CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY

METROLOGY 101: INFRARED THERMOMETER CALIBRATION

Applications of Computer Simulation in Coordinated Measuring Machine Uncertainty Evaluation

Turbine Flow Meter Calibration Using Nonhazardous Fluid Mixtures to Simulate Fuels and Lubricants

What's Below the Iceberg: Determining the True Cost of Ownership of Test and Measurement Equipment

2011
JULY
AUGUST
SEPTEMBER

CAL LAB
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Volume 18, Number 3

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FEATURES

DEPARTMENTS

ON THE COVER: NIST mechanical engineer Daniel Adler uses a coordinate measuring machine to create a 3D digital model of a neutron guide at the NIST Center for Neutron Research. The mirrored aluminum section is one of many to be installed to expand the Center's experimental facilities by extracting five new beams of neutrons from the center's cold source to feed instruments that will be used to probe the atomic structure and dynamics of materials. Copyright Robert Rathe.

CALENDAR

CONFERENCES & MEETINGS 2011

Aug 21-25 NCSL International Workshop & Symposium. National Harbor, MD. 50 Years: Reflecting on the Past – Looking to the Future. Website: www.ncsli.org.

Sep 12-14 10th IMEKO Symposium on Laser Metrology for Precision Measurement and Inspection in Industry. Braunschweig, Germany. Website: www.lasermetrology2011.com.

Sep 19-22 2011 American School of Gas Measurement Technology. Houston, TX. With over 100 exhibitors, The School is the largest gas measurement school in the United States devoted to natural gas measurement, pressure regulation, flow control, and other measurement related arenas. Website: http://asgmt.com.

Sep 20-22 Quality Expo. Chicago, IL. Quality Expo is the leading quality show and conference that provides hand-on access to the newest tools and broadest array of technologies. Website: http://www.canontradeshows.com/expo/qexpo11/index.html

Sep 27-30 Metrologia2011. Natal, Brazil. A global multi-event comprising an international measuring instruments exhibition and four other associated events. Website: www.metrologia.org.br/metrologia2011/.

Oct 3-6 15th International Congress of Metrology. Paris, France. The Congress is a meeting place for specialists in metrology from industry and scientific laboratories whose aim is to contribute to the improvement of measurement in industry and research. Website: www.metrologie2011.com.

Oct 5-8 2nd International Congress on Instrumentation and Applied Sciences. Puebla City, Mexico. To spread the activities and the results of research and development related to the application of science and engineering in the various fields of instrumentation, and to favor the exchange of knowledge and experiences among participants. Website: http://somi.ccadet.unam.mx/icias2011/.

Oct 24-27 3rd Metrology Forum. Accra, Ghana. Legal metrology; accreditation; temperature, volume, mass; measurement uncertainties; interlaboratory comparisons. Website: http://www.ac-metrology.com.

Nov 13-18 26th Annual Meeting of the American Society for Precision Engineering. Denver CO. Website: http://www.aspe.net/meetings/2011_Annual/ASPE_Annual_2011.html.

Dec 8-10 India Lab Expo. New Delhi, India. The 3rd International Exhibition and Conference on Scientific & Lab Instruments. Visit: http://www.indialabexpo.com.

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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

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EDITOR'S DESK

Keep Looking Up

Since the lights of suburbia have gotten brighter over the years and drowned out the stars, it's been awhile since I've dragged out a patio recliner to watch the Perseids Meteor Shower mid-August. As a kid, it signaled the end of summer and the beginning of the school year. I tried to catch glimpses of satellites in the busy sky and imagine the ISS way up there too. During the 1980's, the space shuttle program was in high gear and held our interest, even after a traumatizing live broadcast during my social studies class, of the Challenger falling from the sky.

The space shuttle program was ahead of its time technology-wise, and as a kid, it was exciting and inspiring. So, as an adult, it is hard to see it just go away. The space shuttle program and ISS inspired the next evolution of Buck Rogers in popular culture and continued the momentum of interest in the space race onto the next generation. We shall see if private space exploration will inspire the upcoming generations to pursue physics, math, and related sciences in their lifelong endeavors.

On another note, for those who access Cal Lab from the web, we've recently made downloading and viewing the current issue a little easier with a web-based PDF viewer. This is the latest update we've done with the web site in order to make Cal Lab more accessible online.

So we hope you enjoy this latest issue of Cal Lab, and remember to keep looking up!

Regards,

Sita

CALENDAR

SEMINARS: Online & Independent Study

Basic Measuring Tools – Self Directed Learning. The QC Group, http://www.qcgroup.com/calendar/.

Introduction to CMMs – Self Directed Learning. The QC Group, http://www.qcgroup.com/calendar/.

Introduction to Measurement and Calibration – Online Training. The QC Group, http://www.qcgroup.com/calendar/.

ISO/IEC 17025 Compliance. Workplace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/.

Measurement Uncertainty Analysis – Online Training. The QC Group, http://www.qcgroup.com/calendar/.

Precision Dimensional Measurement – Online Training. The QC Group, http://www.qcgroup.com/calendar/.

Precision Measurement Series Level 1. Workplace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/.

Precision Measurement Series Level 2. Workplace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/.

SEMINARS: Accreditation

Sep 21-23 ISO/IEC 17025 and Accreditation. Charleston, SC. The American Association for Laboratory Accreditation, http://www.a2la.org.

Nov 7-11 ISO 17025 Compliance and Auditing Techniques Including ANSI Z540.3 Requirement. Los Angeles, CA. Workplace Training, http://wptraining.com/workshops.htm.

Nov 16-17 ISO/IEC 17025 and Accreditation. Charleston, SC. The American Association for Laboratory Accreditation, http://www.a2la.org.

SEMINARS: Dimensional

Aug 18-19 Gage Calibration Methods & Hands-On Workshop. Oakland/San Jose Area, CA. The QC Group. http://www.qcgroup.com/calendar/.

Aug 18-19 Gage Calibration Systems and Methods. Los Angeles CA. Mitutoyo Institute of Metrology, tel 888-MITUTOYO, mim@mitutoyo, www.mitutoyo.com.

Aug 22-23 Gage Calibration Methods & Hands-On Workshop. Las Vegas, NV. The QC Group. http://www.qcgroup.com/calendar/.

CALENDAR

Aug 23-24 Basic Dimensional Measurement Tools and Methods. Atlanta, GA. The QC Group, http://www.qcgroup.com/calendar/.

Aug 30-Sep 1 Coordinate Measuring Machine Training. Minneapolis, MN. The QC Group, http://www.qcgroup.com/calendar/.

Sep 8-9 Gage Calibration and Repair. Effingham IL. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, info@consultinginstitute.net, www.consultinginstitute.net.

Sep 13-14 Gage Calibration Methods & Hands-On Workshop. Effingham, IL. The QC Group. http://www.qcgroup.com/calendar/.

Sep 21-22 Basic Dimensional Measurement Tools and Methods. Schaumburg, IL. The QC Group, http://www.qcgroup.com/calendar/.

Sep 21-22 Gage Calibration Workshop. Toledo, OH. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, info@consultinginstitute.net, www.consultinginstitute.net.

Sep 27-28 Basic Dimensional Measurement Tools and Methods. Auburn Hills, MI. The QC Group, http://www.qcgroup.com/calendar/.

Sep 27-28 Gage Calibration and Repair. Minneapolis MN (North). IICT Enterprises, tel 952-881-1637, fax 952-881-4419, info@consultinginstitute.net, www.consultinginstitute.net.

Sep 27-28 Dimensional Metrology. Cincinnati OH. Mitutoyo Institute of Metrology, tel 888-MITUTOYO, mim@mitutoyo, www.mitutoyo.com.

Sep 29-30 Gage Calibration and Repair. Bloomington MN. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, info @consultinginstitute.net, www.consultinginstitute.net.

Sep 29-30 Gage Calibration Systems and Methods. Cincinnati OH. Mitutoyo Institute of Metrology, tel 888-MITUTOYO, mim@mitutoyo, www.mitutoyo.com.

Oct 4-6 Hands-On Gage Calibration. Elk Grove Village IL. Mitutoyo Institute of Metrology, tel 888-MITUTOYO, mim@mitutoyo, www.mitutoyo.com

Oct 6-7 Gage Calibration and Repair. Hew Haven/Waterbury CT Area. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, info @consultinginstitute.net, www.consultinginstitute.net.

Oct 10-11 Gage Calibration and Repair. Albany NY. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, info @consultinginstitute.net, www.consultinginstitute.net.

Oct 18-19 Gage Calibration and Repair. Rapid City SD. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, info @consultinginstitute.net, www.consultinginstitute.net.

Oct 20-21 Basic Dimensional Measurement Tools and Methods. Minneapolis, MN. The QC Group, http://www.qcgroup.com/calendar/.

Oct 25-26 Basic Dimensional Measurement Tools and Methods. Milwaukee, WI. The QC Group, http://www.qcgroup.com/calendar/.

Oct 27-28 Gage Calibration and Repair. Chicago IL. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, info @consultinginstitute.net, www.consultinginstitute.net.

Nov 1-3 Coordinate Measuring Machine Training. Minneapolis, MN. The QC Group, http://www.qcgroup.com/calendar/.

Nov 8-9 Gage Calibration and Repair. Louisville KY. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, info @consultinginstitute.net, www.consultinginstitute.net.

Nov 10-11 Gage Calibration and Repair. Indianapolis IN. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, info @consultinginstitute.net, www.consultinginstitute.net.

Nov 15-17 Hands-On Gage Calibration. Elk Grove Village IL. Mitutoyo Institute of Metrology, tel 888-MITUTOYO, mim@mitutoyo, www.mitutoyo.com

SEMINARS: Flow & Pressure

Sep 13-15 Fundamental Flow Measurement Training Course. Loveland, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com.

Sep 14-16 Principles of Automated Pressure Calibration. Houston, TX. Fluke Calibration, http://us.flukecal.com/training.

Sep 19-22 Comprehensive Flow Measurement Training Course. Loveland, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com.

Sep 19-23 Advanced Pressure Metrology. Houston, TX. Fluke Calibration, http://us.flukecal.com/training.

Sep 21-23 Flow Measurement and Calibration. Munich, Germany. During Octoberfest. For information in English, visit: www.trigasfi.de/html/en_seminars.htm.

Sep 26-30 Precision Pressure Calibration. Phoenix, AZ. Fluke Calibration, http://us.flukecal.com/training.

Nov 1-4 Gas Flow Calibration Using molbloc/molbox. Phoenix AZ. Fluke Calibration, http://us.flukecal.com/training.

Nov 7-8 Fundamentals of Ultrasonic Meters for Natural Gas and Liquid. Santa Cruz, Bolivia. Colorado Engineering Experiment Station Inc., www.ceesi.com.

Nov 9-11 Ultrasonic Meter User's Workshop. Santa Cruz, Bolivia. Colorado Engineering Experiment Station Inc., www.ceesi.com.

Nov 14-18 Precision Pressure Calibration. Phoenix, AZ. Fluke Calibration, http://us.flukecal.com/training.

SEMINARS: General Metrology and Laboratory Management

Sep 12-15 CLM 303 Effective Cal Lab Management. Seattle, WA. Fluke Calibration, http://us.flukecal.com/training.

Sep 20-22 Cal Lab Management: Beyond 17025. Los Angeles, CA. Workplace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/.

LEM

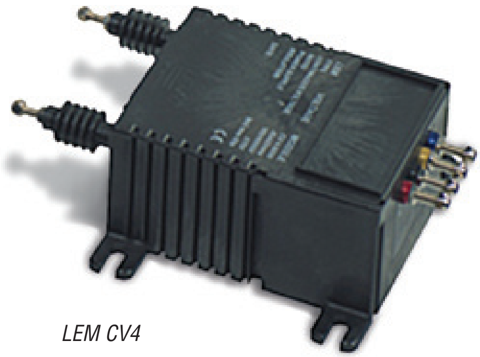
Voltage & Current Measurement

Voltage Transducers

Provide an Analog Output Signal Magnetically Isolated from the Primary Voltage Circuit

- Full-scale Primary Voltages from ±500V to ±8,000V
- Amplitude Accuracy to ±0.2% at dc
- Amplitude Frequency Response dc to 500kHz (-3dB)

Convert High Voltage Levels in Power Converters to Low Level, Low Impedance Signals that can be Used for Accurate and Safe Test Measurements



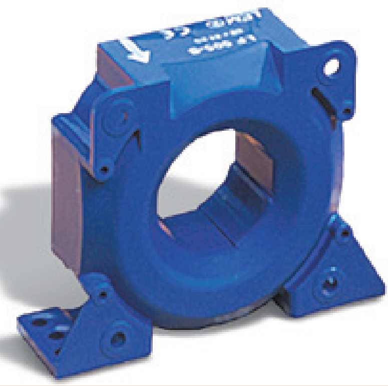
LEM CV4

Closed-Loop Hall Current Transducers

Provide an Analog Output Signal Isolated from the Primary Current Circuit

- Full-scale Primary Currents from ±100A to ±15,000A
- Amplitude Accuracy to ±0.3% at dc
- Amplitude Frequency Response dc to 300kHz (-3dB)
- Common Mode Primary Voltage Isolation
- Split Core Versions Available (±2% at dc)

Suitable for Production Line Testing where Long-term Stability and Reliability are Critical



LEM LF

Closed-Loop Fluxgate Current Transducers

Generate a Very High-Accuracy Output Signal with Electrical Isolation from the Primary Circuit

- Full-scale Primary Currents from ±60A to ±1,000A
- Amplitude Linearity to ±0.3ppm at dc
- Amplitude Frequency Response dc to 300kHz (-3dB)
- Very Low Noise to <5ppm rms (dc to 50kHz) gives Wide Dynamic Range
- Very Low Sensitivity to External Current Conductors

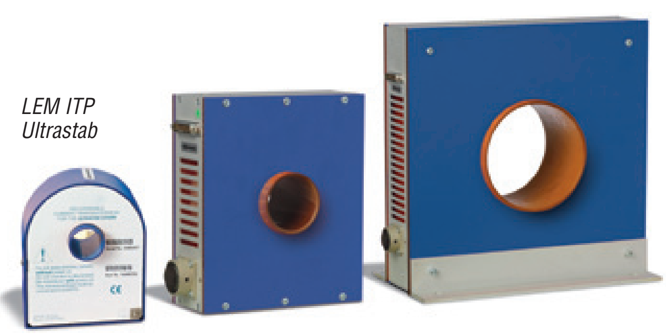
For High-accuracy Power Measurements over an Extended Frequency Range

LEM IT Ultrastab

Closed-Loop Fluxgate Current Measurement Systems

Very High-Accuracy Current or Voltage Output Signal with Electrical Isolation from the Primary Circuit

Optional Heads	600A	2,000A	5,000A
Lowest fs Current	40A	125A	2,500A
fs Current Range Increment	20A	125A	125A



LEM ITP Ultrastab

Very High-accuracy Calibration and Power Measurements

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Sep 26-28 Cal Lab Management: Beyond 17025. Baltimore, MD. Workplace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/.

