CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY

How to Determine Resolution Uncertainty

Uncertainty Propagation for Force Calibration Systems

The Pendulum and Standards of Measure in the Ancient World

2017
JANUARY
FEBRUARY
MARCH

Electric Current Measurement

DS Series Current Transducers

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

DANISENSE

- 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

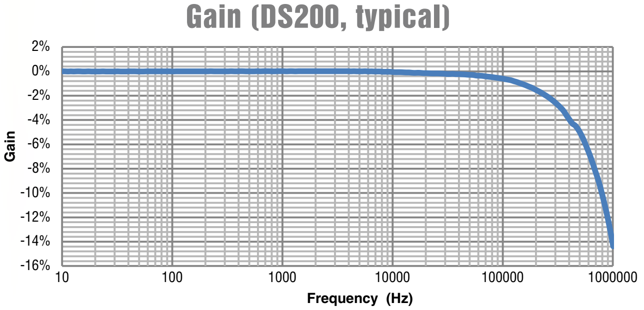
	DS200	DS600	DS2000	DS5000
Primary Current, rms	200A	600A	2000A	5000A
Primary Current, Peak	±300A	±900A	±3000A	±7000A
Turns Ratio	500:1	1500:1	1500:1	2500:1
Output Signal (rms/Peak)	0.4A/±0.6A†	0.4A/±0.6A†	1.33A/±2A†	2A/±3.2A†
Overall Accuracy	0.01%	0.01%	0.01%	
Offset	<20ppm	<10ppm	<10ppm	<5ppm
Linearity	<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˚

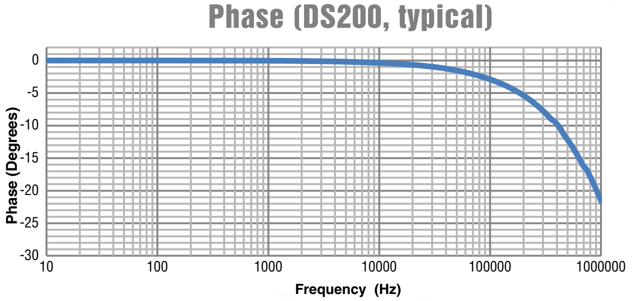
† Voltage Output options available in ±1V and ±10V

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
THE INTERNATIONAL JOURNAL OF METROLOGY

Volume 24, Number 1

www.callabmag.com

FEATURES

DEPARTMENTS

ON THE COVER: Cesar "Jun" Bautista, PhD, Senior Director of Laboratory Services at Masy BioServices in Pepperell, Massachusetts. For over 30 years, Masy BioServices has served the pharmaceutical, medical device, biotechnology, and other regulated industries.

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. METROMEET will show to the experts of the sector the newest working methods and formulas that improve your industrial process and the productivity of your company. 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/.

Mar 27-29, 2017 CIRMS 25th Annual Meeting. Council on Ionizing Radiation Measurement Standards (CIRMS). Hosted by NIST, Gaithersburg, MD. The technical program 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. 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. http://www.forumesure.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 among A2LA stakeholders, i.e., A2LA members, accredited CABs, users of A2LA accreditation, as well as A2LA assessors by providing 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 platform for technology providers to showcase solutions that can perform complex checks, improve quality control and cut precious time off from production processes. http://www.mta-asia.com.

CAL LAB
THE INTERNATIONAL JOURNAL OF METROLOGY

PUBLISHER
MICHAEL L. SCHWARTZ

EDITOR
SITA P. SCHWARTZ

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

Subscription fees for 1 year (4 issues)
$50 for USA, $55 Mexico/Canada,
$65 all other countries.
Visit **www.callabmag.com**
to subscribe.

Printed in the USA.

ISSN No. 1095-4791

EDITOR'S DESK

Standardization of Standards (and Data)

The QWERTY keyboard is a standard we have taken for granted all our lives. It took decades for different manufacturers of typewriters to standardize the placement of their keys. Imagine if you had to relearn typing on a different arrangement of keys each time you changed employers!

I've been reading "Learning by Doing: The Real Connection between Innovation, Wages, and Wealth," by James Bessen, who explains, through the development of the power loom, how new technologies failed to capture real growth until the new technology became standardized. Through trial and error, this process of standardization took time.

In this issue, author Roland Boucher, in his article "The Pendulum and Standards of Measure in Ancient Metrology," goes into detail how different ancient civilizations developed their standards of measure and how they compared, or were similar, to standards of other ancient civilizations.

Civilizations all have a need to measure critical aspects of human life such as time, volume, length, etc. We couldn't move forward with building, trading, or sailing until we figured a standard way to measure. The fact that nations all over the globe recognize International Standards of Units (SI) today is an incredibly momentous achievement for humankind… we've standardized our standards! This achievement is a constant work in progress, but still quite incredible.

In this issue's Automation Corner, Michael Schwartz and David Zajac talk about creating a metrology *data standard*. This is a path on which the metrology industry has yet to embark. No longer are we confined to keeping our data on paper! But while civilization has quickly developed a standard way of sharing, moving, and storing all of our digital data, the metrology industry has yet to agree upon standardizing all its own data.

Without standardizing our data, it has little value because it can't be compared to other existing data; each set of data is still an island. The development of a standard taxonomy is the first hurdle in organizing *all that data*. Michael and David explain the creation of a metrology data taxonomy currently in progress through a NCSL International working group on Measurement Information Infrastructure (MII).

But if you're only here for the practical stuff, we've got that in this issue as well! For our technical papers, we have two great articles on calculating measurement uncertainty. First, Richard Hogan, of ISOBudgets.com, generously shared his guide on "How to Determine Resolution Uncertainty," from his blog. And finally, Henry Zumbrun and Alireza Zeinali, of Morehouse Instruments, share with us a guideline for calculating measurement uncertainty for force calibrations titled "Uncertainty Propagation for Force Calibration Systems."

Happy Measuring,

Sita Schwartz
Editor

Apr 4 -5, 2017 Metrology for LNG Workshop. Noordwijk, Netherlands. VSL and CEESI. Two workshops join forces: Metrology for LNG workshop and European Flow Measurement Workshop present joint programs. 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 conference is offering a series of excellent technical programs covering the various disciplines of the measurement sciences. http://www.msc-conf.com.

May 8-11, 2017 Annual Technical Meeting and Exposition of IEST. Louisville, KY. http://www.iest.org.

May 15-19, 2017 EURAMET General Assembly. Madrid, Spain. http://euramet.org.

May 22-25, 2017 International Instrumentation and Measurement Technology (I2MTC). Torino, Italy. I2MTC 2017 conference spans research, development and applications in the field of instrumentation and measurement science and technology. http://2017.imtc.ieee-ims.org/.

May 30-Jun 1, 2017 SENSOR+TEST. Nurnberg, Germany. The AMA Conferences 2017 (SENSOR and IRS^{2}) will run in parallel to the exhibition and enrich the event with scientific facts and prognoses for the future of this industry. http://www.sensor-test.de.

May 30-Jun 1, 2017 TC3 Conference on the Measurement of Force, Mass, Torque. Helsinki, Finland. http://www.imeko.org.

May 30-Jun 1, 2017 TC5 Conference on the Measurement of Hardness. Helsinki, Finland. http://www.imeko.org.

May 30-Jun 1, 2017 TC22 Conference on Vibration Measurement. Helsinki, Finland. http://www.imeko.org.

Jun 9, 2017 ARFTG Microwave Measurement Symposium. Honolulu, HI. http://arftg.org.

Jun 21-23, 2017 IEEE Workshop on Metrology for Aerospace. Padua, Italy. The program is designed to raise the interest from metrology and aerospace fields, by presenting the most innovative solutions in this field from the scientific and technological point of view. http://metroaerospace.org.

CALENDAR

SEMINARS: Dimensional

Mar 13-16, 2017 Dimensional Measurement Training: Level 2 – Measurement Applier. Coventry University, UK. National Physical Laboratory. 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.

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 5-6, 2017 The Gauge Block Handbook. Anaheim, CA. MSC Training Symposium. Presented by the NIST Dimensional Metrology Group. This is a two-day course on the maintenance, care, use, and proper calibration of gauge blocks for dimensional measurements. http://annualconf.msc-conf.com/nist-seminars/.

Apr 18-20, 2017 Hands-on Gage Calibration. Aurora (Chicago), IL. Mitutoyo Institute of Metrology. The Hands-On Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. http://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/.

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. 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 9-11, 2017 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/.

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.

May 22-23, 2017 Hands-On Gage Calibration and Repair. Phoenix, AZ. 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 23-25, 2017 Hands-on Gage Calibration. Aurora (Chicago), IL. Mitutoyo Institute of Metrology. The Hands-On Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. http://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/.

Jun 5-6, 2017 Hands-On Gage Calibration and Repair. Colorado Springs, CO. 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.

CALENDAR

Jun 8-9, 2017 Hands-On Gage Calibration and Repair. Omaha, NE. 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.

Jun 13-15, 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.

Jun 20-22, 2017 Hands-on Gage Calibration. Aurora (Chicago), IL. Mitutoyo Institute of Metrology. The Hands-On Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. http://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/.

Jun 21-22, 2017 Hands-On Gage Calibration and Repair. Dallas, TX. 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.

Jun 28-29, 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.

SEMINARS: Electrical

Apr 6, 2017 Laser Power Measurement Fundamentals. Anaheim, CA. MSC Training Symposium. Presented by the NIST Applied Physics Division. This is an overview of the available technologies for laser power measurement and their proper implementation with exercises covering damage threshold calculation, measurement setup, data and uncertainty analysis. A 45-minute module on laser safety will cover lab safety and personal protective equipment. http://annualconf.msc-conf.com/nist-seminars/.

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. We will also teach various techniques used to make good measurements using calibration equipment. 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. We will also teach techniques for making good high precision measurements using reference standards. http://us.flukecal.com/training.

May 15, 2017 Uncertainty Evaluation of DC and LF Electrical Calibrations. Delft, Netherlands. VSL Dutch Metrology Institute. http://vsl.nl/en/services/training.

May 16-18, 2017 DC and LF Electrical Measurement & Calibration Techniques. Delft, Netherlands. VSL Dutch Metrology Institute. http://vsl.nl/en/services/training

SEMINARS: Flow

Apr 5, 2017 Flow Rate Technology Fundamentals & Viscosity Measurement. Anaheim, CA. MSC Training Symposium. 1/2 day tutorial. http://annualconf.msc-conf.com/tutorial-workshops/.

Apr 5, 2017 Liquid Flow Rig Measurement Uncertainty Assessment. Anaheim, CA. MSC Training Symposium. 1/2 day tutorial. http://annualconf.msc-conf.com/tutorial-workshops/.

Apr 6, 2017 Flow Metrology - Coriolis Meter Measurement Uncertainty Analysis. Anaheim, CA. MSC Training Symposium. 1/2 day tutorial. http://annualconf.msc-conf.com/tutorial-workshops/.

SEMINARS: General & Management

Mar 27-28, 2017 Calibration Lab Operations. Las Vegas, NV. Technology Training, Inc. This course is for individuals who are involved in standards and calibration laboratories and for others who want a clear understanding of the special requirements that must be met by managers and other personnel in standards and calibration work. https://ttiedu.com/node_sku_269231.

Mar 28, 2017 Basic Metrology. Delft, Netherlands. VSL Dutch Metrology Institute. http://vsl.nl/en/services/training.

Mar 29-31, 2017 Instrumentation for Test & Measurement. Las Vegas, NV. Technology Training, Inc. Course 163 offers understanding of modern instrumentation and systems unknown a decade ago. https://ttiedu.com/node_sku_269233.

Apr 5, 2017 Metrology 101: Back to Basics. Anaheim, CA. MSC Training Symposium. Full day tutorial. The Back to Basics Tutorial was created for measurement personnel that may be new to a discipline or new to the industry. http://annualconf.msc-conf.com/tutorial-workshops/.

Apr 5, 2017 Healthcare Metrology Program Documentation Best Practices - An Industry Perspective. Anaheim, CA. MSC Training Symposium. Full day tutorial. http://annualconf.msc-conf.com/tutorial-workshops/.

Apr 6, 2017 VIM and the International System of Units (SI). Anaheim, CA. MSC Training Symposium. 1/2 day tutorial. http://annualconf.msc-conf.com/tutorial-workshops/.

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/.

Jun 28, 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

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 5, 2017 Particle Counting in Critical Manufacturing Environments. Anaheim, CA. MSC Training Symposium. This full day technical session will cover the metrology and measurement concepts behind how particle counters work, go into detail on cleanroom standards and industry regulations that govern clean manufacturing environments, cover how particle counters are calibrated and then review viable sampling technology and function. http://annualconf.msc-conf.com/tutorial-workshops/.

Apr 10-12, 2017 ISO 17025:2005 Testing/Cal Labs Brea, CA. IAS. Analysis of ISO/IEC 17025:2005 standard, Management and Technical requirements for Testing and Calibration Laboratories, IAS assessment process, Auditing techniques. Includes update of new requirements to new under development ISO/ IEC 17025. http://www.iasonline.org/training/.

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. In this course, you will be introduced to the A2LA accreditation process and will gain insight into the interpretation of the requirements of this international laboratory standard. http://www.a2la.org/.

May 7-9, 2017 ISO 17025:2005 Testing/Cal Labs. Doha, Qatar IAS. Analysis of ISO/IEC 17025:2005 standard, Management and Technical requirements for Testing and Calibration Laboratories, IAS assessment process, Auditing techniques. http://www.iasonline.org/training/.

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. In this course, you will be introduced to the A2LA accreditation process and will gain insight into the interpretation of the requirements of this international laboratory standard. http://www.a2la.org/.

May 18, 2017 ISO/IEC 17025 Advanced: Beyond the Basics. A2LA Headquarters – Frederick, MD. 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/.

May 22-26, 2017, ISO/IEC 17025 Lead Assessor Training. Oak Brook, IL. ANAB. This 4.5-day course will enable attendees to develop a solid understanding of the ISO/IEC 17025 standard and be able to plan and lead an ISO/IEC 17025 assessment. http://anab.org/training/

Jun 26-27, 2017 ISO/IEC 17025 and Laboratory Accreditation. Detroit, MI. A2LA. This course is an introductory look at ISO/IEC 17025 and its requirements for demonstrating the technical competence of testing and calibration laboratories. In this course, you will be introduced to the A2LA accreditation process and will gain insight into the interpretation of the requirements of this international laboratory standard. http://www.a2la.org/.

SEMINARS: Mass & Weight

Apr 5, 2017 Weighing Practices: A Risk-Based Approach to Selection, Calibration and Testing of Weighing Instruments. Anaheim, CA. MSC Training Symposium. Full day tutorial. http://annualconf.msc-conf.com/tutorial-workshops/.

