CAL LAB
THE INTERNATIONAL JOURNAL OF METROLOGY

2016
OCTOBER
NOVEMBER
DECEMBER

Electric Current Measurement

DS Series Current Transducers

±300A to ±8000A, high accuracy for Power Analyzers and improved performance for Power Amplifiers

- Very high absolute amplitude and phase accuracy from dc to over 1kHz
- Low signal output noise
- Low fluxgate switching noise on the pimary
- Enhanced electrostatic shielding to increase rejection of primary dV/dt coupling
- Increased operating temperature range
- Reduced mechanical dimensions
- Options: Voltage Output Signal; Calibration Winding
- Amplitude and Phase measurement to 300kHz included with each head

DS200

DS2000

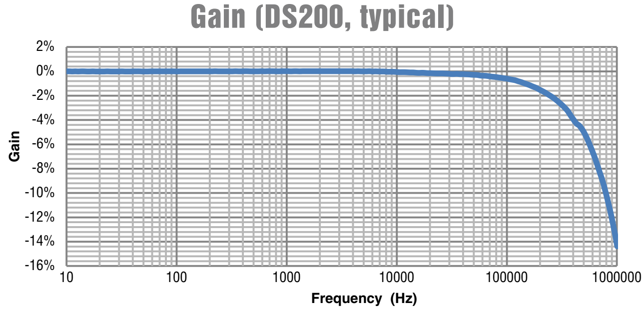
	DS200	DS600	DS2000	DS5000
Primary Current, rms	200A	600A	2000A	5000A
Primary Current, Peak	±300A	±900A	±3000A	±7000A
Turns Ratio	500:1	1500:1	1500:1	2500:1
Output Signal (rms/Peak)	0.4A/±0.6A†	0.4A/±0.6A†	1.33A/±2A†	2A/±3.2A†
Overall Accuracy	0.01%	0.01%	0.01%	
Offset	<20ppm	<10ppm	<10ppm	<5ppm
Linearity	<1ppm	<1ppm	<1ppm	<1ppm
Operating Temperature	-40 to 85˚C	-40 to 85˚C	-40 to 85˚C	0 to 55˚C
Aperature Diameter	27.6mm	27.6mm	68mm	150mm

Bandwidth Bands for Gain and Phase Error	DS200			DS600			DS2000			DS5000	
	<5kHz	<100kHz	<1MHz	<2kHz	<10kHz	<100kHz	<500Hz	<1kHz	<10kHz	<5kHz	<20kHz
Gain (sensitivity) Error	0.01%	0.5%	20%	0.01%	0.5%	3%	0.01%	0.05%	3%	0.01%	1%
Phase Error	0.2˚	4˚	30˚	0.1˚	0.5˚	3˚	0.01˚	0.1˚	1˚	0.01˚	1˚

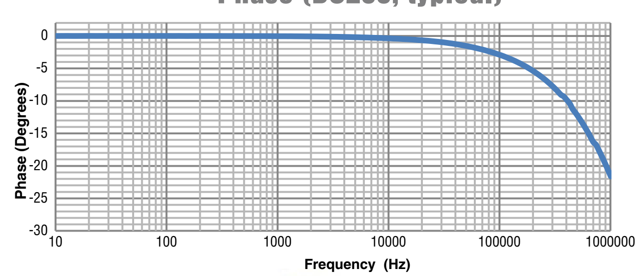
† Voltage Output options available in ±1V and ±10V

Gain / Phase

Gain (DS200, typical)



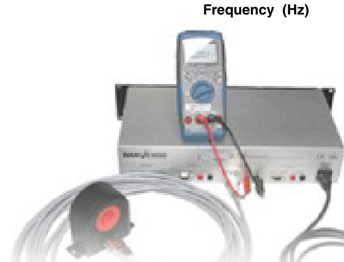
Phase (DS200, typical)



DSSIU-4 for Multi Channel Systems

4-channel Transducer Interface Unit and Power Supply improved performance for Power Amplifiers

- Power and Signal connections for up to four Current Transducer heads
- Heads may be mixed (e.g.: One DS2000 Head and three DS200 Heads)



DSSIU-4

CAL LAB
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VOLUME 23, NUMBER 4

FEATURES

DEPARTMENTS

ON THE COVER: Dr. Raúl Herrera Basurto of the Universidad Aeronáutica en Querétaro (UNAQ) and Melva Jeanette Moreno del Rincon of the Universidad Politecnica de Querétaro (UPQ) at a NIST Office of Weights and Measures Fundamentals of Metrology course in Querétaro, Mexico. The course was held at the Universidad Politecnica de Santa Rosa Juaregi, sponsored by NIST, the Fulbright Specialist Program, and the host University. Balances for the course were donated by Sartorius Corporation; Mass standards were donated by Troemner, LLC. Credit: René Suárez Osnaya, Universidad Politecnica de Santa Rosa Juaregi.

CALENDAR

UPCOMING CONFERENCES & MEETINGS

Mar 15-16, 2017 South East Asia Flow Measurement Conference. Kuala Lumpur, Malaysia. TUV NEL. Accurate flow measurement is crucial to ensure company needs are met with as small as financial exposure as possible. It is important now more than ever to stay ahead of developments in technology, regulation and practice. The 2017 South East Asia Flow Measurement Conference will continue to meet these issues head on. http://www.tuvnel.com

Mar 21-23, 2017 Frontiers of Characterization and Metrology for Nanoelectronics. Monterey, CA. The FCMN will bring together scientists and engineers interested in all aspects of the characterization technology needed for nanoelectronic materials and device research, development, and manufacturing. http://www2.avs.org/conferences/FCMN/.

Mar 22-24, 2017 METROMEET. Bilbao, Spain. During the two days, international leaders in the Industrial Dimensional Metrology sector will show you how to improve the quality of your product and the efficiency of its production. http://metromeet.org.

March 27-29, 2017 CIRMS 25th Annual Meeting. Council on Ionizing Radiation Measurement Standards (CIRMS). Hosted by NIST, Gaithersburg, MD. This Silver Anniversary Meeting will focus on "Past, Present, and Future." The technical program next year will consist of oral and poster presentations and three parallel working group sessions that address measurement and standards needs in medical applications, radiation protection and homeland security, and industrial applications and materials effects. Abstracts accepted through Jan. 14th. http://cirms.org.

Mar 27-29, 2017 Exhibition on Measurement & Quality (FORUMESURE). Nantes, France. The African Committee of Metrology (CAFMET). FORUMESURE is an annual event, for companies and also institutions wishing to present their know-how, new products and services to hundreds of international visitors. As the same time as the exhibition, the 7th International French meeting, **Les Rencontres Francophones sur la Qualité et la Mesure (RFQM) 2017**, will take place. http://www.forumesure.com /www.rfqm2017.com

Mar 31-Apr 2, 2017 A2LA Technical Forum & Annual Meeting. Reston, VA. The mission of the Tech Forum is to promote collaboration, training and development, and communication through an annual event consisting of the meeting of the members, technical advisory meetings, training, and other sessions targeted to this specific community. http://www.a2la.org/.

Apr 4-7, 2017 MetrologyAsia2017. Singapore EXPO. Held alongside Manufacturing Technology Asia (MTA) 2017, dedicated for cutting-edge metrology and inspection tools, MetrologyAsia2017 is a leading platform for top technology providers to showcase the latest solutions that can perform complex checks, improve quality control and cut precious time off from production processes. http://www.mta-asia.com.

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CS-1	<0.005 %	CS-200	<0.02 %
CS-5	<0.01 %	CS-300	<0.025 %
CS-10	<0.01 %	CS-500	<0.02 %
CS-20	<0.01 %	CS-1000	<0.025 %
CS-50	<0.01 %	MCS	MULTIPLE

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EDITOR'S DESK

Accessibility and Presence

Lately, construction in and around our area has caused a few network interruptions to our service. Unless I've got a lot of work to do off the local server or my own desktop, I'm dead in the water without internet. Print has become somehow liberating: you can forget it at the airport or pass it on to a stranger; you can access it on a mountain, in the tub, in a blackout, or leave it on your bookshelf indefinitely without having to worry about batteries leaking or catching on fire. Also, each issue is compostable, recyclable, non-toxic, and made of renewable resources. Needless to say, I'm a big advocate of print and we will be printing as long as we're able.

But, for those times when we must be connected, Cal Lab magazine is online. We aim to be accessible in all forms as we believe accessibility to the calibration and metrology world is important. Just recently, Cal Lab magazine was made available through Magzter, a digital magazine newsstand. Even more recently, **www.callabmag.com** went through a *major* overhaul, with more of a digital magazine look and feel. We hope users find it easier to navigate and find lots of information they didn't know existed.

In this issue, Chris Grachanen grapples with the issue of the metrology industry's presence in the US workforce in his petition to the US Bureau of Labor Statistics' Standard Occupational Classification System. Apparently, the powers that be have yet to fully understand the breadth of the metrology industry and important players. Grachanen's petition provides a thorough explanation of why the titles of Metrologist and Calibration Engineer should be included in the 2018 SOC.

Our last issue included an article contributed by the International Accreditation Service (IAS) on upcoming changes to ISO 17025. It was quite a hit online. Dr. Anastapoulous of IAS traveled all the way to Geneva, Switzerland this past September to attend the latest ISO/CASCO working group. As a result, he was able to provide us a follow-up article, highlighting the Draft International Stage (DIS) of the new ISO 17025.

But we begin this issue with two technical articles. Hening Huang of Teledyne RD Instruments revisits the Ballico paradox and proposes an alternative resolution. It should be of great interest to anyone who uses the Welch-Satterthwaite formula for uncertainty estimation in their work.

And our second technical article, from Richard Fertell of Proteus Industries, is part one in a series on how to calibrate liquid flow instruments outside of the typical range of +5 to +90 °C.

We are pleased to finish off the year with a great lineup of articles for our readers. No matter where you are in the World, may peace be with you to keep you safe, and as always…

Happy Measuring,

Sita Schwartz
Editor

CALENDAR

Apr 4 -5, 2017 Metrology for LNG Workshop. Noordwijk, Netherlands. VSL and CEESI. Two workshops join forces: Two workshops join forces: Metrology for LNG workshop and European Flow Measurement Workshop present joint programs. We invite manufacturers, end users, academics and government organizations to submit their technical abstracts for presentation. http://www.lngmetrology.info.

Apr 5-7, 2017 European Flow Measurement Workshop. Noordwijk, Netherlands. VSL and CEESI. The 5th European Flow Measurement Workshop has joined forces with the Metrology for LNG workshop. VSL and CEESI invite you to join in "Setting the Standard." http://www.efmws.eu.

Apr 5-7, 2017 Measurement Science Conference (MSC). Anaheim, CA. The Measurement Science Conference organizing committee invites you to join us April 5 - 7, 2017 in Anaheim, California. Our 2017 theme is Science, Technology & Measurement – Changing Our World. The conference is offering a series of excellent technical programs covering the various disciplines of the measurement sciences. http://www.msc-conf.com

SEMINARS: Dimensional

Dec 5-8, 2016 Dimensional Measurement Training: Level 2 – Measurement Applier. Telford, UK. Hexagon Metrology. A four day training course for those who have a good basic understanding of measurement principles gained through the Level 1 training course. Level 2 is applicable to all industrial sectors as a stand-alone qualification or as a building block for further NPL Dimensional Measurement Training Levels - 3 & 4. http://www.npl.co.uk/training.

Dec 5-8, 2016 Dimensional Measurement Training: Level 2 – Measurement Applier. Coventry University, UK. A four day training course for those who have a good basic understanding of measurement principles gained through the Level 1 training course. Level 2 is applicable to all industrial sectors as a stand-alone qualification or as a building block for further NPL Dimensional Measurement Training Levels - 3 & 4. http://www.npl.co.uk/training.

Dec 6-8, 2016 Dimensional Metrology. Aurora (Chicago), IL. Mitutoyo Institute of Metrology. Our Dimensional Metrology curriculum is intended for anyone who wishes to learn about dimensional measuring equipment and strategies for implementation. http://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/.

Dec 8-9, 2016 Hands-On Gage Calibration and Repair. Bloomington, MN. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.

Jan 10-11, 2017 Hands-On Gage Calibration and Repair. Chippewa Falls, WI. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.

Jan 12-13, 2017 Hands-On Gage Calibration and Repair. Minneapolis, MN. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.

Jan 23, 2017 Geometric Dimensioning and Tolerancing (GD&T) Application to Gage Calibration Requirements. NCSLI Technical Exchange - Orlando, FL. This course is suitable for those individuals needing a basic understanding of the concepts related to drawing and CAD model definition. http://www.ncsli.org/te.

Jan 24, 2017 Measuring and Characterizing Surface Topography. NCSLI Technical Exchange - Orlando, FL. This tutorial will focus on the topography of surfaces—the texture and roughness. This tutorial provides an introduction to surface metrology and to the evaluation of roughness. http://www.ncsli.org/te.

Jan 24-25, 2017 Hands-On Gage Calibration and Repair. Chicago, IL. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.

Feb 8-9, 2017 Hands-On Gage Calibration and Repair. Louisville, KY. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.

Feb 20-21, 2017 Hands-On Gage Calibration and Repair. Orange County, CA. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.

Feb 21-23, 2017 Dimensional Measurement Training: Level 1 – Measurement User. Coventry University, UK. National Physical Laboratory. A three day training course introducing measurement knowledge focusing upon Dimensional techniques. Applicable to all industrial sectors as a stand-alone qualification or as a building block to further NPL Dimensional Measurement Training Levels – 2 & 3. http://www.npl.co.uk/training.

Feb 23-24, 2017 Hands-On Gage Calibration and Repair. Los Angeles, CA. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.

Feb 28-Mar 1, 2017 Hands-On Gage Calibration and Repair. Las Vegas, NV. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.

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Mar 13-16, 2017 Dimensional Measurement Training: Level 2 – Measurement Applier. Coventry University, UK. National Physical Laboratory. Level 2 is applicable to all industrial sectors as a stand-alone qualification or as a building block for further NPL Dimensional Measurement Training Levels - 3 & 4. http://www.npl.co.uk/training.

Mar 20-21, 2017 Hands-On Gage Calibration and Repair. Akron, OH. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.

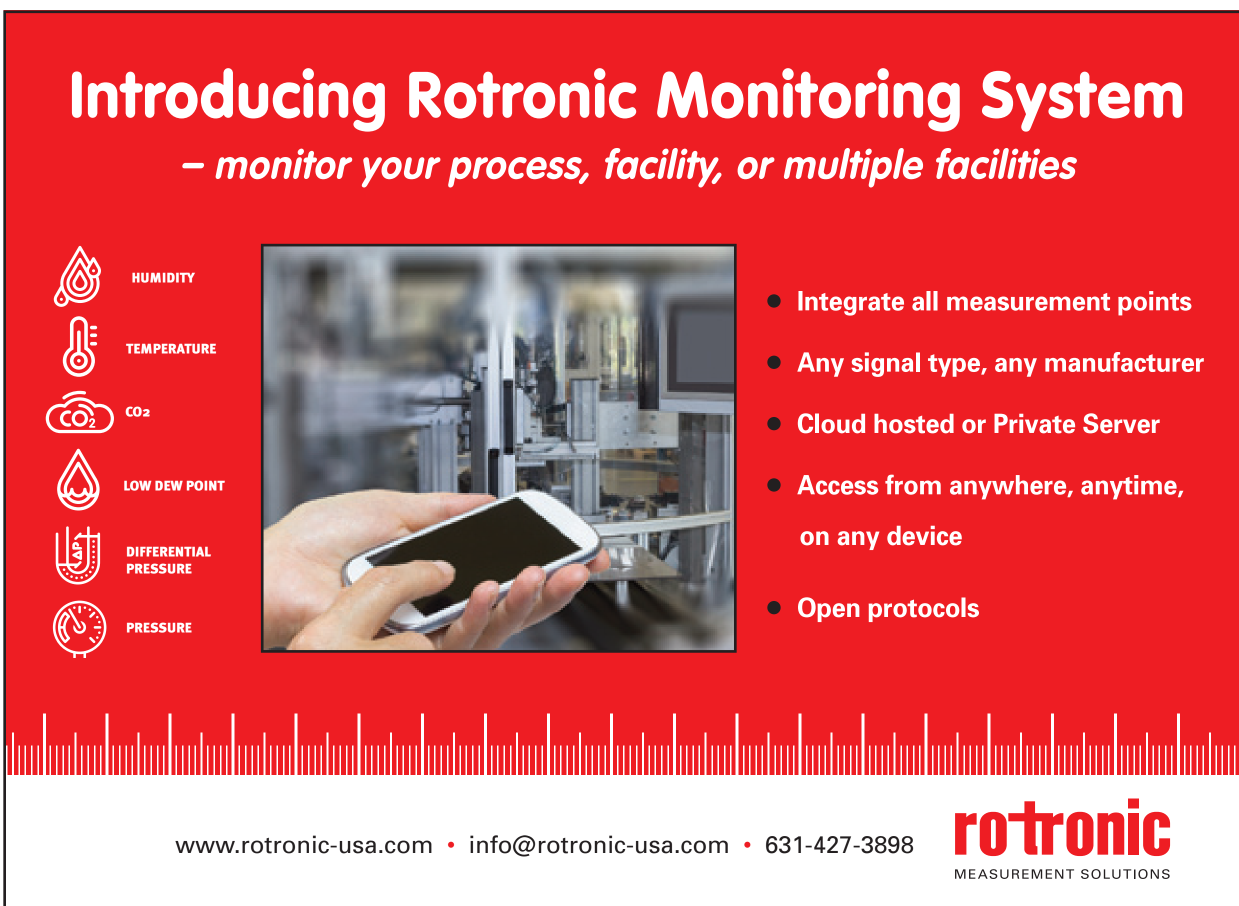
Mar 23-24, 2017 Hands-On Gage Calibration and Repair. Detroit, MI. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.

Apr 4-6, 2017 Hands-On Gage Calibration and Repair. Atlanta, GA. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.

Apr 18-20, 2017 Dimensional Measurement Training: Level 1 – Measurement User. Coventry University, UK. National Physical Laboratory. A three day training course introducing measurement knowledge focusing upon Dimensional techniques. Applicable to all industrial sectors as a stand-alone qualification or as a building block to further NPL Dimensional Measurement Training Levels – 2 & 3. http://www.npl.co.uk/training.

Apr 20-21, 2017 Hands-On Gage Calibration and Repair. Minneapolis, MN. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.

May 10-11, 2017 Hands-On Gage Calibration and Repair. Hartford, CT. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.



May 18-19, 2017 Hands-On Gage Calibration and Repair. Las Vegas, NV. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com.

SEMINARS: Electrical

May 1-4, 2017 MET-101 Basic Hands-on Metrology. Everett, WA. Fluke Calibration. This course introduces the student to basic measurement concepts, basic electronics related to measurement instruments and math used in calibration. http://us.flukecal.com/training.

May 8-11, 2017 MET-301 Advanced Hands-on Metrology. Everett, WA. Fluke Calibration. This course introduces the student to advanced measurement concepts and math used in standards laboratories. The student will learn how to make various types of measurements using different measurement methods. http://us.flukecal.com/training.