Oct 4-5 Introduction to Measurements and Calibration. Minneapolis, MN. The QC Group, http://www.qcgroup.com/calendar/.

Oct 17-21 Fundamentals of Metrology. Gaitersburg, MD. NIST, http://www.nist.gov/pml/wmd/labmetrology/schedule.cfm.

Oct 24-27 MET-101 Basic Hands-on Metrology. Seattle, WA. Fluke Calibration, http://us.flukecal.com/training.

Oct 31-Nov 3 MET-301 Advanced Hands-On Metrology. Seattle, WA. Fluke Calibration, http://us.flukecal.com/training.

SEMINARS: Mass & Weight

Oct 24-Nov 4 Mass Seminar. Gaitersburg, MD. NIST, http://www.nist.gov/pml/wmd/labmetrology/schedule.cfm.

SEMINARS: Measurement Uncertainty

Aug 23-24 Estimating Measurement Uncertainty. Chicago IL. Mitutoyo Institute of Metrology, tel 888-MITUTOYO, mim@mitutoyo, www.mitutoyo.com.

Sep 13-15 Measurement Uncertainty Analyst Class. Fenton, MI. Quametec Institute of Measurement Technology, http://www.qimtonline.com/.

Sep 19-20 Introduction to Measurement Uncertainty. Columbus, OH. The American Association for Laboratory Accreditation, http://www.a2la.org.

Sep 26-28 Measurement Uncertainty Training Course. Loveland, CO. Colorado Engineering Experiment Station Inc. www.ceesi.com.

Oct 24-25 Basic Math and Statistics for Metrology Technicians. Los Angeles, CA. Workplace Training, http://wptraining.com/workshops.htm.

Oct 31-Nov 1 SPC and Excel for Metrology Applications. Orlando, FL. Workplace Training, http://wptraining.com/workshops.htm.

Nov 2-4 Measurement Uncertainty. Orlando, FL. Workplace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/.

Nov 8-10 MET-302 Introduction to Measurement Uncertainty. Seattle, WA. Fluke Calibration, http://us.flukecal.com/training.

Nov 14-15 Introduction to Measurement Uncertainty. Charleston, SC. The American Association for Laboratory Accreditation, http://www.a2la.org.

Nov 15-17 Measurement Uncertainty Analyst Class. Fenton, MI. Quametec Institute of Measurement Technology, http://www.qimtonline.com/.

SEMINARS: Software

Sep 19-23 MET/CAL Database and Reports. Seattle, WA. Fluke Calibration, http://us.flukecal.com/training.

Sep 26-30 MET/CAL Procedure Writing. Seattle, WA. Fluke Calibration, http://us.flukecal.com/training.

Oct 3-7 Advanced Programming Techniques. Seattle, WA. Fluke Calibration, http://us.flukecal.com/training.

SEMINARS: Temperature

Aug 17-18 Advanced Topics in Temperature Metrology. American Fork, UT. Fluke Calibration, http://us.flukecal.com/training.

Oct 17-18 Principles of Temperature Metrology. American Fork, UT. Fluke Calibration, http://us.flukecal.com/training.

SEMINARS: Vibration

Aug 23-25 Fundamentals of Random Vibration and Shock. Santa Barbara, CA. Equipment Reliability Institute, http://www.equipment-reliability.com/vibration_course1.html.

SEMINARS: Volume

Aug 16-18 Gas Measurement Auditing & Troubleshooting Training Course. Farmington, NM. Colorado Engineering Experiment Station Inc. (CEESI), www.ceesi.com/events.aspx.

The Constants They Are A Changin': NIST Posts Latest Adjustments to Fundamental Figures

The electromagnetic force has gotten a little stronger, gravity a little weaker, and the size of the smallest "quantum" of energy is now known a little better. The National Institute of Standards and Technology (NIST) has posted* the latest internationally recommended values of the fundamental constants of nature. The constants, which range from relatively famous (the speed of light) to the fairly obscure (Wien frequency displacement law constant) are adjusted every four years in response to the latest scientific measurements and advances. These latest values arrive on the verge of a worldwide vote this fall on a plan to redefine** the most basic units in the International System of Units (SI), such as the kilogram and ampere, exclusively in terms of the fundamental constants.

The values are determined by the Committee on Data for Science and Technology (CODATA) Task Group on Fundamental Constants,*** an international group that includes NIST members. The adjusted values reflect some significant scientific developments over the last four years.

Often the biggest news in a fundamental constant value is a reduced uncertainty—scientists know the value better. The uncertainty in the value of the fine-structure constant alpha (α = 7.297 352 5698 x 10^{-3}), which dictates the strength of the electromagnetic force, has been slashed in half to 0.3 parts per billion (ppb). Since alpha can be measured in a uniquely broad range of phenomena from the recoil of atoms to the magnetic properties of electrons, the consistency of the measurements acts as a barometer of scientists' general understanding of physics. Alpha will also be a critical constant after a redefinition of the SI: it will remain an experimentally determined constant, while quite a few others' values will be fixed to define the basic measurement units.

Also improved is the Planck constant h, which defines the size of the smallest possible "quantum" (packet) of energy, and is central to efforts to redefine the SI unit of mass. The latest value of h (6.626 069 57 x 10^{-34} joule seconds) takes into account a measurement of the number of atoms in a highly enriched silicon sphere. That value currently disagrees with the other fundamental method for determining h, known as the watt-balance****. Even so, when all the values are combined, the overall uncertainty of h (44 ppb) is smaller than in 2006, and the values from the two techniques are getting closer to each other.

The 2010 CODATA values incorporate two new experimental measurements of G, the Newtonian constant of gravitation, which dictates the strength of gravity. The latest value of G (6.673 84 x 10^{-11} m^3 kg^{-1} s^{-2}) is about 66 parts per million smaller than the 2006 value. Other adjustments have been seen in the constants such as the radius of the proton and other constants related to atoms and gases such as the Rydberg and molar gas constants.

The CODATA task group is preparing a full report on the 2010 adjustments (for now, there is a brief overview*****), and the report will include recommendations for future measurements. A plan to adopt a fully constant-based SI, being voted upon this October by the General Conference on Weights and Measures, is contingent upon the values of the fundamental constants such as h reaching certain levels of precision and accuracy that will require further measurement advances in the coming years.

* http://physics.nist.gov/constants

** See: "Sí' on the New SI: NIST Backs Proposal for a Revamped System of Measurement Units," NIST Tech Beat for Oct. 26, 2010, at www.nist.gov/public_affairs/tech-beat/tb20101026.cfm#SI.

*** www.codata.org/taskgroups/TGfundconst/

**** www.nist.gov/pml/quantum/fundamental_electrical/kilogram.cfm

***** http://physics.nist.gov/cuu/Constants/briefOverview2010.pdf

Source: http://www.nist.gov/public_affairs/tech-beat/tb20110719.cfm.

INDUSTRY AND RESEARCH NEWS

Pan-European Research Project for Clean Air

They can cause lung cancer and other severe diseases: the minute soot particles from the exhaust gas of diesel-engined vehicles. The quantity of these particles has increased steadily. In order to keep the harmful effects to one's physical health due to soot particles low, the limit values for diesel soot have been lowered drastically step by step, from 180 mg/km (EURO 1, 1993) down to 5 mg/km in EURO Standard 5, which is valid for new models, effective September of this year. In this standard, it is no longer only the mass concentration of soot particles which is considered, but their number, because this value is much more relevant for health hazards. To this end, novel measuring instruments must be approved. In order to adapt the entire measuring system – from approval tests to calibrations and to the exhaust inspections at regular intervals – to the new specifications, a pan-European project has been started. Under the auspices of the Physikalisch-Technische Bundesanstalt (PTB), several national metrology institutes are working together therein with cooperation partners from industry.

Besides the diesel soot, it also addresses two additional materials problematic for health which pollute the air: smallest particles of platinum and other elements from catalyzers as well as those mercury compounds which are created in the combustion of fossil energy sources in power plants. The aim of the pan-European project is to compare the individual approaches, to further develop measuring instruments and to attend to correct traceability of measuring results. Internationally harmonized standards are to be developed on the basis of the number of particles (instead of their mass, as hitherto), which then will facilitate the approval and calibration of measuring instruments. The project laid out for three years is a so-called Joint Research Project (JRP) within the scope of the European Metrology Research Progamme EMRP. Besides the experts of PTB and the Bundesanstalt für Materialforschung und -prüfung (BAM) (Federal Institute for Materials Research and Testing), colleagues from Denmark, Switzerland, Slovenia, France, Finland, Great Britain, the Netherlands and the Joint Research Centre JRC of the EU Commission are participating.

Even though the legal specifications are the same all over Europe, the controls are not yet the same. After all, also in other countries very strict environmental regulations are being put into effect or are in effect already. The European automobile industry and its suppliers have to stay on the ball in order to sustainably retain their good global market position. The metrology institutes will help to achieve this.

Source: http://www.ptb.de/en/aktuelles/archiv/presseinfos/pi2011/index.html.


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Trescal Acquires Stork Intermes

Trescal (www.trescal.com), the international specialist for calibration services, continues its geographic expansion with the acquisition of Benelux leader Stork Intermes, from Stork Materials Technology (SMT), a material testing group headquartered in the Netherlands. Founded in 1972, Stork Intermes (www.storksmt.com) specializes in temperature, pressure, electrical, humidity, mechanical and geometrical calibration. The company is based in Antwerp (Belgium) and Hengelo (The Netherlands) and is also active in France and Switzerland. With a turnover of € 13 million and 120 staff, the company's success is based on its high service levels and its technical skills. Stork Intermes' leading position in the Benelux enables it to work with over 3,000 customers cross the aeronautical, pharmaceutical and petrochemical industries.

Stork Intermes' reputation and philosophy are perfectly aligned with Trescal's objectives: offering technical excellence and one-stop-shop convenience wherever its customers are located.

The acquisition brings together complementary technical skills; Stork Intermes specializes in non-electrical (e.g. pressure and temperature) services, while Trescal's current offering focuses predominantly on electrical fields (e.g. high frequency, data / telecom and fiber optics).

This is Trescal's third acquisition (following DTI in the US and Antech Engineering in the UK) since 3i and TCR Capital invested in the company in September 2010, allowing Trescal's pro-forma turnover to increase by c30% in 2011.

Smart Grid Panel Approves Six Standards for Catalog

The Smart Grid Interoperability Panel (SGIP) has made the first six entries into its new Catalog of Standards, a technical document now available as a guide for all involved with Smart Grid-related technology.

The six standards, all of which had been approved previously by the SGIP's Governing Board, received approval by greater than 90 percent of the broader SGIP membership in voting earlier this month. The SGIP, a consensus-based group of more than 675 public and private organizations (with nearly 1,800 individual members), was created by the National Institute of Standards and Technology (NIST) to coordinate the development of Smart Grid standards. While the SGIP does not develop or write these standards directly, a vote of approval signifies that its member organizations have agreed on the inclusion of a group of standards in the catalog.

The six entries relate to high-priority national standards needed to create a modern, energy-efficient power grid with seamlessly interoperable components. In order to convert today's power grid–which still functions largely as it did when grids were created in the 19th century–into a power distribution network that can enable the wide use of electric vehicles, as well as incorporate renewable energy sources such as wind and solar, a number of new standards must be established. Among these are the catalog's first six entries, which include:

- internet protocol standards, which will allow grid devices to exchange information;
- energy usage information standards, which will permit consumers to know the cost of energy used at a given time;
- standards for vehicle charging stations, necessary for ensuring electric vehicles can be connected to power outlets;
- use cases for communication between plug-in vehicles and the grid, to help ensure that the vehicles–which will draw heavy power loads–will not place undue strain on the grid;
- requirements for upgrading smart meters, which will replace household electric meters; and
- guidelines for assessing standards for wireless communication devices, which will be needed for grid communication but can have far less tolerance for delay or interruption of signals than there is among general data communication devices, such as cell phones.

The Catalog itself is available at: http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/SGIPCoSStandardsInformationLibrary

Source: http://www.nist.gov/smartgrid/sgip-072611.cfm (or http://www.nist.gov/allnews.cfm).

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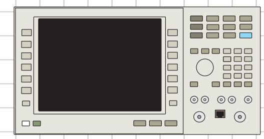
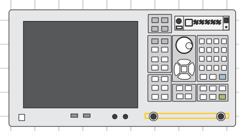
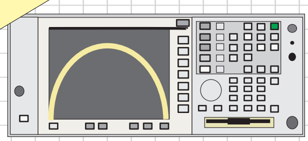


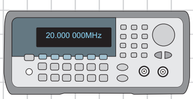
Communication Test Sets



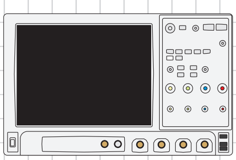
Network Analyzers



Signal Generators



Spectrum Analyzers



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AMETEK Launches California Instruments CSW Series AC/DC Power Sources

NCSLI Conference Booth # 225, 227

AMETEK Programmable Power introduced the California Instruments CSW Series, a completely new generation of AC/DC power sources that address the demands for more features without additional cost. By combining a flexible AC/DC power source with a high performance power analyzer, the compact CSW Series is capable of handling complex applications that have traditionally required multiple systems. This high level of integration simplifies wiring, saves valuable rack space, and ultimately reduces system cost.

A direct-coupled, transformerless design allows the CSW Series to output AC and DC on up to three separate phases or on the same phase. A single unit provides up to 5,550 kVA output, and up to six units may be connected in parallel to provide up to 33,300 kVA output. Built around a modern, DSP-based digital controller, the CSW Series offers powerful waveform-generation capabilities allowing users to more easily generate complex harmonic waveforms, transient waveforms, and arbitrary waveforms than ever before. This controller allows the power source to provide both AC and DC outputs simultaneously on any of the three outputs. The AC outputs can run at frequencies up to 5 kHz, much higher than the typical 1.2 kHz offered by most other AC power sources.

The supplied Windows Graphical User Interface (GUI) program can be used to define harmonic waveforms by specifying amplitude and phase for up to 50 harmonics. The waveform data points are generated and downloaded by the GUI to the AC source through the remote interface.

Using the GUI program, users can also specify and generate arbitrary waveforms. The program includes a catalog of custom waveforms and also allows real-world waveforms captured on a digital oscilloscope to be downloaded to one of the many AC source's waveform memories.

The CSW series can also be ordered with firmware that provides pre-programmed test sequences for avionics testing and EMC testing. The CSW Series includes a measurement system that digitizes voltage and current waveforms in real time and stores measurements in a 4K deep sample buffer. The front panel LCD displays captured waveforms with cursor readouts. The included GUI program also allows acquired waveform data to be displayed, printed, and saved to disk.

