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THE INTERNATIONAL JOURNAL OF METROLOGY

VOLUME 17, NUMBER 4

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FEATURES

DEPARTMENTS

ON THE COVER: Automated calibration systems: DC-50GHz at Agilent Technologies' calibration laboratory in Petach-Tikva, Israel. (Photo courtesy of Agilent Technologies, Petach-Tikva, Israel.)

CONFERENCES & MEETINGS 2011

Feb 8-10 Human Life Science Test (HuLST) Expo. Koelnmesse, Cologne, Germany. The four fairs under the HuLST umbrella are: Medical Device and Technology Test Expo; Food and Beverage Test Expo; Pharma Test Expo, and Biotech Test Expo. Exhibits and technical presentations at the HuLST Expo cover all types of testing, inspection and quality assurance, as well as contracted service and engineering support. www.hulst-expo.com.

Feb 9-11 The 6th International Gas Analysis Symposium & Exhibition — GAS2011. Beurs-WTC Rotterdam, the Netherlands. Topics include natural gas, LNG, alternative fuels, sampling, process analysis, trace contaminants, gas sensors, metrology, accreditation, chemometrics, safety, health and the environment. Participants from 40 countries. www.gas2011.org.

Mar 7-8 American Society for Precision Engineering Spring Topical Meeting. University of North Carolina, Charlotte, North Carolina. Characterization challenges of freeform surfaces. Information at http://www.aspe.net/meetings/2011_Spring/2011_Spring.html or contact Erika Deutsch-Layne, tel (919) 839-8444.

Mar 14-18 Measurement Science Conference. Pasadena, CA. NIST Seminars Mar 14-15, ASQ Training March 14-15, Tutorial Workshops Mar 15-16, MSC Technical Program Mar 17-18. Topics: Intrinsic Standards, Nano Technology, DC and LF, Microwave, Dimensional, Temperature, Chemical Metrology, Accreditation, Six Sigma, Training, Quality Standards, Automation, Analytical Metrology, Mathematical Analysis, Equipment Management. Visit www.msc-conf.com for more information.

Mar 17-18 Quality and Productivity Management for East African Laboratories. Nairobi, Kenya. http://www.marcusevans.com/marcusevans-conferences-event-details.asp?EventID=17376&SectorID=31. Topics: Laboratory Information Systems (LIMS); Quality Assurance and Quality Control; Accreditation; Method Validation; Maximizing Productivity and Profitability through Lean Laboratory; Decreasing Turnaround Time; Revolutionized Systems to Boost Productivity.

Mar 31-Apr 1 METROMEET: 7th International Conference on Industrial Dimensional Metrology. Bilbao, Spain. Topics: Advances of Micro- and Nanometrology; Measurement Issues of Large Work Pieces; Metrology and Economics; New Developments in Virtual Metrology; Recent Developments in Metrology Software; Challenges of Multi-Sensor Coordinate Metrology; Accreditation and Certification; Future Metrology Trends; Optical and Non-contact Measurement and 3D Systems; Methods, Organisation and Best Practices in Industrial Metrology; Metrology Education; New Developments in Measurement Instruments; Overview of Industrial Process Quality Requirements and Metrology-

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EDITOR & PUBLISHER
CAROL LEHMAN SINGER

CAL LAB
1413 NE 93rd Court
Vancouver, WA 98664
TEL 360-433-2522 • FAX 360-433-2681
office@callabmag.com
www.callabmag.com

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Correction

Our Jul-Aug-Sep 2010 issue incorrectly identified Morehouse Instrument Company's new 2,250,000 lbf force machine as being developed by NPL. The new force device shown above was developed by Morehouse engineer William H. Lane.

(We confused this cover artwork with a future cover with the NPL device, also contributed by Morehouse to announce their new capability of torque measurement to 2kN/m with accuracy to .002%.)

Our sincere apologies to Morehouse and Mr. Lane for the mistake.

EDITOR'S DESK

The End of an Era

Before writing my Editor's Desk this time, I took a few moments to go back and read the first Editor's Desk I wrote in the March/April 1995 issue. That was my first issue of Cal Lab as publisher and I talked about the concept of *carpe diem* — seizing the day. That expression had just become popular through the movie Dead Poet's Society where fictional professor John Keating urges his students to live by that philosophy and not to shrink from challenges, but to embrace them and thereby live lives of passion and devotion to what they believe in. I had been working in the marketing department of Wavetek in San Diego for five years and feeling that, although I had enjoyed the friendships and knowledge I had gained from this industry, I felt unfulfilled as a journalist and writer, which had been my twin passions since childhood.

Suddenly the opportunity to fulfill one of my dreams — publishing a magazine, virtually fell from the sky when the founder of Cal Lab, former *Test & Measurement World* editor Charles Masi was forced to give it up after a few months. I considered that I had never edited or published a magazine before, much less tried to secure advertising commitments or run a business. I was basically a shy writer with a love for the people of this industry and a passion to do something that would benefit the world and enable me to use my creativity, my journalistic instincts and every cell of my brain to build this tiny magazine into a useful media for the exchange of information and further development of the field. I seized the day and stepped into the abyss of an investment in money and energy that I hoped would prove successful. Like thousands of other business owners, I spent the first few months with sleepless nights and immense doubts that I could do this and make it work.

But what I also felt at the time, and many times since, was an incredible sense of excitement and adventure that I had thrust myself into a challenge that was my passion. I was happy from the beginning that publishing Cal Lab would keep me in contact with the incredible people I had met while attending the Measurement Science Conference and NCSL International Symposiums with Wavetek. Not only have those friendships deepened over the years, but I have added so many more from distant lands that I have felt a sense of reward far beyond any monetary one.

The success and survival of Cal Lab has always depended on the support of advertisers and subscribers, and I am so sincerely thankful to those who have supported this endeavor over the years, some for many years. I owe immense thanks to Fluke, Wavetek (now part of Fluke) and Tony Anderson (whose support spanned two companies) for being supporters from the very beginning. Many thanks too to my many other loyal advertisers, excellent authors and my supporters who helped by handing Cal Lab out to customers and colleagues. Finally, huge thanks to my long-suffering, neglected but supportive husband, Paul and my two daughters who grew up thinking Cal Lab was their younger sibling that always seemed to need more time from me than they did.

When I started thinking a few months ago about what I would write in this Editor's Desk, I knew that this would be my last one, and I thought at the time that I would be announcing the end of Cal Lab. Thankfully, I have a much happier announcement — Cal Lab has a new publisher and will continue! I will continue to be involved as an advisor and sometime contributor for the immediate future.

So what are my plans beyond helping the new publisher? Some of you have heard me lament at conferences that my first love and passion was writing, and while I have enjoyed so much publishing and editing and metrology, I have recently longed to return to the wider world beyond metrology and seize a new day as a freelance journalist and fiction writer. If you want to stay in touch csinger@callabmag.com will still work or you can use my new address csinger@webnetmail.net.

With best regards always,

Carol Singer

based Process Improvements; Solutions for In-line Inspection; Uncertainty Traceability and Reliability with CMMs; Sports Metrology. METROMEET, tel +34 94 480 51 83, info@metromeet.org, www.metromeet.org.

Apr 6-8 Conference on Metrological Traceability in the Globalization Age. Paris, France. Presented by CITAC, College Francais de Metrologie, IMEKO. Info: www.citac.cc.imeko.pdf. Contact: philippe.charlet@lne.fr.

Apr 11-13 Quality Conference. Charlotte, NC. Quality Magazine in collaboration with UNC Charlotte and the Charlotte Research Institute. www.qualitymagconference.com.

May 2-5 Fourth Conference on Pressure Measurement together with the **5th CCM International Conference on Pressure and Vacuum Metrology** Berlin, Germany. Info: www.inrim.it/events/docs/CCM%20International%20Conference_Web.pdf. Contact: karl.jousten@ptb.de.

May 12-15 Advances in Applied Physics and Materials Science Congress. Antalya, Turkey. Global forum for researchers and engineers to present and discuss recent innovations and new techniques in Applied Physics and Materials Science. Companies and institutions are also encouraged to showcase their products and equipment in the conference area. Further information at www.apmas2011.org or for questions use info@apmas2011.org.

May 23-24 The 4th International Conference on Metrology: Measurement and Testing in the Service of Society. Jerusalem, Israel. Israeli Metrology Society. Co-sponsored by NCSL International, The Israel Analytical Chemistry Society, Cooperation on International Traceability in Chemistry (CITAC). Topics: Trends in Metrology •Measurement Methods and Validation • Measurement and Test (analytical) Method Transfer • Measurement Uncertainty by Industry •Uncertainty from Sampling • Measurement Uncertainty and the Customer • Metrological Traceability • Traceability of Medical Laboratory Results • Issues between Measuring and Calibration Laboratories • Effect of Quality Results on the Decision Making Process • Conformity Assessment • Interlaboratory Comparisons - What Can Be Learned? • Legal Metrology • Metrology Software • Metrology Ethics • Accreditation for Measurement and Calibration Laboratories. Further conference info at www.isas.co.il/metrology2011.

May 26-27 20th Symposium on Photonic Measurements. Linz, Austria. Info at www.emt.uni-linz.ac.at.

Jun 20-22 Ninth Conference on Advanced Mathematical and Computational Tools in Metrology and Testing. Goteburg, Sweden. Organized by SP Sveriges Tekniska Forskningsinstitut, Euramet, IMEKO, and Chalmer's University of Technology. Deadline for paper abstract submission is February 28, 2011. Visit www.amctm.org for more information.

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Aug 21-25 NCSLI Conference. National Harbor, MD. Conference theme: 50 Years: Reflecting On The Past - Looking To The Future. Info at www.ncsli.org.

Sep 12-14 10th Symposium on Laser Metrology for Precision Measurement and Inspection in Industry. Braunschweig, Germany. Info at www.lasermetrology2011.com. Contact r.tutsch@tu-bs.de.

Sep 27-29 LabAsia 2011. Kuala Lumpur, Malaysia. Info at www.lab-asia.com.

Oct 3-6 Fifteenth International Congress of Metrology. Paris, France. Info at www.metrologie2011.com, info@cfmetrolgie.com, or telephone 33 (0)4 67 06 20 36.

Oct 24-27 Third Metrology Forum. Accra, Ghana. Legal metrology; accreditation; temperature, volume, mass; measurement uncertainties; interlaboratory comparisons. www.ac-metrology.com/METROLOGYFORUM2011.

SEMINARS Asia

Feb 15-18 2011 Comprehensive Hydrocarbon Measurement. Singapore. CEESI. www.ceesi.com.

Feb 21-23 2011 Fundamentals of Ultrasonic Flowmeters. Singapore. CEESI. www.ceesi.com.

Feb 23-25 2011 Singapore Ultra-Sonic Meter Measurement Training Series. Singapore. CEESI. www.ceesi.com.

SEMINARS: ISO17025

May 11-13 Understanding ISO 17025. Technology Training, Inc., toll free 866-884-4338, brian@ttiedu.com, www.ttiedu.com.

SEMINARS: Dimensional

Jan 27-28 Gage Calibration and Repair. Kansas City KS. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

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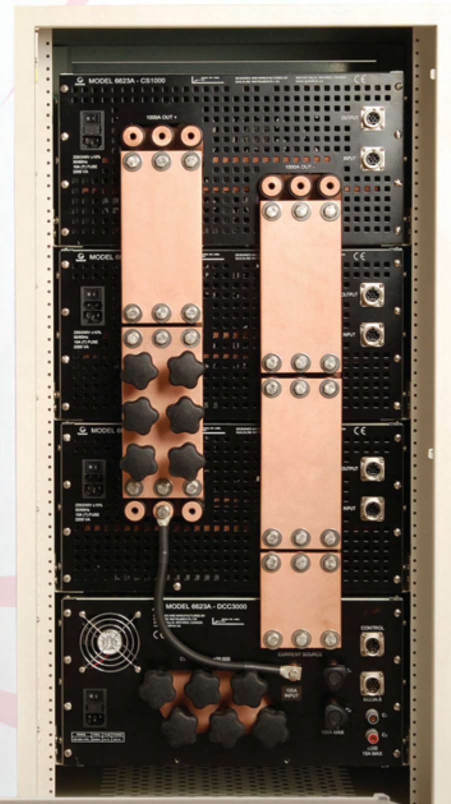

Model 6623A-150 (above) is only slightly larger than 5" in height. The 6623A-300 adds only 2" to total height (7"). Both units are capable of operating off 120VAC line voltage.