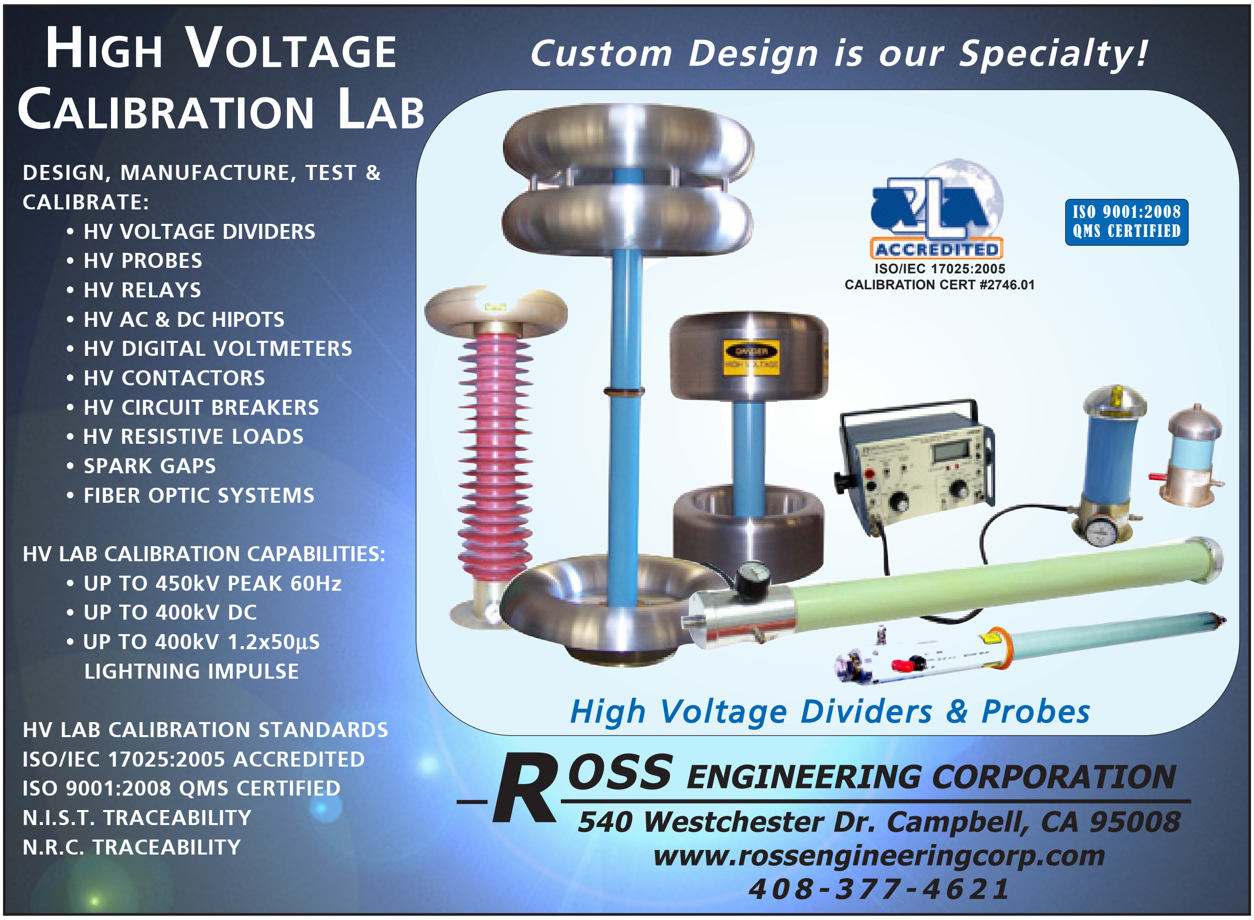
SEMINARS: Flow & Pressure

Jan 23-24, 2017 Pressure and Vacuum Measurement. NCSLI Technical Exchange - Orlando, FL. This two-day course will cover the fundamentals of pressure measurements, focusing on the selection and proper use of appropriate gauging technology for a given application. http://www.ncsli.org/te.

Jan 23-24, 2017 Flow Measurement and Uncertainties. NCSLI Technical Exchange - Orlando, FL. Methods of flow meter calibration used in laboratory, including NIST standards will be covered. Field conditions will be discussed as well as installation effects and how distorted velocity profiles affect flowmeter accuracy. Flow calculations and uncertainty analyses for certain flow meter types will be taught. http://www.ncsli.org/te.

Jan 30-Feb 3, 2017 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). http://us.flukecal.com/training.

May 8-12, 2017 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. http://us.flukecal.com/training.



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SEMINARS: General & Management

Dec 6-8, 2016 Cal Lab Management; Beyond 17025 Training. Los Angeles, CA. WorkPlaceTraining. Does your lab manager have formal management training or experience? This course is designed for new lab managers or managers who would like a refresher or different perspective. http://www.wptraining.com/.

Dec 9, 2016 Root Cause Analysis and Corrective Action. Frederick, MD. A2LA. The Root Cause Analysis and Corrective Action (RCA/CA) course consists of presentations, discussions and exercises that provide participants with an in-depth understanding of how to analyze a system in order to identify the root causes of problems and to prevent them from recurring. http://www.a2la.org/training/index.cfm.

Jan 23, 2017 Risk Based Thinking in Metrology. NCSLI Technical Exchange - Orlando, FL. This ½ day module will help those involved planning, managing, implementing and reviewing any aspect of laboratory management systems to apply risk based thinking to determine what these statements mean to their particular situation. http://www.ncsli.org/te.

Feb 6-10, 2017 Fundamentals of Metrology. Gaithersburg, MD. NIST. This seminar will introduce the participant to the concepts of measurement systems, units, measurement uncertainty, measurement assurance, traceability, basic statistics and how they fit into the laboratory Quality Management System. https://www.nist.gov/news-events/upcoming_events.

Feb 9, 2017 Root Cause Analysis and Corrective Action. A2LA Headquarters – Frederick, MD. The Root Cause Analysis and Corrective Action (RCA/CA) course consists of presentations, discussions and exercises that provide participants with an in-depth understanding of how to analyze a system in order to identify the root causes of problems and to prevent them from recurring. http://www.a2la.org/.

Feb 13-17, 2017 Fundamentals of Metrology. Gaithersburg, MD. NIST. This seminar will introduce the participant to the concepts of measurement systems, units, measurement uncertainty, measurement assurance, traceability, basic statistics and how they fit into the laboratory Quality Management System. https://www.nist.gov/news-events/upcoming_events.

Feb 27-Mar 3, 2017 Fundamentos de Metrología. Gaithersburg, MD. NIST. El seminario presenta al participante los conceptos de sistemas de medición, unidades de medida, incertidumbre de medida, aseguramiento de la medición, trazabilidad, estadísticas básicas, y cómo todo esto forma parte del Sistema de Gestión de la Calidad del laboratorio. https://www.nist.gov/news-events/events/2017/02/5447-fundamentos-de-metrologia.

Feb 28-Mar 2, 2017 Cal Lab Management; Beyond 17025 Training. Boca Raton, FL. WorkPlaceTraining. Does your lab manager have formal management training or experience? This course is designed for new lab managers or managers who would like a refresher or different perspective. http://www.wptraining.com/.

Apr 26, 2017 Root Cause Analysis and Corrective Action. Chicago, IL. A2LA. The Root Cause Analysis and Corrective Action (RCA/CA) course consists of presentations, discussions and exercises that provide participants with an in-depth understanding of how to analyze a system in order to identify the root causes of problems and to prevent them from recurring. http://www.a2la.org/.

May 22-25, 2017 Effective Cal Lab Management. Everett, WA. Fluke Calibration. Effective Cal Lab Management is ideal for anyone in a lead or supervisory position in a cal lab looking for ways to better communicate and manage personnel, and to bring about efficiency and customer satisfaction improvement. http://us.flukecal.com/training.

May 24, 2017 Root Cause Analysis and Corrective Action. A2LA Headquarters – Frederick, MD. The Root Cause Analysis and Corrective Action (RCA/CA) course consists of presentations, discussions and exercises that provide participants with an in-depth understanding of how to analyze a system in order to identify the root causes of problems and to prevent them from recurring. http://www.a2la.org/.

SEMINARS: Industry Standards

Dec 5-6, 2016 ISO/IEC 17025:2055 and Laboratory Accreditation. Frederick, MD. A2LA. This course is an introductory look at ISO/IEC 17025 and its requirements for demonstrating the technical competence of testing and calibration laboratories. http://www.a2la.org/training/index.cfm.

Dec 7-8, 2016 Internal Auditing. A2LA. Frederick, MD. This 2-day training course practices the internationally-recognized approaches of ISO 19011:2011 to conducting effective internal audits. http://www.a2la.org/training/index.cfm.

Dec 9, 2016 Fundamentals of SOP Writing. A2LA. Frederick, MD. Using the ISO/IEC accreditation standards and information provided during the class, participants will review the basic concepts of procedure structure, content, and development; will practice developing Standard Operation Procedures, both technical and administrative. http://www.a2la.org/training/index.cfm.

Dec 12-16, 2016 ISO/IEC 17025 Lead Assessor Training. Orlando, FL. ANAB. Want to learn better audit practices using the ISO/IEC 17025 standard? This course will prepare you to meet technical demands of the standard while providing practical exercises to aid comprehension. http://www.asq.org/courses/iso-iec-17025-lead-assessor.html.

Dec 13-15, 2016 Internal Auditing to ISO/IEC 17025 (presentado en Español). Tepotzotlan, Mexico. ANAB. El curso de capacitación de Auditoría Interna a ISO / IEC 17025 de 2.5 días prepara al auditor interno para entender claramente las cuestiones técnicas relacionadas con una auditoría. Los asistentes a este curso aprenderán a coordinar una auditoría del sistema de gestión de calidad con ISO / IEC 17025: 2005 y recoger evidencia de auditoría y observaciones de documentos, incluyendo técnicas para un cuestionamiento y una escucha efectivos. http://anab.org/training/isoiec-17025-training/internal-auditing-to-isoiec-17025/.

Jan 23, 2017 Understanding ISO/IEC 17025 Requirements. NCSLI Technical Exchange - Orlando, FL. Beginner course content is designed for students with no previous experience Full-day tutorial will cover highlights of ISO/IEC 17025 requirements. http://www.ncsli.org/te.

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Crystal XP2i

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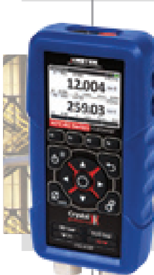
JOFRA ASC-400

M & G PKII



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Jan 24, 2017 Achieving Accreditation: Traceability, CMC Software Validation and Assessment Survival. NCSLI Technical Exchange - Orlando, FL. This ½ day seminar will discuss several topics regarding various aspects of achieving accreditation including: how traceability to the SI is created and defined, maintenance of the traceability chain, how traceability plays a critical role in 17025, developing Calibration and Measurement Capabilities (CMCs) for inclusion in a Scope of Accreditation, and more. http://www.ncsli.org/te.

Jan 24, 2017 Root Cause Analysis. NCSLI Technical Exchange - Orlando, FL. This ½ day course will give you the tools you need to perform root cause analysis, create clear corrective actions and preventative actions, and implement continual improvements to quality management systems. The emphasis will be on ISO/IEC 17025 requirements, and the course objectives will be achieved through lecture and several in-class activities. http://www.ncsli.org/te.

Jan 30-31, 2017 ISO/IEC 17025 and Laboratory Accreditation. Phoenix, AZ. A2LA. This course is an introductory look at ISO/IEC 17025 and its requirements for demonstrating the technical competence of testing and calibration laboratories. http://www.a2la.org/.

Feb 6-8, 2017 Internal Auditing to ISO/IEC 17025. Saint Petersburg, FL. ANAB. The 2.5-day Internal Auditing to ISO/IEC 17025 training course prepares the internal auditor to clearly understand technical issues relating to an audit. http://anab.org/training/isoiec-17025-training/internal-auditing-to-isoiec-17025/.

Feb 15-16, 2017 ISO/IEC 17025 and Laboratory Accreditation. A2LA Headquarters – Frederick, MD. This course is an introductory look at ISO/IEC 17025 and its requirements for demonstrating the technical competence of testing and calibration laboratories. http://www.a2la.org/.

Feb 17, 2017 ISO/IEC 17025 Advanced: Beyond the Basics. A2LA Headquarters – Frederick, MD. This is an advanced course in the application of ISO/IEC 17025 requirements. The course will provide a brief overview of the requirements of this laboratory standard, as well as provide an understanding of how to apply specific sections of the Standard in your laboratory. http://www.a2la.org/.

Mar 2-3, 2017 ISO/IEC 17025 and Laboratory Accreditation. San Antonio, TX. This course is an introductory look at ISO/IEC 17025 and its requirements for demonstrating the technical competence of testing and calibration laboratories. http://www.a2la.org/.

Mar 6-7, 2017 ISO/IEC 17025 and Laboratory Accreditation. A2LA Headquarters – Frederick, MD. This course is an introductory look at ISO/IEC 17025 and its requirements for demonstrating the technical competence of testing and calibration laboratories. http://www.a2la.org/.

Mar 27-28, 2017 Introduction to ISO/IEC 17025. Indianapolis, IN. ANAB. The 1.5-day Introduction to ISO/IEC 17025 training course will help attendees understand and apply the requirements of ISO/IEC 17025:2005. Attendees will examine the origins of the standard and learn practical concepts such as document control, internal auditing, proficiency testing, traceability, measurement uncertainty, and method witnessing. http://anab.org/training/isoiec-17025-training/introduction-to-isoiec-17025/.

Apr 11-12, 2017 ISO/IEC 17025 and Laboratory Accreditation. A2LA Headquarters – Frederick, MD. This course is an introductory look at ISO/IEC 17025 and its requirements for demonstrating the technical competence of testing and calibration laboratories. http://www.a2la.org/.

May 16-17, 2017 ISO/IEC 17025 and Laboratory Accreditation. A2LA Headquarters – Frederick, MD. This course is an introductory look at ISO/IEC 17025 and its requirements for demonstrating the technical competence of testing and calibration laboratories. http://www.a2la.org/.

May 18, 2017 ISO/IEC 17025 Advanced: Beyond the Basics. A2LA Headquarters – Frederick, MD. This is an advanced course in the application of ISO/IEC 17025 requirements. The course will provide a brief overview of the requirements of this laboratory standard, as well as provide an understanding of how to apply specific

sections of the Standard in your laboratory. http://www.a2la.org/.

SEMINARS: Mass & Weight

Jan 24, 2017 Good Weighing Practices. NCSLI Technical Exchange - Orlando, FL. During this session, we will break down how measurement uncertainty exhibits itself, across the capacity of an electronic balance or scale. http://www.ncsli.org/te.

Mar 13-24, 2017 Mass Metrology Seminar. Gaithersburg, MD. NIST Office of Weights and Measures. 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 trainee performs measurements by applying procedures and equations discussed in the classroom. https://www.nist.gov/news-events/events/2017/03/5435-mass-metrology-seminar.

May 15-26, 2017 Mass Metrology Seminar. Gaithersburg, MD. NIST Office of Weights and Measures. 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 trainee performs measurements by applying procedures and equations discussed in the classroom. https://www.nist.gov/news-events/events/2017/05/5436-mass-metrology-seminar.

SEMINARS: Measurement Uncertainty

Jan 24, 2017 Measurement Uncertainty – Fundamental Applications. NCSLI Technical Exchange - Orlando, FL. This is a full-day, beginner to intermediate level workshop targeted towards metrologists, technicians and engineers. This workshop will also be useful for specifiers of calibration services. http://www.ncsli.org/te.

Jan 24-25, 2017 The NIST Uncertainty Machine and the NIST Consensus Builder. NCSLI Technical Exchange - Orlando, FL. This course will provide a hands-on familiarization with the NUM and with the NICOB, using concrete examples and real data from a wide range of fields of measurement science. http://www.ncsli.org/te.

Feb 9-10, 2017 Fundamentals of Measurement Uncertainty. Saint Petersburg, FL. ANAB. Learn a practical approach to measurement uncertainty (MU) applications, based on fundamental practices. http://asq.org/training/fundamentals-of-measurement-uncertainty_FMU.html.

Feb 27, 2017 Introduction to Measurement Uncertainty. San Antonio, TX. A2LA. Participants who have never developed uncertainty budgets usually develop the required skill well before the end of the class. Others who seek explanations of GUM complexities obtain clarifications expressed in simple terms. http://www.a2la.org/.

CALENDAR

Feb 28-Mar 1, 2017 Applied Measurement Uncertainty for Calibration Labs. San Antonio, TX. A2LA. https://www.a2la.org/training/index.cfm.

Mar 27, 2017 Introduction to Measurement Uncertainty. Reston, VA. A2LA. Participants who have never developed uncertainty budgets usually develop the required skill well before the end of the class. Others who seek explanations of GUM complexities obtain clarifications expressed in simple terms. http://www.a2la.org/.

Mar 28-29, 2017 Applied Measurement Uncertainty for Calibration Labs. A2LA Tech Forum – Reston, VA. https://www.a2la.org/training/index.cfm.

SEMINARS: RF & Microwave

Jan 23, 2017 Microwave Measurement Basics. NCSLI Technical Exchange - Orlando, FL. An introduction to the measurement concepts for microwave power and scattering-parameters will be covered: transmission line theory, practical handling or the do's and don'ts for transmission lines and microwave connectors, VNA calibration/measurements and real world sources of uncertainties, microwave power detectors types, power measurements and uncertainties, and verification techniques. http://www.ncsli.org/te.

Jan 24, 2017 Understanding RF Power Calibrations at 1 mW and 250 W. NCSLI Technical Exchange - Orlando, FL. This one day workshop provides a practical introduction to 1mW RF power transfer between two coupled ports with discussions on key components and methods for power sensor calibrations. It includes Gamma correction and how to use Gamma correction to calculate power transfer and port match, and the importance of vector measurements to the precise knowledge of power transfer. http://www.ncsli.org/te.

SEMINARS: Software

Mar 27-31, 2017 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.

Apr 24-28, 2017 Advanced MET/CAL® Procedure Writing. Everett, WA. This five-day in-depth workshop is for experienced MET/CAL programmers who wish to enhance their procedure writing skills. Students will focus on the use of instrument communication with the IEEE, PORT, VISA, MATH and LIB FSCs, the use of memory registers in procedures, and will create a complex procedure using live instrumentation. http://us.flukecal.com/training.

SEMINARS: Temperature

Jan 23, 2017 Realizing the ITS-90 and Maintaining Traceability. NCSLI Technical Exchange - Orlando, FL. This full-day course covers realization of ITS-90 fixed-point cells over the range from the argon triple point to the zinc freezing point, uncertainty statements for fixed point cells, calibration of SPRTs, and uncertainty statements for SPRT calibrations, measurement assurance using statistical process control, establishing and maintaining traceability to the SI, and more. http://www.ncsli.org/te.

Jan 23, 2017 Humidity Calibration Uncertainty. NCSLI Technical Exchange - Orlando, FL. This half-day course covers chamber calibration related topics with special emphasis on humidity chambers in terms of the most recent updates, proposed changes, recommended practices, compliance to the mandates and conformance to established local and international standards and guidelines, and measurement uncertainties that may necessarily be considered when calibrating climatic chambers. http://www.ncsli.org/te.

Jan 23-24, 2017 Selection, Calibration, and Use of Contact Thermometers. NCSLI Technical Exchange - Orlando, FL. In this seminar, we will discuss contact thermometers commonly used in industry for applications that use platinum resistance thermometers, thermistors, and thermocouples. http://www.ncsli.org/te.

Jan 24, 2017 Temperature Monitoring and Traceability in the Cold Chain. NCSLI Technical Exchange - Orlando, FL. Participants will learn effective temperature monitoring strategies for use in cold-chain transport and storage of temperature-sensitive products. http://www.ncsli.org/te.

Mar 13, 2017 Temperature Measurement and Calibration Course. Teddington, UK. NPL. The course will be suitable for technicians and technical managers closely concerned with temperature measurement and calibration. Covering the range -200 °C to 3000 °C, it will concentrate on those methods of measurement which are of greatest technological and industrial importance. http://www.npl.co.uk/training.

Mar 14-16, 2017 Practical Temperature Calibration Training. American Fork, UT. Fluke Calibration. Three day course loaded with valuable principles and hands-on training designed to help calibration technicians and engineers get a solid base of temperature calibration fundamentals. http://us.flukecal.com/training.

Mar 16, 2017 Humidity Measurement and Calibration Course. Teddington, UK. NPL. A two day course on humidity measurement covering dew point, relative humidity and other humidity quantities. http://www.npl.co.uk/training.

SEMINARS: Vibration

Jan 23, 2017 Vibration and Shock Sensor Theory and Calibration. NCSLI Technical Exchange - Orlando, FL. This four-hour tutorial on vibration calibration will dive into calibration theory, standards, and methodology for dynamic sensors as well as explanations of different sensor types and the operational theories behind them. Target audience is beginner to intermediate level. http://www.ncsli.org/te.

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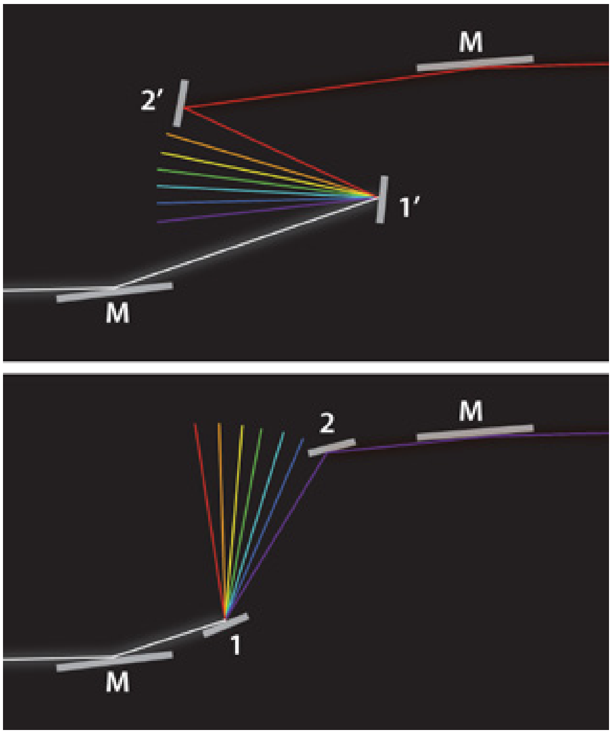
Supported by Granite, New SURF Beamline Is Real Heavyweight

September 21, 2016 NIST News — If your work involves sensing, measuring or using ultraviolet light, the National Institute of Standards and Technology (NIST) has great news for you: Granite is good for more than just kitchen countertops.

