eight frequentist methods examined in this case study, the arithmetic average is simplest in terms of formulation and calculation. The results it gives are comparable to those of the other seven frequentist methods. However, this is true only for this dataset. In general, the arithmetic average is not preferred as the consensus value.

Method	ρ	d	$u(d)$	RMSPE (%)
Arithmetic average	0.091	10.0	61.8	0.427
ZSNR	0.092	7.8	60.9	0.419
Inverse-σ^2 WA	0.027	21.6	62.8	0.453
Inverse-σ WA	0.052	15.9	62.5	0.440
PM	0.064	12.8	62.3	0.434
ML	0.061	13.3	62.4	0.436
REML	0.063	13.0	62.3	0.435
DL	0.062	13.0	62.3	0.435

Table 4. Results for ρ, d, $u(d)$, and RMSPE for the NIST measurement result (unit for d and $u(d)$: kBq)

Laboratory	y	σ	ρ	d	$u(d)$	RMSPE (%)
BKFH	14685	32	0.091	51.8	35.0	0.427
IAEA/RCC	14663	24	0.146	29.8	27.5	0.277
PTB	14609	25	0.160	-24.2	28.1	0.254
NIST	14641	60	0.092	7.8	60.9	0.420
NPL	14668	55	0.086	34.8	56.3	0.452
ANSTO	14548	54	0.055	-85.2	55.8	0.696
CMI-IIR	14709	36	0.066	75.8	38.9	0.582
LNE-LNHB	14603	36	0.118	-30.2	38.1	0.332
NMIJ	14576	23	0.090	-57.2	27.6	0.434
BARC	14511	28	0.044	-122.2	32.3	0.864
KRISS	14728	50	0.052	94.8	52.1	0.739

Table 5. Comparison of the performance of all eleven laboratories (the consensus value is estimated with the ZSNR estimator: $\widehat{\mu}$ = 14633.2 kBq and $u(\widehat{\mu})$=17.43 kBq) (unit for y, σ, d, and $u(d)$: kBq)

It is always a good idea to use different methods to calculate the consensus value and the associated uncertainty. The ZSNR estimator may be preferred because it is a robust estimator and has the smallest standard uncertainty for this dataset. The ZSNR estimator also minimizes the heterogeneity variance.

The Bayesian results of Possolo (2021) and Mana (2021) are comparable to the frequentist results of this case study. However, the Bayesian methods are much more complicated than the eight frequentist methods in terms of formulation and calculation

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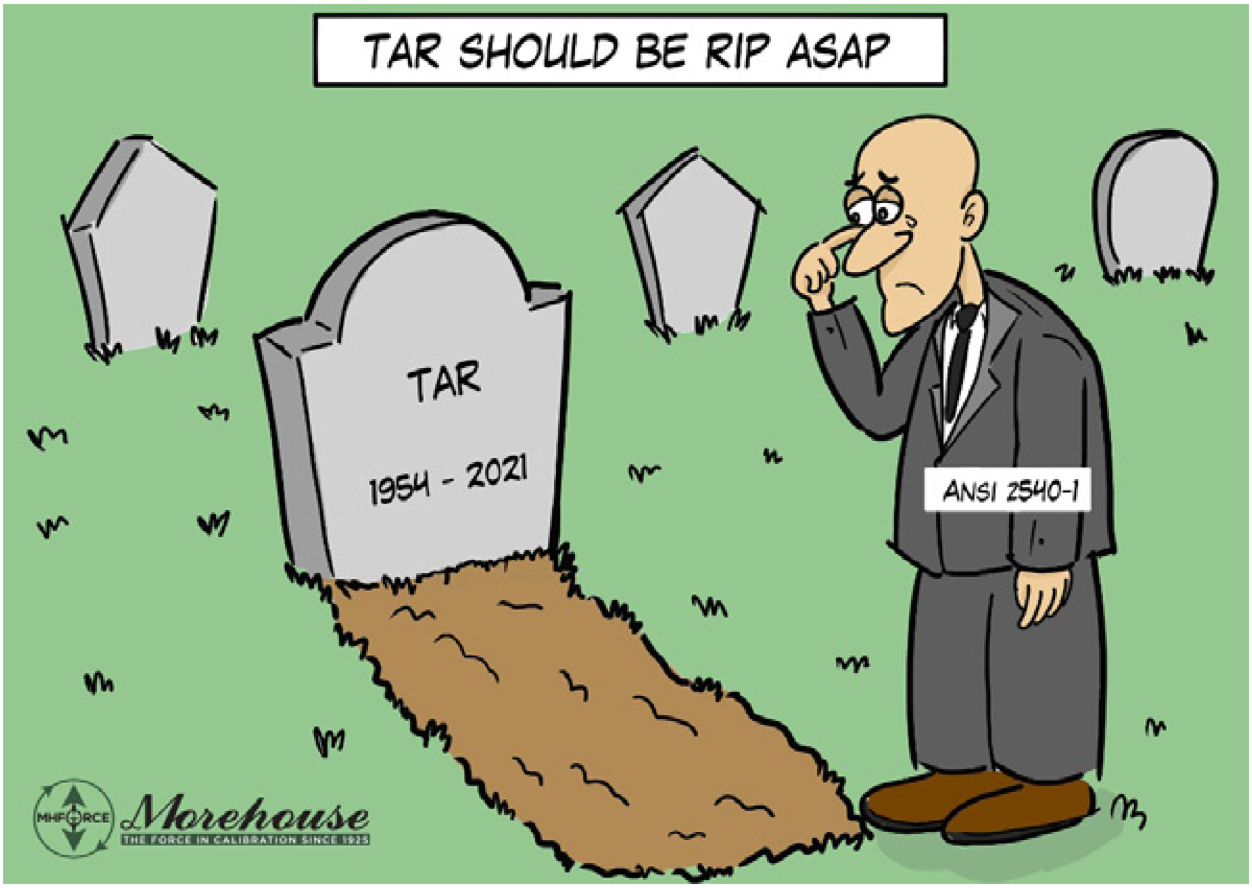
Hening Huang (heninghuang1@gmail.com), Teledyne RD Instruments (retired), 14020 Stowe Drive, Poway, CA 92064, USA.