Apr 5, 2017 Traceability, Operations, and Good Measurement Practices for Balances in an Analytical Environment. Anaheim, CA. MSC Training Symposium. Presented by NIST Office of Weights and Measures. This tutorial is designed for the beginner to advanced user of balances, calibration managers, quality managers, ISO/IEC 17025 assessors, and those wanting a better understanding of accurate weighing methods where analytical weighing is an integral part of operations. http://annualconf.msc-conf.com/nist-seminars/.

Apr 6, 2017 Calibration Weights & Mass Reference Standards: An overview of calibration methods, use, proper handling, and documentary standards (ASTM E617-13, OIML R111-1 & NIST Handbook 150-1). Anaheim, CA. MSC Training Symposium. Presented by NIST Office of Weights and Measures. http://annualconf.msc-conf.com/nist-seminars/.

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. Successful completion of the Fundamentals of Metrology Seminar is a prerequisite for the Mass Metrology Seminar. https://www.nist.gov/news-events/events/2017/05/5436-mass-metrology-seminar.

SEMINARS: Measurement Uncertainty

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. Measurement uncertainty problems are solved by brainstorming methods so as to generate interaction by all participants. 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.

Apr 5-7, 2017 Measurement Uncertainty: Hands-on on Assessing and Reporting. Anaheim, CA. MSC Training Symposium. This NIST short course covers the propagation of measurement uncertainty using the methods outlined in the JCGM Guide to the Expression of Uncertainty in Measurement from a statistical perspective. http://annualconf.msc-conf.com/nist-seminars/.

Apr 13-14, 2017 Uncertainty of Measurement. Brea, CA. IAS. Introduction to metrology principles, learn how to calculate UoM, many examples and practical exercises. http://www.iasonline.org/training/.

Jun 19, 2017 Introduction to Measurement Uncertainty. Frederick, MD. 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. Measurement uncertainty problems are solved by brainstorming methods so as to generate interaction by all participants. http://www.a2la.org/.

Additel

Additel 760 Automatic Handheld Pressure Calibrator

Taking portable pressure calibration to a whole new level!

- ***Fully automatic calibrator with built-in pump and controller***
- ***Switchable internal pressure modules for expandable ranges***
- ***Accuracy (1 year) of 0.02%FS***
- ***External pressure modules available (measure only)***
- ***Less than 4 lbs (1.8 kg) for handheld operation***
- ***Source pressure, measure pressure and electrical***
- ***Optional HART communications***
- ***Optional data logging and task documenting***
- ***USB, Wi-Fi, and Bluetooth communications***
- ***4 Channels***

Pressure Specifications

Specification	*760-LLP*	*760-D*	*760-MA*
Max Pressure Range	±30 inH_2O (75 mbar)	-12.5 to 35 psi (-0.86 to 2.5 bar)	-12.5 to 300 psig (-0.86 to 20 bar.g)
Accuracy	0.05%FS[1]	0.02%FS[1]	0.02%FS[1][3]
Stability	<0.005%FS[2]	<0.005%FS[2]	<0.005%FS[2]
Pressure Type	Differential, Gauge	Differential, Gauge	Gauge, Absolute
Resolution	6 digits		
Barometric Accuracy	N/A	N/A	40 Pa[4]
Connection	Barb fitting	Hose, 5 ft (1.5 m), with built-in filter to 1/4BSPF, 1/4NPTF, and M20F adapters	Hose, 5 ft (1.5 m), with built-in filter to 1/4BSPF, 1/4NPTF, and M20F adapters

[1] FS specification applies to the span of the module range.
[2] Stability based on FS of the internal pressure module. Internal module is switchable.
[3] Specification based on gauge measurement. An additional 40 pa uncertainty will need to be included when measuring in absolute mode.
[4] 40 Pa uncertainty (k=2) includes calibration uncertainty, linearity, and long-term stability (<30 Pa per year). Barometer range of 60 to 120 kPa.

Electrical Specifications

Specification	*Range*	*Resolution*	*Accuracy*	*Note*
mA Measure	±30 mA	0.0001 mA	0.01%RD+0.005%FS	Impedance <10Ω
V Measure	±30 V	0.0001 V	0.01%RD+0.005%FS	Impedance >10MΩ
mA Source	24 mA	0.001 mA	0.01%RD+0.005%FS	20 mA @ 1K
Loop Power Source	24 V	N/A	±0.5 V	100 mA (Max Loading)
Pressure Switch	Open, close. Support for mechanical switches and NPN/PNP digital switches.			
Temperature Compensation	41°F to 95°F (5°C to 35°C)			
Temperature Coefficient	< ± (0.001%RD + 0.001%FS) / °C outside of 5°C to 35°C			

Phone: 714-998-6899
Fax: 714-998-6999
E-mail: sales@additel.com

Corporate Headquarters
2900 Saturn Street #B
Brea, CA 92821, USA

Salt Lake City Office
1364 West State Rd. Suite 101
Pleasant Grove, UT 84062, USA

www.additel.com

CALENDAR

Jun 20-21, 2017 Applied Measurement Uncertainty for Calibration Labs. A2LA Headquarters – Frederick, MD. https://www.a2la.org/training/index.cfm.

Jun 20-22, 2017 Uncertainty Calculation. Delft, Netherlands. VSL Dutch Metrology Institute. http://vsl.nl/en/services/training.

Jun 27-29, 2017 MET-302 Introduction to Measurement Uncertainty. Fluke Calibration. This course will teach you how to develop uncertainty budgets and how to understand the necessary calibration processes and techniques to obtain repeatable results. http://us.flukecal.com/training.

SEMINARS: Pressure & Vacuum

Apr 5-6, 2017 Pressure and Vacuum Measurement. Anaheim, CA. MSC Training Symposium. Presented by the NIST Thermodynamic Metrology Group. This two-day course will cover the fundamentals of pressure measurements from 10^{-8} Pa to 10^{+5} Pa (10^{-10} torr to 10^{+3} torr), focusing on the selection and proper use of appropriate gauging technology for a given application. http://annualconf.msc-conf.com/nist-seminars/.

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.

SEMINARS: RF & Microwave

Apr 5, 2017 Microwave Measurement Fundamentals. Anaheim, CA. MSC Training Symposium. Presented by the NIST RF Electronics Group. An introduction to the measurement concepts for microwave power and scattering-parameters will be covered. http://annualconf.msc-conf.com/nist-seminars/.

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.

Apr 25-28, 2017 VNA Tools Course. Switzerland. METAS. VNA Tools II supports most of the Vector Network Analyzers (VNAs) in today's market. The three day course provides a practical and hands-on lesson with this superior and versatile software. State of the art, primary S-parameter traceability and how the software can support it is covered on the last day. Registration deadline is Mar 31st. http://www.metas.ch/metas/en/home/dl/kurse---seminare.html.

Jun 19-23, 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/software-training.

SEMINARS: Temperature

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, and will broadly follow the pattern established in previous courses. 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.

Apr 5, 2017 The Use of Portable Single Pressure Mixed-Flow Temperature/Humidity Generator Chamber in the Calibration of Industrial Hygrometers. Anaheim, CA. MSC Training Symposium. http://annualconf.msc-conf.com/tutorial-workshops/.

Apr 6, 2017 Temperature Monitoring and Traceability in the Cold Chain. Anaheim, CA. MSC Training Symposium. Presented by the NIST Thermodynamic Metrology Group. In this seminar, participants will learn effective temperature monitoring strategies for use in cold-chain transport and storage of temperature-sensitive products. http://annualconf.msc-conf.com/nist-seminars/.

Apr 6, 2017 Fundamentals of Humidity Measurement. Anaheim, CA. MSC Training Symposium. 1/2 day tutorial. http://annualconf.msc-conf.com/tutorial-workshops/.

SEMINARS: Volume

Jun 12-16, 2017 Volume Metrology Seminar. Gaithersburg, MD. NIST. This 5 day OWM volume metrology seminar is designed to enable metrologists to apply fundamental measurement concepts to volume calibrations. A large percentage of time is spent on hands-on measurements, applying procedures and equations discussed in the classroom. https://www.nist.gov/news-events/events/2017/06/5441-volume-metrology-seminar.

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

Trescal Acquires Exphil Calibration Labs Inc.

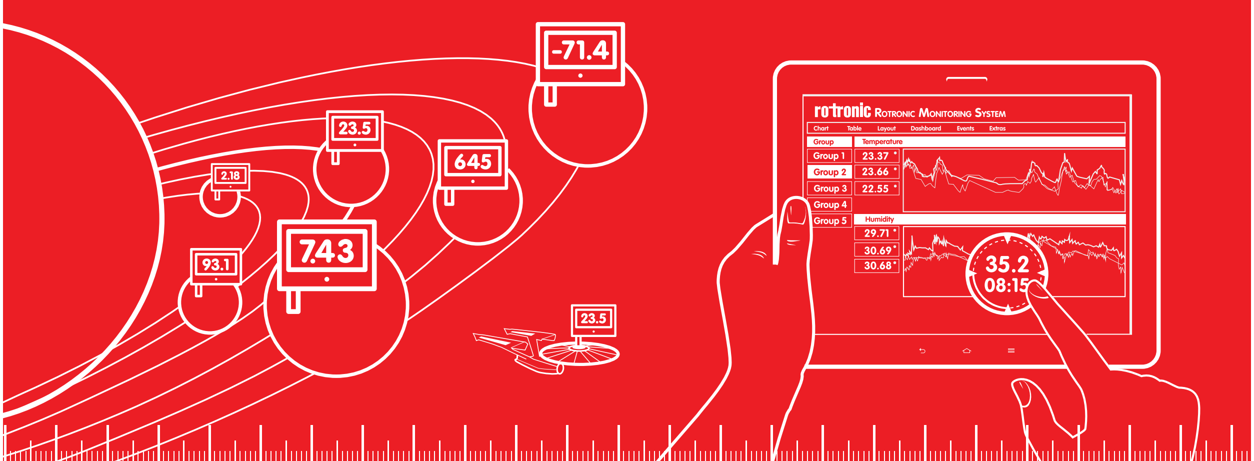
Paris, January 3rd 2017. Trescal, the international specialist in calibration services, announces the acquisition of Exphil Calibration Labs Inc., a calibration services provider based in Long Island (New York). The transaction consolidates Trescal's geographical footprint and technical coverage in the United States. This acquisition has been completed with the support of Ardian, its majority shareholder.

Founded in 1977, Exphil is a one-stop-shop A2LA accredited laboratory with strong technical skills in electrical DC/Low Frequency. Exphil employs 17 people, generates a turnover of 2 M$ and is mostly active in the aeronautics sector. Guillaume Caroit, Trescal Deputy CEO, said: "This new acquisition is fully consistent with our strategy of strengthening our network in North America to better address national tenders and serve our large customers. We still have to penetrate 5 states in the USA."

This acquisition will bring Trescal's network in the USA to sixteen accredited calibration laboratories in thirteen states with over 400 employees. It is the eighteenth acquisition since the change of ownership to Ardian in July 2013.

Trescal acquires Digital Measurement Metrology Inc.

February 2, 2017. Trescal is proud to announce the acquisition of Digital Measurement Metrology Inc. (DMM), a calibration services provider based in Brampton (Toronto - Ontario). The transaction consolidates Trescal's geographical footprint and technical coverage in Canada. It has been completed with the support of Ardian, its majority shareholder. Founded in 1989, DMM is a one-stop-shop L-A-B accredited laboratory with strong technical skills in dimensional, force and temperature. DMM employs 12 people, generates a turnover of 2 MCAD and is mostly active in the pharmaceuticals and aeronautics sectors. Digital Measurement Metrology founder, Bassant Gobin, will remain in his current position to continue leading the growth of the business in the coming years. Guillaume Caroit, Trescal Deputy CEO, said: "DMM acquisition allow us to be present in Ontario, a key state in Trescal's development in North America. We are now targeting the Canadian west coast." This acquisition is the nineteenth acquisition since the change of ownership to Ardian in July 2013.



Heads Up, High School Class of '19: New Measurement Unit Definitions Are Coming

NIST News, January 23, 2017 - Next year, scientists expect to change the way we define the basic units with which we measure our universe. An article by scientists at the National Institute of Standards and Technology (NIST) written for teachers will help ensure high school physics students are hip to the news.

The brief, six-page article (link is external), which appears in this month's issue of The Physics Teacher, is designed to be a resource for teachers who are introducing the International System of Units (SI) into their classrooms. The SI, as the modern form of the metric system, has seven fundamental units, including the meter and the second. It is expected that in 2018, for the first time in history, all seven of these units will be defined in terms of fundamental constants of the universe such as the speed of light or the charge of a single electron. Only recently were all the relevant fundamental constants known with sufficient certainty to make such a redefinition possible, and the authors are eager to help students realize the change's importance.

"It's a historic moment," said NIST physicist Peter Mohr, one of the article's authors. "Back in the 19th century, James Clerk Maxwell—one of history's great scientific visionaries (link is external)—dreamed of a measurement system based on universal constants. Now that we are on the verge of realizing his dream, we want to explain why these constants have a relationship to SI units in a way high school students can understand."

The article, written in everyday English, begins with a brief history of measurement units and shows how their limitations over past centuries have led to the need to redefine them. The kilogram, for example, is currently defined by a metal artifact (link is external), which has a mass that has apparently been changing over time. This prompted an international effort to redefine it in terms

Crystal pressure

nVision lets you visualize measurements graphically, with or without a pc, in real time as it is being recorded. Separate, easily replaceable modules for pressure, temperature, and voltage and current make nVision tremendously flexible.

ametekcalibration.com

Crystal XP2i

Crystal GaugeCalHP

JOFRA ASC-400

M & G PKII

JOFRA RTC Series

- Gauge/Absolute Pressure Datalogger to 15 000 psi / 1000 bar / 100 MPa
- Differential Pressure with up to 0.025% of reading accuracy
- Switch, Voltage, Current, and Temperature Measurement
- 500 000 Data Points at 10 Readings per Second from 2 Modules
- Interactive Real-time Graphing of Measurements
- Compensates Accuracy for Temperature Effects from -20 to 50°C
- Connect to a PC to view live readings; or export to tamper-proof digital records

AMETEK®
SENSORS, TEST & CALIBRATION
ametekcalibration.com
805.595.5477

In 2018, the SI's seven base units (top row) are expected to be redefined in terms of invariant fundamental universal constants (bottom). A new publication will help high-school teachers communicate this change in the classroom. Credit: N. Hanacek/NIST

of electrical energy. Most of the article comprises brief summaries of each unit's relation to universal constants, allowing teachers to show physics students these relationships right from the beginning of a course, when units are generally taught.

"One of the things that makes good sense for me is the unit of electrical charge," said co-author Sandy Knotts, who recently retired after a career of teaching physics at Perkiomen Valley High School in Collegeville, Pennsylvania. "Now we can start out using the measurement of the electron rather than the ampere."

At present, the ampere is defined in relation to the force between two parallel electrical wires of infinite length.

