The Biennial Conference of the Metrology Society of Australasia
3 - 5 March 2020, Angliss Conference Centre, Melbourne
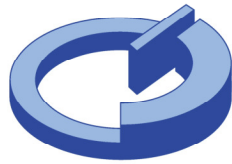
NATA MSA Conference 2020

Conference Programme

MSA2020 – The Biennial Conference of the Metrology Society of Australasia
The Angliss Conference Centre, Level 5, 555 La Trobe St, Melbourne, 3000
Tuesday 3rd March to Thursday 5th March 2020

Metrology Society of Australasia

The MSA is an association of professional metrologists, engineers, scientists, technicians and measurement experts throughout Australia, New Zealand and around the world, who measure, evaluate, calibrate, maintain, educate, train, design, sell, invent and develop measurement technologies and research the Science and Art of Metrology.

www.metrology.asn.au

MSA Committee

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Daniel Turner
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Keith Fordham
Liam Shanahan
Paul McMullen
Tiger Chen

Conference Venue

**The Angliss Conference Centre
Level 5, 555 La Trobe Street
Melbourne, Vic, 3000**

Conference Dinner Venue

**The Melbourne Cricket Ground
Brunton Ave
Richmond, Vic, 3002**

Conference Schedule

Monday 02/03/2020

Time	
6:30 PM	Welcome reception (6:30 pm to 8:30 pm)
	Conference registration opens

The welcome reception will be held at the conference venue:

The Angliss Conference Centre
Level 5, 555 LaTrobe St, Melbourne

Tuesday 03/03/2020

Time	Who / what		Title
8:30 AM			Registration
9:00 AM	MSA President, NATA (Sponsor)		Welcome, introductory statements, housekeeping
9:20 AM	Keynote address: Dr Barry Inglis	Pg 9	The international bureau of weights and measures (BIPM) and its role in the 21st century
10:00 AM			Morning tea
10:30 AM	Invited talk: Dr Murray Early	Pg 11	The 2019 SI redefinition: now what?
	Session 1: Traceability and the SI Revision		
11:10 AM	Peter McDowall	Pg 18	A pressure-based Kibble balance for realising New Zealand's kilogram
11:30 AM	Tony Bergen	Pg 19	Calibration of photometers – impact of the SI revision and future directions
11:50 AM	Robert J. Williams	Pg 20	Verifying stopwatches using the NMIA webtimer
12:10 PM	Calla Klafas	Pg 21	Transitioning to the re-definition of the SI units
12:30 PM			Lunch
	Session 2: Temperature		
1:30 PM	Nigel Gibson	Pg 22	Optimising a 16-bit digital to analog converter for a low cost 2 decimal point thermometer
1:50 PM	Daryl Pettit	Pg 23	High temperature calibration of themocouples
2:10 PM	Rod White	Pg 24	Hysteresis in bimetallic dial thermometers
2:30 PM	Workshop 1	Pg 52	Method for Dry Block Spatial Surveys (Temperature)
3:15 PM			Afternoon tea
3:45 PM	Workshop 2	Pg 53	Calibration of Microwave Furnaces (Temperature)
4:30 PM	Fluke (Sponsor Session)		MET/CAL MET/TEAM
5:00 PM			Close of day 1
6:00 PM			Buses leave to MCG
6:30 PM			Tour of the MCG
7:30 PM			Conference dinner - Olympic Room, MCG (7:30 pm to 10:30 pm)

Shading guide

Special sessions: keynote/invited talk, opening, closing
Oral presentation sessions
Workshops and sponsor sessions
Breaks
Social activities
MSA Annual General Meeting

Conference Schedule (cont.)

Wednesday 04/03/2020

Time	Who / what		Title
	Session 3a: Lab Management and MU		
8:30 AM	Paul McMullen	Pg 25	Transition to ISO/IEC 17025:2017 & ISO 17034:2016, an accreditation point of view
8:50 AM	Allister Prosser	Pg 26	Implementation of an integrated management system to meet world best practice
9:10 AM	Tony Bergen	Pg 27	Monte Carlo analysis of complex measurement uncertainty tasks
	Session 3b: Anti-doping analysis		
9:30 AM	Fong-Ha Liu	Pg 28	A new steroid reference material to underpin stable carbon isotope ratio measurement in anti-doping analysis
9:50 AM	Somanath Bhat	Pg 29	Fairness in sport - a DNA test for detecting gene doping in athlete blood samples
10:10 AM	Morning tea		
10:40 AM	Invited talk: Dr Jonathan Mittaz	Pg 13	Applying principles of metrology to earth observation satellite data
	Session 4: Environment		
11:20 AM	Mauro Scungio	Pg 30	On the influence of different methodologies in the estimate of ultrafine particle dose received by population in all-day activities
11:40 AM	Robert Kay	Pg 31	Intercomparison of CSIRO (Au) – JAMSTEC (Japan) – NCOSM (China) oceanographic calibrations facilities
12:00 PM	Jane Warne	Pg 32	Consistent measurement in a dynamic world, measuring temperature in the real world
12:20 PM	Lunch		
	Session 5: Dimension and Pressure		
1:20 PM	Neil Sturrock	Pg 33	The development of an automated dimensional calibration system to verify the performance of radial gauges
1:40 PM	Richard Crendal	Pg 34	Alternative methodology for establishing a vacuum scale using a static expansion system
2:00 PM	Robert Clayton	Pg 35	Zeroing absolute pressure transducers
2:20 PM	Workshop 3	Pg 54	Pressure Interest Group
3:05 PM	Afternoon tea		
	Session 6: Humidity		
3:35 PM	Wenwen Lei	Pg 36	Hysteresis effects on capacitance humidity sensors
3:55 PM	Jarkkko Ruonala	Pg 37	Improving the performance of relative humidity measurements in high-humidity environments.
4:15 PM	Workshop 4	Pg 55	Humidity (Aus-NZ cooperation to facilitate consistency)
5:00 PM	Metrology Society of Australasia Annual General Meeting		
6:00 PM	Drinks and canapes (6:00 pm to 7:00 pm)		

Shading guide

Special sessions: keynote/invited talk, opening, closing
Oral presentation sessions
Workshops and sponsor sessions
Breaks
Social activities
MSA Annual General Meeting

Conference Schedule (cont.)

Thursday 05/03/2020

Time	Who / what		Title
	Session 7: Electrical (1)		
8:30 AM	Bill Spath	Pg 38	PMU calibration - why and how?
8:50 AM	Adam Knight	Pg 39	Modelling the errors of a transfer power standard for improved calibration efficiency
9:10 AM	Tieren Zhang	Pg 40	Calibration techniques for new-generation digital multimeters and calibrators
9:30 AM	Wei Yan	Pg 41	Calibration of high-voltage modules of electromagnetic compatibility test sets
9:50 AM	Morning tea		
10:20 AM	Invited talk: Dr Colin Allison	Pg 15	Chemical metrology of atmospheric greenhouse gas measurements
	Session 8a: Electrical (2)		
11:00 AM	Ilya Budovsky	Pg 42	NMI standard of electrical power as a reference for phase measurement and characterisation of voltage and current scaling devices
11:20 AM	Wei Yan	Pg 43	Traceable calibration for partial discharge calibrators
	Session 8b: Environment (2)		
11:40 AM	Jane Warne	Pg 44	Wave Measurement, a comparison of methods
12:00 PM	Lunch		
	Session 9a: Flow		
1:00 PM	Simon Dignan	Pg 45	Preliminary results of Coriolis meter testing over a wide viscosity range
1:20 PM	Salam Matalka	Pg 46	A facility for the calibration of flow meters using high viscosity fluids
1:40 PM	Khaled Chahine	Pg 47	Establishment of an Ultra-High-Accuracy 670l PVTt Gas Flow Primary Standard at NMIA
	Session 9b: Education and outreach		
2:00 PM	Cynthia Lendrum	Pg 48	Outreach – why, what and how?
2:20 PM	Lenice Evergreen	Pg 49	Boosting the metrology workforce – one apprentice at a time
2:40 PM	Afternoon tea		
3:10 PM	Workshop 5	Pg 56	Can model-based testing be accredited and is it traceable?
3:55 PM	MSA President		Closing remarks
4:00 PM			Close of conference

Shading guide

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Metrology Society
of Australasia

Invited
Speakers

Keynote address

Dr Barry D Inglis

Comité International des Poids et Mesures (retired)
France

*"The International Bureau of Weights and Measures (BIPM)
and its Role in the 21st Century"*

Dr Barry Inglis is the immediate past President of the International Committee of Weights and Measures (Comité International des Poids et Mesures, CIPM), the peak expert body established under the Metre Treaty in 1875. Dr Inglis was elected a member of CIPM in 2000 and served as President from 2010 to 2019. He was the 15th President of the CIPM, the first Australian to hold this position and only the second person from outside of Europe and the UK.

Dr Inglis was a Research Scientist at the CSIRO from 1968-2004, serving as Director of the National Measurement Laboratory from 1994-2004. In 2004 he was appointed the inaugural CEO and Chief Metrologist of Australia's National Measurement Institute (NMI), a division of the Commonwealth Department of Industry, Innovation & Science, a position he held until his retirement in 2007. He has an outstanding international reputation in metrology, particularly in the field of electrical metrology and has played a leadership role in all aspects of Australia's technical infrastructure. He was a member of the Council of Standards Australia (1994 – 2004), a Commissioner on the governing board of the National Standards Commission (1994 – 2004), and from 1992 to 2011 he was a Director on the Board of the National Association of Testing Authorities (NATA), serving as Chair from 2003 to 2011. He has also been active in metrology issues in the Asia Pacific region over many years and was Regional Coordinator/ Chairman of the Asia Pacific Metrology Programme (APMP) from 1994 to 1999.

THE INTERNATIONAL BUREAU OF WEIGHTS AND MEASURES AND ITS ROLE IN THE 21ST CENTURY

Dr Barry Inglis[1,2]

[1] CIPM, Paris, France (Immediate Past President)

[2] National Measurement Institute, Sydney, Australia (Honorary Fellow)

Correspondence: bdi1000@bigpond.com

The International System of measurement (SI) has its origin in the signing of the Metre Convention (Metre Treaty) by 17 foundation member States on 20 May 1875. The signing of the Treaty was in recognition by the signatories of the need for a common international measurement system in order to facilitate international trade, commerce and scientific exchange. The Treaty created the International Bureau for Weights and Measures (BIPM) as a "scientific and permanent international bureau" to be maintained by the member States. Since its creation, the role of the BIPM has evolved with time and need, as too has its membership. There are currently 61 member States and 41 Associate States and Economies that are parties to the Treaty. (Australia became a Member State in 1947 and New Zealand in 1991).

At the time of its creation, the primary role of the BIPM was to maintain prototype standards for length and mass and conduct comparisons against these for member States. In 1921 its role was extended to electrical units and scientific research related to physical constants that could impact measurement standards. Also, to coordinate work related to physical constants in other institutes with a view to establishing a truly international system of measurement with long-term stability. In 1960 an SI based on the six units of metre, kilogram, second, ampere, kelvin and candela was agreed with the mole as the seventh base unit added in 1971.

At the 26th General Conference on 16 November 2018 definitions for the base units of the International System of measurement (SI) were revised such that all base units were defined in terms of fundamental constants of nature. The revised definitions came into effect on 20 May 2019. Under the revised definitions any NMI or indeed any individual can, in principle, realise the base units of the SI directly without reference to the BIPM. This then raises the question as to what is the role of BIPM post the redefinitions?

The SI is based on the Metric System and this presentation will provide a brief history of the Metric System, the Metre Convention and the evolution of the SI before going on to consider the role of BIPM and some of its challenges in the 21st Century.