TAR Versus TUR: Why TAR Should RIP ASAP

Henry Zumbrun
Morehouse Instruments

There is a bit of a disconnect regarding risk mitigation practices in the metrology and calibration provider community. Most likely, this comes from a misunderstanding of terminology or legacy requirements that have passed from year to year without any thought of updating them to a more acceptable method of risk-based thinking. This paper examines several outdated, and to some extent wrong, practices such as Test Accuracy Ratio (TARs) and requesting NIST traceable calibrations. When compared to Test Uncertainty Ratio (TUR), which is a metrologically better approach, TAR has significant flaws.



Introduction

Why examine TAR and TUR? Has each topic not been covered for decades now? When we examine both TAR and TUR concepts, we find that many in the metrology community have adopted TUR. Both guidance documents and standards have moved away from TAR. However, when we look at the laboratories making measurements, they seem decades behind the latest standards and guidance documents.

If you look at many purchase orders, there is still language such as NIST traceable calibration where the standard must be four times more accurate than what is being tested. Essentially, the request is saying we expect that you purchased a standard with manufacturers' specifications or accuracy claims that are at least four times greater than the equipment we are about to send for calibration.

$$\text{TAR} = \frac{\textbf{Accuracy of the Unit Under Test}}{\textbf{Accuracy of the Reference Standard}}$$

Hence, the concept of TAR is simply a ratio comparing the accuracy of the Unit Under Test with the Accuracy of the Reference Standard. Pretty simple, right? Though simplistic, it is riddled with issues because accuracy is not the same as uncertainty. Calculating uncertainty correctly is a requirement of ISO/IEC 17025 and several additional ILAC documents examined later in this paper. Some may even define TAR by replacing the accuracy of the reference standard with the Measurement Uncertainty of their equipment. This creates another dilemma regarding the importance of definitions we will be discussing later.

Suppose they do not follow all the guidelines outlined in these documents. In that case, they will likely confuse accuracy with uncertainty and omit many uncertainty contributors that make an instrument look so much better than it is. In these cases, some manufacturers take shortcuts and proceed with a game of accuracy specmanship.

They may omit significant error sources like reproducibility or resolution and base specifications on averages rather than good metrological practices. Thus, comparing the accuracy of each instrument against another does not follow well-established metrological guidelines. Not to mention, when TAR is used, uncertainty is not calculated correctly, which is likely when accuracy is substituted for uncertainty. When this happens, your measurements are not traceable! Let us compare TAR with TUR.

$$\frac{\textbf{TUR = Span of the} \pm \textbf{UUT Tolerance}}{\textbf{2 x } k_{95\%}\textbf{(Calibration Process Uncertainty)}}$$

TUR compares the Span of the ± UUT Tolerance and divides that by twice the Calibration Process Uncertainty (CPU). This describes the actual capability of the calibration lab by defining the calibration process uncertainty. If followed correctly, the definition of TUR gives the end-user a meaningful ratio. The ratio can be used to calculate the risk associated with the equipment calibration. That calculated risk can then be used in a meaningful way to make decisions. Is the medical equipment used for my surgery tested properly? Are parts of the airplane I'm flying on tested so it doesn't break up in mid-flight? Is the high rise I live in or the hotel I'm at appropriately built, so it does not collapse?

If the testing is conducted with equipment based on accuracy specifications alone, there can be significant problems, and your safety is likely impacted. To further understand TAR and TUR, we need to know how TAR came into existence. Then we will explore when TAR can work and when it doesn't. Lastly, we will examine how TUR, if calculated correctly, can give us a better picture of risk to make decisions that keep us safer.

History of Measurement Decision Risk Related to TAR and TUR

The roots of measurement decision risk can be traced back to early work done by Alan Eagle, Frank Grubbs, and Helen Coon, which include papers published around 1950. These measurement decision risks concepts were complex for many and did not gain much traction.

About five years later, Jerry Hayes of the United States Navy established accuracy ratios versus decision risks for the calibration program. TAR was introduced because it simplified much of the measurement decision risk. First, a consumer risk of 1 % was accepted, which would be a Probability of False Accept (PFA) today. This means that about a 3:1 accuracy ratio would be required.

Then, working with Stan Crandon, Hayes decided to add this ratio to account for some uncertainty in the reliability of tolerances. Thus, 3:1 became 4:1, and the US Navy adopted a policy, which was also adopted by many in the metrological community. More details about this history are found in "Measurement Decision Risk – The Importance of Definitions" by Scott Mimbs [1].