Harmonic content can be displayed in both tabular and graphical formats on the front panel LCD for immediate feedback to the operator. Alternatively, the included GUI program can be used to display, print and save harmonic measurement data.

For more information, contact AMETEK Programmable Power sales at http://www.programmablepower.com or contact an authorized sales representative.


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AKTAKOM ADS-2061M Digital Oscilloscope

NCSLI Conference Booth # 208

T&M Atlantic, distributer of the test and measurement equipment, unveiled a portable digital oscilloscope by AKTAKOM that features 60 MHz bandwidth, 2 channels with a 500 MSa/s sample rate, and an 8 inch color TFT-LCD screen with 800x600 resolution. It also offers huge amounts of memory(10Mpts), and USB flash storage support. ADS-2061M is user friendly with a unique "HELP" function that allows you get a User Manual on the oscilloscope's screen. The unit contains 2 passive probes that are switchable between 1:1 and 10:1 input ratio.

This highly portable and versatile unit is a hybrid between handheld and benchtop models. With a large screen and slim body it weighs under 4 lbs. and is 340x155x70 mm in dimension. With its optional battery, it can run for up to 4 hours.

This portable oscilloscope could be utilized for electronic circuit debugging, design and manufacturing, automobile maintenance and testing, circuit testing, education and training. It can also detect the peak and average values of a waveform, and store as much as 5000 waveform points on each channel. Visit www.tmatlantic.com for more information.

Ashcroft® GC35 Digital Pressure Sensor

The Ashcroft® GC35 digital pressure sensor provides remote signaling, local reading and pressure control, all in one small, rugged design. Equipped with a 4-20mA analog output, 4 digit LED display and programmable switch contacts, this multi-function instrument performs the functions of a transducer, digital indicator and pressure switch. The GC35 is offered in ranges from 0/50 through 0/7500 psig and compound ranges to 300 psi, and is available with either a back or bottom-located pressure connection. Unique qualities include a nickel plated cast aluminum housing and a brilliant, tri-color "GloBand™" to provide a 360° visual indication of switch status. Other standard features include min/max recall and adjustable analog scaling along with RoHS and CE compliance.

For more information, call 1-800-328-8258 or visit: www.ashcroft.com.

Fluke ScopeMeter® 190 Series II

NCSLI Conference Booth # 613, 615, 617, 619, 621, 712, 714, 716, 718, 720

The ScopeMeter® 190 Series II 2-channel handheld portable oscilloscopes combine the power of a 2 channel oscilloscope with a 5000 count digital multimeter and paperless recording modes, creating an advanced test and measurement tool that service and maintenance professionals can rely on for troubleshooting equipment performance problems in the field.

The 2-channel models join the recently-introduced 4-channel ScopeMeter 190 Series II models to create the first full line of high-performance portable oscilloscopes with 2 or 4 independently isolated input channels, rugged sealed case and CAT III 1000V / CAT IV 600V safety rating. Popular enhancements in the new 190 Series II include extended battery life, hot-swappable batteries and a higher safety rating. The ScopeMeter operates for up to 4 hours with a 2400 mAh Li-Ion pack (standard with 2 channel models) or up to 7 hours with the high capacity 4800 mAh Li-Ion pack (standard with 4 channel models optional for the 2 channel models). Independent electrically isolated inputs safety rated to CAT III 1000 V / CAT IV make it safe for engineers or technicians to measure everything from low voltage control signals all the way up to a 3-phase mains power supply.

The ScopeMeter 190 Series II is available in 200 MHz and100 MHz, either 2 or 4 channel, plus an additional 2 channel 60 MHz model. With up to 2.5 GS/s sampling rate and deep memory of up to 10,000 sample points per input the new 190 Series II will capture and display just about any waveform or waveform anomaly. With two electrically isolated USB ports, users can conveniently store data to a USB memory device or easily connect to a PC and transfer waveforms or screen images for data analysis or archive

For more information about Fluke ScopeMeter series, go to www.fluke.com/scopemeter.

Crystal Engineering 15,000 psi nVision Pressure Modules

NCSLI Conference Booth # 220

Responding to the demands of customers in the oil & gas industry, Crystal Engineering is releasing new pressure modules for the nVision Reference Recorder with ranges of 15k psi, 100 MPa, 1000 bar and 1000 kg/cm². The one year accuracy specification is 0.1% of reading with digital temperature compensation from -20° to 50°C. As with all Crystal products, the new modules come with an ISO 17025, NIST-traceable calibration certificate with test data at 5 temperatures.

The nVision Reference Recorder, rated Intrinsically Safe and IP-67 (submersible up to 1 meter), has become increasingly popular for applications that require long-term, high-accuracy recording because of its ability to record 500,000 data points of temperature, pressure, current or voltage at 10 readings/second with up to 0.025% of reading accuracy in nearly any environment.

For more information on the nVision Reference Recorder, visit crystalengineering.net/nVision.

Crystal Engineering is based in San Luis Obispo, California and produces highly accurate, field-grade testing and calibration equipment for measurement applications in oil & natural gas, offshore drilling, oil refineries, gas distribution, power generation, nuclear power, waste water, water supply, manufacturing, aerospace, and aircraft maintenance.

Rohde & Schwarz SGS100A

NCSLI Conference Booth # 803

The new R&S SGS100A signal generator from Rohde & Schwarz covers the frequency range up to 12.75 GHz and has been optimized for use in automated test systems. The signal source is exceptionally compact. It fits in just one-half the width of a 19" rack and requires a single height unit. With typical frequency and level setting times of 280 µs, the R&S SGS100A is three times faster than its conventional counterparts. This means higher production test throughput in addition to significantly reduced space requirements.

The compact R&S SGS100A provides RF performance comparable with that of high-end signal generators. It offers a very high output level of typ. +22 dBm as standard and has an electronic step attenuator covering the entire frequency range. Its low nonharmonics of –76 dBc up to 1.5 GHz make the generator the ideal signal source for converter tests.

The R&S SGS100A is available in two models: The CW version generates frequencies up to 12.75 GHz. It can be used as a local oscillator as well as for interference testing against mobile radio standards. The vector signal generator version with integrated I/Q modulator offers a maximum frequency of 6 GHz and covers the most important frequency bands for digital communications standards. RF signals from multiple R&S SGS100A can optionally be phase-locked to support beamforming applications for the aerospace and defense industry.

The R&S SGS100A also reduces operating and capital expenditures: Its initial costs are significantly lower than of comparable equipment. In addition, it consumes less power and dissipates less heat. This also translates into higher reliability. The calibration interval of three years helps to keep the total cost of ownership down.

The new R&S SGS100A is now available from Rohde & Schwarz, http://www2.rohde-schwarz.com.

Wahl C150 On-site Multifunction Calibrator

The ergonomically designed Wahl C150 On-site Multifunction Calibrator features unique built in "easy connect" terminals, portable and bench top flexibility, and easy to use intuitive embedded software. Fully protected with an external anti-shock rubber boot with IP 54 rating, it features five user-selectable languages, 0.005% accuracy over 1 year, NIST traceability, and HART transmitter compatibility. Featuring an elastomer keypad to protect the unit from dirt and grease, its raised keys allow the Wahl C150 to be used with gloves. Alphanumeric keypad, navigation and function keys step you through programs easily. Adjustable contrast and programmable backlit display for ease of reading in all conditions. Choose your needed accuracy with adjustable resolution. Extended battery life offers eight hours of use. The Wahl C150 comes complete with six testing leads, a quick battery charger, CD instruction manual, heavy duty carrying case, NIST Certification, and one year warranty.

Call 1-800-421-2853 or visit our web site at www.palmerwahl.com.

Agilent Technologies PNA Network Analyzers

NCSLI Conference Booth # 416, 418

Agilent Technologies Inc. recently introduced five new PNA microwave vector network analyzer models, up to 67 GHz. The new PNA Series is based on Agilent's PNA-X architecture and is the world's highest performing microwave network analyzer, setting a new price/performance standard in the industry.

The Agilent PNA is used to test a wide variety of passive and active devices such as filters, duplexers, amplifiers and frequency converters. The high-performance characteristics of the PNA make it an ideal solution for these types of component characterizations as well as millimeter-wave, signal integrity and materials measurements.

The PNAs are available with:

- Two-port internal single-source or four-port internal dual-source configuration in five frequency models: 13.5, 26.5, 43.5, 50 and 67 GHz.
- The highest source output power: +11 dBm at 67 GHz (N5227A 67 GHz model).
- 0.1 dB receiver compression point higher than +10 dBm (all models).

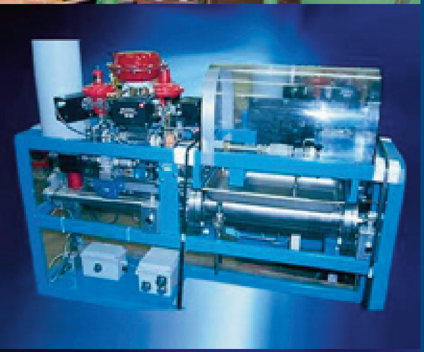
The PNA Series provides high-power sources and the best linear receivers, giving it the most accurate S-parameter measurements with the widest power range in the market, making the new PNA Series the most dependable tool in microwave network analysis.

The PNA Series now offers the majority of advanced measurement options currently available on the PNA-X Series and includes noise figure measurements, gain compression, two-tone IMD/spectrum analysis, true-mode stimulus, source phase control and fast CW mode. In the design and production of passive and active devices, these advanced applications improve accuracy and productivity for high-performance microwave component characterization and testing.

The PNA is compatible with Agilent's Physical Layer Test System, materials measurement software and multiport test sets.

Agilent's PNA Series network analyzers (N522XA) are available now starting at $60,000.

Visit Agilent's website for more information: www.agilent.com.



Infrared Thermometer Calibration

By Frank Liebmann

Training Objective: The objective of this article is to give laboratory personnel a basis to set up a calibration program for infrared thermometers. While this information is not a complete set of instructions, it contains a number of factors that commonly result in errors to people who are calibrating these devices.

What Is an Infrared Thermometer Measuring?

An infrared thermometer is a non-contact thermometer, since it doesn't touch the surface being measured. It measures thermal radiation in the infrared region of the electromagnetic spectrum beyond where the eye can see. A common spectral band for measuring temperatures from below ambient up to 500 °C or 1000 °C is the 8 – 14 µm band. This is partly because at room temperature, the peak energy occurs just below 10 µm.

As temperatures get higher, this peak wavelength becomes shorter. Most people have seen a "red hot" piece of metal. This is because the human eye can see this thermal radiation. The metal is red hot because the radiation has a significant enough amount of energy in the shorter wavelengths where the human eye can see, between 0.3 and 0.7 µm. This occurs at some point above 600 °C. The Sun's surface temperature is at a temperature between 5000 and 5500 K. The peak wavelength for these temperatures is roughly 0.5µm, right in the middle of the range visible to the human eye.

Pitfalls in Infrared Thermometer Measurement

There are a number of factors which can increase uncertainty and cause errors when using infrared thermometers. An adequate uncertainty budget should help point these out. There are two which cause people more problems than others, emissivity and size-of-source.

Emissivity

Emissivity is a material's ability to radiate compared to a perfect blackbody. It can have a value from anywhere from 0.0 to 1.0. Bare metal tends to have a low emissivity; oxidized metal tends to have a moderate emissivity; non metals tend to have high emissivity [1]. Typically, it is difficult to control a surface's emissivity to within ±0.01 [2]. In the 8 – 14 µm band, an uncertainty in emissivity of 0.01 translates to a uncertainty of 0.6 K at 100 °C and 3.4 K at 500 °C. This is illustrated in Figure 1.

Field-of-View

Handheld IR thermometers usually come equipped with a laser pointer. This serves as a guide to show where the infrared thermometer is pointed. However, these pointers can be misleading in two respects. First, the laser provides a finite point. In fact, the infrared thermometer is typically measuring a non-finite area or spot which will be discussed shortly. Second, typically the laser center does not represent the center of the spot.

Using IEC terminology, the measure for the size of this spot is field-of-view [3]. In a nutshell, field-of-view specifies that the infrared thermometer will measure a certain percentage of energy within a specified diameter at a given distance. What about the energy measured outside of this diameter? This is called scatter, and the infrared thermometer is measuring it as well. Most infrared thermometers come with a diagram, or a specification of distance to size ratio (D:S). The diameter specified by this ratio only contains a certain percentage of the radiation received by the infrared thermometer. For a measurement, it is best to have at least two times this ratio in diameter [1] as is shown in Figure 2. For calibration, the diameter of the source should be at least three times this diameter [4]. For this reason, a flat-plate is often used as a thermal radiation source instead of a cavity. At a minimum, the measuring distance and diameter of the source should be stated on the calibration certificate.

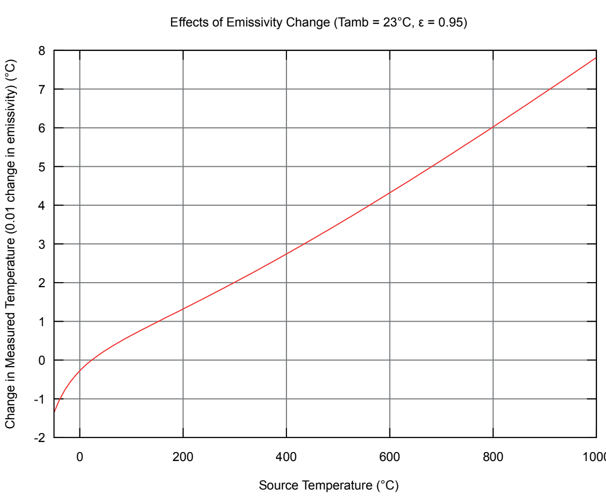


Figure 1. Effect of emissivity error.