Invited talk
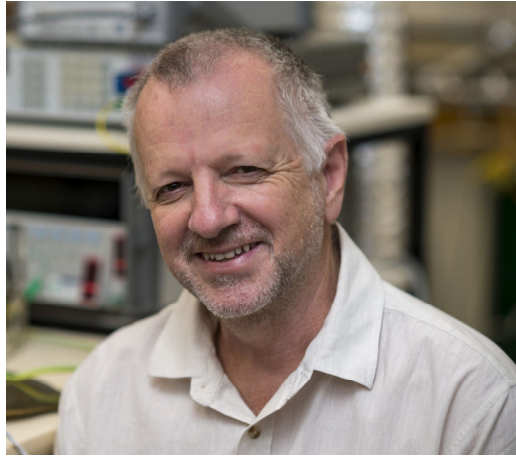
Dr Murray Early

Measurement Standards Laboratory
New Zealand

"The 2019 SI Redefinition: Now what?"

Murray is a Principle Research Scientist at MSL working on a wide range of electrical metrology topics including cryogenic current comparators and the quantum Hall effect. More recent interests encompass the conceptual foundation of the Giorgi system (on which the SI is based) and the educational challenge of the revised SI. He recently completed a three year term as chair of the Technical Committee for Electricity and Magnetism for APMP (Asia Pacific Metrology Program) and represents New Zealand's interests at the BIPM Consultative Committee of Electricity and Magnetism (CCEM) where he also chairs the Working Group on Low Frequency.

THE 2019 SI REDEFINITION: NOW WHAT?

Murray Early[1]

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World Metrology Day 2019 marked the most significant revision of the International System of measurements (the SI) since its inception in 1875. Having rebuilt the foundations of the SI, there is now a sound basis for an improved and innovative measurement infrastructure to support the technological developments of coming decades. The clear separation of definition and the means of realisation (a profound limitation of the old base units) now provides opportunities for ongoing improvements in how units and scales are realised in practice. The redefinition requires a different approach to some experiments. For example, the Kibble Balance now employs the Planck constant (accessible via quantum electrical standards) to realise mass. Experiments to measure the Boltzmann constant no longer make sense but can be used instead to realise temperatures other than the triple point of water.

That the redefinition largely came and went without significant adjustment for most users belies the profound change in the system. This testifies to the enormous global effort by NMIs to ensure that this would be so, and that the transition would be smooth. While the set of seven defined constants is a more abstract idea for the wider public to appreciate, its roots in the best present understanding of physics will ensue its success for some considerable time. However, it would be a mistake to consider that the development of the SI is now finally completed. Instead ongoing technical developments are likely to see further refinements. For example, the relentless improvement in the use of isolated atoms for timekeeping means that there is growing interest in an improved definition of the second, the most fundamental of all our units.

The pragmatic approach of the SI undoubtedly led to its almost universal adoption and effectiveness in providing a globally uniform and accurate basis for measurements. However, as researchers seek a more rigorous basis for a complete description of measurement (particularly in support of a fully digital representation of SI quantities), there are still issues to be resolved. For example, a recent paper [1] is concerned with how the dimensionless ratio of angle should be properly represented in the SI, and the debate over the nature of measurement uncertainty is ongoing [2]. In this presentation I will touch briefly on the new areas of research that are opening up following the redefinition and also describe some aspects of the SI that appear to require further development.

References

[1] Kalinin, M.I., On the status of plane and solid angles in the International System of Units (SI), Metrologia 56(6), 2019, doi:10.1088/1681-7575/ab3fbf

[2] White, D.R., In pursuit of a fit-for-purpose uncertainty guide, Metrologia 53(4), 2016, doi:10.1088/0026-1394/53/4/S107

Invited talk

Dr Jonathan Mittaz

University of Reading
UK

*"Applying principles of metrology to
Earth Observation satellite data"*

Jonathan Mittaz is a National Physical Laboratory Senior Research Fellow at the University of Reading. Starting with a Physics degree from Oxford University and a PhD in Astronomy from University College London he spent some time as an astronomer/astrophysicist before switching to Earth Observation in 2006 starting at the University of Maryland. There he worked as part of the team working on Sea Surface Temperature products within the National Oceanic and Atmospheric Administration Science Center as well as undertaking studies on Earth Observation satellite infrared sensor calibration. From there he moved to a joint position at the University of Reading and at the UKs National Physical Laboratory with a remit to apply the principles of metrology to Earth Observation satellite data. This has mostly involved looking at the long historic satellite data time series records used in climate change studies and has resulted in a number of projects including the Horizon 2020 project FIDUCEO.

APPLYING PRINCIPLES OF METROLOGY TO EARTH OBSERVATION SATELLITE DATA

Jonathan Mittaz[1]

[1] University of Reading, Reading, UK

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Approaches from metrology can assist earth observation (EO) practitioners to develop quantitative characterisation of uncertainty in EO data. This is necessary for the credibility of statements based on Earth observations in relation to topics of public concern, particularly climate and environmental change. In this talk I will present the application of metrological uncertainty analysis to EO satellite data of use for climate studies. I will first discuss the requirements on satellite observations within the GCOS (Global Climate Observing System) framework and show some of the difficulties in meeting these specifications. I will then discuss some of the issues inherent in creating and using satellite data for climate applications concentrating on the IR part of the spectrum using some of the pre-launch analyses as an example.

I will then move onto the metrological approaches we have been developing to derive estimates of uncertainty that are traceable from the satellite sensor through to products describing the evolution of the geophysical state of the Earth. EO radiances have errors with complex error correlation structures that are significant when performing common higher-level transformations of EO imagery. Principles of measurement-function-centred uncertainty analysis will be described that apply sequentially to each EO data processing level and I will present methods for organising and traceably documenting the uncertainty analysis. These principles and tools will be demonstrated with concrete examples including some specific sources of error seen in EO satellite data as well as with an example of the estimation of sea surface temperature (SST) from satellite infra-red imagery including the development of an ensemble SST product. This SST product is then used to illustrate the relevance of a metrological based EO-based climate datasets to the wider climate community.

Invited talk

Dr Colin Allison

CSIRO
Australia

*"Chemical metrology of atmospheric
greenhouse gas measurements"*

Colin Allison studied Chemistry in Melbourne and Sydney and completed a PhD in Physical Chemistry at the University of New South Wales. After two years post-doctoral work in Canada he returned to Australia and joined the CSIRO Division of Atmospheric Research measuring greenhouse gases in the atmosphere. Colin's expertise in the measurement of the stable isotopic composition of carbon dioxide has led to collaborations with many international organizations including the IAEA and BIPM. Colin continues this work in metrology as an Honorary Fellow with CSIRO and will describe the role of metrology in this aspect of climate change research.

CHEMICAL METROLOGY OF ATMOSPHERIC GREENHOUSE GAS MEASUREMENTS

Colin Allison[1]

[1] CSIRO Oceans and Atmosphere, Aspendale, Australia (Climate Science Centre)

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The amount of a greenhouse gas (GHG) in the atmosphere is a function of the amount released into the atmosphere (source) and the amount removed from the atmosphere (sink). If the sources and sinks are in balance, then an equilibrium amount (concentration) of the GHG will be attained. If the sources of greenhouse gases increase without increases in the relevant sinks, then the amount of the gases in the atmosphere will increase. Figure 1 shows recent GHG emissions and their contribution to radiative forcing: about 75% of the total GHG emissions is carbon dioxide (CO_2).
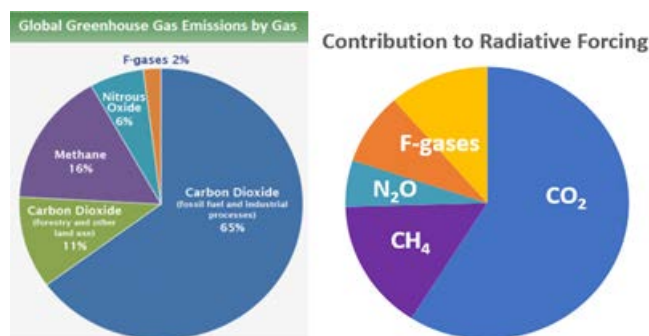
Figure 1: Greenhouse gas emissions (left) and their contribution to radiative forcing (right) [1]

For thousands of years the amount of CO_2 in the atmosphere varied between about 200 ppm (parts per million by mole) and 300 ppm with these limits being driven by driving forces such as the ice-ages (low CO_2). However, the industrial revolution initiated a massive increase in the amount of fossil fuel being consumed and land being cleared that perturbed the long-term balance and has caused the atmospheric concentrations of CO_2, methane (CH_4) and nitrous oxide (N_2O) to increase (Figure 2). These increases are linked to global warming and climate change.
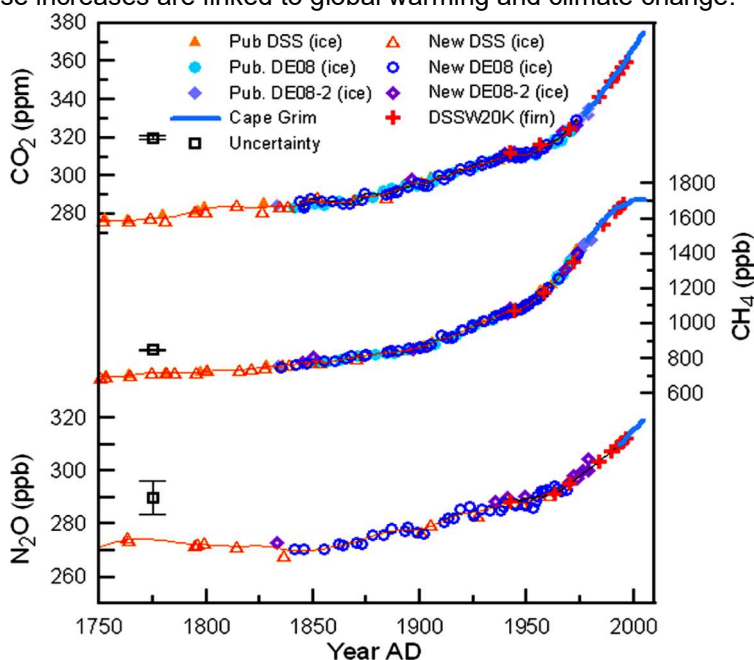

Figure 2: Atmospheric concentrations of CO_2, CH_4 & N_2O over the last 250 years inferred from ice-core measurements [2]

How do we know the concentration of CO_2 and other GHGs is increasing? By precise chemical measurement in many laboratories, in many locations, in various environments, over long periods of time. To ensure that meaningful results are obtained it is necessary to have good measurement practices, i.e. sound metrology. I will present some aspects of the chemical metrology employed, focusing on measurements of CO_2 and its stable isotopic composition. This will demonstrate two approaches to traceability, one using a primary method that provides a link to the SI, and the other using a primary reference material (an artefact) that forms the basis of an extensive measurement methodology.

References

[1] Images from US EPA (www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data, accessed on 10 January 2020) and generated from data contained in IPCC AR5 (www.ipcc.ch/reports/)

[2] MacFarling-Meure, C., Etheridge, D., Trudinger, C., Steele, P., Langenfelds, R., Van Ommen, T., Smith, A., and Elkins, J., Law Dome CO_2, CH_4 and N_2O ice core records extended to 2000 years BP, Geophys. Res. Lett., 33, L14810, 2006, doi:10.1029/2006GL026152
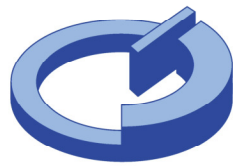
Oral Presentations

A PRESSURE-BASED KIBBLE BALANCE FOR REALISING NEW ZEALAND'S KILOGRAM

P. D. McDowall[1], R. J. S. Hawke[1], Y. H. Fung[1], M. T. Clarkson[1]

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The definition of the SI unit for mass, the kilogram, was changed on the 20th of May 2019. For the first time, National Metrology Institutes, and potentially industry partners, can realise the kilogram. Furthermore, the new definition provides a more stable basis, meaning in theory it can be disseminated with less uncertainty and be realised at points on the scale other than just 1 kg. There are several methods for realising the kilogram following the redefinition with the most widely used among them being the Kibble balance.

