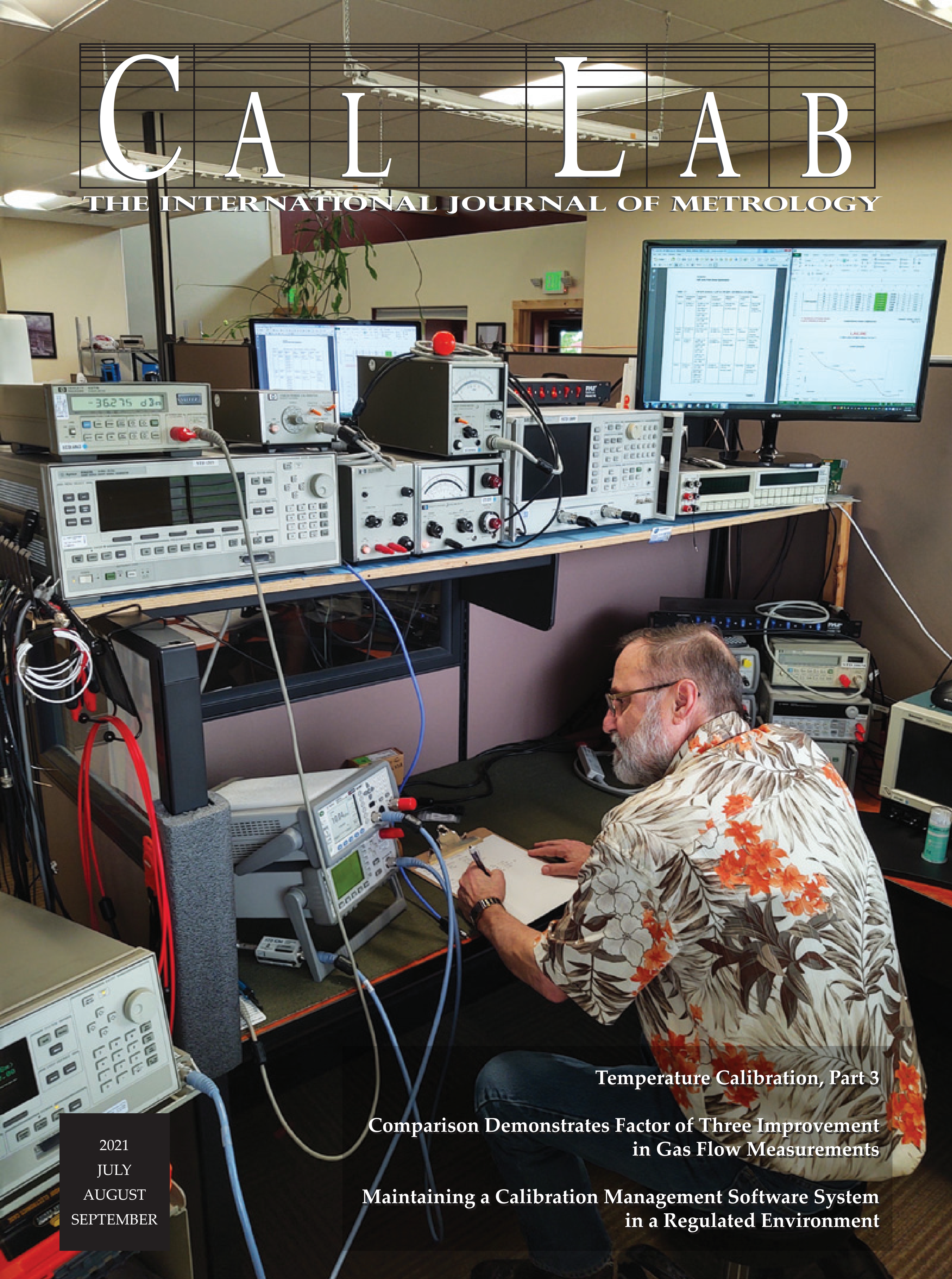
CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY



Temperature Calibration, Part 3

Comparison Demonstrates Factor of Three Improvement in Gas Flow Measurements

Maintaining a Calibration Management Software System in a Regulated Environment

2021
JULY
AUGUST
SEPTEMBER

CAL LAB
THE INTERNATIONAL JOURNAL OF METROLOGY
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Volume 28, Number 3

FEATURES

DEPARTMENTS

ON THE COVER: Technician Jim Newkirk performing an RF calibration in style at Laerie Calibration & Metrology Services in Fort Collins, Colorado.

UPCOMING CONFERENCES & MEETINGS

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

Aug 21-26, 2021 NCSL International Workshop & Symposium. Orlando, FL. NCSL International provides the best opportunities for the world's measurement science professionals to network and exchange information, to promote measurement education and skill development and to develop a means to resolve measurement challenges. https://www.ncsli.org

Aug 30-Sep 3, 2021 The XXIII IMEKO World Congress. Virtual Event. For all people working in metrology and measurement science coming either from academia or industry, from scientists to engineers, from mathematicians to chemists and physicists, from instrumentation designers to measuring techniques developers, to exchange and share information. http://www.imeko2021.org/

Sep 7-9, 2021 CIM. Lyon, France (Hybrid Event). The 20th International Metrology Congress is a showcase for industrial applications, advances in R&D and prospects dedicated to measurements, analysis and testing processes. https://www.cim2021.com/

Sep 29-Oct 1, 2021 IEEE AMPS. Virtual Workshop. The 11th International Workshop on Applied Measurements for Power Systems deals with all the aspects related to measurement applications in current power systems and in future Smart Grids and has the main goal of encouraging discussion on these topics among experts coming from academia, industry and utilities. https://amps2021.ieee-ims.org/

Oct 4-6, 2021 International Workshop on Metrology for the Sea; Learning to Measure Sea Health Parameters. Reggio Calabria, Italy. As everyone may know, measuring is a step that allows major knowledge of a phenomenon or an asset. That is why METROSEA will serve as a forum for presenting recent advances in the field of measurement and instrumentation to be applied for the increasing of our knowledge for protecting and preserving the Sea. http://www.metrosea.org/

Oct 25-27, 2021 At ASQ's Quality 4.0 Summit. San Antonio, TX (Hybrid). Engage in learning and networking activities to increase your understanding and awareness of the current state of digital transformation practices as well as what they mean for your organization's pursuit of team excellence. https://asq.org/conferences/quality-4-0

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EDITOR'S DESK

Tom is Awesome

Humans are obsessed with measuring things, including every bodily function possible: blood sugar, blood pressure, heart rate, ketones! What is a ketone anyway? Sensor technologies allow us to measure pressure, light, temperature, and they are everywhere in our pipelines, on our airplanes, and inside our chests and on our wrists.

The first Cal-Toon calendar we put together with Ted Green featured a cartoon with the caption "Never, ever ask Tom to measure something for you." It has Tom sitting in an office cubicle hung with dials, a mobile made of calipers, a rubber chicken, and oversized measuring tape. Tom is us. Tom is awesome. Measuring helps us to answer questions and solve problems. Measuring helps us to define what we can see and what we can't.

I'm writing this as we get ready for NCSLI Workshop & Symposium in Orlando, Florida. At first, the pared down show looked plenty full, but the latest news has us deflated a bit. Despite that, we're vaccinated and going with masks in hand—we're ready. There will be Committee meetings, keynote speakers, tutorials, an exhibitor floor, and a 60th Anniversary poolside party. And there will be faces in full 3D, connected to voices in real-time. I hope many of you will get your shot and come join us!

In this issue, the Metrology 101 series continues with Sine Calibration School's third installment of Temperature Calibrations. This series is meant to compliment an online program, so be sure to check it out if you want to brush up on temperature fundamentals!

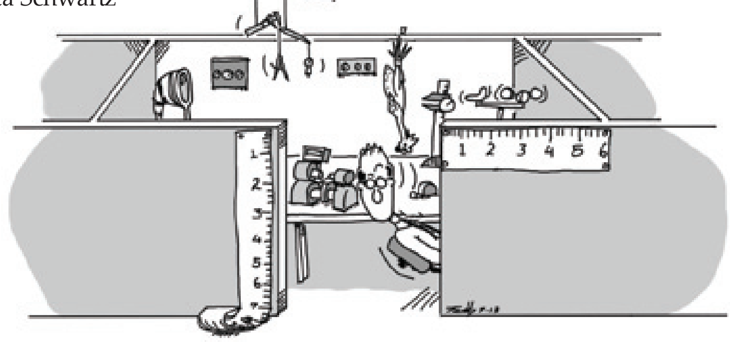
Next, we have a contribution from NIST on a collaborative comparison of gas flow measurements, "Comparison Demonstrates Factor of Three Improvement in Gas Flow Measurements," using both a traditional and probability-based criterion. The participants were able to show improvement by a factor of three, based on their comparisons from 2003.

And finally, Walter Nowocin from IndySoft, wraps up his series of articles with "Maintaining a Calibration Management Software System in a Regulated Environment." Mr. Nowocin will be presenting a 4-hour tutorial on Saturday, August 21st at NCSLI Workshop & Symposium in Orlando, called "How to Select and Implement Calibration Management Software Systems in a Regulated Environment." More info can be found at: https://ncsli.org/page/ws21tut. He is also scheduled to give a related, full-day tutorial at MSC Training Symposium in Anaheim, CA on Tuesday, November 16th. More information about that can be found at: https://annualconf.msc-conf.com/tutorial-workshop/.

So, measurement nerds of the world… you are awesome. I'm looking forward to fist bumping and shaking hands again with you this year.

Happy Measuring,

Sita Schwartz



CALENDAR

Oct 26-27, 2021. FORUMESURE. Casablanca, Morocco. An event to meet exhibitors on Measurement, Quality and Instrumentation. FORUMESURE 2021 offers you a lot of activities in free access: Tutorials, Conferences, Round Tables, Collaborative Projects. FORUMESURE 2021 is organized during the International Conference of Metrology - CAFMET 2021. https://www.forumesure.com/

Oct 26-28, 2021 CAFMET. Casablanca, Morocco. Le CAFMET, en partenariat avec l'EHTP de Casablanca, organise la 8ème Conférence Internationale de Métrologie en Afrique. CAFMET 2021 constitue un carrefour d'échanges d'information, d'idées et d'expériences en Métrologie et en Management de la Qualité, autour de conférences, de tables rondes, d'ateliers techniques et de stands d'exposition. https://www.cafmet-conference.com/

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/

SEMINARS & WEBINARS: Certification

Nov 15-16, 2021 Certified Calibration Technician Training. Anaheim, CA. ASQ. Two full days of CCT training will be given during the MSC Training Symposium. https://annualconf.msc-conf.com/

SEMINARS & WEBINARS: Dimensional

Sep 8-9, 2021 Gage Calibration & Repair. 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/schedule

Sep 21-23, 2021 Dimensional Gage Calibration. Aurora (Chicago), IL. Mitutoyo Institute of Metrology. 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/support/mitutoyo-institute-of-metrology/

CALENDAR

Sep 22-23, 2021 Gage Calibration & Repair. 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. https://www.calibrationtraining.com/schedule

Oct 5-6, 2021 Dimensional Gage Calibration (2-day Version). Novi (Detroit), MI. Mitutoyo Institute of Metrology. 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/support/mitutoyo-institute-of-metrology/

Oct 6-7, 2021 Gage Calibration & Repair. 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/schedule

Oct 11-12, 2021 Gage Calibration & Repair. Schaumburg, IL. IICT Enterprises. Specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop is "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. https://www.calibrationtraining.com/schedule

Oct 13-14, 2021 Gage Calibration & Repair. Madison, WI. IICT Enterprises. Specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop iss "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. https://www.calibrationtraining.com/schedule

Oct 19-21, 2021 Dimensional Gage Calibration. Aurora (Chicago), IL. Mitutoyo Institute of Metrology. 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/support/mitutoyo-institute-of-metrology/

Oct 29, 2021 Dimensional Metrology Quality. Aurora (Chicago), IL. Mitutoyo Institute of Metrology. This 1-day course focuses on measurement quality – including how to understand and assess the errors in dimensional measuring systems. The primary topic of this course is Gage Repeatability and Reproducibility (Gage R&R), a common tool to study variation in measuring systems. https://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/

Nov 2-3, 2021 Dimensional Gage Calibration (2-day Version). Mason (Cincinnati), OH. 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/support/mitutoyo-institute-of-metrology/

CALENDAR

Nov 3-4, 2021 Gage Calibration & Repair. 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/schedule

Nov 9-10, 2021 Gage Calibration & Repair. Des Moines, IA. 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/schedule

Nov 16-18, 2021 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/support/mitutoyo-institute-of-metrology/

Dec 1-2, 2021 Gage Calibration & Repair. 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/schedule

Dec 7-9, 2021 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/support/mitutoyo-institute-of-metrology/

Dec 9-10, 2021 Gage Calibration & Repair. 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/schedule

SEMINARS & WEBINARS: Electrical

Sep 20-23, 2021 MET-301 Advanced Hands-On Metrology. Everett, WA. Fluke Calibration. A four-day course on advanced measurement concepts and math used in upper echelon calibration labs and primary standard labs. https://us.flukecal.com/training

Oct 18-21, 2021 MET-101 Basic Hands-On Metrology. Everett, Washington. Fluke Calibration. A four-day "how to" course that introduces basic measurement concepts, basic electronics related to measurement instruments, and math used in calibration. https://us.flukecal.com/training

Nov 15, 2021 N04 - DC Resistance. Anaheim, CA. This tutorial will cover the fundamentals of DC resistance metrology with the aim of providing knowledge and measurement techniques to assist metrologists in making accurate and reliable DC resistance measurements. The art of resistance metrology will be explained beginning with the quantum Hall effect that serves as the basis of the US representation of the ohm and the measurement techniques and instrumentation used in scaling and disseminating resistance at different decade levels from the quantum Hall resistance standard. https://annualconf.msc-conf.com/nist-seminar/

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

Sep 23-24, 2021 Flow Measurement and Calibration Seminar. Neufahrn, Germany. TrigasFI. This Training Seminar is intended for individuals with responsibility to select, calibrate and use liquid and gas flowmeters. It is designed to be an objective, independent review and evaluation of the current state of flow metering and calibration theory and technology for flowmeter users and metrologists. Featuring networking event with lunch hosted at the Munich Oktoberfest. https://www.trigasfi.de/en/training-and-seminars/

Oct 4-7, 2021 Gas Flow Calibration Using molbloc/molbox. Phoenix, Arizona. Fluke Calibration. A four-day course on the operation and maintenance of a Fluke Calibration molbloc/molbox system. https://us.flukecal.com/training

SEMINARS & WEBINARS: General

Sep 13-17, 2021 Fundamentals of Metrology. Gaithersburg, MD. The 5-day Fundamentals of Metrology seminar introduces participants to the concepts of measurement systems, units, measurement uncertainty, measurement assurance, traceability, basic statistics and how they fit into a laboratory Quality Management System. https://www.nist.gov/pml/weights-and-measures/about-owm/calendar-events

Nov 15-16, 2021 N03 - Fundamentals of Metrology. Anaheim, CA. At the end of this 2-day session (similar, but not a substitute for the 5-day seminar given by NIST), participants will be able to: identify and use reference materials to ensure quality, accurate, and traceable measurement results; explain highlights and key concepts of each topic to each other and to your managers and demonstrate how these topics fit in to a management system using ISO/IEC 17025:2017 as the basis. https://annualconf.msc-conf.com/nist-seminar/

SEMINARS & WEBINARS: Industry Standards

Aug 24-25, 2021 Understanding ISO/IEC 17025 for Testing and Calibration Labs. Webinar (Timed for the Americas). IAS. To learn about ISO/IEC 17025 from one of its original authors. To learn its Principles and what it requires of laboratory staff. This Training Course applies to testing and calibration laboratories and regulatory agencies seeking to specify 17025 within their policies and regulations. https://www.iasonline.org/training/testing-cal-labs/