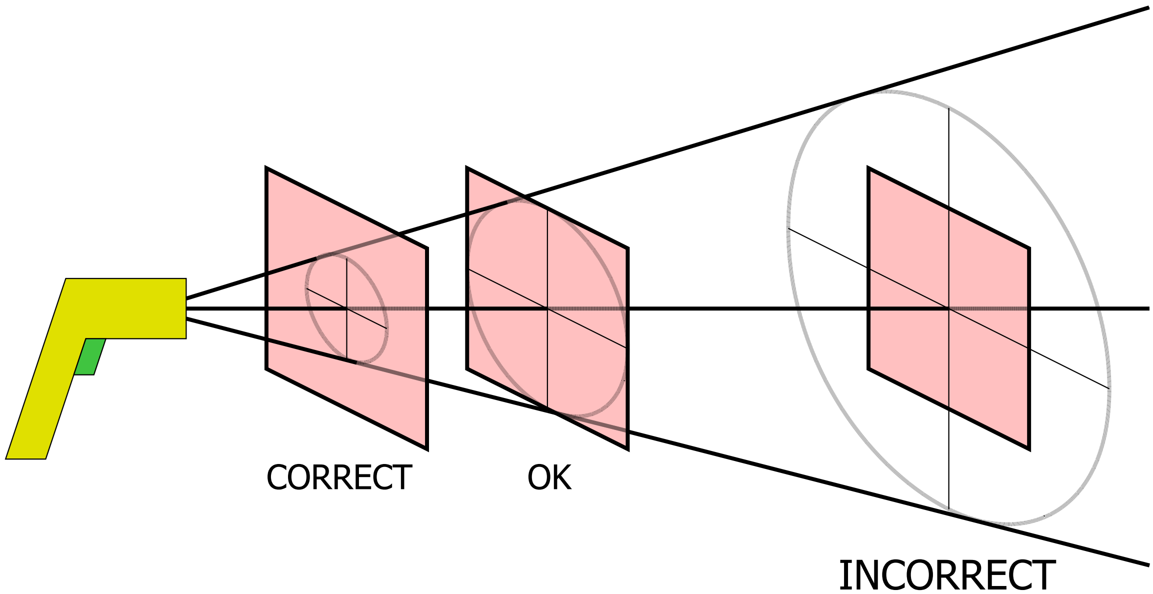


Figure 2. Proper measurement size-of-source.

Equipment Needed for Calibration

Table 1 provides a list of equipment for infrared thermometer calibration [5].

Mandatory Equipment	
Thermal Radiation Source	Two Types: • Cavity (preferred) • Flat-plate (large size-of-source)
Transfer Standard	Two Types: • Contact thermometer • Radiation thermometer
Ambient Temperature Thermometer	Monitors laboratory temperature.
Mounting Device	Tripod, fixture, or technician's hand.
Distance Measuring Device	Can be a by ruler, tape measure, or fixturing.
Optional Equipment	
Aperture	Needed only if requested by user or required by manufacturer.
Purge Device	• Cold Temperatures: Prevents ice or dew build-up • High Temperatures: Prevents oxidation • May also improve temperature gradients

Table 1. Mandatory and optional calibration equipment.

Calibration of the Thermal Radiation Source

There are two methods to calibrate the radiation source. One is using a contact transfer and the other a radiometric transfer. The contact calibration has the advantage in that it is not wavelength dependant. The contact transfer does not account for the 'heat exchange' error [6]. When a flat-plate source is used, it also may result in a large uncertainty for emissivity [5]. The radiometric transfer has the advantage in that it accounts for the errors caused by heat exchange (between the reference probe and the radiation source's surface) and for not well defined emissivity. The radiometric transfer standard must be of the same wavelength as the infrared thermometer's calibrated using the thermal radiation source [5].

Basic Infrared Thermometer Calibration Procedure

Before calibrating an infrared thermometer, the infrared thermometer should be allowed to reach room temperature. This is especially important when moving an infrared thermometer from one environment to another. Typically, 30 minutes is sufficient.

The basic infrared thermometer procedure for a calibration point should include the following steps [5]:

1. If a purge device is used, set up the purge.
2. Allow the thermal radiation source to stabilize at its set-point.

3. If available, set the infrared thermometer's reflected temperature setting to the reflected temperature.
4. Set the infrared thermometer's emissivity to the emissivity of the thermal radiation source.
5. Set the measuring distance of the infrared thermometer.
6. Align the infrared thermometer so that it is centered on the thermal radiation source.
7. Perform the measurement.
8. Repeat these steps for repeatability if needed.

There are a few notes and exceptions to consider when performing these steps. First, most infrared thermometers do not have a reflected temperature setting. Instead, the reflected temperature is detected within the instrument. Second, some infrared thermometers do not have an adjustable emissivity setting. In these cases, if the emissivity setting of the infrared thermometer does not match the emissivity of the thermal radiation source, mathematical corrections may be made.

When using a handheld infrared thermometer, it is typical to initiate a measurement by pulling a trigger. The trigger should be held a significant amount of time longer than the infrared thermometer's specified response time. Finally, the number of set points measured should be driven by the customer. If the infrared thermometer is only used over a narrow temperature range, one or two points may be sufficient. If the infrared thermometer is used over a wide range, three or more points may be necessary. This should be driven by the customer. However, the calibration laboratory should be ready to offer advice.

Where to go for more information?

Reading

- *Radiometric Temperature Measurements, Vol. 1: Fundamentals*, eds. Z. Zhang, B. Tsai, G. Machin (2009, Academic Press)
- *Theory and Practice of Radiation Thermometry* by D.P. DeWitt and Gene D. Nutter (John Wiley & Sons)
- R*adiation Thermometry: Fundamentals and Application in the Petrochemical Industry* by Peter Saunders (SPIE)

Courses

- Radiation Thermometry Short Course (NIST) – Held once a year in Gaithersburg, MD
- Snell Thermography Courses – Held at various locations in the US and Canada
- Fluke Infrared Thermometry Metrology Seminar – Held once a year in American Fork, UT

Standards Organizations

- ASTM: http://www.astm.org/; http://irthermometry.blogspot.com/
- BIPM CCT-WG5: http://www.bipm.org/wg/CCT/CCT-WG5/Allowed/Miscellaneous/Low_T_Uncertainty_Paper_Version_1.71.pdf
- MSL TG22: http://www.msl.irl.cri.nz/sites/all/files/training-manuals/tg22-july-2009v2.pdf

References

[1] *ASTM E2758 - 10 Standard Guide for Selection and Use of Wideband, Low Temperature Infrared Thermometers*, ASTM, West Conshohocken, PA, 2010.

[2] F. Liebmann, "Quality Control for Emissive Surfaces," Proceedings of the National Conference of Standards Laboratories International, 2009.

[3] *IEC/TS 62492-1 Ed. 1.0 Industrial Process Control Devices - Radiation Thermometers - Part 1: Technical data for radiation thermometers*, IEC, Geneva, 2008.

[4] F. Liebmann, "Determining Size of Source for Handheld Infrared Thermometers – Theory and Practice," Proceedings of the Measurement Science Conference, 2008.

[5] *ASTM WK27665 - New Procedure for Accuracy Verification of Wideband Infrared Thermometers*, ASTM, West Conshohocken, PA, not yet published.

[6] J. Fischer, P. Saunders, M. Sadli, M. Battuello, C. W. Park, Z. Yuan, H. Yoon, W. Li, E. van der Ham, F. Sakuma, Y. Yamada, M. Ballico, G. Machin, N. Fox, J. Hollandt, S. Ugur, M. Matveyev and P. Bloembergen, "Uncertainty budgets for calibration of radiation thermometers below the silver point", CCT-WG5 working document CCT-WG508-03, Sèvres, France, May 2008.

Frank Liebmann is a Senior Design Engineer for Fluke Calibration.

Applications of Computer Simulation in Coordinate Measuring Machine Uncertainty Evaluation

Jon M. Baldwin, Kim D. Summerhays, Daniel A. Campbell
MetroSage LLC

Comprehensive tools for evaluating the uncertainty of measurements made with coordinate measuring machines (CMMs) have been available for several years, yet their widespread application generally has lagged the existing technology, presenting significant problems for producers and consumers of CMM measurement results as well as for auditors of CMM measurement operations. In searching for reasons for this slowness to embrace currently available tools, we regularly come upon two factors. The first of these is confusion about the significance and applicability of various indices of CMM measurement uncertainty. Secondly, the depth of understanding of CMM measurement strengths and weaknesses, and their impact on product profitability, which can be developed from a comprehensive investigation of CMM measurement uncertainty, are not widely understood. We hope to clarify some of these issues and to encourage both producers and users of CMM results as well as auditors to enhance the value and significance of CMM data by application of these now technically mature tools.

Computer simulation techniques excel in offering the best combination of thorough coverage of measurement influence factors, defendability of results and general applicability for complex measurement systems such as CMMs. In this presentation, we briefly discuss the principles of computer simulation methods and the concept of task-specific measurement uncertainty as it applies to CMMs. Following this, we present several practical examples, adapted from real-world measurement problems, of the use of simulation methods in CMM uncertainty evaluation, ranging from traceability demonstration and measurement process optimization to analysis of measurement uncertainty impacts on product profitability.

Introduction

Many of the conventional methods for measurement uncertainty evaluation are not readily applicable to CMM measurements, due to the number, ranges, interactions and generally unknown sensitivity coefficients of the parameters that can influence the measurement result, as shown in Figure 1. Not only is it necessary to deal with the obvious effects of CMM geometry errors, sensors and measurement environment, but one must also consider the sometimes more subtle effects of data processing algorithms and the interaction of probing strategy with feature form errors.

The situation is further complicated by the fact that in a typical CMM measurement session, multiple diverse dimensional parameters (e.g., sizes, locations, forms and orientations) are determined simultaneously for multiple part features. The number of factors and complexity of their possible interactions generally renders the traditional GUM method of propagation of uncertainties unwieldy [1]. Of the several general methods for evaluating the uncertainty of CMM measurement results computer simulation methods [2] offer a generally powerful and desirable mix of features, often making them the method of choice for those tasks. The details of a software system for CMM uncertainty evaluation by simulation have been described elsewhere [3] and will not be repeated here, where we will focus instead on a range of practical applications.

We begin this paper by reviewing some important aspects of CMM uncertainty evaluation. We follow this with a series of descriptions of real-life applications and benefits to be derived from them, ranging from the fundamental and strictly technical role of uncertainty in CMM measurements traceability, through optimization of CMM measurement decisions, to the important economic issue of CMM measurement uncertainty impact on product profitability.

CMM Performance Test Data vs. Task-specific Measurement Uncertainty

The most commonly and readily available estimates of CMM errors are performance test data derived according to some prescribed standard, the most prominent being those promulgated by the ASME B89 subcommittee 4 on Coordinate Measurement Technology [4,5] and the ISO Technical Committee 213 on Dimensional and Geometrical Product Specifications and Verification [6]. One or the other of these figures of merit are commonly quoted by CMM manufacturers for each model they offer, and are fairly readily available for a specific CMM through the services of various CMM calibration service organizations. Thus they are typically the numbers one first hears when inquiring about the capabilities of a CMM.

Unfortunately, these performance tests do not tell the whole story when trying to provide a useful answer to questions most often of interest to the producer or consumer of a manufactured item, such as the following: "What is the uncertainty at 95% confidence of the diameter of the maximum inscribed cylinder that will just fit inside this nominally 3-inch diameter hole, measured with this particular CMM and probing hardware, under these specified conditions of measurement strategy, data processing software and environment?"

Referring again to Figure 1, CMM performance tests typically do a reasonable job of capturing errors arising from CMM geometry and the sensor system. They may, or may not, do a tolerable job of accounting for thermal environmental factors, depending on the thoroughness of the investigation. In general, due to the fact that performance tests emphasize procedures designed to be executed quickly, they are likely to miss longer term environmental effects. Due to these tests' reliance on artifacts of perfect form and their general specification of least squares fitting algorithms (commonly only to spheres and planes), they do almost nothing to capture the influences of data processing, form errors and sampling patterns. Performance tests can, however, provide important input to a comprehensive uncertainty estimate based on computer simulation, as we will see in the discussion to follow.

Furthermore, CMM performance tests provide only an incomplete representation of the errors they do capture. Take, for example, the B89.4.10360.2 tests [5]. This suite of tests yields up to seven scalar parameters that attempt to capture CMM geometry and probing errors for a three-axis CMM. These are: the overall length measurement error, three individual axis length measurement errors, the repeatability range of the length measurement error, point coordinates repeatability and the length measurement error with a 150 mm stylus tip offset. In contrast, a rigid body characterization [7] of a 3 axis CMM, which provides a rather complete description of the major CMM geometric errors, requires a linearity function, 2 straightness functions, roll, pitch and yaw functions for each axis, and 3 axis squareness parameters, for a total of 18 functions and 3 scalar parameters. It should be clear that the reduced set of parameters derived from the performance test cannot completely capture all the information contained in the far richer set provided by the rigid body characterization.

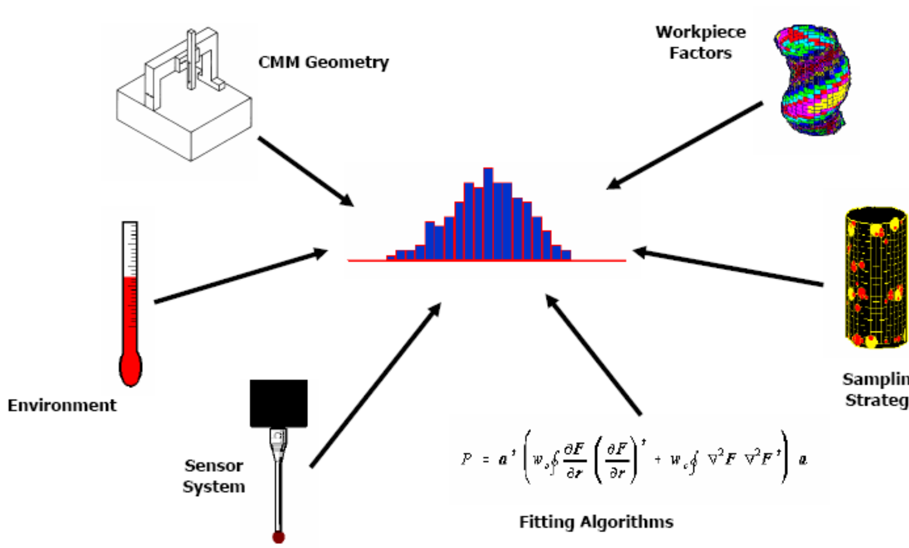


Figure 1. General categories of CMM influence quantities.

Simulation Methods for CMM Uncertainty Evaluation

A variety of approaches to CMM task-specific uncertainty might be considered, including sensitivity analysis (the classic GUM approach [1]), expert judgment, substitution, examination of measurement history and computer simulation [8]. Due to the factors mentioned earlier in this article, computer simulation possesses distinct advantages [3] and is applied in all the practical examples to follow.

The simulation technique used here is outlined in Figure 2. At the heart of the method is a National Institute of Standards and Technology (NIST) developed method called simulation by constraints (SBC) [9]. This choice of method was based largely on a desire for flexibility in cost/benefit tradeoffs. SBC provides this by allowing simulations to be set up and executed in the face of incomplete information from CMM performance tests. This can be seen by reference to Figure 2 where, for the purpose of illustration, we focus on just one aspect of CMM uncertainty evaluation, the effect of rigid body mechanical errors. The method begins with the recognition that the information available to describe the uncertainty source may be incomplete; in this case, using a CMM performance test that does not completely define the CMM geometry. For example, there will be many sets of 21 rigid body parameters that would result in the same discovered set of B89 parameters, the bounding measurement set (BMS). The SBC method would begin with generation of an adequate number (on the order of 1000) of rigid body parameter sets that would result in B89 numbers near the BMS values. Each of these sets of 21 parameters (3 scalars and 18 functions) can be thought of as a virtual CMM, each of which could possibly be *our* CMM. For each virtual CMM, the error of each individual point measured on the work piece is computed. These points (with their errors) are submitted to the CMM data processing algorithms to obtain the corresponding substitute geometries for all the measurement features of concern. The substitute geometries are used to evaluate all the GD&T parameters of interest and the bias and range of the distribution of the results for each parameter provides an estimate of its measurement uncertainty. The extension of the SBC concept to other error sources, such as thermal environment, is straightforward. Readers wishing a more detailed description of the simulation software used in this work are referred to [3].