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May 23-26 Dimensional and Thermodynamic Calibration Procedures. Technology Training, Inc., toll free 866-884-4338, brian@ttiedu.com, www.ttiedu.com.

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SEMINARS: Electronics

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SEMINARS: Flow

Sep 21-23, 2011 Flow Measurement and Calibration. Munich, Germany. (during Octoberfest) In English. www.trigasfi.de/html/en_seminars.htm.

Feb 15-18 2011 Comprehensive Hydrocarbon Measurement. Singapore. CEESI. www.ceesi.com

Feb 21-23 2011 Fundamentals of Ultrasonic Flowmeters. Singapore. CEESI. www.ceesi.com.

Feb 23-25 2011 Singapore Ultra-Sonic Meter Measurement Training Series. Singapore. CEESI. www.ceesi.com.

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Aug 1-4 Met 301 Advanced Hands-on Metrology. Seattle, WA. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

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Oct 24-27 Met 101 Basic Hands-on Metrology. Seattle, WA. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Oct 31-Nov 3 Met 301 Advanced Hands-on Metrology. Seattle, WA. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

SEMINARS: Measurement Uncertainty

Mar 29-31 Met 302 Introduction to Measurement Uncertainty. Seattle. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Apr 4-7 CLM 303 Effective Cal Lab Management. Seattle. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

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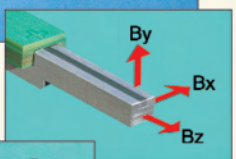
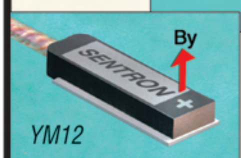
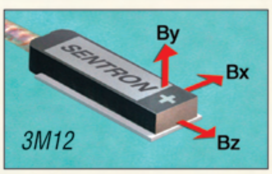


3RTP



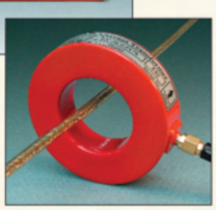


Application	Product	Range	Resolution	Bandwidth
Linear field sensing. Non-contact measurement of position, angle, vibration, current. Small size, low power.	CSA-1V 1-axis Hall IC, SOIC-8	± 5mT	~ 10µT	dc to 100kHz
	2SA-10 2-axis Hall IC, SOIC-8	± 40mT	~ 50µT	dc to 10kHz
High sensitivity and accuracy for low fields. Survey and monitor sites for magnetically sensitive equipment.	MAG-01 1-axis Fluxgate Teslameter	± 2mT	± 0.1nT	dc to 10Hz
	MAG-03 3-axis Fluxgate Transducer	± 1mT	± 0.1nT	dc to 3kHz
Linear field measurement. Feedback control. Quality control. Magnet mapping. Unique 3-axis at one point.	YM12 1-axis Hall Transducer	± 2T	± 12µT	dc to 5kHz
	3M12 3-axis Hall Transducer	± 2T	± 20µT	dc to 1kHz
	3RTP 3-axis Hall Transducer	± 2T	± 100µT	dc to 10kHz
Hand-held 3-axis for fringe field mapping, quality control, safety monitoring.	7025 3-axis Hall Teslameter	± 2T	± 10µT	dc
Precision field measurement and control. Laboratory and process magnets. Analytical instruments.	DTM-133 1-axis Hall Teslameter	± 3T	± 5µT	dc to 10Hz
	DTM-151 1-axis Hall Teslameter	± 3T	± 0.1µT	dc to 3Hz
Calibration of magnetic standards and sensors. Very high resolution and long-term stability.	2026 total field NMR Teslameter	0.04 to 20T	± 0.1µT	dc
	FW101 total field NMR Teslameter	1.4µT to 2.1T	± 0.5nT	dc
Precision flux change measurement.	PDI 5025 Digital Voltage Integrator	40 V.s	± 2E-8V.s	1ms to 2^{23}ms

Conversion of magnetic flux density (B) tesla to gauss: 0.1nT = 1µG, 100µT = 1G, 1T = 10kG

Electric Current (isolated measurement)

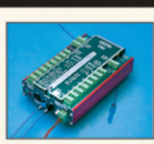
CT-36



Application	Product	Range	Resolution	Bandwidth
High sensitivity for low currents, currents at high voltage, differential currents.	IPCT Current Transducer	± 5A	± 10µA	dc to 4kHz
Linear sensor for low-noise, high accuracy, high stability power supplies or amplifiers.	867-400 Current Transducer	± 400A	< 4ppm	dc to 100kHz
	866-600 Current Transducer	± 600A	< 4ppm	dc to 100kHz
Instruments for development, quality control, calibration, precision power measurement.	860R Current Transducer	to ± 2000A	< 5ppm	dc to 300kHz
	862R Current Transducer	to ± 25kA	< 5ppm	dc to 10kHz
	866R 6-channel Current Transducer	to ± 600A	< 10ppm	dc to 100kHz
Passive current transformer for rf and pulse current. Low loss, high frequency.	CT Current Transformer	to ± 10kA	to 5V/A into 50 ohm	to 2GHz
	ICT Charge Transformer	to ± 400nC	± 0.5pC	1µs to <1ps

Fiber-Optic I/O

FTR



CNA

Application	Product	Range	Resolution	Bandwidth
Input/Output modules that can be placed locally at the transducer or controlled unit. For high voltage, high noise environments. RF signal transmission.	FTR RS-232-C link			50 to 40 kB
	CNA Digital & Analog link	± 100mV to ± 10V	16-bit	dc to 30Hz
	p2p Digital & Analog link	- 20dBm to + 20dBm	< 25dB for 0dBm	dc to 3GHz

June 27-30 Measurement Uncertainty. Technology Training, Inc., toll free 866-884-4338, brian@ttiedu.com, www.ttiedu.com.

Sep 12-15 CLM 303 Effective Cal Lab Management. Seattle. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Nov 8-10 Met 302 Introduction to Measurement Uncertainty. Seattle. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

SEMINARS: Software

Feb 28-Mar 4 Met/Cal Database and Reports. Seattle. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Mar 7-11 Met/Cal Procedure Writing. Seattle. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Apr 11-15 Advanced Programming Techniques. Seattle. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

May 16-20 Met/Cal Procedure Writing. Research Triangle, NC. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Jun 6-10 Met/Cal Database and Reports. Seattle. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Jun 13-17 Met/Cal Procedure Writing. Seattle. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Sep 19-23 Met/Cal Database and Reports. Seattle. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Sep 26-30 Met/Cal Procedure Writing. Seattle. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Oct 3-7 Advanced Programming Techniques. Seattle. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

SEMINARS: Vibration

Feb 28-Mar 3 Fundamentals of Vibration for Test & Design Applications. Technology Training, Inc., toll free 866-884-4338, brian@ttiedu.com, www.ttiedu.com.

Mar. 14-17 Mechanical Shock and Modal Test Techniques. Technology Training, Inc., toll free 866-884-4338, brian@ttiedu.com, www.ttiedu.com.

Apr. 11-15 Fixture Design for Vibration and Shock Testing DTS. Technology Training, Inc., toll free 866-884-4338, brian@ttiedu.com, www.ttiedu.com.

June 1-3 Fundamentals of Vibration for Test Applications. Technology Training, Inc., toll free 866-884-4338, brian@ttiedu.com, www.ttiedu.com.

NPL United Kingdom Manufactures World's Most Stable Commercial Microwave Oscillator

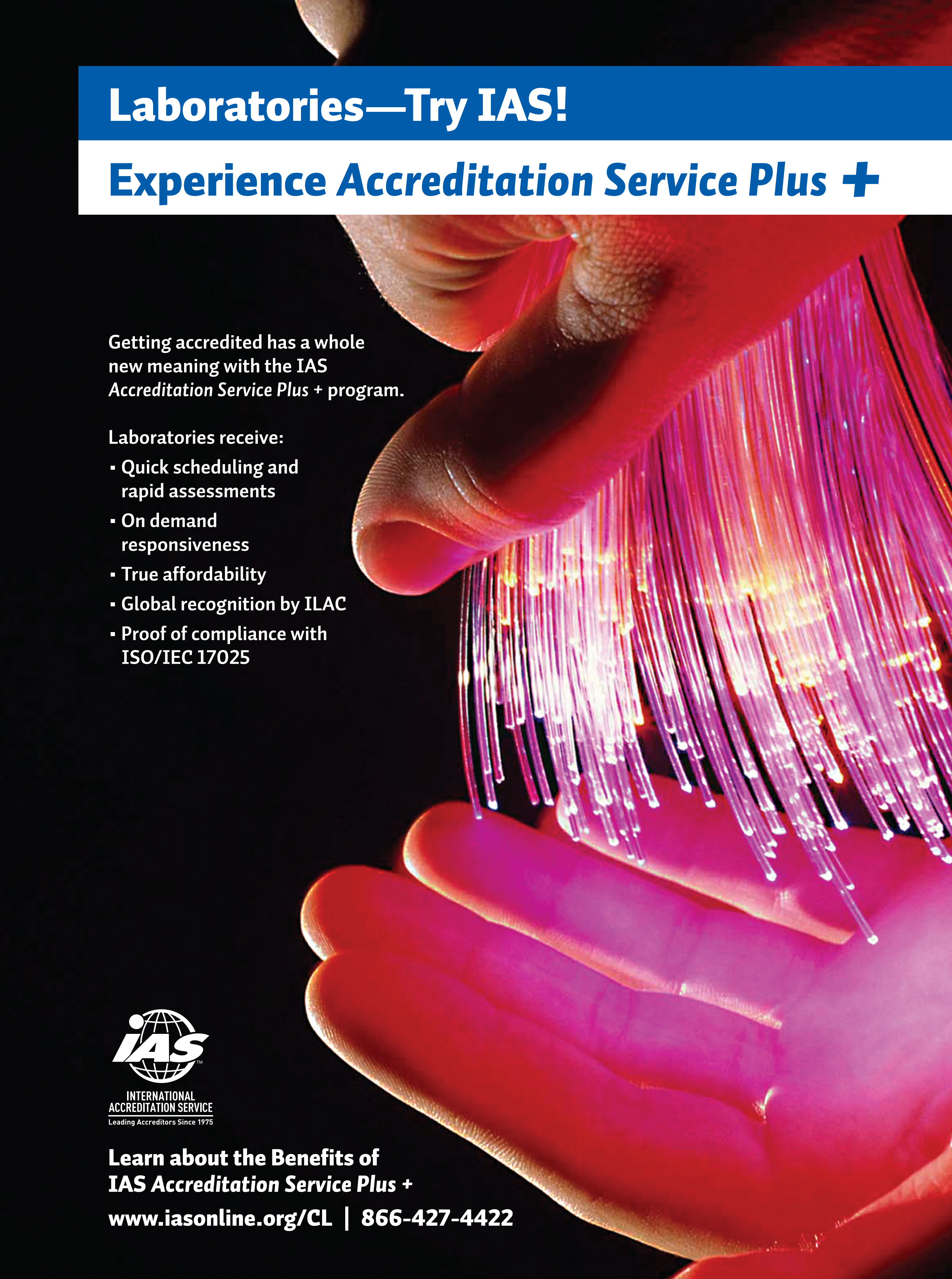
The National Physical Laboratory, United Kingdom (NPL) has just completed the manufacture of the world's most stable commercial microwave oscillator, a cryogenic cooled sapphire oscillator better than one part in 10^{14} over time intervals of 1 second to 1000 seconds. The project, which was funded by the European Space Agency, was carried out by a leading group of quantum physicists from NPL, Femto-ST and TimeTech. Oscillators based on cryogenic sapphire resonators can supply the levels of microwave phase noise and frequency stability required for advanced time-and-frequency applications such as: Doppler radar, global navigation satellite systems (GNSS), deep space navigation, very-long-base-line interferometry (VLBI), gravitational wave detection, tests of fundamental physics, primary frequency standards and the synchronization of advanced linear particle accelerators and their associated x-ray free-electron lasers.