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RTC-159
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RTC-187
- Our Hottest Cold Temperature Calibrator

RTC-158
- Combination Liquid Bath and Dry Block Calibration

CTC-652
- 190 mm Immersion Depth for Long Sensors

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ametekcalibration.com

Aug 24-25, 2021 Internal Audit Course for All Standards. Webinar (Timed for the Americas). IAS. Training for internal auditors in all organizations with quality systems (labs, inspection bodies, certification bodies, proficiency testing providers). https://www.iasonline.org/training/internal_audit_for_accredited_organizations

Sep 7-8, 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. This Training Course applies to testing and calibration laboratories and regulatory agencies seeking to specify 17025 within their policies and regulations. https://www.iasonline.org/training/testing-cal-labs/

Sep 13-16, 2021 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories. Virtual. A2LAWPT. 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/events

Sep 20-23, 2021 Auditing Your Laboratory to ISO/IEC 17025:2017. Virtual. A2LA WPT. This 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

Sep 22-23, 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

Oct 12-13, 2021 Understanding ISO/IEC 17025 for Testing and Calibration Labs. Webinar. IAS. To learn about ISO/IEC 17025 from one of its original authors. To learn its Principles and what it requires of laboratory staff. This Training Course applies to testing and calibration laboratories and regulatory agencies seeking to specify 17025 within their policies and regulations. https://www.iasonline.org/training/ias-training-schedule/

Oct 12-13, 2021 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories. Frederick, MD. 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/events

Oct 14-15, 2021 Auditing Your Laboratory to ISO/IEC 17025:2017. Frederick, MD. 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

Oct 19-21, 2021 Introduction to ISO/IEC 17025:2017. Cary, NC. ANAB. The Introduction to ISO/IEC 17025 training course will provide attendees an overview of the requirements of ISO/IEC 17025:2017. Those involved with the standard and potentially seeking accreditation should attend this course. For full description visit https://anab.ansi.org/training/17025/intro

Oct 19-21, 2021 Internal Auditing to ISO/IEC 17025:2017. Cary, NC. ANAB. This training is designed for laboratory managers, technical staff, and others who want or need to learn better audit practices. For full description visit https://anab.ansi.org/training/17025/internal-auditing

Nov 15-16, 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

Nov 17-18, 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

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/

CALENDAR

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

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SEMINARS & WEBINARS: Management & Quality

Sep 8-9, 2021 Quality Fundamentals. Virtual. A2LAWPT. During this course, the participant will gain an understanding of the basic concepts of quality fundamentals terms and quality principles. https://www.a2lawpt.org/events

Oct 4-5, 2021 Quality Fundamentals. Virtual. A2LAWPT. During this course, the participant will gain an understanding of the basic concepts of quality fundamentals terms and quality principles. https://www.a2lawpt.org/events

SEMINARS & WEBINARS: Mass

Sep 20-30 Advanced Mass Seminar. NIST Gaithersburg Campus, MD. This 9-day, hands-on mass calibration seminar focuses on the comprehension and application of the advanced mass dissemination procedures, the equations, and associated calculations. https://www.nist.gov/pml/weights-and-measures/about-owm/calendar-events

Oct 18-29 Mass Metrology Seminar. NIST Gaithersburg Campus, MD. The Mass Metrology Seminar is a two-week, "hands-on" seminar. It incorporates approximately 30 percent lectures and 70 percent demonstrations and laboratory work in which the participant performs measurements by applying procedures and equations discussed in the classroom. The seminar focuses on the comprehension and application of the procedures, the equations, and calculations involved. https://www.nist.gov/pml/weights-and-measures/about-owm/calendar-events

Nov 16, 2021 N0 - Realization and Dissemination of Mass in the "New SI." Anaheim, CA. This course will provide information on realization and dissemination of mass after the redefinition of the kilogram is adopted in 2019. Details will be presented on the motivation for redefining the unit of mass and the experiments involved in tying the kilogram to an invariant of nature, the Planck constant. The effect of the redefinition on uncertainties of the NIST mass scale and customer calibrations will also be presented. https://annualconf.msc-conf.com/nist-seminar/

SEMINARS & WEBINARS: Measurement Uncertainty

Aug 18, 2021 Measurement Uncertainty and Calibration Workshop. Auckland, New Zealand. Measurement Standards Laboratory. This course gives a broad high-level overview of measurement and calibration principles, and calculation of uncertainty. https://www.measurement.govt.nz/training/

Aug 18-19, 2021 Uncertainty of Measurement for Labs. Webinar (Timed for the Americas). IAS. Evaluation and Estimation of Uncertainties of Measurement. Introduction to metrology principles, examples and practical exercises. https://www.iasonline.org/training/uncertainty-of-measurement/

Sep 13-14, 2021 Introduction to Measurement Uncertainty. Virtual. A2LA WPT. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2lawpt.org/events

Sept 20-23, 2021 Applied Measurement Uncertainty for Calibration Laboratories. Virtual. A2LA WPT. During this course, the participant will be introduced to several tools and techniques that can be applied in the calibration laboratory environment to efficiently and effectively create measurement uncertainty budgets which comply with ISO/IEC 17025 requirements. https://www.a2lawpt.org/events

Oct 5-6, 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

Oct 12, 2021 Introduction to Measurement Uncertainty. Frederick, MD. A2LA WPT. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2lawpt.org/events

Oct 12-14, 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. For full description visit https://anab.ansi.org/training/forensic/practicalapplicationsmc150

Oct 13-14, 2021 Applied Measurement Uncertainty for Testing Laboratories. Frederick, MD. A2LA WPT. During this workshop, the participant will be introduced to several tools and techniques that can be applied in the testing laboratory environment to efficiently and effectively create measurement uncertainty budgets which comply with ISO/IEC 17025 requirements. https://www.a2lawpt.org/events

Oct 13-14, 2021 Uncertainty of Measurement for Labs. Webinar timed for ME and South Asia. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/ias-training-schedule/

Oct 14-15, 2021 Applied Measurement Uncertainty for Calibration Laboratories. Frederick, MD. A2LA WPT. During this course, the participant will be introduced to several tools and techniques that can be applied in the calibration laboratory environment to efficiently and effectively create measurement uncertainty

budgets which comply with ISO/IEC 17025 requirements. The tools presented are generic in nature such that they may be applied in a variety of calibration laboratories. https://www.a2lawpt.org/training

Oct 26-29, 2021 Measurement Uncertainty & Conformity Decision Risk Analyst Webinar Class. This class has been provided by Quametec since 1998, instructed by James D Jenkins. It has recently been expanded to cover measurement-based statement of conformity decision risk analysis, along with the UncertaintyToolbox™ template set. https://www.qimtonline.com/

Nov 8-9, 2021 Introduction to Measurement Uncertainty. Virtual. A2LA WPT. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2lawpt.org/training

Nov 15-17, 2021. N01 - Hands-on Workshop on Assessing and Reporting Measurement Uncertainty. Anaheim, CA. This NIST short course will be held at the Measurement Science Conference in Anaheim, CA. The 3-day course consists of lectures, short exercises, and hands-on applications covering many aspects of the propagation of uncertainty using examples from NIST work. https://annualconf.msc-conf.com/nist-seminar/

Nov 15-18, 2021 Applied Measurement Uncertainty for Testing Laboratories. Virtual. A2LA WPT. During this workshop, the participant will be introduced to several tools and techniques that can be applied in the testing laboratory environment to efficiently and effectively create measurement uncertainty budgets which comply with ISO/IEC 17025 requirements. https://www.a2lawpt.org/events

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SEMINARS & WEBINARS: Photometry & Radiometry

Nov 17-18, 2021 Photometry and Radiometry. Lindfield NSW, Australia. NMI. 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://www.industry.gov.au/client-services/training-and-assessment

SEMINARS & WEBINARS: Pressure

Aug 17, 2021 Pressure Calibration Workshop. Auckland, New Zealand. Measurement Standards Laboratory. This workshop is a practical one-day session dealing with all aspects of pressure gauge and transducer calibration. https://www.measurement.govt.nz/training/

Sep 20-24, 2021 Principles of Pressure Calibration. Phoenix, AZ. Fluke Calibration. A five-day training course on the principles and practices of pressure calibration using digital pressure calibrators and piston gauges (pressure balances).The class is designed to focus on the practical considerations of pressure calibrations. https://us.flukecal.com/training

Oct 18-22, 2021 Advanced Piston Gauge Metrology. Phoenix, Arizona. Fluke Calibration. A five-day course focusing on the theory, use and calibration of piston gauges and deadweight testers. https://us.flukecal.com/training

Nov 15-16, 2021 N02 - NIST Pressure and Vacuum Measurement. Anaheim, CA. This two-day course will cover the fundamentals of pressure measurements from 10^-8 Pa to 10^+8 Pa, focusing on the selection and proper use of appropriate gauging technology for a given application. A survey of calibration techniques will be presented along with recommendations for obtaining best performance. https://annualconf.msc-conf.com/nist-seminar/

Nov 17, 2021 N08 - Gas Pressure Measurement Via Fixed Length Optical Cavity (FLOC) Pressure Standards. Anaheim, CA. The metrologist planning to make use of this portable standard will need to be trained in the basics of FLOC laser cavities and alignment, use and operation of optical refractometers, requirements for making primary measurements, and basics of a FLOC uncertainty estimation. The class will feature hands on demonstrations along with the classroom instruction. https://annualconf.msc-conf.com/nist-seminar/

SEMINARS & WEBINARS: RF & Microwave

Sep 7-9, 2021 VNA Tools Training Course. Bern-Wabern, Switzerland. Federal Institute of Metrology METAS. VNA Tools is 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

Sep 21-23, 2021 VNA Tools Training Course. Beaverton, OR. Federal Institute of Metrology METAS. VNA Tools is 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

Nov 9-11, 2021 VNA Tools Training Course. Bern-Wabern, Switzerland. Federal Institute of Metrology METAS. VNA Tools is 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

Nov 15, 2021 N05 - Microwave Measurement. Anaheim, CA. An introduction to the measurement concepts for microwave power and scattering-parameters will be covered. Specific topics covered will include transmission line theory, practical handling or the do's and don'ts for microwave connectors and connections, Vector Network Analyzer calibration/measurements and real world

CALENDAR

sources of uncertainties, nonlinear microwave measurements, microwave power detectors types, power measurements and uncertainties, a brief introduction to the NIST Microwave Uncertainty Framework and the session will conclude with a discussion of verification techniques for microwave measurements. https://annualconf.msc-conf.com/nist-seminar/

SEMINARS & WEBINARS: Software

Aug 30-Sep 2, 2021 TWB 1051 MET/TEAM® Basic Web-Based Training. Fluke Calibration. This web-based course presents an overview of how to use MET/TEAM Test Equipment and Asset Management Software to develop your asset management system. You will learn a systematic approach to recording the information you need to manage your lab assets routinely, consistently and completely. http://us.flukecal.com/training

Sep 20-24, 2021 MC-207 Advanced MET/CAL® Procedure Writing. Everett, Washington. Fluke Calibration. A five-day course for advanced users of MET/CAL calibration software. http://us.flukecal.com/training

Oct 25-29, 2021 TWB 1031 MET/CAL® Procedure Development Web-Based Training. Fluke Calibration. A five-day (2-hour sessions), instructor-led web-based training, course on creating procedures with the latest version of MET/CAL. http://us.flukecal.com/training

Nov 8-12, 2021 MC-206 Basic MET/CAL® Procedure Writing. Everett, WA. Fluke Calibration. In this five-day Basic MET/CAL Procedure Writing course, you will learn to configure MET/CAL software to create, edit, and maintain calibration solutions, projects and procedures. http://us.flukecal.com/training

SEMINARS & WEBINARS: Temperature & Humidity

Aug 19, 2021 Temperature Measurement and Calibration Workshop. Auckland, New Zealand. Measurement Standards Laboratory. This course covers the use, care, and calibration of liquid-in-glass, platinum resistance, thermocouple, and radiation thermometers. https://www.measurement.govt.nz/training/

Aug 20, 2021 Humidity and Moisture Calibration Workshop. Auckland, New Zealand. Measurement Standards Laboratory. This practical one-day course will introduce you to humidity generation, calibration and measurement, along with the conceptual framework for understanding the various limitations in humidity measurements. https://www.measurement.govt.nz/training/

Sep 13-17, 2021 Advanced Topics in Temperature Metrology. American Fork, UT. A three-day course for those who need to get into the details of temperature metrology. This course is for experienced calibration technicians, metrologists, engineers, and technical experts working in primary and secondary-level temperature calibration laboratories who would like to validate, refresh, or expand their understanding of advanced topics in temperature metrology. https://us.flukecal.com/training

Oct 4-6, 2021 Practical Temperature Calibration. American Fork, Utah. Fluke Calibration. A three-day course designed to help calibration technicians and engineers get a solid base of temperature calibration fundamentals. https://us.flukecal.com/training

Oct 5-7, 2021 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

Nov 17, 2021 N09 - NIST Humidity Seminar. Anaheim, CA. Humidity is not a single quantity but a family of quantities that involve moisture content in a gas, including relative humidity, dew point, water amount fraction, and water mass ratio. This course will teach the fundamentals of these quantities and explain how they relate to each other and are influenced by other quantities, such as temperature and pressure. https://annualconf.msc-conf.com/nist-seminar/

SEMINARS & WEBINARS: Time & Frequency

Oct 20-21, 2021 Time and Frequency Measurement. Lindfield, NSW. Australia NMI. This two-day course (9 am to 5 pm) covers the broad range of equipment and techniques used to measure time and frequency and to calibrate time and frequency instruments. https://shop.measurement.gov.au/collections/physical-metrology-training

SEMINARS & WEBINARS: Vibration

Nov 9-11, 2021 Fundamentals of Random Vibration and Shock Testing. San Diego, CA. Equipment Reliability in collaboration with WESTPAK. Review basic vibrations, sources and causes, then explore vibration measurements, analysis and calibration. Our discussion is supported by projected visuals and video clips. We'll compare sinusoidal vs. random vibration with emphasis on testing systems, specifications, standards and procedures. https://equipment-reliability.com/open-courses/

SEMINARS & WEBINARS: Weight

Aug 17, 2021 Balances and Weighing. Auckland, New Zealand. Measurement Standards Laboratory. There are increasing demands on laboratories to demonstrate quality assurance in their measurements. This course provides training to assist laboratory personnel to meet these demands. https://www.measurement.govt.nz/training/

Sep 9, 2021 Calibration of Weights and Balances. Lindfield NSW, Australia. NMI. 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

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Escape From Flatland: Calibration Method Enables Microscopes to Make Measurements in 3 Dimensions

June 24, 2021, NIST News — Conventional microscopes provide essential information about samples in two dimensions—the plane of the microscope slide. But flat is not all that. In many instances, information about the object in the third dimension—the axis perpendicular to the microscope slide—is just as important to measure.

For example, to understand the function of a biological sample, whether it is a strand of DNA, tissue, organ or microscopic organism, researchers would like to have as much information as they can get about the three-dimensional structure and motion of the object. Two-dimensional measurements yield an incomplete and sometimes unsatisfying understanding of the sample.

Now researchers at the National Institute of Standards and Technology (NIST) have found a way to convert a problem affecting nearly all optical microscopes—lens aberrations, which cause imperfect focusing of light—into a solution that enables conventional microscopes to accurately measure the positions of points of light on a sample in all three dimensions.