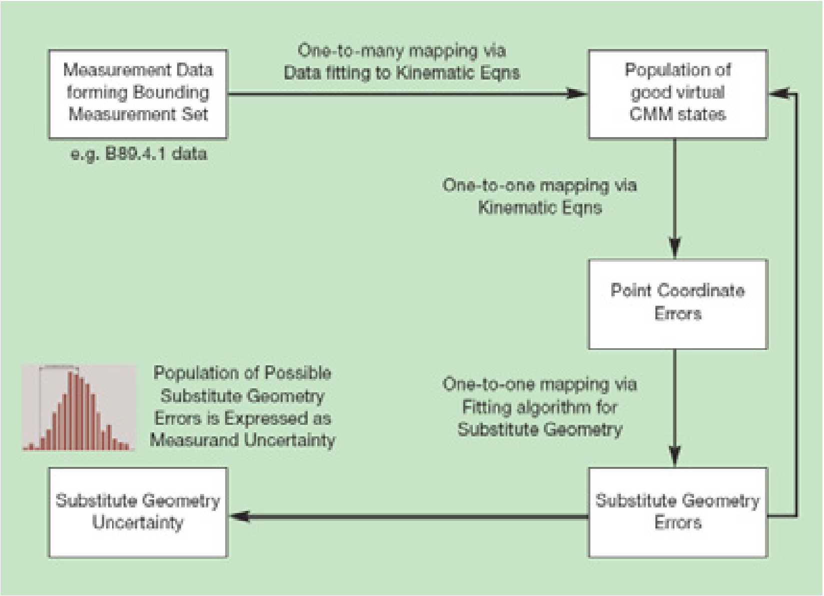


Figure 2. CMM uncertainty evaluation using simulation by constraints.

Applications of CMM Measurement Uncertainty Evaluation

Proof of Traceability

One problem of major significance in CMM measurement uncertainty evaluation is in demonstrating measurement traceability to national or international standards. This process is illustrated for CMMs in Figure 3. ISO 17025 [10], for example, states that traceability is achieved by means of an unbroken chain of calibrations or comparisons which include the measurement uncertainty of each step. Implicit in this, and other standards on traceability, is the requirement that the uncertainty be specific to the particular measurand in question as a task-specific uncertainty. An example of a task-specific uncertainty statement might be "The diameter of the maximum inscribed cylinder that will just fit inside this nominally 0.5-inch diameter hole, measured with this particular CMM, under these specific conditions is ±0.0008 inch at 95% confidence." Thus generic statements of CMM performance, such as are commonly produced by CMM calibration services are alone not adequate for proving traceability.

The traceability chain for a CMM measurement begins with a primary length standard maintained by NIST or some other national measurement institute. This standard length is conveyed by calibration to other, secondary or transfer standards and generally ends up with a calibrated length assigned to a physical calibration artifact. As said before, each step contributes something to the uncertainty of the calibrated value.

Usually, these higher level steps are

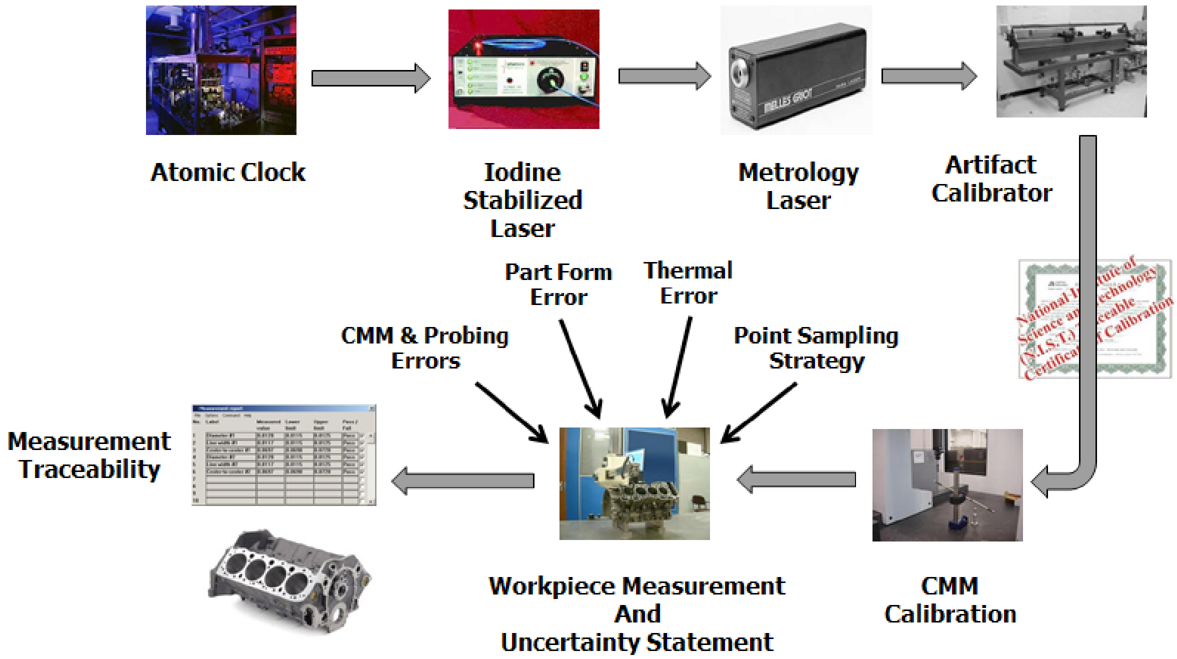


Figure 3. The CMM measurement traceability chain.

not directly accessible to the CMM practitioner, but the accumulated uncertainty is easily obtained, most often from a statement on the artifact calibration certificate. The uncertainties of subsequent steps are then left to be obtained by those concerned with the CMM calibration and CMM measurement functions, where computer simulation methods possess particular power and versatility.

Optimizing Tolerance Schemes

Designers and metrologists often ask themselves (or *should* ask) "What is the best way to control the dimensions this specific part feature?" A classic example of this problem is the short arc problem. It is generally well known that short angular sections of arcs are difficult to measure reliably. The exact magnitude of the problem and the extent to which it can be alleviated are less well understood, since generally it is not practical to conduct a sufficient set of physical experiments. It is, however, completely practical to conduct a set of virtual experiments using computer simulation.

We begin this experiment by looking at the uncertainty of the diameter measurements under conditions representative of our particular CMM operation (Figure 4), where, the calculated uncertainty is plotted as a function of the nominal arc diameter, for various values of included arc angle and see that, while there is the expected influence of included angle on the measurement uncertainty, the diameter of the arc has no influence whatsoever. Although the results for other parameters (position, orientation) are not shown here we did, of course, look at these since with simulation this can be done with almost no additional effort. As here, we found that the influence of feature size was negligible and could then go on to look more carefully at other factors.

Figure 5a shows again the size uncertainty, this time as a function of the number of points taken and the included angle of the arc. We see that, for large included angles, the uncertainty is uniformly low but grows dramatically as the included angle decreases. We see also that, although there can be some benefit from the often used strategy of sampling at a larger number of locations, the effectiveness of that tactic is limited. Similar effects, although not illustrated here, were seen for positional or coordinate tolerances used to control feature location. If we choose

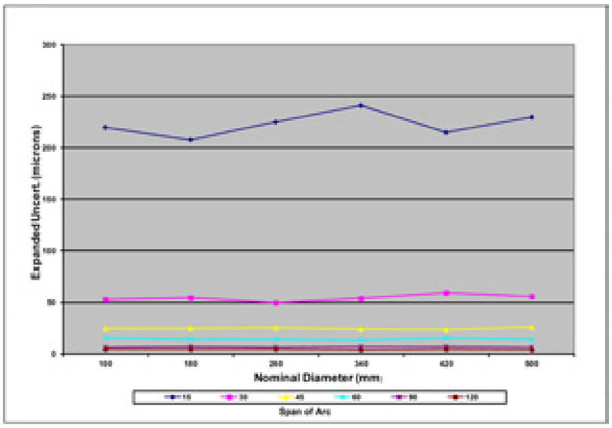


Figure 4. Measurement uncertainty as a function of arc diameter.

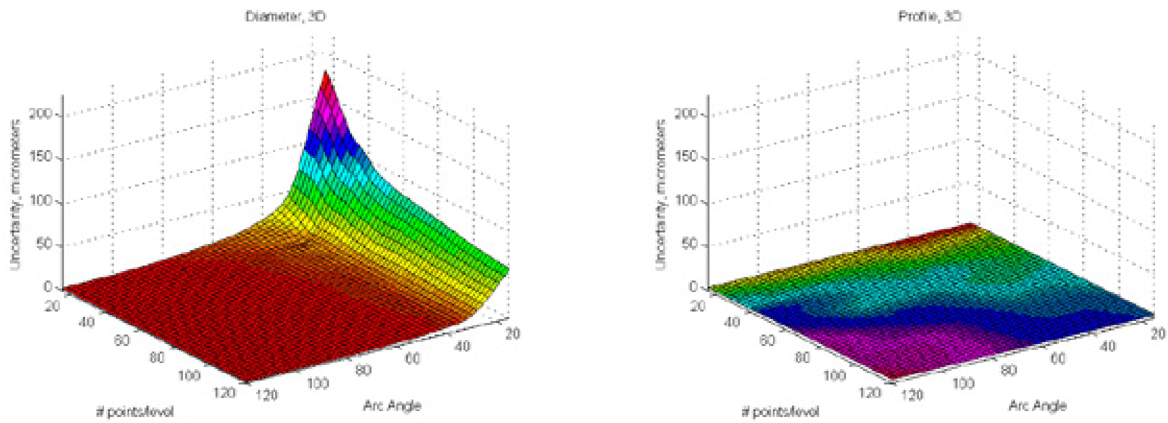


Figure 5. Measurement uncertainty of short arc segments: (a) Size controlled by a diameter tolerance, (b) Size controlled by a profile tolerance.

to control all aspects of this feature with a profile tolerance (Figure 5b), we find the best of all possible worlds; small uncertainty essentially independent of arc length and measurement protocol. As important, since these virtual experiments yield quantitative results, can be conducted quickly, and do not tie up the CMM, we can readily determine the optimum measurement protocol for our specific requirements.

Selecting the Best CMM for a Specific Measurement Task

A question often wrestled with by CMM users is "Given several CMMs that might be used to measure a specific part, which of them are up to the task, and which offers the best cost/measurement time tradeoff?" In Table 1, we have data on four CMMs, each characterized by its set of B89 performance parameters. They vary considerably in their measurement capability, but how will each perform for a specific set of measurements? For simplicity, we equip each with an identical probing system and make all other measurement conditions identical. Figure 6 shows the measurement uncertainties for five critical dimensional characteristics, as measured with each of the candidate CMMs. Also shown are the uncertainties produced by a perfect CMM (black bars), with the only errors coming from other sources (probing system, temperature, etc.).

Clearly there are significant differences in the measurement uncertainties associated with different GD&T parameters. The uncertainties in angularity are, across the board, much smaller than those for the profile on the same feature. There are dramatically different sensitivities of uncertainties to the CMM being employed. For example, the positional callout on the 25.000 mm Hole is quite sensitive to CMM choice, while its size is almost totally insensitive and is identical to that given by a perfect CMM. This gives us the valuable indication that we will do no better on this particular measurement, regardless of which CMM we use. If we need better information here, we will have to improve some other aspect of the measurement system.

Further studies showed that the uncertainties in hole size and face profile are prominently influenced by the probe behavior, that the hole position and the face angularity have major CMM contributions to their uncertainty, and that the 65.000 mm Hole concentricity has major contributions from thermal conditions.

	CMM A	CMM B	CMM C	CMM D
X-Linear Accuracy (µm)	1.2	3.5	5.7	8.5
Y-Linear Accuracy (µm)	1.2	3.5	5.7	8.5
Z-Linear Accuracy (µm)	0.93	3.2	5.3	8
Volumetric Performance (µm)	3	7.5	9	13.8
Offset Volumetric Performance (ppm)	5	12	15	24
Repeatability (µm)	0.48	4	4	6

Table 1. Performance parameters for four candidate CMMs.

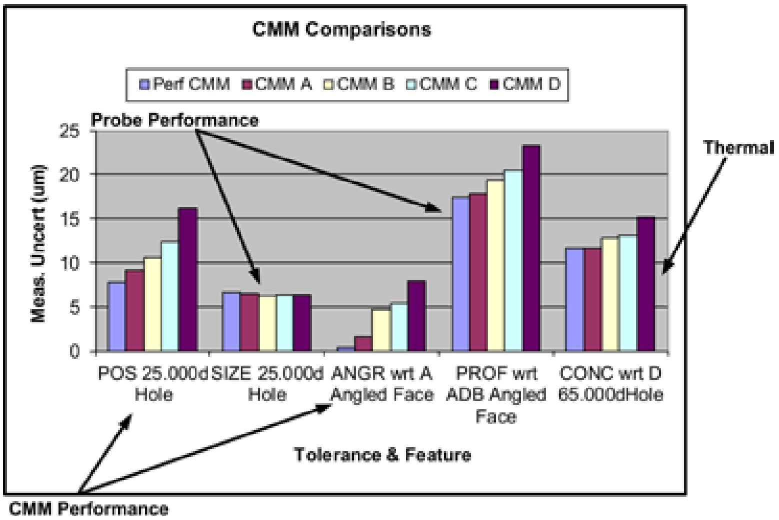


Figure 6. Measurement uncertainties for critical dimensions, measured with each CMM.

Traditionally, various rules of thumb have been developed such as the "4:1 test uncertainty ratio" (TUR) and the "10:1 Rule" expressing the ratio of the size of the tolerance zone to the required measurement uncertainty. For the handful of GD&T callouts considered here, we can make the comparisons shown in Table 2.

Maximum uncertainty values suggested for the set of GD&T parameters in this study are given in the third and fourth columns of the table. Comparing these with the uncertainty values from our simulations, we see that most of the CMMs considered could not meet *any* of the 10-to-1 Rule requirements. Indeed, given the other conditions of measurement described above, even a *perfect* CMM could not satisfy the 10-to-1 Rule needs. For the more relaxed 4-to-1 TUR requirements, the situation is somewhat brighter. Shown here, in a color-coded format, is the CMM comparison of uncertainties relative to the 4-to-1 TUR. Green indicates compliance, red indicates a failure to comply, and yellow identifies a marginal case.