A Kibble balance compares the gravitational force on a mass with the electromagnetic force on a current-carrying coil in a magnetic field. A novel design being developed at New Zealand's Measurement Standards Laboratory (MSL) relies on a twin pressure balance arrangement to compare these two forces (see Figure 1). This design offers some potentially unique advantages over other Kibble balances around the world.

In this presentation we provide a general overview of the MSL Kibble balance and its progress to date, highlighting some of the promising features that set it apart from other Kibble balances. One of the defining features is the coupling of the coil to a piston cylinder unit. This coupling allows us to exploit the self-centering effect of the piston to maintain alignment of the coil along a well-defined and stable axis. Moreover, by careful manipulation of the pressure under the piston, we can also control motion of the coil through the magnetic field.
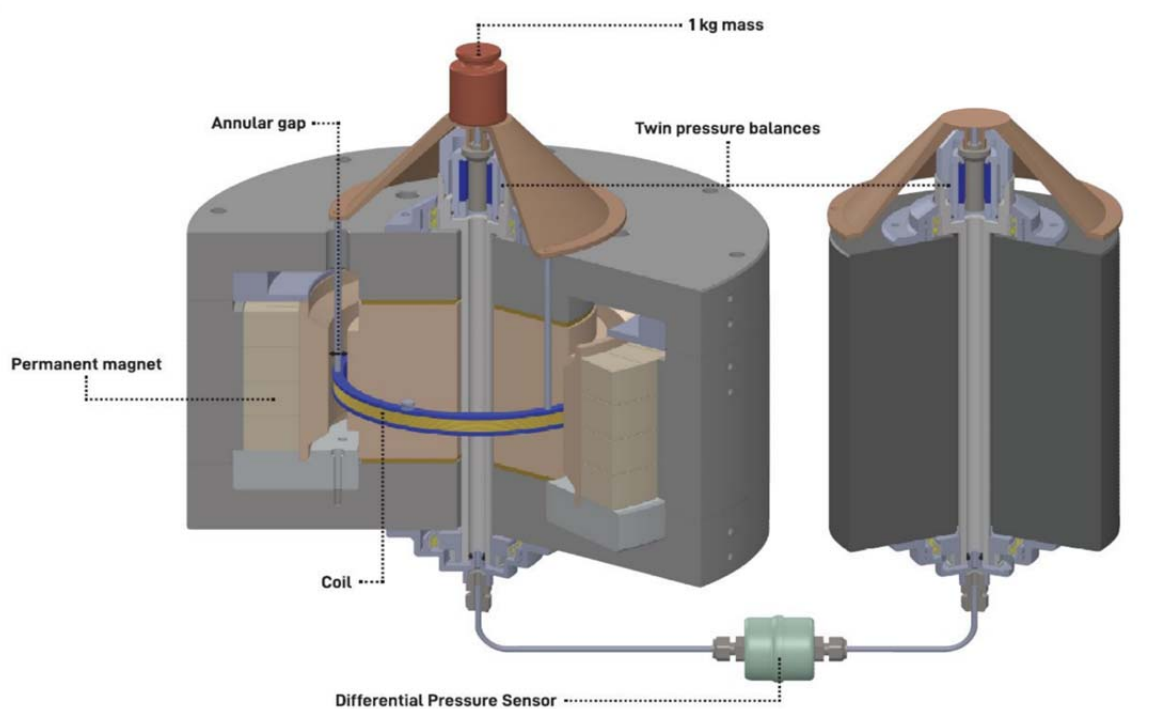

Figure 1: Schematic of the MSL Kibble balance design based on a twin pressure balance

CALIBRATION OF PHOTOMETERS –
IMPACT OF THE SI REVISION AND FUTURE DIRECTIONS

Tony Bergen[1]

[1] Photometric Solutions International, Melbourne, Australia

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The recent redefinition of the SI has largely unaffected the field of photometry and radiometry, where measurement uncertainties are typically of the order of a few tenths of a percent up to a few percent. However, a quirk in rounding errors has led to a small redefinition in the properties of the light sources used to calibrate photometers.

The International Commission on Illumination (CIE) has defined standard illuminants, which are standardised tables of spectral data that are representative of common light sources [1]. CIE standard illuminant A is intended to represent typical tungsten filament lighting, and is calculated by the normalized Planck's Law based originally in 1931 on a Planckian radiator at a temperature of approximately 2848 K. The small changes in fundamental constants over the years has resulted in the temperature of the Planckian radiator changing, and the recent redefinition of the SI has resulted in a further "tweak" of this temperature from 2856 K to 2855.5 K.

According to ISO/CIE 19476 [2], photometers (illuminance meters and luminance meters) are calibrated using CIE Source A, a gas-filled tungsten filament lamp which is a practical realisation of CIE standard illuminant A. This has been used since it was first adopted (by convention) in the early 20th century. Errors can occur when the spectral content of a light source being measured differs from that of the source used in the calibration. These errors, known as spectral mismatch errors, have become more prominent since the recent large-scale adoption of LED lighting. In order to minimise these errors, the CIE is currently working on a LED reference spectrum to compliment standard illuminant A for photometer calibrations [3].

References

[1] International Commission on Illumination, publication CIE 015:2018 "Colorimetry, 4th Edition", Vienna, Austria, 2019

[2] International Organization for Standardization, ISO/CIE 19476:2014 "Characterization of the performance of illuminance meters and luminance meters", Geneva, Switzerland, 2014

[3] CIE TC 2-90, www.cie.co.at/technicalcommittees/led-reference-spectrum-photometer-calibration, accessed 24/10/2019

VERIFYING STOPWATCHES USING THE NMIA WEBTIMER

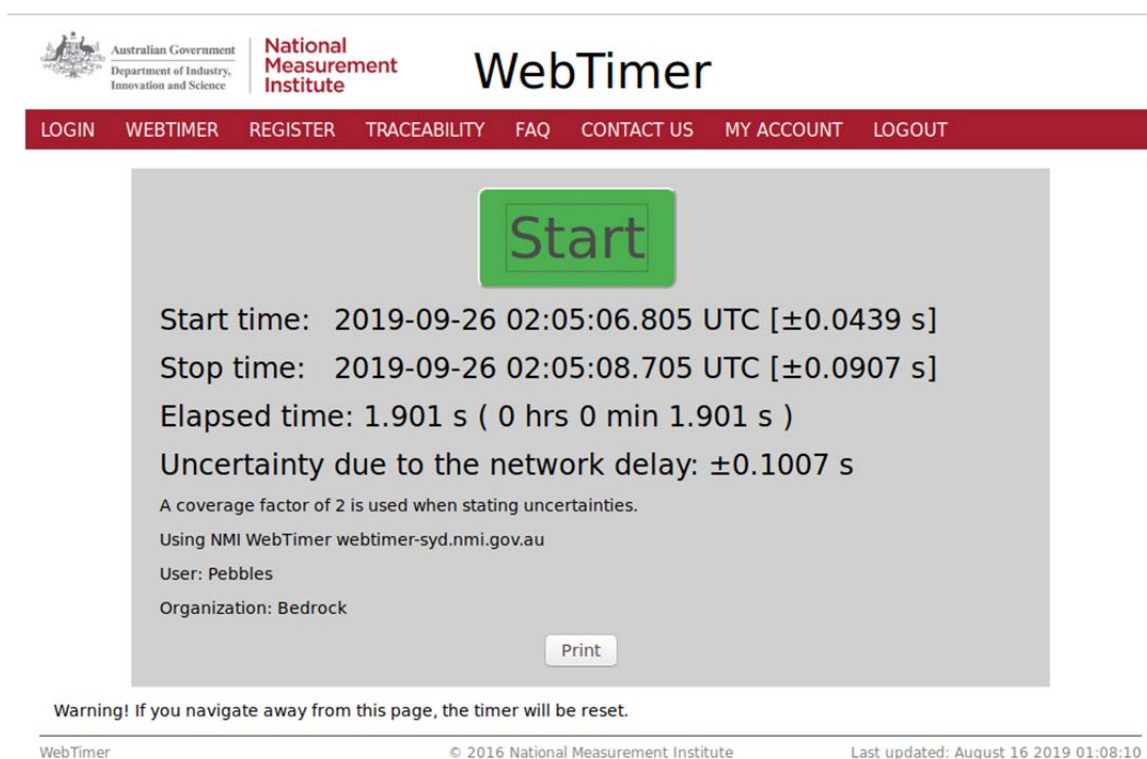**Robert J. Williams**[1], Michael J. Wouters[1], E. Louis Marais[1], Stephen Quigg[1]

[1] National Measurement Institute, Lindfield, Australia

Correspondence: Robert.Williams@measurement.gov.au

Stopwatches are commonly used in testing laboratories for timing processes such as chemical reactions. The accuracy requirements for this time interval measurement are typically modest. For example, one of our clients requires ±20 s accuracy over a time-interval of 4 hours, corresponding to a frequency error of 1 part in 10^3. This accuracy can be met by a crystal oscillator such as is used in a stopwatch.

In Australia, the National Association of Testing Authorities (NATA) recommends that stopwatches be checked against a credible time source every 6 months. Until recently, the recommended reference was the national speaking clock service. This service was shut down on the 30th of September 2019.

We have now implemented the WebTimer [1], a web-based service that can be used to verify stopwatches. The WebTimer works like a stopwatch. The user clicks on a button to get a start time, and then clicks again to get a stop time. These time stamps are obtained from the WebTimer server, whose time is traceable to the Australian national standard for time. The WebTimer reports the time interval between the two timestamps and an estimate of its uncertainty.

Figure 1: The NMI WebTimer main page

The WebTimer is now operational and publicly accessible (Figure 1). We have characterised its operation for many combinations of operating system and web browser. Network delays are the principal source of uncertainty in the reported measurements. The network delay uncertainty is about ±0.2 s (k = 2) and is similar to the corresponding uncertainty associated with the speaking clock service. We have developed a detailed uncertainty budget, including advice on the calculation of uncertainties, and made this documentation available to users. In the future, we plan to duplicate the WebTimer service in several other Australian cities to provide distributed redundancy and reduced network delays for remote users.

References

[1] webtimer-syd.nmi.gov.au

TRANSITIONING TO THE RE-DEFINITION OF THE SI UNITS

C Klafas[1], G W Small[1]

[1] National Measurement Institute, Lindfield, Australia

Correspondence: calla.klafas@measurement.gov.au

For more than 20 years, the Thompson-Lampard calculable cross-capacitor [1][2] was a primary standard used in realising the most precise measurement of capacitance, inductance and resistance in terms of the SI units. In more recent years with quantum-based discoveries, the Quantum Hall Resistance (QHR) has offered a more precise means of realising these units, by approximately an order of magnitude. In May 2019, as part of the re-definition of the SI units, the method of comparing the QHR became an officially adopted realisation of resistance, since Planck's constant (h) and the electron charge (e) were defined as fixed constants, allowing the QHR to be expressed as an integer multiple of the exact quantity of the von Klitzing constant (R_K) [3].

$$R_{QHR} = \frac{R_K}{n} = \frac{h}{ne^2}$$

A new calculable capacitor is currently being developed by the National Measurement Institute of Australia, with a target uncertainty of 0.01 µF/F [4][5]. Parts of the project have been an international collaboration with the International Bureau of Weights and Measures, the National Institute of Metrology, China, and the National Research Council of Canada. The project's aim is to provide a calculable cross-capacitor with the precision that is sufficiently high to provide a measurement chain that links to the realisation of the QHR. This helps in understanding the transition between the QHR and the previous realisation of capacitance.

An overview, including the working principles and method of operation, are presented along with the design challenges for achieving a system with the target uncertainties.

References

[1] Clothier, W.K., "A Calculable Standard of Capacitance", Metrologia, 1(2), 36–55, 1965, doi:10.1088/0026-1394/1/2/002

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OPTIMISING A 16 BIT DIGITAL TO ANALOG CONVERTER FOR A LOW COST 2 DECIMAL POINT THERMOMETER

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It was determined a modern approach with multiple probes, with a system of automated logging and timestamping could save over 120 actions each calibration check compared to current method for each device tested. The Arduino family of microcontrollers looked to be the best fit.