The stability of this oscillator derives from a cryogenically cooled resonator containing a ring of high-purity monocrystalline sapphire that supports a "whispering-gallery" electromagnetic mode with a Q-factor in the order of 1 billion. This mode provides a frequency reference to which the oscillator is locked by way of a Pound servo. The oscillator is cooled and maintained at cryogenic temperatures using a two-stage pulse-tube refrigerator and at these low temperatures, the frequency of the whispering gallery mode exhibits a turning point as a function of temperature. This turning point, combined with the high Q-factor of the whispering gallery mode, provides extreme frequency stability and low phase noise, characterstics that have the ability to greatly improve advanced time and frequency applications.

For further information: Robert Elliot, tel 020 8943 6332, robert.elliott@npl.co.uk.

NIST Team Develops Lowest Temperature Scanning Probe Microscope

A research team from the National Institute of Standards and Technology (NIST), the University of Maryland, Janis Research Company, Inc., and Seoul National University, has designed and built the most advanced ultra-low temperature scanning probe microscope (ULTSPM) in the world.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Detailed in a recent paper published in *Review of Scientific Instruments*, the ULTSPM operates at lower temperatures and higher magnetic fields than any other similar microscope, capabilities that enable the device to resolve energy levels separated by as small as 1 millionth of an electron volt. This extraordinary resolution has already resulted in the discovery of new physics.

The NIST team had to overcome many technical challenges to achieve this level of precision and sensitivity, according to Young Jae Song, a postdoctoral researcher who helped develop the instrument at NIST. Past designs used mechanical systems to move the probe tip that did not work over a wide range of temperatures. Researchers overcame this by creating piezoelectric actuators that expand with atomic scale precision when voltage is applied.

For vibration control, the group built the ULTSPM facility on top of a separate 110-ton concrete block buffered by six computer-controlled air springs. The ULTSPM, itself, sits on a 6-ton granite table, isolated from the concrete block by another set of computer-controlled air springs.

To achieve the ULTSPM's ultra low operating temperature of 10 millikelvins, the team designed a low noise dilution refrigerator to supplement the device's chilly 3-meter deep, 250-liter liquid helium bath. Because electromagnetic radiation entering through wires and cables can heat up the microscope, the ULTSPM lab is nested inside a separate, electromagnetically shielded room.

In order to ready new samples and probes without disturbing ongoing measurements, experimenters built a vacuum-sealed "railroad" system that they can disconnect from the chamber.

"The ability to create these kinds of experimental conditions opens up a whole new frontier in nanoscale physics," says Robert Celotta, founding director of the NIST Center for Nanoscale Science and Technology. "This instrument has been five years in the making, and we can't help but be excited about all the discoveries waiting to be made."

The research team includes Y. Song, A. Otte, V. Shvarts, Z. Zhao, Y. Kuk, S. Blankenship, A. Band, F. Hess and J. Stroscio. Their paper is titled "A 10 mK Scanning Probe Microscopy Facility.

PTB, Germany Develops Nanoparticle Measurement Method

The Physikalisch-Technischen Bundesanstalt (PTB), Germany, has developed a novel measuring method for nanoparticles. It unites the advantages of various types of electron microscopes: Scientists upgraded a scanning electron microscope (SEM) with a transmission detector. This upgrade is far more cost-saving than a transmission electron microscope (TEM). With the aid of the transmission detector, the particle boundaries can in many cases be represented more accurately than with a conventional SEM.

A problem with the highly accurate measurement of nanoparticles is the precise determination of the particle boundary which is blurred in electron microscopic images. With which grey scale value does the particle begin and which image pixel still belongs to the background? A program developed at PTB calculates the detector signal for a particle of a determined size, for

example 150 nm, and thereby takes into account the interactions of the electrons with the particle and the characteristics of the detector. Then a comparison is made. If the calculated signal agrees with the measured signal, then it is possible to make conclusions about the real size of the investigated particle from the simulation. If not, then the calculation is continued with another particle size, for example, 151 nm, until there is an agreement between the two signals.

PTB scientists investigated samples from the material classes of metals, ceramics and plastics and it was possible to show that the detector signal changed along with the material properties. Thus, the electrons interact, for example, with very dense gold differently than with latex, which is less dense. The customary approach, to use the same criterium for all particles for the data evaluation, regardless of which material it is and how large they are, thus has its weaknesses.

In order to take into account both the size as well as the material of the particles, PTB has developed an automatic evaluation. On the basis of the simulation results, it calculates for each individual particle an individual detector signal for the particle rim. This enables a precise size determination to be made, which is adjusted to the respective particle. In spite of this time-consuming procedure it is possible to evaluate several hundred micrographs in a few minutes.

PTB scientists have additionally developed a method to be able to automatically take many nanoparticle pictures successively. Thus, they are now able to characterize a sample within one day by measuring and evaluating up to some thousand particles.

The novel PTB measuring method could contribute to the production of certified reference materials within the European Union. Reference materials serve to compare all measurements made Europe-wide with a defined standard. Only in this way is it possible to standardize measuring results of various laboratories.

For further information: Tobias Klein, PTB Working Group 4.22, Quantitative Microscopy, tel +49 531 592-4229, tobias.klein@ptb.de.

Revised Recommended Practice Helps Boost Particle Counting Accuracy

A technology developed at PTB will be utilized for the KATRIN experiment which is aimed at determining the neutrino mass: after the example of PTB's standard voltage divider, a new precision high-voltage divider for direct voltages has been designed which allows a decisive measurand of the neutrino experiment to be determined with an uncertainty of less than 2 µV/V.

Neutrinos are the lightest elementary particles. They are not completely massless as has meanwhile been shown by many neutrino oscillation experiments.

At the Karlsruhe Institute of Technology (KIT), the KATRIN (KArlsruhe TRItium Neutrino) experiment will now be conducted to determine the neutrino mass – for the first time directly and independent of the model – with an uncertainty of up to 0.2 eV. The technology developed for that purpose now allows measurements to be performed with an accuracy which is up to 10 times higher than before. This will be the first time it is possible to use the determination of the neutrino mass to derive a statement regarding the influence of neutrons in the development of the universe.

Neutrinos are produced in the β-decay of a neutron into a proton, an electron and a (electronic anti-) neutrino. In the case of KATRIN, tritium with a half-life of 12.3 years decays into a stable helium isotope. The decay energy of 18.6 keV corresponds (according to $E = mc^2$) to the known proton and electron rest masses and to the variable – but measurable – kinetic energy of the electrons in particular.

In the KATRIN experiment, the energy of the fastest electrons will now be measured for three years via the electrostatic analysis potential of the main energy filter at the final point of the tritium-β-spectrum.

If a diminutive amount of energy is missing, this would correspond to the mass of the neutrino. For the measurement, the potential difference between the source and a special electrostatic spectrometer is monitored as exactly as possible. At the Institute for Nuclear Physics of Münster University, a voltage divider for direct voltages up to 35 kV, which utilizes the principle of a 100 kV standard voltage divider developed at PTB, has been designed in cooperation with PTB. In a shielded and temperature-controlled, gas-insulated container, the load-dependent drift of the divider ratio was reduced by selection of the divider resistances. The very low temperature coefficients are achieved in this way then furnished with an additional temperature stabilization to ± 0.2 K – an extremely stable divider ratio. The behaviour in the case of loading also turned out to be excellent so that the uncertainty of the divider ratio at 18 kV is smaller than 2 µV/V (k = 2) and thus remains below the limiting value of 3 µV/V demanded for KATRIN.

For further information: M. Schmidt, matthias.schmidt@ptb.de, tel +49 531-592-2325.

NIST Develops Chemical Analysis Based on Quartz Crystal Pitch

A new chemical analysis technique developed by a research group at the National Institute of Standards and Technology (NIST) uses the shifting ultrasonic pitch of a small quartz crystal to test the purity of only a few micrograms of material. Since it works with samples close to a thousand times smaller than comparable commercial instruments, the new technique should be an important addition to the growing arsenal of measurement tools for nanotechnology, according to the NIST team.

As the objects of scientific research have gotten smaller and smaller—as in nanotechnology and gene therapy—the people who worry about how to measure these things have been applying considerable ingenuity to develop comparable instrumentation.* This new NIST technique is a variation on thermogravimetric analysis (TGA). A sample of material is heated, very slowly and carefully, and changes in its mass are measured as the temperature increases. The technique measures the reaction energy needed to decompose, oxidize, dehydrate, or otherwise chemically change the sample with heat.

TGA can be used, for example, to characterize complex biofuel mixtures because the various components vaporize at different temperatures. The purity of an organic sample can be tested by the shape of a TGA plot because, again, different components will break down or vaporize at different temperatures. Conventional TGA, however, requires samples of several milligrams or more of material, which makes it hard to measure very small, laboratory-scale powder samples—such as nanoparticles—or very small surface chemistry features such as thin films.

What's needed is an extremely sensitive "microbalance" to measure the minute changes in mass. The NIST group found one in the quartz crystal microbalance, essentially a small piezoelectric disk of quartz sandwiched between two electrodes. An alternating current across the electrodes causes the crystal to vibrate at a stable and precise ultrasonic frequency—the same principle as a quartz crystal watch. Added mass (a microsample) lowers the resonant frequency, which climbs back up as the microsample is heated and breaks down.

In a paper published by *Analytical Chemistry* (online Nov. 16, 2010), researchers E. Mansfield, A. Kar, T.P. Quinn and S.A. Hooker describe their technique in "Quartz Crystal Microbalances for Microscale Thermogravimetric Analysis." The NIST materials science group demonstrates that their microbalance TGA produces essentially the same results as a conventional TGA instrument, but with samples about a thousand times smaller. They can detect not only the characteristic curves for carbon black, aluminum oxide and a sample organic fluid, but also the more complex curves of mixtures.

New IEST Guide for Calibrating and Characterizing Optical Particle Counters

A newly updated Recommended Practice (RP) from the Institute of Environmental Sciences and Technology (IEST) provides guidance for calibrating and characterizing the performance of optical particle counters (OPCs) that detect and measure the size of single particles in air and other gases. *IEST-RP-CC014.2: Calibration and Characterization of Optical Airborne Particle Counters* presents a standardized calibration methodology to minimize variability among different OPCs. This is important because contamination control professionals often need to use different OPCs operating at different locations or different OPCs at the same location at different times, but they must then contend with discrepancies that arise from measurement variability among those OPCs. Applying a standardized calibration methodology helps users obtain more reliable data from OPCs — data that are used to verify cleanroom and clean device classification, to characterize air filter performance, to verify installed filter system integrity, and to characterize particle emissions from potential contamination sources.

For more information about the new RP or to order a copy, visit the IEST website at www.iest.org or contact IEST by e-mail at information@iest.org or call (847) 981-0100.

IAS Becomes Accreditation Body Member of IAF

International Accreditation Service (IAS) has been accepted as an accreditation body member of the International Accreditation Forum (IAF). IAS membership in the IAF will increase recognition and facilitate acceptance of IAS accredited product certification agencies' reports in over 50 countries.