On this basis, we can rule out CMM D, and probably should also exclude CMM C. CMM A and CMM B both meet requirements in every instance. It is now a decision between these two. CMM A is the more precise machine, but is also more expensive to operate and may represent some overkill for the problem at hand. CMM B, though within the 4-to-1 specifications in each instance, does approach the limit in the case of the profile tolerance. The final judgment, as is so often the case, may require consideration of additional economic factors.

Measurement System Optimization

An issue similar to the one just discussed arises if available measurement systems are found inadequate to the task at hand. The question now is "What aspect of the measurement system would most advantageously be improved to enhance overall performance?" Simulation techniques offer insight into such issues due to the fact that it is easy, in software, to reduce the error contribution from any influence factor to zero, that is, to make that aspect of the measurement system behave as if it is perfect. Sequential examination of the effect of each uncertainty contributor then leads to information as to where system improvement dollars might be most advantageously spent.

In this study, the effects of CMM geometry errors, probe errors and thermal nonidealities were considered. The CMM performance was measured by the B89 test suite, with linear accuracies of 3.0, 2.1 and 2.5 µm for the x, y and z axes, respectively. The volumetric performance was 7.2 µm, the offset volumetric performance was 7.1 µm/m and the repeatability was 1 µm. A piezo probe was used, with a random error of 5 µm. The CMM scales were temperature insensitive; the part was aluminum, temperature compensated with an expansion coefficient of 22±2 ppm/ºC at a temperature of 25±3 ºC. The computed uncertainties are shown separately in Figure 7 for size, location and form, and for every possible combination of error sources. (The notation "101"

Dimension	Tolerance (µm)	4:1 TUR (µm)	10:1 rule (µm)	CMM A	CMM B	CMM C	CMM D
Position 25.000d Hole	60	15	6	9.1	10.5	12.4	16.1
Size 25.000d Hole	40	10	4	6.5	6.2	6.3	6.4
Ang wrt A angled face	40	10	4	1.6	4.7	5.4	7.9
Prof wrt ABD angled face	80	20	8	17.8	19.4	20.4	23.2
Conc wrt D 65.000d Hole	60	15	6	11.6	12.8	13	15.1

Table 2. CMM comparison.

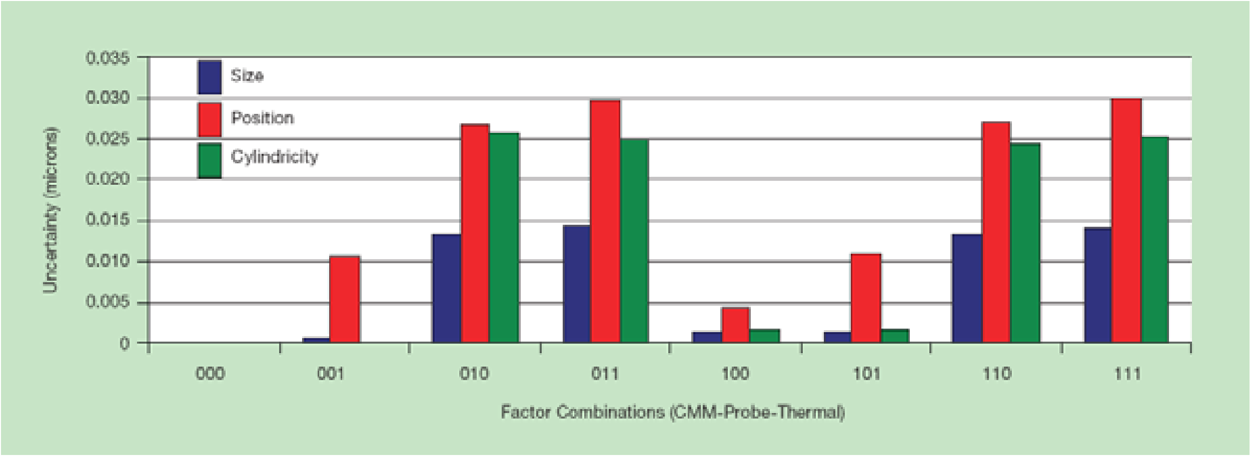


Figure 7. Relative importance of error sources.

signifies, for example, that CMM and thermal errors were considered in that particular experiment, but not probe error.)

We see readily that those experiments in which the probing system was considered, either alone or in combination, have the greatest uncertainty, followed in importance by the thermal environment, whereas the CMM in this instance contributes hardly at all, leading to a clear set of priorities for improving overall measurement system performance.

Measurement Profitability Analysis

Thus far, we have considered legal and technical motivations for understanding CMM measurement uncertainty. There are economic considerations as well.

To an ever greater degree, a major factor in manufacturing competition is the ability to produce increasingly complex components, with both higher accuracy and lower cost, which also drives product quality metrics such as improved function and higher reliability. One aspect of higher accuracy and lower cost in precision manufacturing involves optimizing the metrology process to yield maximum economic return.

However, the business perspective on product metrology often is that measurements do not add value and thus should be treated as an expense to be kept to a minimum. This is truly the case only if *a priori* there is 100% certainty that all production output is within specification. In the far more typical case, some fraction of product will be out of specification. Identifying and reducing accept/reject errors reduces a host of costs such as unnecessary scrap and rework, warranty expense, customer dissatisfaction, damaged brand reputation and lawsuits. Ideally, all of these can be captured in cost functions that express the cost of making incorrect decisions. If this can be done and if measurement uncertainty is known, the cost of incorrect decisions and their effect on profitability can be quantified. It then becomes the role of measurement to identify and minimize "negative value" product. Viewed in this context, metrology becomes a value-added activity in the production process. Thus there are multiple reasons for considering the effect of measurement cost on product profitability, beginning with the global objective of improving competitive posture, just discussed.

The effect of measurement cost becomes yet more intensely focused when, as is often the case, measurements are also fed back to control the manufacturing process. Process control is highly desirable as it not only reduces the number of measurements (and hence costs), but it proactively adjusts the process and thus can reduce the number of out-of-specification components. Costs are now "leveraged up" as a few process control measurements may affect several hundred manufactured components. Additionally, an erroneous measurement system now has the opportunity to misadjust the manufacturing parameters, creating out-of-specification components, and then to pass them on to the customer. At a lower level, an understanding of measurement cost can be applied to optimize the contribution of measurement resources to the financial bottom line, to justify and predict the benefits of measurement resource expenditures and to focus available metrology resources to best promote profitability.

It is not our purpose here to go into the details of the effects of measurement uncertainty on product profitability. The topic was discussed in detail in an earlier paper [11]. Instead, we offer the results of just one study, that shows the part measurement uncertainty plays in the profitability equation.

It is common practice to guard band measurements to reduce the incidence and cost of measurement errors. Most commonly, it is the cost of Type II errors that is of major concern; hence the acceptance zone is reduced by some amount (known as "stringent acceptance") and an increased probability of rejecting a good part is accepted

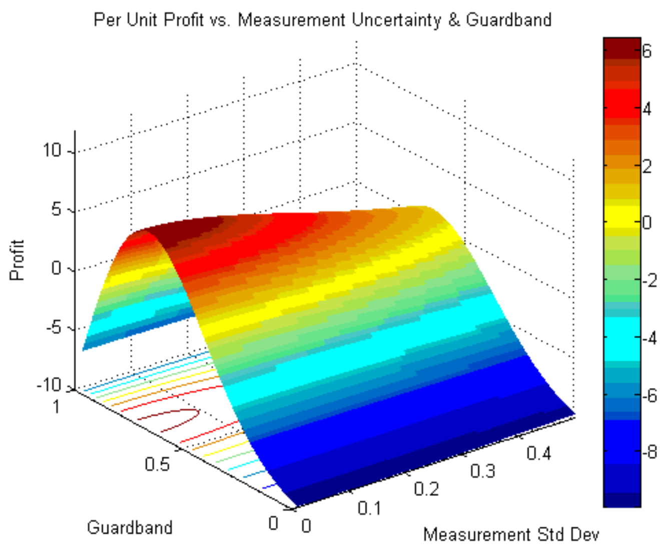


Figure 8. Effect of measurement uncertainty and guard banding on product profitability.

in the interest of not exposing the customer to bad parts. It is useful to know, for a given measurement uncertainty, the guard band choice that will maximize profit. In this example, we are considering the measurement of a 100 mm diameter shaft with tolerance limits of ±1 mm. The production process is centered; that is it produces parts with a mean size of 100 mm. The production standard deviation is 0.33 mm. The measurement process is unbiased. The selling price of one part is \$30, the cost of producing a part is \$7.50, and the cost of shipping a bad part is taken to be \$300. This is typical of what might be regarded as a critical or "high consequence" part, where the ratio of Type II error cost to selling price is often found to be ≈10.

Interestingly, we see that for many values of guard band, it is impossible to make a profit on this particular item. Proper guard banding is required in order to achieve profitability, with the optimum guard band being on the order of 0.65 of the tolerance. There is a significant effect of measurement uncertainty, with the profit approaching zero at the high end of the range studied.

Conclusion

In summary, we've looked at several practical applications of CMM measurement uncertainty evaluations, covering legal/contractual issues, technical questions and product profitability. All provide strong motivations for understanding and controlling the uncertainty of measurements we make with our CMMs. Furthermore, we have seen that computer simulation methods possess unique power, versatility and economy as tools for measurement uncertainty evaluation with complex measurement systems such as CMMs.

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Jon M. Baldwin, Kim D. Summerhays and Daniel A. Campbell, MetroSage LLC, 26896 Shake Ridge Road, Volcano, CA 95689, 415-336-2244.

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Turbine Flow Meter Calibration Using Nonhazardous Fluid Mixtures to Simulate Fuels and Lubricants

John Ball
University of Alabama in Huntsville/SMAP Center
US Army Product Director for Test, Measurement, and Diagnostic Equipment
Redstone Arsenal

Precision turbine flow meters are widely applied in Army research, development, and test facilities. Helicopters, tanks, and many other military machines are dependent upon engine and hydraulic test stands located at depots throughout the world. Turbine flow meters are key components in such test facilities, and periodic calibration is essential to maintain accuracy. If the candidate nonflammable, environmentally friendly fluid currently under study can be used to simulate hydrocarbon fuels and lubricants for calibration, turbine flow meter support may become significantly less expensive, less dangerous, more accurate, and also nonpolluting. This report summarizes current Army and Air Force turbine flow meter calibration programs, influences of fluid properties on calibration coefficients, the results of recent Army-Air Force inter-laboratory comparisons in hydrocarbon and surrogate fluid mixtures, problems that remain to be solved, and future work.

Introduction

The US Army supports helicopters, tanks, trucks, and other systems with an array of depots, rework facilities, and test stands located worldwide. Accurate fluid pressure and flow measurements are essential elements in the testing and maintenance of the advanced engines and hydraulic systems that power Army weapons, vehicles, and machines. Testing takes place in peacetime and in war, on the factory floor, and in theaters of military operation. Not only mission success but the lives of military and civilian men and women depend upon Army testing programs.

Periodic calibration is necessary to maintain test equipment accuracy and reliability. Army calibration is conducted by specialized military teams on the battlefield and military and civilian calibrators in shops and labs throughout the world. At the top of this hierarchical system, the Army Primary Standards Laboratory (APSL) provides traceability to NIST and the SI for the hundreds of thousands of pieces of test, measurement, and diagnostic equipment (TMDE) in the Army program.

Turbine meters, Coriolis meters, positive displacement meters, orifice meters, venturis, and other flow meters are all commonly applied in test stands. All precision measuring devices, including the flow meters in test stands, must be calibrated. Some Army flow meters are calibrated in situ against specially designed Army flow transfer kits that use turbine meters as reference standards. In most cases, however, flow meters are shipped to the APSL or another remote calibration facility for recertification.

The flow laboratory at the Army primary laboratory, Redstone Arsenal, Alabama, is one of the best equipped and highest accuracy facilities in the world. Multiple dynamic displacement provers provide calibration support from approximately 0.01 to 300 GPM in hydrocarbon fuels and lubricants.

Figure 1. Turbine meter sliced open.

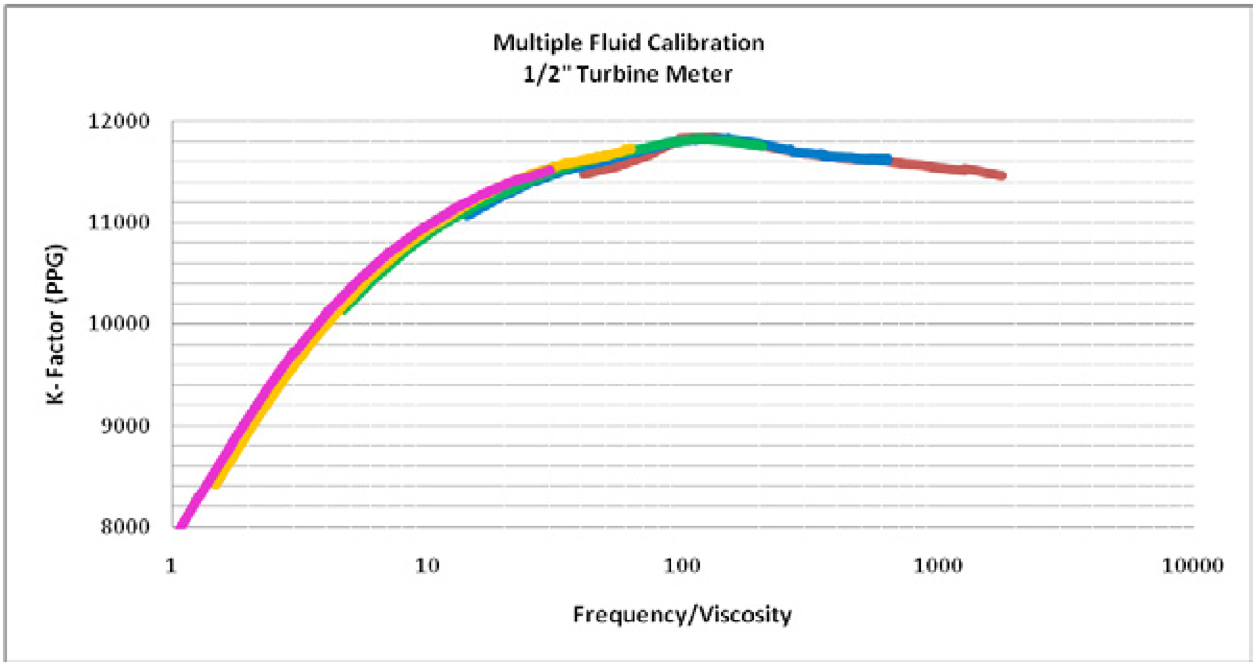

Figure 2. Response curves for one meter calibrated in five fluids.