"That's something that doesn't exist in nature," Knotts said. "Whereas an electron is an electron."

Teaching the relationships this way is intended to help eliminate potential confusion in the early weeks of a physics course. The redefinition also has the advantage of allowing students (and scientists) to do work with a clear relationship to the universal constants.

"Defining the constants precisely provides a practical way to establish SI units," Mohr said. "That allows you to do experiments and get answers in terms of these constants."

This changeover in unit definitions may be the last one physics students will need to absorb for a long time, Mohr added.

"The definitions are such that they're not dependent on technology," he said. "We may come up with better ways to measure, but the definitions themselves won't have to change."

Paper: S. Knotts, P.J. Mohr and W.D. Phillips. An Introduction to the New SI. January 2017. *The Physics Teacher*, DOI: 10.1119/1.4972491

Source: https://www.nist.gov/news-events/news/2017/01/heads-high-school-class-19-new-measurement-unit-definitions-are-coming.

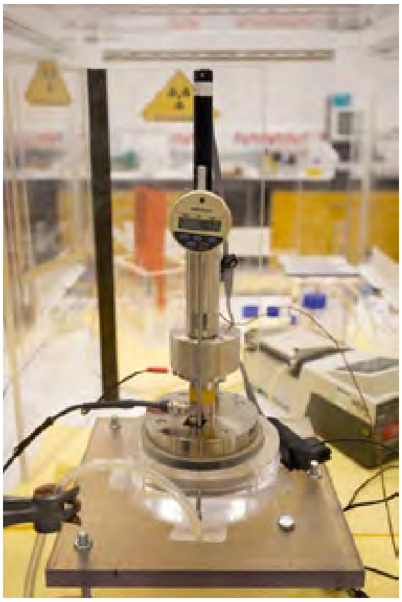
World's First Primary Standard Developed for Molecular Radiotherapy

Researchers at the National Physical Laboratory (NPL) have developed the world's first primary standard for molecular radiotherapy (MRT) to ensure its safe, effective use in the treatment of cancer.

The new standard will help improve the consistency of treatments with MRT, in which radioactive molecules, or radiopharmaceuticals, are injected directly into a patient's body to target and kill cancerous cells. Such standardization is vital to encouraging more widespread use of MRT and the development of new and improved radiopharmaceuticals.

Like any form of radiotherapy, the success of MRT relies on the delivery of an extremely precise dose of radiation – the goal is to maximize the dose delivered to the tumor, while minimizing damage to surrounding healthy tissue. However, in contrast to other forms of radiotherapy, dosimetry for MRT is not well established.

Patients are generally treated with the maximum activity known to be tolerated by healthy tissue,



The new primary standard. Credit: NPL

based on information from clinical trials. Treatment outcomes could be improved if the radiation dose received by patients undergoing MRT could be better measured and tailored to the individual. But until recently, not only were there no measurement methods, there was also no primary standard available to compare calculated doses to and ensure clinicians are administering consistent treatments.

To address this problem, researchers from NPL's Radiation Dosimetry and Radioactivity groups developed the new standard, the first of its kind in the world. Described in a publication in Metrologia*, the standard consists of a gas-filled ionisation chamber containing two parallel electrodes, an adjustable distance apart, and enables the user to measure the absorbed radiation dose to water from a radioactive solution. The standard was validated using yttrium-90 chloride, a radionuclide used to treat liver cancer, and produced results well within the level of uncertainty required for MRT dose calculations.

Work on the new standard is programmed to continue for the next two years, with developments to further reduce the uncertainty and extension to other radionuclides used for MRT, such as iodine-131 and lutetium-177.

* "Development of a primary standard for absorbed dose from unsealed radionuclide solutions" authored by I Billas, D Shipley, S Galer, G Bass, T Sander, A Fenwick and V Smyth in *Metrologia*, Volume 53, Number 6.

Source: http://www.npl.co.uk/news/worlds-first-primary-standard-developed-for-molecular-radiotherapy.


METROLOGY.NET®
21st Century Technology
• Flexible Standards
• Uncertainty Calculations
• Automated Calibrations
• Manual Calibrations
• iPad/Android
• All-in-one System
To find out more, go to:
www.metrology.net
Contact us today, to see what
Metrology.NET® can do for you!
Cal Lab Solutions, Inc. | Aurora, Colorado
(303) 317-6670 | sales@callabsolutions.com

Photo Credit: Spark Calibration Laboratory Ankara

How to Determine Resolution Uncertainty

Richard Hogan
ISOBudgets

Introduction

Resolution uncertainty is the uncertainty in measurement contributed by resolution of measurement equipment. Resolution Uncertainty is a factor that contributes to uncertainty in measurement. Its influence should be considered in every uncertainty budget. However, evaluating resolution uncertainty can vary depending on several factors. So, I have written these procedures to help you appropriately identify and evaluate the resolution uncertainty of various measurement equipment.

In this article, I am going to teach everything that you need to know about resolution uncertainty and more; it is more complex than you ever imagined.

Why is Resolution Uncertainty Important?

Resolution uncertainty is important because it considers the limitations of measurement equipment. The accuracy, precision, and capability of your measurements are limited by the resolution of the measurement standard and unit under test. No matter how careful or scientific, you measurement results are limited by the resolution of your measurement standards and the unit under test.

It is important to consider all equipment in the measurement system. The device with the worst resolution will limit your measurement capability. For example, you can compare the voltage output of a multifunction calibrator (e.g. Fluke 5700A) to a 3.5 digit multimeter, the resolution of unit under test will have a considerable influence on the measurement result and associated uncertainty.

In another example, you can compare the length of a gage block to a digital calibrator, but the resolution of the digital caliper will affect the measurement result and associated uncertainty; even if you are using a grade 0 gage block.

In both examples, industrial measurement equipment were calibrated using precision equipment and the measurement result and measurement uncertainty were significantly influenced by the poor resolution of the unit under test. For this reason, resolution uncertainty is considered important, regardless of whether or not its influence is significant to the calculated uncertainty in measurement.

Resolution Uncertainty and Uncertainty Analysis

Resolution uncertainty is a factor that should be considered in your uncertainty analysis. However, you have to consider all of the measurement equipment in your measurement system.

Simple Calibrations

For simple measurements or calibrations, you may only have two measurement devices; the measurement standard and the unit under test. In this scenario, you need to consider the resolution of both the measurement standard and the unit under test. If you are performing measurements or calibrations where the type of unit under test is always the same, you should include the resolution of the unit under test in your uncertainty budget to your CMC uncertainty calculations.

On the other hand, if you are performing measurements and calibrations where the unit under test can routinely change, you should omit the UUT resolution from your CMC Uncertainty estimates. Instead, you should include the UUT resolution later when **calculating calibration uncertainty in accordance with ILAC P14** [1]. This way, you are not overestimating your uncertainty in measurement by considering the resolution of two UUTs.

Complex Calibrations

When performing complex calibrations, you will likely have several measurement standards involved in your calibration process, plus a unit under test. In this scenario, you need to consider the resolution of every measurement standard in your process. If your measurement standards have different units of measurement, you will need to perform additional work to **calculate sensitivity coefficients or fractional uncertainty**. When using sensitivity coefficients or fractional uncertainty, be sure to follow the **rules of propagation for uncertainty analysis**.

Similar to simple calibrations; if the type of UUT in your calibration process does not change, you should include the UUT resolution in your CMC uncertainty analysis. If your calibration process can be used to calibrate several different types of UUTs, then you omit UUT Resolution from your CMC uncertainty analysis and consider it later when calculating calibration uncertainty.

Resolution Uncertainty Equation

When determining resolution uncertainty, there are several equations that can be used to evaluate the resolution of measurement equipment. The biggest challenge for many people is deciding which equation should be used.

To select the appropriate equation, it is important to evaluate these factors:

- type of device (e.g. digital display, analog scale, or artifact);
- theory of operation; and
- measurement resolution.

Full Digit/Scale Resolution

The equation below is used when the full resolution of the measurement equipment is considered to contribute to uncertainty in measurement.

In this equation, the resolution of the measurement device is the resolution uncertainty.

$$U_{res} = R_i$$

U_{res} = Resolution Uncertainty
R_i = Resolution of Instrument Scale

Half Digit/Scale Resolution

The equation below is used when half of the resolution of the measurement equipment is considered to contribute to uncertainty in measurement.

In this equation, the resolution of the measurement device is divided by two to calculate the resolution uncertainty.

$$U_{res} = \frac{R_i}{2}$$

U_{res} = Resolution Uncertainty
R_i = Resolution of Instrument Scale

Precision Scale Resolution

The equation below is used when estimating the resolution uncertainty of analog scales and devices.

In this equation, the resolution of the measurement device is divided by the **estimated fineness of the analog scale**.

$$U_{res} = \frac{R_i}{f_i}$$

U_{res} = Resolution Uncertainty
R_i = Resolution of Instrument Scale
f_i = Fineness That Scale Divisions Can Be Sub-Divided

This equation is reserved for experienced metrologists and technicians who are capable of properly estimating the fineness of the analog scale.

When working with analog devices, many experts recommend dividing the resolution of the analog scale in half. This may work for many devices, but what if half the distance between scale markers exceeds specifications and tolerances?

In this scenario, the half-digit resolution method fails to adequately estimate resolution uncertainty. Instead, you should consider how finely you can estimate the resolution of the scale between the markers.

How to Determine Fineness

To accomplish this, you need to consider the following factors:

- scale resolution;
- width of the scale markers; and
- width of the dial, pointer, or indicator.

1. Determine the resolution of the analog scale.
2. Evaluate the width of the scale marker and the dial pointer.
3. Determine the fineness: how many times the scale resolution can be sub-divided.
   a. Determine how many scale markers can fit between the scale markers.
   b. Determine how many dial pointers can fit between the scale markers.
   c. Choose the smallest number. This is the value for fineness.
4. Divide the resolution of the analog scale (from step 1) by the fineness of the scale (from step 3c.).

Calculate Resolution Uncertainty by Device Type

Resolution uncertainty is affected by the type of measurement equipment being evaluated. Below, you will find step-by-step instructions for determining the resolution uncertainty of various measurement devices.

How to Determine Resolution Uncertainty of Digital Devices

To find the resolution of measurement equipment with a digital display, just:

1. find the least significant digit (Hint: it's the last number on the right-hand side);
2. determine the smallest incremental change (e.g. 1, 2, 5, etc.);
3. determine whether the instrument counts or rounds the last digit; and
4. divide the resolution by 1 for counted values or 2 for rounded values.

How to Determine Resolution Uncertainty of Analog Devices

To find the resolution of measurement equipment with an analog scale or display, just:

1. find the minimum scale interval (i.e. distance between the scale markers);
2. observe the width of the scale marker and the dial pointer (if equipped);
3. determine how many times the scale can be subdivided (e.g. 1, 2, 5, etc.); and
4. divide the resolution of the scale by the value determined in step 3.

How to Determine Resolution Uncertainty of Artifacts

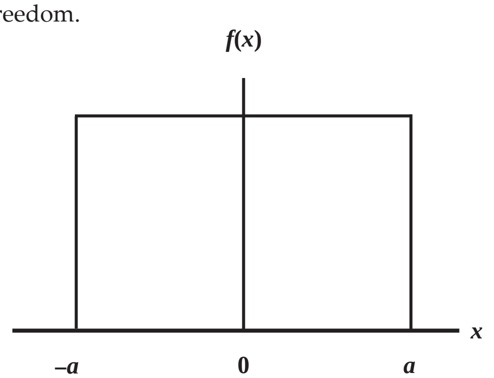
To find the resolution of measurement equipment without a scale or display, just:

1. refer to the artifact's calibration report;
2. find the reported value and uncertainty of the artifact;
3. determine which value has less resolution; and
4. select the value with the least resolution.

Convert Resolution to Standard Uncertainty

When converting resolution uncertainty to standard deviation equivalents, there are two equations that are widely accepted for use. The first equation divides the resolution by the square root of 3 and the second equation divides the resolution of the square root of 12. Determining which that you should use depends on how you decide to evaluate resolution uncertainty. So, I will explain this in more detail below.

The probability distribution associated with the resolution measurement equipment is the Uniform or Rectangular distribution. Therefore, the resolution is divided by the square root of three and has infinite degrees of freedom.



PRO TIP: To express infinity, I like to use a Googol [2] or a one followed by 100 zeros (i.e. 1.0E+100).

Standard Method to Convert Resolution to Standard Uncertainty

When converting to standard uncertainty, it is common to use the standard method. In this method, you will divide the resolution by the square root of 3.

$$u_{res} = \frac{R_i}{\sqrt{3}}$$

u_{res} = Resolution Uncertainty
R_i = Resolution Uncertainty of Measurement Equipment

This method is best used when you have already evaluated and sub-divided the resolution of your measurement standards and unit under test. Whenever you are in doubt, use the standard method.

Alternative Method to Convert Resolution to Standard Uncertainty

Sometimes, you may want to evaluate resolution uncertainty as a half digit. Rather than divide the resolution by 2 and then by the square root of 3, you can convert it to a standard deviation equivalent by dividing resolution by the square root of 12.

If you are unfamiliar with this method, give it a try. You will find that the result is the same.

$$u_{res} = \frac{R_i}{\sqrt{12}}$$

u_{res} = Resolution Uncertainty
R_i = Resolution of Instrument Scale

This method is best used when you are evaluating the resolution of your measurement standards and unit under test as a half-digit or half-scale resolution. If resolution is evaluated any other way, use the standard method.

Overstating and Understating Uncertainty in Measurement

It is never wise to overstate or understate estimates of uncertainty in measurement. However, it happens more often than you think; and, mostly by accident. So, it is important to consider how you evaluate resolution uncertainty.

It is very easy to understate uncertainty in measurement if you decide to subdivide the resolution of your measurement standards or unit under test. Additionally, it is just as easy to overstate uncertainty in measurement if you decide to not to subdivide. Therefore, you need to **evaluate your estimated uncertainty calculations** to verify that you do not overstate or underestimate uncertainty.

Understating uncertainty is more common when evaluating lower resolution digital devices. For example, when the uncertainty of your measurement process is much better than the resolution of the unit under test and you decide to evaluate UUT resolution as a half-digit, you are more likely to understate the uncertainty of your measurement results.

Overstating uncertainty is more common when evaluating low resolution analog devices. For example, when the uncertainty of your measurement process is much better than the resolution of the unit under test and you decide to not subdivide the UUT resolution, you are more likely to overstate the uncertainty of your measurement results.

In my opinion, I never subdivide the resolution of digital devices where the uncertainty estimate will be less than the resolution of the UUT. Additionally, I always subdivide analog scales, where practical, to avoid reporting an uncertainty estimate that is larger than the tolerance of the measurement. So, take these points into consideration and use your best judgment next time you calculate uncertainty in measurement.