Membership in IAF reflects IAS's commitment to the further development and implementation of accreditation programs that meet the international standards and guides, which are endorsed by IAF. As part of membership, accreditation bodies must declare their intention to join the IAF Multilateral Recognition Agreement (MLA), recognizing the equivalence of other members' accreditations to their own.

Accreditation body membership of IAF is open to organizations that accredit certification programs for products, services, quality programs, environmental management systems, personnel, and other similar forms of conformity assessment.

The International Accreditation Service (IAS) is a nonprofit, full-service accreditation body and a subsidiary of the International Code Council (ICC). IAS accredits product certification agencies, building departments, third-party building department service providers, special inspection agencies, inspection programs for metal building manufacturers, fabricator inspection programs, testing and calibration laboratories, inspection agencies, training agencies, curriculum developers, and field evaluation bodies. IAS is signatory to several international mutual recognition arrangements (MRAs), which facilitates acceptance of its accreditation certificates around the world.

The International Accreditation Forum, Inc. (IAF) is the world association of Conformity Assessment Accreditation Bodies and other organizations interested in conformity assessment in the fields of management systems, products, services, personnel, and other similar programs. Its primary function is to develop a single worldwide program of conformity assessment that reduces risk for business and its customers by assuring them that accredited certificates may be relied upon. Accreditation assures users of the competence and impartiality of the body accredited. IAF members accredit certification or registration bodies that issue certificates attesting that an organization's management, products, or personnel comply with a specified standard (called conformity assessment).

More information about IAF can be found at www.iaf.nu/.For more information about the IAS Product Certification Agency Accreditation Program, visit the IAS website at www.iasonline.org.

Fluke Corporation Announces Calibration Products Consolidation

Fluke Corporation has announced the consolidation of its six calibration product lines under a single logo — Fluke Calibration. The change represents the unification of Fluke Calibration's measurement disciplines, including electrical, RF, temperature, pressure, flow, and calibration software. Product lines that will be under the new brandname include Ruska, Pressurements, Hart Scientific, and DH Instruments. This initiative will bring customers a variety of benefits, including:

- Coordinated pre- and post-sales support and training programs, and better communications that make it easier to get help and answers when customers need them.
- A single, global Fluke Calibration website with product and application information about all things calibration, making it easier to find information about calibration products and applications.
- A more unified calibration software platform that provides increased convenience for labs that perform calibrations in multiple disciplines and makes it easier for calibration technicians to learn software across disciplines.
- More new products, faster.

New Products introduced by Fluke Calibration at the August NCSL International Workshop and Symposium include:

Electrical Calibration —

• 5080A Multi-Product Electrical Calibrator: High compliance calibrator for demanding electrical workload including analog and digital instruments.

Temperature Calibration —

• 1594A/1595A Super-Thermometers: With "Ratio Self-Calibration," an unmatched combination of accuracy, reliability, and usability.

• 1551A/1552A Stick Thermometers: Intrinsically safe, portable, and accurate to ± 0.05 °C - the perfect replacement for mercury-in-glass thermometers.

Calibration Software —

• Manual MET/CAL® Calibration Management Software: The easy, efficient way to collect, store and report calibration data.

• COMPASS® for Pressure Version 3.0 Pressure Calibration Management Software: Universal platform for automating pressure calibration

RF Calibration —

• 9640A-LPNX RF Reference Source: The core of a RF calibration system, maximizing utility and efficiency. Now with superior phase noise performance, optional frequency counter, and wide-offset phase noise filter accessory.

Flow Calibration —

• molbox 1+ Flow Terminal: ± 0.125 % of reading - lowest uncertainty for gas flow calibration.

Pressure Calibration —

• E-DWT-H Electronic Deadweight Tester: Hydraulic deadweight tester performance with digital measurement convenience.

- PPC4 Pressure Calibrator: Premium performance, maximum versatility, outstanding reliability.

For more information on Fluke calibration products, visit Fluke Calibration Instruments at http://us.fluke.com/fluke/usen/Products/Calibration-Instruments.htm or contact Fluke Corporation, tel 800-760-4523.

Agilent Technologies Announces PXI Digital Multimeters

Agilent Technologies Inc. has introduced two digital multimeters (DMMs) to complement its growing family of PXI products. These new 6.5 digit PXI DMMs offer the industry's highest measurement speeds within their price range, along with excellent accuracy and stability. Test engineers in aerospace, defense, electronic manufacturing and automotive industries now have an alternative when designing their mission-critical PXI test systems.

The M9182A 6.5 digit DMM and M9183A 6.5 digit enhanced-performance DMM measure common parameters such as DCV, DCI, ACV, ACI, 2- and 4-wire resistance and temperature. Each offers 30 parts-per-million basic DCV and 300 parts-per-million basic ACV 1-year accuracies and inputs up to 300 volts. The DMMs deliver 4,500 readings-per-second and 20,000 readings-per-second, respectively. These fast reading speeds translate into higher test system throughput and lower cost of test.

The M9183A enhanced-performance DMM is capable of additional measurements, such as capacitance. This may reduce the need for additional instruments in a test rack, conserving rack space and budget. Both DMMs are compatible with PXI, PXI Hybrid, and compactPCI instrument mainframes, including Agilent's recently announced PXI mainframe products.

Each DMM ships with a full suite of software to enable easy system integration regardless of what software environment end-users have on their PCs. An intuitive software front panel enables DMM set-up, measurement and system troubleshooting without programming. The DMMs include IVI-COM, IVI-C, and LabVIEW G-drivers that are compatible with C++, Visual Basic, NI LabVIEW, and many other PC software environments.

Prices for the Agilent M9182A 6.5 digit DMM start at $1,395. The pricing for the Agilent M9183A 6.5 digit enhanced DMM starts at $2,095. Both instruments are available for order, with shipments beginning in February, 2011.

For more information on Agilent's new PXI DMMs, go to www.agilent.com/find/PXI-DMM.

NEW PRODUCTS AND SERVICES

A2LA Announces Information Technology Program

A2LA is proud to announce a new program for Information Technology testing laboratories that tests software designed to generate the Calibration and Measurement Capability (CMC) claims placed on an accredited organization's Scope of Accreditation. The new program was developed to expand A2LA's current IT testing program to specifically include laboratories that test CMC generating software.

The new requirements may be found in R214 - Specific Requirements - Information Technology Testing Laboratory Accreditation Program. As part of the new program, A2LA has also developed new requirements for end users who elect to utilize the software in lieu of creating traditional uncertainty calculations. These new requirements are found in R205b - Annex to Specific Requirements - Calibration Measurement Uncertainty Software. Both documents are available on our website at www.A2LA.org.

The CMC software is designed for automated measurement processes in which the function of the software is to take the necessary measurements where the calculations and the contributing factor values are generated by the equipment set and other significant contributing factors (environment, repeatability measurements, etc.) necessary to calculate the CMC values in accordance with ISO/IEC Guide 98 "Guide to the Expression of Uncertainty in Measurement" (GUM).

It should be made clear that this program is only applicable to the testing of software that can generate CMC values that support an accredited organization's Scope of Accreditation. It is not intended to be applied to software where the main function is to determine the actual uncertainty of a particular measurement to report to the client or to be a "number cruncher" that simply runs inputs through an equation.

The intent of this new program is to offer an option for those accredited organizations that prefer to rely on CMC generating software rather than traditional uncertainty calculations and it should also allow for greater uniformity of measurement uncertainty claims. In addition, Information Technology testing laboratories gain the benefit of having their procedures validated for calculating the CMC values per the GUM requirements.

It is important to note that, for those organizations that prefer to rely on traditional uncertainty calculations to support the Scope of Accreditation, they may continue to do so even if they use some form of software to simply tabulate and sum manually entered contributors. This new program allows for an option of using CMC generating software solely in lieu of this traditional process.

If you are an organization that currently is testing CMC software and are interested in pursuing accreditation or if you have any questions please contact Mr. Robert Knake at rknake@a2la.org or 301-644-3218.

E+E Offers New Flow Meter for Compressed Air and Gases

The EE771 flow meter from E+E Elektronik measures mass flow or volumetric flow in your supply system with the greatest accuracy. The flow meter can be used effectively to measure the consumption of compressed air, nitrogen, helium, argon, oxygen or other non-corrosive gases.

The design of the new EE771 flow meter is based on the direct thermal mass flow measuring principle. At its heart is an E+E hot-film sensor element proven over several million installations in the automotive industry.

The large 400:1 measuring range ensures precise evaluation throughout the supply system. Even the smallest volumetric flow rates are accurately recorded – an essential prerequisite whether you are calculating usage fees or finding leaks.

The unique mounting concept in combination with a ball valve permits rapid installation and removal of the device that remains operational at all times. That the measuring head can be exchanged in seconds without disconnecting the measuring line is another useful feature for periodic recalibration. The integrated USB interface allows the customer to easily adapt the flow meter to specific tasks.

Two outputs are available and can be configured either as analogue outputs (current or voltage), switching outputs or pulse outputs.

For further information: tel +43 – 7235-605-0, Martin Raab, Fax +43 – 7235-605-8 or www.eplus.com.

ASL U.S. Announces the New F500 Precision Thermometer

The ASL U.S. F500 provides you with high accuracy, dual channel temperature measurement for Platinum Resistance Thermometers (PRT) and exploits the inherent advantages of AC bridge technology to maintain repeatable measurements with unique levels of performance and speed.

The F500 comes with two channels as standard, but four and six channel variations are available with each channel able to work with up to 72 user-defined probes. It can also provide a sequential channel scan with a data logging function that can also be sent to PC or USB Memory Stick.

Using calibrated probes with the F500 you can choose between storing the calibration data into the memory of the instrument or if using ASL 'Smart' probes the data can be reviewed, edited, and stored directly in the probe. The F500 can also generate coefficients from reference temperature / resistance data pairs.

The F500 has 25ohm and 100ohm Internal Standard resistors, and with an extended range of 0-500 ohms is capable of measuring temperature ranges to meet ITS90, CVD, EN60751, & IEC751 standards. Results are delivered via an anti-reflective LCD backlit display with large numeric, Average, Std Dev, Min, Max, and n sample count statistical or graphical information. USB interface as standard, but optional RS232, IEEE or LAN interfaces are also available.

Contact sales@aslus.com or visit www.aslus.com

Starna Offers NIR-Traceable Photometric Linearity Reference

Starna Scientific is now offering near infrared (NIR) traceable photometric linearity reference sets to pharmaceutical Q.A. labs and customer support organizations looking to qualify their NIR systems. Starna's NIR traceable photometric linearity reference sets offer Operational Qualification (OQ) and Performance Qualification (PQ) of the transmittance scale in the NIR using industry standard protocols.

The sets are based on easy to handle, non-consumable Certified Reference Materials for qualifying the NIR Transmittance scale. The wavelength range covered is 1100 to 2850 nm, with a %T (A) range of 1.5 %T (1.82 A) to 61 %T (0.21 A).

Starna's filters are produced in an ISO/IEC 17025 and ISO Guide 34 Accredited environment and are certified traceable to NRC (Canada).

Visit www.starna.com or email sales@starnacells.com for more information.

Evaluating and Documenting Substitution Inspection, Measuring & Test Equipment

Graeme C. Payne
GK Systems, Inc.

Many work environments require conformance to standards for quality management, laboratory quality and technical competence, government regulatory requirements, or legal requirements. These types of standards or requirements contain language requiring use of documented work procedures, and control of those documents. There are many cases where an approved work document, such as a calibration procedure, specifies an item of inspection, measuring and test equipment (IM&TE) that is not available. It is then necessary to substitute a different item of IM&TE in order to accomplish the task. It is important that the organization have an effective process for determining if a proposed instrument is an acceptable substitute for what is listed in the documented work procedure. This discussion focuses on electronic IM&TE but the principles are adaptable to all measurement and test disciplines. The information is applicable to calibration and test laboratories, but also to any organization where measurements are made during the process of producing goods or services. While metrologists have the knowledge, training and experience to determine an acceptable substitute, it is quite likely that a typical worker in industry – even in a technical or engineering role – may not and therefore be unable to make a correct substitution determination. In addition, there is very little published guidance readily available on this subject.