Turbine Flow Meters

A turbine flow meter is essentially a propeller mounted in a fluid stream. A pickoff mounted on the outside of the meter body detects the moving blades and generates pulses at a frequency proportional to the rotational velocity of the turbine. These pulses are related to flow rate through a meter coefficient, such as pulses per gallon, known as the "K-factor." If meter coefficient is plotted against frequency divided by fluid viscosity, the results of multiple fluid calibrations can be represented by a single curve, often called a "universal viscosity curve" (see Figure 2). In the example below, actual APSL calibration data for five hydrocarbons (lubricants and fuels) with viscosities from about 1 to 70 cSt are presented on a single chart. The calibration results for the five fluids are shown in five colors [1].

Turbine meter repeatability can be ±0.05% of indication or better and single fluid uncertainty can be ±0.1% or better across the flow range.

While it is obvious from Figure 2 that a single curve fit might be used to describe the performance of this meter across a f/v range of 1000:1, it is also clear that the individual curves do not fall perfectly on top of one another. This effect limits the accuracy obtainable with a universal curve.

Propylene Glycol as a Surrogate Fluid

There are obvious reasons for calibrating a turbine meter in the fluid and under the conditions in which it will actually be used. The APSL maintains barrels of hydrocarbon liquids which are used in pure form and in mixtures to produce fluid properties as close as possible to the fluid in which the meter will actually be used. Multiple-fluid calibrations are routinely conducted and data is fitted to "universal curves" for meters that are expected to be used over a wide viscosity range and for meters used as standards to calibrate other flow meters.

Hydrocarbon fuels and lubricants are flammable, explosive, hazardous to human health, and damaging to the environment. The APSL's multiple viscosity calibration process involves the production of hydrocarbon mixtures which are routinely flushed out of the provers to become hazardous waste. For years, the Army has been interested in developing a surrogate calibration fluid to replace hydrocarbons. Propylene glycol and water (PGW) is the best candidate identified to date. It has the delightful characteristics of being environmentally friendly, harmless to people and pets, and nonflammable. It can also be mixed with water to make viscosities from about 40 to about 1 cSt, which covers the Army's principal range of interest. To make matters even better, the fluid has been used for some time by the Air Force Arnold Engineering Development Center (AEDC) to simulate hydrocarbon fuel in turbine meter calibrations.

However, the Army is interested in using PGW across its full viscosity range and for more than one type of turbine meter. The Army meters calibrated in PGW might be used as reference standards for calibrating other flow meters. It is possible that thin mixtures of PGW might simulate fuels of 1 cSt quite well but thick mixtures might not simulate lubricants of 40 cSt. It is also possible that PGW might work well for some types or sizes of meters but not others.

A study by the Navy [3] showed differences between water and hydrocarbon calibrations of turbine meters. Smaller meters showed the largest differences. These tests involved pure water with a viscosity of 1.07 cSt. (See Fig. 3) The viscosity of the hydrocarbon was 1.27 cSt. While the viscosities were similar, the fluid densities were considerably different (water: 0.999 gm/ml; solvent: 0.770 gm/ml). Will similar issues show up in PGW? Such a question can only be answered with test data.

Unfortunately, the APSL provers are not available for experimentation that involves filling them with water-based liquids.

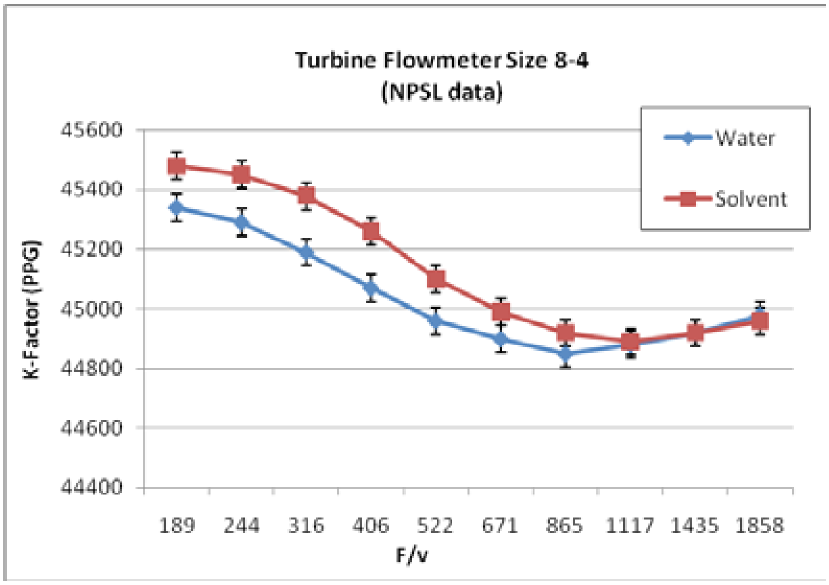

Figure 3. Turbine meter multiple fluid calibration curve.

Fluid Response Issues

Figure 4 is a multiple fluid curve for the same well behaved turbine flow meter discussed earlier. The data were taken by Michael Vickers of the APSL in late 2010 and have been plotted in terms of dimensionless Strouhal and Roshko numbers that improve upon simple K versus f/v characterization [2]. The lack of overlap that was apparent in Figure 2 has been made more visible by using a logarithmic horizontal scale and limiting the range.

The differences in meter coefficient for this meter are greater than 1% at the same Roshko value, even though each of the three single fluid calibrations has an estimated uncertainty of about ±0.1%. This effect causes undesirably high uncertainties for this "universal curve fit," even for a very well made meter.

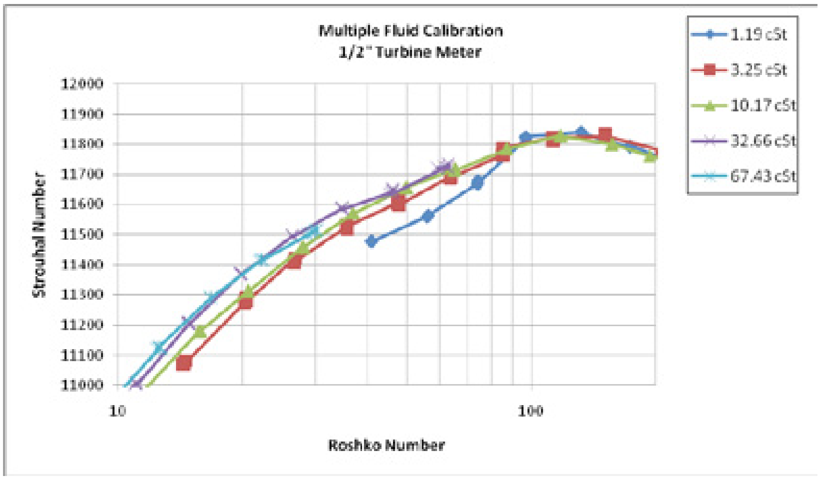

Figure 4. Turbine meter multiple fluid overlay magnified.

If the performance of turbine flow meters can be better understood and characterized, their utility in multiple fluids might be significantly improved. In this project, we will extensively study the performance of turbine meters in PGW and hydrocarbons at the multiple viscosities.

Joint Service Serendipity

The Air Force has a project underway to improve the performance of calibration provers at Precision Measurement Equipment Laboratories (PMELs). The project includes research using a flow prover at the University of Tennessee Space Institute (UTSI) that has been extensively studied and modified to maximize its accuracy. Recent work on significant flow measurement uncertainty improvements related to temperature monitoring and corrections was presented by Jeremy Latsko at NCSLI 2010 [4].

The Army has just completed an independent effort to reduce Army primary laboratory calibration prover uncertainty, one aspect of which is the subject of an MSC paper at the 2011 conference [9].

Obviously, researchers in both these calibration organizations are interested in better understanding turbine meter performance and further improving calibration accuracy.

Contacts between flow researchers at the APSL and the Air Force's Arnold Engineering Development Center (AEDC) led to the development of a joint project which addresses the interests of both services.

In essence, the Army-funded portion of the project consists of calibrating turbine meters in hydrocarbons and PGW mixtures at various viscosities using the Air Force research PGW prover and Army hydrocarbon provers, then applying a new mathematical approach to the data analysis. The project team includes scientists, engineers, and technicians from the APSL, Air Force METCAL, AEDC, and Dr. George Mattingly, former lead flow researcher at NIST.

Air Force – Army Correlation

Before data for the same meters at the same viscosities from an Air Force prover can be compared to data from an Army prover, the provers must be correlated. Otherwise, effects due to provers and calibration methods would pollute meter performance data.

In November 2010, PGW fluid samples from 30 to 1 cSt were measured by both laboratories to eliminate possible biases because viscosity errors are indistinguishable from frequency shifts. Measurement intercomparisons were begun immediately.

Preliminary correlation of the Air Force and Army provers was accomplished using matched pairs of dual turbine meters and a process similar to that described by Jalbert [10]. Data were taken at both laboratories using one inch flow meters in 1 cSt fluid – PGW at the Air Force

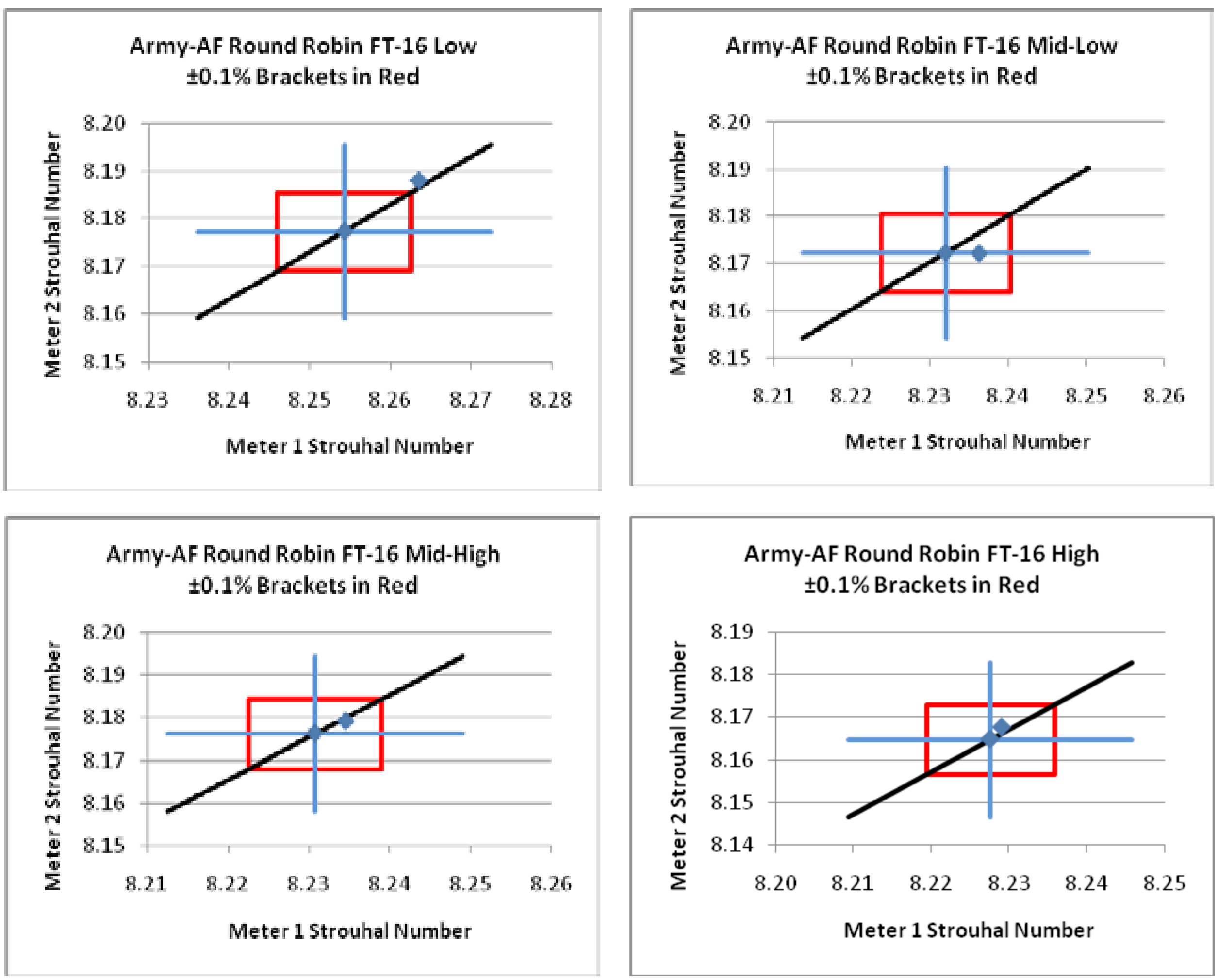

Figure 5. Youden-style plots for Army-Air Force correlation at four points over the range.

and hydrocarbon at the Army. Each meter was measured in upstream and downstream locations. For this paper, the Strouhal Numbers from upstream and downstream measurements were averaged and plotted in a Youden-style format with the Army as the pivot. Four flow rate comparisons across the range are shown in Figure 5 [7].

In this series of tests, Air Force and Army provers appear to agree to better than ±0.1% of reading except at the lowest flow rate, and it is expected that the source of this problem will be quickly tracked down and removed. These provers are expected to soon be solidly correlated to better than ±0.025% across their operational flow ranges.

Detailed studies will follow during the next year involving turbine meters of several sizes and types that will be calibrated in PGW and hydrocarbon liquids across a viscosity range of 40 to one. The data analysis will be more comprehensive and take full advantage of Youden analysis to estimate random and systematic differences [5][6].

Mathematical Analysis

The Buckingham Pi theorem can be applied to the analysis of turbine meter response to flow rate and other fluid parameters. Dimensionless parameters will be developed and used to create three dimensional models from the data gathered in this new study. This approach has been applied to gas turbine meters with success [8] but ours will be the first use for liquids.

Status and Conclusions

This project has already enhanced the collegial relationship between Army and Air Force flow calibration laboratories. Correlating the flow provers for the two organizations improves uncertainty budgets for both and provides instruments, tools, and processes that can be used for future inter-laboratory comparisons.

If this project results in methods that permit multiple sizes and types of turbine meters to be calibrated in viscous PGW and then used at high accuracy in hydrocarbons, the Army will be able to shift to environmentally friendly calibration fluids at many calibration locations. The cost savings, system design simplifications, and safety improvements will be significant. Army calibration laboratories would also eliminate a significant source of hazardous waste, a goal which is worthwhile for its own sake.

The theoretical and mathematical aspects of this project may well result in more than improved methods for analyzing data.

This is a work in progress. Watch for future papers.

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John Ball, University of Alabama in Huntsville / SMAP Center, US Army Product Director for Test, Measurement, and Diagnostic Equipment Calibration Sets Program, Redstone Arsenal, (256) 313-0352, john.m.ball@us.army.mil.