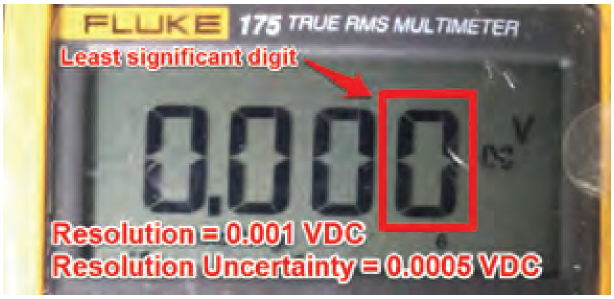
Resolution Uncertainty Examples

Evaluating resolution uncertainty is not as easy as most people think it is. There is a lot to take into consideration when evaluating resolution that many take for granted.

To help you better understand how to evaluate resolution uncertainty, I have decided to give you plenty of examples. In this section, you will see me calculate the resolution uncertainty of several different types of devices. Use these examples to help you calculate resolution uncertainty for your measurement results and calibrations.

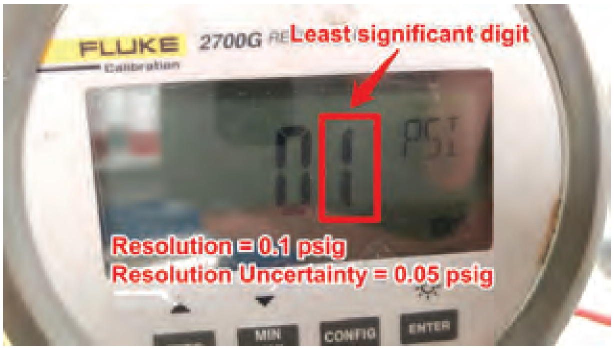
Now, understand that these results below are subjective; they are my opinion. What one metrologist, scientist, or technician determines as the resolution uncertainty may not agree with another. It is subject to interpretation, capability, and skill. So, be sure to use your best judgment and common sense.

Digital Multimeter Resolution Uncertainty



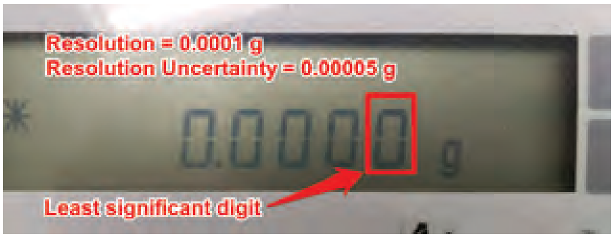
The digital multimeter in the image above has a resolution of 0.001 VDC. Since the last digit is rounded, it is acceptable to divide the resolution by 2. This makes the resolution uncertainty 0.0005 VDC.

Digital Pressure Gauge Resolution Uncertainty



The digital pressure gauge in the image above has a resolution of 0.1 psig. Since the last digit is rounded, it is acceptable to divide the resolution by 2. This makes the resolution uncertainty 0.05 psig.

Digital Scale/Analytical Balance Resolution Uncertainty

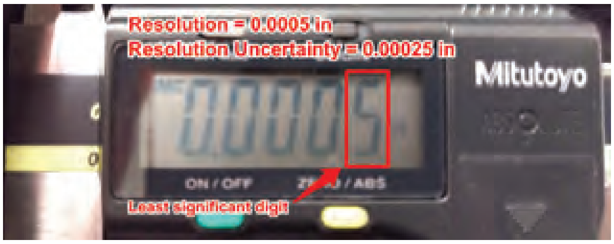


The digital scale or analytical balance in the image above has a resolution of 0.0001 g. Since the last digit is rounded, it is acceptable to divide the resolution by 2. This makes the resolution uncertainty 0.00005 g.

Digital Stopwatch Resolution Uncertainty

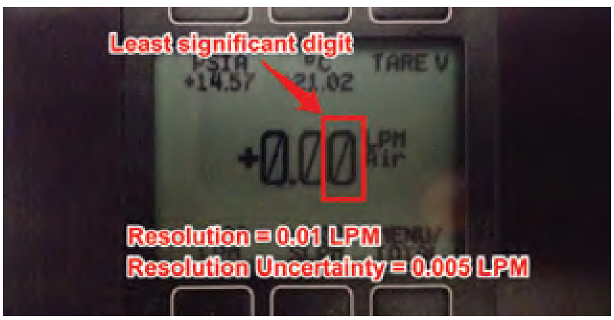
The digital stopwatch in the image above has a resolution of 0.01 sec. Since the last digit is counted, it is not acceptable to divide the resolution by 2. Instead, the resolution should be divided by 1 or remain the same as the resolution. This makes the resolution uncertainty 0.01 sec.

Digital Caliper Resolution Uncertainty



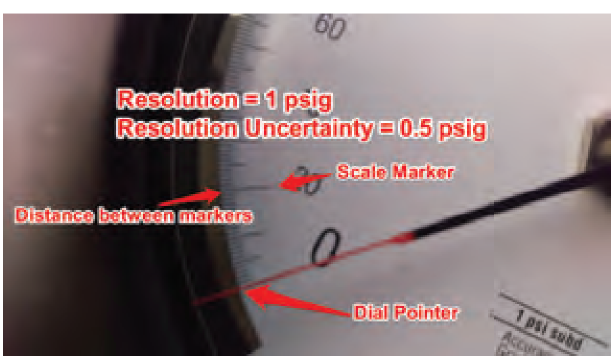
The digital caliper in the image above has a resolution of 0.0005 in. Since the last digit is rounded, it is acceptable to divide the resolution by 2. This makes the resolution uncertainty 0.00025 in.

Digital Flowmeter Resolution Uncertainty



The digital flowmeter in the image above has a resolution of 0.01 lpm. Since the last digit is rounded, it is acceptable to divide the resolution by 2. This makes the resolution uncertainty 0.005 lpm.

Analog Pressure Gauge Resolution Uncertainty

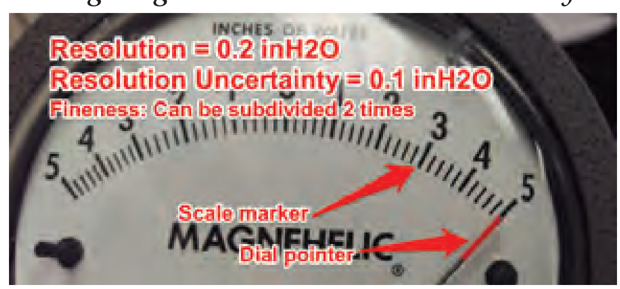


The analog pressure gauge in the image above has a resolution of 1 psig. Since the scale markers are very close together, it is acceptable to divide the resolution by 2. This makes the resolution uncertainty 0.5 psig.

Analog Pressure Gauge Resolution Uncertainty

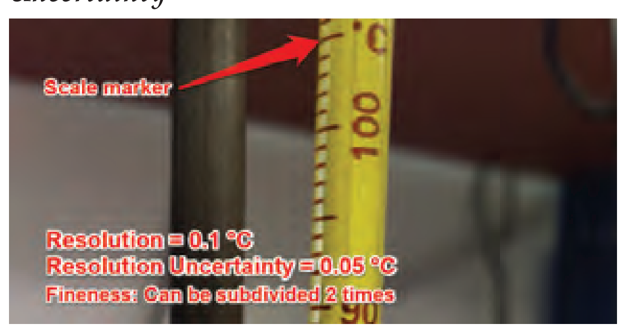
The analog pressure gauge in the image above has a resolution of 2 psig. Since the scale markers are spaced far apart, it is acceptable to divide the resolution by 4. I believe that you can fit 4 markers in between the marker intervals. This makes the resolution uncertainty 0.5 psig.

Analog Magnehelic Resolution Uncertainty



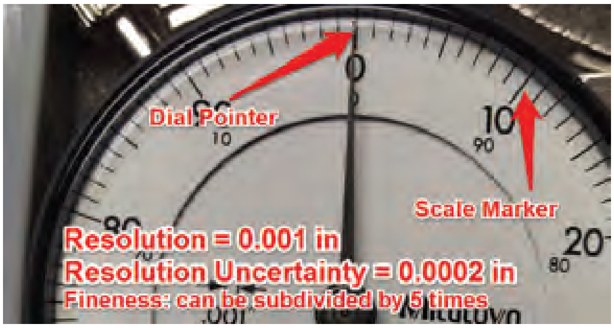
The analog magnehelic gauge in the image above has a resolution of 0.2 inH2O. Since the scale markers are very close together, it is acceptable to divide the resolution by 2. This makes the resolution uncertainty 0.1 inH2O.

Liquid in Glass Thermometer Resolution Uncertainty



The liquid-in-glass thermometer in the image above has a resolution of 1 °C. Since the scale markers are very close together, it is acceptable to divide the resolution by 2. This makes the resolution uncertainty 0.5 °C.

Dial Indicator Resolution Uncertainty

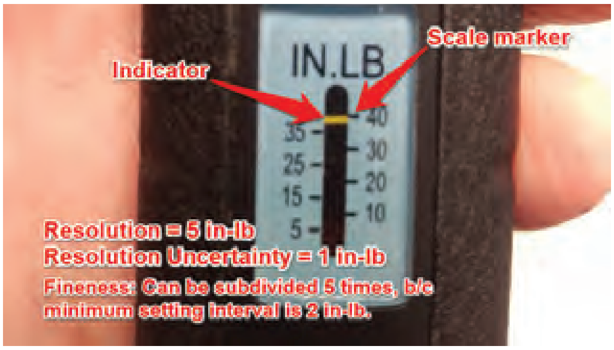


The dial indicator in the image above has a resolution of 0.001 in. Since the scale markers are spaced far apart, it is acceptable to divide the resolution by 5. I believe that you can fit 5 markers in between the marker intervals. This makes the resolution uncertainty 0.0002 in.

Torque Wrench Resolution Uncertainty

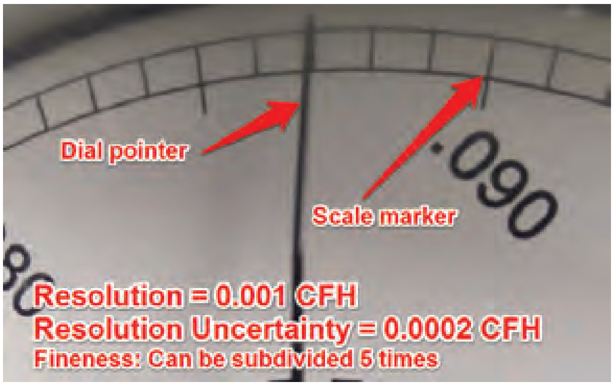
The torque wrench in the image above has a resolution of 1 in-lb. Since the torque wrenches minimum setting interval is 1 in-lb, it is acceptable to divide the resolution by 2. This makes the resolution uncertainty 0.5 in-lb.

Torque Screwdriver Resolution Uncertainty



The torque wrench in the image above has a resolution of 5 in-lb. Since the torque wrenches minimum setting interval is 2 in-lb, it is acceptable to divide the resolution by 5. This makes the resolution uncertainty 1 in-lb.

Dry Gas Meter Resolution Uncertainty

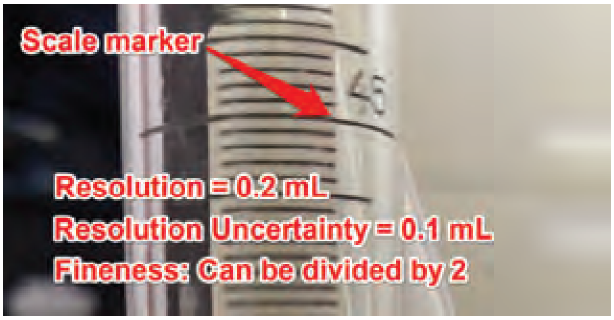


The analog dry gas meter in the image above has a resolution of 0.001 CFH. Since the scale markers are spaced far apart, it is acceptable to divide the resolution by 5. I believe that you can fit 5 markers in between the marker intervals. This makes the resolution uncertainty 0.0002 CFH.

Variable Area Flowmeter Resolution Uncertainty

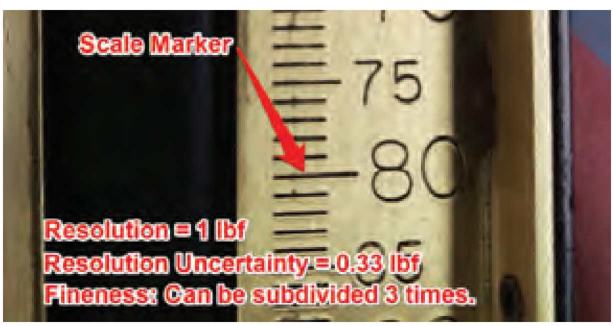
The variable area flowmeter in the image above has a resolution of 0.05 CFM. Since the scale markers are spaced far apart, it is acceptable to divide the resolution by 5. I believe that you can fit 5 markers in between the marker intervals. This makes the resolution uncertainty 0.01 CFM.

Burette Bubble Flowmeter Resolution Uncertainty



The burette bubble flowmeter in the image above has a resolution of 0.2 mL. Since the scale markers are very close together, it is acceptable to divide the resolution by 2. This makes the resolution uncertainty 0.1 mL.

Spring Scale / Force Gauge Resolution Uncertainty



The analog spring scale or force gauge in the image above has a resolution of 1 lbf. Since the scale markers are spaced far apart, it is acceptable to divide the resolution by 3. I believe that you can fit 3 markers in between the marker intervals. This makes the resolution uncertainty 0.33 lbf.

Calibration Mass Resolution Uncertainty

The calibration mass or weight in the image above has a measurement result reported with a resolution of 0.0000001 g. However, the associated measurement uncertainty reported in the calibration certificate has a resolution of 0.000001 g.

Since the reported measurement uncertainty has less resolution, the measurement result should have been rounded to match the resolution of the uncertainty in measurement (in accordance with ILAC P14 policy). Therefore, the appropriate resolution should be 0.000001 g.

Additionally, I do not recommend subdividing the resolution of artifacts, so the resolution uncertainty should match the resolution of the measurement result or 0.000001 g.

Gage Block Resolution Uncertainty

The gage block in the image above has a measurement result reported with a resolution of 0.1 μin. Additionally, the associated measurement uncertainty reported in the calibration certificate has a resolution of 0.1 μin. Since the reported measurement uncertainty has the same resolution as the measurement result, the resolution uncertainty should be 0.1 μin. I do not recommend subdividing the resolution of artifacts, so the resolution uncertainty should match the resolution of the measurement result or 0.000001 g.

Conclusion

Resolution uncertainty is an important influence for estimating uncertainty in measurement. With advancements in technology and reduction in tolerances, knowing how to determine and evaluate the resolution of measurement equipment is becoming increasingly more important. In this guide, I have provided you with everything that you need to know to properly evaluate resolution uncertainty.