The famously tough rock is also the sturdy base for a new device at NIST's Synchrotron Ultraviolet Radiation Facility (SURF III), which has just improved its instrument calibration abilities. The upgrade, made to SURF's Beamline 3, will allow NIST to calibrate or characterize devices that work in the ultraviolet (UV) region of the spectrum far more accurately and across the complete range of UV wavelengths for the first time. It's a change that will benefit designers of computer chips and satellite-mounted sensors alike, and it involves modern technology as well as several tons of stone.

SURF is a room-sized particle accelerator built in the 1940s that has gained new life as a light source, spanning wavelengths from the extreme UV to the infrared. As charged particles—electrons in SURF's case—are swiftly accelerated to nearly the speed of light, the process makes them emit a broad range of wavelengths of light called synchrotron radiation. The new device allows precise selection of specific wavelengths of light within the emitted radiation, making it a valuable metrology tool.



In this simplified example, SURF III's new beamline 3 directs UV light (white beam) to a grating (1), which acts a prism. Only the desired UV wavelength strikes the mirror (2), which helps reflect the light toward devices that need calibration. By repositioning the grating and mirror, the beamline can generate UV ranging from long to short wavelengths–represented here by red (top) and violet (bottom), respectively. Credit: Natasha Hanacek/NIST

Varied scientific and technological applications require light of different UV wavelengths, from as short as 3 nanometers (extreme UV (link is external), used in observing the sun's corona) up to 250–400 nm (useful for rapid curing of adhesives and biological studies). Up until now, SURF III has needed to use two separate groups of instruments of limited capability to produce tunable UV across this range. The upgrade means NIST can retire these older instruments, located on beamlines 4 and 9, and do more accurate work.

Precisely tuning the UV light to the desired wavelength hinges—literally—on movable optical elements mounted on the 6-ton granite slab used to steady them. Changing the angle at which the UV light strikes the elements alters the transmitted wavelength, so the elements must be moved into exact locations and remain there, rock-steady, while the beamline is in operation.

The SURF III facility performs about 100 extreme UV calibrations and characterizations a year. Up until now, NIST has not had a tunable instrument with sufficient power to make measurements over large regions of the UV that are traceable to the international system of measurement units. NIST physicist Tom Lucatorto said that Beamline 3's upgrade will change that.

"We now can perform calibrations traceable to the SI from 3 to 400 nanometers," Lucatorto said. "This will allow us to reduce the uncertainty in our measurements to less than 1 percent, where before it could be as high as 8 percent. The improvements should please both the industrial and research communities."

Source: *https://www.nist.gov/news-events/news/2016/09/supported-granite-new-surf-beamline-real-heavyweight.*

Two New International Standards Published

Traceable verification techniques for electrical measurements developed in EMRP project feed into industry-level documentation

November 16, 2016 EURAMET News — Traceable electrical measurements are essential for cutting-edge electronics that operate in the radio frequency, microwave and millimeter-wave areas. EMRP project Metrology for new electrical measurement quantities in high-frequency circuits (SIB62 HF Circuits) has developed the traceable electrical measurement verification techniques that were previously lacking. The project has also provided significant inputs to European and international industry-level documentation so that industry can benefit directly from the work.

The IEEE (Institute of Electrical and Electronics Engineers) has used outputs from the project to help establish two new international standards:

- IEEE Std 1785.2-2016, "IEEE Standard for Rectangular Metallic Waveguides and Their Interfaces for Frequencies of 110 GHz and Above – Part 2: Waveguide Interfaces."
- EEE Std 1785.3-2016, "IEEE Recommended Practice for Rectangular Metallic Waveguides and Their Interfaces for Frequencies of 110 GHz and Above – Part 3: Recommendations for Performance and Uncertainty Specifications."

In addition, a draft has been produced for the revision of "EURAMET Guidelines on the Evaluation of Vector Network Analysers (VNA)." Finally, the work on millimeter-wave and submillimeter-waves has been submitted as a new Calibration and Measurement Capability (CMC) to the BIPM.

For more information visit the project website at: http://projects.npl.co.uk/hf-circuits/.

Source: *http://www.euramet.org/publications-media-centre/news/.*

Mathematical Center of Excellence Launched

European Centre for Mathematics and Statistics in Metrology (MATHMET) established as an outcome of EMRP project

October 10, 2016 EURAMET News — MATHMET emerged from EMRP project NEW04 Novel mathematical and statistical approaches to uncertainty evaluation and was founded by four European national metrology institutes (NMIs) from France (LNE), the United Kingdom (NPL), Germany (PTB) and Sweden (SP). It provides a European platform for metrologists, academia and industry regarding mathematical and statistical research in all metrological areas. It provides guidelines, best practices, and collaboration in scientific projects, workshops and training materials.

Results from this project will continue to be disseminated through the dedicated webpage (www.mathmet.org), a conference series (7 - 9 November 2016, Berlin), sessions at metrology conferences and events, and dedicated topical workshops. The first General Assembly was held in July 2016 at PTB. MATHMET membership is open to further European NMIs and other interested institutions and organizations.

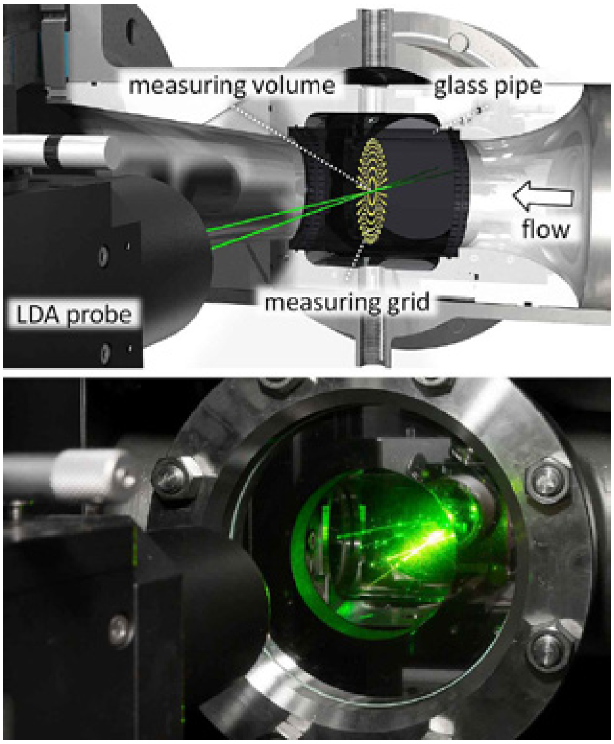
Source: *http://www.euramet.org/publications-media-centre/news/.*

Laser Optical Volume Flow Standard

PTB News 3.2016, September 1, 2016 — The in-situ calibration of volume flow rate measuring devices allows an increased efficiency of thermal power plants

The decisive factor for increasing the energy efficiency of thermal power plants is to reduce the measurement uncertainty of the hot water volume flow rate measurement. The current uncertainty of approx. 2 % is not sufficient to optimize the control of power plants, which limits their efficiency. For this reason, PTB has developed a laser optical volume flow measurement standard (LVN) which allows the calibration of measuring instruments with an uncertainty of 0.15 %.

At 2 %, the current uncertainty of volume flow rate measurements in power plants is too high. This is, in part, due to the fact that there is no test facility in the world which enables the calibration of volume flow measuring instruments under conditions that are similar to those encountered in power plants (i.e. at water temperatures of 400 °C and pressures of 300 bar). On the other hand, internal fittings such as valves or bends have an influence on the velocity profile inside a pipe, and thus on the measurement. For this reason, PTB has developed a compact laser optical volume flow rate measurement standard (LFS) which allows measuring instruments to be calibrated on site (i.e. while they are mounted and in operation) with an uncertainty of only 0.15 %.



In the case of the LDA method, two laser beams are made to overlap. At the point where the beams cross, the measuring volume forms which allows fluid velocities to be measured. The velocity profile inside the pipe is measured on a measuring grid (yellow in the top picture) through a window; by integration, this provides the volume flow rate.

This procedure is based on laser Doppler anemometry (LDA) which is, itself, based on the scattering of light on small water impurities. Hereby, two laser beams are made to overlap at a certain angle. At the point where the two beams cross, which is the measuring volume, an interference fringe pattern forms. An impurity particle moving through the measuring volume with the flow generates a scattered light signal whose frequency is proportional to the particle velocity. The fluid velocity is measured by means of LDA at several positions which are distributed across the section of the pipe. From this data, the velocity profile is reconstructed and integrated in order to calculate the volume flow rate.

The main challenge in developing the LFS was to considerably reduce the current measurement uncertainty of 4.5 % of the LDA volume flow measurement technique. The highest uncertainty contribution hereby came from the local resolution of the measurement procedure, which corresponds to a measuring volume of approx. 2000 µm in length. Due to the extended measurement procedure, the local resolution has already been improved to reach 6 µm. For this purpose two measuring volumes with variable interference fringe intervals are superimposed, which allows the position at which the particles cross the measuring volume to be determined more accurately. Superimposing the two measuring volumes places high requirements on the positioning of the laser beams. At each measurement point within the pipe cross section, four laser beams with a diameter of 150 µm each must be made to overlap. Measurement procedures have therefore been developed which allow the position of the laser producbeams to be determined for the first time with high metrological accuracy.

This method provides a measurement uncertainty of 0.15 %, i.e. improved by more than a factor of 10. A comparison measurement carried out with the heat meter test section – a gravimetric standard measurement facility used to realize the volume flow up to 90 °C with an uncertainty of 0.04 % – showed excellent agreement.

Contact

Markus Juling,Department 7.5, Heat and Vacuum, Phone: +49 (0)30 3481-7815, markus.juling(at)ptb.de

Scientific Publication

M. Juling: Rückgeführte Volumenstrommessung mittels ortsaufgelöster Laser-Doppler-Anemometrie. Dissertation, TU Berlin (2016), doi:10.14279/depositonce-5170

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

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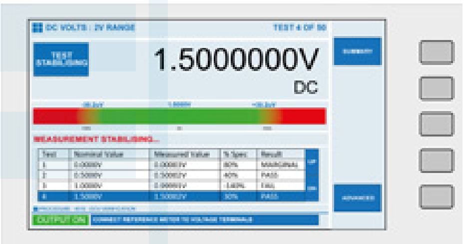

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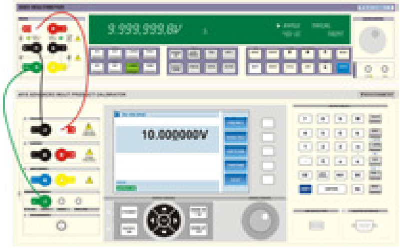

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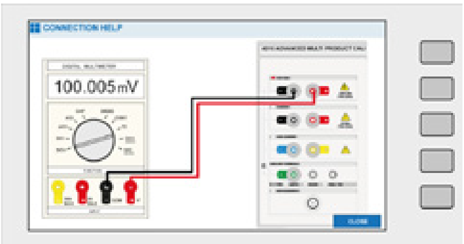

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Fluke Acquires eMaint Enterprises

EVERETT, Wash., Sept. 23, 2016 / PRNewswire/ — Fluke Corporation, the world leader in electronic test tools and software, has acquired eMaint Enterprises, LLC, a global leader in computerized maintenance management software (CMMS). eMaint's award-winning software platform is used by more than 50,000 maintenance professionals in 55 countries providing asset management solutions in multiple markets including food processing, healthcare, facilities, fleet, services, manufacturing, and more. No further details were announced.

Fluke's comprehensive line of industry-leading handheld test tools and portable sensors are used by service and maintenance technicians, electricians and plant engineers around the world. eMaint's web-based, Software as a Service (SaaS) solution can be accessed on PCs, smartphones, tablets, and other browser-based devices. Fluke tools, software and data expertise together with eMaint's SaaS offering represents a critical convergence of maintenance solutions to ensure uptime and maximize return on assets for maintenance and operations managers.

"eMaint brings not only world-class software development but the sales and customer support to help maintenance professionals succeed," said Fluke President Wes Pringle. "Their leadership in maintenance management software combined with Fluke's brand strength and expertise will drive new generations of connected technologies with groundbreaking levels of support for our customers."

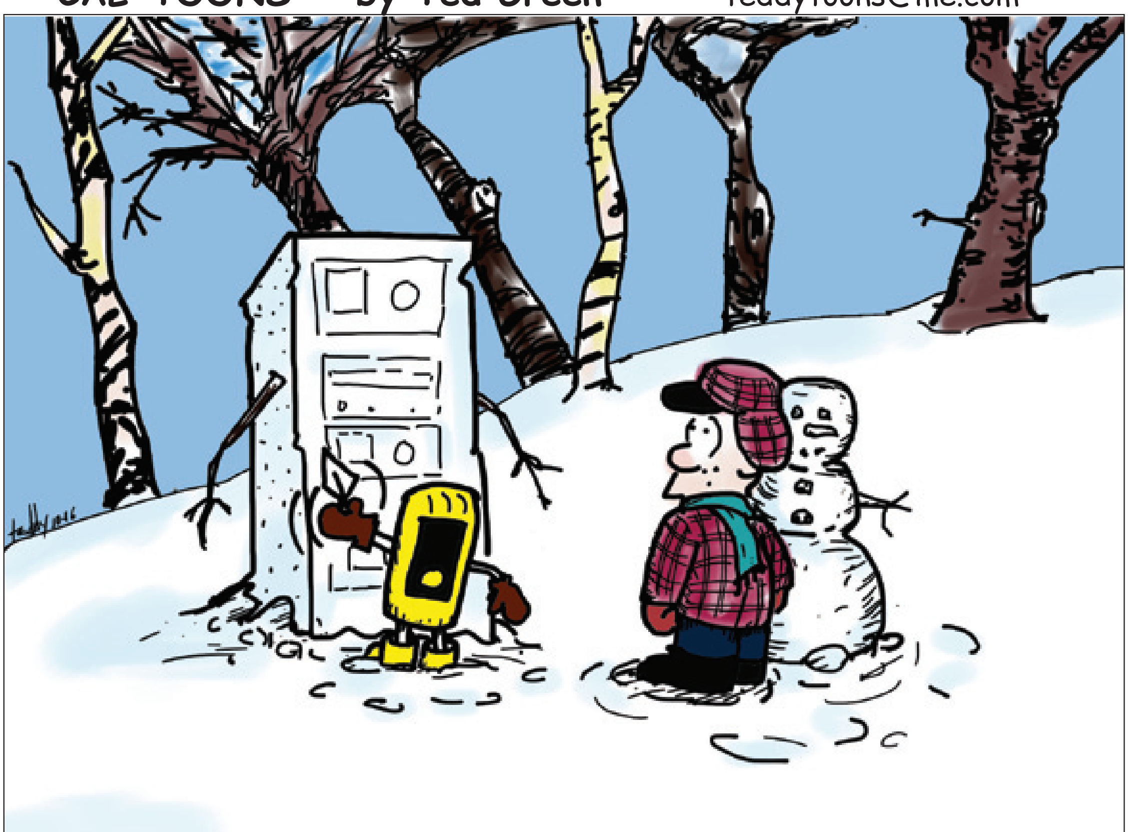
For information on Fluke tools and applications, or to find the location of a distributor, call (800) 44-FLUKE (800-443-5853), e-mail fluke-info@fluke.com or visit the Fluke Web site at www.fluke.com.

About Fluke

Founded in 1948, Fluke Corporation is the world leader in electronic test tools and software. Fluke customers are technicians, engineers, electricians, maintenance managers, and metrologists who install, troubleshoot, and maintain industrial, electrical, and electronic equipment and calibration processes.

Fluke is a registered trademark of Fluke Corporation. For more information, visit the Fluke website.

CAL-TOONS by Ted Green teddytoons@me.com



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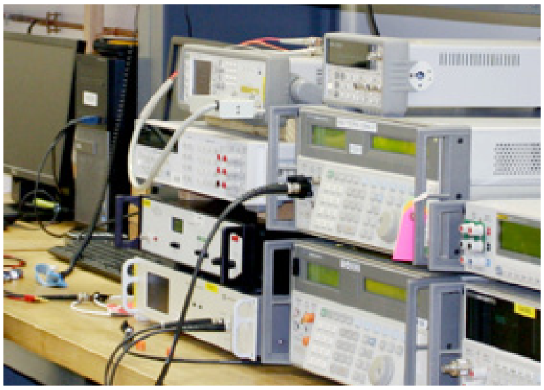

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On the Welch-Satterthwaite Formula for Uncertainty Estimation: A Paradox and Its Resolution

Hening Huang
Teledyne RD Instruments

The Welch-Satterthwaite (WS) formula estimates an "effective degrees of freedom" of an approximate Chi-square distribution formed from a combination of several sample variances of independent normal populations. The effective degrees of freedom is then used to determine the coverage factor (i.e. the *t*-score) for the calculation of expanded uncertainties. This is referred to as the WS-*t* approach in this paper. However, the expanded uncertainty estimated by the WS-*t* approach exhibits a paradoxical behavior, which was first discovered by Ballico [1] in 2000 (referred to as the Ballico paradox). This study revisited the Ballico paradox. We considered a simplified problem: the sum of two uncertainty components, one having an unknown variance and few of degrees of freedom and the other having a known variance and an infinite degrees of freedom. The results reaffirmed the existence of the Ballico paradox, i.e. the estimated expanded uncertainty sometimes decreases with increasing the variance of an uncertainty component. The cause of the Ballico paradox was explored. It is concluded that the WS formula is valid for estimating the effective degrees of freedom; the Ballico paradox is due to the use of the *t*-interval in uncertainty estimation. An alternative approach, which employs an uncertainty estimator in connection with the effective degrees of freedom estimated by the WS formula, is proposed. The proposed approach resolves the Ballico paradox.

Introduction

The Welch-Satterthwaite (WS) formula is well known in statistics and in measurement uncertainty analysis. It estimates an "effective degrees of freedom" of an approximate Chi-square distribution formed from the combination of several sample variances of independent normal populations. In measurement uncertainty analysis, the effective degrees of freedom is traditionally used to determine the coverage factor (i.e. the *t*-score) for calculation of the expanded uncertainty (i.e. the half width of the *t*-interval) resulted from different uncertainty sources. This approach, referred to as the WS-*t* approach, is recommended by the International Organization for Standardization (ISO) "Guide to the Expression of Uncertainty in Measurement" (GUM) [2]. In 2000, however, Ballico [1] discovered a paradoxical behavior of the expanded uncertainty estimated by the WS-*t* approach in a real world application. According to Ballico [1], during a routine calibration and associated uncertainty calculation at the CSIRO National Measurement Laboratory (NML), two ranges of a high-precision thermometer were calibrated and the uncertainties calculated. Contradictory to common sense, the estimated uncertainty for the 1 mK range was *greater* than that for the 10 mK range! Concerned that the underlying approach may allow for more serious discrepancies, Ballico [1] examined a simplified example. Their example showed that the WS-*t* approach produced the counter-intuitive result, which affirmed the existence of the paradox.

Hall and Willink [3], however, commented that the Ballico's calculation example fails to test the coverage of a procedure against its nominal value. They [3] considered the WS-*t* approach as a random interval procedure that calculates a confidence interval and used the long-run coverage probability as a performance criterion to assess the WS-*t* approach. They presented a calculation example and employed Monte Carlo simulation to generate the *t*-intervals with the effective degrees of freedom estimated by the WS formula. Their results for the mean width of the simulated *t*-intervals showed some anomalous behavior, which essentially confirmed the existence of the Ballico paradox. However, Hall and Willink [3] didn't resolve the paradox. They stated that: "Although it may cause the validity of the approach to be questioned, such behavior is acceptable if one adheres to the frequentist model, in which the coverage probability is the primary performance measure."

The Ballico paradox indeed raises a question about the validity of the WS-*t* approach and calls for a resolution. However, no resolution, either from a frequentist or Bayesian approach, has been proposed since Ballico [1] discovered the paradox until this study.

This study revisited the Ballico paradox with three objectives: (1) to reaffirm the existence of the Ballico paradox, (2) to explore the cause of the Ballico paradox, and (3) to propose a resolution to the Ballico paradox.