Although other methods have enabled microscopes to provide detailed information about three-dimensional structure, these strategies have tended to be expensive or require specialized knowledge. In one previous approach to measuring positions in the third dimension, researchers altered the optics of microscopes, for instance by adding extra astigmatism to the lenses. Such alterations often required reengineering and recalibration of the optical microscope after it left the factory.

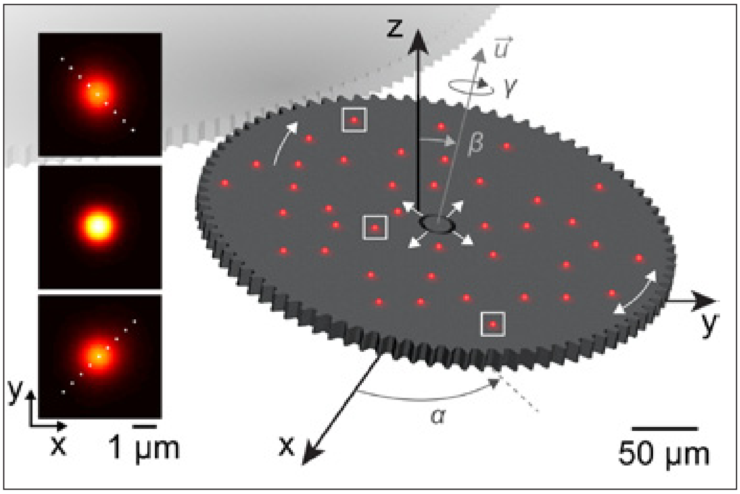
The new measurement method also enables microscopes to more accurately and precisely locate the positions of objects. Optical microscopes typically resolve the positions of objects to a region no smaller than a few hundred nanometers (billionths of a meter), a limit set by the wavelength of the light that makes the image and the resolving power of the microscope lenses. With the new technique, conventional microscopes can pinpoint the positions of individual light-emitting particles within a region one-hundredth as small.

NIST researchers Samuel Stavis, Craig Copeland and their colleagues described their work in the June 24 issue of Nature Communications.

The method relies on a careful analysis of images of fluorescent particles that the researchers deposited on flat silicon wafers for calibration of their microscope. Due to lens aberrations, as the microscope moved up and down by specific increments along the vertical axis—the third dimension—the images appeared lopsided and the shapes and positions of the particles appeared to change. The NIST researchers found that the aberrations can produce large distortions in images even if the microscope moves just a few micrometers (millionths of a meter) in the lateral plane or a few tens of nanometers in the vertical dimension.

The analysis enabled the researchers to model exactly how the lens aberrations altered the appearance and apparent location of the fluorescent particles with changes in the vertical position. By carefully calibrating the changing appearance and apparent location of a particle to its vertical position, the team succeeded in using the microscope to accurately measure positions in all three dimensions.

"Counterintuitively, lens aberrations limit accuracy in two dimensions and enable accuracy in three dimensions," said Stavis. "In this way, our study changes the perspective of the dimensionality of optical microscope images, and reveals the potential of ordinary microscopes to make extraordinary measurements."



Left: Images of fluorescent particles that are above, at and below (top to bottom) the vertical position of best focus of a microscope. Calibrating the effects of lens aberrations on the apparent shape and position of the particle images enables accurate measurement of the position in all three spatial dimensions using an ordinary optical microscope. Right: Tracking and combining information from many fluorescent particles on a tiny rotating gear tests the results of the new calibration and elucidates the motion of a complex microsystem in all three dimensions. Credit: NIST

Using the latent information provided by lens aberrations complements the less accessible methods that microscopists currently employ to make measurements in the third dimension, Stavis noted. The new method has the potential to broaden the availability of such measurements.

The scientists tested their calibration method by using the microscope to image a constellation of fluorescent particles deposited randomly on a microscopic silicon gear that rotated in all three dimensions. The researchers showed that their model accurately corrected for the lens aberrations, enabling the microscope to provide full three-dimensional information about the position of the particles.

The researchers were then able to extend their position measurements to capture the entire range of motion of the gear, including its rotating, wobbling and rocking, completing the extraction of spatial information from the system. These new measurements highlighted the consequences of nanoscale gaps between microsystem parts, which varied due to imperfections in the fabrication of the system. Just as a loose bearing on a wheel causes it to wobble, the study showed that the nanoscale gaps between parts not only degraded the precision of the intentional rotation, but also caused unintentional wobbling, rocking and even flexing of the gear, all of which could limit its performance and reliability.

Microscopy laboratories could easily implement the new method, Copeland said. "The user just needs a standard sample to measure their effects and a calibration to use the resulting data," added Stavis. Aside from the fluorescent particles or a similar standard, which already exist or are emerging, no extra equipment is needed. The new journal article includes demonstration software that guides researchers in how to apply the calibration.

Paper: Craig R. Copeland, Craig D. McGray, B. Robert Ilic, Jon Geist and Samuel M. Stavis. Accurate localization microscopy by intrinsic aberration calibration. Nature Communications. June 24, 2021. DOI: 10.1038/s41467-021-23419-y

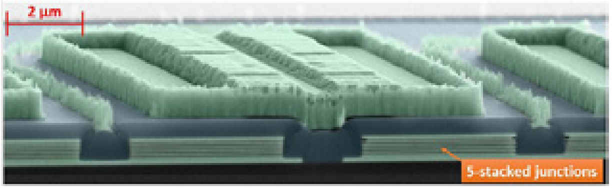
Source: *https://www.nist.gov/news-events/news/2021/06/escape-flatland-calibration-method-enables-microscopes-make-accurate*

Multilayer Sandwich

PTB News 2.2021 — Josephson arbitrary waveform synthesizers (JAWS) allow quantized AC voltages to be synthesized with arbitrary and spectrally pure waveforms. At PTB, a pulse-driven Josephson standard for the generation of AC voltages with series arrays has been realized. These arrays are based on stacks of up to five Josephson junctions. This new technology has allowed the integration density of the circuits – and thus their output voltage – to be considerably increased: With up to 30 000 junctions per chip, it is now possible to generate an effective voltage of 0.5 V RMS (0.7 V peak). The yield of the fabrication process has been clearly increased by adapting various parameters.

Pulse-driven Josephson AC voltage standards enable a large number of metrological applications and are based on series arrays of superconducting Josephson junctions of the kind manufactured in the Clean Room Center of PTB. In the long run, it is planned that the output voltage will be further increased to reach values between 7 V and 10 V to extend the range of possible applications.

One of the measures envisaged in order to achieve such an increase consists in raising the integration density of



SEM image of a series array with 5 stacked Josephson junctions (cross section view). The height of the junction stacks amounts to approx. 800 nm; all layers taken together are roughly 3 µm in height. Credit: PTB

Josephson junctions on the chips. Since the junctions are integrated into a high-frequency structure (a coplanar waveguide), the possibility to increase the length of the series array is limited. To increase the number of junctions on each chip, the junctions were stacked vertically. This was made technologically possible by the material layer combination of the Josephson junctions, which consist of Nb and Si.

After several modifications and enhancements of the standard process used at PTB, which is based on electron beam lithography, stacks of up to 5 Josephson junctions have now been successfully implemented with a high process yield. Two important process enhancements are worth mentioning in this context: For one thing, a chemical-mechanical polishing procedure was introduced for the planarization of the array surfaces. Thanks to this procedure, the successive superconducting layers can be deposited and then structured in compliance with high quality requirements (high superconducting current carrying capacity). For another, a non-conducting silicon oxide layer was deposited between the electrically conducting structures by means of atomic layer deposition (ALD) in collaboration with the Leibniz Institute of Photonic Technology (IPHT) in Jena. Contrary to the silicon oxide non-conducting layers that had previously been manufactured at PTB by means of plasma-enhanced chemical vapor deposition, ALD layers have the advantage of covering edges perfectly. They thus provide good edge isolation even at extreme aspect ratios such as those prevailing in 5-fold stacks of junction arrays.

PTB is planning to make the ALD technology available in its own Clean Room Center in the future. All in all, the complex fabrication process in which 30 000 Josephson junctions are integrated onto a chip with a surface of (10 × 10) mm2 consists in depositing 16 layers in approx. 40 individual process steps.

Contact: Oliver Kieler (oliver.kieler(at)ptb.de), Department 2.4, Quantum Electronics, Phone: +49 531 592-2410

Scientific publication: O. Kieler, R. Wendisch, R. Gerdau, T. Weimann, J. Kohlmann, R. Behr: Stacked Josephson junction arrays for the pulse-driven AC Josephson voltage standard. IEEE Trans. Appl. Supercond. 31 (2021)

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

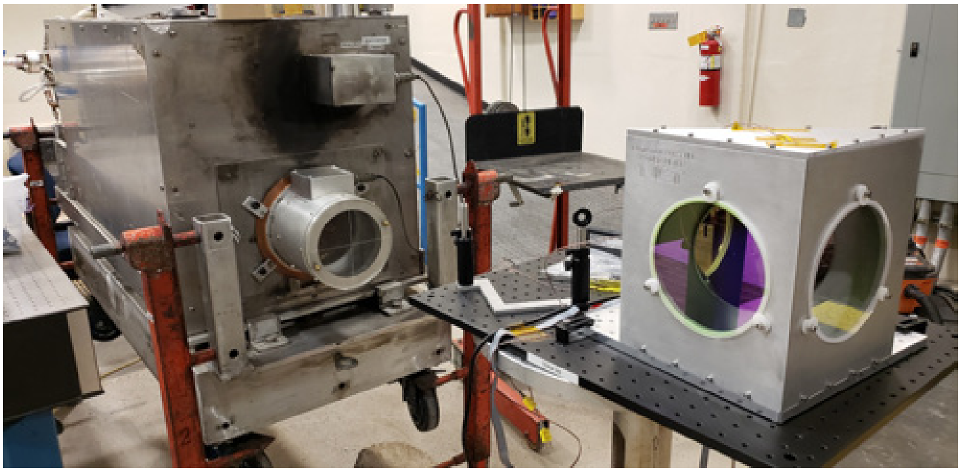
Big Berthas Used to Measure Laser Power

By Daryl Mayer, AFLCMC Public Affairs / Published June 29, 2021

WRIGHT-PATTERSON AFB, Ohio (AFLCMC) – The Air Force Metrology and Calibration Division is using some unique mobile "Big Bertha" series High Energy Laser primary reference calorimeters to support Air Force Research Laboratory's national defense programs work on lasers.

The HEL calibration supports the Laser Hardened Materials Evaluation Laboratory (LHMEL) of the Air Force Research Laboratory's Materials and Manufacturing Directorate at Wright Patterson AFB and the AFRL Directed Energy Directorate at Kirtland AFB in Albuquerque, NM. For over 35 years, AFRL's LHMEL has provided the aerospace community with a comprehensive source for high temperature characterization of current and emerging materials using a variety of infrared laser sources and environmental simulation capabilities.

The calibrations performed by AFMETCAL enable LHMEL to accurately simulate high service life temperatures experienced by parts within a jet engine.


The calorimeter designated Big Bertha 1 (left) will eventually be replaced by the Air Force's new High Energy Laser standard Radiation Pressure Power Meter (right). (Courtesy photo)

These calorimeters, designated BB1 and BB2 (Big Bertha 1 and 2), which are the national standards for HEL measurements very precisely measure the energy in a laser shot. AFMETCAL is the division of the Air Force Life Cycle Management Center responsible to ensure Air Force systems and equipment are accurate, uniform, reliable and traceable to National Institute of Standards and Technology (NIST) or other approved sources for SI units of power and energy for optical radiation measurements.

Typically, calibration work of this type is done at the AFMETCAL facilities in Heath, Ohio. In this instance, the AFRL Directed Energy Directorate at Kirtland AFB, NM needed on-site High Energy Laser calibration support using some very specialized pieces of equipment. AFMETCAL calibration services for laser power and energy meters have been provided by use of calorimeters that were electrically calibrated and directly traceable to SI units through electrical standards.

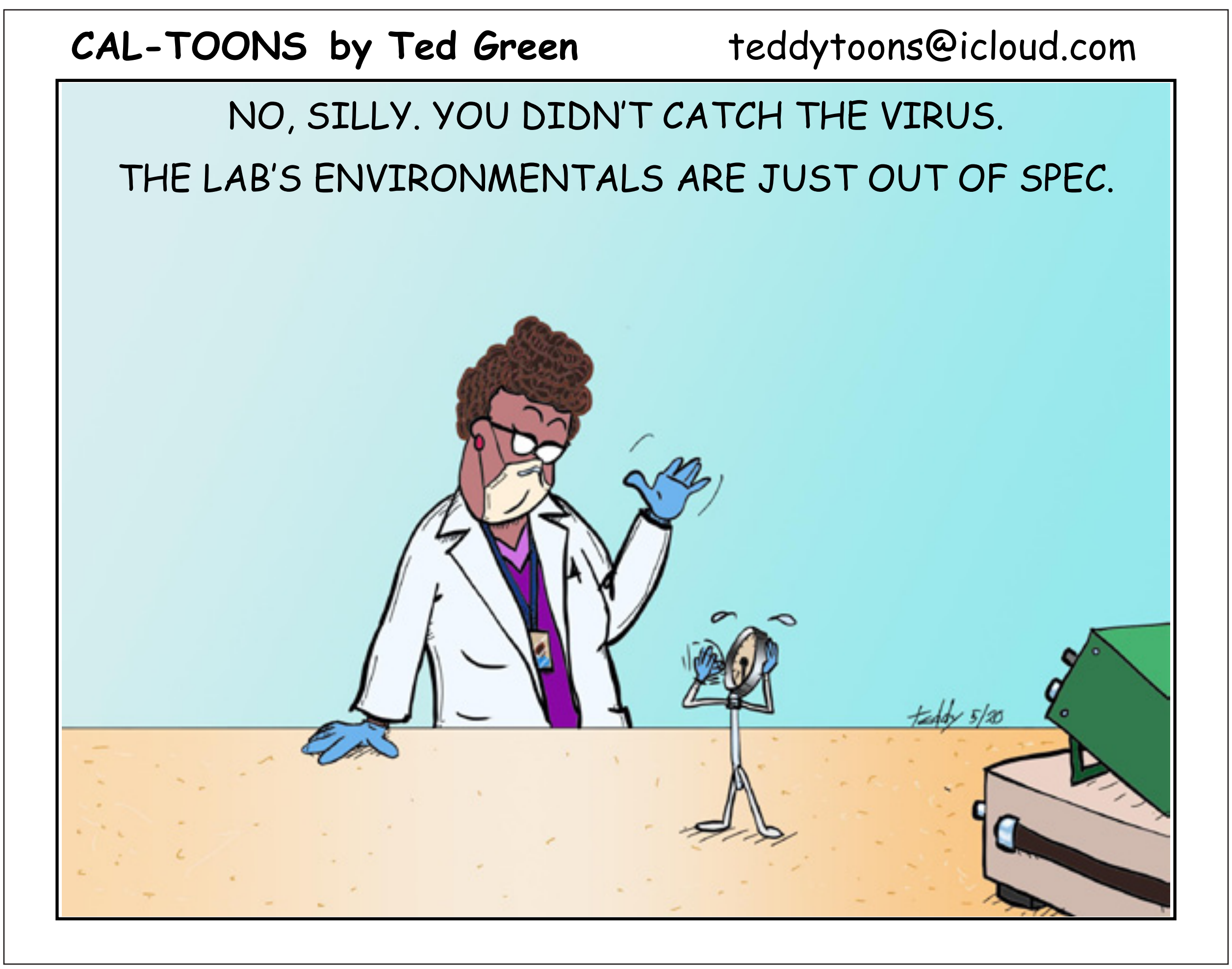
"There are only two of them that actually exist in the in the world," said Jennifer Landry, AFMETCAL Electrical Engineer and project lead.