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What's Below the Iceberg: Determining the True Cost of Ownership of Test and Measurement Equipment

Duane Lowenstein
Agilent Technologies

Understanding the true cost of ownership of an asset is always hard, for Test and Measurement equipment, even harder. This difficulty is due to variables like calibration, technological life span, depreciation and a number of others. Determining what variables are needed and how to financially organize them is similar to filling out your taxes. Like your taxes, all the numbers are probably known, but where to find them and how to plug them in is the difficult part. With new tax software now most people can fill out their own tax returns less painfully. This paper will take a similar approach for understanding the true "cost of ownership" of your Test and Measurement equipment. It will develop a model that will allow a repeatable approach in understanding the Capital and Operational costs over an asset's total life from purchase to disposal. It will break down the different elements that make up the costs including acquisition, maintenance, support and others, ultimately helping you understand how different factors sway the sensitivity of the total cost to your bottom line.

Introduction

If you do an internet search on Total Cost of Ownership (TCO), you will get a list of millions of sites that reference the term. Some are relevant, though, most are not. Even after looking at the relevant sites, they leave you with more questions than answers. The sites are very good at laying out the framework, but they leave you hanging when it comes to implementing the calculations. This gap between theory and practicality reminds me of the process of manually doing your income taxes on the IRS's paper forms.

The IRS's 1040 forms lay out a very comprehensive, yet complicated, process for determining your tax liability. With very few inputs, one can determine an answer. What makes the process so complicated is the amount of manipulation that is done with the inputs on the different lines and forms. And much like a word problem in math class, making a wrong assumption or an incorrect calculation will cause a chain of false answers. A secondary effect is the inability to understand how the combinations of inputs will ultimately change your liability. An example of this would be determining how much deductions will affect your overall taxes; some have 2% thresholds of adjusted income and some are affected by the alternative minimum tax laws. The bottom line is that you really do not know the answer until you are done, and even then you never know if it is really correct.

Determining TCO has the same dynamics and complexity. Although there are a finite set of numbers that determine the answer, the calculations, assumptions and manipulations of the variables not only make the process complicated, but it will also make the answers very different depending on the process by which the answer is determined. By reducing the number of variables to those that are most relevant and minimizing the manipulation of the model, one can come up with a simple process that can be both repeatable and relevant to understanding the TCO of any test and measurement asset [1].

Defining the TCO

For simplicity, the TCO is defined as the total outlay of money for the ability to own and maintain an asset over a given period of time. There are several assumptions to this definition. The first is the word "own." We consider the cost of "owning" an asset as the monies it takes for the exclusive right to use that asset. Therefore, the purchase, lease or rental of the asset is all included in the definition. Similarly, the word "maintain" is not just maintenance and calibration; it also includes any other categories of monies that are spent because one owns the asset—for example, floor space, power consumption, taxes, etc.

With this definition, the number of variables that are needed to be determined is finite. In fact there are only three variables that are needed. The easiest is the time period, the estimated period of time in which the asset will be "owned" and "maintained." This is different than just the time period that the asset will be used, which is a common mistake when determining the TCO. The fact is that whether an asset is being used on a production floor or sitting in a closet, both have many similar costs associated with them when determining TCO.

The second easiest variable is the "own" cost. This should be the cost over the defined time period. The biggest difference when looking at this cost is whether it was bought with capital or by other means. Renting, leasing or using customer/government furnished equipment all have a simplified expense to them for acquisition cost. The main advantage of buying equipment with capital is its residual value or trade-in value. Depending on the make, model and age this can vary and can somewhat be predicted using historical data. Understanding an asset's residual value will allow you to realize that sometimes paying more upfront can give you a lower TCO. To use a car analogy, for example, if you had a 2006 Chevrolet Malibu with 75,000 miles and a 2006 Honda Accord with 75,0000 miles, both with similar options, according to Kelley Blue Book, you could get up to $5200 more for the Honda. When these two cars were new, the Honda may have cost $2000 or $3000 more, but in the long run, the "own" cost of the Honda would ultimately be lower.

The last and most complicated variable is "maintain." Depending on the resolution of the number, this can become an exhaustive list with many of the items not changing the outcome in any significant way. The trick here is to pick the items that conform to the 80-20 rule; the 20% of the variables that make up 80% of the cost structure in maintaining the asset. For the most part, this list is fairly obvious for test and measurement equipment and usually is a combination of:

- Installation & Setup
- Metrology (e.g. calibration)
- Repair
- Downtime Mitigation (e.g. spares and extra test capacity)
- Training & Education
- Technology Refresh (e.g. code compatibility)
- Facilities (e.g. floor space, electrical)
- Consumables (e.g. cables)

Depending on how the equipment is being used and what it is being used for, the criticality and expense for these items could change for the same type of assets. An example would be the cost of downtime mitigation for a test asset used in a high volume manufacturing line and a similar asset used in a repair depot. The high volume line may be testing a product every minute compared to a depot that may be testing one product per hour. That would mean that for every hour the high volume line was down compared to the depot line, there would be a delay of 59 products per hour not including shipping.

Once these variables are determined, the rest is just plugging in numbers, very much like using a computer program to do your taxes. Table 1 is an example of a framework for the type of numbers one would need to understand the TCO. With these numbers and an understanding of how the assets are used, a set of algorithms can be developed to calculate the TCO with greater than 80% accuracy.

	Product A
Purchase Price	$100,000
Useful Life	8 years
Test Time per DUT (seconds)	75
Throughput (DUT's per week)	4400
Calibration Interval (years)	2
Annual Fail Rate	8%
Annual Contracted Repair Cost	$2,200
Downtime during Repair (days)	2.0
Downtime Mitigation (Reserved Capacity)	4%
Cost for Code Development	$10,000
Resale Value	$25,000

Table 1. Summary of Key Ownership Factors.

The Impact of an Asset's Age on TCO

Despite the simplicity of the above explanation on developing a model to calculate the TCO, the single most important attribute that will determine the TCO is the age of the asset— not just the absolute number, but how all the above variables will change over time. Again using a car analogy, a new car comes with some type of warranty, for example all new 2011 Volvos come with:

- 5 Year Wear & Tear Coverage
- 5 Year Complimentary Factory Scheduled Maintenance
- 5 Years/Unlimited Miles Roadside Assistance

Therefore, for the first five years of owning a Volvo, the only other expense besides the purchasing price is gas and other consumables. The TCO could easily be calculated for the first five years by taking the purchase price and adding it to the estimated cost of gas for the mileage that would be driven; or, purchase price + ((Estimate of miles driven for 5 years/average miles per gallon of gas) * average cost per gallon of gas). So what happens in year six and beyond?

There are several factors that are fairly universal when understanding the TCO of an aging asset. The first is that the older an asset is, the greater probability it will fail or go out of calibration. The failure rate can be determined by using many different statistical tools and benchmarks of historical or similar asset types. Other factors will impact this number like usage, environmental factors and maintenance.

The second factor is the cost of fixing a broken asset. Although most companies keep spare parts, they cannot keep them indefinitely. The cost of keeping spares is expensive, and in many instances, especially electronics, can no longer be manufactured after a certain period of time. Anyone who has tried to get a piece of electronic equipment repaired that was produced prior to 1990 will find that many of the components, mostly "through hole," are no longer manufactured or available.

The third factor is downtime mitigation. This is really a function of the above two factors. If equipment fails more with age, and it's harder to get them fixed over time, then logically the assets would be offline longer. Therefore, there is a cost of either not being able to produce products because the asset is not available, or the cost of having a spare asset that can be used while the other is being repaired. Unlike a car, where the type or model for a rental may not matter, a test and measurement asset needs to be replaced with a spare; it usually needs to be the exact model and configuration with the same software.

Taking all of these factors into account, the TCO model can be expanded to understand the cost over time and include factors that are impacted by age. Figure 1, shows such an example of the capital expense, the "own" variable, and the "maintain" variable over the estimated life of an asset. With this information a company can start developing a strategy for determining what equipment to buy for its individual use using this model.

Developing a TCO strategy

Understanding TCO is the first step to developing an asset strategy. It is required information to make the best economical choices when procuring and maintaining a test and measurement asset base. The fundamental reason for having an understanding of a TCO tool is to ensure that you can measure and/or determine the pros and cons of one strategy versus another. For many companies there are several strategies depending on the business unit or the product portfolios or even different segments of the product development cycle, R&D, production, and repair.

When developing a TCO strategy, one of the most critical elements to understand is that TCO is not all about the purchase price. As discussed earlier in this paper, purchase price is just one element; equally important are the elements that go into the "maintain" variables. Over the last several years, when looking at the "maintain" variables, we have seen that over an 8-10 year life time of some test and measurement assets, these "maintain" variables can range from 40% to 65% of the TCO over the asset's life. This becomes a very important point when developing procurement and calibration and repair strategies. To that end, the GAO published a report in 2003 [2] that studied the tradeoffs of development, procurement and operational and support costs for US Navy platforms. They concluded that ultimately over the lifetime of a Naval vessel, more money could be saved through innovation in operation and

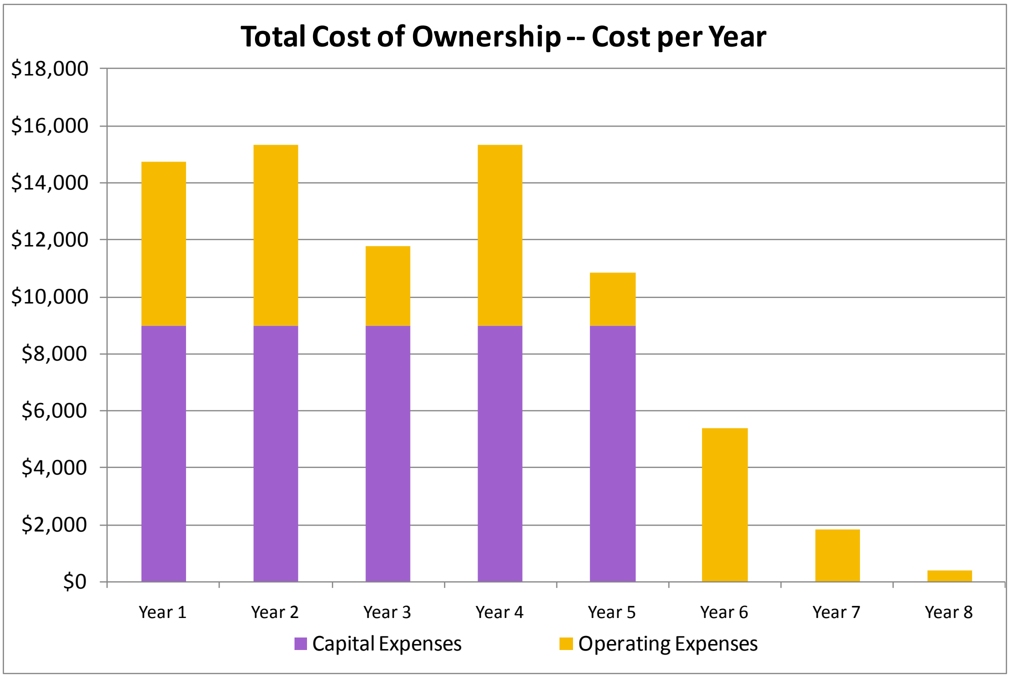

Figure 1. Total Cost of Ownership over time.

support expenses than could be saved in procurement cost. In other words, focusing on the cost of "maintain" variables has a greater impact on the TCO than the cost of "own" variables.

It seems that most procurement groups rarely take this into account and make most of their decisions only on the procurement cost and getting the largest discount possible; thus, possibly adding extra support costs for the asset on other groups that need to maintain the equipment. And consequently, in the long run, adding significant dollars to the overall TCO. To emphasize this dynamic, Figure 2 shows the comparison of the lifetime cost of ownership of two assets. Although Product A is less expensive to purchase, it is more expensive to support. Subsequently, Table 2 breaks down all the costs of the TCO variables. This example hopefully exemplifies how understanding the TCO over the lifetime of an asset can drastically change how a decision could be made.

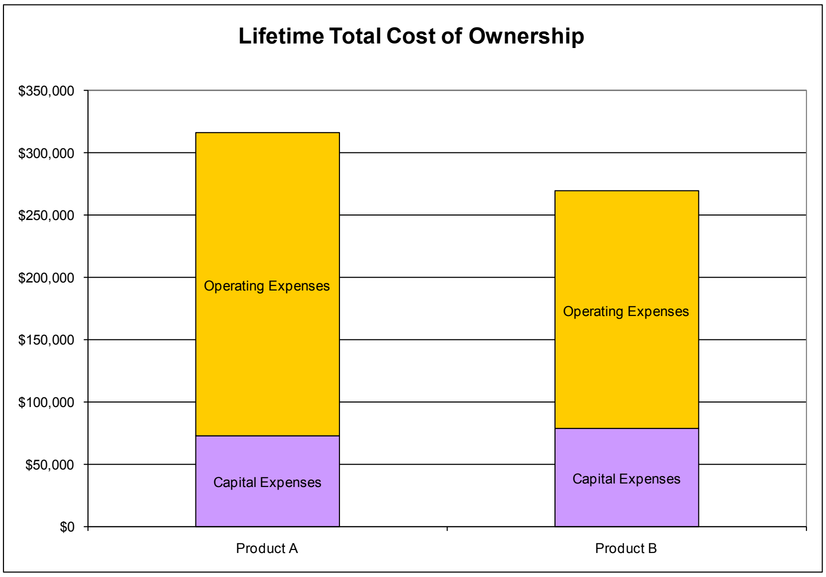

Figure 2. Lifetime Total Cost of Ownership.

Lifetime Total Cost of Ownership		Product A	Product B
Purchase Price		$72,000	$78,000
Operating Expenses			
	Metrology	$170,008	$113,680
	Repair	$46,978	$34,322
	Downtime Mitigation	$7,650	$4,650
	Technology Refresh	$250	$20,000
	Training & Education	$16,000	$16,000
	Energy	$1,680	$1,680
	Floorspace	$230	$230
	Consumables	$480	$480
	Other	$ -	$ -

Table 2. Summary of Lifetime Total Cost of Ownership.

Although this is a simple example, adding other dynamics of how assets are used could even enhance the strategy to drive cost out of ownership costs of an asset base.

Summary

In Summary, understanding the variables that go into the purchasing, maintaining and disposing of your assets could significantly impact your overall cost of doing business. But just as important, it can change how the selection of the assets are made. By developing a model once and ensuring the variables for your individual business are accurate, making the best financial decisions become easy. This creates the ability to model different scenarios, manipulate different variables and ultimately understand the sensitivity and tradeoffs. Much like filing your taxes using a tax program with very few numbers, the program can determine where they need to be on what form and what rules will impact them quickly and accurately. Although in either case you may not like the answer, at least it is repeatable, and you can understand why the answer is what it is.

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Duane Lowenstein, Agilent Technologies, 978-681-2199, Duane_Lowenstein@agilent.com.

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