In the following sections, we first present calculation examples to reaffirm the existence of the Ballico paradox. Second, we propose a WS-*z* approch to expanded uncertainties as an alternative to the WS-*t* approach. Third, we evaluate the performance of the three uncertainty estimators considered in this study. Fourth, we apply the proposed WS-*z* approach to the real world example: the Ballico [1] data to demonstrate the resolution to the Ballico paradox.

The WS-*t* Approach and Calculation Examples

Consider the sum of two random variables, one is denoted by X and the other by Y, both are normally distributed with means μ_x, μ_y and standard deviations σ_x and σ_y respectively. We assume μ_x and μ_y are unknown. We randomly take n samples from X: x_1, x_2, ..x_n and one sample from Y: y. Then the sample mean, $\bar{x} + y$ which is also normally distributed, is an unbiased estimate of the combined mean $\mu_x + \mu_y$. The measurement error, though is unknown, is $\varepsilon = (\bar{x} + y) - (\mu_x + \mu_y)$. If both σ_x and σ_y are known, the expanded uncertainty of the sample mean $\bar{x} + y$ at the 95% coverage probability (i.e. the confidence level) can be calculated as the z-based uncertainty, denoted by U_z

$$U_z = z_{95}\,\sigma_C = z_{95}\sqrt{\frac{\sigma_x^2}{n} + \sigma_y^2} \tag{1}$$

where z_{95} is the coverage factor or the z-score at the 95% coverage probability, and $\sigma_C = \sqrt{\sigma_x^2/n + \sigma_y^2}$ is the "true" combined standard uncertainty.

This study considered the case where σ_x is unknown and σ_y is known. It is hereafter referred to as the two-sample problem. According to GUM [2], the combined standard uncertainty is estimated as $u_C = \sqrt{s_x^2/n + \sigma_y^2}$ and the expanded uncertainty is estimated as the t-based uncertainty, denoted by U_t,

$$U_t = t_{95,\,\hat{v}}\, u_C = t_{95,\,\hat{v}}\sqrt{\frac{s_x^2}{n} + \sigma_y^2} \tag{2}$$

where $t_{95,\,\hat{v}}$ is the coverage factor (i.e. the t-score) at the 95% coverage probability, and $\hat{v}$ is an estimate of the effective degrees of freedom v

$$\hat{v} = (n-1)(1+n\hat{\alpha}^2)^2 = (n-1)[1 + n\,(\frac{\sigma_y}{s_x})^2]^2 \tag{3}$$

where $\hat{\alpha} = \sigma_y/s_x$ is an estimator of α; $\alpha = \sigma_y/\sigma_x$ is the ratio between the two population standard deviations σ_y and σ_x. Equation (3) is a special case of the WS formula for the two-sample problem considered. Thus, Eq. (2) is the WS-*t* approach for the two-sample problem. It is based on an assumption that the combined sample statistic ε / u_C approximately follows a t distribution with $\hat{v}$ degrees of freedom.

Ballico [1] considered a calculation example of the two-sample problem at n=4 and 5, with the parameter values μ_x =0, μ_y=0, σ_x=1, and σ_y ranging from 0 to 2. They calculated the combined standard uncertainty as $\sqrt{\sigma_x^2/n+\sigma_y^2}$ and the effective degrees of freedom using the WS formula. The t-based uncertainty U_t was then calculated using each fixed pair of combined standard uncertainty and effective degrees of freedom. Their results showed the paradoxical behavior of the WS-*t* approach.

Hall and Willink [3], however, disagreed with Ballico [1] and stated that "…its performance for any fixed pair of [combined standard uncertainty and] degrees of freedom can only be assessed with reference to all possible sets of data obtainable with population parameters assumed fixed." They considered a calculation example of the two-sample problem at n=4, with the parameter values μ_x=0, μ_y=0, σ_x=2, and σ_y ranging from 0 to 2. They conducted Monte-Carlo simulation, randomly taking samples of size n=4 from X and samples of size one from Y. They then estimated the combined standard uncertainty $u_C = \sqrt{s_x^2/n+\sigma_y^2}$ and the corresponding effective degrees of freedom $\hat{v} = 48u_C^4/s_x^4$ [i.e. Eq. (3) at n=4], from which, $U_t = t_{95,\hat{v}}\, u_C$ and the t-interval $[(\bar{x} + y) - t_{95,\hat{v}}\, u_C, (\bar{x} + y) + t_{95,\hat{v}}\, u_C]$ at the nominal coverage probability 95% were generated. Their results were presented as the mean of the simulated U_t (however, the mean U_t was called the mean width of the t-intervals in Table 1 of their paper [3]). The coverage probabilities of the simulated t-intervals were estimated and found close to the nominal value, 95%.

In this study, we obtained the mean U_t analytically for the calculation examples at n=2, 3, and 4, with the same parameter values used in [3]. When α, the ratio between σ_y and σ_x, is known, the effective degrees of freedom can be obtained as

$$v = (n-1)(1 + n\alpha^2)^2. \tag{4}$$

The derivation of Eq. (4) is presented in the appendix. Using v to replace $\hat{v}$, Eq. (2) becomes

$$U_t = t_{95,v}\, u_C = t_{95,v}\sqrt{\frac{s_x^2}{n} + \sigma_y^2} \tag{5}$$

where $t_{95,v}$ is the t-score at the 95% coverage probability with the effective degrees of freedom v. The mean U_t can then be obtained by taking the expectation of Eq. (5)

$$\mathrm{E}(U_t) = t_{95,v}\,\mathrm{E}(u_C) = t_{95,v} c_{4,v}\,\sigma_C = t_{95,v}\, c_{4,v}\sqrt{\frac{\sigma_x^2}{n} + \sigma_y^2} \tag{6}$$

where $c_{4,v}$ is the approximate bias correction factor for u_C; it is a function of v

$$c_{4,v} = \sqrt{\frac{2}{v}}\,\Gamma\!\left(\frac{v+1}{2}\right)\Big/\Gamma\!\left(\frac{v}{2}\right),$$

where $\Gamma(.)$ stands for Gamma function (e.g. [4]).

It should be pointed out that, in real situation, the estimated effective degrees of freedom from samples is a random variable. So the expectation of U_t should be taken from Eq. (2). However, for the calculation example considered, directly taking expectation of Eq.

(2) is unnecessary because the ratio α between σ_y and σ_x is known so that the effective degrees of freedom becomes deterministic as shown in Eq. (4).

We calculated E(U_t) at n=2, 3, and 4 as a function of σ_y. The results are shown in Figure 1. The results for E(U_t) at n=4 from the Monte Carlo simulation of Hall and Willink [3] are shown in Figure 1(c). The z-based uncertainty U_z, Eq. (1), at n=2, 3, and 4 are also shown in the figure for comparison.

It can be seen from Figure 1(c) (n=4) that our analytical results for E(U_t) agree very well with the simulated results of Hall and Willink [3]. The simulated intervals or uncertainties are "approximate" because they are derived using the effective degrees of freedom estimated by the WS formula. In contrast, Eq. (5) may be considered as the "exact" expanded uncertainty because U_t is derived using the "true" effective degrees of freedom. Accordingly, its corresponding t-interval $[(\bar{x} + y) - t_{95,v}\, u_C, (\bar{x} + y) + t_{95,v}\, u_C]$ may be considered as the "exact" interval generated from a combined sample $(\varepsilon, u_C)_v$, which warrants the nominal coverage probability, 95%.

Figure 1 clearly shows the paradoxical behavior of the E(U_t) estimated by the WS-t approach. The paradoxical behavior is mostly obvious at n=2 in which E(U_t) decreases significantly with increasing σ_y for σ_y<1.5. The situation is similar at n=3 for σ_y<0.9, and n=4 for σ_y<0.5.

It can also be seen from Figure 1 that the z-based uncertainty U_z continuously increases with increasing σ_y; it does not exhibit the paradoxical behavior as E(U_t) does. Note that E(U_t) and U_z has a big discrepancy when σ_y is small (or the ratio α is small). However, E(U_t) converges to U_z when σ_y becomes large (or the ratio α becomes large). This is expected because when the ratio α is large, the uncertainty component having known variance and infinite degrees of freedom becomes dominant over the other uncertainty component having unknown variance and a small number of degrees of freedom.

The paradoxical behavior of E(U_t) reaffirms the existence of the Ballico paradox, which is an inherent property of the WS-t approach. However, the paradox is not due to the WS formula. The concept of the effective degrees of freedom and the WS formula are valid. The paradox is due to the use of the t-based uncertainty U_t as the expanded uncertainty. Jenkins [5] and Huang [6-8] independently revealed that the t-based uncertainty has large bias and precision errors with respect to the z-based uncertainty for small samples. Because of its large bias and precision errors, the use of the t-interval in uncertainty estimation caused the so-called uncertainty analysis paradox [7], i.e. the incompatibility of the t-based uncertainty with the z-based uncertainty. The incompatibility also results in a paradox in determining the minimum sample size needed for estimating the population mean with a maximum permissible error, which was discovered by Du and Yang [9]. As a matter of fact, the Ballico paradox is another representation of the uncertainty analysis paradox. Because of the paradoxes, the validity of

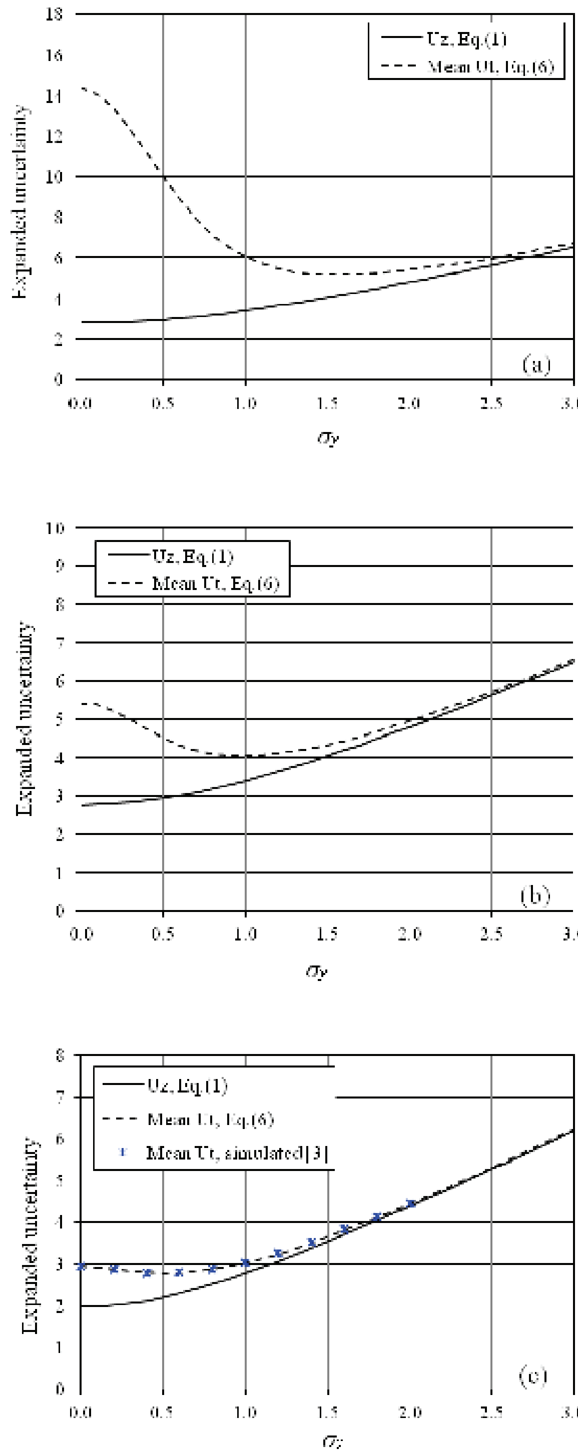

Figure 1. The mean of the t-based uncertainties and the z-based uncertainty as a function of σ_y: (a) n=2, (b) n=3; (c) n=4.

the t-based uncertainty (or the t-interval) for uncertainty estimation becomes questionable. A recent study [10] suggested that: "…the measurement quality control based on the t-based uncertainty is overly conservative and may be misleading when the sample size is very small. ..." Thus, the t-based uncertainty is not appropriate for uncertainty-based measurement quality control [10, 11]. In addition, it should be mentioned that, most recently, the journal *Basic and Applied Social Psychology* has banned the use of the null hypothesis significance testing procedure (p-values, t-values, and F-values) and confidence intervals [12]. The ban is on the t-interval or sample-based intervals, not on the z-interval or population-based intervals [13].

The Proposed WS-z Approach

This section presents an alternative approch to the WS-t approach to expanded uncertainties. It should be pointed out that, if both σ_x and σ_y are known, the "true" combined standard uncertainty $\sigma_C = \sqrt{\sigma_x^2 / n + \sigma_y^2}$ is known and $U_z = z_{95}\, \sigma_C = z_{95}\sqrt{\sigma_x^2 / n + \sigma_y^2}$ is the "true" expanded uncertainty. It is important to note that, U_z is a *population quantity* because it depends on the population parameter σ_C. Thus, the estimation of U_z is mathematically equivalent to the estimation of σ_C. For the two-sample problem considered, σ_x is unknown and σ_y is known. We introduce an estimator of σ_C, denoted by $\hat{\sigma}_C$, which is assumed to have a general form

$$\hat{\sigma}_C = C_{\hat{v}}\, u_C = C_{\hat{v}}\sqrt{\frac{s_x^2}{n} + \sigma_y^2} \tag{7}$$

where $C_{\hat{v}}$ is the estimator coefficient that depends on the estimation criterion based on which the estimator $\hat{\sigma}_C$ is developed and the effective degrees of freedom estimated by the WS formula. Accordingly, U_z can be estimated by an uncertainty estimator, denoted by $\hat{U}_z$:

$$\hat{U}_z = z_{95} C_{\hat{v}}\, u_C = z_{95} C_{\hat{v}}\sqrt{\frac{s_x^2}{n} + \sigma_y^2}\,. \tag{8}$$

Equation (8) is a counterpart of the uncertainty estimator presented in [11] for the one-sample problem that deals with one uncertainty component only. It is referred to as the WS-z approach to the expanded uncertainty for the two-sample problem. It can be seen from Eqs. (7) and (8) that, the estimation of the uncertainty U_z turns out to be the estimation of the combined standard uncertainty σ_C using the estimator $\hat{\sigma}_C$, to which the classical theory of parameter estimation for population standard deviation applies.

It should be pointed out that, similar to the point estimation of the population standard deviation from a sample standard deviation which does not involve a coverage probability specification (or statement), the estimator $\hat{U}_z$ should not be interpreted by the concept of confidence intervals with a stated coverage probability. Instead, $\hat{U}_z$ is an estimator of U_z; it is to be developed based on an estimation criterion.

Huang [11] addressed a number of estimation criteria for developing uncertainty estimators for the one-sample problem, including the mean-unbiased criterion, median-unbiased criterion (i.e. the risk balance criterion), minimum mean absolute error criterion, and minimum mean squared error criterion. In principle, any of these criteria can also be used to develop an estimator $\hat{U}_z$ (or $\hat{\sigma}_C$) for the two-sample problem considered; each of the criteria will yield a unique uncertainty estimator. In the following, we present a median-unbiased estimator and a mean-unbiased estimator. A median-unbiased estimator is considered to be the optimal estimator for uncertainty-based measurement quality control, whereas the mean-unbiased estimator may be preferred when the unbiasedness is desirable in estimating the z-based uncertainty [11].

The Median-Unbiased Estimator

A median-unbiased estimator for the two-sample problem can be developed based on the recently developed acceptance probability approach to quantifying the risk in the decision-making (to accept or reject a measured value) with the risk balance criterion [11]. The risk balance criterion yields a balance between the false acceptance and false rejection when the measurement quality index (MQI) is equal to unity [11]. For the two-sample problem considered in this study, the risk balance criterion is $\Pr(\hat{U}_z / U_z \le 1) = 50\%$, which is equivalent to $\Pr(\hat{\sigma}_C / \sigma_C \le 1) = 50\%$, i.e.

$$P_a = \Pr\left(\sqrt{\hat{v}}\,\frac{u_C}{\sigma_C} \le \frac{\sqrt{\hat{v}}}{C_{\hat{v}}}\right) = 50\% \tag{9}$$

where the quantity $\sqrt{\hat{v}}(u_C / \sigma_C)$ is assumed to follow the Chi distribution with $\hat{v}$ degrees of freedom, and P_a is the cumulative probability function of the Chi distribution (or the Chi-square distribution) with $\hat{v}$ degrees of freedom. Eq. (9) yields a median-unbiased estimator of U_z, denoted by U_{med}

$$U_{med} = z_{95} C_{med}\, u_C = z_{95} C_{med}\sqrt{\frac{s_x^2}{n} + \sigma_y^2} \tag{10}$$

where C_{med} is the coefficient that can be derived in the same way as that for the one-sample problem discussed in [11]

$$C_{med} = \left(1 - 0.0167\, e^{-0.9(\hat{v}-1)}\right)^{-1}\left(1 - \frac{2}{9\hat{v}}\right)^{-\frac{3}{2}}. \tag{11}$$

The Mean-Unbiased Estimator

For the two-sample problem considered, the mean-unbiased criterion is: $E(\hat{U}_C) = U_C$, which is equivalent to: $E(\hat{\sigma}_C) = \sigma_C$. Let U_{mean} denote the mean-unbiased estimator. It is readily derived that

$$U_{mean} = \frac{z_{95}}{c_{4,\hat{v}}}\, u_C = \frac{z_{95}}{c_{4,\hat{v}}}\sqrt{\frac{s_x^2}{n} + \sigma_y^2}\,. \tag{12}$$

The acceptance probability P_a at MQI=1for the mean-unbiased estimator can be calculated as

$$P_a = \Pr(\sqrt{\hat{\nu}}\,\frac{u_C}{\sigma_C} \le c_{4,\hat{\nu}}\,\sqrt{\hat{\nu}}\,). \quad (13)$$

Compare Eq. (13) with Eq. (9). Apparently, $P_a \neq 50\%$ for the mean-unbiased estimator. The P_a value at MQI=1 for an estimator is a performance measure of the estimator from the measurement quality control perspective [11].

The proposed WS-z approach, which includes the two estimators U_{med} and U_{mean}, provides a compatible and reasonable estimation of expanded uncertainties. Both estimators do not exhibit the paradoxical behavior as the t-based uncertainty does. Note again that the expectation of U_{mean} is approximately U_z. The expectation of U_{med} is

$$\mathrm{E}(U_{med}) = z_{95} C_{med}\,\mathrm{E}(u_C) = z_{95}\, c_{4,\hat{\nu}}\, C_{med}\, \sigma_C = c_{4,\hat{\nu}}\, C_{med} U_z \quad (14)$$

which is only $1.19U_z$ at n=2, 1.02 U_z at n=5, and 1.01 U_z at n=10. The expectation of U_{mean} or U_{med} is much smaller than the expectation of U_t for small samples with low α values.

In addition, for the sake of comparison, the t-based uncertainty U_t is treated as an uncertainty estimator of the form Eq. (8). That is: $U_t = z_{95}(t_{95,\hat{\nu}} / z_{95})u_C$. Thus, $C_{\hat{\nu}} = t_{95,\hat{\nu}} / z_{95}$. The P_a at MQI=1 for U_t can be calculated as

$$P_a = \Pr\left(\sqrt{\hat{\nu}}\,\frac{u_C}{\sigma_C} \le \sqrt{\hat{\nu}}\,\frac{z_{95}}{t_{95,\hat{\nu}}}\right). \quad (15)$$

Performance Evaluation

The performance of an uncertainty (or interval) estimator should be measured and evaluated by a performance criterion. In principle, a performance criterion consists of two components: a performance measure (i.e. what is to be assessed) and the ideal level of the performance measure.

Hall and Willink [3] judged their simulation results using the "coverage" criterion, in which the coverage probability, interpreted as the long-run success rate, is taken as the performance measure and its nominal value (say 95%) as the ideal performance level. On one hand, they suggested that the anomalous behavior showed by their simulations be acceptable because the coverage criterion was met. On the other hand, they stated that: "We have also emphasized that other performance criteria may be chosen with respect to the distribution of the widths of the intervals, in particular that smaller intervals are preferred." Note again that Hall and Willink [3] didn't resolve the Ballico paradox, although their results met the coverage criterion. Since the coverage criterion does not help resolve the Ballico paradox, its validity as the performance measure is questionable. In addition, it should be mentioned that, Bayesians do not accept the long-run success rate as a measure of the performance of intervals [14, 15]. The interpretation of the coverage probability has been a long-lasting debate between frequentists and Bayesians (e.g. [14-20]).