Landry with AFMETCAL engineers, Thomas Jenkins, Tyler Youngman, and Tesfatsion Sereke teamed with Air Force Primary Standards Laboratory (AFPSL) personnel transporting primary reference standards to the Kirtland on-site location.

Upon request, these BB series calorimeter standards are used to perform NIST SI traceable calibrations at DoD research and development facilities. "These calibrations support materials testing by Air Force Systems Command laboratories and are also used to provide accurate measurement for Strategic Defense Initiative programs on laser weaponry," said Sereke, AFMETCAL Senior Metrology and Calibration Engineer.

These calorimeters were developed through a collaborative research and development effort between NIST, which is a part of the U.S. Department of Commerce, and the Air Force. Each calorimeter system weighs more than 1000 pounds, and both calorimeter systems are mounted on a specialized HEL Mobile Calibration Van to go on site for customer support

"This van was prepared specifically for this purpose. So



it is reinforced to be capable of carrying the weight and it has all the necessary electrical hookups in it," Landry said. "It also has physical tie downs that provide stability so we're not worried about shipping problems in the entire transportation process."

During the test, the device actually captures energy from the laser source to measure it.

"It is a large, roughly 30 inches wide by 72 inches long by 48 inches high, metallic rectangle with a cavity about 10 inches in the middle," Landry said. "The laser shot gets directed into that cavity and on the inside of it is absorbed by some sensitive electronic gear that precisely measures the energy."

AFPSL technicians configure the measurement set-up where a laser is shot through a "chopper wheel" and into the BB, according to Landry. Through this process AFMETCAL is able to accurately calibrate these calorimeters and determine the energy levels these items can support. This enables LHMEL to perform laser/materials interaction testing that determines the amount of energy a material can absorb before damage is incurred, and Kirtland to be able to accurately support the Directed Energy efforts.

The request to support the research presented a challenge, especially during the pandemic. In preparation for the onsite calibration deployment, the AFMETCAL team of engineers provided pre-calibration support, updated software and went onsite to provide troubleshooting as needed to ensure mission success, according to Youngman.

"The calibration support effort also includes testing of the Air Force's new HEL standard Radiation Pressure Power Meter (RPPM), which will eventually be replacing the bulky BB standards mentioned above," Landry said. "The RPPM is the product of a RDT&E project developed by NIST. The footprint of the RPPM is much smaller and will alleviate the Air Force's reliance on a HEL van."

Source: *https://www.wpafb.af.mil/News/Article-Display/Article/2675263/big-berthas-used-to-measure-laser-power/*

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Temperature Calibrations, Part 3

Ryan Egbert and Joseph Rindone
Sine Calibration School

The following article is part three 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. More information will be provided along the way, but let us not waste any more space here in this article.

Introduction

In our last edition, we just discussed thermocouples. We explored the phenomena of how the thermoelectric voltage (Seebeck effect) works with two dissimilar metals. What is notable is that this voltage occurs directly without a current source. Now, as we press forward to a different type of variable device, which is ***resistance variable temperature devices***, you will find that we need to supply the current to make the sensor work. This is the vital difference between these type of temperature sensors and thermocouples. In resistive temperature devices, the voltage is not a result of a natural phenomenon, instead there is an external constant current source that provides a small stable current to the resistive element. *Please understand that for the purposes of this instruction we are proceeding with the assumption that you have basic electronic knowledge—more specifically, understanding of Ohm's Law and how the variables voltage, resistance, and current can be derived from each other.*

We now know our new variable, but you may have noticed that we have been using the plural word devices when talking about resistance variable ones. This is because we are going to talk about two different distinct types of resistance thermometers in this course: Resistance Temperature Detectors (or RTDs) and Thermistors. First, we will do a deep dive on RTDs because those will most likely be the most common for you as you are working in the field.

Resistance Temperature Detectors, or RTDs

RTDs are very commonly the "next step up" in accuracy for most customers that find thermocouples are not quite meeting their needs. This isn't to say that thermistors might not be a perfect fit for an application and even be significantly less expensive, it is more that the awareness of them as a pure temperature sensor is not as prevalent. Another reason that RTDs may be more common in manufacturing applications is that it has an International Standard associated with its accuracies and manufacturing requirements: ***IEC 60751:2008 or ASTM E1137***.

Unfortunately, thermistors do not have an international guiding document for their manufacture and temperature versus resistance curves. In the United States there is ASTM E879-20 that gives specification guidance, but many thermistors that customers will purchase will not follow this standard. Always look for manufacturer supplied specifications whenever possible.

A famous German electrical engineer, Werner von Siemens, invented the first Platinum Resistance Temperature Detector in 1871. Unfortunately, this first RTD did not catch on due to design flaws that would cause unstable temperature readings. It was later in 1885 that British physicist Hugh Longbourne Callendar designed the first commercially successful RTD (1). The next year in 1886, Callendar authored a paper discussing his redesigned RTD and presented a third order equation for defining the resistance over the temperature range of 0 °C to 550 °C. This equation was later extended in 1925 to -200 °C by the late Milton S. Van Dusen who was a researcher at the National Bureau of Standards, or what we all know now as NIST.

This Callendar-Van Dusen equation has now been used for nearly a century, but it should be mentioned that it is not the best fit for platinum RTDs. The limitations come from the equation used; the third order equation was a very real limitation in science at the time because all of the scientists had to do the calculations by hand. That is why in 1968 the International Electrotechnical Commission (IEC) defined a 20-term polynomial equation for the resistance versus temperature curve for 100 Ohm platinum RTDs, this is the same entity that manages it today with IEC 751. Just as an idea of our advantages with technology, a 20-term polynomial equation would have taken scientists several days to calculate back in Callander and Siemens' time.

Heat Increases Resistance

Many of you reading this will be familiar with the effects of temperature on the electrical resistance of metals, as the temperature rises, so does the resistance. This is the basic principle behind resistance temperature detectors, but

Material	Base Resistance	Temp Coefficient	Description
Platinum	100 Ω at 0.01 °C	0.00392	ITS-90 reference curve
Platinum	100 Ω at 0 °C	0.00385	IEC 751
Copper	9.035 Ω at 0 °C	0.00427	
Nickel	120 Ω at 0 °C	0.00672	
Nickel-Iron	908.4 Ω at 0 °C	0.00527	1000 Ω at 70 °F

Table 1.Temperature Coefficients of RTD metals

you must also understand that not all RTDs are platinum and that different metals will increase their resistance at different rates or have different ***Temperature Coefficients of Resistance***. In Table 1, you will see many different coefficients for different metals. Although we do mention the many different possible metals that could be used or seen in RTD applications, we will say that the vast majority most of you will see is platinum.

Temperature coefficients are defined as the resistance of the RTD at 100 °C minus the resistance at 0 °C divided by 100. That result is then divided by the resistance at 0 °C. What this resulting number tells us is the average resistance change per degree from 0 °C to 100 °C, but this is not an exact number. There are many factors that can alter the resistance change slightly, but just understand it will be very close to the coefficient number.

When looking at the table above you will notice that there are two different platinum coefficient curves. The first coefficient, 0.00392, is the ITS-90 reference curve typically used in Standard Platinum Resistance Thermometers, or SPRTs. This curve is due to a purer form of platinum used in construction and results in a more accurate, but also more expensive sensor. The second is the IEC 751 manufacturing requirements for most of the platinum RTDs you will find in your day-to-day job. To be more specific, you will often find 3-wire PT100 RTDs with a 0.00385 curve being the most common manufacturing RTD, so… what does that all mean?

Classifying RTDs is not as complex as it may seem at first glance and we will discuss the number of wires present in the video portion of this instruction, but the second piece of information, PT100, is as simple as the Pt being the periodic table symbol for platinum and 100 representing the resistance of the sensor at 0 °C. If you are ever stuck in a situation where you do not know exactly what type of resistance sensor you have in your hand, a good troubleshooting step is to check its resistance in a proper ice bath. If it is 100 Ω, there is a pretty decent chance you have a PT100. If you have something that is measuring over 1000 Ω, like 3000 Ω, 10,000 Ω, or even 30,000+ Ω at 0 °C… you most likely have a thermistor.

We will talk in depth about the accuracy of RTDs in our video portion, but we have mentioned previously that they are the most accurate of our temperature devices. The Table 2, below, shows the Classification Tolerances as per ASTM E1137.

Temperature in °C	Grade A Tolerances (°C)	Grade B Tolerances (°C)
-200	0.47	1.1
-100	0.30	0.67
0	0.13	0.25
100	0.30	0.67
200	0.47	1.1
300	0.64	1.5
400	0.81	1.9
500	0.98	2.4
600	1.15	2.8
650	1.24	3.0

Table 2. Classification Tolerances as per ASTM E1137

These values are representing values for 3-wire and 4-wire PRTs. We will discuss the configuration of these devices in our video lecture.

As a last side note in the RTD portion, it is important for someone going into metrology to be familiar with Standard Platinum Resistance Thermometers, or SPRTs. These are very special and fragile PRTs that typically are only used by higher level metrologists. While you may not actually use these early in your career, you must understand WHY lab management does not want you using them and that is because of how sensitive they are to even the lightest of impacts or vibration. These types of PRTs are usually not even taken out of the lab, so please do not snag one on your way out the door to do on-site appointments for the day.

Thermistors

Thermistors were invented and patented in 1930 by Samuel Ruben of Vega Manufacturing Corporation. For those of you unfamiliar, Vega actually made guitars and Samuel noticed some special characteristics about an electrical pickup he was working on that showed a rather large negative temperature coefficient. This led to Mr. Ruben securing the patent to the thermistor that same year.

Note: When Michael Faraday discovered the first NTC thermistor in 1833, there was no use for it at that time.

Unlike RTDs, thermistors are non-linear in function and follow a classic logarithmic curve. While the ITS-90 is used for determining voltage from temperature, ITS-90 can determine resistance as well. You know about the ITS-90 and how it is developed from many measurements extrapolated into a table for use. Although not precisely linear, the Best Fit Straight Line is linear to a point. The thermistor has a very curved response, and it is most accurate when it is about 50° C of the target temperature.

The thermistor can be manufactured to specific values. In fact, they are "Thermal Resistors." When configured with other electronic devices, they operate like normal resistors in electrical circuitry. Normal resistors have a specified wattage, so design engineers create custom thermistors out of metallic oxides in regard to the circuit requirements. As you saw in the CJC circuit board picture, the thermistor is mounted directly on the board between the junction points. This is the most accurate technique, when used directly on a surface next to the device requiring temperature coefficients.

Basic elemental metals are known for their "Positive Temperature Coefficient" (PTC) numbers. As the temperature increases, so does the resistance by the PTC/°C. PTC Thermistors are designed to be switches. Have you ever had a device like an electric iron shutting off because it got too hot? That was due to a thermistor acting like a safety switch. These are special thermistors when the temperature increases so does the resistance they exhibit.

Now that we know the positive temperature coefficient, the same thing is the opposite effect of the Negative Temperature Coefficient (NTC); as heat goes up, resistance goes down. It would be easy to say that's all there is, but we have just scratched the surface. The basic operating range of thermistors is -55 °C to 150 °C. This may seem like a limited range, but remember, thermistors are very accurate, and their measurements are highly reproducible. This is why they are used in CJC circuits found in process calibrators. These devices allow us to use the temperature coefficients in determining as accurate a temperature as possible. Although we want you to know of temperature coefficients, you won't be required to become proficient with them until you continue higher in your metrology training.

When it comes to accuracy, thermistors do not have an industry or government standard related to their manufacturing or accuracy requirements. There are at least 5 different temperatures versus resistance curves for 10 kΩ thermistors in the HVAC world and accuracies can be as good as ±0.2 °C for glass and epoxy coated sensors, or ±0.1 °C for extra precision thermistors. Another important note when it comes to thermistors is that the reference temperature for the typical 10,000 ohm of resistance is at 25 °C (77 °F). It is important to have manufacturer's information when doing calibration on thermistors for this very reason—you could have as much as 6 °F error between differing temperature curves.

We will also mention that there are standard thermistors that you may come across as well in your time in calibration labs. These can have slightly better accuracies and uncertainties, but also hold the benefit of not requiring as much insertion depth as thermocouples and RTDs do. These upsides do not come without the downsides of the sensor however, for instance, the problem of the limited temperature range is compounded by hash intolerance to over-ranging the sensor. This is not to say that it is okay to over range any temperature reading device, but from experience, thermistors are some of the most sensitive to over ranging and thus should be only used by well trained and observant personnel.

Conclusion

This is as far as we are going to go into the resistance variable temperature sensors here in the written portion of this course. In the online portion, we will show you the different types of RTD wiring, as well as the demonstrations of the calibration of resistance temperature devices.

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Comparison Demonstrates Factor of Three Improvement in Gas Flow Measurements

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A comparison of seven gas flow calibration laboratories piloted by NIST used four laminar flow meters as the transfer standards for nine nitrogen gas flows ranging from 1 sccm to 10 slm.† The comparison reference value was calculated from the uncertainty weighted average of the three participants with independent flow traceability chains. The 63 comparison results were evaluated by the traditional criterion (normalized degree of equivalence, $|E_n| \leq 1$) and also by a probabilistic criterion that allows the possibility of inconclusive results. The $|E_n| \leq 1$ criterion determined that 2 of the 63 results were outside of uncertainty expectations. The probability-based criterion found the same 2 results were outside of uncertainty expectations and 3 results were inconclusive. Based on these results and other evidence, all participants were found proficient over the range of flows they tested. A comparison of the present results to those from a similar comparison between four of the same participants conducted in 2003 shows that the labs have improved their flow measurement capabilities by a factor of three.

Introduction

The US Department of Defense (DOD) Calibration Coordination Group (Physical/Mechanical) asked NIST to assess the proficiency of a set of gas flow laboratories. NIST piloted a comparison among the participating laboratories to test their uncertainty specifications and capabilities using transfer standards, protocols, and calculation methods developed for international key comparisons during the past two decades by the members of the Working Group for Fluid Flow (WGFF) and the Consultative Committee for Mass and Related Quantities (CCM). An overview of the consensus comparison methodology is given in reference [1] and guidance documents and templates can be found in the CCM and WGFF web pages [2].

In 2003, NIST also piloted a gas flow comparison involving four of the same labs [3]. The gas flow standards in all of the labs have evolved significantly over those 16 years, improving in uncertainty, maintenance costs, and ease of operation. NIST automated and reduced the

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† sccm = standard cubic centimeter per minute at reference conditions of 0 °C and 101.325 kPa.
slm = standard liters per minute at the same reference conditions.