References

[1] ILAC P14:01/2013 *ILAC Policy for Uncertainty in Calibration,* http://ilac.org/publications-and-resources/ilac-policy-series/.

[2] http://mathworld.wolfram.com/Googol.html

Richard Hogan is the Metrology Manager at ACR Technical Services and the President of ISOBudgets Consulting. Richard has 15 years of Metrology experience and holds a Masters Degree in Engineering. Contact Richard at rhogan@isobudgets.com or visit his website at www.isobudgets.com.

Uncertainty Propagation for Force Calibration Systems

Henry Zumbrun and Alireza Zeinali
Morehouse Instruments

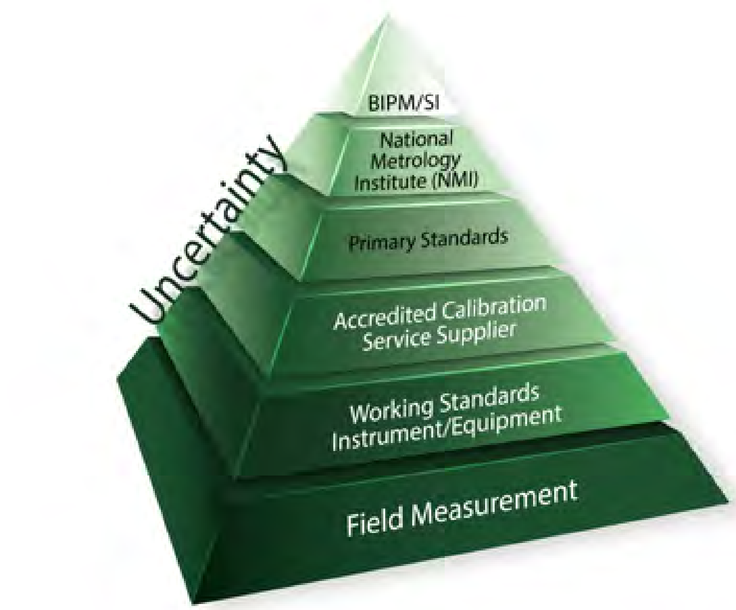


Figure 1. Measurement Uncertainty Pyramid

Introduction

There are several labs operating throughout the world, whom do not follow a designated guideline for calculating measurement uncertainty for force calibrations. Realizing the need for a guidance document, Morehouse decided to draft this document explaining how to calculate measurement uncertainty and how uncertainty propagation for force calibration systems works. Calibration and utilization of measurement instruments will imply some level of uncertainty. As an instrument calibration is traced back to SI units, a higher number of intermediate calibration stages results in higher levels of measurement uncertainty (Figure 1) [1]. In other words, uncertainty of the unit under test is typically higher than the standard with which it was calibrated. It is not possible for the expanded measurement uncertainty of the unit being calibrated to be less than the machine or force measuring device that is used to calibrate the unit itself. This paper describes the propagation of uncertainties using Calibration and Measurement Capability (CMC) for force measurement instruments through the traceability chain to SI units. For the instrument users who require some minimum level of expanded uncertainty, this paper provides information on what level of calibration is needed for their reference standards.

Test Plan and Equipment

A 445 kN (100k lbf) Morehouse Ultra-Precision Load Cell was chosen for the testing plan. The calibration test setup is shown in Figure 2. The Morehouse load cell provides relatively high stability, resolution, and repeatability. Consequently, the testing plan represents an almost best-case scenario: the lowest level of Calibration and Measurement Capability (CMC) that a load cell user can achieve at each level of the traceability chain. A 89 kN (20k lbf) test point was chosen for analysis based on historical data. This load point was chosen for studying the CMC propagation to follow the ILAC P14 requirements [2]. Morehouse Ultra-Precision 445 kN (100k lbf) systems can often use this load cell in the Tier 2 group from 20 % to 100 % of capacity for force calibration purposes without switching standards. The reference standard of Tier 2 in this paper represents a load cell that is calibrated in accordance with ASTM E74 standard test method with using other load cells with ASTM Class AA designation [3]. Additionally, the 20 % point represents a pivot point for achieving CMC of approximately 0.02 % of applied force. At higher forces, the CMC is typically lower. However, at lower than 20 % of capacity forces, CMC starts to increase; it continues to increase to the 10 % and lower force points, where the CMC becomes higher than 0.05 % of applied force. Therefore, it is often recommended that the end user in Tier 2 only uses the load cell from 20 % through capacity in order to maintain CMC's better than 0.02 % of applied force.

Tier 0: CMC for Primary Standards

In this tier, Calibration and Measurement Capability (CMC) for Morehouse's deadweight calibration systems were determined.

Table 1 contains the uncertainty contributors for this calculation, along with their appropriate divisors. It should be noted that the testing for this study was conducted based on United States customary units, and then converted to SI units in Table 1 to make it more tangible for international users. Degrees of freedom and coverage factors were calculated separately using the Welch-Satterthwaite equation [1]. In this tier, Morehouse had the reference deadweights calibrated directly by N.I.S.T. These weights, pictured in Figure 3, were adjusted for the local gravity, material density, and air buoyancy, and their traceability is derived from the international prototype kilogram (SI unit symbol kg) [3].

When the calibration was performed in a Morehouse deadweight machine, CMC was calculated using these weights. A repeatability study was conducted with three high quality Morehouse load cells (445 kN; 111 kN; and 44 kN capacities) throughout the entire range of the machine. Morehouse's CMC resolution for 89 kN (20k lbf) load was used for UUT resolution in Tier 0 only. This value was determined based on a 111 kN (25k lbf) load cell with 4 mV/V output at capacity and 0.00001 mV/V readability.

The environment was controlled by better than +/- 1.0 °C [3], while the stability of the weights was calculated using historical values for the material and years of wear history from our other deadweight machines. The resolution of the weights was zero since they are physical standards, and

Figure 2. 445 kN (100k lbf) Load Cell in Deadweight Machine Being Calibrated

Figure 3. View of Deadweight Machine

TIER >>>			TIER 0 Primary Standards	TIER 1 Primary Lab	TIER 2 Secondary Lab	TIER 3 Working Standard
UUT Info >>>			No UUT (Deadweight CMC Calculation)	Load Cell Calibrated by Primary Standard (Class AA Assigned)	Load Cell Calibrated by Secondary Standard (Class A Assigned)	Load Cell Calibrated in Force Press
Uncertainty Source		**Divisor**	**Primary Cal (Deadweight)**	**Primary Cal (Deadweight)**	**Working Cal (UCM)**	**Field Cal Lab (scale calibrator)**
Reference	U_{REF}	2	0.396893 N †	1.42 N	17.57 N	27.45 N
Resolution (Reference)	$U_{RES,REF}$	3.464	N/A (deadweight)	1.07 N	1.07 N	1.07 N
Resolution (UUT)	$U_{RES,UUT}$	3.464	0.2780 N ††	1.07 N	1.07 N	1.07 N
UUT Repeatability	U_{REP}	1	0.2567 N	1.7646 N	1.7646 N	1.7646 N
B/W Techs Reproducibility and Repeatability	$U_{R\&R}$	1	0.49 N	3.910 N	3.910 N	3.910 N
Stability	U_{STA}	1.732	0.0178 N	4.45 N	4.45 N	4.45 N
Environmental	U_{ENV}	1.732	Included in U_{REF}	0.667 N †††	0.667 N	0.667 N
Side Load Sensitivity	U_{MISC}	1.732	N/A (deadweight frame)	2.67 N	2.67 N	2.67 N
ASTM Lower Limit Factor (LLF)	U_{ASTM}	2.4		18.296 N (Class AA Assigned)	23.718 N (Class A Assigned)	33.36 N *
Expanded Uncertainty	U	-	0.0016 % (1.42 N) ‡	0.01974 % (17.57 N) ‡‡	0.031 % (27.45 N) ‡‡‡	0.106 % (97.42 N)

Table 1. Uncertainty Propagation Analysis for Load Cell Calibrations [1-5]

Notes:
Expanded Uncertainty may be the CMC of the lab, depending on the Tier.
Table is made based on data from a 445 kN (100k lbf) Morehouse Ultra-Precision load cell. Testing was conducted at 88.964 N (20k lbf) force (20% of capacity).
UCM: Universal Calibrating Machine
† Includes: uncertainty of deadweight calibrations by NIST, uncertainty of material density, uncertainty of gravity, uncertainty of air density
†† CMC Resolution = Capacity (25 kip) / (load cell output) × Readability (This was added on top of the regular UUT resolutions. There is an ongoing debate on whether or not this extra item is necessary.) This is the resolution of the electronic indicator(s).
††† 0.0015% per °C (± 1 °C)
‡ Coverage factor = 2
‡‡ Coverage factor = 1.97
‡‡‡ Coverage factor = 1.98
* LLF was calculated according to the E74 standard method. However, this would not be valid since the standard requires a minimum Class A limit for calibration standard.

the resolution of a good measurement system (Morehouse Ultra-Precision Load Cell coupled with HBM DMP 40 indicator) was used as an uncertainty contributor for UUT resolution. Various technicians' tests were compared to determine the repeatability and reproducibility per point of the Morehouse deadweight calibration machine. All of these efforts, combined with continued process monitoring, yielded a CMC of better than 0.0016 % of applied force.

Tier 1: Using Primary Standard Deadweights to Calibrate a Load Cell

For Tier 1 calibration, the deadweight calibration machine was utilized to calibrate a load cell in accordance with the ASTM E74 standard [3]. More on this calibration procedure is explained online at: http://blog.mhforce.com/2016/02/astm-e74-calibration-procedure.html. A Morehouse 445 kN (100k lbf) load cell was calibrated in this tier by deadweight primary standards known to have a CMC better than 0.016 % of applied load.

To calculate the CMC of the calibration, a repeatability and reproducibility (R&R) study was done for Tier 1 using a 111 kN (25k lbf) Ultra-Precision load cell. Moreover, an environmental condition of ±1 degree Celsius, along with a stability value of 0.005 % (50 parts per million), was used for calculating uncertainty values. The actual resolution of the UUT load cell 1.07 N (0.24 lbf) was employed for uncertainty calculations in Tier 1. It might be noteworthy to mention that the reference uncertainty used in Tier 1 already included the UUT resolution embedded in deadweight CMC calculations. Basically, UUT resolution is considered twice in the calculation of uncertainties for Tier 1–3 [4]. This method is on the conservative side of the uncertainty calculations, and there is ongoing debate about whether or not the resolution from CMC must be included in higher calibration tiers.

Load cell output stability is another of the uncertainty contributors when the cell is calibrated per ASTM E74. Stability is calculated by comparing the load cell output to the previous calibration data [3]. Most Morehouse Ultra-Precision load cells provide a one year stability of around 0.005 % through 0.01 %. Typically, the actual numbers would be used for this evaluation; however, this test was controlled, and the experiment could not wait another year to obtain the actual UUT load cell's stability numbers.

Ideally, load must be applied to the primary loading axis of any load cell in order to produce most repeatable and accurate results. This primary loading axis for shear web load cells such as the one used in this study, generally falls on the axisymmetric axis of the cell. However, in reality, some side loading is traduced into the loading system which can influence the load cell output. Side loading on a shear web load cell is demonstrated in Figure 4. Morehouse Universal Calibrating Machine (UCM) can provide side loading of better than 1/16th of an inch. Additionally, the side load sensitivity of a Morehouse Ultra Precision load cell is 0.05 % of load per inch of side loading. Multiplying 1/16th of an inch by 0.05 % yielded an uncertainty contribution of 0.003 % of applied load.

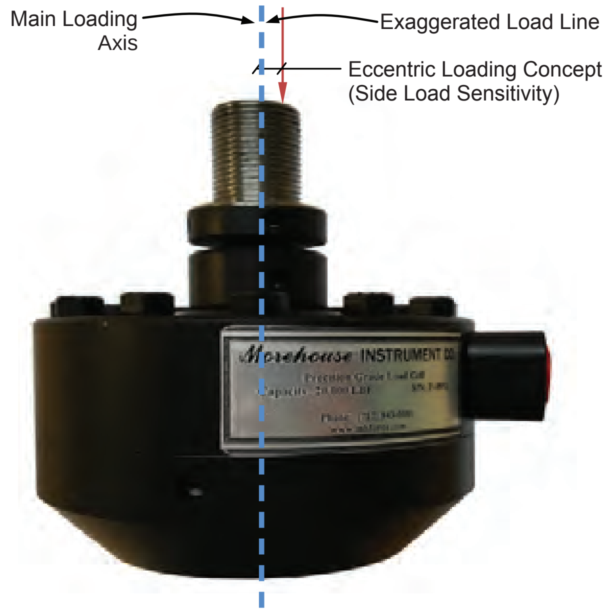


Figure 4. Side Loading on a Load Cell

The ASTM E74 calibration and analysis results in a Lower Limit Factor (LLF), which is the standard deviation of variations in different runs multiplied by a coverage factor of 2.4. The UUT load cell in Tier 1 was assigned a Class AA loading range, which provides a test accuracy ratio (TAR) of better than 5:1 when used to calibrate another load cell in accordance with the ASTM E74 standard. In this range, the calibrated load cell (UUT) can be used to calibrate other load cells that will be used to calibrate force measuring or testing machines [3]. As presented in Table 1, the expanded uncertainty for Tier 1 calibration was 0.01974 % of applied force, or 17.57 N (3.95 lbf) at 89 kN (20k lbf) force. This value was applied as the reference uncertainty in Tier 2 calibration.

Tier 2: Using a Load Cell Calibrated by Primary Standards to Calibrate Other Load Cells

In this tier, the Working Standard load cell was calibrated in accordance with the procedures outlined in the ASTM E74 standard. ASTM E74 fits the data points to a higher order curve using the least squares fit method [3]. This is different than just linearizing a load cell. To run the test, a second Morehouse 100k lbf Ultra-Precision load cell was calibrated using the Morehouse Universal Calibrating Machine (UCM). As previously stated, this paper represents a chain of calibration for high quality instruments and calibrations currently available in the industry. For this reason, the Morehouse Ultra-Precision load cell was used for all calibration levels. Using other instruments with lower performance quality would potentially increase the uncertainty results reported.

In Tier 2 Calibration, identical resolutions were used for both the reference cell and the Unit Under Test (UUT). The first Morehouse Ultra-Precision cell that was calibrated to primary standards in Tier 1 was employed in Tier 2 to calibrate the UUT (the second 445 kN Morehouse Ultra-Precision load cell). The CMC that resulted from Tier 1 calibration (17.57 N) was employed as the reference uncertainty at this level. The same uncertainty contributors were used and a new ASTM LLF was calculated.

Based on the calibration data, the LLF was calculated and an ASTM Class A loading range that provides a test accuracy ratio (TAR) of better than 4:1 was assigned[1]. This calibration produced a working standard with an assigned class A loading range [3]. As shown in Table 1, the resulting expanded uncertainty for Tier 2 calibration is 0.031 % of applied force, or 27.45 N (6.17 lbf) at 89 kN (20k lbf).