In this study, we used three alternative criteria, each of which is from a specific perspective. The first criterion uses the acceptance probability P_a as a performance measure; its ideal performance level is P_a=50%; it is from the decision-making risk balance perspective [11]. The formulation of P_a for the three estimators (including U_t for comparison) has been shown in the previous section. The second criterion uses the relative bias error (RBE) with respect to U_z as a performance measure; RBE is defined as the ratio between $[\mathrm{E}(\hat{U}_z) - U_z]$ and U_z; its ideal performance level is zero; it is from the unbiasedness estimation perspective. The third criterion uses the root mean squared percentage error ($RMSPE$) respect to U_z as a performance measure; $RMSPE$ is defined as the ratio between the square root of the mean square error (MSE) and U_z: $RMSPE = \sqrt{MSE}\ /\ U_z = \sqrt{\mathrm{E}[(U_z - \hat{U}_z)^2]}\ /\ U_z$; its ideal performance level is also zero; it is from the estimation accuracy perspective. It should be pointed out that either bias error (e.g. RBE) or mean squared error (e.g. $RMSPE$) is the most common measure of performance of an estimator in statistical estimation. Either the unbiasedness or the least squares criterion is a general principle which has been widely used in practice. For example, $RMSPE$ has been commonly used in measuring the accuracy of forecast methods (e. g. [21, 22]). Table 1 shows the formulas for RBE and $RMSPE$ of the three uncertainty estimators.

In our opinion, the three performance criteria used are intuitive, easy to understand, and more meaningful than the coverage criterion. The physical meaning of P_a is related to the risk (Type I or Type II error) in the decision making in

Uncertainty Estimator	*RBE*	*RMSPE*
U_t (WS-t approach)	$c_{4,v}\,(t_{95,v} / z_{95}) - 1$	$\sqrt{1 - 2c_{4,v}\,(t_{95,v} / z_{95}) + (t_{95,v} / z_{95})^2}$
U_{mean} (WS-z approach)	zero	$\sqrt{(1 - c_{4,v}^2)}\,/c_{4,v}$
U_{med} (WS-z approach)	$c_{4,v}C_{med} - 1$	$\sqrt{1 - 2c_{4,v}C_{med} + C_{med}^2}$

Table 1. Formulas for *RBE* and *RMSPE* of the three uncertainty estimators.

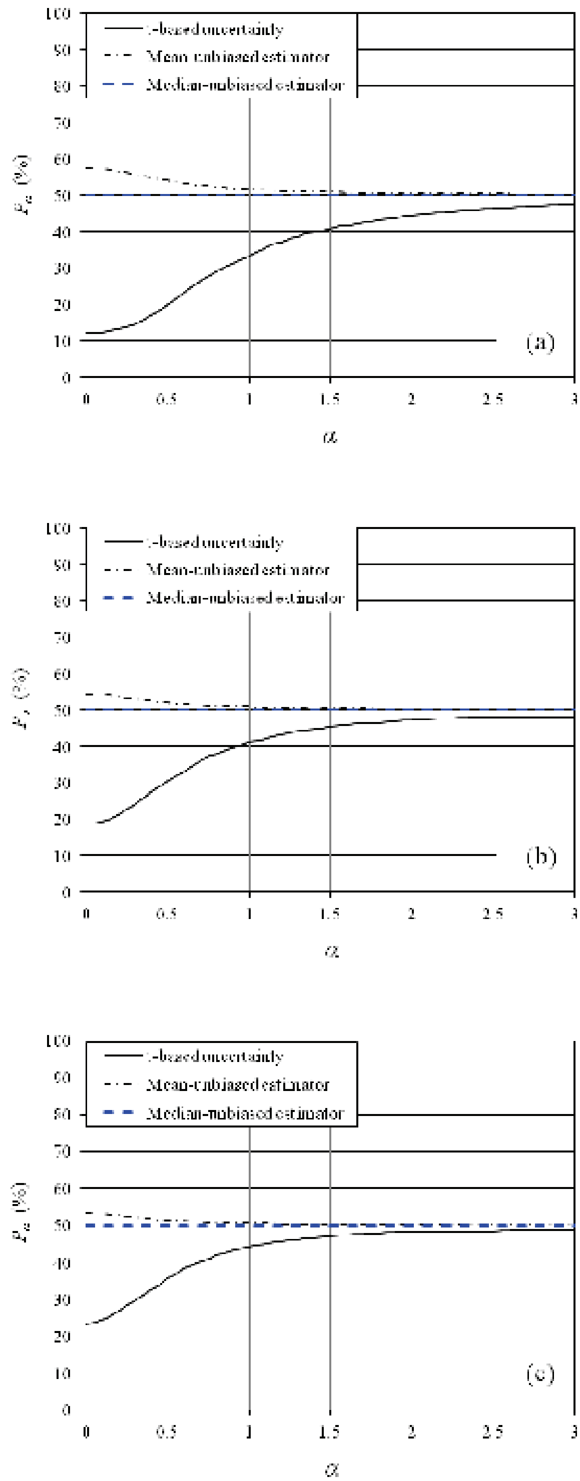

Figure 2. Comparison for P_a of the three uncertainty estimators at *MQI*=1: (a) *n*=2; (b) *n*=3; (c) *n*=4.

uncertainty based measurement quality control. According to [10], at *MQI*=1, 1-P_a is the false rejection probability; however, when *MQI* is just slightly smaller than unity, P_a becomes the false acceptance probability. Thus, the risk balance criterion is P_a = 50% at *MQI*=1, which results in the median-unbiased estimator U_{med}. Any other estimators would have $P_a \neq$ 50%, which would lead to an unbalanced risk in the decision making.

The physical meaning of *RBE* or *RMSPE* is clear by its definition. *RBE* measures the bias of an estimator with respect to U_z; *RMSPE* measures the overall error with respect to U_z. The mean-unbiased estimator U_{mean} meets *RBE*=0. The other estimators would have *RBE* ≠ 0. However, none of the three estimators meets *RMSPE*=0. An uncertainty estimator that meets R*MSPE*=0 for the one-sample problem was presented in [11]; it is only slightly different from its counterpart median or mean-unbiased estimator. Therefore, the estimator $\hat{U}_z$ that meets *RMSPE*=0 for the two-sample problem can also be developed, but it is not discussed in this paper.

Figure 2 shows a comparison for P_a at *MQI*=1 of the three uncertainty estimators considered. It can be seen from Figure 2 that, as expected, the median-unbiased estimator yields P_a=50 %, leading to the false acceptance probability 50% or the false rejection probability 50%. The mean-unbiased estimator would yield a slightly higher false acceptance probability (P_a) (e.g. 57.5% at *n*=2, 54.4% at *n*=3, and 53.3 % at *n*=4 for α=0) than the median-unbiased estimator. However, U_t would yield very high false rejection probability (1-P_a) (e.g. 87.7 % at *n*=2, 81.3% at *n*=3, and 76.8% at *n*=4 for α=0). Thus, the risk in the decision-making based on U_t would be high, particularly for small samples and low α values.

Figures 3 and 4 show the plots for *RBE* and *RMSPE* respectively. It can be seen from Figures 3 and 4 that, among the three uncertainty estimators, U_t has the highest *RBE* (which is a positive bias), and the highest *RMSPE*. Its *RBE* is as high as 417%, 94.6%, and 49.6 at *n*=2, 3, and 4 respectively; its *RMSPE* is as high as 572 %, 139%, and 80.3% at *n*=2, 3, and 4 respectively. But its *RBE* and *RMSPE* decreases rapidly as α increases. Apparently, U_t is not a good estimator under the criterion of minimizing *RBE* or *RMSPE*. As expected, the *RBE* of the mean-unbiased estimator is zero. The *RBE* of the median-unbiased estimator is very small and decreases with increasing α; it is less than 1% when α is greater than one. The *RMSPE* of the median-unbiased estimator is slightly greater than that of the mean-unbiased estimator; the *RMSPE* of the two estimators are about the same when α is greater than 0.5.

In summary, the performance of the presented median-unbiased estimator or the mean-unbiased estimator is superior to the *t*-based uncertainty, particularly for small α, or a small number of effective degrees of freedom (a small α value corresponds to a small number of effective degrees of freedom). Note that, at α=0, the two-sample

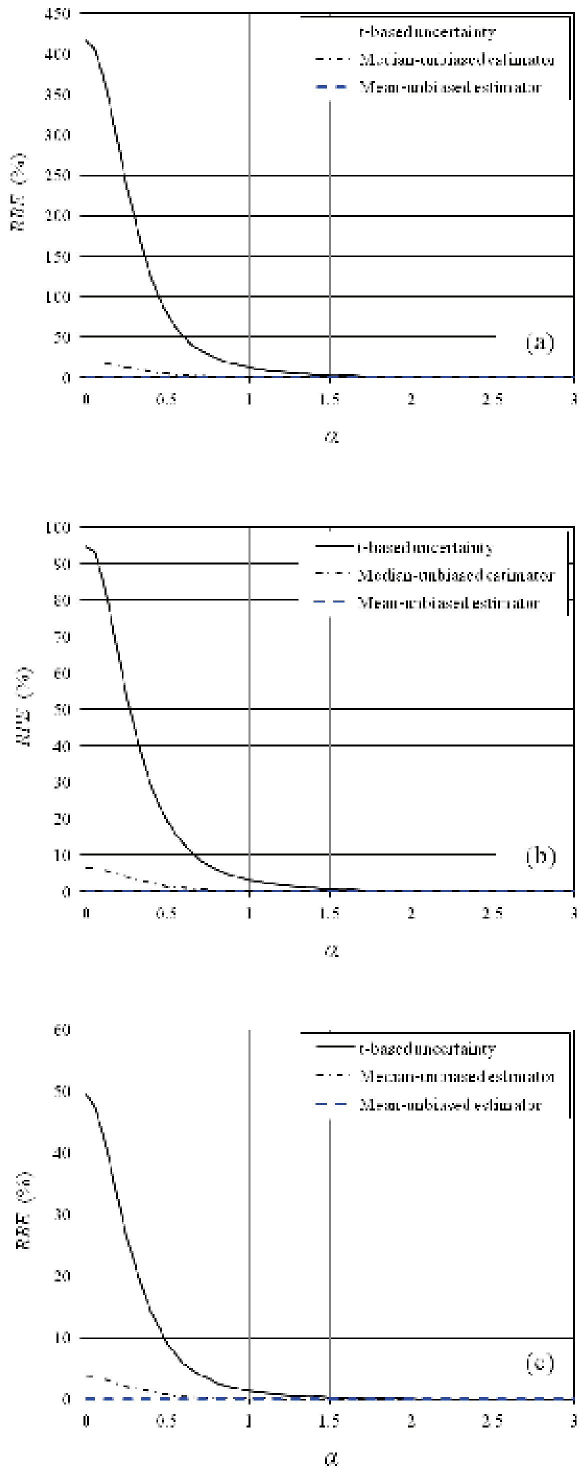

Figure 3. Comparison for *RBE* of the three uncertainty estimators: (a) n=2; (b) n=3; (c) n=4.

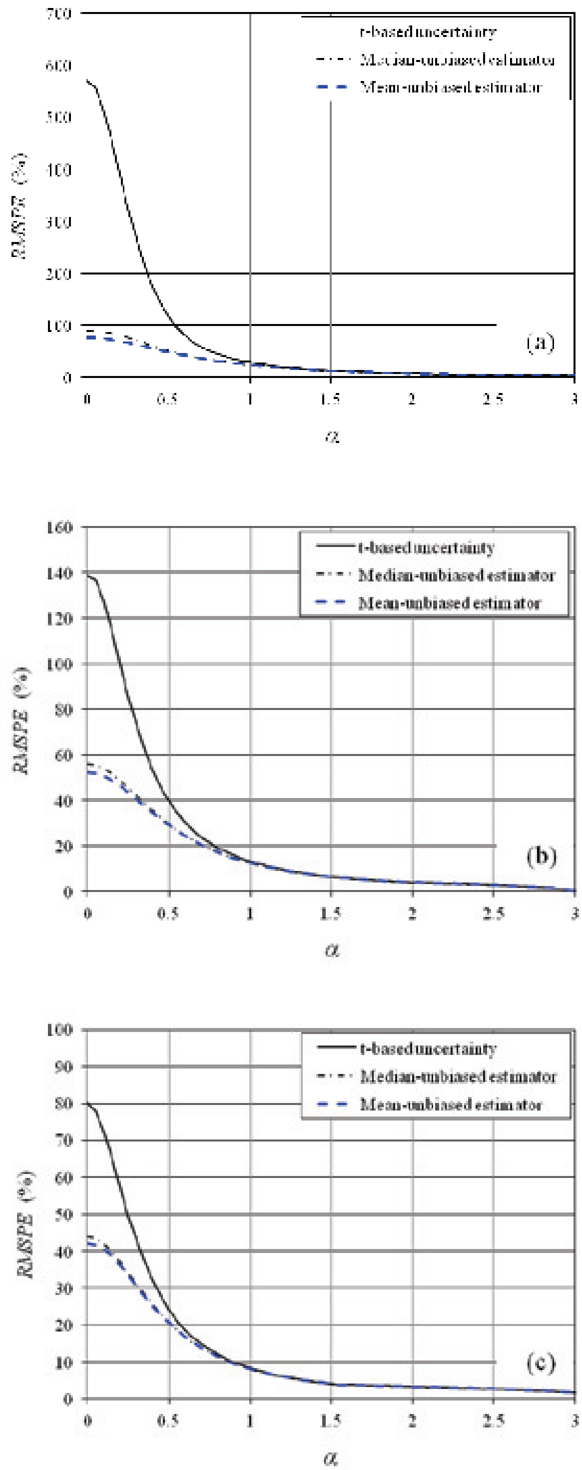

Figure 4. Comparison for *RMSPE* of the three uncertainty estimators: (a) n=2; (b) n=3; (c) n=4.

	u_c	$\hat{v}$	U_t	U_{med}	U_{mean}
1 mK range	12.22	3.22	37.39	26.73	25.75
10 mK range	14.36	6.05	35.07	29.78	29.34

Table 2. Expanded uncertainties estimated by the WS-*t* approach and those estimated by the proposed WS-*z* approach for the Ballico [1] calibration data.

problem is reduced to the one-sample problem, which has been discussed in [11]. The study [11] indicated that the performance of the *t*-based uncertainty is the worst among the eight estimators considered in the study for small samples. However, the performance of the either estimators is getting close as the sample size increases. The difference in performance between the eight estimators is negligible for sample size greater than 20. This conclusion also applies to the two-sample problem considered here. That is, the performance of U_{med}, U_{mean}, and U_t will be about the same for the effective degrees of freedom greater than 20.

Application Example

The proposed WS-*z* approach to the expanded uncertainty of the sum of two samples can be extended to a general case that involves multiple uncertainty components. That is, $\hat{U}_z = z_{95} C_{\hat{v}}\, u_c$ can be used for a combination of multiple uncertainty components. As an application example, we consider the high-precision thermometer calibration data presented in Ballico [1]. Table 2 shows the expanded uncertainties estimated by the WS-*t* approach and those estimated by the proposed WS-*z* approach.

It can be seen from Table 2 that the U_t of the 1 mK range is higher than that of the 10 mK range, which is clearly counter-intuitive as discussed in Ballico [1]. In contrast to U_t, either U_{med} or U_{mean} of the 1 mK range is lower than that of the 10 mK range, which agrees with common sense. As expected, U_{med} is slightly greater than U_{mean}. The proposed WS-*z* approach resolves the Ballico paradox.

Conclusion

This study reaffirmed the existence of the Ballico paradox, which is an inherent property of the WS-*t* approach. However, the Ballico paradox is not due to the WS formula. The WS formula is valid for estimating the effective degrees of freedom; the Ballico paradox is due to the use of the *t*-based uncertainty (or the *t*-interval) in uncertainty estimation. Thus, the WS-*t* approach should not be used to estimate expanded uncertainties unless the effective degrees of freedom are large, say, greater than 20.

The proposed WS-*z* approach to expanded uncertainties employs an uncertainty estimator in conjunction with the effective degrees of freedom estimated by the WS formula. It is essentially based on the classical theory of statistical estimation. Two uncertainty estimators are presented for the two-sample problem considered: the median-unbiased estimator and the mean-unbiased estimator. Either of the estimators provides a compatible and reasonable estimation of expanded uncertainties. Both estimators do not exhibit the paradoxical behavior as the *t*-based uncertainty does. The analysis results indicate that the performance of the two estimators is superior to the *t*-based uncertainty, particularly for a small number of effective degrees of freedom. The two uncertainty estimators can be extended to a general case that involves multiple uncertainty components. The proposed WS-*z* approach leads to the resolution of the Ballico paradox.

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Appendix: Derivation of the Effective Degrees of Freedom ν, Eq. (4)

For the two-sample problem considered in this study, the combined standard uncertainty is estimated as $u_C = \sqrt{s_x^2/n + \sigma_y^2}$. Accordingly, the estimated combined variance is

$$u_C^2 = \frac{s_x^2}{n} + \sigma_y^2. \tag{16}$$

The ratio between the estimated variance and the true variance is

$$\frac{u_C^2}{\sigma_C^2} = \frac{\frac{s_x^2}{n} + \sigma_y^2}{\frac{\sigma_x^2}{n} + \sigma_y^2}. \tag{17}$$

Substitute $\sigma_y^2 = \alpha^2\sigma_x^2$ $(\alpha = \sigma_y/\sigma_x)$ into Eq. (17). After rearranging, we have

$$\frac{u_C^2}{\sigma_C^2} = \frac{1}{(1 + n\alpha^2)}\frac{s_x^2}{\sigma_x^2} + \frac{n\alpha^2}{(1 + n\alpha^2)}. \tag{18}$$

Assume that $\nu(u_C^2/\sigma_C^2)$ approximately follows a Chi-square distribution χ_ν^2 with ν degrees of freedom. That is $\nu(u_C^2/\sigma_C^2) \propto \chi_\nu^2$. The expectation of $\nu(u_C^2/\sigma_C^2)$ is ν, the same as the expectation of χ_ν^2. The variance of $\nu(u_C^2/\sigma_C^2)$ is

$$\begin{aligned} Var[\nu\frac{u_C^2}{\sigma_z^2}] &= \nu^2 Var[\frac{1}{(1 + n\alpha^2)}\frac{s_x^2}{\sigma_x^2} + \frac{n\alpha^2}{(1 + n\alpha^2)}] \\ &= \frac{\nu^2}{(1 + n\alpha^2)^2}\frac{Var[s_x^2]}{\sigma_x^4} \\ &= \frac{\nu^2}{(1 + n\alpha^2)^2}\frac{2}{(n-1)}. \end{aligned} \tag{19}$$

On the other hand, the variance of χ_ν^2 is 2ν. By matching the variance of $\nu(u_C^2/\sigma_C^2)$ with the variance of χ_ν^2, the effective degrees of freedom ν can be determined as $\nu = (n-1)(1 + n\alpha^2)^2$, i.e. Eq. (4).

It should be pointed out that ν is a population parameter because it depends on the population parameters σ_y and σ_x. In the two-sample problem considered in this study, σ_y is known; σ_x is unknown and is estimated by s_x; $\hat{\nu}$ is an estimator of ν, i.e. Eq. (3) is a special case of the WS formula.

Calibrating Liquid Flow Instruments Beyond +5 °C to +90 °C — Part 1

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York Xu, Osborne Gumbs, Tammy Tran
Proteus Industries Inc.

This article is the first of a series describing how to perform liquid flow rate calibrations at fluid temperatures below +5°C and above +90 °C. We will examine closed-loop recirculating liquid flow rigs with master flow meters for the calculations of Measurement Uncertainty for Mass Flow and Volumetric Flow, as well as the density influence on the Volumetric Flow (Vol Flow = Mass Flow/Density) and the viscosity influence on Volumetric Flow sensed by the Unit-Under-Calibration. The fluid temperature ranges during the flow rate calibration will extend from -40 °C to +5 °C and +90 °C to +200 °C. In this article, Coriolis meters serve as the master flow references for calibrating a paddlewheel/turbine meter. Viscosity and density of the fluid in the flow rig is measured to establish the behavior of the fluid sample at different temperatures and ensure the confidence of the Coriolis meter density measurement for fluid temperatures outside of the +5 °C to +90 °C range typically used for flow rate sensor calibrations. In addition, we will address other factors that influence Volumetric Flow.