Introduction

Whatever your business (or your parent company's business), you need to have confidence in the measurements that provide the data your business decisions are based on. Part of what gives you that confidence — in addition to calibration, of course — is assurance that the measurements are being made correctly and with instruments that are known to be capable. There are many cases where a documented work instruction specifies a particular item of inspection, measuring and/or test equipment (IM&TE) which, for any of several reasons, is not available for use. We may need to or want to use something else. When working under a defined quality management system, or in a regulated industry where compliance to regulations is mandatory, we need to have a defined process for determining what an acceptable substitute is and for approval of its use. In all other areas of work, it is still a highly recommended good practice.

This information is based on more than 30 years experience in metrology and equipment testing, the requirements of a number of regulations and standards, and other sources. Names of specific companies are not used, because situations could arise in any company or industry. Brands and models of equipment are used only for examples and clarity of explanation and do not imply any endorsement, or that the particular equipment is either the most or least suitable for the described purpose. While IM&TE comes in many forms, it is important to point out that this includes not only traditional inspection and metrology equipment, but also tools that perform a measurement function during the process of being used – like torque wrenches, for example. This paper focuses on electronic IM&TE, because that is where my main experience lies and because the equipment and issues are often more complex than with physical/dimensional measurement equipment. However, the basic principles are applicable to equipment in *all* metrology disciplines.

Every case of IM&TE substitution should be documented. There are several reasons for requiring documentation, including regulatory requirements, quality management system requirements, standards documents (industry, national, international), good work practice, and knowledge preservation.

Substitute IM&TE may also be referred to as "equivalent," "alternate" or similar terms.

Where, When and Why Substitution May Be Required

In most cases, equipment preventive maintenance, repair and calibration requires use of a documented work instruction of some sort. This could be the equipment manufacturer's operating or repair manual, a calibration procedure, an internal work process instruction, or some other type of document. If the organization operates under some kind of quality management system, regulatory authority, or simply follows proven good business practices, the work instructions need to be controlled to some extent, and *actually used* for the applicable tasks. These documents — documented and authorized work instructions — usually include some indication of what IM&TE must be used while performing the tasks.

There are a number of situations where it is not possible to use the IM&TE that is identified in a documented work instruction. The most common reason is that it is not available; it may be out for repair or calibration, broken and beyond economic repair, lost or stolen, never owned by the organization, and so on. If the work is to be done, some substitute equipment or method must be used. The requirements may occur in any type of industry and for a number of reasons, but the problems are more acute when equipment with a long service life is being maintained. Other situations may be requirements of regulatory bodies, requirements of quality management systems, unobtainable replacements, and knowledge preservation. All of these reasons also provide requirements for proper analysis and documentation of the substitution.

Maintaining Long-Life Equipment

There are many types of equipment and facilities that are specifically designed for long lifetimes – decades or more. Examples include many types of industrial plants, power generating plants, aircraft, heavy construction equipment and so on. Some examples:

- The median age of active hydro-electric power generators in the US is 59 years (3,818 generators, range 2 to 120 years). Grand Coulee Dam, on the Columbia River, was opened in 1942 and is still operating. [1]
- The median age of active coal-burning power generators in the US is 44 years (1,392 plants, range 2 to 86 years). [1]
- The median age of active nuclear power plants in the US is 32 years (104 plants, range 14 to 41 years). The Davis-Besse plant in Toledo, Ohio was designed in the late 1960s, opened in 1978 and is still in service. [1]

Grand Coulee Dam, Washington state.

Davis-Besse nuclear power plant, Ohio

- Most operating oil refineries in the United States are over 30 years old. [2]
- Commercial aircraft types made by Boeing and currently operated by the largest US airline fleets include the 737, 737 Next Generation, 747, 757, 767 and 777. [3]

The earliest of these types, the original 737 models, first flew in 1967 and that series was in production for about 33 years. The newest of these types, the 737 Next Generation models, first flew in 1997 and are still in production. Many of the 737-NG components were also used on the original 737 types, so maintenance instructions for them could still date to the 1960s.

The 747 type first flew in February 1969 and is still in production 40 years later. It is easily the most recognizable commercial aircraft in use. There are many passenger, freight and special-use variants of this airframe. The one shown in the photograph, referred to by the US Air Force as a VC-25, is used to transport the President of the United States. The newest variant of this airframe, the 747-8 Super Freighter, made its first flight in the second week of February 2010.

Boeing 747 example (USAF VC-25)

Boeing B-52H

All of these aircraft types – except the first generation 737 and the 757 – are still in production.

- Military equipment can also be long-lived, again especially aircraft. The best-known example is the Boeing B-52. This aircraft was designed in the early 1950s, went into service in the mid-1950s and production ended in 1962. Over 100 are still in active and reserve service, and there are several cases of crew members flying the same aircraft flown by their grandfathers. It is expected to remain in active service for at least another 30 years. [4, 5]

Whenever any of these facilities or aircraft are built, or any other long-life product or facility is created, the maintenance instructions are written at or about the same time as the design is finalized. The maintenance instructions are written with reference to measurement practice and IM&TE *that is current at that time*. When maintaining something that was designed or made 30 years ago (for example) several things have to be considered.

- How much new technology has been invented?
- How much technology has become obsolete?
- How many IM&TE manufacturers have vanished?
- What standards documents have been revised, canceled or created?
- What changes have there been in the SI over that time, and how do they affect the measurements?

Another thing to consider, especially in electronics, is that the typical life cycle of an IM&TE product (concept through production to end-of-support) is often less than 10 years (or 2 years for consumer-grade products!) How many items can you still buy *as new items today* that were listed in the 1969 issues of the Fluke, Hewlett-Packard or Tektronix catalogs when the Boeing 747 made its first flight? What about IM&TE from companies like Leeds & Northrup, Shallcross, Industrial Instruments, Beckman Industrial, Weston or a host of other companies that no longer exist?

Regulated Industries

A number of industries are heavily regulated by government agencies. Examples in the United States are nuclear power (Department of Energy, DOE); aviation (Federal Aviation Administration, FAA); food, drugs & cosmetics (Food and Drug Administration, FDA); workplace health and safety (Occupational Health and Safety Administration, OSHA) and several more.

A common requirement in government regulations is that all maintenance work be performed using the IM&TE specified by the original equipment manufacturer, and that any substitute must be approved by the regulating agency. Another common requirement is that the work instructions be followed exactly – sometimes called verbatim compliance.

Quality Management Systems and Other Standards Documents

The international standard for business quality management systems, ISO 9001:2008, addresses measuring and monitoring equipment in clause 7.6. The use of calibrated equipment is required for all measurements that affect the quality of the product. The same requirement is also found in industry sector-specific adaptations of ISO 9001, such as AS9100, TL 9000 and ISO 13485.

Editions of ISO 9001 prior to the 2008 revision also included a note directing users to ISO/IEC 10012 for guidance on the requirements of a measurement management system. This standard gives the requirements for managing the measurement system of a product realization process from beginning to end. This starts with defining the measurements to be made, what measurements are made at each point of the product realization process, what the instrument operating environment is at each place measurements are made, requirements for validation of the measurement capability of the instruments, requirements for regular metrological confirmation of the instruments as well as calibration (the two are *not* the same), and more. A lot of these requirements are also the same things that need to be considered in determining if one instrument is a suitable substitute for another.

As most people in measurement science know, ISO/IEC 17025 also contains numerous requirements relating to measurements, but specifically applying to calibration and testing laboratories. The same is true of ISO 15189, which applies to medical testing laboratories. Both of these standards also contain the same quality requirements that are in ISO 9001.

A common feature of all of these and other standards documents is the requirement for work procedures or instructions, and that those are part of the controlled document system. In the cases where a work instruction requires a specific item of IM&TE, the work process must be evaluated and the work instruction changed before a substitute item can be used.

Original IM&TE Is Beyond Economical Repair With No Replacement

For a variety of reasons, substitute IM&TE may be required because the original instrument is damaged beyond economical repair and no exact replacement is available. Similarly, the original instrument may be missing with no replacement available. An exact replacement may be unobtainable for any of several reasons.

- The specified model is discontinued and the manufacturer indicates that there is no "direct" replacement.
- The manufacturer of the IM&TE no longer exists.
- The instrument type or measurement technology is obsolete.
- The specified instrument is not available on secondary markets such as alternate manufacturers, used equipment outlets, rental houses, or private sale sites.

In any of these cases a suitable substitute must be determined and documented.

Another Reason Why – Knowledge Preservation

Formal evaluation and documentation of IM&TE substitution is a very important *knowledge preservation* method. In the metrology community we are particularly aware of the acute need for knowledge preservation, because of the shortage of well educated and trained people entering the profession behind us. This problem is an emphasis of the ASQ Measurement Quality Division, several NCSLI Committees and the Measurement Science Conference.

The people that developed older equipment and measurement methods, and the people who learned to use the equipment and implemented the methods, have left or are leaving the workforce. In many cases the knowledge is considered "obsolete" for modern technology; obsolete technology is not considered relevant so it is not taught. Therefore, young people coming into the metrology career field (or any area where maintenance of older equipment is likely) don't know anything about the instruments referred to in older documentation, the acronyms that it was called by, or significant leading characteristics of equipment types, or some of the measurement methods used.

In 2008 I happened across a case where a measuring instrument was referred to by the manufacturer name, model number and the acronym "DVM" – the full name of the acronym was not spelled out anywhere in the maintenance manual used for the work. The request was to use a common handheld digital multimeter (from the same IM&TE manufacturer) as a substitute for AC voltage measurements. The maintenance manual for the unit under test was written in the early 1970s and that company no longer exists. The analyst working on the request contacted the IM&TE manufacturer, and was told that the company never made a "digital voltmeter" with that model number so it must be a misprint. The analyst then asked me for assistance. First, I recognized the equipment listed in the old manual – I have calibrated many of them – and recognized that in this case "DVM" meant Differential Voltmeter, and that this particular model was a DC and AC version. It took a few seconds to get over my surprise that representative of the IM&TE manufacturer did not know what a differential voltmeter (DVM) was, and apparently could not look it up anywhere…of course, it has been about 20 years since a DVM graced the pages of that company's catalog.

An occasional requirement in older manuals is to make a measurement using a differential input amplifier plug-in on an oscilloscope mainframe. A common request is to use a two-channel oscilloscope and it's (A + (-B)) function as a substitute. Unfortunately, this reveals lack of understanding of what a true differential measurement is and what the defining characteristics of a differential amplifier are. This is especially surprising given that most computer data bus systems use differential signals and require differential input instruments to measure them correctly.

Sometimes a test procedure specifies using a VTVM. A common set of questions is what is a VTVM, what does it do, and can I substitute this handheld digital multimeter that I got at the home improvement center? Very often the answer requires first explaining what a vacuum tube is, then the concept of input impedance and the effect on the measured value, and then moving on to the other issues.

For knowledge preservation, continual quality and process improvement, compliance to regulations, and other reasons, proper substitution of IM&TE – and documentation of each one – must be a continuing process. It cannot be a one-shot deal. Why?

First, today's current hot technology will be obsolete and practically forgotten in 30 years – maybe even in 10 years. It is likely that when you retire you will be the last person in your organization who knew anything about it. If the essential knowledge is not recorded somewhere and easily retrievable, it is worthless.