Tier 3: Using a Working Standard Load Cell to Calibrate Field Equipment

Tier 3 was meant to simulate the conditions of a field calibration test. In the ASTM E74 pyramid, the working standard that was calibrated in Tier 2 (accredited calibration supplier or secondary standard) could only be used to calibrate testing machines. However, the testing plan presented was conducted in a controlled laboratory environment to simulate the best-case scenario for uncertainty propagation. Thus, the same testing regime, with load cell and UCM, was followed for Tier 3. Nonetheless, an aircraft scale calibrator (such as Morehouse 804000) could have been used. For this calibration, the ASTM LLF was reduced to a pooled standard deviation to perform what would normally be the calibration of a testing machine. Since an identical setup as in Tier 2 was utilized for this test, the uncertainty contributors remained the same; however, the ASTM LLF increased again. The ASTM LLF increase was due to the higher expanded uncertainty bands of the reference.

1 Normal Metrology Practices discourage TAR. ASTM E74 was developed in 1974 and still relies on a method using TAR where the maximum error of primary standards are to be no more than 0.005 % of applied force, Secondary Class AA Standards are no more than 0.05 % and Field Standards are no more than 0.25 % [3]. This equates to TAR's of 10:1, 5:1, and 4:1. Contemporary conventions of metrological science no longer focus on a TAR in establishing decision risk criteria. Most modern practices focus on TUR (Test Uncertainty Ratio) for a measure of adequate decision risk criteria [6].

Repeatability and Reproducibility (R & R) tests were conducted at each tier. In Tier 0, we used the same R & R values as reported in our CMC. In Tiers 1 through 3, we used a R & R study we conducted in house and repeated the number throughout tiers 1 through 3 [1]. The full explanation for B/W Techs Reproducibility and Repeatability can be found in section 7. We would expect the R & R between technicians to grow larger throughout the remaining tiers as well as the resolution of the Unit Under Test because the UUTs at each tier will typically be less accurate than what was used for these tests.

The uncertainty calculations in Table 1 resulted in CMC for Tier 3 equal to 0.106 % of applied force at 89 kN (20k lbf). It might be worth mentioning that actual Tier 3 testing would produce much higher CMC than shown in Table 1 since the stability per point would most likely increase, as would the resolution of the UUT. It is important to note that the end calculation will inevitably be higher than what we have shown.

Explaining CMC Calculations Contributors

All Calibration and Measurement Capabilities were calculated using a combination of A2LA document R205, ILAC P-14, GUM, and the appendix in ASTM E74, which call for the following [1-4]:

1. **Repeatability** – Repeatability was defined as the standard deviation of 10 measurements with the same load cell at a 89 kN (20k lbf) force point. The Tier 0 number was derived from Morehouse's Calibration and Measurement Capability, which was submitted to the company's accreditation body. For Tiers 1–3, repeatability was measured between two technicians, using a 111 kN (25k lbf) load cell, loaded to 89 kN (20k lbf), 10 times each in a 445 kN (100k lbf) Universal Calibrating Machine (UCM).
2. **Resolution** – Resolution was recorded as the resolution of both the Unit Under Test and the Reference Standard. In Tier 1, there was only one contribution from the UUT since the deadweight calibration machine is equipped with intrinsic standards. Per JCGM 200:2012 Resolution is the smallest change in quantity being measurement that causes a perceptible change in the corresponding indication.
3. **Reproducibility** – Reproducibility was determined using an R&R study. Each of the two technicians performed 10 runs of data, and their overall results were compared against one another. A standard deviation of the average was calculated between technicians and used for the final reproducibility number for all tiers.
4. **Reference Standard Stability** – For Tier 0, historical data and Statistical Process Control Data were used

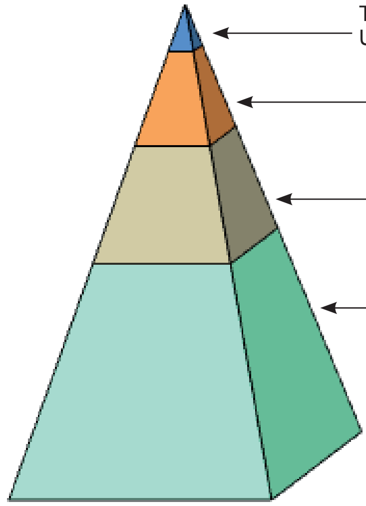


Figure 5. Uncertainty Propagation for 89 kN (20k lbf) through Various Tiers

to calculate stability. For Tiers 1–3, stability of 0.005 % was assumed. This is based on historical data on Morehouse Ultra Precision Load Cells. The number represents an approximation of historical data from several of these load cells.

5. **Environmental Factors** – A change of ±1 degree Celsius was used, and the corresponding effect on load cell output was determined. Generally, load cells of this type have a temperature specification of 0.0015 percent reading per °C.
6. **Miscellaneous Errors** – This consisted of side load sensitivity for the Morehouse calibration machine assuming a maximum of 1/16th of an inch of misalignment.
7. **ASTM LLF** – This is calculated as per the ASTM E74 standard and was reduced to a pooled standard deviation. The ASTM E74 standard can be found online at: https://www.astm.org/Standards/E74.htm. The ASTM E74 standard uses a method of least squares to fit the data points. The standard deviation of the all of the deviations from the predicted values versus the observed values is found by taking the square root of the sum of all of the deviations divided by the number of samples minus the degree of polynomial fit used minus one.
8. **Reference Standard Calibration Uncertainty** – This was calculated using the Welch-Satterthwaite equation, and is a combination of the sum of the squares of all above contributors. The reference standard uncertainty was then transferred from tier to tier, absorbing additional uncertainty contributors per tier.

Conclusions

Based upon the testing information presented from and supported by years of testing, this summary should help guide users in determining what uncertainty they can obtain while using various force standards. If a CMC of better than 0.03 % of applied force is desired, calibration by primary standards (deadweight) is necessary. Figure 5 illustrates the predicted minimum uncertainties that can be achieved by various laboratory tiers. The figure indicates that an additional reference standard would be needed at every 20 % interval to maintain better than 0.02 %. In other words, a 500-kN Universal Calibrating Machine would need reference standard load cells or proving rings with capacities of 445, 89, and 22 kN (100k, 20k, and 5k lbf respectively) to achieve 0.02 % of applied load or better with a force range of 4.450 kN (1k lbf) through 445 kN (100k lbf).

The testing proved the importance of the reference standard in relation to overall expanded uncertainty. Deadweight primary standards are predictably the best possible reference standard. A laboratory using secondary standards—those standards calibrated by deadweight—can achieve CMC's as low as 0.02 % of applied load if they are using several standards. Nonetheless, the downside of using several standards is that this method involves standards to be changed at least once during the calibration. Laboratories that claim CMC's of 0.01 % of applied or better may have to make three to four standard changes, or, they would need to have very expensive reference load cells and meters calibrated direct by a NMI such as N.I.S.T. These changes will add to the overall uncertainty of the force measuring instrumentation being calibrated. Standard changes take time, which often results in higher deviations

How Good Does Your Calibration Provider Have to Be? (T.U.R. Table)

Calibration Standard Required			Tolerance Required					
			0.010%	0.020%	0.050%	0.100%	0.200%	0.500%
Deadweight	Calibration Lab Capability (CMC)	0.002%	4.329	8.657	21.644	43.287	86.575	216.437
Deadweight		0.005%	1.949	3.897	9.743	19.486	38.972	97.429
Deadweight/Lever		0.010%	0.993	1.987	4.967	9.934	19.868	49.669
High End Load Cell		0.020%	0.499	0.998	2.496	4.992	9.983	24.958
High End Load Cell		0.050%	0.200	0.400	1.000	1.999	3.999	9.997
Good Load Cell		0.100%	0.100	0.200	0.500	1.000	2.000	5.000

This table is based on a Calibration Grade Load Cell with 0.01 lbf Resolution; 0.1 lbf Repeatability.
Anything in Red would have too much measurement risk.

Figure 6. T.U.R. Table

between the test points calibrated with one standard when compared to the test points using the additional standard. This additional error is directly related to timing issues and often raises the ASTM LLF, which affects the Class A loading range [3]. Therefore, if the end user wants the lowest possible loading range, it is recommended that calibration be performed using deadweight primary standards.

Furthermore, the CMC of the calibration laboratory is critical in regards to making statements of compliance. This would be whether or not an instrument is within the required tolerance. ISO/IEC 17025:2005 states "When statements of compliance are made, the uncertainty of measurement shall be taken into account" [5]. Figure 6 shows a table calculating Test Uncertainty Ratios for various CMC's and instrument tolerances. The calculation of T.U.R. involves taking the measuring device's tolerance and dividing by the expanded uncertainty [6]. The CMC discussed in this paper along with the resolution of the unit under test make up the expanded uncertainty. The repeatability of the UUT may be substituted with the repeatability calculated in the CMC for calculation of expanded uncertainty.

$$T.U.R. = \frac{Tolerance}{Expanded\ Uncertainty}$$

Many laboratories often publish their best possible CMCs on their scope of accreditation, or they might publish a reference uncertainty value such as 0.05 % of applied force as it correlates to using a secondary standard with a Class AA loading range. ASTM E74 Class AA operates on a Test Accuracy Ratio (TAR) of 5:1 to ensure that the Class AA standard is at least 5 times better than the force measuring instrument being calibrated [3]. If deadweight calibration is not possible, it is important to ask your calibration provider for the actual measurement process uncertainty, and to find out how many standard changes they will make to assure the attainment of the lowest possible CMC, which will ultimately be transferred to your equipment.

References

[1] JCGM 100:2008 E*valuation of measurement data — Guide to the expression of uncertainty in measurement*.

[2] ILAC P14:01/2013 *ILAC Policy For Uncertainty in Calibration*, http://ilac.org/publications-and-resources/ilac-policy-series/.

[3] ASTM E74-13a *Standard Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machine*, https://www.astm.org/Standards/E74.htm.

[4] A2LA R205 *R205 - Specific Requirements: Calibration Laboratory Accreditation Program*, American Association for Laboratory Accreditation, 2015, https://www.a2la.org/requirements/17025_calibration_req.pdf.

[5] ISO/IEC 17025:2005 *General requirements for the competence of testing and calibration laboratories*, International Organization for Standardization/International Electrotechnical Commission, 2005.

[6] ANSI/NCSLI Z540.3-2006 *Requirements for the Calibration of Measureing and Test Equipment Handbook*, 2013.

Disclaimer

Any views and opinions expressed in this paper represent those of the authors only, and not necessarily the organizations mentioned in the paper. Morehouse calibration equipment was used to conduct the testing in this study since they were easily accessible to the authors and technicians. However, any laboratory using primary standards better than 0.0016 % of applied force, calibrated by an accredited laboratory, should be able to achieve similar results.

Henry Zumbrun (hzumbrun@morehouse.com) & Alireza Zeinali, Morehouse Instrument Company, 1742 Sixth Avenue, PA 17403, www.mhforce.com.

Reference Standards Calibrations

TRANSCAT® has got you covered

Reference Mass Calibrations
- Echelon II and III standards
- Class 1—7 weights
- Facilities throughout North America

Reference Temperature Calibrations
- Ranges from –195° - 660°C
- Industry best uncertainties
- Comparison and fixed point methods

Reference Electrical Calibrations
- Reference multimeters
- Reference multi-function calibrators
- AC standards and more

Reference Pressure Calibrations
- Pressure calibration to 72,500 PSI
- Low pressure to -60” H20
- Deadweight tester calibration

FOR RENT

Rental Standards Available
- Short and long term rentals available
- Lease to own
- Used equipment for sale

800.828.1470 TRANSCAT.com

TRANSCAT®
Trust in every measure

The Pendulum and Standards of Measure in the Ancient World

Roland A. Boucher

When the French proposed their first metric system in 1723, they had no idea it had been invented by the ancient Mesopotamians 5000 years earlier. Just as the French proposed to use the length of a one-second pendulum to create standards of length, volume and weight, the Sumerians had created nearly identical meters, liters and kilograms. Our research shows that the Sumerians in ancient Mesopotamia used both the Moon and the Sun as their clock. It appears that the Egyptians improved on the timing accuracy by using the stars. Later the Minoans introduced the use of the planet Venus as a clock.

These concepts spread throughout the Ancient world from Britain in the West to Japan in the East. The Minoan standards are immortalized in the Magna Carta of 1215. The old English saying "a pint a pound the world around" had been true for over 3000 years. In the 19th Century, both Stuart and Penrose accurately measured the dimensions of the Parthenon finding its width to be 0.9997 arc seconds on the polar circumference of the Earth. This accuracy puzzled scholars for 150 years. Our research shows the width of the Parthenon in Athens was designed to be 1/30 of the perimeter of the Great Pyramid of Giza. The same pendulum formula, when timed with Venus rather than the Sun, increased the pendulum length just the right amount. This precision was not dumbfounding – it was just dumb luck.

Introduction

We intend to prove that ancient societies in the Third Millennium B.C.E. made use of the properties of the pendulum to develop precise standards of length, volume and weight and that these standards spread throughout the Ancient World, some surviving to modern times.

Our search began with the development of a number of proposed pendulums, each based on the timed motion of celestial objects such as the Moon, the Sun, the Stars, and the planet Venus.

Standards of volume and weight were then developed from the resulting pendulum lengths.

Next, these pendulum standards were compared with examples of standards of length, volume and weight which have survived for 4 or 5 millennia. Few physical standards of length and volume have survived, however many examples of ancient calibrated weights were found. This search for these standards took place over a number of years, in libraries and in the archives of archeological journals.

The Sumerians of ancient Mesopotamia used a sexagesimal numbering system, counting in multiples of both 6 and 10. The division of the meter or yard, called a Step, was divided into 60 Fingers as well into Cubits of 30 Fingers and Feet of 20 Fingers. The standard volume of approximately one liter was that of a 1/10 step or 6 finger wide cube called a Sila. The standard weight of approximately 1/2 kilogram, called the Mina, was 1/2 the weight of one Sila of water. The weight of 60 mina was called a talent and the weight of 1/60 mina was called a Shekel.

Many of these Ancient civilizations also retained a binary division of volume where the dimensions of the container are reduced in halves. As an example, the volume of a cubic foot, sometimes called an Amphora, was divided into 1/2 foot cubes creating an ancient gallon of 1/8 cubic foot, which was further divided into pints of 1/64 cubic foot. The binary standard of weight, the pound, was established as the weight of one pint of water. The binary division of the foot into 16 fingers was also common.