Since there was limited computing power, the 4:1 TAR ratio was an easy-to-follow rule that solved a problem. The TAR is a ratio of the tolerance of the item being calibrated divided by the accuracy of the calibration standard. Thus, if I have a device that needs to be accurate to 1 %, I need a calibration standard that is four times better or 0.25 %. Since the concept was so simple, many followed it and continued to follow it. Initially, TAR was supposed to be a placeholder until more computing power became available to the masses.

In the 1990s, we had enough computing power, and TUR should have replaced the TAR concept. More computing power did become available, and it is rumored that ANSI/NCSL Z540-1-1994 originally contained TUR, and at the last minute, edits were made to change TUR back to TAR. When we look at these concepts, we can question why it took five decades to replace TAR with TUR.

TUR is not simple enough for masses and relies on arguably more complex calculations than TAR. Therefore, it is elementary to understand why many still opt to keep using TAR. Let us look at TUR in a bit more detail.

TUR is a ratio of the tolerance of the item being calibrated divided by the uncertainty of the entire calibration process. Evaluation of the TUR is a rigorous process that includes additional contributors to the uncertainty beyond just the uncertainty of the calibration standard. ANSI/NCSLI Z540.3 and the Handbook published in 2006 have the complete definition of TUR. It relies on knowing how to calculate uncertainty following a calibration hierarchy, including metrological traceability.

Today, there are still laboratories using TAR, TUR, and Test Value Uncertainty (TVU). No matter what acronym you use, it is essential to understand the potential shortcomings of using outdated terms. In 2007, Mr. Hayes reflected on his earlier work, "the idea was supposed to be temporary until better computing power became available or a better method could be developed."

In 2021 we certainly have more computing power available, and TAR should RIP ASAP. Remember when they buried the word "DEF?" Maybe we, as metrologists, need to do that with TAR. We will examine it in more detail and let you decide after learning about the difference between TAR and TUR. First, we must understand Metrological Traceability.

Metrological Traceability, Not Traceable to NIST

The International Vocabulary of Metrology (VIM) defines metrological traceability as the "property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty [2]."

The International System of Units (SI) is at the top of the measurement hierarchy pyramid (Figure 1). The next tier in the pyramid is a National Metrology Institute (NMI) such as the National Institute of Standards and Technology (NIST), which is recognized by the International Committee for Weights and Measures (CIPM) and has derived its capability from these base SI units of better than 0.0005 %.

Per NIST, "Metrological Traceability requires the establishment of an unbroken chain of calibrations to specified reference standards: typically national or international standards, in particular realizations of the measurement units of the International System of Units (SI). NIST assures the traceability to the SI... [3]" Therefore, traceability is not to NIST. Calibration is performed using measurement standards traceable to the SI through a National Metrology Institute (NMI), such as NIST.

Why is Measurement Uncertainty Important?

If you are accredited to ISO/IEC 17025:2017, the uncertainty of the measurement is required to be reported on a certificate of calibration. This is essential because your customer may want you to make a statement of conformance on whether the device or artifact is in tolerance or not. Additionally, if you do a test and want to know if the device passes or fails, then it may be a consideration.

Measurement uncertainty is required to establish your measurement traceability. It is crucial because you want to know that the laboratory calibrating your device or artifact can perform the calibration. If you need a device to be known to be within less than 0.02 %, then you must use a calibration provider that gives you the best chance of achieving that result. If the calibration provider has a stated measurement uncertainty of 0.04 %, then mathematically, they are not the right calibration lab to calibrate or verify your device or artifact.

Measurement uncertainty also keeps us honest. If a laboratory claims Traceability to SI through NIST, the further away it is from NIST, the larger the uncertainty