Manufacturers of the equipment that needs maintenance may change it in ways that significantly improve it or alter it, but which do not change the maintenance requirements. For example, a motor may have new case alloys, better bearings, more efficient fans, different formulations of the wire insulation and a host of other improvements. Yet it still requires a periodic insulation resistance test, and they may see no need to change the procedure that was written in the 1950s using equipment made by a company that has not existed since the 1960s. Since then the measurement instruments have drastically changed, safety standards have changed or been created, and there may be new regulatory considerations. Therefore the substitute equipment and the measurement process may have to be evaluated and documented again.

There may be other changes that significantly affect measurements. A fairly recent example is the changes in the SI conventional values of the volt and the ohm at the beginning of 1990, and the changes to the thermodynamic temperature scale at the same time. This can affect a lot of older maintenance instructions, especially if resistance temperature devices or thermocouples are used. I have found that in practical industrial use the changes are not usually important if the old manual referred to IPTS-1968, but I have seen a few processes old enough that they refer to the 1948 temperature scale (ITS 1948) and the differences from that one can be significant.

How to Evaluate and Document a Substitution

You may be fortunate enough to work in an environment where you never have to worry about any of this. All measurement requirements are clearly stated with nominal values and tolerances, and all IM&TE may be identified by generic type and minimum performance capability. In most cases though, it is common to see measurement requirements that are not clear, and IM&TE listed by specific manufacturer and model and with the full performance specifications listed. In many cases those items were the best available at the time instead of the minimum required to make the measurements. Very often there is a statement similar to “use the equipment listed in this table or a suitable equivalent”. The rest of this is detail on how to meet that “or equivalent” requirement.

There are a number of things to consider when evaluating and documenting an equipment substitution:

- What are the requirements of the regulatory or quality system?
- What are the requirements of the documented work instructions?
- What are the details of the work being done?
- What are the characteristics of the original equipment and the substitute equipment?
- How do you compare the equipment and the measurement requirement?
- Does use of the substitute equipment still allow following the work instruction as written?

Evaluation

1. What is the measurement being asked for in the work instruction? If necessary it should be restated in SI units, and in terms of nominal ± tolerance, or as a limit type of measurement (not to exceed, for example.) Examine how the measurement is made – the measurement model and process. Special attention must be paid to temperature measurements. If the work instruction was written before 1990 (and in some cases even after) then the temperature measurements may have to be studied further, especially for thermocouple measurement.
2. What are the characteristics of the instruments specified in the work instruction? What features, functions and ranges are actually used? (Note that only the features, functions and ranges relevant to the measurement need to be evaluated.) What is the measurement technology of the specified instrument? (You will need this information to help determine differences between that instrument’s specifications and those of the proposed substitute.) This is where you will be looking for things that may affect the measurement result or uncertainty with respect to modern equipment.
3. Is the IM&TE listed in the work instruction “over-specified”? This is the case where the measurement performance of the instrument is far better that what is required for the measurement. An example would be requiring use of an Agilent 3458A long-scale digital multimeter to measure aircraft DC power bus voltage, typically +28 V DC (+2 V, -6 V).
4. What are the characteristics of the proposed substitute IM&TE? Note again that only the features, functions and ranges relevant to the measurement need to be evaluated. What effects do changes in the instrument technology have? Some examples are digital instead of analog, electronic sensor instead of mechanical, input impedance differences, vector instead of scalar measurements, and so on.
5. What measurement issues are involved? For example, there may have been changes in SI unit names, definitions and assigned values. Also, measurement uncertainty must now be considered where in the older process it may not have been considered at all.
6. Are there any issues with the measurement work process if the substitute equipment is used? If the work process can be followed exactly as written using the substitute equipment, that is fine. Otherwise the work instruction will have to be evaluated and revised using your organization’s existing engineering change process. What needs to be changed will vary according to the nature of the measurement. Also verify if there are any special conditions that apply to the measurement, for performance or safety reasons, for example.

Example 1: the measurement requirement may be to “check for continuity” between various points, using an analog volt-ohmmeter (VOM). The customer may ask for any number of devices that could be used for this task: a current model of a different brand of VOM, a handheld digital multimeter (DMM) with a continuity function indicator (symbol or buzzer), a laboratory-grade digital low-resistance meter, or a lab-made box with a 6 V lantern battery, lamp and a pair of test leads. All of these are capable of meeting the requirement to “check for continuity.” If the laboratory low-resistance meter is used (or even the substitute VOM), it may be desirable to define an upper limit (in ohms) for what constitutes “continuity.” It is likely that the laboratory-grade instrument uses a 4-wire connection, which would require a change to the written instructions for the test.

Example 2: In the case of a continuity test, different meters may be specified for different purposes, even though the goal is to measure low resistance (less than 1 Ω, for the purpose of this example.) If the the purpose of the test is to verify electrical bonding as a safety test, then it is common to require application of 10 A or more during the measurement. If the measurement is being made in a potentially hazardous environment, or for doing something like testing detonators for explosives, then a very low current must be used – typically much less than 10 mA. The same instrument cannot be used for both tests, and a conventional VOM or DMM cannot be used for either test.

Comparison

Comparison of the original instrument and the substitute instrument has two major phases: comparing the instruments to each other, and comparing each instrument to the requirements of the measurement that is being made.

First, compare the *relevant* functions and ranges of the instruments, looking at the performance specifications of each. (Alternatively, calculate the measurement uncertainty of each instrument at each measurement or test point value.) Determine and document if the proposed substitute is capable of making the same measurement and has equal or better performance. In this phase also consider how changes in technology may affect the measured value. For instance, if the original instrument is a DC differential voltmeter (which has infinite effective input impedance at the null point) then how much can the measurement be expected to change if a DMM with 10 MΩ input impedance is used?

The second phase is to compare *both the original and proposed substitute instruments* to the measurement and task requirements.

- When comparing the instruments to the measurement requirements, measurement science professionals would normally use measurement uncertainty analysis methods, and determine guardbands using methods such as those described by Castrup [6, 7], Deaver [8], Hurll [9] and others. However, someone who is not educated in measurement science but is doing this type of task will be more likely to use the old definition of the test accuracy ratio (TAR) – comparing the published performance specifications. For typical industrial measurement that type of analysis may be considered minimally acceptable, especially if the computed TAR is ≥ 10:1. Either way, determine and document if the calculated uncertainty or TAR is acceptable for measuring the nominal value to its stated tolerance limits.
- Determine and document if the user can make the measurement using the substitute instrument and following the original work instruction exactly as written. If this is not possible then the work instruction needs to be modified as mentioned earlier.

Note that it is not unheard of to find that the instrument specified by the manufacturer of the equipment being tested is not capable of making the measurement. In such a case it is best to continue with the process to get your own records in order, and also notify the equipment manufacturer (if possible) of the issue.

Documentation

There are two main ways that measuring equipment substitutions can be documented and approved — a blanket approval that covers all uses of the IM&TE within the organization, or a limited approval, typically limited to a specific work instruction or task.

The substitution can be on a blanket basis, for example "*In all cases where manufacturer A model B is specified, manufacturer C model D may be use as a substitute.*" An example of this type of substitution that many may be familiar with is the U.S. Department of the Navy's sub-category (SCAT) code system for test, measuring and diagnostic equipment (TMDE). The Navy system lists a 4-digit number and either a specific instrument or a generic type (such as "Oscilloscope, dual channel, 100 MHz"), and then all of the instruments that are under that SCAT code. In general, any of them may be used for any task that requires another item of the same SCAT code.

Alternatively, the substitution can be done on the basis of being specific to a particular task, for example "*When performing direct voltage measurements during maintenance of manufacturer E model F mod 3 Rev A black box, the manufacturer C model D may be used as a substitute in place of manufacturer A model B that is specified in the maintenance manual.*"

There are valid arguments for and against each method. In general, a blanket substitution may be appropriate for dimensional and physical measuring instruments and tools, and some single-function electronic instruments. In the case of most electrical-electronic measurements, though, it is usually better to limit substitutions to specific tasks. It is more work, but gives better control of the process and makes it easier to justify the substitution to interested parties such as customers, assessors, auditors, regulatory agency representatives, lawyers and so on.

Many work instructions contain wording allowing the use of *equivalent* test and measurement equipment. That is a good thing, and particularly fine if the table of required equipment only lists functional generic descriptions, measurement functions and the minimum performance specifications required to make the measurements. *You will still need to be able to show that what you are using meets or exceeds the stated requirements*, but that is a simpler task. You can also develop a master list of equipment in your organization's inventory that is acceptable for use with that maintenance instruction.

However, as soon as the table of required equipment lists specific manufacturers and model numbers, or performance specifications other than the minimum required to make the measurements listed in the manual, it is a more difficult task. It is always your organization's responsibility to be able to prove that you are actually using equipment that is "equivalent" to what is listed, how that determination is made, and how the process is controlled. The manufacturer of the equipment being serviced (if they still exist), or the test equipment manufacturer (if they still exist) generally cannot or will not tell you if whatever you want to use is "equivalent". A regulator, auditor, assessor, customer or lawyer is not likely to just take your word for it. So, you need to analyze, verify and document it, every time.

What to Document

- Equipment being worked on
- Authorized work instruction (maintenance manual?), and the specific task if applicable
- Measurement requirements (nominal value ± tolerance); some examples include:
  - Direct voltage up to ± 28 V with tightest tolerance ± 2% of nominal
  - Resistance 0.100 Ω maximum; measurement current 5 mA maximum
  - Resistance 0.010 Ω maximum, measurement current 10 A minimum
  - Measure on/off ratio of data pulses on a differential data bus
  - Measure 100 kHz 1 V RMS data stream on a 60 Hz 120 V RMS base signal
- Make, model, options, characteristics and specifications of the IM&TE originally specified in the work instruction
- Measurement uncertainty of the measurement system using the IM&TE originally specified in the work instruction
- Make, model, options, characteristics and specifications of the proposed substitute IM&TE
- Measurement uncertainty of the measurement system using the proposed substitute IM&TE
- Specific statement of the determination of acceptability of the proposed substitute IM&TE for this task.

There are also a number of suggestions – some alluded to earlier – about how to write the substitution or equivalency statements to make future changes easier.

- Try to make the substitution statement as general as possible. This is often applicable when the organization has many models that could be used as substitutes; and/or to allow for future changes.
- Describe the substitute IM&TE in terms of generic descriptions and minimum performance requirements as they apply to the measurements made in the current work instruction. For example: "Digital multimeter with at least 0.0001 V resolution on the lowest range that measures 1.0000 V (DC or AC), measures 10 mV DC to 500 V DC with accuracy of ± 0.025% of reading or better into an input impedance of at least 10 MΩ, true rms AC voltage from 100 mV to 500 V with accuracy of ± 0.25% of reading or better into an input impedance of at least 1 MΩ over the frequency range 10 Hz to 100 kHz, and resistance from less than 0.1 Ω to more than 10 MΩ with accuracy of ± 0.25% of reading or better."
- Record the data and make it accessible to everyone in the organization that needs it, as easily as possible, and as close to the point of work as possible.
- Information must be available to the people doing the work at the time and place they are planning or doing the work.
- Work the information into your existing document management system.
- Use a searchable database, if possible. Search first by the equipment being worked on, and then the task being performed.
- Review your organization's applicable policies and procedures, and revise them as necessary.
- Verify conformance to the quality program requirements by adding it to your organization's internal audit schedule.

Examples – Bad, Acceptable, Excellent

The following examples are abstracted from actual examples I have seen. They are examples of different types of quality of output from a substitution evaluation process. The use of measuring instrument manufacturers and model numbers are only for illustration and are not intended to imply anything positive or negative about the companies or their equipment, or the fitness of any of them for the particular use. These examples also are not complete – even the "good" do not necessarily reflect all ideal attributes, because they are samples, abbreviated and examples.