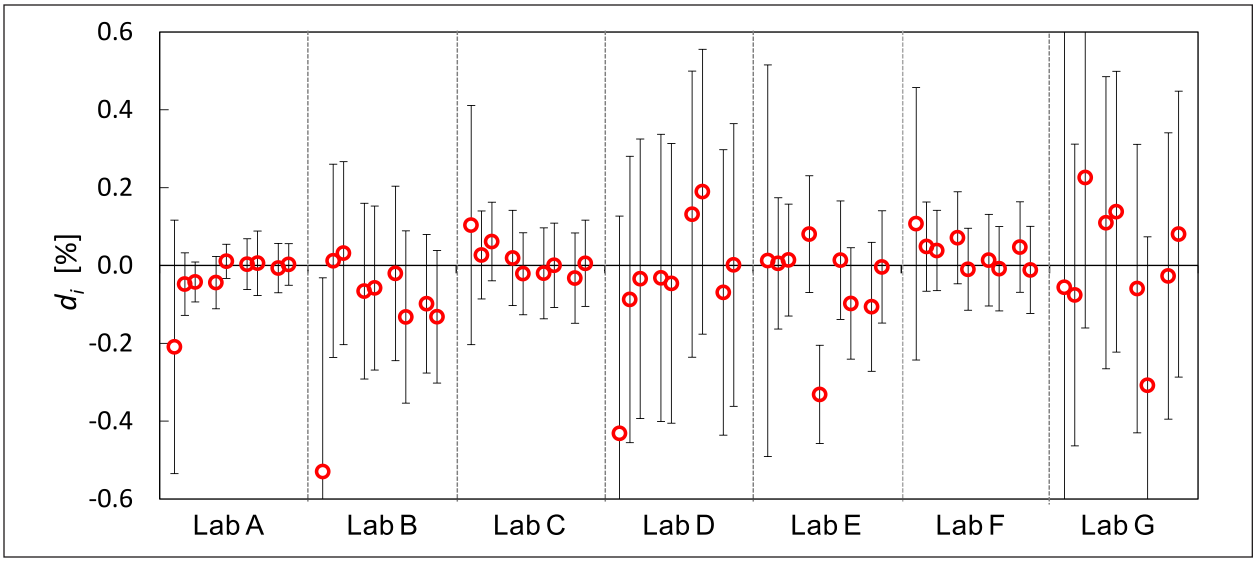

Figure 1. Degrees of equivalence for each laboratory with respect to the comparison reference value (CRV). The symbols represent the nine flow set points used in the seven participants' labs. The error bars show the expanded uncertainty of the degree of equivalence for each calibrated value. Degree of equivalence d_i is defined as the difference between each participant's result and the comparison reference value. In general, error bars crossing the d_i = 0 line indicate a comparison result within uncertainty expectations.

uncertainty of its primary standards by switching from bell and piston provers (0.19 %*) [4] to a *PVTt* standard (0.025 %) [5]. NIST's uncertainty reduction and the documented long-term calibration stability of commercially available flow meters [6] enabled the DOD Primary Standards Labs (PSLs) to send working standards (Molblocs† and critical flow venturis) to NIST for calibration and also enabled the PSLs to use the working standards to calibrate their customers' instruments. This approach is easier to maintain and operate than the piston and bell provers they used in the past but still meets DOD uncertainty goals. (Some PSLs still maintain primary standards such as piston or bell provers.) DOD secondary labs also use sets of working standard Molblocs and critical flow venturis to calibrate other flow meters.

Since 2003, the participants have also responded to their calibration customers' demands and extended their flow capabilities to lower flows: the minimum flow set point in the 2003 comparison was 40 sccm; the present minimum is 1 sccm. Flows below 10 sccm are challenging to calibrate due to leaks and temperature effects.

* Unless otherwise noted, all uncertainties are expanded, k = 2, approximately 95 % confidence level values.

† Certain commercial entities, equipment, or materials may be identified in this document in order to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that entities, materials, or equipment are necessarily the best available for the purpose.

List of Participants, Facilities Used, Circulation Scheme

The participants and the abbreviations used for their labs are given in the list of authors' affiliations on the title page of this report or in Table 1. The transfer standards circulated in a single loop between the participants between June 2018 and August 2019.

Most participants used working standard Molbloc (MB) laminar flow meters (LFMs), either directly upstream or downstream from the transfer standard. Except for the case of Fluke, the working standard MBs are traceable to NIST and/or AFMETCAL gas flow standards via periodic calibrations (dependent traceability). NIST used the 34 L *PVTt* and Rate of Rise (RoR) standards [7, 8], Fluke used their dynamic Gravimetric Flow Standard (GFS) [9], and APSL used its GFS and Constant Pressure Flow Meter (CPFM) [10]. The NIST, Fluke, and APSL standards have independent traceability to mass, time, temperature, pressure, and humidity and their data were used to calculate the comparison reference value.

Transfer Standard and Comparison Protocol

The transfer standard (TS) package included four laminar flow meters (Molbloc-L, manufactured by Fluke) with full scale flows of 10 sccm, 100 sccm, 1000 sccm, and 10 slm (Figure 2). Laminar flow meters use variations of the Hagen-Poiseuille equation to calculate flow from the gas species (in this case nitrogen), the absolute pressure

Participant	Type of reference standard	Reference flow uncertainty (*k*=2, %)	Date of test	Independent traceability?
NIST	34 L *PVTt* and RoR	0.12 to 0.025	Jun 2018	Yes
AFMETCAL	Downstream MBs	0.24 to 0.14	Aug 2018	No, to NIST/Fluke
APSL	GFS, CPFM	0.1	Sep 2018	Yes
Robins	Upstream MBs	0.35	Nov 2018	No, to AFMETCAL
NPSL	Upstream MBs	0.24 to 0.1	Feb 2019	No, to NIST
Fluke	GFS, Downstream MBs	0.2 to 0.1	Apr 2019	Yes
Tinker	Downstream MBs	0.35	Aug 2019	No, to AFMETCAL

Table 1. Participants, facilities used, reference standard uncertainty, dates of test, and traceability links between participants. See title page for explanation of acronyms.

and temperature of the flowing gas, and the differential pressure between the upstream and downstream side of a narrow flow passage. Instrumentation for pressure and temperature measurements and the flow calculation (a Molbox1+) was shipped as part of the TS to reduce uncertainties that would be introduced by using different instrumentation in each laboratory. The Molbox calculates differential pressure by subtracting absolute pressure measurements made on the downstream and upstream sides of the LFM. The comparison protocol reduced errors in the differential pressure by "taring" the two pressure sensors while flowing at each set point before collecting data. Similar instrumentation and protocols have been used successfully in other comparisons [3, 11, 12].

A control box for mass flow controllers was included with the transfer standard equipment and used to set and maintain the comparison flow set points. Accessories necessary for operating the transfer standard, e.g. pressure regulators, shut-off valves, mass flow controllers, and filters, were also included (Figure 3). The TS pressure regulator was set to 350 kPa and acceptable pressures at the outlet of the TS ranged from 90 kPa to 300 kPa. This allowed the TS to be calibrated with working standard Molblocs positioned either up or downstream of the TS. Figure 4 shows the NPSL upstream MB working standard installed in series with the transfer standard.

The nominal flow set points are listed in Table 2. Note that three of the set points (10 sccm, 100 sccm, and 1000 sccm) were measured by two LFMs, one used at 10 % of its full-scale flow, the other at 100 % of full scale. The 1 sccm set point was outside the operating range of two participants and they tested at 2 sccm instead. The slope of the error curve for the 10 sccm LFM was small enough that the measurements made at 2 sccm could be handled without correction along with the other labs' 1 sccm results without introducing significant uncertainty to the data processing.

The protocol called for 15 min stabilization time at each set point, then five, 60 s long averages were collected using the Molbox averaging capability. This was done on two different occasions. Transfer standard flow, pressure and

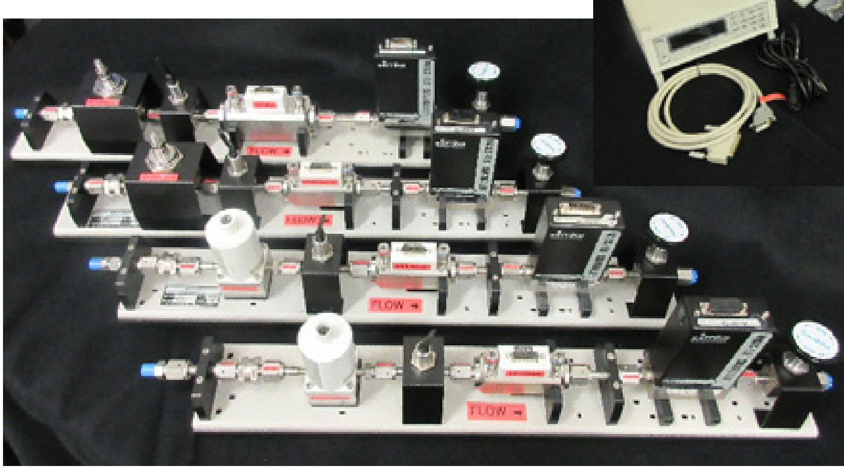

Figure 2. Pictures of the transfer standard package.

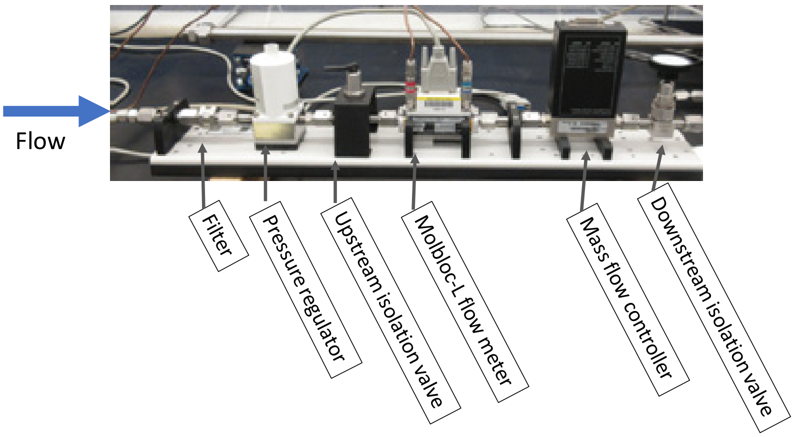

Figure 3. A picture of one of the four transfer standard laminar flow meters. The regulator and mass flow controller maintain reproducible pressure conditions at the laminar flow meter.

temperature, reference flow, and uncertainty data were reported to the pilot lab in a spreadsheet template. The data were not shared between the participants. The percent difference between the reference and the TS was calculated for each 60 s average. The resulting 10 points at each set point were averaged to deliver the data presented in this report. The standard deviation of the mean of the ten 60 s averages was used to quantify the reproducibility (Type A uncertainty) of the averages produced in each lab.

Uncertainty Due to the Transfer Standard

The uncertainty introduced by the transfer standard must be considered in a comparison because TS calibration drift or sensitivities can be mistaken for lab-to-lab differences or accidentally cause labs to seemingly agree with each other when they don't [13]. In practice, much of the work of a comparison involves characterizing the sensitivities of the TS to operating conditions so that the effects of these conditions can be corrected or treated as quantified uncertainties. For this comparison, the variables considered include gas temperature, pressure, gas composition, leaks, and the TS reproducibility.

Reproducibility: The TS uncertainty was primarily due to its long-term calibration instability, particularly at the lowest flow for each LFM (10 % of full scale) where differential pressure uncertainties have the largest effect. The calibration instability was quantified by the standard deviation of four or more calibrations made by the pilot laboratory before and after the TS was shipped between the participants. An example of the multiple calibration sets and their standard deviation at the 10 %, 50 %, and 100 %

Transfer Standard Full Scale	Low Set Point (sccm)	Medium Set Point (sccm)	High Set Point (sccm)
10 sccm	1	5	10
100 sccm	*10*	50	100
1000 sccm	*100*	500	1000
10 slm	*1000*	5000	10,000

Table 2. The flow set points used in the comparison. The italicized values were given less importance for uncertainty reasons (see text).

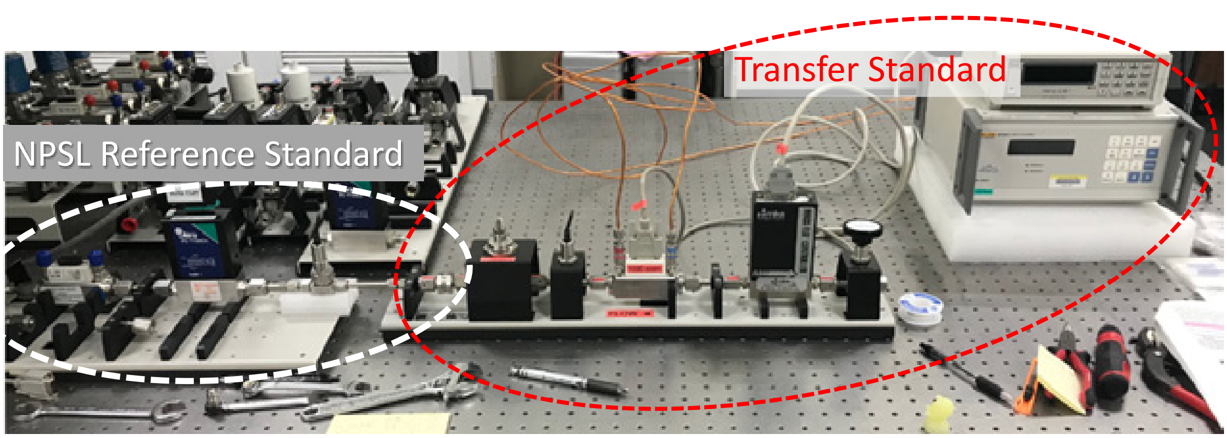

Figure 4. The transfer standard being calibrated with their NPSL upstream Molbloc working standard in February 2019.

of full-scale set points is shown in Figure 5. The Y-axis is the difference between the LFM and the NIST *PVTt* gas flow standard, ε. By design, measurements were made with two different LFMs at the 10 sccm, 100 sccm, and 1000 sccm. The larger LFM operated at 10 % of its full scale (FS); the smaller at 100 % of FS. Because the reproducibility uncertainty was smaller for the LFMs used at 100 % of FS, we focused on those measurements and only considered the 10 % FS results to study the TS performance and, if necessary, as confirmation of conclusions from the 100 % FS measurements. Of course we did not have that option at the lowest set point of the comparison (1 sccm) and accepted the larger TS uncertainty there.

Temperature: Prior research found temperature sensitivity of 0.01 % / °C for a particular Molbloc [14]. We reviewed historic NIST calibration data for several Molblocs over the lab temperature variations that occur in the NIST lab and found temperature sensitivity ranging from negligible levels to as large as 0.01 % / °C. With the exception of one participant, the LFM temperature measurements in each lab were 23.12 °C ± 1.87 °C. One participant's temperatures ranged between 17.76 °C and 21.75 °C. Based on these figures, a temperature sensitivity uncertainty of 0.02 % was assumed at 95 % confidence level.

Pressure: Each TS had a pressure regulator and mass flow controller on either side of the LFM (Figure 3). The regulators maintained consistent pressures for each flow set point, thereby minimizing pressure effects on the TS flow meters. In actuality, the pressure at the MB inlet varied between 198 kPa and 374 kPa depending on the participant and the flow set point. A review of NIST's Molbloc calibration data at various pressures led to an estimated pressure sensitivity uncertainty of 0.03 % at the 95 % confidence level.

Composition: Participants used nitrogen gas cylinders with manufacturer specified purity of 99.995 % or higher. Gas manufacturers list possible contaminants as hydrocarbons, oxygen, carbon dioxide, carbon monoxide, and water. An analysis based on the worst-case impurities determined that their effect on the gas's viscosity and density was negligible compared to other uncertainty components.

Leaks: Participants followed a leak check procedure specified in the comparison protocol. They pressurized the TS to 350 kPa between the closed isolation valves (Figure 3), tared the Molbox, and observed 60 s averages of the flow indicated by the Molbloc. The leak values they measured are listed in Table 3 as a percentage of the minimum flow set point used (50 % of the LFM full-scale except for the 10 sccm LFM). The uncertainty due to leaks attributed to the transfer standard was assumed to be 0.02 % of reading at the 95 % confidence level based on leak tests performed at the pilot lab prior to circulation. In four cases (bold font in Table 3), the leaks measured in the participants' labs were larger than 0.02 %. However, the < 0.02 % leak criterion was achieved for each LFM in several labs. This implies that the larger leaks were in the participants' setups but not in any of the transfer standards.