The problem, reading multiple temperature locations to 2 decimal points, manufacturing a device that can be customised for specialised life science applications using low cost components with open source design software.

Can a new device not only improve data collection can it incorporate a reduction in hazards in Biohazard environments in Hospitals or Research facilities?

The Solution is a low-cost Arduino Microcontroller using a Blue Tooth transfer of data to low cost Android device. Use a 16 bit 4-channel Analog to digital converter with a standard library within Arduino software and adding a custom Shield to Arduino see Figure 2.

The Blue Tooth transfer allows safety to Calibration officer to minimise time in a Hazardous Laboratory or Biohazard Hazard Lab or clean room environments, less interruption to laboratory staff.

Considerations for improving the accuracy of 16 bit ADC for temperature measurement to 2 decimal places.

Compact design use SMD where possible.

Reference Voltage – Stability, free of noise.

Voltage Divider Components – Low resistance Temperature Coefficient ±25 ppm, Tight resistance tolerance 0.1 %

Thermistor - Consideration, what is the temperatures range is of interest? Other considerations are Bead size, Lead types, connector types, response time.
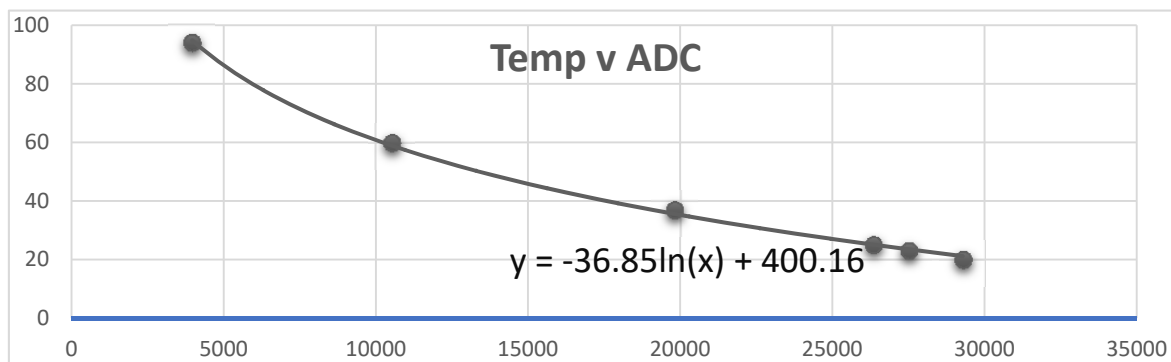

Temp v ADC

$y = -36.85\ln(x) + 400.16$

Figure 1: Temperature versus Analog to Digital value
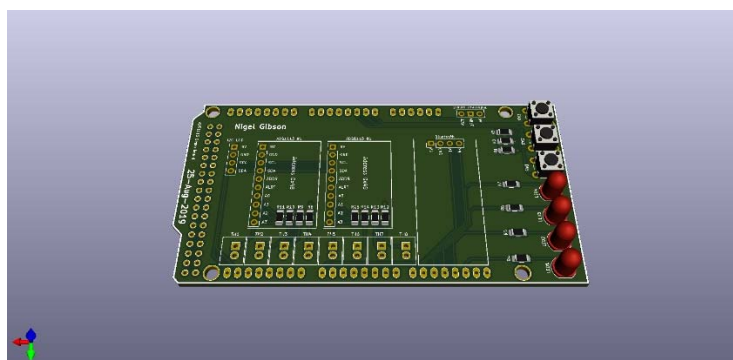

Figure 2: Custom Arduino Shield

HIGH TEMPERATURE CALIBRATION OF THEMOCOUPLES

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The author has extensive experience, with over 30 years in the QC/QA environment and 15 years in calibration & metrology so pretty much has been there, done that, seen it all and got the photos to prove it.

So when a customer asked if we, WIKA Instruments, could calibrate three high temperature thermocouples and issue an IANZ endorsed calibration certificate for an urgent job they were told yes after doing the mental checklist:

> Is this within WIKA's IANZ Scope of Accreditation? Yes—or so it was thought, a bit of a story here

> Do WIKA have the equipment available? Yes

> Do WIKA have the staff available? Yes

And besides what could go wrong?

It is only thermocouples. You know basic "K" type thermocouples that have been used since the days of "Noah and the ark", thermocouples that are used everywhere, for everything. It's not like this is something new, some groundbreaking technology that has never been tried before, it's only "K" type thermocouples, and it's not rocket science???

What could go wrong???

Well the answer is **everything!**

Come and join Daryl and he will take you through WIKA's experience and share the things that they have learnt, who knows you may even learn something as well.

HYSTERESIS IN BIMETALLIC DIAL THERMOMETERS

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Bimetallic dial thermometers are amongst the simplest, lowest cost, and one of the most common thermometers used by industry. With industry becoming increasingly aware of the need for calibration to ensure the reliability of measurements, even dial thermometers are becoming subject to calibration. However, calibration of any measuring instrument requires a knowledge of the sources of error that may affect the instrument readings, and very little is understood or written about the sources of error in bimetallic thermometers. In this study, nine different bimetallic dial thermometers were cycled over a significant fraction of their nominal temperature range to investigate the magnitude of any hysteresis that may occur. It was found that for most of the thermometers, there was a weak indication that hysteresis was present, but the magnitude was typically negligible, being less than one-tenth of a scale division in the indicated temperature. However, for two of the thermometers, the hysteresis was several tenths of a scale division. Since most of the thermometers required corrections a factor of twenty of more larger than the magnitude of hysteresis, the hysteresis in most dial thermometers can be considered to be negligible.

TRANSITION TO ISO/IEC 17025:2017 & ISO 17034, AN ACCREDITATION POINT OF VIEW

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Introduction

In 2016 the ISO publication used to support the general competence of reference material producers ISO Guide 34 was superseded by ISO 17034 and in 2017 the ISO standard used to support the general competence for calibration and testing laboratories ISO/IEC 17025 was technically revised. The 2017 third edition of ISO/IEC 17025 cancelled and replaced the second edition of 2005.

Changes in the standards and associated accreditation requirements

Both 17034 [1] & 17025 [2] have been prepared by the ISO committee on Conformity Assessment (CASCO) and follow the new standard layout which includes General requirements, Structural requirements, Resource requirements, Process (technical and production) requirements and Management system requirements.

For Management system requirements, there are two options:

- Option A: Detailed requirements, as per the previous editions; or

- Option B: ISO 9001 requirements and certification.

Laboratories and producers that comply with the standards will also operate generally in accordance with the principles of ISO 9001. Both standards introduce a risk-based approach on the principles and requirements.

In 2017 the ISO Publication used for setting requirements for Accreditation Bodies ISO/IEC 17011 was also technically revised leading to additional changes for accreditation bodies, in particular introducing set requirements for scopes of accreditation.

Supporting metrological traceability infrastructure

Both 17034 & 17025 provide better structure for activities that support metrological traceability by adding requirements for:

- More detailed requirements for technical competency for key authorised staff;

- Traceability statements in reporting and having distinct requirements between calibration vs testing, certified reference materials vs reference materials; and

- Decision rules when reporting conformance to a specification (JCGM 106 [3] & OIML G19).

Other supporting technical infrastructure documents that influence the accreditation process will be acknowledged including ISO Guide 35 [4] & ISO/TR 16476 [5].

References

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[4] ISO Guide 35 Reference materials - Guidance for characterisation and assessment of homogeneity and stability
[5] ISO/TR 16476 Reference material producers - Establishing and expressing metrological traceability of quantity values assigned to reference materials

IMPLEMENTATION OF AN INTEGRATED MANAGEMENT SYSTEM TO MEET WORLD BEST PRACTICE

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Introduction of Management System Integrations

All new ISO standards develop in alignment with the High Level Structure (HLS) this has spawned the trend of Integrated Management Systems (IMS) to increase in prevalence, whilst IMS development has been around since the early stages of ISO9001 the development this concept is not new, but is still relatively uncommon in Laboratories settings.

ARPANSA is Australia's authority on radiation protection and nuclear safety.

ARPANSA started a journey in 2016 to implement an organisation wide business management system, this system needed to be designed to meet the operational requirements of APRNSA and ISO17025[1]. ARPANSA's operational requirements include many international ISO standards, a number of IAEA [2] and Regulatory codes and standards[3].

The purpose of this paper is to present the ARPANSA approach to design and implementation of a large scale IMS in a laboratory setting.

The ARPANSA model IMS covers the bounds of 4 different NATA accreditation groups, Calibration, Environment, Manufactured Goods, Food and Beverage, and each of the 7 services within the categories are different.

To achieve a management system that has been accepted by ARPANSA we separated the implementation of the system into stages. These stages allowed a progressive roll out across the accredited services then the non-accredited supporting services

During this progressive implementation of the ARPANSA model IMS we had many opportunities for in implementation improvements, these improvements came in the way the implantation was handled for the individual sections, training and communications were paramount to successful implementation of the IMS.

These strategies have enable a smooth transition to a single management system that encompasses 10 International standards [1], 5 Australian government operational requirements [3], 3 IAEA [2] and 8 ARPANSA [3] codes and standards, 1 specific Act of Federal Parliament[3].

During the implementation of the ARPANSA model IMS NATA performed a transition Audit, whilst this audit was inconveniently timed, the outcomes indicated the rapid progression and uptake of the ARPANSA IMS, ARPANSA successfully transitioned to the 2017 version of ISO17025 from this Audit.

Conclusion

With ARPANSA's New IMS the organisation is a better place to deliver the best radiation measurement services, regulation and advice in the most effective and efficient manner to the Australian public and our to meet our international obligations, ARPANSA is part of the way through the implementation of our designed IMS, with an anticipated completion by the end of June 2020.

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[3] ARPANS Act, PGPA, Public service Act, PSPF, PBS, PID act, RHS 24, RPS 11, RPS C6, RPS C5, RPS12, RHS22, RPS3, ICNIRP guidelines

MONTE CARLO ANAYSIS OF COMPLEX MEASUREMENT UNCERTAINTY TASKS

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The Guide to the expression of Uncertainty in Measurement (GUM) [1] provides guidance for determining uncertainties of measurement and is used almost universally in testing and calibration laboratories and in NMIs. Most laboratories will approach this by considering factors which may influence a measurement, estimating their magnitude and sensitivity, and summing them in quadrature. This is shown by the left term in Figure 1, highlighted in blue.

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i) + 2\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} u\left(x_i, x_j\right)$$

Figure 1: The Law of Propagation of Uncertainties

However, most laboratories will ignore the right term in Figure 1, highlighted in green, which deals with input quantities that are correlated, i.e. where one parameter may jointly influence other parameters and hence each of these parameters cannot be considered independently.

Furthermore, there are many examples of situations where there isn't a simple relationship between the measured values and the reported output quantity(ies). One example of this is where intermediate quantities are calculated from the measured data and then a further output quantity is derived from the intermediate quantities, such as determining correlated colour temperature from the spectral distribution of a light source, via the chromaticity coordinates. Another example is where measurements are fed into an equation and regression is used to determine an output quantity, such as the determination of the strain modulus of a foundation (earthworks, roads, etc.) from the load-settlement curves obtained from a plate load test.

The Monte Carlo method, described in Supplement 1 of the GUM [2], provides a convenient way of dealing with such complex situations. Essentially, one uses a spreadsheet software like Excel to set up a calculation whereby the output quantity is calculated from the input data. The input data are then fluctuated according to the estimated magnitude and probability distributions of the uncertainty contributions influencing the input data, and the probability density function (PDF) of the output quantity can be found. The PDF can then be analysed statistically.

In this presentation, the Law of Propagation of Uncertainties will be introduced, and the use of the Monte Carlo method detailed including worked examples and showing how one can deal with correlations. The presenter will use as an example a complex measurement uncertainty challenge that he was recently presented with.