The Accuracy We Could Expect From an Ancient Pendulum

The Platinum ball and iron wire used by the French in their first proposed metric system would not have been available to the Sumerians. However, they would have

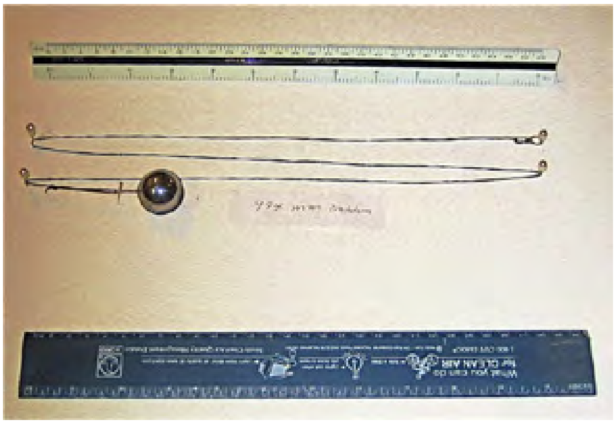


Figure 1. 994 mm Test Pendulum

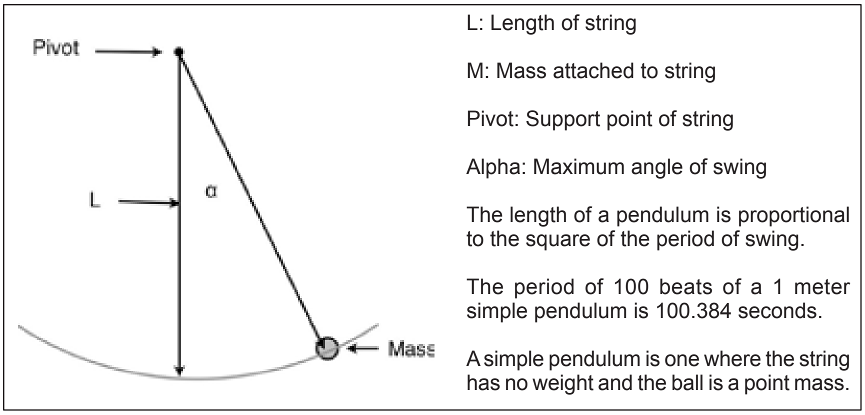


Figure 2. A Simple Pendulum

gold, copper, or stone available for the ball and waxed flax string to replace the iron wire. I constructed a number of such pendulums using brass or steel balls and waxed flax string and found that a 944 mm pendulum would consistently swing through 100 beats in 100.00 seconds, a precision of one part in 10,000. *The Sumerians could easily reproduce this pendulum.*

How a Pendulum Can Be Used to Establish a Unit of Length

Developing a comprehensive and precise set of measurement standards was not a trivial problem faced by ancient civilizations. Human body parts are not precisely reproduced from parent to child and are not suitable as standards of measurement. However, the names of some body parts have provided convenient names for some standards. Nature provides no standard of length, weight, or volume. Fortunately, it can provide four standards of time:

- the Diameter of the Full Moon passing by a line of sight can divide the day into 720 parts;
- the line of sight to the Sun rotating one degree in azimuth divides the solar day into 360 parts;
- the line of sight to a star rotating one degree in azimuth divides the day into over 360 parts; and
- the line of sight to Venus rotating one degree in azimuth divides the day into under 360 parts.

The "beat" of a pendulum is the time it takes the pendulum to make one-half swing, i.e., the time from when the swinging pendulum is vertical, or the point where it would hang if at rest, through the extension of the swing to its highest point, until it swings back and reaches vertical again.

The beat is determined almost exclusively by the Earth's gravity and the length from the pendulum's pivot point to the center of its mass. Unless the physical properties of a standard pendulum are carefully chosen, errors can occur [1, 2]. Increasing the angle of the swing will cause the period of a pendulum to increase about 600 parts per million when the swing increases to 5 degrees each side. Fortunately, the non-Zero weight of the string in a real standard pendulum will cause the period to decrease. This compensating effect in this case will completely cancel the increased period when the weight of the string reaches about 1/120 the weight of the ball. With care, five figure accuracy can be achieved. In any case, it would be highly unlikely to expect an error greater than 0.1 percent even if the user had no knowledge of this effect.

The force of gravity is relatively constant anywhere on the Earth's surface [3]. Therefore, the only two variables in a swinging pendulum are the length of the string and the time of the beat. If one of these two variables is known, the other can be determined. In other words, if two pendulums have the same length of string, they will have exactly the same beat anywhere on Earth. Conversely, if two pendulums have the same beat, then they will have exactly the same length of string. This fact, combined with the relative ease of building a pendulum, makes it an ideal and logical starting point for a universal system of linear measurement. The only prerequisite is determining an accurate measure of a time.

Establishing Accurate Intervals of Time

The simplest method which seems to have been used was to mark the interval of time it took the diameter of a full Moon to rise or set, or the interval of time it took the moon's disk to pass a north-south line of sight. This interval, when viewing the full moon near apogee is about 121 seconds. The length of a simple pendulum, allowed to complete 60 swings or 120 beats in this interval, would be about 1012 mm.

The second method which seems to have been used was to apply the interval of time it took the Sun's shadow to rotate through one degree west to east. This angle can be constructed by using a wheel to mark a distance of 180 diameters in a north-south direction from a peg. Then roll the wheel for 1/2 circumference to each side of the south end of the line, planting stakes at both ends, and stretching a string from the peg to each stake. The interval of time it takes for the center of the sun's shadow to move from one string to the next is 240 seconds. This interval is the Sumerian Gesh or 1/360 parts of the Solar day. The length of a simple pendulum, allowed to complete 120 swings or 240 beats in this interval, would be about 994 mm.

Element	Solar day	Star day	Venus day
length of day	***86400 sec***	***86164.08 sec***	86560.33 sec
length of 1/360 day	***240.00 sec***	***239.3447 sec***	240.4454 sec
length of 1/366 day	***236.065 sec***	***235.421 sec***	236.504 sec

Table 1. Timing intervals for Sun, Star, and Venus.

The Egyptians may have been the first to use a star to mark an interval of time. The interval of time it takes for a star in the equatorial plane to move 1/366 of a complete circle is 235.421 seconds. A star, as a mere pinpoint of light, can provide a much higher level of precision than the Sun. The length of a simple pendulum allowed to complete 366 beats in this interval would be about 300 mm.

The Minoans on the island of Crete may have been the first to use the planet Venus to mark the interval of time. The planet Venus is closer to the Sun than the Earth and orbits the sun in 244 days. By viewing Venus when it is on the opposite side of the Sun from the Earth, its motion cancels out some of the apparent motion caused by the spinning Earth. The interval of time it takes for Venus to move 1/366 of a circle is 236.504 seconds. The length of a simple pendulum allowed to complete 366 beats in this interval would be about 303 mm.

Creating an accurate interval of time of about four minutes or multiples thereof was obviously something the Ancients would have no trouble achieving.

Establishing Proof That a Pendulum Length is Actually an Ancient Standard of Length

While our study began in Sumeria, it soon took us to Egypt and to the Minoan civilization on the island of Crete. These studies convinced us that these three great civilizations of the ancient Near East had indeed used a pendulum to create their standards of length. Evidence was found that pendulum-derived standards of length were used in China and Japan to the East, Greece, Italy, Germany and France, and finally in England to the west. One of these ancient standards, the English pound, is still in use in the USA today. We suspect that the Ancient Japanese Foot may still be used by some Japanese carpenters and wood workers today.

Proof that these Ancient Standards of length were pendulum-derived is not always as easy as comparing pendulum-derived length to an Ancient standard of length. In some cases, the only standards that remain are those of volume or weight. Fortunately, standards of volume were derived directly from the cube of a linear dimension, just as is done today. Standards of weight, in turn, were derived from the weight of a standard volume of water at room temperature. (The metric system today specifies that the weight be established with the water temperature at 4 °C). Finally, some standards of weight were derived from the weight of a volume of grain; in some cases standards existed for a variety of grains in the same culture. Fortunately, a liquid standard using water was always established.

Creating Four Standards of Length Using a Pendulum in Ancient Sumeria

We cannot be sure of the chronological sequence of these developments, however they occurred in the third millennium BCE or earlier. The first three we will discuss using only the sexagesimal number 360 and its multiples; the last introduced the number 366 which represents the number of days in a star or sidereal year.

The Sumerian Pendulum of the Moon and Gudea

Pendulum 1 was timed with the Moon. Its length as a simple pendulum was 1012 mm. The proof of its existence is found in both a preserved standard of length and a preserved standard of volume as follows.

Berriman [4] states that Gudea was the Governor of Lagash circa 2175 B.C.E. In 1881, de Sarzec found eight headless statues of Gudea in the ruins of Lagash, a port city in Sumeria. Two of the statues show Gudea with a ruler on his lap. The ruler had a scale of 16 nominally equal divisions with a total length of 269 mm. The average

Figure 3. Gudea's Rule

Figure 4. Entemena's Vase

length of the divisions is 16.81 mm. If this length were a Sumerian Shusi then the length of Gudea's Sumerian Step of 60 Shusi (two cubits) would be 1008.75 mm. This length is only 0.4 percent shorter than our simple pendulum and is well within the expected range of a real pendulum. This would also establish Gudea's Foot at 1/3 Step, 20 Shusi, or 336.25 mm.

Berriman [5] writes that Entemena's Vase, a fine example of the silver smith's art (2400 B.C.E.) was found by de Sarzec during his excavation of ancient Lagash, at Tello; it is now in the Louvre. An inscription records its dedication by Entemena to the god Ningirsu in his temple of Eninnu, during Dudu's high priesthood; Entemena was the fifth governor at Lagash, during the Third Dynasty of Kish. Thureau-Dangin [5] published its volume as 4.71 liters. This is the volume of a 16.7626 mm cube. If this volume were 1000 cubic Shusi, or the volume of a 10 Shusi cube, the length of the 60 Shusi Seed Cubit would be 1005.75 mm. The volume of Entemena's Vase might also be considered a gallon of 1/8 a cubic foot. The corresponding foot would be 335.25 mm.

It appears that Gudea's Foot traveled to Europe where it became the Anglo Saxon Foot of 335.28 mm. This four-figure match in dimension is unlikely to have been the result of chance. This Anglo Saxon Foot then traveled to England where the Furlong of 600 Anglo Saxon Feet was used to establish all land boundaries. This Furlong later became the British Furlong of 660 British Imperial Feet from which all British linear measures were derived [6].

Detail of Calculations for a Lunar Pendulum

The length of the Lunar Pendulum 1 would be adjusted to swing through 120 beats in 121 seconds. In Table 2-A we establish the theoretical length for this simple pendulum, then applying modest corrections for the length of a real pendulum, we show the resulting volume of one Sila and the weight of one Mina. Finally, we show corresponding measured values from documented sources including a surprising match to the Anglo-Saxon Foot. In Table 2-B we establish the Bushel as a cubic foot, and in Table 2-C we establish the Talent of 60 Mina. We show these three variations because each has historical significance in the measured records.

Pendulum 1	Length,mm	Sila, ml	Mina, gm	Matching values
P=1.00833 sec	1008.95	1039.5	518.2	values for simple pendulum
L - 0.15%	1008.8	1030.82	515.4	1008.8 mm Gudea's Rule [4]
L + 0.26%	1011.6	1035.15	516.05	516 g # 16 Susa 5 shekel [7]
L + 0.26%	1011.6	1035.15	516.05	516 g # 15 Susa 2 shekel [7]
L -0.32%	1005.75	1017.35	507.37	506.6 g #20 Telloh 3 mina [7]
L - 0.32%	335.25	NA	NA	335.28 mm Anglo-Saxon Foot

Table 2-A. The length of the lunar pendulum with associated volume and weights standards.
Note: The Mina is 1/2 the weight of one Sila of water at room temperature.

Pendulum 1	R1	Length	Volume	R2	Weight	Matching Values
Bushel	20	335.25	37680	8000	37568	values for one cubic foot
Gallon	10	168.83	4710	1000	4696.03	4710 ml Entemena's Vase
Pint	5	84.417	588.7	125	587.0	no match
cubic finger	1	16.883	4.71	1	4.696	1/1000 Entemena's Vase

Table 2-B. The Cubic Foot as a Bushel with Gallon, Pint, and Cubic Finger (L -0.32 percent).
Note: R1 is the length of the equivalent cube in fingers R2 is the volume in cubic fingers. The weights are computed from the volume of water at room temperature.

Pendulum 1	Ratio	Weight gm	Matching Values	
Talent	60	30903	30900 g	Talent # 13 Arthur Evans, Crete [8]
Mina	1	516.05	516 g	#5 and #2 Susa shekels [7]
Shekel	1/60	8.6	4.29 x 2 g	# 17 half shekel [7]

Table 2-C. The Mina, Talent of 60 Mina, and Shekel of 1/60 Mina (period adjusted +0.26 percent).

Figure 5. Mina N

Figure 6. Limestone Duck

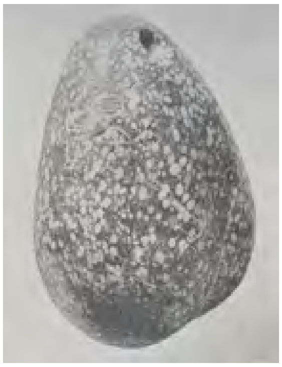


Figure 7. Mina D

Pendulum 2: The One Second Pendulum

Pendulum 2 was timed with the Sun and was allowed to beat 240 times in 1/360 Solar day or 240 seconds. The length of this simple one-second pendulum at the latitude of Lagash is 992.34 mm. The proof of its existence is found preserved in a number of ancient standards of weight.

In the British Museum, there is a weight (No. 91005) that Berriman calls Mina N because its inscription certifies it to be a copy of a weight that Nebuchadnezzar II (605-562 B.C.E.) made matching a weight that belonged to Shulgi of the Third Dynasty of Ur (c 2100 B.C.E.) [9]. Its mass weighed by Belaiew was 978.3 gm. This weight is equal to 981.1 ml of water at room temperature (20 °C)—the volume of a Sila created from a 993.7 mm Sumerian Step or Double Cubit. The length of a physical one-second pendulum with ball/string ratio of 60 and a half swing of 1/10 its length would be is 993.7 mm. The weight of a Mina derived from this Sila is 489.2 grams and identical to the Mina N.

In the Ashmolean Museum, there is Babylonian Limestone Duck weight from Erech [10]. Its published mass is 2417 gm. If intended to be 5 mina in mass, one mina would equal 483.4 gm. A Talent of 60 mina would weigh 29,004 grams. Its volume of water at room temperature of 20 °C would be 29090 ml. This is the volume of a 307.55mm cube. A double cubit at 3 times this length would be 992.65 mm, a little longer than our simple pendulum. We conclude that the weight of the Babylonian Limestone Duck Weight is derived from our simple one-second pendulum.