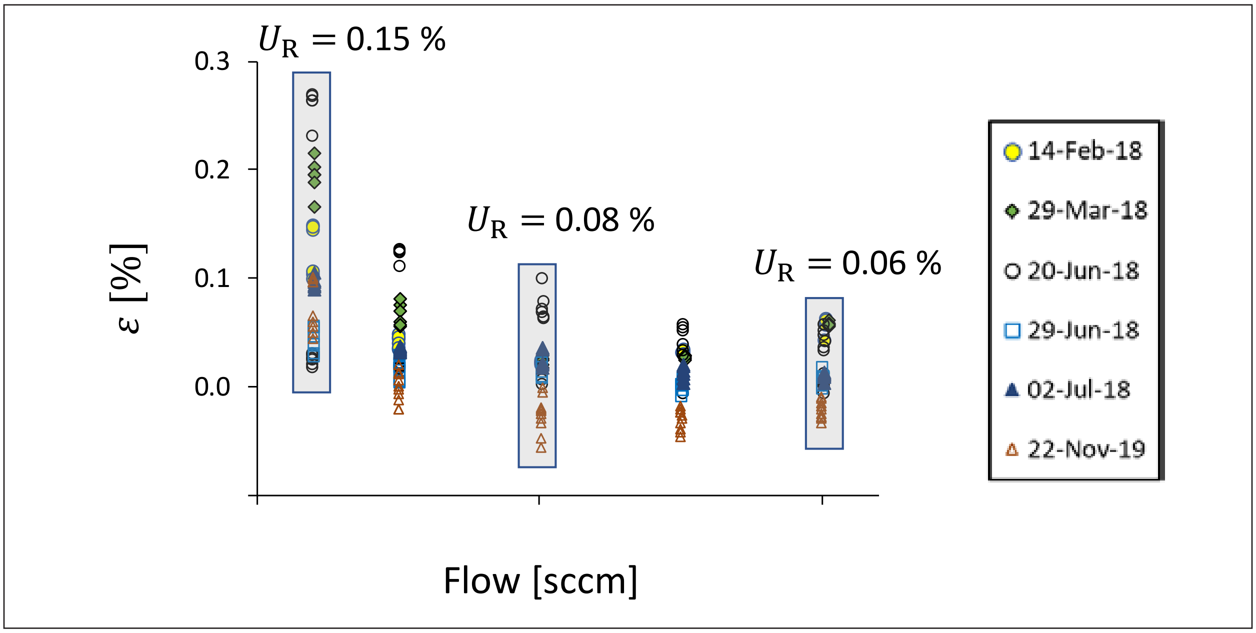

Figure 5. Six calibration data sets measured at NIST for the 10 slm LFM before and after circulation of the transfer standard. The 95 % confidence level reproducibility uncertainty was quantified by doubling the standard deviations of 4 or more calibrations of each LFM at NIST before and after circulation of the TS.

Lab	10 sccm (% of 1 sccm)	100 sccm (% of 50 sccm)	1000 sccm (% of 500 sccm)	10 slm (% of 5 slm)
A	0.020	0.004	0.004	0.004
B	0.010	-0.002	0.000	0.000
C	-0.004	**0.106**	-0.001	0.001
D	**0.050**	0.004	0.002	0.004
E	0.010	0.020	-0.002	0.000
F	0.010	0.001	0.001	0.001
G	0.010	**0.128**	0.006	**0.024**

Table 3. Leaks measured by participants as a percentage of the flow set points.

The uncertainty components for reproducibility, leaks, and temperature and pressure sensitivity were combined by root-sum-of-squares to arrive at the transfer standard uncertainty for each flow set point (U_{TS}) that ranged from 0.37 % to 0.06 %.

Data Processing and Computation of the Comparison Reference Value (CRV)

The protocol, report format, and the data processing for this comparison used templates developed during the past decade for international flow comparisons. The templates are available from NIST for others to use. The data processing followed the methods documented by Cox [15] to calculate the comparison reference value (CRV) using Procedure A (uncertainty weighted mean and χ-squared consistency test). The necessary inputs are the measurements made by the participant, the base uncertainty of the lab*, the reproducibility of the transfer standard for each lab, and the uncertainty of the transfer standard.

Four of the seven participants used reference standards with traceability to NIST or AFMETCAL, so the three labs with independent traceability (NIST, APSL, and Fluke) determined the uncertainty weighted CRV. The uncertainty weighted mean gives greater significance to labs with lower uncertainty estimates. Whether or not a participant has independent traceability impacts the calculation of the comparison reference value and the uncertainty of the degree of equivalence: dependent labs are not included in the reference value calculation because it would be analogous to including the lab that is the source of traceability more than one time in the averaging process. The χ-squared consistency test removes labs from the reference value calculation if their difference from other independent results is larger than expected for their uncertainty estimate. In this comparison, the three independent labs passed the χ-squared consistency test at all flow set points, so there was no need to remove discrepant results.

* The base uncertainty of a flow reference does not include the Type A uncertainty for the best existing device, see *WGFF Guidelines for Calibration Measurement Capabilities Uncertainty and Calibration Report Uncertainty*, October 21, 2013, https://www.bipm.org/utils/en/pdf/ccm-wgff-guidelines.pdf.

Results

The comparison results shown in Figure 1 include only the results from duplicate set points made at 100 % of the LFM full scale flow. Table 4 lists the most commonly used means of assessing comparison results, the standardized degree of equivalence for laboratory i, $E_{n,i} = d_i / U_{d_i}$, where d_i is the degree of equivalence and U_{d_i} is the uncertainty of the degree of equivalence [13]. Values of $|E_n| \leq 1$ indicate that a participant's result agrees with the comparison reference value within uncertainty expectations. The same criterion can be applied visually to Figure 1 by seeing whether or not the error bars of each participant cross the $d_i = 0$ line (which represents the CRV).

In this comparison, all results passed the $|E_n| \leq 1$ criterion except Lab B at 1 sccm and Lab E at 100 sccm. We note that because uncertainties are specified at the 95 % confidence level, we would expect 5 % of the comparison results from a proficient lab to fail the $|E_n| \leq 1$ criterion. We also considered other evidence at the set points where $|E_n|$ was greater than 1. We observe that the reference flow standards at Labs F and G are traceable to (i.e., periodically calibrated by) Lab B and Labs F and G both passed the $|E_n| \leq 1$ criterion at 1 sccm. This may indicate that Lab B's result at 1 sccm is not indicative of their typical performance. The 1 sccm set point is the most challenging measurement of this comparison because it has the highest sensitivity to possible leaks and to the transfer standard's stability. Note also that the second Lab E result at 100 sccm that used a Molbloc at 10 % of full scale (not shown in Figure 1) passed the $|E_n| \leq 1$ criterion. These factors and the large fraction of passing results over the range of flows tested lead us to believe that all of the labs are proficient.

Set Point [sccm]	Lab A	Lab B	Lab C	Lab D	Lab E	Lab F	Lab G
1	*-0.642*	**-1.063**	0.338	*-0.773*	0.024	0.306	-0.078
5	-0.597	0.048	0.237	-0.237	0.032	0.422	-0.196
10	-0.828	0.134	0.608	-0.095	0.097	0.372	0.584
50	*-0.657*	-0.293	0.157	-0.087	0.536	0.603	0.293
100	0.243	-0.276	-0.202	-0.128	**-2.628**	-0.095	0.383
500	0.050	-0.092	-0.172	0.358	0.090	0.114	-0.160
1000	0.068	-0.598	0.003	0.517	-0.682	-0.076	-0.808
5000	-0.106	-0.552	-0.280	-0.189	-0.641	0.405	-0.073
10000	0.045	-0.775	0.050	0.003	-0.027	-0.104	0.219

Table 4. Standardized degree of equivalence between a lab *i* and the key comparison reference value, $E_{n,i}$ for the set points plotted in Figure 1. Failed results have bold font, inconclusive results are in italics font.

Inconclusive Results

Members of the Working Group for Fluid Flow (WGFF) have performed over 30 international comparisons during the 21 years since its formation in 2000. The present comparison has followed the recommendations of the WGFF. Specifically, the WGFF and we recognize the importance of quantifying the uncertainty contributed by the transfer standard and including it in the analysis of comparison results. The WGFF observed that if a transfer standard has uncertainty that is large relative to the participants' uncertainties, the $|E_n| \leq 1$ criterion can give passing (or failing) results that should be deemed inconclusive. For many measurands, transfer standards with uncertainties comparable to or better than the reference standards being compared do not exist. In this situation, a comparison using the traditional $|E_n| \leq 1$ criterion, and very large transfer standard uncertainty ensures that all participants will pass, thereby completely undermining the purpose of comparisons.

To deal with the limitations of transfer standards, reference [13] proposed several new approaches that assess comparison results as passing, failing, or inconclusive (instead of only passing or failing) and those approaches were applied to this comparison. "Criterion B" in reference [13] considers the $|E_n| \leq 1$ assessment conclusive if the ratio of TS uncertainty U_{TS} to the participant's base uncertainty is 2 or less. For the results shown in Figure 1, $U_{TS} / U_{base,i} <$ 1.84 except for Lab A and Lab C where it is as large as 3.7. Eight of the 63 entries in Table 4 are inconclusive according to Criterion B. "Criterion D" applies a probability-based approach that finds three results in Table 4 inconclusive: Lab A at 1 sccm and 50 sccm and Lab D at 1 sccm. Labelling these results inconclusive indicates that we should not rely on them to assess the participant's proficiency because of the uncertainty of the comparison process.

Youden Analysis

The measurements made with two different LFMs at 10 sccm, 100 sccm, and 1000 sccm are statistically independent and can be used to generate Youden plots where the degrees of equivalence from one LFM (at 10 % full scale, d_{10i}) are plotted on the x-axis and those from the other LFM (at 100 % of full scale, d_{100i}) on the y-axis. The point (0, 0) corresponds to the comparison reference value and the distance along the diagonal line indicates the difference between the lab and the CRV. A point falling on the diagonal line indicates that a consistent degree of equivalence for that lab was measured by both LFMs. The distance away from the diagonal line is a measure of the randomness of the entire comparison process (due to either or both the reference and transfer standards).

A similar NIST piloted comparison with four of the same participants as this comparison was conducted with a different set of Molblocs between March 2002 and September 2003. The improvement in the reference standards during the past 16 years is apparent in Figure 6. This "comparison of the comparisons" is a Youden plot for the 1000 sccm set point showing only the four common participants. In the 2003 comparison the point at (0, 0) is NIST's result; in 2019, the point at (0, 0) is the uncertainty weighted mean of independent participants. In 2003, the lab farthest from (0,0) was located at (-0.43 %, -0.37 %); in 2019, it is (-0.15 %, -0.13 %), a nearly three-fold improvement in agreement. The average of the degrees of equivalence for these four labs has dropped from -0.14 % to -0.04 %, a more than three-fold improvement. The error bars on the data points represent the standard deviation of the data collected in the participating labs; they show the irreproducibility of the reference and transfer standards. For many of the labs, the error bars for the 2019 comparison have improved and are too small to be visible in this plot.

Summary and Conclusions

We conducted a comparison of seven gas flow calibration laboratories using four Molbloc laminar flow meters that circulated between the labs from June 2018 to August 2019. The range of flows was 1 sccm to 10 slm. The uncertainty components for the TS included pressure and temperature sensitivity, gas purity, leaks, and the long-term calibration stability measured in the pilot lab. To minimize the effects of the transfer standard's uncertainty, the comparison used measurements made at 50 % and 100 % of the transfer standards' full scale (except at the smallest flow set point of 1 sccm). The 95 % confidence level uncertainty of the transfer standard was 0.37 % at the lowest flow and was as small as 0.06 % at the TS full scale flows.

The protocol, spreadsheets for sending data to the pilot lab and performing the comparison calculations, and the format of the comparison report followed templates developed for comparisons between national metrology institutes organized by the Working Group for Fluid Flow and the Consultative Committee for Mass under the guidance of the International Bureau of Weights and Measures (Bureau International des Poids et Mesures). These templates improved the efficiency of the comparison and reduced errors in calculations. These templates are available through the references [2] or directly from the corresponding author of this paper.

The comparison showed agreement between the participants within uncertainty expectations and demonstrated proficiency over the tested range for all participants. The $|E_n| \leq 1$ criterion determined that 2 of the 63 cases were outside of uncertainty expectations. The probability-based criterion from reference [13] also determined that 2 of the 63 cases were outside of uncertainty expectations and 3 cases were inconclusive. None of the > 0.02 % leak values in bold font in Table 3 correlate with the two comparison results that had $|E_n| > 1$.

Upon comparing these results to a similar comparison performed in 2003, we conclude that the improvements to the methods during the past 16 years have improved agreement between the four shared participants by a factor of 3 or more while also reducing maintenance costs in the DOD labs.

Acknowledgements: The financial support for this study by the Department of Defense Physical/Mechanical Calibration Coordination Group under Project Number 679 is gratefully acknowledged.

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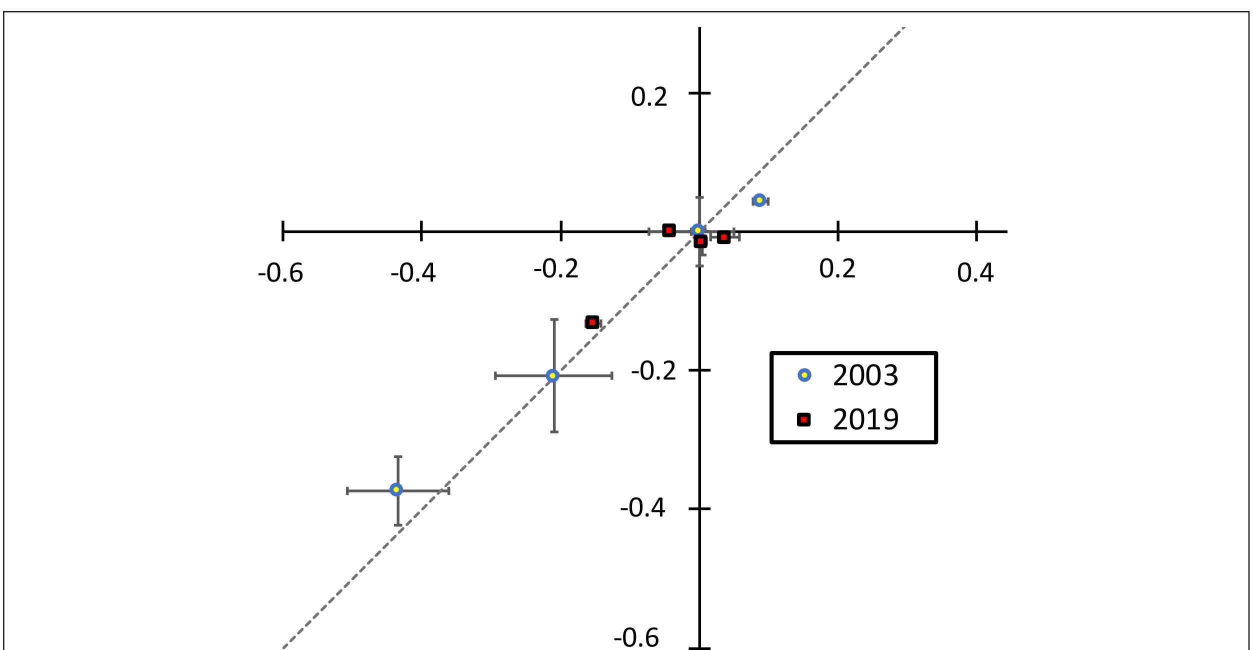

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Maintaining a Calibration Management Software System in a Regulated Environment

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Maintaining a Calibration Management Software System is a critical process for a calibration laboratory, especially in a bio-medical regulated environment. However, there are few examples or documents that explain this process from a user's perspective. The objective of this paper is to explain the software system maintenance process, provide examples of the documentation used, and to pass along lessons that were learned. The following topics will be discussed: Maintenance Process Overview, Change Control, Configuration Management, and System Operation. The Maintenance Process is the longest running phase of the System Development Life Cycle (SDLC) and therefore requires careful planning, design, and documented procedures. It is the intent of this paper to help users more effectively maintain their Calibration Management Software System.