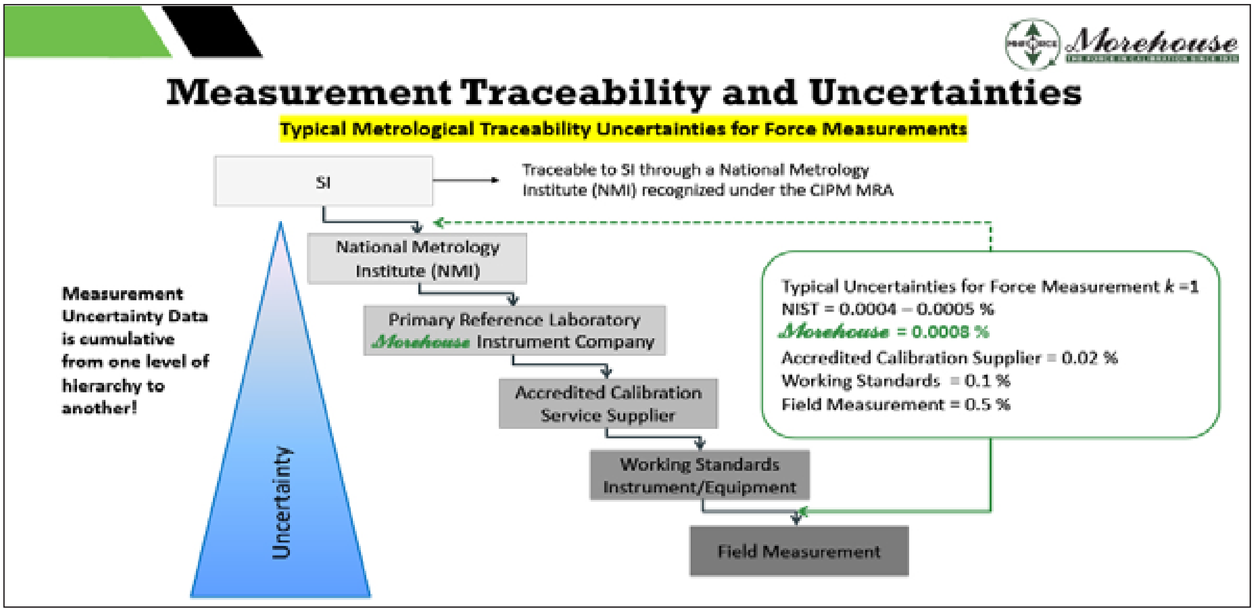


Figure 1. Metrological Traceability Pyramid for Force Measurements

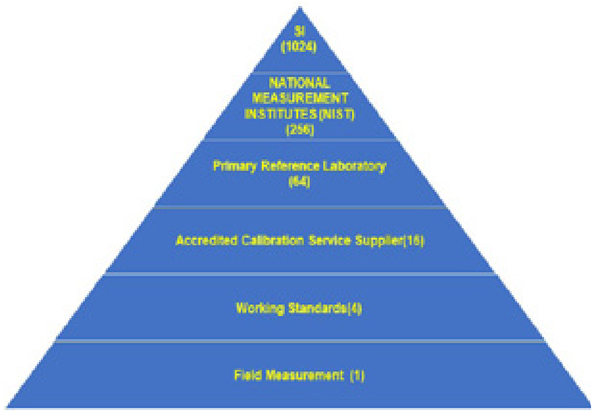


Figure 2. Test Accuracy Ratio (4:1)

likely becomes. Figure 1 shows that the further away from SI units, the more significant the uncertainty. For example, field measurement is six steps away from SI. Measurement uncertainties get larger at each level and end at a standard uncertainty of 0.5 %. If we try to build this pyramid using TAR, what happens? Can it work?

TAR – When It Doesn't Work

When using a six step pyramid to figure out TAR, it is not sustainable if it needs to be four times better at every step. The working standards could be four times better than the field measurement. The accredited calibration provider might be sixteen times better than the process measurement. However, by the time we get to the primary reference laboratory, NIST, and SI, we cannot maintain the 4:1 ratio.

This example gets complicated when the different tiers claim lower than expected uncertainties. For instance, we have seen working standards laboratories accredited at numbers unbelievably low, such as 0.05 %. The accredited calibration service supplier cannot be four times better at 0.02 %. In today's world, many uncertainties are under-reported, and a 4:1 ratio is not maintainable.

When technology was in its infancy, TARs were easy. However, the early system typically had very conservative specifications, and the expectation was not to the tightest tolerances achievable. As a result, technology sometimes eclipsed the standards and requirements. One example is a National Bureau of Standards Certificate for Thomas 1 Ohm with an uncertainty of ±1.5 ppm. Now that exact measurement is readily achievable on a Fluke 8508.

I caution others to watch out for TAR numbers like 4:1 or 10:1 because later they may find out the real uncertainty is high or that uncertainty is under-reported. This is the main problem with TARs not inherent in accepted standards, such as ASTM & OIML.

A great example is The Quest Metrology Thread measuring system, which was "accurate" to ±1 µin. However, the uncertainty was ±30 µin because the best calibration system was only able to achieve ±30 µin. In practice, it certainly seemed capable of resolving and repeating a much lower number. The lesson for us is to know and understand Metrological Traceability, as described above, and apply the fundamentals to our measurement uncertainty calculations.

TAR – When It Works

TAR can work with procedures with clear guidance and when the end-user can control the systems they use. We can use a small ratio and pretty easily maintain a TAR. One of the best examples where this works is the ASTM E74 standard.

ASTM E74 was developed in 1974 and has a statistical approach that randomizes the condition of the measurement, capturing the reproducibility condition well. The standard requires 30 or more data points to be taken as part of the calibration procedure and uses these to generate a pooled standard deviation. The agreed-upon formulas are such that about 98 % of the error is captured at calibration time.

The caveat is that the end-user is still responsible for doing additional testing using their machines and understanding that changing adapters, loading conditions, and the environment will increase the error. In general, with the agreed-upon formula, the ratios in Figure 3 work well. When the ASTM standard is combined with a robust Proficiency Test Plan or ILC, Statistical Process Control, and the additional accreditation guidelines for measurement uncertainty, the standard is the defacto method to ensure your force-measuring system is as good as needed. If you want to mitigate measurement risk, calculate measurement uncertainty correctly, and make better measurements, strongly consider having your force-measuring equipment calibrated to the ASTM E74 standard.

This example shows how TAR can work well in a controlled environment. That environment may be the end-user specifying their equipment for use and the appropriate equipment or laboratory for calibration. When you specify the exact equipment, you can do internal testing and make the appropriate determinations for your needs.