References

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A NEW STEROID REFERENCE MATERIAL TO UNDERPIN STABLE CARBON ISOTOPE RATIO MEASUREMENT IN ANTI-DOPING ANALYSIS

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Gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS) is the only technique approved by the World anti-doping Agency (WADA) to detect doping with illicit synthetic forms of endogenous steroids like testosterone. This technique is able to differentiate a synthetic form of endogenous steroid based on the $^{13}C/^{12}C$ ratio expressed as delta (‰) value. Isotope ratio measurements are not absolute but are reported relative to an international standard as:

$$\delta^{13}C_{sample} = \frac{R\left(\frac{^{13}C}{^{12}C}\right)_{sample} - R\left(\frac{^{13}C}{^{12}C}\right)_{standard}}{R\left(\frac{^{13}C}{^{12}C}\right)_{standard}}$$

The validity of these measurements therefore relies on the availability and selection of reference materials for calibration. The principle of 'identical treatment' where samples and standards are processed similarly is critical for carbon isotope ratio measurement of urinary steroids. Accuracy and comparability of data between WADA laboratories can only be realised through certified reference material traceable to an international standard.

NMIA has produced a pure steroid CRM (MX018) certified by elemental analyser-isotope ratio mass spectrometry (EA-IRMS) and GC-C-IRMS for δ13C values with metrological traceability to the VPDB-LSVEC. This CRM facilitates a novel approach to carbon isotope calibration via GC-C-IRMS by eliminating the need to know accurately the δ13C of reference CO_2 required by the conventional approach. This material assists the WADA laboratories in validating their accuracy and traceability of stable carbon isotope measurements in compliance with WADA protocol (TD2019IRMS).

The CRM is packaged as three ampoules containing thirteen steroids certified for δ13C$_{VPDB-LSVEC}$ from −13.58 to −31.63 ‰ (Table 1). A single injection of the MX018 mixtures following the identical treatment principle results in a typical calibration curve with linear correlation of $R^2 > 0.999$ (Figure 1). A measured δ13C of an unknown sample within the calibration range can now be normalised to the international reference through

$$\delta^{13}C_{VPDB-LSVEC} = m.\delta^{13}C_{measured} + c$$

where *m* refers to the slope and *c* the intercept of the linear regression equation.

Table 1. NMIA MX018 Steroid CRM

| Ampoule		δ^{13}C$_{VPDB-LSVEC}$ (‰)	k	V$_{eff}$
MX018-1	Etiocholanolone	−27.94 ± 0.24	2.0	41
	Androsterone	−27.79 ± 0.21	2.1	15
	11-oxoetiocholanolone	−13.58 ± 0.23	2.1	28
	Testosterone	−27.87 ± 0.24	2.1	24
	11β-hydroxyetiocholanolone	−29.51 ± 0.36	2.0	58
MX018-2	5β-androstane-3α,17β-diol	−29.86 ± 0.16	2.0	57
	5α-androstane-3α,17β-diol	−31.14 ± 0.24	2.0	52
	Pregnanediol	−16.79 ± 0.42	2.0	39
	Epitestosterone	−30.17 ± 0.36	2.0	50
	11β-hydroxyandrosterone	−28.59 ± 0.22	2.0	59
MX018-3	16-androstenol	−30.96 ± 0.37	2.0	47
	Dehydroepiandrosterone	−31.63 ± 0.54	2.0	40
	Testosterone	−22.52 ± 0.33	2.0	54
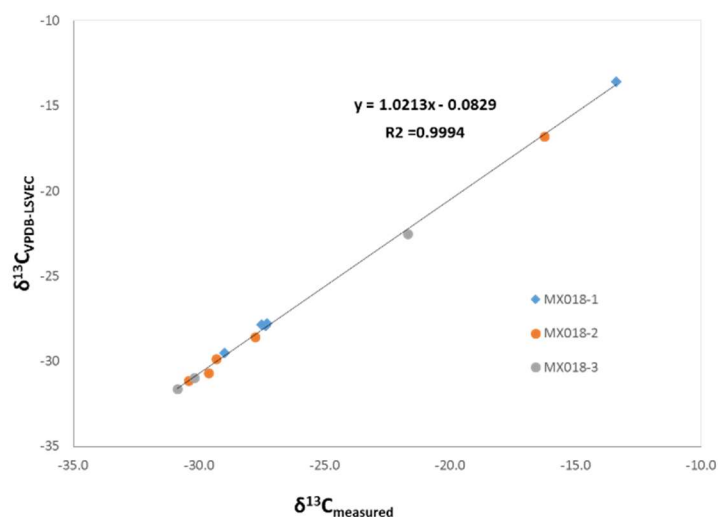
Figure 1: Calibration of GC-C-IRMS using MX018 steroid mixtures

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FAIRNESS IN SPORT - A DNA TEST FOR DETECTING GENE DOPING IN ATHLETE BLOOD SAMPLES

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Gene doping is the misuse of gene transfer technology for improvement of athletic performance in sport and represents a threat to the integrity of sport and health of athletes. Gene or cell doping is defined by the World Anti-Doping Agency (WADA) as: "the use of polymers of nucleic acids or nucleic acid analogues, the use of gene editing agents designed to alter genome sequences and/or the transcriptional, post-transcriptional or epigenetic regulation of gene expression and the use of normal or genetically modified cells with the potential to enhance sport performance" [1]. To protect the integrity of sport and health of athletes, methods that will enable the detection of gene doping are vital.

Here we present the work of the National Measurement Institute in developing a DNA test for detection of Erythropoietin gene doping in athletes blood samples [2 - 4]. The availability of a test will deter athletes to attempt to use this banned form of performance enhancement and assist in the global fight against doping to maintain fairness in sport.

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ON THE INFLUENCE OF DIFFERENT METHODOLOGIES IN THE ESTIMATE OF ULTRAFINE PARTICLE DOSE RECEIVED BY POPULATION IN ALL-DAY ACTIVITIES

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Background: In everyday life, people are exposed to different levels of airborne particle concentration depending on the microenvironment where they perform the different activities [1]. A measure of the exposure level can be evaluated by calculating the received particle surface area dose, which depends on the particle number concentration (PNC), time activity pattern (TAP) and inhalation rate (IR), as well as on the subject itself. While it is relatively easy to have a measure of the PNC which people are exposed to, it is not common to calculate the received dose referring to actual time activity patterns and, more important, to actual inhalation rates. In this paper, a full-direct method is proposed and evaluated for the calculation of the received ultrafine particle (UFP) dose, in which all the parameters are measured in real life conditions (PNC, TAP and IR).

Methods: 34 volunteers were continuously monitored for seven days and the data of particle number concentration, physical activity performed and heart rate (which was used for the evaluation of the inhalation rate [2]) were recorded for each of them. The received dose for the population sample was calculated with the proposed full-direct method and compared with those obtained from different combination of measured and statistical data of TAP and IR obtained from literature, as reported in Table 1.

Table 1. Combination of PNC, IR and TAP for different methodologies of UFP dose calculation (M): data obtained through experimental campaign measurements (Measured); data obtained through literature survey (Standard).

	M1	M2	M3	M4	M5
PNC	Measured	Measured	Measured	Measured	Standard
IR	Measured	Measured	Standard	Standard	Standard
TAP	Measured	Standard	Measured	Standard	Standard

Results: Figure 1 shows the distribution of the total daily doses received by the population sample. The numbers inside the box represent the median value of the total daily dose as calculated with the corresponding methodology.
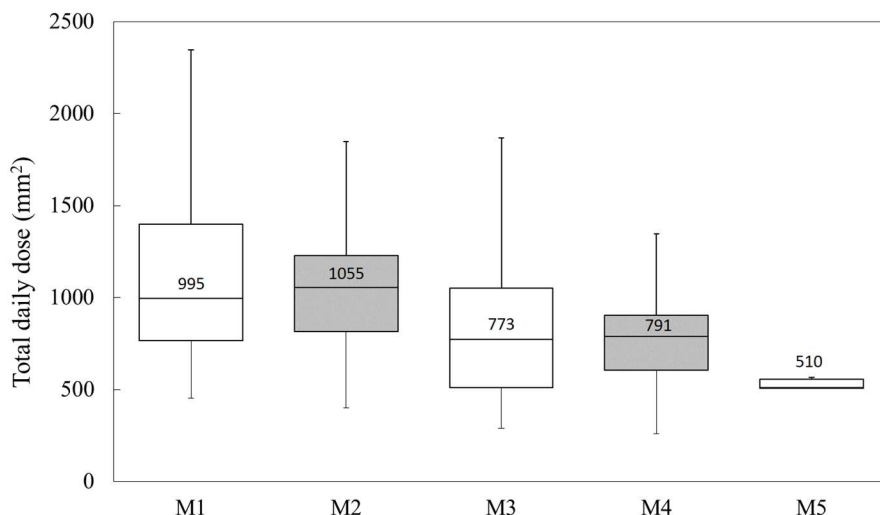

Figure 1: Total daily dose received by the population sample as calculated with the methodologies reported in Table 1

The results demonstrate that depending on the methodology used, the differences in the received total daily dose can be of the order of 49%, while looking at the single microenvironment/activity, these differences can be much higher, with a general underestimation of the standard methods with respect to a full-direct method.

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INTERCOMPARISON OF CSIRO (AU) – JAMSTEC (JAPAN) – NCOSM (CHINA) OCEANOGRAPHIC CALIBRATIONS FACILITIES

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Abstract

The CSIRO Oceanographic Calibration Facility has been in continuous operation for more than 30 years. The facility provides calibration services for high precision instruments used by oceanographers to measure the primary ocean parameters of temperature, conductivity and pressure. The facility provides the means for Australia to develop and maintain a world class calibration capability in the Southern Hemisphere that underpins data integrity for oceanographic science within Australia and the Asia-Pacific region. Oceanographic CTD (Conductivity, Temperature, Depth) instruments offer high measurement capability with typical temperature specification of ±0.002°C and pressure specification of 0.1%. The CSIRO calibration facility has developed measurement systems and traceable references to enable calibration of these sensors with NATA accreditation for temperature and pressure. To provide ongoing confidence in our calibration capability, the facility engages in laboratory inter-comparisons, however finding a partner laboratory with an equivalent level of accuracy and precision is not straightforward. The facility has recently initiated an international laboratory inter-comparison program with science institutes in the Asia-Pacific region these being, Japan Agency for Marine-Earth Science (JAMSTEC, Mutsu, Japan) and National Center for Ocean Science and Metrology (NCOSM, Tianjin, China). This paper describes the technical and logistical challenges of this inter-comparison work, outlines the methodologies used, reviews the accumulated data and discusses the value of undertaking this type of project.

CONSISTENT MEASUREMENT IN A DYNAMIC WORLD
— MEASURING TEMPERATURE IN THE REAL WORLD

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Introduction

The Bureau of Meteorology was formed in 1908 under the Meteorological Act of 1906 [1]. This gave the Governor General the authority to establish observatories and appoint the Commonwealth Meteorologist to gather observations and provide forecasts on a variety of weather and warning services. It drew on the services of state governments that started as much as 120 years prior. The Bureau still has the records of these pioneers who understood the relationship this country has with the environment and the dependence people have with the weather to survive. Today the Bureau carries forward this legacy, building on their records and refining and improving the methods of observation.

Some History

One of the earliest pioneers of meteorological observations was William Dawes [2] who set up the first observatory at the now "Dawes Point" Sydney Cove in 1788. His footprints were followed by great men such as Charles Todd who pioneered the telegraph system from Adelaide to New South Wales and Adelaide and Darwin in the late 1870s. Todd organised his operators to collect and dispatch meteorological observations. By the mid-1800s, most colonies had one or more observatories and surveyors [3]. Melbourne had Robert Ellery and Prof Neumayer who built Melbourne Observatory. Henry Chamberlain Russell, the first Australian born Government Astronomer and meteorologist who established a network of 290 stations across New South Wales from 1870 to 1882. Another of the key characters of this story is Clement Lindley Wragge, who Government Meteorologist in Queensland had by 1893 established a network of 97 meteorological network stations and 398 rainfall stations. These networks would form the backbone of the fledging National Weather Service 1908.