Why Flow Measurement Is Important

Errors in flow measurement can have a direct impact on industries such as power, manufacturing, and medical industries. Utilities' operational integrity is put at risk, whenever safety margins are decreased based upon projected lower flow measurement uncertainties for fluid temperatures above +90 °C, in an effort to increase power plant output. Petroleum pumping errors account for upwards of $100 billion per year because fluid flow measurements are not questioned until exceeding 3% difference at point of transfer (on or off ships, in or out of transfer terminals, out of gas pumps, etc.). Manufacturing process yields may not increase because cooling fluid thermal energy transfers do not happen as predicted for fluid temperatures below +5 °C and above +90 °C. The safety and well-being of patients is put at risk where drug dosage delivery equipment is inaccurate or calibrated improperly. These are just a few examples how flow measurement impacts multiple industries and why it is so important to understand volumetric flow outside the typical range of temperature during calibration.

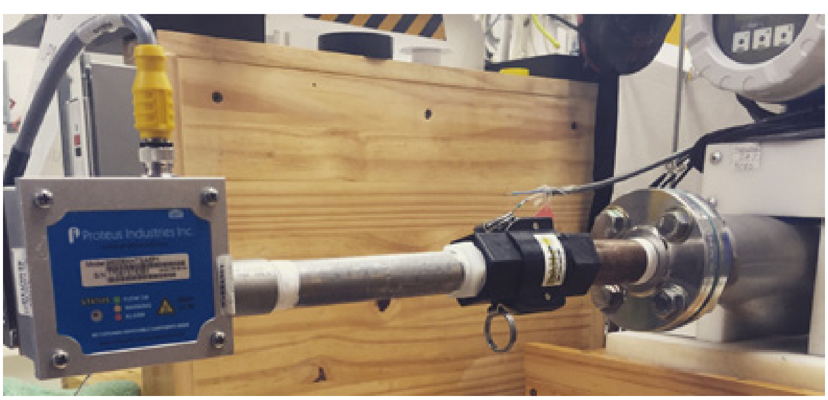


Figure 1. Calibrating Proteus Flow Meter with Master Meter, E+H Coriolis Meter, with temperatures outside of +5 °C to 90° C.

Approach to the Problem

To ensure 1.5% of reading for the Unit-Under-Test (UUT), an ISO 17025 Measurement Uncertainty of 0.375% of reading is required to achieve a Z540.3 Handbook <2% False Acceptance (using a 4:1 Test Uncertainty Ratio). (Harben & Reese, 2011) This system budget Measurement Uncertainty will be exceeded, and corrected, in the +187 °C example below.

Calibrating liquid flow instruments with room temperature water or other fluids is a challenge in its own right. Many flow and calibration laboratories work with room temperature fluids in flow ranges from Nano liters per hour to Mega liters per minute. In addition, flow instrument manufacturers work with water temperatures from +5 °C to +90 °C; and thus use mathematical analysis & curve projections to describe instrument performance, behavior & estimated error, below +5 °C & above +90 °C fluid temperature ranges.

Direct comparison is accomplished with flow reference, timed dispense flow dump, weigh standard, standing pipe, etc. However, using an in-line flow reference is the simplest and most cost effective method and can provide excellent results (see Figure 1).

Checklist for All Measurements

Below are key criteria and a simple checklist to review when going through the calibration process. One may use these methods to obtain the best measurements from the meter. For example, a Coriolis meter was used to measure fluid density at +180 °C but was only calibrated at +20 °C water; the result was a density measurement of 0.8266 g/cc versus an expected density of 0.7001 g/cc – capable of measurement but not calibrated for intended use.

- Is meter capable of measuring parameter range?
- Is meter capable of measuring parameters in temperature range?
- Is meter calibrated to measure parameter range in temperature range?
- Is measurement uncertainty calculated for parameters in temperature range?
- Can measurement & uncertainty be proven?

What About Coriolis Meters?

Mass & Volumetric Flow

Coriolis meters directly measure mass flow (mass/time) and density (mass/volume) which makes mass flow and density values as derived units from primary unit (mass, time, length in 3 directions for volume) measurements. Volumetric flow is calculated by dividing the mass flow by its density, making volumetric flow a calculated measurement: volume/time = mass/time / mass/volume. Depending upon the process, one measurement is more desirable than the other. Either measurement can be verified using timed dispense into a container, for example, a bucket and stopwatch. More on assessment of flow at temperature will be discussed in detail in the next series of articles that will address the topic of verifying flow by timed dispense at room temperature water; +5 °C to +20 °C water, +20 °C to +90 °C water, <0 °C fluid, >+90 °C fluid.

Measurement Uncertainty

The Measurement Uncertainty is calculated at room temperature and then further extended to the desired temperature, per the manufacturer's error calculation and specifications (American Society of Mechanical Engineers, 2006). However, the issue is not all Coriolis meter manufacturers state their error using the same principle, thus obscuring measurement uncertainty calculations. Coriolis meters accuracy specifications can include the combination of linearity, repeatability, hysteresis, and zero stability. If zero stability is given as a separate parameter, mass per time and zero stability must be calculated for each flow point and added to the combined effects of linearity, repeatability, and hysteresis (ISO, 2015).

Source	Type	Distribution Factor to Convert to Statistical Type Data
Coriolis Repeatability	A	1
Coriolis Systemic	B	0.5774 = 1/sqrt(3), unless proven otherwise
Coriolis Cal Lab	B	0.5774 = 1/sqrt(3), unless proven otherwise
UUT Flow Rig Stability (Std Dev of 10 readings)	A	1
UUT Flow Rig Systemic (Offset of control signals)	B	0.5774 = 1/sqrt(3), unless proven otherwise

Table 1. General Measurement Uncertainty Formula. $U_e = k * (U_a^2 + U_b^2)^{1/2} = k * (U_{a1}^2 + U_{a2}^2 + \ldots + U_{b1}^2 + U_{b2}^2 + \ldots)^{1/2}$, *Expanded Combined Uncertainty* (NIST, 1994).

Source	Equation (accepted form)
Coriolis Systemic Mass Flow	+/-0.1% +/-[(zero stability / measured valued) * 100]% o.r.
Coriolis Repeatability Mass Flow	+/-0.05% +/-[1/2*(zero stability / measured valued) * 100]% o.r.
Coriolis Systemic Volume Flow	+/-0.15% +/-[(zero stability / measured valued) * 100]% o.r.
Coriolis Repeatability Volume Flow	+/-0.05% +/-[1/2*(zero stability / measured valued) * 100]% o.r.
Influence of Medium Temperature	When there is a difference between the temperature for zero point adjustment and the process temperature, the typical measured error is +/-0.0002% of the full scale value/°C
Zero Point Stability	0.030 kg/h (0.001 lb/min)

Table 2 . Coriolis Error Source Equations per Manufacturer for a DN 8 (mm inlet/outlet orifice) (Endress + Hauser, 2013).

All Coriolis meters have zero point stability errors which effect mass flow measurement and can be eliminated by performing a zero stability calibration when the Coriolis meter is installed in the process; in this case, the flow rig. The zero stability calibration should be performed every time the Coriolis meter is moved to a different location or the process temperature may alter in comparison to the default calibration temperature; otherwise, the zero stability calibration error must be included in the measurement uncertainty calculation. Table 1 shows the General Measurement Uncertainty Formula for the entire flow rig. Table 2 shows Coriolis error source equations for a manufacturer's specification.

The Measurement Uncertainty for the Mass Flow of the Coriolis Meter on the UUT Flow Rig is calculated several ways. In Table 3, the best uncertainty for −29.8 °C fluid temperature is achieved for the Coriolis meter by running the zero point check at the process temperature. The new zero point compensates both mass flow and density measurements at the process temperature and eliminates the error caused by the temperature difference between the process and original lab calibration. It is important to remember to run the fluid at the process temperature for an extended time to allow the measuring tube and carrier tube RTDs to achieve a stable temperature, instead of using the Coriolis meter in a state of thermal shock. If the zero point is not run at the process temperature, then the influence of medium temperature error is included for the Coriolis meter. For a low process temperature of −29.8 °C, the additional error is 0.247% which results in the Uc (Expanded Combined Uncertainty) to change from 0.187% to 0.341% of reading (o.r.). On the other hand, for a high process temperature of +187.1°C, the additional error is 1.029% for an Uc of 1.213% of reading—a large change from 0.249% of reading and exceeds the system error budget of 0.375% for a 1.5% of reading calibration for UUT. Table 4 & Table 5 below show the additional error compensated in the Uc change for Mass Flow & Volumetric Flow.

Flow point (lb/min)	Coriolis Systemic Error (Type B)	Influence of Medium Temp (Type B); delta temp of zero point adjustment and the process temperature	Coriolis Repeatability (Type A)	Coriolis Cal Rig Error (Type B)	UUT Flow Rig Stability (Type A) std dev of actual 10 readings (avg std dev 0.0066)	UUT Flow Rig Systemic (Type B) offset from controlled signals (0.024% for 1 VDC)			
18.79	0.105%	0.000%*	0.053%	0.05%	0.04%	0.024%			
distribution factor	0.577	0.577	1.000	0.577	1.000	0.577		Combined Uncertainty	
applied distribution factor	0.061%	0.000%	0.053%	0.029%	0.04%	0.014%	sum of squares	RSS	Uc * K = 2
squared value	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.093%	0.187%

Table 3. Mass Flow Coriolis Meter DN 08 Measurement Uncertainty compensated for temperature at -29.8 °C.
*Z point check run at process temperature. For process temperatures of −29.8 °C, the additional error is 0.247% which results in Uc to change for 0.187% to 0.34% of reading.

Flow Point (lb/min)	Coriolis Systemic Error (Type B)	Influence of Medium Temp (Type B); delta temp of zero point adjustment and the process temperature	Coriolis Repeatability (Type A)	Coriolis Cal Rig Error (Type B)	UUT Flow Rig Stability (Type A) std dev of actual 10 readings (avg std dev 0.0075)	UUT Flow Rig Systemic (Type B) offset from controlled signals (0.024% for 1 VDC)			
8.84	0.111%	0.000%*	0.056%	0.05%	0.08%	0.024%			
distribution factor	0.577	0.577	1.000	0.577	1.000	0.577		Combined Uncertainty	
applied distribution factor	0.064%	0.000%	0.056%	0.029%	0.08%	0.014%	sum of squares	RSS	Uc * K = 2
squared value	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.124%	0.249%

Table 4. Mass Flow Coriolis Meter DN 08 Measurement Uncertainty compensated for temperature at +187.1 °C.
*Z point check run at process temperature. For process temperatures of +187.1 °C, the additional error is 1.029% which results in Uc to change for 0.249% to 1.213% of reading.

Flow Point	Coriolis Systemic Error (Type B)	Influence of Medium Temperature (Type B); delta temp of zero point adjustment and the process temperature	Coriolis Repeatability (Type A)	Coriolis Cal Rig Error (Type B)	UUT Flow Rig Stability (Type A) std dev of actual 10 readings (avg std dev 0.0075)	UUT Flow Rig Systemic (Type B) offset from controlled signals (0.024% for 1VDC)			
(8.84 lb/min) 1.34 GPM	0.161%	0.000%*	0.056%	0.05%	0.08%	0.024%			
distribution factor	0.577	0.577	1.000	0.577	1.000	0.577		Combined Uncertainty	
applied distribution factor	0.093%	0.000%	0.056%	0.029%	0.08%	0.014%	sum of squares	RSS	Uc * K = 2
squared value	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.141%	0.283%

Table 5. Volumetric Flow Coriolis Meter DN 08 Measurement Uncertainty compensated for temperature at +187.1 °C.
*Zero point check run at process temperature. For process temperatures of +187.1 °C, the additional error is 1.029% which results in Uc to change for 0.283% to 1.221% of reading.

Importance of Insulation

Insulation serves several purposes in the calibration process. It reduces energy consumption, allows higher or lower temperatures to be achieved, allows a more homogenous temperature inside the flow tubes of the units and reference, and ensures a similar temperature at the master reference and unit under calibration. Insulate flow path and insulate to prevent personnel scolding or freezing contacts with plumbing. Figures 2 shows frost build-up without insulation; Figure 3 shows frost-free condition with insulation installed.

Position of Flow Reference & Unit-Under-Calibration

To ensure the same results are independent of location of either instrument, swap positions of the calibration reference and unit-under-calibration. Swapping positions can be accomplished physically by altering the positions of the reference or unit. Alternatively, one may swap using ball valves to reroute flow in the designated path.

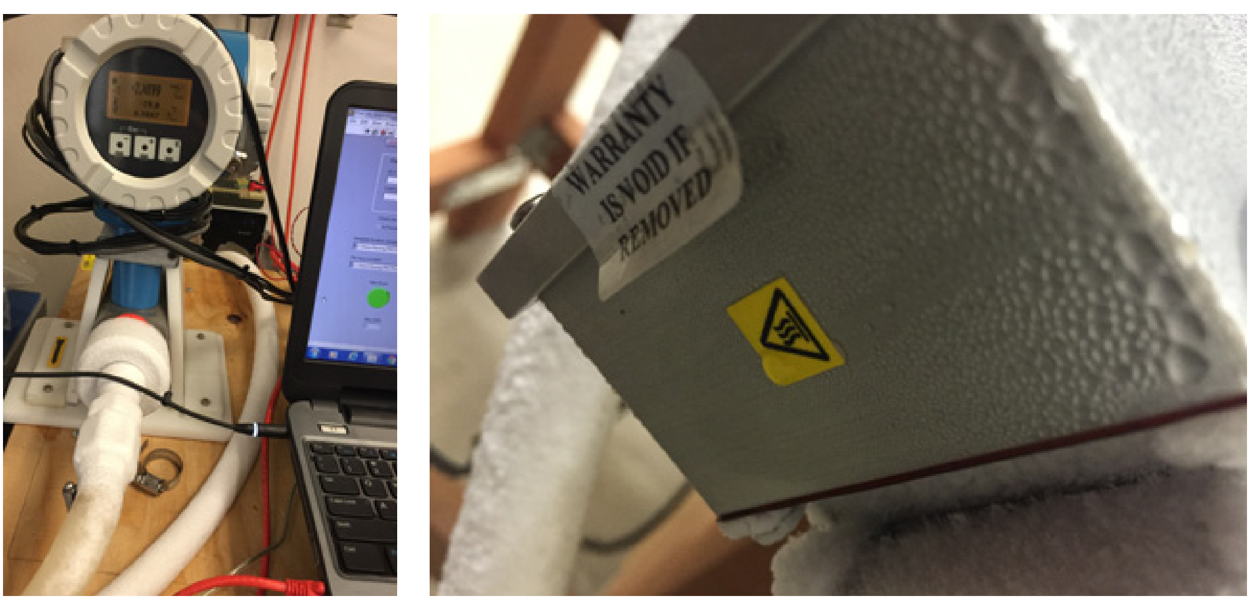


Figure 2. Calibration process without insulation, buildup of frost and freezing contacts.

Source	Equation
Coriolis Density Systemic	+/-0.01 g/cc std cal; 0.001g/cc special factory 0.0005 g/cc field density or reference conditions
Coriolis Density Repeatability	+/-0.00025g/cc
Coriolis Temperature Systemic	+/-0.5C+/-0.005 * T in °C +/-1F +/-0.005 * T in °F
Coriolis Temperature Repeatability	+/-0.25C +/-0.0025 * fluid Temp in °C +/-F+/-0.03*(T-32), T in °F

Table 6. Coriolis Density & Temperature Error Source Equations per Manufacturer (Endress + Hauser, 2013).

Density

Coriolis meters measure fluid density. The calibrated range must be specified (typically at time of purchase) or the Coriolis meter will only be calibrated at one fluid density and may not be capable of measuring the full intended density range. Laboratory calibration over the entire density range will ensure the density measurement is within known error limits; Table 6 shows density error sources with measurement uncertainty impacts. Table 7 shows an actual full density range calibration within tolerance. If measuring out of the calibrated range, then an error projection curve will need to be created—this will be examined in our future article on density measurement assessment.

Medium	Temp. (°F)	ρ target (kg/m³)	ρ meas. (kg/m³)	Δρ (kg/m³)	Freq. (Hz)
Air	74.0	1.20	1.98	0.78	574.2
Air	74.0	1.20	1.95	0.75	574.2
Air	73.9	1.20	1.92	0.72	574.2
Water	177.4	971.81	971.90	0.09	489.8
Water	177.4	971.82	971.89	0.07	489.8
Water	177.4	971.83	971.89	0.06	489.8
Water	140.2	983.32	983.24	-0.08	491.5
Water	140.2	983.32	983.24	-0.08	491.5
Water	140.2	983.33	983.24	-0.09	491.5
Water	104.5	992.28	991.96	-0.32	492.8
Water	104.5	992.29	991.95	-0.34	492.8
Water	104.5	992.30	991.97	-0.32	492.8
Water	85.9	995.77	995.29	-0.48	493.8
Water	85.9	995.78	995.30	-0.48	493.8
Water	85.8	995.79	995.30	-0.49	493.8
Water	67.9	998.32	997.82	-0.50	494.7
Water	67.9	998.32	997.82	-0.50	494.7
Water	67.9	998.32	997.82	-0.50	494.7
Water	40.4	1000.09	999.75	-0.34	496.3
Water	40.4	1000.09	999.77	-0.32	496.3
Water	40.4	1000.09	999.76	-0.33	496.3
Sodium polytungstate	73.3	1247.20	1247.19	-0.01	479.1
Sodium polytungstate	73.3	1247.21	1247.20	-0.01	479.1
Sodium polytungstate	73.3	1247.22	1247.19	-0.03	479.1
Sodium polytungstate	73.4	1819.45	1820.38	0.93	448.7
Sodium polytungstate	73.4	1819.45	1820.36	0.91	448.7
Sodium polytungstate	73.5	1819.47	1820.36	0.89	448.7
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-

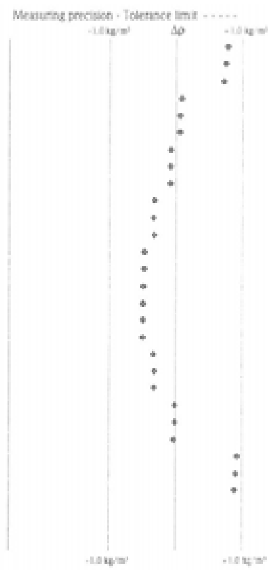
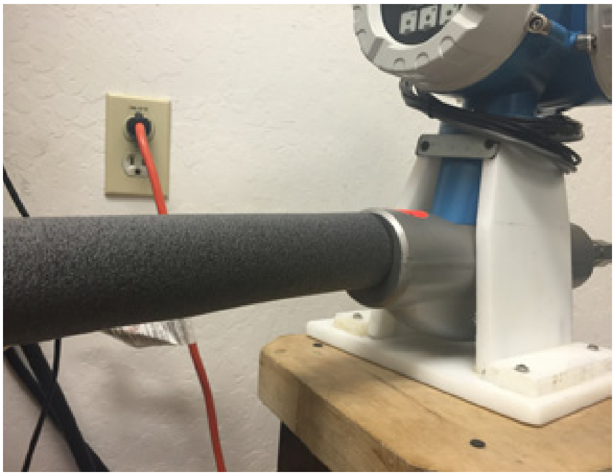


Table 7. Coriolis Meter Density Calibration Report Table (Endress + Hauser, 2016).



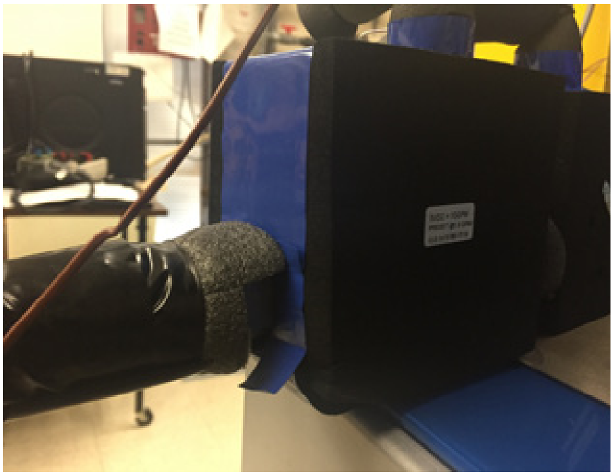


Figure 3. Calibration process with insulation and heat and cooling protection.

Density Verification

Check the density with town water at different temperatures with 2 to 3 flow rates versus the NIST Water Density Equation. The deviation from the water equation should be <0.1% of reading, <0.05% depending upon water quality. The density at different flow rates ensures gas entrapment, cavitation, and/or calibration error isn't present before proceeding to higher or lower temperatures and/or a larger density range.

Bench top density measurement comparisons of test fluid at target temperature(s) with 100cc standard cup, insulator plate, and scale can yield results with <0.1% error versus the NIST Water Density Equation Reference from ITS-90. Air-free water or air-saturated water at 24.5 °C is 0.9972~ g/cc with an uncertainty as high as 0.21kg/m3 for 1 °C uncertainty at 20 °C (Jones & Harris, 1992).