Background

In a preceding paper, "Selecting a Calibration Management Software System in a Regulated Environment," we discussed how as Microsoft kept updating their Windows Operating System with less compatibility with DOS, it became increasingly clear that we were at risk in continuing to use a custom-designed Calibration Management Software System written in Paradox DOS [1].

In the earlier paper, we also highlighted that the most important aspect of selecting a calibration management software system was in identifying your business requirements as it pertains to your software system needs. We ended up using the business requirements list throughout the selection process and it was the key to our project success [2].

In the second paper, "Implementing a Calibration Management Software System in a Regulated Environment," we introduced the concept of System Development Life Cycle (SDLC) and described the seven phases: planning, analysis and requirements, design, development, testing, implementation, and maintenance [3]. This paper will focus on the last phase of SDLC, which is the maintenance phase.

In regulated industries, software system maintenance is considered a critical process. Therefore, it will require careful planning, detailed documentation, and identifying specific roles and training to successfully use the software system in an operational work environment.

Due to regulatory focus on software systems, bio-medical companies will have dedicated policies and procedures targeted at maintaining software systems. My previous company, Medtronic PLC, had a System Development and Validation Lifecycle process which helped us maintain our Calibration Management Software System for over 17 years after implementation. Many bio-medical companies will have a high-level IT policy on how to manage software systems in a regulatory compliant state. It is the intent of this paper to give in-sights into lessons learned from years of experience specifically operating a calibration software system to company and regulatory requirements, in addition to providing recommendations on how to incorporate risk-based approach methods to improve system effectiveness.

Assumptions

We have identified several assumptions for you to consider when using recommendations in this paper:

- There is no one standard approach to maintaining software systems. We will share our examples and lesson learned as well as new insights.
- Our process was scaled to support a large equipment database with a complex workflow. Your process may be less complex and therefore can use a sub-set of these recommendations.
- These recommendations can be used outside of the bio-medical industry according to your own business requirements.

Figure 1. Maintenance Lifecyle of a Software System.*

The Maintenance Lifecyle of a Software System

The software system maintenance process we used is illustrated in Figure 1. There were three main processes: (1) Change Management, (2) Configuration Management, and (3) System Operation. This process was further harmonized from several input sources: (a) Medtronic SDVLC [5], (b) general SDVC processes [6],[7], and (c) GAMP 5: *A Risk-Based Approach to Compliant GxP Computerized Systems* [8].

Change Management

The purpose of the change management process is to ensure that the calibration management software system is maintained in a constant state of operational readiness for the compliant and validated intended use. This activity is performed using a formal change control process (configuration management) that documents all changes made to software, hardware, and infrastructure of the software system. Change management process is comprised of these types of changes:

- System Administration
- Updates and Patches
- Repairs
- Improvements
- Backup and Restore

* Free SVG (clipart). https://freesvg.org. 2019-2020.

New Learnings: In reviewing GAMP 5, this is an area that can benefit from a risk-based approach to ensure that change documentation is scaled to the nature, risk, and complexity of the change.

System Administration

System administration is the process of providing dedicated administrative support for the calibration management software system. This role is traditionally identified as a System Administrator who is trained in IT principles and methods. The System Administrator can be assigned to the owning database department or can be within the company's IT reporting structure and assigned to supporting the software system as well as other systems. Some of the standard tasks are identified below and should be identified in local standard operating procedures (SOPs) on how to maintain the calibration management software system. These tasks should be classified as administrative in nature and not requiring change control documentation based on a low-level risk assessment.

Standard tasks:

- Setting up new employee accounts and training
- Resetting user passwords
- Responding to customer and employee requests
- Updating user accounts
- Running and monitoring standard reports
- Responding to incident reports
- Interfacing with company IT and software supplier as needed
- Provide software records for audits
- Uploading system administrative database records

Lessons Learned: For larger software systems it is recommended that the System Administrator be assigned to the owning department. For smaller software systems, the System Administrator can be assigned to the company's IT department and support multiple systems.

New Learnings: The United States Food and Drug Administration (FDA) will soon be transitioning from a traditional Computer System Validation approach to a new Computer Software Assurance approach [9]. In the new approach, a calibration management software system would be classified as an "indirect system" as it does not directly impact product quality and patient safety. As such, unscripted tests can be used for lower risk attributes. Unscripted tests do not require detailed test scripts; no step-by-step test procedure. Instead, the tests can be assigned a test objective and have a "pass or fail" test result. The FDA objective is to lower the documentation burden by 80% and change from a compliance-centric culture to a quality-centric one. This is advancing GAMP 5 concept of taking a more risk-based approach and for increasing the use of supplier's testing data and not duplicating their validation efforts.

Updates and Patches

Updates and patches are provided by the supplier of the calibration management software system on a scheduled or unscheduled basis. Scheduled updates are performed to make improvements to the software from feedback received from customers and from feedback on software company learnings. Unscheduled updates are performed to take more immediate action to resolve a security or high-risk quality software requirement. Your local IT SOP should classify these categories of updates and assign a risk-based approach to implementing the update and patch. Change records should be sufficient to show the current release level when updates have been applied.

GAMP 5 does a nice job of defining a risk-based approach in Management Appendix M3 Science Based Quality Risk Management [8]. The risk assessment is based on two scales of probability/severity and detectability/risk class. Your level of testing and change management can be aligned to the appropriate risk-level assigned.

- Probability: Likelihood of the fault occurring assessed at low, medium, and high.
  - Severity: Impact on patient safety, product quality, and data integrity assessed at low, medium, and high.
- Detectability: Likelihood that the fault will be noted before harm occurs assessed at low, medium, and high.
  - Risk class: Severity times probability and assigned a class rating of 1, 2, or 3 level.

Lessons Learned: We assigned every Update/Patch at the same risk-level which required a complete software validation. As a result, we did not update our software for each supplier release. Based on learnings from GAMP 5 and from the new FDA Computer Software Assurance, we would assign risk-levels for each Update and then perform change management appropriate to the risk. We could then more frequently update the software system and take more frequent advantage of new features and improvements which is the objective of the FDA.

Repairs

Repair activities can be with the software, hardware, or supporting configured applications. The repair process takes a more simplified change control route as the specifications are not changing. These changes are classified as "like for like" replacement with test verification activities appropriate to the low-level of risk; e.g., unscripted tests. Higher level of risk repairs can feed into the Incident Reporting process.

Improvements

Continuous improvement to the Calibration Management Software System is an important activity to ensure that the system is maintained to released specifications for compliance, quality, and operational readiness. Improvement activities are outputs of System Operations such as performance monitoring, incident management, CAPAs, periodic reviews, etc.

One of the keys to successful change management is to ensure that valuable changes are made without compromising regulated processes and with minimum disruption to system operation. Improvement activities should be prioritized based on requirement needs and assessed on a risk-based approach method. Where needed, user training should be updated and delivered as part of any improvement activity.

Backup and Restore

Backup and restore activities should not be confused with the archiving and retrieval record process. Backup is the process of protecting original documents and records and software by making copies of them in a separate location. Restore is the succeeding process of returning backup copies of records, data, or software that may have been compromised.

Typically, an organization's IT department will help work with the owning software system department to develop a strategy, define procedures, and monitor the backup process to ensure that the calibration management software system can be restored to any previous original record status in the event of a compromised record. A backup strategy usually is comprised of a daily, weekly, monthly, quarterly, and annual frequency. A test of the backup and restore process should be performed on a periodic basis to ensure that the process is functional and will work when needed on an unscheduled basis. A successful backup and restore process needs to be designed, tested, and implemented as part of the calibration management software system validation (installation qualification).

Configuration Management

Configuration management and change management work hand-in-hand to ensure that any change to the configuration of the calibration management software system is traceable through documentation to determine at any point in time the system requirements state in respects to the how, what, where, when, and why. Configuration management begins at the hand-over from implementation to the retirement of the computer system. The four main activities within configuration management are: version control, change control, configuration item storage, and delivery control.

Version Control

For each calibration management software system configurable item (hardware, software, and applications), a unique name and the current version number should be documented. This will meet the regulatory requirement to ensure the traceability of the current configured validated and verified state of the calibration management software system. Besides the benefit for regulatory compliance, tracking version and revision levels of configurable items will assist in the recreation of the computer system for recovery from corrupted data, records, or software. Tracing version and revision levels for computer system configurable items should also be performed when the software supplier performs the changes. See Figure 2 for example of using version control data fields in a change control record (see blue highlighted section).

Change Control

Change control is the most important aspect for managing your calibration management software system. Change control incorporates the aspects of describing the change, documenting and justifying the change, evaluating risks and impact of the change to the configured computer system, accepting or rejecting the change request, developing and verifying the change, and approving and implementing the change. See Figure 2 for an example of a change control request form.

The form example is comprised of four elements:

- Change Request Information
- Change Request Review
- Change Details
- Change Request Completion and Approval

Some comments regarding the form example. First, in this example there will be a need for a separate form to document the testing plan and test results for the change. Or it can be just additional parts of the original change control request form. Each way has its own advantages and disadvantages. Second, priority levels will normally be defined in an SOP or policy level document. Same for the correlation of the Risk Class Levels to the Testing Methods selected for the change. And third, testing results that are accepted with any deviation or accepted deficiency should be well described and provided with supporting rationale. This can either be in the testing form itself or in the change control request form.

<u>Lessons Learned:</u> Our change control templates went through periods of updates to incorporate feedback from internal and external audits. It may be worthwhile to perform periodic reviews of change records for any gaps to current regulatory changes or best practices.

CHANGE REQUEST		
Requestor:	Computer System:	Date:
Proposed Change Description:		
Change Reason/Rationale:		
Priority Level:	☐ Critical ☐ Urgent	☐ Routine
CHANGE REQUEST REVIEW		
Change Approval Status:	☐ Accepted	☐ Rejected Reason:
Event Configured:	Current Revision Level:	New Revision Level:
Risk Assessment Classification:	Comments:	Testing Method:
☐ Risk Class 1 – High ☐ Risk Class 2 – Medium ☐ Risk Class 3 – Low		☐ Scripted ☐ Unscripted ☐ Administrative
System Admin Name:	Signature:	Date:
Manager/Supervisor Name:	Signature:	Date:
CHANGE DETAILS		
Summary of Testing Results:		
☐ Fully Passed	☐ Limited Pass – With Accepted Deviation	☐ Failed – Change Not Made
Testing Comments:		
CHANGE REQUEST COMPLETION AND APPROVAL		
Completed By Name:	Signature:	Date:
Approved By Name:	Signature:	Date:

Figure 2. Configuration Management Change Control Form Example.

Storage

Storage considerations are not only for the change control documents but also for the actual configured item. Storage considerations whether for documents or configured items need to ensure that the changes will be protected from alterations that are unintended or intended. For software configured changes, robust calibration management software systems will provide both security level access management and revision control level identification within the configured items such as a calibration workflow event.

Delivery

Changes that have been verified and approved need to be released to the operational state of the calibration management software system. A best practice method for releasing changes to production is by having two different server locations (these different locations can either be physical or virtual within the server architecture.) One server is designated as a test server where the changes can be designed, planned, and tested. And when ready to be released, migrated to the production server. This change release method for computer systems is typically managed by the organization's IT department.

System Operation

In comparison to computer system validation, we tend to think that computer system operation is a simpler process. Yet, in both complexity and time, computer system operation will take more resources to support the system as the system can stay operational for many years. And as far as complexity, there are many aspects to computer system operation to contend with along the lines of number of people interfacing with the system and the number of roles and skill set needed to sustain operations. Some of the operations to be defined are support services, performing monitoring, incident reporting with CAPA, periodic review, business continuity, security, archiving and retrieval, and retirement.

Support Services

Most calibration management software systems are purchased from outside suppliers and as such will need some level of supplier support during the operations of the software system. A formal supplier agreement should be performed that documents the two main focus areas for operational support: incident reporting with priority commitment and upgrades.

The supplier agreement should detail the process to report software deficiencies and the priority level for response commitments. For example, there can be three levels of priority from routine, urgent, to critical along with a response level commitment such as routine response in five days, urgent response in three days, and critical response in one day.

The supplier agreement should detail what is part of the annual supplier maintenance agreement which will include at what cost and timing software updates can take place. Additionally, the time and cost expectations for other type of requests such as creating reports, customizing workflows, implementing new hardware interfaces, etc.

Once a supplier agreement is in place, there should be a periodic review or audit of the supplier to ensure that all contract terms are still in place and committed to and that the supplier is still in a state of compliance and healthy financial and organizational readiness.

Performance Monitoring

Performance monitoring is an often-neglected part of the overall operations of software systems. Performance monitoring is intended to collect data of key software system activities that can then be used to identify potential issues. Performance monitoring can be used as inputs into other operational aspects of calibration management software systems such as periodic reviews, incident reporting and CAPAs, and change management. See Figure 3 for an example of a performance monitoring program. The key aspects of the monitoring are to identify trigger levels that will identify when an action is required and to identify what that action will be.

Lesson Learned: We did not have a formally established performance monitoring plan. If we did, we would have discovered issues before they impacted the operations of the calibration management software system. Another aspect of the monitoring plan is to design workflow alarm triggers that identify when a critical workflow data field is missing when other configuration designs cannot program this functionality into the workflow itself; e.g., PM schedule missing though checked off on the equipment input form as being required. Essentially, designing in error detection alarms.

Incident Reporting and CAPA

Incident reporting is a formal process that allows users to identify an issue with the calibration management software system. The incident report is then reviewed to determine a course of action. This action should be based on a documented process that assigns risk-levels to categories of incidents. Actions can take several forms: assign a priority level for the repair workflow, open a Corrective Action/ Preventative Action (CAPA) record due to a high-risk level assessment, or contact the software system supplier for correction design assistance. A CAPA process is used by bio-medical companies to escalate critical issues into a formal process that will ensure a robust investigation, plan, correction, and effectiveness actions are taken and documented.

PERFORMANCE MONITORING			
ACTIVITY	ACTION LIMIT	MONITORING FREQUENCY	ACTION
Password Reset Request	Individual = 3 times Group = 10 times	Quarterly	Retraining
User Request to Correct Events	Individual = 3 times Group = 10 times	Quarterly	Retraining Review Workflows
Number of Concurrent Users	>90% of Licenses	Quarterly	Review Adequate Number of Licenses
Instances of Unavailable Licenses	>3 instances	Monthly	Review Adequate Number of Licenses
System Alarm Messages	Individual = 3 times Group = 10 times	Quarterly	Retraining Review Workflows

Figure 3. Performance Monitoring Example.

Periodic Review

There should be a formal process that defines what activities will be performed to do a periodic review of the effectiveness of the calibration management software system for its designed intended purpose to meet organizational quality, compliance, and regulatory requirements. The periodic review can include other aspects of the system operations, such as reviewing the incident reporting and CAPA log records, reviewing the performance monitoring data for trends, and reviewing recent change control records.

Essentially, a periodic review process is like performing an audit of the calibration management software system operations. This gap assessment can discover any systemic deficiencies that can then be entered into the incident reporting process for action.

Business Continuity

The objective of business continuity is to ensure that there is a formal plan in place that will be able to effectively recover the calibration management software system in the event of complete system failure. Often termed a "disaster recovery plan," it is typically managed by the IT organization and comprises such topics as: location of backup records and databases, manual processes during shutdowns, and identification of critical talent.

In light of today's challenges with software system hackers, ransomware attacks, and rising climate disasters such as hurricanes, forest fires, etc., disaster recovery planning should take a very high priority.