Figure 1: Adelaide Observatory with Stevenson Screen and Glaisher Stand [5]

These explorers and pioneers of meteorology were also pioneering the field of metrology. The first thermometer was only constructed around 1714 [4], a mere 74 years prior to Daws observations at Sydney. The means of measuring the temperature outdoors, was also bespoke. Figure 1 shows the "Glaisher Stand" for mounting of thermometers that was used for observations of temperature in Adelaide for over 60 years in the early 1800s.

By the 1860s Thomas Stevenson, an engineer (son of Robert Louis Stevenson), had invented the "Stevenson Shelter". It has been used across the world in various guises. In Australia, various designs were trialled through the mid and late 1800s but even in 1888 there was still strong debate between Todd, Wragge, and Russell regarding the most appropriate design. It was not until the early 1900s and under the Commonwealth Bureau of Meteorology that a standard design Stevenson Screen came into common usage. This saw the start of a new era of nationally consistent practices.

To the Future

The Bureau is currently going through a reform of its surface observation network. The physical infrastructure will be replaced over the next two years. For the Climate Sites (ACORN-SAT) this is both a risk and an opportunity. We get to take a snapshot of the state of the measurement network as it is now and how it will be in the future. To ensure continuity in the national Climate record, a parallel measurement study will be undertaken maintaining both the existing technology and using the new technology. This study will take account climatic zones and explore more closely the conditions in and around the screen so that the impact of the screen on the measurements can be better understood. The aim of the study is both to ensure an appropriate transition between technologies and to better understand what atmospheric temperature really is.

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THE DEVELOPMENT OF AN AUTOMATED DIMENSIONAL CALIBRATION SYSTEM TO VERIFY THE PERFORMANCE OF RADIAL GAUGES

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At CSIRO's Geomechanics and Geophysics Laboratory (GGL) [1], dedicated 'radial gauges' (linear measurement transducers) are used to measure the dynamic dimensional changes of cylindrical rock samples, while they are subjected to the extreme forces and pressures of geomechanical testing. Such gauges, as shown in Figure 1, are utilised to measure and help characterise the geomechanical properties of the test sample, as a result of its radial deformation during such tests. These gauges utilise the principle of an electrically balanced Wheatstone bridge of four resistive strain gauges – a common measurement principle adopted in the design of loadcells [2].
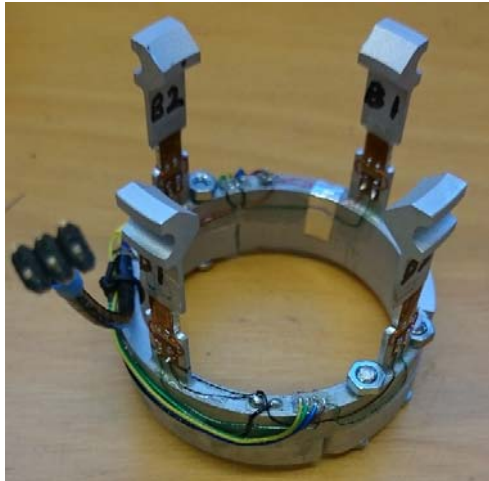

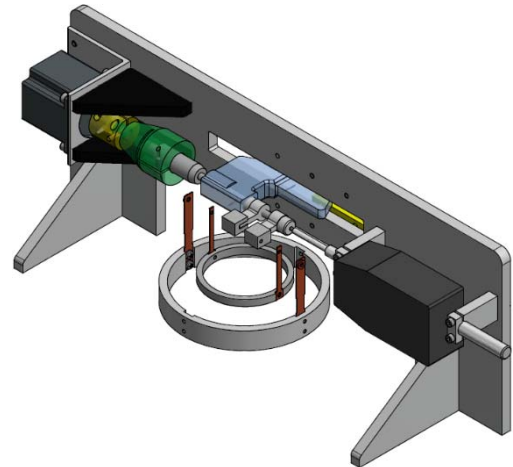**Figure 1: A four arm, two axis, twin bridge radial gauge**

Figure 2: 3D model of the automated radial gauge calibration jig

Up until September 2019, these transducers had been manually calibrated once or twice per a year by one or two technical staff within the GGL. With GGL's operational history dating back to 2001 and a growing inventory of thirty of these transducers, a new and improved dynamic automated calibration procedure [3] was proposed. Among the reasons for the proposal was to add value, alleviate the time required of technical staff of this highly repetitive and time-consuming task and ultimately improve the measurement quality. In summary, we describe our automated system shown in Figure 2 including the concerns addressed, advantages gained, and conclusions discovered.

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[2] Trent, D., Load Cell and Strain Gauge Basics, 2017, www.800loadcel.com/load-cell-and-strain-gauge-basics.html
[3] National Register on Vocational Education and Training (VET) Australia, MSL905006 - Create or modify automated calibration procedures (Release 1), 2018, training.gov.au/Training/Details/MSL905006

ALTERNATIVE METHODOLOGY FOR ESTABLISHING A VACUUM SCALE USING A STATIC EXPANSION SYSTEM

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Vacuum pressure measurements are required in many areas of modern industry and research, including meteorology, aerospace, defence, and other industrial applications of vacuum technology. The accuracy of these measurements often impacts energy efficiency, product quality, and equipment safety, highlighting the importance of maintaining a reliable vacuum calibration service.

The NMI vacuum calibration service relies on two significant devices. The Static Expansion System (SES) and the Vacuum Comparison System (VCS). The SES is a series of volumes connected by valves which can be opened to allow known pressures of gas to expand into pre-evacuated larger volumes, generating lower pressures, calculable using the ideal gas law. The development and operation of the SES as a primary standard was presented at MSA conferences in 2009 [1] and 2011 [2]. Operation of the SES as a standalone reference requires months of calibration effort every two to five years. The VCS is the transfer standard, delivering customer calibrations, and requires several weeks' calibration effort annually. A new calibration strategy has been implemented which significantly reduces the calibration efforts without compromise to the calibration capability. The use of the SES as a pressure divider, linked to a reference pressure balance, enables the calibration of the VCS Capacitance Diaphragm Gauges (CDGs) without requiring determination of the SES volume ratios, and allows a reduction in calibration uncertainty while halving the calibration effort. The implementation of this process contributes improved continuity to the NMI pressure scale from vacuum to 500 MPa.

References

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[2] Ward B, Man J, Vacuum Calibration Facility at NMI, MSA 2011, pages 41–95, 2011

ZEROING AN ABSOLUTE PRESSURE TRANSDUCER TECHNIQUES AND PITFALLS

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Zeroing a pressure transducer is a fairly straight-forward process, unless it is an absolute transducer. The purpose of this presentation is to describe three different techniques that can be used, depending on the available reference standards and the range of the zero-based absolute Device Under Test (DUT):

- The first will be zeroing a transducer near zero absolute pressure using a vacuum transducer;

- The second will be zeroing a transducer using the minimum pressure of a deadweight piston gauge; and

- The third will be zeroing a transducer with a precision barometer.

Each technique has either some physical limitations, or accuracy compromises, that will be discussed and examples quantified. This presentation will also discuss some of the other, more generic problems in generating stable and consistent pressures in the physical calibration setup using a pneumatic medium.

HYSTERESIS EFFECTS ON CAPACITANCE HUMIDITY SENSORS

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This presentation will provide insight into the propagation and assessment of the hysteresis of capacitance humidity sensors drawing on the results of 80 sensors obtained over the past few years of client calibrations at NMI.

The accurate measurement of humidity is important in a vast range of areas: from environmental monitoring to process control in advanced manufacturing industries. Although dew-point meters can provide extremely high accuracies, they are bulky, expensive and have slow response times. The vast majority of ambient pressure humidity measurements are made using miniature polymer-based electrical-capacitive sensors. This type of sensor usually suffers hysteresis because of complexity of the water adsorption and desorption processes, and this behaviour often dominates the achievable measurement uncertainty.

In the study here, NMI has examined our large dataset of calibrations, which encompasses a range of different minimum and maximum humidity conditions to quantify the practical real-world impact. We also present results with a range of soaking-times and recovery times to gain a better understanding of the underlying processes.

IMPROVING THE PERFORMANCE OF RELATIVE HUMIDITY MEASUREMENTS IN HIGH-HUMIDITY ENVIRONMENT

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High humidity applications pose a challenge for accurate measurements by solid-state sensors. Short calibration intervals, hysteresis and short-term drift are traditional problems for standard sensors, which means different technologies must be employed to improve performance and reduce maintenance costs. It is important to use advanced heating controls to safeguard the sensors used in these critical measurements. A deeper dive into these challenges and technology solutions will be detailed as part of our solutions to help ensuring accurate measurements in demanding environments.

PMU CALIBRATION - WHY AND HOW?

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This is a basic presentation about the background of the Verification of Phasor Measurement Units (PMU) and the Standards of how they are to be tested/verified. The development of the IEC/IEEE 60255-118-1:2018[1] PC37.242[2] standards and how they have impacted the testing of PMUs.

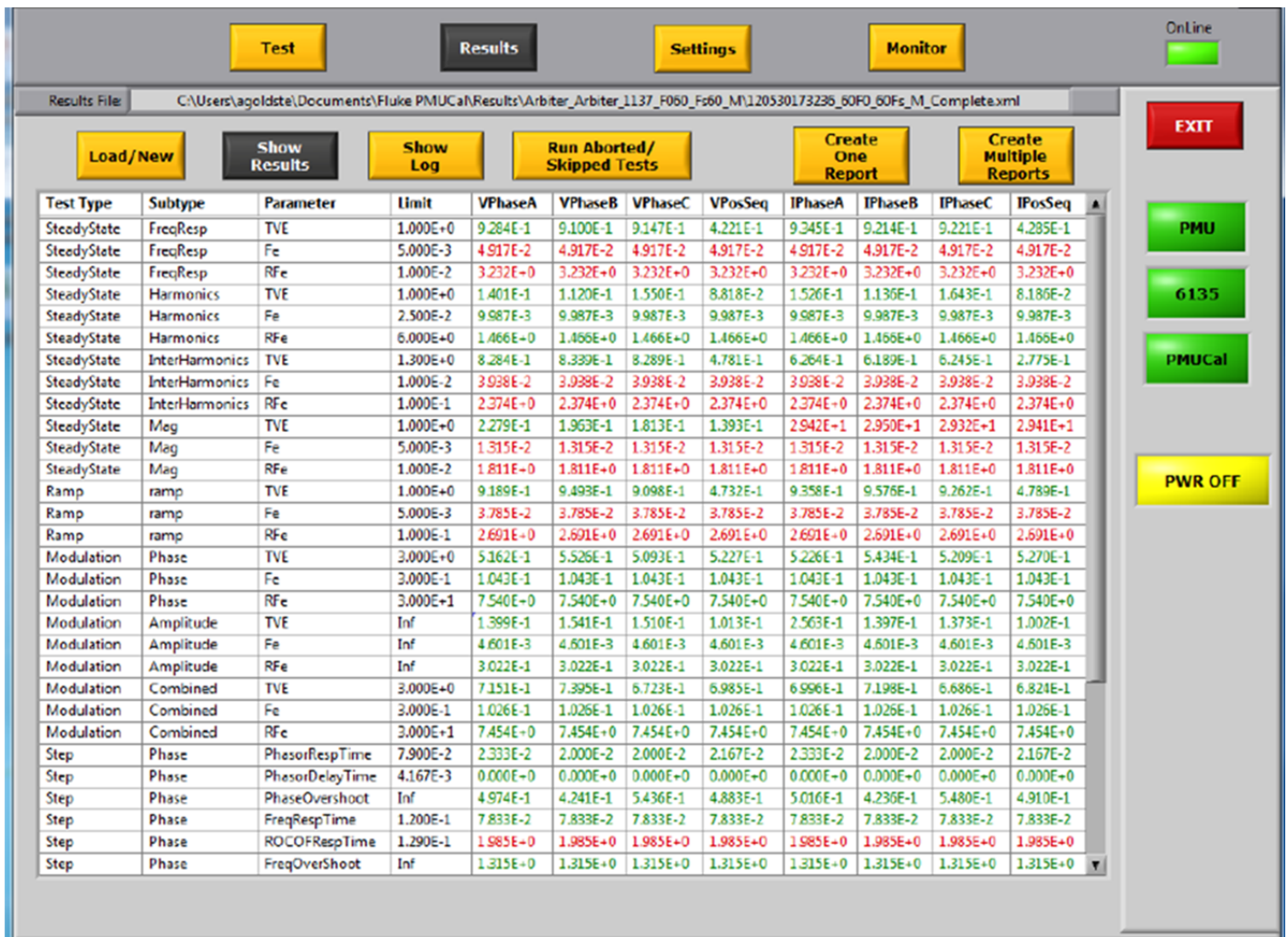The below Figure 1 shows an example of the data that is collected and reported on.