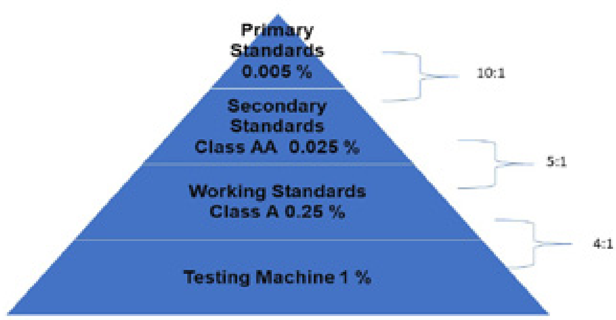


Figure 3. ASTM E74 Ratios

When you know that only two to three measurement tiers will be used, you can choose the measurement process and equipment based on a large sample with actual testing to maintain a four to one requirement. At the least, you can run the tests and make the determination. Typically, this requires a lot of tests and knowledge. In contrast, if you do not know the system, there is a much stronger case for Test Uncertainty Ratios using the appropriate method and guardband for their application.

TUR Defined

Many in the metrology community have invalidated TAR because it does not align with metrological traceability practices. They prefer TUR because uncertainty is cumulative from one level of the hierarchy to another. They argue that it carries a much less risky approach to risk mitigation. To understand how it works, we must first define TUR.

$$\mathbf{TUR} = \frac{\textbf{Span of the} \pm \textbf{UUT Tolerance}}{\mathbf{2 \times k_{95\%}(\textbf{Calibration Process Uncertainty})}}$$

ILAC PP14:09/2020 and the ANSI/NCSLI Z540.3 Handbook are two that reference and define TUR. TUR is defined as:

- The ratio of the span of the tolerance of a measurement quantity subject to calibration to twice the 95% expanded uncertainty of the measurement process used for calibration [4].
- The ratio of the tolerance, TL, of a measurement quantity, divided by the 95% expanded measurement uncertainty of the measurement process where TUR = TL/U [5].

These definitions are similar, but the span of the tolerance in the numerator must be more straightforward. If the tolerance is not symmetrical, then ANSI/NCSL Z540.3 is much clearer. The TUR calculation is drastically different from comparing accuracy ratios as we are now dealing with calculating the calibration process uncertainty (CPU).

The formula's ratio includes a numerator and a denominator. ANSI/NCSLI Z540.3 Handbook describes:

> For the numerator, the tolerance used for Unit Under Test (UUT) in the calibration procedure should be used in the calculation of the TUR. This tolerance is to reflect the organization's performance requirements for the Measurement & Test Equipment (M&TE), which are, in turn, derived from the intended application of the M&TE. In many cases, these performance requirements may be those described by the Manufacturer's tolerances and specifications for the M&TE and are therefore included in the numerator.

In most cases, the numerator is the UUT Accuracy Tolerance. The denominator is slightly more complicated. Per the ANSI/NCSLI Z540.3 Handbook:

> For the denominator, the 95 % expanded uncertainty of the measurement process used for calibration following the calibration procedure is to be used to calculate TUR. The value of this uncertainty estimate should reflect the results that are reasonably expected from the use of the approved procedure to calibrate the M&TE. Therefore, the estimate includes all components of error that influence the calibration measurement results, which would also include the influences of the item being calibrated except for the bias of the M&TE. The calibration process error, therefore, includes temporary and non-correctable influences incurred during the calibration such as repeatability, resolution, error in the measurement source, operator error, error in correction factors, environmental influences, etc.

TUR Versus TAR

Test Accuracy Ratio (TAR) is outdated as in many applications and industries; it does not correctly capture measurement risk. It is certainly not sustainable to propagate from process measurement back to SI. It is the ratio of the accuracy tolerance of the unit under calibration to the accuracy tolerance of the calibration standard used. It can be used in situations where the end-user has control protocols where they have thoroughly evaluated the systems. TUR, on the other hand, is well defined in ANSI/NCSLI Z540.3.

The measurement uncertainty calculation of TUR is well defined and always includes the uncertainty contribution of the reference standard used for calibration. Thus, the TUR definition is clear, and when followed, it allows for a better conformity assessment. That conformity assessment is the key because most end-users want to know if their system passes calibration.

ISO/IEC 17025:2017 states, "When a statement of conformity to a specification or standard for test or calibration is provided, the laboratory shall document the decision rule employed, taking into account the level of risk (such as false accept and false reject and statistical assumptions) associated with the decision rule employed and apply the decision rule [6]." When we combine this statement with the requirements of ILAC P14 regarding stating measurement uncertainty, we get very good alignment with the definition of TUR.

$$\mathbf{TUR} = \frac{\textbf{Span of the} \pm \textbf{Tolerance}}{\mathbf{2 \times k_{95\%}}\left(\sqrt[2]{\left(\frac{\mathbf{CMC}}{\mathbf{K_{CMC}}}\right)^2 + \left(\frac{\mathbf{Resolution_{UUT}}}{\sqrt[2]{\mathbf{12}}}\right)^2 + \left(\frac{\mathbf{Repeatability_{UUT}}}{\mathbf{1}}\right)^2 + \ldots\,(\mathbf{u}_{Other})^2}\right)}$$

Figure 4. Test Accuracy Ratio vs. Measurement Uncertainties

ILAC P14:09/2020 states:

> Contributions to the uncertainty stated on the calibration certificate shall include relevant short-term contributions during calibration and contributions that can reasonably be attributed to the customer's device. Where applicable, the uncertainty shall cover the same contributions to the uncertainty that were included in the evaluation of the CMC uncertainty component, except that uncertainty components evaluated for the best existing device shall be replaced with those of the customer's device. Therefore, reported uncertainties tend to be larger than the uncertainty covered by the CMC.