Bad: "It's good because I say so"

Equipment worked on:	Not listed
Work instruction:	"OEM service bulletin"
Specified tool:	Fluke 8021
Substitute tool:	Fluke 87
Justification notes:	"Supporting documents filed"

- No information was given about the equipment being worked on, what measurements were being made, or what the measurement tolerances are.
- The Fluke 8021 model number is incomplete; it should have either an A or B suffix. It is not described anywhere. (It is a 2000-count hand-held digital multimeter.) The performance specifications are not listed.
- The Fluke 87 designation is incomplete. (Does it refer to the original only, or to any of the models through Series IV

that have substantially similar performance specifications, or to any Fluke 87 model including Series V and later?) It is not described anywhere. (It is a hand-held digital multimeter, and versions through Series IV have a 4000-count display.) The performance specifications are not listed.

- No information was found in the referenced file.

Minimally Acceptable: "Yes, this will probably work because the specs are equal or better"

Equipment worked on:	Part Number listed, no nomenclature
Work instruction:	Maintenance manual
Specified tool:	"Milliohmmeter capable of reading 5 mΩ"
Substitute tool:	Avtron T477W Bonding Meter
Justification notes:	"The manual specifies a milliohmmeter capable of reading 5 mΩ for bonding resistance test. The Avtron meter is capable of this"

- This is minimally acceptable but only because of the special case that the work instruction did not contain much information. The requirement is to measure bonding resistance and verify it does not exceed 5 mΩ.
- It does not specifically state that substitution is approved.

Excellent: "Meter ABC is an acceptable substitute for meter DEF when performing task 123 on component XYZ."

Equipment worked on:	Differential Pressure Sensor XXXXX-XX
Work instruction:	Maintenance manual revision C for Differential Pressure sensor
Specified tool:	Leeds & Northrup 4286 Kelvin Bridge
Substitute tool:	Avtron T477W Bonding Meter

- This is an acceptable documentation example. It contains all of the required information that is relevant and available.

Other Examples

There are other cases that sometimes have to be considered, but which are not presented here. These cases include (but certainly are not limited to) the following:

- The IM&TE specified by the manufacturer of the equipment under test is not capable of the measurement, but the proposed substitute is. Yes, it does happen that equipment OEMs sometimes specify test equipment that is not metrologically capable for the measurement task. The substitute can be approved if capable, and it would be courteous to notify the equipment manufacturer of the problem.
- The IM&TE specified by the manufacturer of the equipment under test is "overspecified". This can be the case where, for example, an Agilent 3458A long-scale digital multimeter is specified to make a measurement of aircraft DC power bus voltage as discussed earlier. Another example might be a laboratory-grade capacitance measuring system for use in measuring the capacitance of vibration accelerometers in turbine engine bearings. Not only is the specified instrument's performance more than 4000 times better than required for the measurement, the environment of a turbine engine rebuild shop is hardly the same as that of a metrology laboratory.
- The proposed substitute is capable of meeting the intent of the measurement, but the work instruction must be changed before it can be used. This is sometimes the case where safety-related measurements are made. Over the past 30 or more years, the IM&TE has changed; also the applicable safety regulations may have changed (or been created if there were none), and the acceptable test and measurement practices may have changed. An example is ground bond testing. It used to be common to use a current source to apply 1 ampere across two points, and to use a VTVM or differential voltmeter to measure the voltage developed; it was generally acceptable for the voltage to be less than 1 volt, meaning that the resistance is less than 1 ohm. Modern safety regulations generally call for applying at least 10 times as much current, and the resistance must be much lower. In addition, there is a wide range of safety test equipment that are integrated units. Taken together, this means that the work instruction must be changed to specify the new equipment, specify test and measurement levels required by new safety regulations, and to modify the instructions to reflect the operating methods of the new equipment.
- The proposed substitute is capable of making the required measurements, and all reasonable efforts have failed to identify any source for information about the IM&TE specified in the work instruction. In this case, the inability to find information should be noted in the records, and the substitute approved for use. As part of the documentation, it may be considered prudent to describe what methods and resources were used to attempt to locate information.

Conclusions

Proper evaluation and documentation of IM&TE substitution is a very important part of any organization's quality management system and measurement management system. If there is no control of what IM&TE is used for each measurement task, there can be no assurance that the correct IM&TE was, in fact, used. As time passes from the time the original equipment under test was designed, available IM&TE ages, becomes obsolete and must be replaced – making substitutes for that equipment necessary. Whenever substitute equipment is considered for use, the relevant measurement process must be re-evaluated to ensure not only that the new IM&TE is capable, but also that other considerations (such as safety, and ability to follow the work instruction as written) have been properly considered.

The people doing the work must be knowledgeable in measurement science, research methods to find the necessary data, and ideally familiar with the type of work done using the IM&TE.

If no system of documenting substitutions exists, it is admittedly a lengthy and difficult task to initiate and develop, but once in place and operating well it will benefit all areas of the organization that make measurements affecting the quality of the product. An effective substitution approval system can reduce the risk of incorrect measurements (and the problems caused by them) and actually streamline the operation by being able to document the new and more efficient IM&TE that may be available. Proper documentation will help in years to come, as today's cutting edge IM&TE becomes obsolete and needs to be replaced; your successor in evaluating substitutions will only have to go back to your work to find all the data he or she needs.

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Graeme C. Payne,Graeme@gksystems.biz, www.gksystems.biz.

Mr. Payne is the President of GK Systems, Inc., providing consulting, writing, training, assessment, internal auditing and other services to clients in measurement science. He is a member of NCSL International, a Senior Member of ASQ, and has been active in metrology and product testing for over 30 years.

A New Compact Low-Cost 1kN Force Standard at NIS, Egypt

M. I. Mohamed, A. Abu-Sinna, A. Abu El-Ezz
Force and Material Metrology Department (FMMD)
National Institute for Standards, Egypt

The National Institute for Standards (NIS), Egypt, has developed and constructed a new primary force standard, a 1kN deadweight machine (DWM) at its facility in Egypt. The new machine features low cost and compact size, making it an excellent option for manufacturing and smaller laboratories. In this paper, the 1kN DWM is introduced with explanation and description of the design criteria, construction features, and uncertainty evaluations. In addition, the paper demonstrates the advantages and disadvantages of this purely local attempt supported by suggested future work.

1. Introduction

The progress of engineering is greatly dependent on the development of new and better materials. Thus, considerable attention has been given to the mechanical properties of such materials, which can be thoroughly assessed. Their behavior in service can be obtained from the results of laboratory tests and experiments. The accurate calibration of materials using testing machines and force verification equipment is essential to the engineering and construction industries.

In order to ensure that NIS can meet industry's needs in this century, a complementary program of upgrading and modernization was undertaken. The core of this program was the building of four dead-weight machines (DWM) to cover the ranges of 5 kN, 50 kN, 500 kN, and 5 MN. While the last three were built by Gassmann Theiss Messtechnik GmbH (*GTM*), Bechinback, Germany [1-3], the first was built completely by the *FMMD* [4]. It was decided that *FMMD* should complete the lower range from 30N to 1kN.

The paper reviews the details of a research program that lead to the design, manufacture, construction, and commissioning of a 1kN DWM. Furthermore, estimation of the achievable relative standard uncertainty of force measurement on the new 1kN dead-weight machine is given.

2. Design of the 1kN DWM

To cover the lower range of force calibration below 1kN, it was decided to take on a project to upgrade the facilities of force calibration at *FMMD* in the lower range through the design, construction, and evaluation of the metrological characteristics of a 1kN DWM. Generally, the new 1kN DWM consists of a main frame, which should be rigid enough, a load generation

Figure 1. Using 1kN DWM to calibrate a load cell.

Figure 2. A photo for the 1kN DWM.

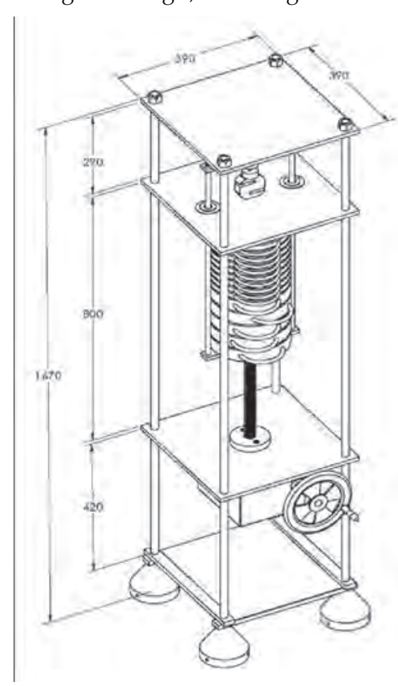

Figure 3. Schematic for the 1kN DWM.

system that produces accurate values of load (standard weights and loading frame) and a load transmission mechanism (lifting table).

Figures 1-3 show photos and a schematic drawing of the 1kN dead-weight machine designed, constructed, and commissioned at NIS. The load generation system consists chiefly of four stacks of weights and the loading frame which are to be adjusted to within 0.0001 % (one part per million) of their nominal values. Weights are traceable to Egyptian primary standard kilogram (copy no. 58 of the International prototype of the kilogram). The four stacks of weights rest on the lower plate of the movable frame and are applied and removed in a manual sequence, which means that to apply a certain load we have to accumulate the weights gradually to reach the desired load.

The first step applied by the DWM is the loading frame itself, equal to 30 N. Table 1 shows the distribution of the weights over the four stacks. The 1kN DWM is composed of 18 different masses along with the loading frame. Masses were made of low carbon rolled steel SAE-AISI1020 (with theoretical density 7900kg/m^3, according to the annual book of ASTM, American Society for Testing and Materials A265). AISI-1020 is available in the local market with the suitable dimensions for the manufacturing of weights.

To characterize accurate forces using dead weights, one has to determine, with the most achievable accuracy, the material density (air density), as it is a part of the air buoyancy correction and the free fall acceleration (local gravity), and therefore, part of the weight calculations. The density of the chosen stainless steel, p_m was calculated according to Equation 1 and by the aid of Archimedes principle of the solids flotation [5].

$$\rho_m = \frac{(\frac{F_a}{F_L}) - (\frac{\rho_a}{\rho_L})}{(\frac{F_a}{F_L}) - 1} \times \rho_L \qquad \text{Eq. 1}$$

where:

p_a = Air density (measured to be equal to 1.166kg/m^3).

p_L = Liquid density (temp. of distilled water 20.8^{o}C, room temp. 20.4^{o}C, atmospheric pressure 1012.35mmHg and relative humidity 36%).

F_a = Force exerted by the weight of the specimen in air.

F_L = Force exerted by the weight of the specimen in water.

p_m= 7900.1kg/m^3

The Egyptian Survey Research Institute, SRI, the Ministry of Public Works and Water Resources measured the local gravity g at the place of construction at NIS and found it to be = 9.79299022m/sec^2 ±2×10^{-8}m/sec^2).

The most important requirement is that the center of gravity of a weight when loaded should coincide with the vertical centerline of the calibration device. To comply with this requirement, the mechanism of the movable frame was designed in order to apply the load centrically by fixing a bar in the center of the lower plate of the movable frame, as shown in Figure 3. This unique idea leads to loading and unloading all weights centrically, regardless the position of the loadcell and the direction of loading.

3. Manufacture and Commissioning of the 1kN Dead Weight Machine

The machine was completely financed locally as a joint project between NIS and the Sixth of October High Institute of Engineering. Prior to the re-assembling and commissioning of the machine, the density of the material used for the weights and the loading frame were determined experimentally. The masses were weighed to work out the actual difference between the actual weights and the calculated ones and then auxiliary adjustment pieces were used to adjust each weight accordingly. Fine adjustments were then made for the weights of 17 masses as well as the loading frame.