Additionally, Standards Reference Fluids allow us to measure a wide range of densities with <0.5%; however the temperature range can be limited from +10 °C to +100 °C or an even smaller range, depending upon the reference fluid. And reference fluids, other than water, for densities <1.0 g/cc may be toxic. Many other fluids do not have batch details for the actual density; the manufacturers provide a nominal behavior curve that usually doesn't have any measurement uncertainty data.

Temperature

A temperature standard is used to measure the fluid temperature for temperatures outside of the liquid water range (+5 °C to +90 °C) because the Coriolis meter fluid temperature error, Table 8, will impact the density measurement verification and the viscosity calculations.

Viscosity

When the flow measurement instrument is sensitive to changes in viscosity, the calibration fluid viscosity needs to be declared. Issues may arise because 1) the customer believes that a fluid's nominal viscosity curve is exact, 2) the customer application fluid temperature is a range and not a single temperature, 3) the surrogate fluid used in the calibration lab has a different viscosity change versus the application fluid over the application temperature range.

Coriolis Meter With Built-In Viscometer

Some Coriolis meters, typically DN 25 or larger, can have an in-line viscometer added. These in-line viscometers are part of the Coriolis meter flow assembly, limited to 10:1 ratios (such as 1 to 10 cP, 10 to 100 cP, etc.), may be temperature limited, and can double the cost of the Coriolis meter. Note, for a general fluid flow laboratory with many flow rigs, the single Coriolis meter with viscometer may restrict calibration applications.

Viscosity Verification

Water viscosity, using NIST Equations, has errors less than 1% to 7% depending upon the physical state of water (M. L. Huber, 2009). Standards Reference Fluids typically have <0.5% error but the temperature range can be limited from +10°C to +100°C or an even smaller range, depending upon the fluid. Many other fluids do not have batch details for the actual viscosity; the manufacturers provide a nominal behavior curve that usually doesn't have any measurement uncertainty data. Therefore, the viscosity value is only an estimate. For Syltherm XLT Fluid at +180°C, the viscosity can be interpolated from the graph in Table 9 but no measurement uncertainty can be stated for the viscosity value (The Dow Chemical Company, 1998). A future article will address viscosity at temperature.

Takeaways on Fluid Safety Fluid Choices

Whenever possible, use fluids that are edible, such as glycerol, propylene glycol, water. No toxicity fluids will ensure maximum safety. Remember that those same fingers used to handle the fluid may be touching your food that enters your mouth.

Fluid Handling

Wear protective garments, gloves, and masks as necessary to limit exposure to fluids.

Toxicity

Non-toxic fluids ensure a healthy life. However, some Standards Reference Fluids are toxic. So are Silicone Oils, ethylene glycol, petroleum and petroleum by products, and so forth. And, the fumes may be even worse than skin exposure.

Temperature Control & Insulation

Insulation is the barrier between people and extreme temperature plumbing and fluids that can burn or blister your skin or eyes. Insulation isn't just for temperature control!

Temperature in °C	-40.0	-29.8	0.0	20.0	153.1	187.1	200.0
Systemic Error	0.70	0.65	0.50	0.60	1.27	1.44	1.50
Repeatability	0.35	0.32	0.25	0.30	0.63	0.72	0.75

Table 8. Temperature Error Coriolis Calculated from manufacturer's error equations in Table 7.

Conclusion

It is accepted practice to use manufacturer error equations for Coriolis meters to account for the measurement uncertainty of measurements of Mass Flow, Volumetric Flow, Density, & Fluid Temperature outside of the +5 °C to +90 °C fluid temperature range; the error equations are estimated by projection and best practice is to consult with the manufacturer about the application. The Mass Flow Error can be reduced by running the Zero Stability check at the process temperature. The Coriolis meter must be calibrated for the density range to be measured otherwise the density measurement error is unknown and will adversely impact the Volumetric Flow Calculation. Insulation controls fluid temperature and is a safety measure for personnel. Fluid safety is a high priority when dealing with high & low temperature fluids because of potential dangerous toxicity through skin, eyes and lungs. Future articles will address assessing the fluid parameter measurements outside of the +5 °C to +90 °C fluid temperature range so that measurement uncertainty can be accurately stated with a calculated level of confidence.

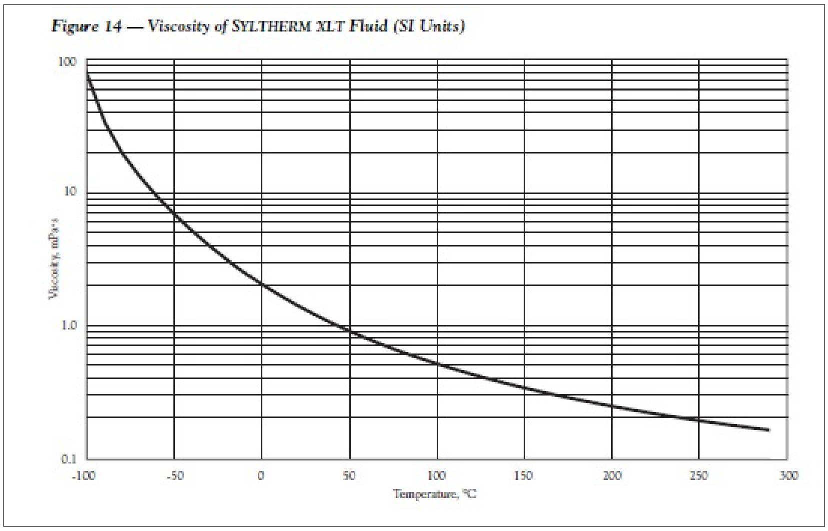


Table 9. Syltherm XLT Fluid Nominal Viscosity Curve

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Richard Fertell (r_fertell@proteusind.com), Hamed Ershad, York Xu, Osborne Gumbs, and Tammy Tran, Proteus Industries Inc., 340 Pioneer Way, Mountain View, CA, 94041.

The New ISO 17025 – DIS Stage

Dr. George Anastasopoulos
International Accreditation Service (IAS)

Background Information

As we discussed in my previous relative article "The New ISO 17025 – What to Expect," ISO/IEC 17025 was first issued in 1999 by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). It is the single most important standard for calibration and testing laboratories around the world, with more than 50.000 laboratories accredited, globally.

At the International Laboratory Accreditation Cooperation (ILAC) General Assembly in October 2013 the Laboratory Committee (which is composed of stakeholder representatives of accredited testing and calibration) recommended that ILAC request that ISO/CASCO establish a new work item to comprehensively revise ISO/IEC 17025:2005. CASCO is the ISO committee that works on issues relating to conformity assessment. CASCO develops policy and publishes standards related to conformity assessment; it does not perform conformity assessment activities. CASCO's standards development activities are carried out by working groups made up of experts put forward by the ISO member bodies. The experts are individuals who possess specific knowledge relating to the activities to be undertaken by the working group (WG).

The 5th ISO/CASCO WG 44 meeting was held on September 20-23, 2016 in Geneva. 96% of CASCO members voted in favor of the CD2 to move to the Draft International Stage (DIS). Fifty-three (53) experts representing certification/accreditation bodies and stakeholders from all over the world participated in that meeting. The deliverable of this meeting was the DIS version of the new ISO/IEC 17025 version. Up to the moment that this article was finalized, the DIS text was not yet released by ISO/CASCO secretariat, so the references to standard clause numbers listed in this article may be changed.

The Draft International Standard (DIS) will be translated and then circulated to all national ISO member bodies for comment and vote. Typically, the national bodies' mirror committees are responsible for monitoring and participating in the work of the relevant ISO committee. At this stage it is anticipated that the DIS will be released by the end of this year.

The DIS can be approved if two-thirds of national member bodies are in favor and not more than one-quarter of the total number of votes cast are negative.

If the DIS is approved the project could go straight to publication. However, should the draft be significantly revised following comments at the DIS stage (even if the DIS has been approved) a decision may be made to prepare a Final Draft International Standard (FDIS) and circulate it to national member bodies for a further vote. In any case the new ISO 17025 is expected to be published in 2017.

DIS Changes

The format of the new standard will be significantly changed to be more in line with new ISO formatting guidelines. The basic format is similar to other new standards such as ISO/IEC 17020 and ISO/IEC 17065.

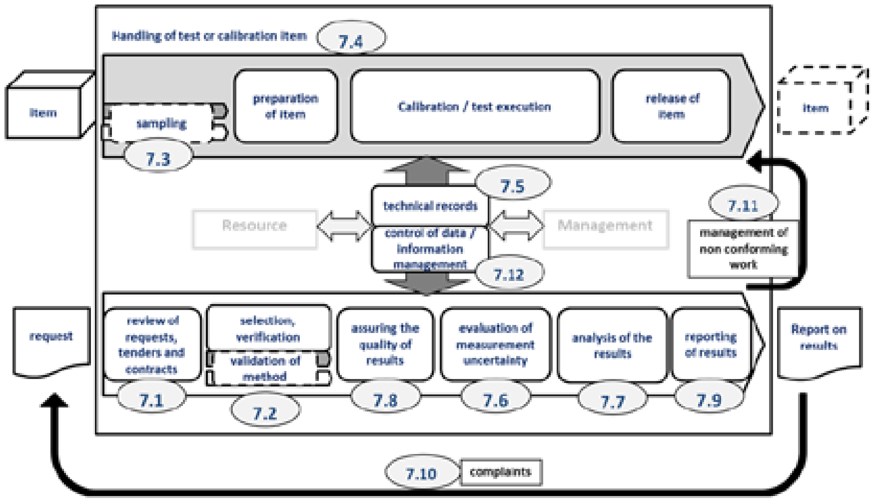
The new DIS is now structured as follows:

1. Scope
2. Normative references
3. Terms and definitions
4. General requirements
5. Structural requirements
6. Resource requirements
7. Process requirements
8. Management requirements
    - Annex A – Metrological Traceability (Informative)
    - Annex B – Management System (Informative)
    - Bibliography

Changes in the Requirements of ISO 17025/DIS

In addition to the changes decided in the previous standard stage, as described in details to my previous article, the following new changes were introduced to the DIS:

- Term "process" is not used in DIS except on the title of chapter 7 "Process requirements" and 7.10 (regarding complaint handling process) where the text is defined from the CPC (Policy Committee).
- Definitions for verification, validation shall not be included in the standard (reference to International Vocabulary of Metrology – Basic and General Concepts and Associated Terms-VIM 3rd edition). WG agreed that to avoid any confusion between "verification & validation" as a conformity assessment activity and the other usages, the definitions were deleted.



- Requirements for documentation were relaxed. The term "documented procedure" is not used in DIS. Example:

  The laboratory shall... document its procedures to the extent necessary to assure the consistent application of its activities and validity of the results. (5.1)

- Requirement "to prevent contamination" was added to clause 6.3 "Laboratory Facilities and Environmental Conditions."
- "Reference data" is now added as part of "Equipment" (6.4.1).
- Requirements for calibration are aligned with ISO 9001:2015 text: "When the measurement accuracy and measurement uncertainty affect the validity of the reported result, or metrological traceability is a requirement, measuring equipment shall be calibrated" (6.4.6). WG took the decision to eliminate *comparisons* where it refers to calibration.
- Requirements regarding externally provided product and services are aligned with ISO 9001:2015:

  The laboratory shall assure the suitability of externally provided products and services that affect laboratory activities, when they:

  a) are intended for incorporation into the laboratory's own activities;

  b) are provided, in part or in full, directly to the customer by the laboratory, as received from the external provider;

  c) are used to support the operation of the laboratory.

  NOTE: Products can include, for example, measurement standards and equipment, auxiliary equipment, consumable materials and reference materials. Services can include, for example, calibration services, sampling services, testing services, facility and equipment maintenance services, proficiency testing services and assessment and auditing services. (6.5.1)

- New requirements for method verification are added:

  The laboratory shall verify that it can properly perform methods before introducing them by ensuring that it can achieve the required performance. Records of the verification shall be maintained. If the method is revised, verification shall be repeated to the extent necessary. (7.2.1.5)

- Use "measurement uncertainty" rather than "uncertainty of measurement."
- WG discussed the in-depth analysis that shows that ISO/IEC 17025 meets each of the principles, but not to the same level as ISO 9001. Each one is taken into account, but to a limited extent.
- Addressing uncertainty in sampling WG added sampling to 7.6.2.
- Annex A is now simplified and shortened.
- Annex B: It is clarified that ISO/IEC 17025 is following the logic of a process, consistent with the process approach and requirements of ISO 9001. A possible representation of this approach is provided in the Annex (see above diagram).
- A lot of re-structuring was performed and clarifications were added.

The Next Step

ISO/CASCO/WG 44 will meet again at Geneva, Switzerland, from July 10 to 14, 2017. The output of that meeting is expected to be the FDIS version of the standard.

Dr. George Anastasopoulos (ganas@iasonline.org), is the Director of Conformity Assessment Accreditation Services, for International Accreditation Service (IAS). He has also served to the Bonn-Germany based, Accreditation Panel of the United Nations Kyoto Protocol system UNFCCC/CDM.

Petitioning the SOC for Inclusion of Job Descriptions for Metrologist and Calibration Engineer

Christopher L. Grachanen
Hewlett Packard Enterprise, Houston Metrology Group

Introduction

On July 22, 2016, the US Bureau of Labor Statistics (BLS) published their second federal register denoting proposed changes and additions for the upcoming 2018 Standard Occupational Classification (SOC) system. The SOC is the official listing of occupations recognized by the US Government and is the basis for categorizing citizen occupations for the US census as well as determining which occupations are contained in the BLS's Occupational Outlook Handbook (OOH). The proposed 2018 SOC will include job descriptions for Calibration Technologists and Technicians[1]. This marks the first time the BLS officially recognizes calibration professionals yet they have decided to reject adding job descriptions for Metrologists and Calibration Engineers.

The SOC provides for a comment period for interested parties to submit their comments regarding proposed changes/additions to the 2018 SOC. Given this opportunity, the American Society for Quality (ASQ), Measurement Quality Division (MQD) and the National Conference of Standards Laboratories, Inc. (NCSL International) partnered together to conduct a survey under the auspices of Greg Gulka, NCSL International's executive director.

Survey results were compiled and meshed with other contentions in order to submit a common response to the SOC regarding the proposed Calibration Technologists and Technicians job description wording and the decision to exclude Metrologists and Calibration Engineers from 2018 SOC consideration. Following are comments submitted to the SOC the 2nd week of September 2016.

1 Results of a formal petition spearheaded by American Society for Quality (ASQ), Measurement Quality Division (MQD), the National Conference of Standards Laboratories International (NCSL International) and Measurement Science Conference (MSC) to get Metrologist, Calibration Engineer and Calibration Technician occupations added to the 2018 SOC.

Comments to 2nd Federal Register, July 22, 2016

Docket Number 1-1311

Metrologists and Calibration Engineers; Calibration Technicians (17-2000, 17-3000)

Docket Number 1-1311 reads as follows:

> *Requested new detailed occupations for (1) Metrologists and Calibration Engineers and (2) Calibration Technicians. The SOCPC* did not accept the recommendation to add Metrologists and Calibration Engineers based on Classification Principle 9 on collectability. However, the SOCPC did accept the recommendation to add Calibration Technicians and proposes establishing a new code for this occupation, 17-3028 Calibration Technologists and Technicians, and removing mention of calibration duties from the appropriate 2010 SOC occupations.*
>
> **Standard Occupation Classification Policy Committee*

The following comments are compiled from American Society for Quality (ASQ), Measurement Quality Division (MQD) and National Conference of Standards Laboratories, Inc. (NCSL International) constituents as well as members of the US measurement community. These comments were obtained via a survey using Survey Monkey (survey notifications sent via email and social media). These comments reflect 159 survey participants addressing the following two major topics:

- SOCPC proposed wording of the short job description for Calibration Technologists and Technicians
- SOCPC decision to reject the recommendation to add Metrologists and Calibration Engineers

Note: Comments are provided with short narratives to help convey the thoughts of survey participants as well as supporting contentions.

SOC Proposed Wording of the Short Job Description for Calibration Technologists and Technicians

The proposed short SOCPC job description for Calibration Technologists and Technicians is as follows:

> *Create and execute procedures and techniques for calibrating measurement devices, by applying knowledge of measurement science, mathematics, physics, and electronics, sometimes under the direction of engineering staff. Authenticate calibration traceability of measurement devices. Determine measurement standard suitability for calibrating measurement devices. Adapt equipment, measurement standards, and procedures to accomplish unique measurements. May perform corrective actions to address identified calibration problems.*

The majority of survey participants were in general agreement with the proposed wording with the following reflecting the most prolific comments, each paraphrased in order to convey singular meaning, presented in no order of importance:

a. Add 'chemistry' to '*knowledge of measurement science, mathematics, physics, chemistry and electronics*'
   - Chemical Metrology is an important component of the pharmaceutical, consumer and industrial materials industries and requires a multitude of calibration workers to meet their metrological/regulatory compliance needs.

b. Remove '*Create and*' from '*~~Create and~~ execute procedures and techniques for calibrating measurement device.*'
   - Calibration Technologists and Technicians are not normally tasked in the creation of calibration procedures and techniques which are, as a rule, created by Metrologists and Calibration Engineers.
   - Calibration Technologists and Technicians routinely provide feedback on created procedures and techniques and often make recommendations for improvements.

c. Remove '*May*' from '*~~May~~ perform corrective actions to address identified calibration problems.*'
   - Performing corrective actions is a universal job expectation for Calibration Technologists and Technicians.
   - Calibration Technologists and Technicians routinely perform corrective actions ranging from impact assessments of out of tolerance conditions to verifying initiated corrective actions are delivering desired results.

d. Remove '*sometimes under the direction of engineering staff* ' from '*Create and execute procedures and techniques for calibrating measurement devices, by applying knowledge of measurement science, mathematics, physics, and electronics, ~~sometimes under the direction of engineering staff.~~'*
   - Calibration Technologists and Technicians are customarily denoted in a company's organizational chart as members of their engineering/technical staff (in contrast to a company's managerial or logistical staff).
   - The vast majority of Calibration Technologists and Technicians activities are self-directed within established procedures and techniques such that non-self-directed activities are atypical.

e. Add '*Perform preventive maintenance on equipment and measurement standards.*'
   - Calibration Technologists and Technicians are tasked in performing preventive maintenance to insure equipment and measurement standards are operating correctly and are within statistical process control.
   - Preventive maintenance activities can be an appreciable workload depending on the equipment and measurement standards employed.

The following is the short job description incorporating the above recommended changes:

> *Execute procedures and techniques for calibrating measurement devices, by applying knowledge of measurement science, mathematics, physics, chemistry, and electronics. Authenticate calibration traceability of measurement devices. Determine measurement standard suitability for calibrating measurement devices. Adapt equipment, measurement standards, and procedures to accomplish unique measurements. Perform preventive maintenance on equipment and measurement standards. Perform corrective actions to address identified calibration problems.*

Decision to Reject the Recommendation to Add Metrologists and Calibration Engineers

The SOCPC decision to deny 2018 SOC inclusion of Metrologist and Calibration Engineers based on Classification Principle 9 on collectability was overwhelmingly disagreed with by the aforementioned survey participants and widely believe that the SOCPC should respectfully reconsider their decision. The premises for uncollectability are understood to be:

a. Metrologist and Calibration Engineer occupations are too obscure as to be recognized by census participants
b. Metrologist and Calibration Engineer populations are too small to warrant collecting in a census

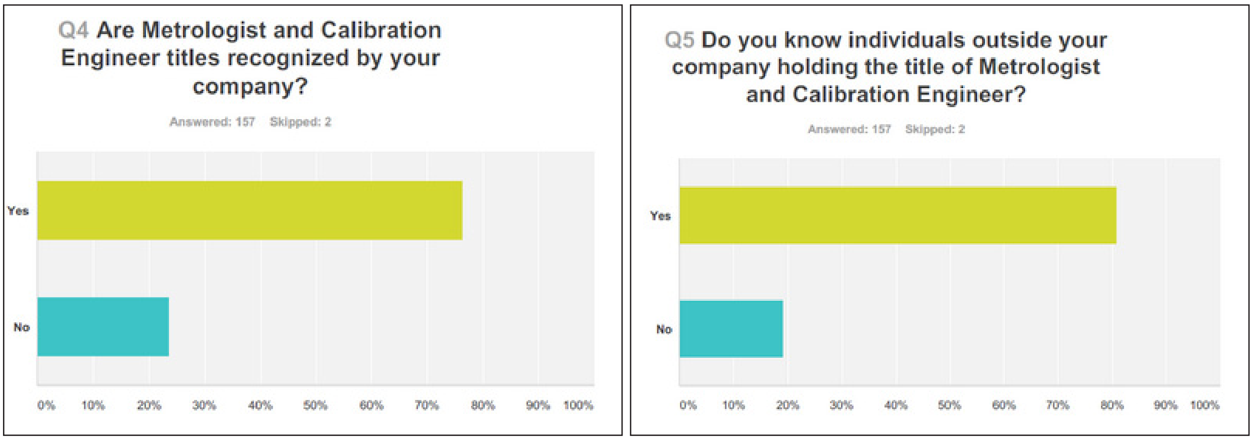


Figure 1. Participant responses to the SOC System survey, collected September 10, 2016.