Therefore, if we calculate measurement uncertainty correctly per ILAC P14 and make a conformity assessment, then TUR provides a technically well-aligned ratio with accreditation guidelines on calculating Measurement Uncertainty.

Using a calibration provider with low uncertainties will help raise the TUR ratio. The higher TUR will result in broader acceptance (compliance) limits. Wider acceptance limits give more room to account for the bias increase that will occur between calibrations. Therefore, it is essential to consider all sources of uncertainty when determining the time between calibration and tolerance limits. The concept of TUR allows us to make more informed decisions on the equipment we are using for testing. It does not hide significant errors as TAR does, as TUR is well defined. These decisions are often based on defining the appropriate level of risk.

Nominal Value	1000.0
Lower specification Limit	999.5
Upper Specification Limit	1000.5
Measured Value	1000.4
Measurement Error	0.4
Std. Uncert. (k=1)	0.047
Total Risk	2.00%
Upper Limit Risk	2.00%
Lower Limit Risk	0.000%
TUR =	**5.350613**
TAR=	**31.25**
Cpk=	**0.6848785**
Simple Guard Band with Subtraction Uncertainty Only	
Guard Band LSL	999.593
Guard Band USL	1000.407
Guard Band Limits for Risk of	**2.00%**
Guard Band LSL	999.596
Guard Band USL	1000.404

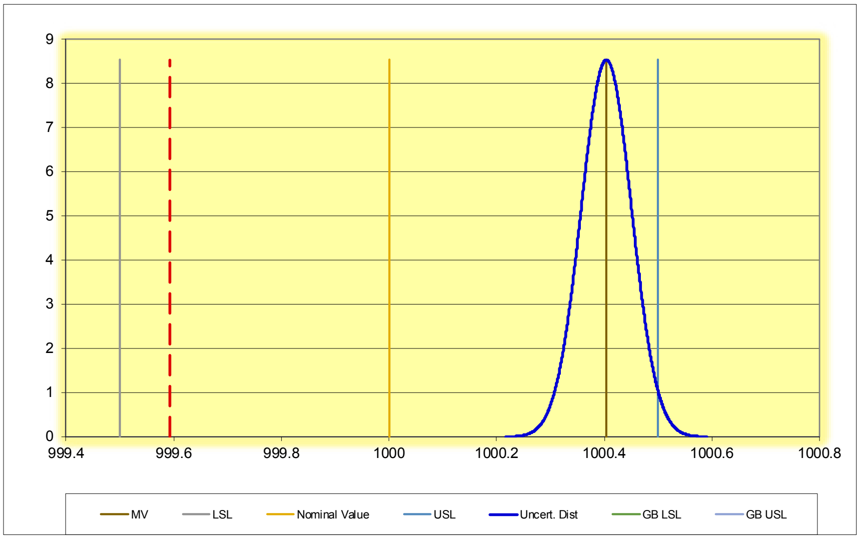


Figure 5. Guard band USL showing a 2 % PFA when Measured Value is at the GB USL.

Measurement Risk

All measurements have a percentage of likelihood that they will designate that something is good when it is bad or something is bad when it is good. This impacts consumer risk, which is the possibility of a problem occurring in a consumer-oriented product. Occasionally, a product that does not meet quality standards passes undetected through a manufacturer's quality control system and enters the consumer market. Figure 5 shows this concept graphically as when the instrument reads 1000.404, there is 2 % risk or Probability of False Accept. The TUR in this example is 5.35:1, while the TAR is 31.25:1 on the same device.

The Probability of False Accept (PFA) is similar to the consumer risk. It is the likelihood of calling a measurement "good" or stating something is "In Tolerance" when there is a percentage of chance that the measurement is "bad" or "Out of Tolerance."

With TUR, there are several published methods to calculate measurement risk appropriately. These decision rules rely on a correct calculation of TUR for the conformity assessment. When used correctly, these risk-based approaches help keep the roads we drive on, the planes we fly in, the structures we sleep in, and the everyday items we use from failing at high rates. Good metrological practices simply keep us a bit safer!

Conclusion

The metrology community must recognize mandatory policy documents such as ILAC-P14 and guidance documents such as the ANSI/NCSLI Z540.3 Handbook. These documents correctly define the calibration process measurement uncertainty used for calibration. The uncertainty reporting in ILAC P14 aligns quite well with the definition of TUR in ANSI/NCSLI Z540.3 Handbook. Using the proper definition of TUR is a starting point to use one of the several guard banding methods in ANSI/NCSLI Z540.3, which correctly reference calculating TUR.

This paper has presented a lot of information to demonstrate that TAR is outdated and can only work in particular applications. TAR should RIP ASAP for most applications. TUR should be used to make conformity assessments and create a sustainable chain of traceability where measurement uncertainty is correctly accounted for at each tier.

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Henry Zumbrun (hzumbrun@mhforce.com), Morehouse Instrument Company, 1742 Sixth Ave., York, PA 17403-2675, (717) 843-0081.