4. Uncertainty Calculations of the 1kN Dead Weight Machine

The calibration of dead weights, the air density calculations, and the measurement of the acceleration of free fall are the main sources of errors that compose the uncertainty budget of the DWM [6]. To evaluate the performance of the new machine in terms of uncertainty achievable, the factors affecting the uncertainty of weights calibration are to be considered. These factors are the reference weight calibration, the secular stability of reference weights, the weighing process, the air buoyancy effect, the environmental conditions, and the uncertainties of weight measurements.

Stack No.	Number of Weights	Weight Value (N)	Total Load (N)
Loading frame	1	30	30
Stack 1	1	10	10
Stack 2	2	20	40
Stack 3	9	50	450
Stack 4	5	100	500
Number of weights	18	Overall load	1030

Table 1. Distribution of the weight numbering and succession in the machine.

4.1 Uncertainty Budget of Weight Measurements

The more common sources of errors and uncertainties in mass calibration may include repeatability of measurement in the weighing process (W_R) (type A) together with reference weight calibration (W_S), secular stability of reference weights (D_S), linearity (C), digital rounding error (I_d) and air buoyancy effect (Ab) (Type B) [7]. They may not be significant at all levels of measurements, but their effect should be considered when estimating the overall uncertainty of measurement.

For the loading frame and the mass stacks 1, 2, 3, and 4, which are 10N, 20N, 50N, and 100N respectively, the NIS Mass department gave the values of (W_S), (D_S) and (C). The value of (I_d) was taken from the comparator technical specifications. The value of (Ab) was estimated as 1ppm [7]. The value of (W_R) was calculated from the dead weights calibration results. The overall combined standard uncertainty, $u_C(W_X)$, the relative standard uncertainty, u_m, and the expanded uncertainty for the overall masses, U, were calculated according to the following equations.

$$u_c(W_X) = \sqrt{\sum_{i=1}^{n} u_{C_i}^2(W_X)} = \pm 87.3213 mg \qquad \text{Eq. 2}$$

$$u_m = \sqrt{\sum_{i=1}^{n} \frac{u_{C_i}^2(W_X)}{m_i}} = \pm 42\,ppm = \pm 4.2 \times 10^{-5}$$

$$U_m = ku_m = \pm 84\,ppm$$

where: m_i is the mass for each weight, and k (coverage factor) is taken as 2 for a confidence level of 95%.

4.2 Uncertainty Budget of the Air Density and Gravity Acceleration

The standard uncertainty in measuring the air density (u_A) was about ±3ppm. As shown in Equation 2, Clause 3, the standard uncertainty for evaluating the acceleration due to gravity (u_g) was found to be less than ±1ppm.

4.3 Uncertainty Budget of the 1kN DWM

The standards do not state a procedure for the determination of DWM uncertainty and the overall uncertainty of the calibration results [6]. Z. J. Jabbour and S. L. Yaniv [8] specified the factors affecting the uncertainty of the dead-weight machines. They stated that the most important factor elements for evaluating the uncertainty of the DWM are u_m, u_A, and, u_g. The relative combined standard uncertainty of the 1kN DWM, u, incorporate the uncertainties associated with the determination of the mass of the dead weights ($u_m = 42ppm$, based on previous calculations), the acceleration due to gravity ($u_g = 1ppm$, based on estimation) and the air density ($u_A = 3ppm$, based on estimation) [8]. As for the effect of dead weight eccentricity, one can neglect it due to the unique design of the movable frame. Hence the relative combined standard uncertainty of the 1kN DWM, $u_{(1kN)}$ is:

$$u_{(1kN)} = \sqrt{u_m^2 + u_A^2 + u_g^2} \qquad \text{Eq. 3}$$

$$u_{(1kN)} = \pm 42ppm = \pm 4.2 \times 10^{-5}$$

$$U_{mach} = ku_{1kN} \cong \pm\, 85ppm$$

where: k (coverage factor) is taken as 2 for a confidence level of 95%.

5 . Conclusion and Future Work

It can be concluded that the DWM constructed for the lower range of primary standard machines at *FMMD*, namely the range of 30N to 1kN has an expanded uncertainty of 85ppm. In addition, the possibility still exists for further improvement in the 1kN machine. This improvement includes the provision of fully automatic controls and facilities for carrying out studies on the machine and force transducer interactions behavior.

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M. I. Mohamed, NIS, Egypt, magdy_i_m@yahoo.com.

Ready to Assemble Ruler Calibrator

Mahesh Chander Gupta
DCL-Dubai Central Laboratory Department (DCL), Dubai
Municipality, Dubai, UAE

Like other instruments, engineering-grade ruled scales require traceable calibration. Because the calibration is usually carried out by sophisticated comparators that are expensive to buy and maintain, only a handful of laboratories are equipped to perform in-house calibration. In view of the high demand for calibration of grade 1 and 2 length scales, Dubai Central Laboratory has developed an inexpensive, easy-to-operate system that can be readily assembled by utilizing available equipment. The arrangement is suitable for graded length scales of grade 1 and 2 used routinely on shop floors for precision work requiring accuracy of 0.15mm to 0.25mm. This paper describes some important feature of the system.

1. Introduction

Length measuring devices are probably the oldest record of human intelligence [1, 2]. In the modern era, although the length measurement capability has reached the nanometer scale, the length measures in millimeter accuracy, such as survey tapes and line scales, still play an important role in the traceability chain for a host of dimensional measurements. This is because the line scales popularly known as rulers are the most widely used length measuring instruments in areas where the accuracy requirement does not exceed 0.25mm over 1 meter length[3-6].

Such rulers are often made up of steel strip or plastic and are used as line gauges in geometrical dimensions, technical drawings, and the printing and engineering environment. The width of markings, graduation spacing and their uniformity over the length are the critical parameters that permeate in to the accuracy of the scale. Since the measurements done by a scale are significant as an initial input to further process, it must be calibrated to control the cascading effects to the quality of the final product.

The basic principle of calibration of a ruler is to compare the test sample against a better, more accurate scale that serves as reference and can be in the form of a material standard or wavelength standard. In the recent past, state-of-art comparators of high accuracy, stability and robustness, of mechanical, opto-electronic and machine vision design have been developed for high accuracy (micro resolution) calibration work, [7-14].They all prove to be unsuitable besides being expensive for calibrating graduated engineering scales of grade 1 and 2. Because their high demand surpasses high accuracy scales of micrometer or nanometer resolution, the need for cost effective and time efficient alternatives is always felt. As a result, the laboratories either use contour projection method or in-house designed and fabricated comparators [3-6, 10, 13, 14]. The limitation of design and fabrication, initial investment and maintenance cost besides housing a dedicated system, forbid small laboratories to venture into this area.

This paper describes a method of calibration of rigid rulers by using commonly available equipment in a calibration laboratory. The method is convenient and is economical. The arrangement can be quickly assembled by using already available equipment in dimensional laboratory for handling various other calibration jobs. The distinguishing feature of the method reported here is that the scale is calibrated in vertical configuration as opposed to conventional horizontal. The reference in the set up is provided by a digital height gauge It is suitable for scales of grade 1 and 2 [3] having length up to 300 mm.

2. Experimental Set up

The common datum forms the guiding principle of the method. It was provided by:

a) the surface plate and box angle plate.
b) the end face of the scale (0 side, serve as the reference point)

A calibrated digital height gauge having resolution of 0.01mm (uncertainty 7μm at K=2) and range 300 mm, already available in the laboratory served as reference. Its scriber was replaced by an especially fabricated fixture to hold a vernier scale. The setup is shown in Figures 1 and 2 (following page). The test unit is mounted vertically on box angle plate and they were placed on a common surface plate. The end edge of the scale rested upon the surface plate.

A clamp holder was used to mount the scale upright position firmly against the surface of the box angle. A thin tape (both sided gummed) can also be used to hold the scale in position. If required, a gauge block was inserted below the end edge of the scale to raise the scale upwards, to coincide the vernier scale (attached to the height gauge carriage) to the ruler line near to zero graduation. The assembly was left for an hour to allow acclimatization to

Figure 1. Set up of the calibrator. (Measuring system)

Figure 2. Mounting of scale.

ambient temperature. The temperature was measured at lower and upper end of the scale by a digital thermometer. On attaining the thermal equilibrium the measurements were started.

3. Making Measurements

The measurement was carried out in following sequential steps.

- The height gauge was placed on the surface plate.
- The vernier scale attached to the carrier of the height gauge was brought adjacent to the side edge of the scale, keeping a sleek gap in between the two.
- The height of the vernier scale was adjusted up-down to coincide with the zero line mark of the scale.
- The height gauge was aligned to ensure that the graduation line axis coincides with the vernier graduation (assuming that the axis of line of the scale are parallel to the side edge). Thus the ruler scale and vernier combination was correctly set for measurements.
- The vernier scale was slowly moved upward to check alignment. It is of the utmost importance that the vernier scale and the ruler scale are adjusted to be parallel and co-planer and remain so throughout the scan range.
- Started the measurements with zero coincidence of vernier to the zero graduation of the ruler scale. Corresponding reading of the height gauge was noted. It was pre-set to zero.
- The carriage of height gauge was moved slowly upward till it reached to next minimum of ruler scale (0.5 mm or 1mm, as the case may be). The vernier coincidence to ruler scale was noted. The reading on the scale corresponding to 0.5 or 1 mm was read and noted down. The carriage was moved up to next interval line and corresponding scale and vernier reading was noted.
- The process was repeated in steps to cover the full range adhering to the sequence of calibration points mentioned in paragraph below.

A magnifier for adjusting and attaining coincidence and reading the scale was helpful. Besides, its use minimized parallax error.

4. The Calibration Points

The test points were selected in such a way as to cover the smallest interline interval and larger cardinal points, and complete the calibration range in minimum time.

The sequence was as follows:

a) 0 - 10 mm : each smallest interval (0.5mm or 1mm)

b) 10 mm – 50mm: every 5 mm interval

c) 50 mm - end: every 10 mm interval

5. Discussion and Conclusion

In all the conventional systems of scale calibration, the comparison is realized in horizontal configuration. The test scale and the master reference are laid side by side on a common bed in horizontal plane with their axis either parallel (transverse comparator) or coaxial (longitudinal comparator). Horizontal lay out ensures neutral axis by minimizing sag due to the deflection, besides maintaining temperature uniformity along the horizontal ambient stratum. But they are expensive, unfit for routine engineering grade scales, hence, are not accepted by many calibration laboratories as a commercially viable proposition. The method described here can be adopted by every laboratory to handle calibration of scales of workshop grade.

The method in principle resembles a vernier caliper. There are several pitfalls in vertical comparison. The most important is the temperature gradient that builds-up along vertical strata. The resolution of the height gauge and that of the test scale are another dominant factors that limit accuracy. Besides, the alignment of perpendicular movement in plane with the scale axis introduces geometric errors.

Out of a host of geometrical errors such as carriage movement deviations, its slight angular disparity with or fluctuation about main axis, the Abbe error is prominently present in conventional comparators. The present set up has the advantage of achieving precise axial alignment due to very nature of the assembly components such as box angle plate. The method allows control of Abbe error to high degree of accuracy within the tolerance limits [3].

The temperature stabilization time is minimized by pre-conditioning the test scales in the vertical position. The calibration time for a scale calibration, thus, was reduced to 2 hours. Using a vernier of 0.01 mm and height gauge of 0.01 resolution, uncertainty 0.007 mm, at k=2, the calibration error for a sample of scale with interval 0.5mm was found to be within 0.02mm , and expended uncertainty ± 0.05 mm at k=2..

Efforts are being made to improve the performance and reduce the time and effort in alignment by using a reticule and modern CCD cameras assembly as graduation locator in place of vernier scale.

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Mahesh Chander Gupta, mc1941@rediffmail.com, tel +971 40 302 7102, fax +9714 302720.

Dr. Gupta retired from NPL India December 2000 as head of National Calibration Services. He earned his Ph.D. degree from I.I.T Delhi in 1973. Currently he is working at DCL, Dubai as Principal Quality Officer, Metrology Section.