The following are contentions/justification for SOCPC decision reconsideration of these premises.

Metrologist and Calibration Engineer Occupations are Too Obscure

Because Metrologist and Calibration Engineers job titles are not listed in the SOC, one cannot readily infer job title recognition numbers from census results and as such other means are needed to infer these numbers. The above (Figure 1) are survey questions/participant's responses indicating better than a 75% business recognition of Metrologist and Calibration Engineers job titles.

Job title recognition in terms of relative obscurity may be inferred by querying on-line social media profiles of individuals posting their job titles. LinkedIn, the world's largest professional social media website, was queried for Metrologist and Calibration Engineer job titles and compared with job title queries for Cartographers and Photogrammetrists. The two 2010 SOC listed occupations, Cartographers and Photogrammetrists, were used for comparison purposes as they are grouped together under a single job description similar to the proposal for Metrologist and Calibration Engineers and are categorized within the SOC major job grouping of Architecture and Engineering Occupations.

One may infer from the below queries results (Table 1) that Cartographers and Photogrammetrists job titles are less frequently profiled than Metrologist and Calibration Engineer job titles owing to one or more of the following:

1) smaller LinkedIn participation,
2) smaller population,
3) smaller job title recognition/usage.

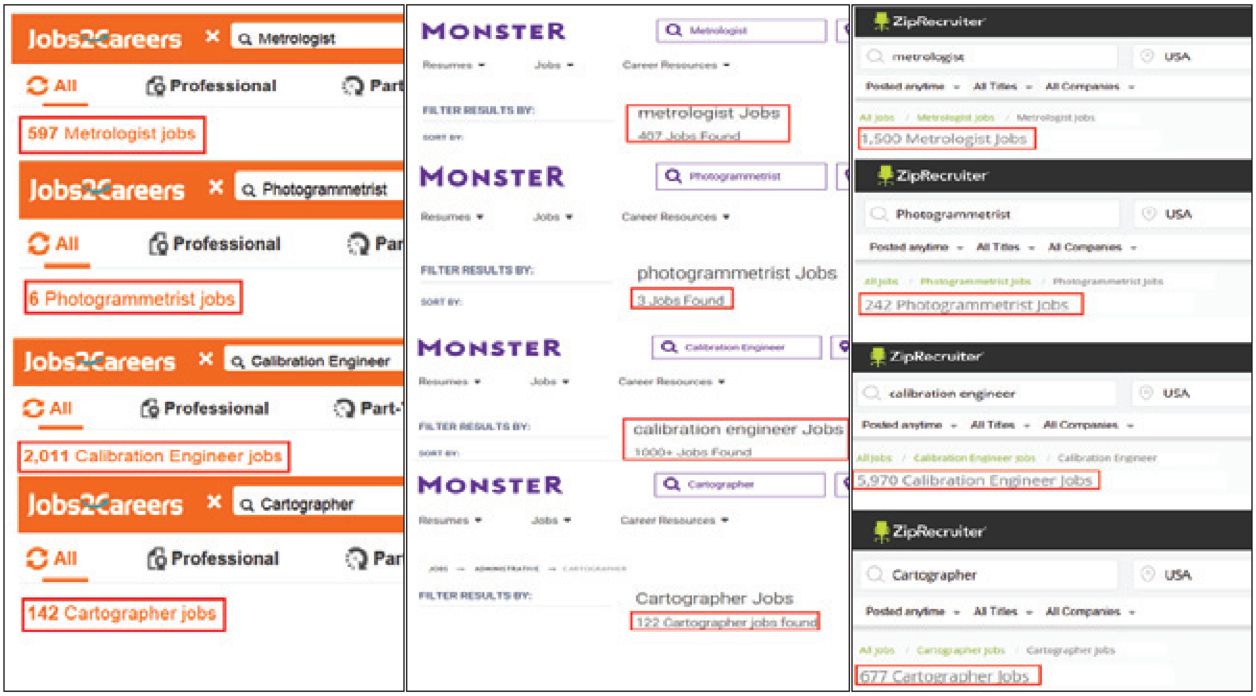
The following is from the SOC website defining the purpose of the SOC:

> *The 2010 Standard Occupational Classification (SOC) system is used by Federal statistical agencies to classify workers into occupational categories for the purpose of collecting, calculating, or disseminating data.*

One may conclude that the SOC purpose is to provide an unambiguous listing of occupations so that worker information may be collected, calculated or disseminated. Key to making this work is that occupations are accurately defined without ambiguity. Following this line of thought the following job description proposed by the SOCPC for

	LinkedIn	Jobs2Careers	Monster	ZipRecruiter
Calibration Engineer	13,180	2,011	1000+	5,970
Cartographer	6,070	142	122	677
Calibration Engineer to Cartographer Ratio = 2.2:1				
Metrologist	5,152	597	407	1,500
Photogrammetrist	510	6	3	242
Metrologist to Photogrammetrist Ratio = 10.1:1				

Table 1. Results from queries collected from various websites.



the 2018 SOC addition of Calibration Technologists and Technicians begs to question what occupations are referred to by 'Engineering Staff.'

> *Create and execute procedures and techniques for calibrating measurement devices, by applying knowledge of measurement science, mathematics, physics, and electronics, sometimes under the direction of engineering staff.*

As Calibration Technologists and Technicians are, as a universal rule, under the technical auspices of Metrologists and Calibration Engineers, one may deduce the need to accurately define the aforementioned 'Engineering Staff' occupations i.e. Metrologists and Calibration Engineers, in order to eliminate ambiguity in keeping with the purpose of the SOC.

Metrologist and Calibration Engineer Populations are Too Small

It cannot be overstated that without SOC recognition of Metrologists and Calibration Engineers, population numbers are not readily available and as such must be inferred from other sources. To this end queries were made to three of the biggest job placement websites Jobs2Careers.com, Monster.com and ZipRecruiter.com for Metrologists and Calibration Engineers. Again for comparison purposes the same queries were conducted for the SOC recognized occupation of Cartographers and Photogrammetrists.

One can easily ascertain from the above query results that Metrologists and Calibration Engineers are substantially more in demand by industry than the SOC recognized occupations of Cartographers and Photogrammetrists. These query results infer much greater population numbers would be collected in a census for Metrologists and Calibration Engineers compared to Cartographers and Photogrammetrists.

Summary

This comments submittal has been made possible by hundreds of volunteers who passionately believe Calibration Technologists, Calibration Technicians, Metrologists and Calibration Engineers need to be included in the 2018 SOC. The US measurement community applauds the SOCPC decision to include Calibration Technologists and Technicians in the 2018 SOC and respectfully petitions the SOCPC to reconsider adding Metrologist and Calibration Engineer given the contentions of this comments submittal.

Christopher L. Grachanen, Distinguished Technologist, Operations Manager, Metrologist, Houston Metrology Group (Hewlett Packard Enterprise), Fellow of American Society for Quality (ASQ), ASQ Liaison for the National Conference of Standards Laboratories Inc. (NCSL International); chris.grachanen@hpe.com.

NEW PRODUCTS AND SERVICES

High Power RF Calibration System for Directional Power Sensors and Wattmeters

GENEVA, Ohio — (BUSINESS WIRE) — TEGAM, Inc., a leading supplier of innovative RF Power measurement instruments, recently released a High Power RF Calibration System that for directional power sensors and RF Wattmeters from virtually all manufacturers including Bird Technologies. The system operates from 250 kHz to 3 GHz and up to 250W with combined uncertainty less than 1%. This frequency range covers the ISM, Land Mobile Radio and common mobile phone bands.

The TEGAM High Power Calibration System can be purchased as separate components to augment a customer's existing hardware or a as a turn-key system for immediate productivity. Properly configured, it can completely automate calibrating an RF Lab's workload to meet or exceed the original manufacturers' specifications. A fully optioned system includes: signal generation, amplification, filters, control software, working standards and an RF calorimeter.

The basis for the High Power Calibration System's unmatched accuracy is TEGAM's exclusive flow calorimeter designed to convert incident RF power into heat with low uncertainties and convenient traceability to SI units. System calibration is also fully automated and achieved on site through a portable AC power standard to minimize station down time. This standard can be sent to most national metrology institutes to provide traceability at the highest level.

"The HPC system is the results of a significant development project at TEGAM and far exceeded our goal for the lowest uncertainty achievable anywhere in the world," said CEO Andy Brush who led the development team. "This system opens up truly traceable RF power measurements to any facility that requires it for their operation," continued Brush.

To learn more about TEGAM's High Power RF Calibration System, visit the TEGAM website and search for "High Power RF".

For more information from TEGAM, Inc., visit the TEGAM website contact TEGAM, Inc., 10 TEGAM Way Geneva, OH USA 44041, or call 1-440-466-6100.

About TEGAM

Headquartered just east of Cleveland, Ohio, TEGAM, Inc. specializes in the design, manufacture and support of a wide variety of test, measurement and calibration instruments. TEGAM is the worldwide leading manufacturer of RF power sensor calibration systems, for commercial and military applications. Founded in 1979, TEGAM has developed a wide variety of measurement instrumentation and markets its products around the world through a network of technical representatives and distributors in more than 40 countries. For more information visit www.tegam.com or contact Sales at Sales@tegam.com.

Source: http://www.businesswire.com/news/home/20161107006182/en/.

SentinelEX PXI Express Switching Modules from VTI Instruments

IRVINE, CA, September 13, 2016 — VTI Instruments (www.vtiinstruments.com) announced today the introduction of its SentinelEX PXI Express (PXIe) Switching Series, the latest addition to its SentinelEX PXIe Test and Measurement Suite. These new PXIe switch modules provide more than 30X better isolation than comparable modules, greatly improving overall performance and allowing test system engineers to maximize the performance of a system's measurement instrumentation. By reducing the false pass/fail errors and intermittent faults often associated with marginal signal levels, PXIe switch modules help improve test system performance and reduce testing costs.

The PXIe Switching Series includes 11 multiplexer modules, 4 matrix modules, 2 general-purpose switching modules, 1 power switching module, 16 RF multiplexer modules, 2 RF matrix modules, and 11 microwave switching modules. They are compatible with 18-slot and 9-slot 3U PXI Express mainframes and a 4-slot portable PXI-hybrid mainframe, as well as digitizer, arbitrary waveform generator, programmable resistor, digital I/O, embedded controller and remote controller modules, all included in the SentinelEX PXIe Test and Measurement Suite.

The PXIe Switching Series offers test system builders exceptional performance and reliability through the use of extensive signal path shielding, which helps reduce cross-talk and improve channel-to-channel isolation. The ability to personalize the switch via software configuration combined with comprehensive, on-board health monitoring help to reduce system-level development and support costs.

The switch modules in the PXIe Switching Series maximize test signal integrity through the use of advanced circuit board layout techniques that minimize the effects of unwanted transmission stubs, shield against radiated signals in adjacent slots, and extend the usable bandwidth of the test system as a whole.

The innovative software driver approach used in SentinelEX PXIe Test and Measurement Suite, which is based on IVI industry standards, allows a single driver session to control multiple modules as a subsystem, providing an application development environment that significantly reduces development time. Advanced triggering and module-to-module synchronization reduce test execution time; chassis smart health-monitoring and relay odometers allow for a predictive approach to maintenance.

The PXIe Switching Series is ideal for a variety of ATE markets and applications:

- Avionics test
- Electronics test
- Oil and gas
- Automotive test
- Defense and aerospace test
- Energy/power generation test

For More Information

For images, data, specifications and to create a quote online, visit http://www.vtiinstruments.com/Products-Services/productlistingSentinel.aspx. Contact VTI Instruments directly at 949.955.1894 or sales@vtiinstruments.com.

Fluke Calibration 700HPPK Pneumatic Test Pump Kit

Everett, Wash., Oct. 20, 2016 — Fluke Calibration introduces the 700HPPK Pneumatic Test Pump Kit, a rugged, portable tool that generates and adjusts pneumatic pressures up to 21 MPa (3000 pounds-per-square-inch) without requiring a nitrogen bottle or other external pressure supplies. It is the ideal solution for generating high pressure in the field to devices under test (DUTs), such as transmitters, controllers, pilots, analog gauges, and more.

The 700HPPK reaches pressure in 20 seconds to full scale into a 30 cm^3 volume. A detachable pressure adjustment system and adjustment control knob allows technicians to make fine pressure adjustments to 0.05% of reading or better.

The lightweight and portable pneumatic pressure kit is designed for use in the lab or the field with collapsible feet, a built-in handhold, and a canvas carrying case making it easy to carry to the field. In-line filter and desiccant systems protect the device against contamination from the DUT. And it works on almost any surface, so technicians don't need a flat laboratory bench or flat area in the field.

The 700HPPK has the versatility to cover a wide range of workloads. It features a 2-meter (6.5 foot) pressure line and assorted pressure fittings to connect to a variety of DUTs for wide workload coverage. Its ¼ NPT female reference gauge connector makes switching reference gauges fast and easy. No PTFE tape or extra tools are required, reducing the equipment and accessories technicians need to carry to the job site, and the calibration manifold attaches and detaches easily via quick detent pins reducing set up and pack up time.

A second model, the 700HPP, is available for people who prefer only a high pressure source.

To learn more about the Fluke Calibration 700HPPK Pneumatic Test Pump Kit, visit http://us.flukecal.com/700hppk.

Morehouse 5 in 1 Force Verification System

York, PA — September 20, 2015 — Morehouse is pleased to announce the introduction of a 5 in 1 Force Verification System. Monitoring your process by putting practices in place to ensure that your measurements are accurate is essential to limiting your risk and keeping the bottom line intact. This system can be used for the following:

- Force Verification
- Statistical Process Control (SPC)
- Intra-laboratory Checks (ILC)
- Proficiency Testing (PT)
- A test standard to accomplish repeatability and reproducibility tests used to calculate Calibration Measurement Capabilities (CMC)
- The system consists of a Morehouse Ultra-Precision Load Cell, High Accuracy Digital Indicator, Mini Computer and Morehouse software, load cell cable and Pelican case.

A good force measurement system will allow you to keep your measurement process in control.

Morehouse Instrument Company is privately-owned and has been providing calibration measurement integrity since 1925. The company is a primary reference laboratory for force and torque measurements. Morehouse also designs, manufactures and sells test equipment and systems for force and torque calibration service applications in a broad range of industries. Find out more at www.mhforce.com or by calling 717-843-0081.

Additel's New 760 Calibrator Series

Yorba Linda, Calif., October 11, 2016 — Additel Corporation introduces their new ADT760 Automatic Handheld Pressure Calibrator which incorporates pressure generation and control in a handheld design less than 4 lbs (1.8kg). There are three models to choose from: low-pressure differential (ADT760-LLP), mid-pressure differential and gauge (ADT760-D), and high pressure absolute and gauge (ADT760-MA). Every ADT760 comes with a calibrated pressure module covering its full range and providing an accuracy of 0.02% FS. Pressure modules are easy to remove and swap and Additel offers a full range from 0.25 inH2O (±0.62 mbar) to 300 psi (20 bar).

Each unit has the capability to measure voltage and current and supply 24V loop power. As an optional feature, each model can be configured to data log pressure readings, setup calibration tasks, and communicate with HART-smart devices.

All ADT760s come with and adaptor set for convenient connection, external power supply, Li-ion rechargeable battery pack, test leads and NIST-Traceable certificate of calibration with data. Additel offers a variety of cases, hose test kits, external pressure modules, and accessories.

The Additel 760 Series are now available for order. For more information, please visit www.additel.com. For information on 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.

Uncertainty Calculations That Excel!

Michael Schwartz
Cal Lab Solutions, Inc.

The other day I read an article titled "Five easy steps for adding measurement uncertainties to your calibration data." It described a very easy process of copying cells from one Microsoft Excel® file to another, then editing the data in the cells. As I continued to read, the article concluded with how this copy and paste operation took a fraction of the time when compared to other software tools built for metrology.

As a software engineer this was counterintuitive to everything I was ever taught as a programmer. "Copy & Paste" was bad mojo, very bad, extremely bad! Don't copy & paste I was always told, it just creates more problems than it's worth. Reading this article caught me by surprise; how could it be such a time saver when compared to tools built for metrology? If copy and paste is such a bad idea for programmers, why didn't the same rule not apply to metrology and uncertainties?

So first some background: As a junior programmer, copy & paste was considered bad programming for two major reasons. First, copying code created multiple copies of the same code in memory. This was highly inefficient when computers have limited memory. So as it was explained to me, create a function and call it instead of duplicating code. Anytime you think you need to copy something, first think of how you can make it a reusable function.

The second and most important problem with copy and pasting code was the potential of duplicating errors. If there is an error in the code that was copied, that error would be duplicated. If there is an error, now it exists in multiple places, and you have no idea where or how many times the error was duplicated. If the error existed in a single function then the error and its effects on the rest of the solution are easier to support.

So it is only reasonable to assume the same problem applies to metrology and uncertainty calculations! If there is an error or problem in the cells of the first spread sheet, they will have been propagated to an unknown number of other Excel files. Just like in software, errors that are found later present a huge cost in fixing them

when compared to the initial cost of development. That is why copy and paste is frowned upon in software development.

But for metrology the problem is bigger! We know different requirements require different uncertainty calculations. And there are some major changes on the horizon with 17025. Updating a single function or a set of functions will prove to be much easier than updating all those Excel files.

Now understand, I use the hell out of Excel. I would rather open a new spreadsheet to make a quick calculation than use the calculator application. I have tons and tons of Excel files. And yes, I have used it to calculate uncertainties.

What I don't like about Excel, when it comes to using it as a metrology based uncertainty calculator or for calibration data collection, is that it mixes data and function in a single file. At first it seems like a good idea, but it is not. Excel is a Band-Aid® that puts both data and formulas in an unstructured file. If the whole goal is to create a file that you will never use again, then Excel is a good fit. But if you want to have data that you can use in the future, Excel—when it comes to metrology—is more problem than solution because it is unstructured.

If your company is serious about metrology and has a focus on using the data that is collected during a calibration, then I suggest you invest in a database. Putting your calibration results in a data table will allow you to recall that data and use it for other things like interval and reliability analysis. Placing your uncertainty calculations inside of your data collection tools is also very bad practice. There is a reason we call them Estimated Measurement Uncertainties; they are estimates and those estimates change. And you never have to re-run a calibration because your estimated uncertainties are part of the data collection process. Data collecting is data collection and uncertainty calculations are something that should be done post process, but that is a topic for another day.

I would like to conclude, there are some amazing tools out there for calculating measurement uncertainties—from the simple to the complex. Just go to Cal Lab Magazine's web site (www.callabmag.com) and look under Metrology Related -> Freeware. There are several free tools that I think you should check out. ❧

"Science, Technology & Measurement – Changing Our World"

47th Annual

MSC TRAINING SYMPOSIUM

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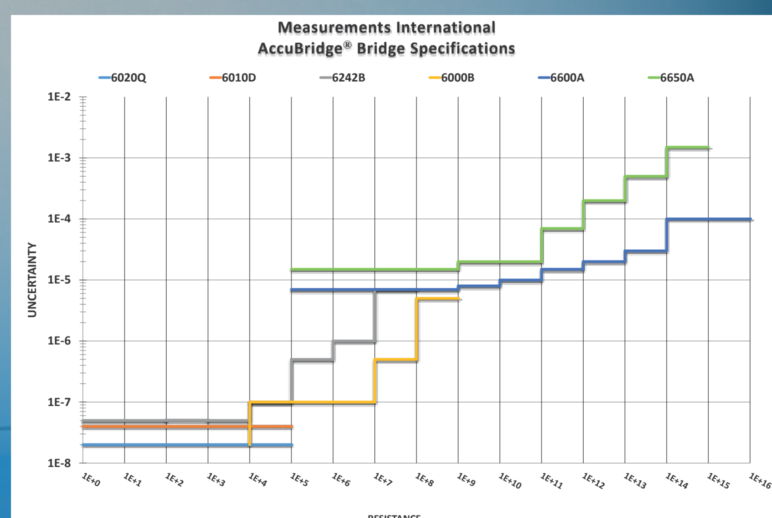

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