Mina D is the oldest extant weight in the Ashmolean Museum at Oxford England. It was signed by Dudu, the high priest at Lagash, c 2400 B.C.E. Berriman reports that it was measured at 680.485 grams [11]. This weight is exactly 150 Sumerian and 100 Minoan gold standards, as well as 50 Egyptian Old Kingdom Deben. Mina D and seven other gold standards are exact multiples of the weight of one cubic finger of water.

When the French proposed their first metric system in the 18th century, they were unaware that it was already over 5000 years old and memorialized in the Mina N. The original French proposal for a metric system in the early eighteenth century defined the meter as the length of a one-second pendulum (993.7 mm) when measured in the Earth's gravitational field at 45 degrees north latitude. Rounding off the length to 994 mm, we maintain excellent correlation to the French Pendulum; the length of the Sumerian double cubit becomes 1.003 original French meter. The volume of the Sumerian Sila (liter) and the weight of the Sumerian Double Mina become 1.009 original French liters and kilograms.

Detail of Calculations for the One Second Pendulum

Pendulum 2 beat 240 times in 240 seconds. In Table 3-A, we establish the theoretical length for this simple pendulum, then applying modest corrections for the period and length of a real pendulum, we show the resulting Sila and Mina. Finally, we show corresponding measured values from Powell and Berriman. In Table 2-B, we establish the foot, the bushel as a cubic foot, and its division into gallon, pint, and Cubic Finger. Finally, we show one corresponding measured value. In Table 2-C, we establish the Talent of 60 Mina and shekel of 1/60 Mina showing corresponding measured values. We show these three variations because each has historical significance.

Alternative lengths for the Sumerian Foot of Pendulum 2 seem to have been established where 1000 feet rather than 1080 feet were equal to the length of the Cable of 360 Step Cubits or pendulum lengths. The length of the simple one-second pendulum in Lagash was 992.34 mm. The length of this new foot would be (360/1000) x 992.376 = 357.255 mm. A pendulum of this length could be obtained directly using 400 beats in 1 Gesh of 240 seconds. This pendulum would be too short to time easily, but one four feet long would work well. It would beat 200 times in 240 seconds. We found no matches in the signed weights of

Pendulum 2	Length, sec	Sila, ml	Mina, gm	Matching Values
P = 1.0000	992.340	977.310	487.210	487.2 g #52 5 Shekels [7]
+ 650 ppm	993.670	981.130	489.120	993.7 mm French Meter
+ 650 ppm	993.670	981.130	489.120	978.3 g #50 Mina N [7]
- 1300 ppm	989.800	969.720	483.400	483.4 g Limestone Duck [10]
- 400 ppm	991.590	975.000	486.050	486.3 g #53 30 mina [7]
- 400 ppm	991.590	975.000	486.050	486 g #54 5 Shekels [7]

Table 3-A. The length of Pendulum 2 and associated volume and weight standards.

Pendulum 2	R	Length	Volume	R	Weight	Matching Values
Bushel	20	331.223	36338	8000	36231	no match
Gallon	10	165.612	4542.3	1000	4528.88	no match
Pint	5	82.806	567.78	125	566.105	no match
cu finger	1	16.561	4.542	1	4.5288	4.53656 = #2 Mina D [7]

Table 3-B. The Cubic Foot as a Bushel divided into Gallons and Pints (period + 650 ppm).
Note: The weight of this cubic finger of water was the Sumerian Gold Standard.
Note: R2 is the volume in cubic fingers; R1 is the length of the equivalent cube in fingers.

Pendulum 2	R	Weight	Matching values	
Talent	60	29347	29,400	Arthur Evans Talent At Knossos [8]
Mina	1	489.1	489.154	Mina N [7]
Shekel	1/60	8.08	7.95	#65 (5.3) Samas 2/3 Shekel [7]

Table 3-C. The Talent of 60 Mina with corresponding Shekel (period + 650 ppm).

Pendulum 2	Length mm	Sila ml	Mina gm	Matching Values
P = 1.0000	992.34	977.31	487.21	487.2 g see Table 2-A
+ 650 ppm	993.67	981.43	489.30	993.7 mm French meter 1793
Foot @ 0.36 L	357.72	NA	NA	360mm Zhou Royal Ch ih [13]
Foot @ 0.36 L	357.72	NA	NA	357.2 mm Bordeaux France [14]

Table 4-A. Alternate One-second Pendulum with 360 pendulum lengths = 1000 Feet.

Pendulum 2	R	Length mm	Volume ml	R	Weight gm	Matching Values
Bushel	1	357.8	45806	1	45671	no match
Gallon	1/2	178.9	5725.7	1/8	5708.8	no match
Pint	1/4	89.45	715.72	1/64	713.6	no match

Table 4-B. The Cubic Foot as a Bushel divided into Gallons and Pints (period +650 ppm).

Pendulum 3	Length mm	Sila ml	Mina gm	Matching Values
P = 0.66667	882.11	686.39	342.18	no match
Foot @ 0.36L	317.56	NA	NA	318 mm China Zhou Market Foot [13]
Foot @ 0.36L	317.56	NA	NA	317 mm fuss Bern Austria [15]

Table 5-A. Lengths (mm), Sila (cu cm), Mina (grams) with some Matching Values.

Pendulum 3	Length mm	Volume ml	R	Weight gm	Matching Values
Bushel	317.56	32,024	1	31,929	32,000 g Talent # 14 A.E. Evans
Gallon	158.78	4003	1/8	3991	no match
Pint	79.39	500.4	1/64	498.9	498.67 g # 31 Shulgi 10 Minas [[7]
Pint	79.39	500.4	1/64	498.9	498.468 g #32 Telloh 5 Shekels [7]
Pint	79.39	500.4	1/64	498.9	498 g #34 2 Minas [7]
1/60 talent	NA	NA	NA	532.15	534.2 g #12 1/6 Mina [7]

Table 5-B. The Cubic Foot as as Bushel, Gallon, and Pint along with associated weights.

Pendulum 4 period	Length, mm	Sila, ml	Mina, gm	Measured values
P=0.99727	986.930	961.300	479.229	479.6 # 61, #58 5 Shekels [7]
Foot @ 1/3 L	328.997	NA	NA	329 mm Assyrian Foot [12]
+ 650 ppm	988.213	965.054	481.101	481.07 #56 1/2 Mina [7]
+ 650 ppm	988.213	965.054	481.101	480.145 #57 1 Mina [7]
- 650 ppm	985.649	957.561	477.365	477.28 # 63 2 Mina [7]
- 1000 ppm	984.959	955.553	476.364	476.1 # 66 no name [7]

Table 6-A. Timing the One Second Pendulum with a Star Created the Assyrian Foot.

Pendulum 4	L	Length mm	Volume ml	R	Weight gm	Measured values
Bushel	1	329.405	35,743	1	35,637	8000 cubic fingers
Gallon	1/2	164.702	4,467.8	1/8	4,455.00	1000 cubic fingers
Pint	1/4	82.351	558.48	1/64	557	557.81 #7 1/6 mina [7]
Mina	NA	NA	595.72	1/60	594	no match
Mina (grain)	NA	NA	595.72	1/60	475.2	475 g # 67 3 mina [7]

Table 6-B. A Bushel of one Cubic Foot divided into Gallon, Pint, and Mina (period + 650 ppm).

Dr. Powell, but did find two good matches in France and China. This is the length of Royal Ch'Ih of the Chinese Zhou Dynasty at 360 mm [13] and the "Pied de Terre" of Bordeaux France at 357.24 mm [14].

Detailed calculations to establish the bushel from our new cubic foot derived from Pendulum 2, as well as its division into Gallons and Pints, showed no match as shown in Table 4-B.

Pendulum 3 and the Chinese Market Foot

Pendulum 3 beat 360 times in 240 seconds. This Pendulum was quite short, so double its length was used. A Cable of 360 double pendulum lengths was equal to 1000 Feet. This new standard Foot seems to have been adopted in later cultures. Proof of its existence can be found in lengths described by A.E. Berriman and in weights described by both M.A. Powell and Sir Arthur Evans. Its double length in Lagash was 882.08 mm with the length of the new foot 317.55 mm. This is the length of the Market Foot in the Chinese Zhou Dynasty, at 318 mm [13] and the Steinbrecherfuss of Bern, Austria at 317 mm [15].

Detailed calculations to establish the volume of the Bushel, Gallon, and Pint from this new Cubic Foot derived from Pendulum 3, as well as the weight of water at room temperature associated with each, as shown in Table 5-B.

Pendulum 4: The Assyrian Foot of Babylon

The Egyptian method of timing a pendulum with a star was later adopted by the Assyrians in Babylon c 1750 B.C.E. The original Sumerian one-second pendulum was allowed to swing the same 240 beats, but in 239.3447 seconds or 1/360 of a celestial day. This pendulum appears to have created the Assyrian Foot and provided a match to six signed weights in references 7 and 12.

Conclusion

Chapter One established five Ancient Sumerian Standards of length through 32 matches among Dr. Powell's inscribed weights, 3 matches among Sir Arthur Evans' Talent weights, and among 7 of Mr. Berriman's lengths, volumes, and weights.

Please join us again in following articles of *CAL LAB* magazine, where we will examine additional standards from Egypt and the Minoan civilization on Crete. Finally, we will establish the design perimeter of the Great Pyramid of Giza at 30 arc seconds and explain the luck of the Greeks who used a version of this formula to establish the width of the Parthenon at almost exactly one arc second on the polar circumference of the Earth.

References

[1] Arthur Bronwell, *Advanced Mathematics in Physics and Engineering*, (New York: McGraw-Hill. 1953), 137-139.

[2] E. Janhke, and F. Emde, *Table of Functions*, (New York: Dover Publications Fourth Edition 1945), 85.

[3] Glen Thorncroft, *Accuracy of Gravity*, ME department California Polytechnic State University, http://www.calpoly.edu/~gthorncr/ME302/documents/AccuracyofGravity.pdf.

[4] A.E. Berriman, *Historical Metrology*, (E.P.Dutton & Co, 1953), 53-54.

[5] Berriman, 63-64.

[6] Ronald E. Zupko, *British Weights and Measures*, The University of Wisconsin Press, 20.

[7] M.A. Powell, *Sumerian Numeration and Metrology*, University of Michigan, 1973, 205.

[8] Arthur J. Evans, "Minoan weights and mediums of currency from Crete, Mycenae, and Cyprus Corolla Numisimatica," *Numismatic Essays in Honor of Barclay V. Head*, 342.

[9] Berriman, 58.

[10] Berriman, 62.

[11] Berriman, 56.

[12] Berriman, 55.

[13] Berriman, 47.

[14] P. Guilhiermoz, *A propos d'une publication récente Bibliothèque de l'Ecole des Chartes, Del'équivalence des anciennes mesures*, 1913, volume 74, 27.

[15] "Obsolete German units of measurement, " https://en.wikipedia.org/wiki/Obsolete_German_units_of_measurement.

Roland A. Boucher (rolandfly@sbcglobal.net), Irvine, California.

Creating a Metrology Taxonomy

Michael Schwartz and David Zajac
Cal Lab Solutions, Inc.

Metrology is the science of measurement. For thousands of years we have been creating newer and better ways of measuring things, but in all that time, metrology still lacks a detailed and standardized taxonomy. Just like the biological and medical sciences, I believe this is something that metrology science would benefit greatly from, if it were created and adopted. This is especially true now, as we integrate information science with metrology, we have determined that the standardization of taxonomy for metrology is a basic requirement for the efficient exchange of measurement data.

Taxonomy is at the top of our list for our company because it is needed for Metrology.NET® to have the ability to check measurement uncertainty calculations against a lab's Scope of Accreditation (SOA). We are creating a system where every measurement in a calibration can be verified against a lab's accredited capabilities. This requires the calculated uncertainty be checked against the lab's accredited capabilities, then for the test report, choosing between the larger of the calculated or accredited value, and maintaining all measurement data to prove the lab's best uncertainties during the next audit!

To do this, we must first define a way to link every measurement to the correct section of the lab's SOA. The system must be able to search and select the correct information from the SOA each and every time! There can be no ambiguity in the interface between the information contained in the SOA and our system!

It is important to note, Cal Lab Solutions has been working on this effort for almost three years now. Most recently, in 2016 we presented a paper on the topic, "Creating a Standardized Schema for Representing ISO/IEC 17025 Scope of Accreditations in XML Data," at NCSLI Workshop & Symposium, St. Paul, MN.* Now we are working in synergy, as part of the Metrology Information Infrastructure (MII). Since the MII meeting in St. Paul, several companies (like Boeing and Qualer) have taken leadership roles in further defining a machine readable SOA.

What we discovered fairly early in developing a prototype search tool—code named Beagle—was we needed a quick and easy way to index the measurement category before we could define the values required to search the SOA. For example, if you are searching for a lab's Watts measurement capabilities, you can't just search on Watts values. Metrology information systems are complicated by factors such as Watts can be the product of Amps and Volts. If we are looking for AC watts, then we need to include frequency; if we are looking at Watts that incorporate Power Factor, we also have to include Phase Angle. Simply searching for Watts without taking into consideration these potential complicating factors can be insufficient and can return unwanted values.

We have created a solution that relies on a robust and standard metrology taxonomy to create a standardizable, hierarchical information backbone for organizing all of metrology's sub categories and subtle variations. This reduces the search complexity by orders of magnitude! Thus, creating a standard for definition metrology based taxonomy is imparative for both Metrology.NET and the MII project.

Our proposed standard will define a syntax for a naming convention with increasing specificity. For example, Measure.Watts.AC or Source.Volts.DC; each dot(.) divides the branch into a more specific subcategory. Every leaf of the taxonomy tree would then contain a parameter list used for sorting and filtering. So for these examples, Measure.Watts.AC would define parameters for Amps, Volts, Frequency, Power Factor, as well as Watts as search inputs. And Source.Volts.DC would have Volts and maybe Input Impedance.

This Metrology Taxonomy definition would be used to categorize the specific hardware and technique implementation. A couple of examples would be Source.Volts.DC(5720) and Source.Volts.DC(5520.Characterized.3458). By indexing both of these specific implementations to a specific leaf on the metrology taxonomy tree, they become equally searchable yet categorically distinguishable.

We will be presenting our version of the Metrology Taxonomy model at the MSC Training Symposium in Anaheim, CA, in April and hope to present a paper relating to the topic at NCSLI 2017 in National Harbor, MD. ❧

*http://www.metrology.net/creating-a-standardized-schema-for-representing-isoiec-17025-scope-of-accreditations-in-xml-data/


18th INTERNATIONAL METROLOGY CONGRESS
CIM 2017
19 21 SEPT
PARIS FRANCE
Analytics
MEASURE
AND CREATE
THE FUTURE
COLLÈGE FRANÇAIS DE
METROLOGIE
BINOME
www.cim2017.com
info@cfmetrologie.com
enova PARIS
OIML
Bureau International des Poids et Mesures
EURAMET
EA EUROPEAN ACCREDITATION
Trescal