NEW PRODUCTS AND SERVICES

EMUGE-FRANKEN N.A. New Line of Ring Gages

WEST BOYLSTON, MA U.S.A. (September 21, 2021) EMUGE-FRANKEN N.A. (https://www.emuge.com/), a leading manufacturer of high-performance taps, thread mills, drills, end mills and other rotary tools, has expanded its thread gaging solutions to include a new line of thread ring gages to complement its thread gage offering. The new line comprises UNC and UNF Go and No-Go ring gages, in addition to metric and metric fine Go and No-Go ring gages, a total of 152 new gages.

"Our expanded line of accurate, high quality gaging solutions is ideal for addressing today's challenging thread gaging applications," said Bob Adamiak, Thread Gages Product Manager, EMUGE-FRANKEN N.A. The new EMUGE Ring Gages accompany the comprehensive line of EMUGE Fixed Limit Thread Gages, consisting of Go/ No-Go Plug Gages and Thread Depth Plug Gages that inspect the pitch diameter and functional thread for internal-threaded components.

EMUGE Go and No-Go Ring Gages are manufactured with hardened tool steel for exceptional durability and feature a fully knurled circumference for maximum gripping ability and safety. No-Go gages are clearly marked with a red ring. UNC and UNF gages have a 2A tolerance. UNC gages are available in 19 sizes from #2-56 to 2-4 ½ and UNF gages are available in 19 sizes from #0-80 to 1 ½ -12. Metric and metric fine gages have a 6g tolerance. Metric gages are available in 19 sizes from M2x.4 to M68x6 and metric fine gages are available in 19 sizes from M8x1 to M48x1. Additional sizes are also available upon request and all gages (UNC, UNF, metric and metric fine) are furnished with a short form gage certificate at no additional charge. Upon request, long form certificates are also available.

Information and a Brochure on the Full Line of EMUGE Thread Gaging Solutions: https://www.emuge.com/products/gages

Measurements at the Quantum Limit with TOPTICA's New CTL 900

October 2021 — Lasers of TOPTICA's CTL product family are made to be ideal tools for exciting micro-cavities or quantum dots, for pumping micro combs, as well as for component testing and spectroscopy.

Their most important property is providing wide and continuous tunability without any mode-hops. They have high power, a narrow linewidth and low drift. Scans can be performed with highest resolution. This unique combination of features makes them outstanding in their field and enables researchers to perform measurements at the quantum limit.

Mode-hops are prevented by an innovative opto-mechanical design (patent US9960569B2) together with an active feedback loop called SMILE (Single Mode Intelligent Loop Engine) that keeps the laser on the same mode at all times. With the fully digital, low noise and drift DLC pro controller, the CTL laser is easy to use and operate via touch-screen and knobs as well as remotely via PC GUI and command language (Python SDK). A test system mode can characterize components or record spectra.

A New Family Member: CTL 900

The latest addition to this family is called CTL 900. It is tunable between 880 nm and 950 nm. The long-awaited wavelength range is especially useful for resonantly exciting quantum dots, for spectroscopy or addressing e.g. rare earth ions or the Caesium D1 line.

The production has already started and the first devices are performing to set a new standard in the lab. Please contact us to apply for a CTL 900 for your application. We are starting cooperations to enable pioneering science in this wavelength range.

Measurements at the Quantum Limit

- Wide mode-hop-free tuning (up to 120 nm)
- Available at wavelengths between 880 nm and 1630 nm
- High resolution (down to kHz level)
- Perform measurements at the (quantum) limit with low noise & drift (linewidth < 10 kHz)
- User friendly control panel and remote control

For details please go to www.toptica.com/continuous

ZYGO Launches Verifire Asphere+

(Middlefield, CT, USA, October 13th 2021) Optical metrology leader Zygo Corporation — a business unit of Ametek Inc. — announces today that it will be revealing its Verifire Asphere+ — which represents the latest addition to the company's Verifire™ series of laser Fizeau interferometers — at the SPIE.OPTIFAB event 18-21 October 2021 in Rochester, NY, USA.

The Verifire Asphere+ (VFA+) builds upon the success of the Verifire Asphere Interferometer, which was made specifically for fast, noncontact, high-resolution 3D metrology of aspheric surfaces.

The VFA+ leverages the benefits of Fizeau interferometry through a unique combination of precise, high-resolution, fast, and full aperture metrology for axisymmetric aspheres. This allows faster convergence on deterministic polishing feedback for more efficient surface generation, and coverage of form error and mid-spatial frequency surface characteristics with one instrument. The system is also flexible, with the ability to measure a range of aspheres with only the change of the reference optic.

The VFA+ supports the trend in industry for the prolific use of aspheric optics. Aspheric surfaces are leveraged in a plethora of optical systems and are a powerful way of reducing the number of elements required in a system, simultaneously enhancing a system's performance and reducing size and weight. The ability to produce aspheres cost-effectively and which conform precisely to design intent is of central importance to many manufacturers working in the optics sector. As a result, ultra-high precision measurement systems are critical infrastructure as it is not possible to produce surfaces better than can be measured.

In addition, an optional secondary stage is integrated in the VFA+ to accommodate a computer-generated hologram (CGH) to push aspheric shape coverage even further, accommodating freeform, cylinder and off-axis conic surfaces. This future compatible investment will open the doors for flexible optical fabrication technology. As a result, quality assurance becomes more cost effective, is easier to execute and delivers results more efficiently.