Figure 1: Collection of PMU Testing Data

This presentation's main objective is to present background and one method to support the verification/testing of PMUs around the world. How can you support the IEC/IEEE 60255-11801:2018 and IEEE PC37.242 standards as related to testing PMU devices? What does it take for effort, time, and expense to be able to support them. Short discussion on the traceability requirements and how to meet them.

References

[1] IEC/IEEE 60255-118-1:2018 Measuring relays and protection equipment - Part 118-1: Synchrophasor for power systems - Measurements
[2] IEEE C37.242-2013 - IEEE Guide for Synchronization, Calibration, Testing, and Installation of Phasor Measurement Units (PMUs) for Power System Protection and Control

MODELLING THE ERRORS OF A TRANSFER POWER STANDARD FOR IMPROVED CALIBRATION EFFICIENCY

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Reference power meter calibrations at MSL can be performed directly against our primary power standard, which is accurate but slow. Alternatively, a more efficient calibration can be made against a Radian RD-31 used as a transfer standard. However, the efficiency is lost when the transfer standard is required to be calibrated at every point that the meter under calibration requires. This can be many points due to the large parameter space of power meter calibrations, i.e. voltage, current, phase and channel, and at both active and reactive power for both star and delta configurations. An alternative to the point by point method is to make selected measurements and model the error.

To identify the shape of the error, a range of RD-31 active power measurements closely spaced in phase and at currents ranging from 0.1 to 5 A were obtained at voltages of 63.5 V, 110 V and 230 V. The error (E) in μw/VA can then be modelled by

$$E = a_0 + a_1 I + (a_2 + a_3 \log I) \sin\left(a_4 + \frac{\theta\pi}{180}\right)$$

where *I* is the current and *θ* is the phase in degrees. Using non-linear regression software, values for the coefficients $(a_0 - a_4)$ were obtained.

By taking a reduced selection of points to fit to this model (Figure 1) it can be shown that the uncertainty in the fit does not significantly impact the overall uncertainty of a measurement point.
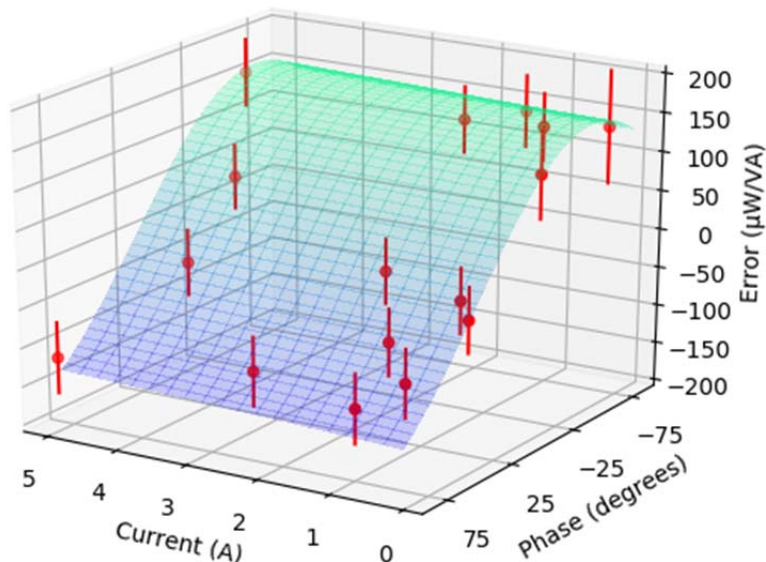
Figure 1: Plot of Selected Points and Fitted Curve at 63.5 V

By characterising the RD-31 error from a few selected points, we can model the error and reduce the total number of measurements required for the transfer calibration. Using this method for obtaining measurement equations across the full range of parameters for reference power meters will allow us to significantly reduce the time to calibrate the RD-31 against the primary power standard.

CALIBRATION TECHNIQUES FOR NEW-GENERATION DIGITAL MULTIMETERS AND CALIBRATORS

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Precision multifunction calibrators and high-end digital multimeters are presently used at many calibration laboratories as primary references for electrical calibrations. In recent years, the accuracy of these instruments has dramatically increased and new calibration techniques have become necessary to realise their full potential.

For direct voltage calibration, we have developed a new facility based on programmable quantum voltage standards and resistive voltage dividers, covering voltages up to 1100 V. Uncertainties as low as 0.1 µV/V have been achieved [1]. A variation of this technique, involving working standards calibrated by the quantum reference, has been implemented as a cost-effective solution that still delivers higher precision than the method used previously. A separate service has been established to calibrate resistive voltage dividers up to 1100 V, which will help many laboratories improve the uncertainty and reliability of measurements at higher voltage ranges.

A suite of calibration techniques and test methods have been developed for all of the functions of a multifunction calibrator such as AC voltage, DC and AC current and resistance. The uncertainties for these calibrations are largely limited by the performance and specifications of the device under test. Measurement techniques have also been established to calibrate multifunction power calibrators such as the Fluke 6105A where, in addition to the above quantities, harmonic voltages and currents and phase defect angle must be measured [2].

References

[1] Georgakopoulos, D., Budovsky, I., Grady, S., & Hagen, T., Quantum calibration system for digital voltmeter from 10 nV to 1 kV, IEEE Transactions on Instrumentation and Measurement, 2013, doi:10.1109/TIM.2012.2225928.

[2] Georgakopoulos, D., Budovsky, I., Benz, S. P., & Gubler, G., Josephson arbitrary waveform synthesizer as reference standard for the measurement of the phase of harmonics in distorted waveforms, IEEE Transactions on Instrumentation and Measurement, 2018, doi:10.1109/TIM.2018.2877828

CALIBRATION OF HIGH-VOLTAGE MODULES OF ELECTROMAGNETIC COMPATIBILITY TEST SETS

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Electromagnetic Compatibility (EMC) immunity testing verifies the ability of electrical and electronic equipment to withstand electromagnetic interference (EMI) form the environment of its use. EMC testing is usually carried out using EMC test sets, which generate a range of EMI signals according to the IEC 61000 series standards. An EMC test set usually contains high-voltage modules, such as an electrical fast transient (EFT)/burst module and a surge module, for generating transient over-voltages and over-currents. These modules need to be calibrated periodically to ensure their performance. However, it can be difficult to measure high-voltage and high-current transients due to a range of influence factors such as the limited bandwidth of the reference measurement system and interference caused by the high-voltage and high-current signals. In this paper, we describe the reference systems for calibrating high-voltage modules of EMC test sets, specifically the EFT/burst module and the surge module.

The EFT/burst modules are calibrated using reference resistive attenuators in compliance with IEC 61000-4-4. The uncertainties of measuring the peak voltage and time parameters due to the limited bandwidths of the reference attenuators are estimated using the step responses of the attenuators and deconvolution. The uncertainty budget for the EFT/burst calibration with discussions of the components will be presented. The least uncertainties that can be achieved for this calibration are 7% for peak voltage and 8% for rise time of the burst pulses from 3 ns to 6 ns.

Surge modules are calibrated using an impulse voltage probe for the voltage surge and an impulse current shunt for the current surge, in compliance with IEC 61000-4-5. For the voltage surge, the uncertainties of measurement are estimated taking account of the frequency characteristics of the voltage probe, the voltage linearity of the probe and the dynamic scale factor of the digital recorder. For the current surge, major uncertainty components being considered include the frequency performance of the reference shunt, the effects of the high current interference on the reference shunt and the digital recorder and the dynamic scale factor of the digital recorder. The uncertainty budgets for the surge calibrations with discussions of the components will be presented. The least uncertainties that can be achieved for calibration of the voltage surge are 2% for peak voltages up to 1000 V and 5% for time parameters of the voltage surge. The least uncertainties that can be achieved for calibration of the current surge are 1% for the peak currents up to 500 A.

NMI STANDARD OF ELECTRICAL POWER AS A REFERENCE FOR PHASE MEASUREMENT AND CHARACTERISATION OF VOLTAGE AND CURRENT SCALING DEVICES

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In recent years the National Measurement Institute of Australia has introduced a working standard of electrical power with an overall uncertainty of less than 10 µW/VA at power frequencies and a high degree of automation. The standard comprises a 1000 V inductive voltage divider with ratio uncertainties at power frequencies less than 0.01 µV/V [1], a computer–controlled multi-range current transformer for currents up to 200 A [2] and a digital power comparator [3], characterised against a thermal power comparator [4].

This paper explores additional possibilities offered by the system, which can be employed to calibrate multifunctional instruments such has power analysers. The new measurements include:

1. Measurement of phase shift between two voltages up to 1000 V, two currents up to 200 A and/or one voltage and one current. The uncertainty is less than 0.001° throughout out the range.

2. Measurement of in-phase and quadrature ratio errors of voltage dividers up to 1000 V at frequencies up to 1 kHz.

3. Measurement of in-phase and quadrature ratio errors of current to voltage converters, such as current shunts and current transformers up to 200 A at frequencies up to 1 kHz.

4. Measurement of voltage and current harmonics (amplitude and phase).

Most of the above capabilities have been realised as calibration services and recently approved by NATA as part of the scope of NMI's accreditation. The paper presents technical details of the new measurements.

References

[1] Small, G.W., Budovsky, I.F., Gibbes, A.M., Fiander, J.R., Precision Three-Stage 1000 V/50 Hz Inductive Voltage Divider, IEEE Transactions on Instrumentation and Measurement, 54(2) 600–603, 2005, doi:10.1109/TIM.2004.843377

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TRACEABLE CALIBRATION FOR PARTIAL DISCHARGE CALIBRATORS

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The partial discharge (PD) test provides "health" information about high-voltage equipment in power systems such as power transformers, transmission cables, circuit breakers, etc. Detection of abnormal PD activities provides an early warning of insulation failures and allows power utilities to take measures to avoid catastrophic failures and breakdowns. Therefore, accurate PD measurement is one of the crucial tests for ensuring the reliability of electricity supply.

PD measurement systems used in the PD tests are usually calibrated against a PD calibrator. Therefore, PD calibrators need to be calibrated regularly to ensure the accuracy of the PD measurements.

This paper describes a reference measurement system developed at the National Measurement Institute for traceable calibration of commercial PD calibrators with charge values from 1 pC to 1000 pC. The system consists of two reference charge generators, a resistor for measuring the charge current, a digital oscilloscope and software for data acquisition and calculation. The reference charge generator includes a charging capacitor, a DC voltage source and a mercury relay for initiating the charge pulse. The reference charge value is based on traceable measurements of the capacitance of the charging capacitor, the DC voltage of the charged capacitor and the resistance of the measuring resistor. The digital oscilloscope is used as a transfer standard for measuring the charge values generated by the reference charge generator and the charge values generated by the PD calibrator under test, which leads to the determination of the errors of the calibrator under test.

The paper provides details of the techniques for ensuring the accuracy and stability of the calibration system, e.g., shielding arrangement for reducing the stray capacitance of the charge capacitor, the arrangement for measuring the reference values and the methods for processing the charge pulses recorded by the digital oscilloscope.

The least calibration uncertainty that can be achieved by the system is 0.03 pC + 3% of charge reading.