Lessons Learned: One segment of our company lost its enterprise system for many days and this shutdown impacted many operational systems including the ability to deliver product. However, our calibration management software was not connected to the enterprise system and we were still operating our calibration laboratory as normal. Lesson learned for the business, be careful about the concept of having every part of the operations on one system. Since this painful experience, the company has taken a new look into its system architecture.

Security

As you can readily understand, security management is the most import aspect of operation integrity for calibration management software systems. Therefore, equally important is selecting a calibration management software system that has a robust security management application. This should be one of the critical requirements for the business when purchasing a new calibration management software system.

One effective way to ensure a secure calibration management software system is to establish different levels of security profiles within the database. For example, you could setup the following security level roles; from higher level database access to lower level, more restricted access:

- System Administrator. Identify a primary role and secondary, backup role.
- Power User. Assigned to Managers and Supervisors.
- Standard User. Assigned to technicians, engineers, etc.
- Admin User. Assigned to entry-level administration roles.
- Client User. Assigned to employees outside of the calibration laboratory for equipment records access.

Another feature of robust security management applications is to further refine security profiles by a variety of database fields and functionality access. This checking and unchecking of feature sets can focus on just the level of access any security profile and role is needed. This level of detail greatly reduces process errors and improves standard level of work expectations.

For bio-medical companies, an important aspect to security management of calibration management software systems is adherence to 21 CFR Part 11-Electronic Records; Electronic Signatures [10]. A robust security management application will help ensure that electronic records and electronic signatures are controlled, unique, and traceable for any changes. Additionally, the security management application will ensure that passwords are kept up-to-date through rigorous password aging methods and that passwords are uniquely assigned to each individual database user and sufficiently controlled to prevent unauthorized use.

Archiving and Retrieval

An important regulatory compliance aspect for control of electronic records stored in calibration management software systems is the concept of a retention period. Typically, a retention period in the bio-medical industry is very, very long. For medical devices for example, it is usually for the life of the product plus additional years. Too long to consider that a record can be removed from a database and not controlled.

When we converted from our custom-built database to a custom commercial off-the-shelf database, we made the conscious decision to transfer all existing equipment records into the new equipment database. This added significant documentation, time, and resources to the project, but it was well worth it as we had over 500,000 records for trending and for meeting any regulatory compliance requirements. In fact, early in the life of the new equipment database, we were asked by our legal department for equipment records from the time of the previous database. We were able to respond to the request in a very timely manner. Additionally, we did not have the burden of having to maintain the previous database in a working condition which becomes more and more difficult as the years go by.

Another purposeful decision we made was to not allow any equipment record to be archived off of the new equipment database. Again, this made record control easier to manage. We did configure an innovative way to manage equipment records that were not as useful and to help customers reduce unnecessary records for present work. We did this by allowing records to be "archived" away from the current department and into a newly designated department solely for the purpose of holding outdated equipment records. In this way, the database still contained the record, but not in the current department. This method helped us manage equipment inventory in an easier way for our customers.

Retirement

Retirement of a calibration management software system is a planned event which needs to be documented as part of configuration management. The simplest retirement is one where the database records are converted to the new database. If the database records are not converted, then the "retired" database needs to have plans put into place which ensures that the previous database is kept in working order for any need to "retrieve" previous records for the required retention period.

Summary

We tend to think that once we have selected and implemented a new calibration management software system, that the hardest work is behind us. This may be true in some respects, but because a software system can remain operational for many years, the operational lifecycle becomes increasingly more important and critical.

Therefore, it is a good practice to have a well-defined plan to manage the new database in an operational state. This plan should be comprised of the three main components of change control, configuration management, and system operations. Defining roles, providing training, and establishing policies and procedures will ensure that the calibration management software system will remain operational for its intended purpose to meet organizational quality, compliance, and regulatory requirements.

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Measurement Data in IoT Networks

New PTB service for the metrological validation of digital data

PTB News 2.2021 — PTB offers users from industry a new service. It can now validate whether measurement data that are transmitted within IoT networks comply with essential metrological requirements. For this purpose, PTB's TraCIM service, which has already been established for many years, has been enhanced.

Measurement data that are used in Industry 4.0 and in IoT networks must be error-free and unambiguous for both people and machines alike. Digital applications such as those used in healthcare or for domestic meters would be absolutely unimaginable if the data formats used were not reliable. To this end, PTB, together with partners from metrology, industry and research, is developing digital approaches to deal with measurement data. A basis for exchanging metrological data has therefore been created within the scope of the SmartCom European EMPIR project entitled "Communication and validation of smart data in IoT networks." This includes the digital system of units (D-SI), a data model for the SI-based, machine-interpretable communication of measurement data and measuring instrument data. It was developed to establish the SI as a link between different systems in such a way that the units used for a machine are always automatically SI units. SmartCom DCC is the name of the digital calibration certificate that complies with these requirements.

By means of PTB's new validation server, it is now possible to check whether these measurement data also comply with the fundamental metrological requirements of the International System of Units (SI), the International Vocabulary of Metrology (VIM), and the Guide to the Expression of Uncertainty in Measurement (GUM) during and after being transmitted within IoT networks.

The validation server has existed for a number of years under the name of TraCIM (traceability for computationally intensive metrology) and was first used to analyze evaluation algorithms used in coordinate metrology. The server was extended step by step and has now been equipped with a new module for the validation of the new SI-based formats.

For the validation service to be applied, all data must be made available in XML, in accordance with the D-SI format, for instance, in a SmartCom DCC. After uploading the data or DCCs, the server assesses the SI units used and checks the completeness of all the metrological information. A test certificate is generated automatically. It shows the quality class achieved: PLATINUM (all units are SI base units); GOLD (SI units with a prefix or units derived from the SI with their own symbol); SILVER (permitted non-SI units); BRONZE (units that were removed from the SI after its revision in 2019); and IMPROVABLE (e.g. data without units). This new PTB service is aimed, in particular, at clients from industry.

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Website of PTB's TraCIM Server II: https://smartcom-tracim.ptb.de/tracim-server-2.0/

User manual of the new service: Traceability for computationally-intensive metrology – Test for communication interfaces used for the exchange of metrological data. doi.org.10.5281/zenodo.3953555

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

Force Calibration eBook Now Available

Ensure repeatable results through the entire measurement chain

York, Pa, July 28, 2021: Morehouse Instrument Company, Inc. is excited to announce our new eBook, *Force Calibration for Technicians and Quality Managers: Top Conditions, Methods, and Systems that Impact Force Calibration Results*, written by Henry Zumbrun.

Since force calibration is mechanical in nature, there are many factors to consider. This eBook introduces basic topics of force calibration, the methods and instruments used, industry standards, and best practices. It provides guidance on factors that ensure repeatable results through the entire measurement chain.

For force-measuring devices, there are various mechanical and electrical interfaces that matter. At the time of calibration, these consist of:

- Selecting the right calibration method
- The loading conditions
- Adapters
- Verification of the adjustments
- Meters

This project has been in the making for a decade and is backed by over a century of experience on the topic. The eBook is available for $3.99 through Amazon at https://amzn.to/3jLMnVV. To learn more about Morehouse Instrument Company, visit our website at www.mhforce.com

Morehouse Instrument Company: At Morehouse we create a safer world by helping our customers make better force and torque measurements. We believe in changing how people think about force and torque calibration. We challenge the "just calibrate it" mentality by educating our customers on what matters, what causes significant errors, and focus on reducing them. Morehouse makes simple to use calibration products. We build fantastic force equipment that is plumb, level, square, rigid, and provide unparalleled calibration service with less than two-week lead times.

Force Calibration eBook on Amazon

Meatest 9010 Multifunction Calibrator

Brno, July 27, 2021 – Meatest, European maker of electrical calibrators launches sales of 9010 Multifunction Calibrator – first calibrator from new generation of 9000 series multi-product calibrators. Compared with previous M140 series, 9000 series comes with more functions to calibrate not just the usual workload like multimeters, clamp meters and power meters but also oscilloscopes, power analysers, insulation testers, transducers and many more. 9010 Multifunction Calibrator offers the following functions:

- DC/AC Voltage (35 ppm, 15 Hz – 300 kHz)
- DC/AC Current (150 ppm, 1000 A current coil)
- DC/AC Power & Energy (phase shift, harmonic distortion, dual output)
- Resistance (fixed, variable, high-voltage)
- Capacitance (fixed, variable)
- Scope calibration (400 MHz HF mode, 200 V LF mode, impedance meas.)
- Temperature source & measurement (RTD, TC)
- Process signal measurement (10 V, 4-20 mA, resistance, frequency)

Precision calibration equipment tends to be sensitive and repairs caused by unintentional damage can be costly. Meatest addressed this issue in 9010 calibrator by extensive terminal protection and modular block design. Protective elements are placed close to terminals so that reference circuits stay shielded from most external shocks and all damage is limited to inexpensive peripheral circuits. Damage that spreads beyond peripheries in case of extreme output overload can be quickly fixed by replacement of specific reference module with internal calibration data within 9000 series calibrator, reducing downtime to a minimum.

Software drivers and calibration procedures are available for popular metrology software solutions including Caliber, Metrology.NET and MET/CAL, making it easier to include 9010 into existing laboratory work environments. Furthermore, comprehensive remote control manual and variety of PC interfaces allow 9010's users to set up customized, fully automated test systems for online checks on metering equipment production lines.

"More multi-product calibrators are under development to complete the 9000 series with an entry-level calibrator of 3 – 4½ digit multimeters and high-precision calibrator of modern day 6½ digit multimeters." says Filip Kessner, Meatest's sales manager. "With wide range of calibrators and 2-5 year warranty plans we have the right solution for every calibration lab." Learn more about 9010's functions and parameters on: https://www.meatest.com/products-9010-multifunction-calibrator-detail-3990

Additel's New 226 and 227 Multifunctional Process Calibrator Series

Additel's new Multi-functional Process Calibrator series takes portability, functionality, and accuracy to a whole new level and packages it with an intuitive and easy to use color touchscreen display. The ADT226 is a powerful yet cost effective process calibrator, which is available in an ATEX certified intrinsically safe version - ADT226Ex allowing you to perform calibration work in the harshest of environments. While the ADT227 series includes an advanced documenting pressure calibrator (ADT227) and an advanced documentation process calibrator with a built-in HART communicator (ADT227-HART) and is also available in an ATEX certified intrinsically safe options (ADT227Ex).

Additel's 226 Calibrator provides an electrical accuracy of 0.015% RDG + 0.005% FS and many great features, such as a built-in barometer, dual channel pressure module ports, high-static differential pressure mode with accuracy to 0.002% FS, Wi-Fi, USB & Bluetooth communications. The ADT227 Calibrator provides all the same great features with an improved electrical accuracy of 0.005% RDG + 0.005% FS. The ADT227 also adds a full HART communicator, automated task management, datalogging capability and many other time saving features. The ADT226, ADT226Ex, ADT227 & ADT227Ex all come with an easy-to-use color touchscreen display which can be clearly viewed indoors or outdoors.

Product Availability

The Additel Multifunctional Documenting Process Calibrators are available now. For more information, please visit www.additel.com. For information about other Additel products and applications, or to find the location of your nearest distributor, contact Additel corporation, 2900 Saturn Drive, #B, Brea, CA 92821, call 1-714-998-6899, Fax 714-998-6999, email sales@additel.com or visit the Additel website at www.additel.com

About Additel

Additel Corporation is one of the leading worldwide providers of process calibration tools. Additel Corporation is dedicated to the design and manufacture of high-quality handheld test tools and portable calibrators for process industries in precision pressure calibration and test instrumentation. With more than 18 years in the industry, Additel has successfully developed Dry Well Calibrators, Thermometer Readouts, Pressure Controllers, Portable Automated Pressure Calibrators, handheld Digital Pressure Calibrators, Documenting Process Calibrators, Multifunction Process Calibrators, Digital Pressure Gauges, and various Calibration and Test Pumps.

Explain It

Michael Schwartz
Cal Lab Solutions, Inc.

Recently, I was asked to explain Metrology.NET®, usually an easy task, so I thought. What is it that Metrology.NET does, without comparing it to a completely different software product. And, I was asked to explain it in terms a non-programmer/non-metrologist could easily understand.

So, for the past few weeks, I have been racking my brains thinking of a way to explain software without talking about software like a typical programming nerd; putting it into words and concepts everyone can understand. For me, this is not an easy task!

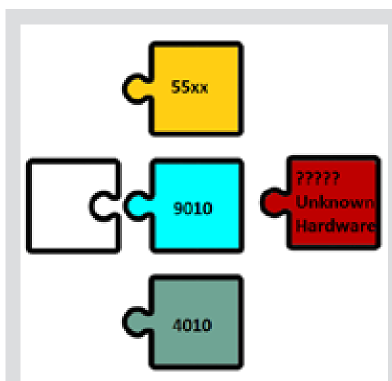
Then I remembered a technical paper I was going to write for the 2020 MSC Training Symposium and later recorded for the NCSLI Technical Exchange.*

The topic was on "Model Driven Software Engineering." Yes, it has software in the title, but the idea is a carry over from Model Driven Engineering, something engineers have been working on since the beginning of Industry 2.0.

The idea is simple, and it all falls around the idea of interchangeable parts, the cornerstone of modern industry and manufacturing. Back in the 1800s, manufacturing was one-off; a company would make products that were sized to fit that product. Rather than build to a specification, if something didn't fit, it would be shaved or filed down to fit. This made each item and its parts unique in size.

If you watch This Old House, or have ever been in a turn of the century kitchen, you will notice the cabinets were built for that specific house. They were most likely built on-site to the exact measurements of the kitchen. It was truly a custom fit!

The transition to Industry 2.0 moved production into assembly lines. This required that each part be built to an exacting specification so that it fit into place when the item rolled down the production line. Cabinets today are built to a specification, the lower kitchen cabinets are 30 inches high and 24 inches deep. Architects draw the kitchen layout, knowing the cabinet's dimensions come in a 24, 30, 36 or 40 inch width. A modern kitchen really isn't custom as it is drawn to spec.



The Fluke 55xx, Meatest 9010 and Transmille 4010 are known multi-function calibrators. Tomorrow, a new calibrator could enter the market and it will work with the current version of Metrology.NET®, even though it's an unknown!

So now let's shift gears and talk about software. Most software and automated calibration procedures built today are built with an Industry 1.0 philosophy. They are built to work only in that limited scope of the tasks and features they were built to perform. They are not built to use interchangeable parts; everything has to be known when they are built.

If new hardware comes out, the software has to be recompiled and redistributed to include the new feature or hardware. Under the hood, everything is built like industry 1.0 technology--all the parts only work together as a whole. So the application has to be built to support the new hardware, recompiled linking all of it's internal custom built parts together, and then sent out to replace all the previous versions of the software with the new one.

Think about that for a minute. The inefficiency of it all. If every time you wanted to upgrade the tires on your car, you had to buy a new car because your current car doesn't support the latest Goodyear all season radials.

Metrology.NET is the first metrology based software solution engineered and built on the principle of interchangeable parts. Yes, those parts are software parts. But just like in an Industry 2.0 assembly line, the part fits if it was built to specifications and made to be interchangeable.

And like the car analogy, it can be easily upgraded with parts built to specification. You can upgrade and accessorize the software.

The technology was built to be very flexible, adaptable, and interchangeable. Recently, Meatest introduced the 9010 Multi-Function Calibrator. All we had to do was write a driver to spec, drop it in the \Drivers directory, and we were calibrating digital multimeters that day.

We didn't have to rewrite hundreds of automated calibration procedures to add the new calibrator. We didn't have to recompile and distribute a new copy of Metrology.NET to add the new hardware. No! All we did was add an interchangeable part! ❧

* If you are a current member of NCSLI, you can watch the video for free at https://ncsli.org/page/MSMD.

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