The Verifire™ series represents a complete line of high-performance metrology instruments for the measurement of plano, spherical, and aspherical surfaces and material characteristics, and provides a variety of proprietary acquisition techniques to ensure optimum metrology in a wide range of environments.

Introducing the P5514B Hydraulic Pressure Comparator

August 2021 — Introducing the newest addition to the Fluke Calibration pressure instrument lineup: The P5514B Hydraulic Pressure Comparator. It is a simple, robust, and economical pressure test pump for calibrating gauges, switches, and transducers with accurate, fine adjust capabilities. Plus, this pressure comparator offers a series of improvements over the previous version of this model, the P5514.

In redesigning the P5514B Hydraulic Pressure Comparator, the new format was ergonomically engineered to make performing tests easier on you. The new, horizontal layout can be easily mounted on a bench, or the portable design allows for mobile applications as well.

One of the new features added to the pump is a new Vernier fine adjustment control. This control knob means that when you generate pressure up to 10 000 psi (70 MPa), you can now enable cardinal point calibrations. Its robust design, with improved reservoir valve sealing, makes it a more stable pressure generator than previous versions of this model.

The test connectors have been updated to improve the functionality and the seals. There are truly no tools required. You can easily grab the UUT connector, connect a gauge and tighten it for tool-free connections.

Along with this update, the seals were improved to ensure leak-free connections, allowing for easier connection and disconnection of all reference standards as well as what you're testing.

A pressure comparator or hydraulic test pump, like the P5514B, supplies pressure to both a reference gauge and the device under test for calibration. Fluke Calibration hydraulic test pumps offer a precisely controlled, consistent pressure for checking instruments against master test gauges, indicators, or transducers. These cost-effective instruments, which include several features from our popular line of hydraulic deadweight testers, are capable of easily generating high pressures and often include a Vernier control knob for precise, fine adjustments.

Combining the Fluke Calibration P5514B Pressure Comparator with a 2700G Reference Pressure Gauge creates an easy-to-use alternative to traditional deadweight testers. These two units working together cover a wide range of workload needs. In fact, these two bundled together build a complete bench top pressure calibration solution, providing the accuracy, reliability, and capability you need to calibrate dial gauges, digital test gauges, and pressure transmitters.

To learn more, visit: https://us.flukecal.com/products/pressure-calibration/manual-pressure-calibration/hydraulic-pressure-comparators-pumps/p55-0

The Hidden Costs of Software Development

Michael Schwartz
Cal Lab Solutions, Inc.

There is a hidden cost in developing and supporting automated calibration procedures, that is the cost of supporting and updating the software after the initial development cost. The industry sets an average metric of 80%. When I first saw this number I thought NO WAY! I thought like everybody else thinks, my software is better than that. There is no way it cost 80% more!

I am here to tell you, those hidden costs are no joke. Even the best software developers and projects have those hidden support costs. There is no stopping them, there are too many unknowns.

Last month we got hit with one of these hidden unknowns that breaks software. Microsoft updated the TSL v1 on their Azure service. This broke a tool we wrote many years ago called MetMigrate, a tool that moves data from MET/CAL® to another database. With the recent changes to web security, this TSL v1 update broke the MetMigrate application and it could no longer push data with a REST service call.

And the cost is not just the hours it takes to update the application to resolve the issue. For one, there is an upset customer with a work stoppage, plus the time it takes to create and implement a work-around until the software is fixed and tested. Also, there may be some errors that need to be corrected because of the manual work-around.

On the development side, this project's source code was four years old. Like many projects, the developers have moved on to other projects and may not have the time to fix this issue on the customer's timeline. This adds the cost of bringing in another developer up to speed on how the code is structured.

Sometimes we get lucky and fix it in one shot. But most of the time, it is several iterations before the updated software is 100% with all the changes. With each iteration comes testing costs, inching ever closer to that 80% cost and sometimes going over it.

I like to use Scotty from Star Trek as an example. He always multiplied the time it took to do something by seven. Not to make himself out to be the hero, but I think in the back of his mind nothing goes as planned.

Something I have learned over the years: take the estimated time, then multiply it by some factor, because no battle plan survives first contact. Now I think about the 80%, and the 80% of the 80%—yes, when you fix something there is a 64% hidden cost to that work as well.

Even in simple projects like the Power Supply calibration, these costs always seem to be there.

After the initial development and testing of the software around the Fluke 8588A and EL34xxxA electronic load, we needed to add the N3300A loads. This required some refactoring of the code to support using multiple electronics loads in series or parallel. Those changes required additional testing to ensure we didn't break the EL34xxxA code (the 80% of the 80% hidden cost).

Then we updated the code to support the HP/Agilent/Keysight 3458A. This requires some additional refactoring of the code to support current shunts because the 3458A's maximum current is limited to 1 Amp. And like before, we needed to test these updates didn't break the 8588A code. Plus, we wanted to allow the 8588A to use current shunts as well, so more testing and code updates.

Then as we are testing one of the newest power supplies, the Keysight E362xxA Series, we discover they have added multiple line and load regulation test points. So now we have to update the test process to support multiple test points for each test group, adding even more cost to that 80% estimate.

Most software has a five year life. Most software companies charge 20% for their support and maintenance (5 * 20%)—pretty easy to see where that number comes from! But metrology software and test equipment often have a life way longer than five years. So Scotty may not be too far off with his 7x the initial estimate. ❧

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