WAVE MEASUREMENT, A COMPARISON OF METHODS

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The characteristics of open ocean waves, particularly wave height and direction, is a critical element of safety at sea and of oceanographic and weather forecasting. Traditionally an observation estimated by sailors on ocean going vessels, in the last 20 years there has been a growing number of remote ocean buoys that can as a monitor the amplitude of waves. In the past few years this has exploded with the advent of lower cost systems that provide spectral data with both the amplitude and direction of the waves.

This presentation will look at a field comparison two wave buoy system and look at some novel approaches to understanding waves in open water.

PRELIMINARY RESULTS OF CORIOLIS METER TESTING OVER A WIDE VISCOSITY RANGE

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We report here on preliminary results from an international collaboration to assess the viscosity dependence of Coriolis liquid flow meters. Coriolis meters are becoming increasingly widely used for high-accuracy flow metering: for example for the custody transfer of high-value products such as light hydrocarbons (LNG, LPG, condensate) or other products such as anhydrous ammonia. Calibration in water ($v = 1$ cP) is generally used by industry as it is easy and convenient. Although the design of these meters generally provides excellent independence of the measured mass flow rate on produce density and viscosity, corrections for pressure, temperature and viscosity are generally required to achieve the required accuracy for custody transfer applications. In the study 4 flowmeters of different designs have been calibrated at facilities in Japan and Australia to assess the magnitude of this error over a range of flow rates. Butane ($v = 0.1$ cP), D130 ($v = 9$ cP) and silicone oil ($v = 1000$ cP) testing is done in Australia, whilst water ($v = 1$ cP), Spindle oil ($v = 28$ cP) and Light oil ($v = 9$ cP) testing has been done in Japan.

We present some early results from this collaboration, together with some preliminary conclusions.

A FACILITY FOR THE CALIBRATION OF FLOW METERS USING HIGH VISCOSITY FLUIDS

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Meter performance is highly dependent on fluid viscosity. With limited availability of high viscosity test facilities, metering manufacturers' often base performance of high viscosity meters on data from meters tested low viscosity fluids.

NMI Londonderry flow facility has developed a high viscosity meter test facility which can be used to determine actual meter performance using high viscosity fluids. This facility is used to test meters gravimetrically at up to 120 L/min and 12 bar using two silicone-based test fluids of 1000cSt and 10kcSt in a closed loop test circuit. System control and data capture is done using LabVIEW and the system was successfully validated via comparison with the Londonderry flow facility 60 L piston proving system.

The system has been used to test seven prototype meters for a local meter manufacturer with performance and pressure drop data used to refine the design of the meters and replace previous estimated pressure drop tables.

ESTABLISHMENT OF AN ULTRA-HIGH-ACCURACY 670-L PVTT GAS FLOW PRIMARY STANDARD AT NMIA

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The continuous demand of better uncertainties in the measurement of gas flowrates necessitates the establishment of a new gas flow standard based on direct measurements of pressure, volume, temperature, and time: PVTt system. To calculate the mass of gas inside a known volume (V), the new standard relies on accurate measurements of pressure and temperature of a gas with a well-determined equation of state such as air or nitrogen. Using a diverter valve and a high accuracy timer, the elapsed time of collecting gas from a device under test (DUT) can be measured and mass flowrate through this DUT can therefore be determined.

The PVTt standard consists of 8 hollow stainless-steel cylinders submersed inside a water bath with a nominal volume of 670 L. This new standard will be used to calibrate gas flow measuring devices (mainly critical flow Venturi nozzles) for a flow range from 1 L.h^{-1} to 100 m³.h^{-1} at pressures up to 700 kPa.

A comprehensive uncertainty analysis of the mass flowrate as measured by the PVTt system will be presented, which will include descriptions of:

      (1) the method used to determine and validate the volumes of the cylinders;

      (2) the assessment of the temperature uniformity and stability of the water bath; and

      (3) the effect of the diverter valve on the total uncertainty.

In addition, results of internal comparisons between the PVTt system and NMIA's existing primary standards, a 300-L bell and mercury-sealed piston provers, are also presented.

OUTREACH – WHY, WHAT AND HOW?

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In this presentation you will hear about what the Measurement Standards Laboratory of New Zealand did to raise awareness about the SI redefinition in 2019, measuring success, understanding how to do this better in the future and motivating the metrology community to get involved.

Why do Outreach? The simple answer for a national measurement institute is it's about making metrology visible. MSL's engagement strategy is all about being active, being seen and being relevant to the audience.

Over the first 6 months of 2019 MSL embarked on an ambitious campaign sharing the SI redefinition with New Zealand. The campaign included building a Kilogram display stand, creating a competition to throw away one of the MSL reference kilograms with a guest appearance from a Commonwealth Gold medallist, touring NZ visiting five cities with the display stand and presenting on the Redefinition, and followed this up with a LEGO kibble balance video and an update of Measurement (MSL) related content on New Zealand's Science Learning Hub website.

How was success measured and how can the metrology community get involved in Outreach?

BOOSTING THE METROLOGY WORKFORCE —ONE APPRENTICE AT A TIME

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The greying of hair in the metrology field warns of an impending shortage of skilled technicians. The Measurement Standards Laboratory (MSL) is New Zealand's national metrology institute and has recognised that metrology services are key in helping NZ businesses remain competitive in rapidly advancing technological areas on the international stage.

To achieve this vision, MSL looked at various ways of promoting metrology as a career choice. Should we be looking for school leavers or more experienced workers seeking a change in direction? Should we focus on theoretical education through schools, polytechnics and universities or practical based on-the-job training in conjunction with employers? How to identify individuals with the right mix of personal qualities and practical skills?

In this presentation, an overview will be given of apprenticeships in New Zealand and how MSL's motivation to address the lack of metrology education available in NZ led to forming our own metrology apprenticeship scheme.

Development of the program including educational resources and real work experience will be discussed, followed by recruiting and choosing the perfect candidate. Finally, the introduction of MSL's first-ever Early Career Measurement Technician together with a review of her progress so far and the lessons learned along the way.
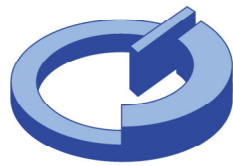
Workshops

DRY BLOCK CALIBRATORS: OPERATION AND CALIBRATION

Chair: Rod White[1]
Presenters: Peter Saunders[1]

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Dry-block calibrators are widely used in second-tier calibration laboratories and throughout industry as a calibration medium for temperature measurement and control systems. The main advantages are convenience and safety – they are portable, compact, quick to respond to setpoint changes, and usually contain no hot or flammable working fluids. To make traceable calibrations with dry blocks, it is essential to measure the spatial and temporal temperature variations of the calibrator and determine the corresponding uncertainties. The purpose of this workshop is to provide users with an overview of the operating principles of the calibrators and describe a simple method for surveying a dry-block calibrator and assessing its accuracy as a calibration medium. The workshop builds on the newly published MSL technical guide on the calibration of dry-block calibrators [1].

References

[1] P Saunders, MSL Technical Guide 42: Calibration of dry-block calibrators, 2019, measurement.govt.nz/download/54

CALIBRATION OF MICROWAVE FURNACES

Chair: Daryl Pettit[1]

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The author has extensive experience, with over 30yrs in the QC/QA environment and 15 yrs in calibration & metrology so pretty much has been there, done that, seen it all and got the photos to prove it, until now.

Typically laboratory furnaces up to now have been of the traditional muffle furnace type and the calibration of these has been reasonably straight forward. However as technology advances, laboratory equipment also evolves and morphs into bigger, better, faster and more efficient devices. It appears that laboratory furnaces as we know them, are at that stage. Recently a customer has asked for a calibration to be done on their newly purchased microwave furnace. They have advised that they are looking at replacing all their traditional muffle furnaces with microwave furnaces. Needless to say this has thrown a spanner or two into the finely turned calibration wheel.

It would be good if the following could be discussed

Has anyone else seen or been asked to calibrate microwave furnaces?

How are they calibrated?

Is the spatial temperature likely to be more or less variant than the muffle furnace?

Is a spatial calibration required?

Can you use the manufacturer's calibration module to check/calibrate the display probe?

If it is used to ash samples only, does it need to be calibrated?

What extra precautions, if any, need to be taken?

And just general discussion with topics from the floor.

PRESSURE WORKSHOP – MSA TEST METHODS, STATUS AND UPDATES

Chair: Randall Anderson[1]
Presenters: Neville Owen[2], Liam Shanahan[1]

[1] Australian Pressure Laboratory, Melbourne, Australia

[2] National Measurement Institute, Melbourne, Australia

Correspondence: pressuregroup@metrology.asn.au

In 2008, the MSA Pressure Interest Group developed and published two test methods for calibration of digital and mechanical pressure gauges, which have been widely adopted by pressure calibration laboratories in Australia. These are freely available at www.metrology.asn.au/testmethods.

The pressure workshop will review the current state of these test methods, and discuss areas requiring revision to ensure they remain contemporary and fit-for-purpose, in response to developing technologies and testing practices.

Anyone with an interest in pressure measurement and calibration is welcome to attend. There will be opportunities to ask questions and provide feedback during the workshop. At the conclusion, there will be an opportunity for experienced and motivated MSA members to sign-on to participate in a smaller working group, tasked with drafting and ratifying the revisions to MSA Test Methods 1 and 2 during the year.

HUMIDITY (AUS-NZ COOPERATION TO FACILITATE CONSISTENCY)

Chair: Ferdouse Jahan[1]

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Humidity measurement is an important and commonly measured quantity in a wide range of industries. It can be measured and expressed in many different ways. Although humidity measurements have been made for hundreds of years, the field of humidity measurement has not reached the same level of standardisation as has been implemented in other fields of measurement. It is not in the SI unit system.

The intent of this workshop is to seek agreement on standard methods to be employed by primary and secondary calibration labs located throughout New Zealand and Australia. The facilitator will inform of current practices and issues related to the calibration of humidity measuring instruments.

Discussions will cover the:

i) Adoption of a common unit of expressing relative humidity and its uncertainty. There is no internationally-accepted unit for expressing relative humidity. Do we need a unit, acceptable by everybody, and how will it look?

ii) Measurement of hysteresis and it's implication in the uncertainty of humidity measurement. Do we always need to measure hysteresis and include it in the uncertainty? What is the best way to measure hysteresis?

iii) Use of reference functions to calculate relative humidity and their non-uniqueness. Is there an accurate method of calculating humidity?

iv) Use of traceable salt solutions to calibrate RH sensors. Can they be trusted?

CAN MODEL-BASED TESTING BE ACCREDITED AND IS IT TRACEABLE?

Chair: Ilya Budovsky[1]
Presenters: Paul Pokorny[2], Murray Early[3]

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The facilitators will present an account of the issues related to the increasing use by electricity utilities and metering providers of "model-based" testing (MBT) techniques for the indirect calibration of instrument transformers (current & voltage transformers for revenue and other uses) in the field. The dependence of the accuracy on the test object itself, the assumptions of the model, and measurements being made under conditions that are not the normal transformer operating conditions represent a challenge to the metrologist, and raise a question over the traceability of MBT measurements. Presently, in Australia and New Zealand, there are no 17025-accredited laboratories with scopes strictly covering MBT set calibration or in situ instrument transformer calibration using these devices.

The accuracy of an MBT set depends on the transformer circuit model used, how the set determines the model parameters, its derivation of the errors, the design and condition of the transformer, the transformer operating voltages and the interference effects of magnetic/electric fields found in substations. Although it is recognised that there are limitations with this technology, due to their convenience, MBT sets are being used to commission instrument transformers, often without calibration by primary injection of voltage or current being carried out in parallel. The common method of calibrating MBT sets is to use artefacts that have been calibrated via primary injection. Many of the parameters measured by MBT sets, such as dc winding resistance, knee point, excitation, admittance, inductance, etc., can possibly be made traceable though existing accredited calibration techniques.

References

[1] Pokorny, P.E. (Power System Support Pty Ltd) & Hansom D.S. (J.S. Hansom Pty Ltd), Concerns as to the validity of electrical power and energy measurements based on model-based accuracy testing of instrument transformers, J.S. Hansom Pty Ltd, 2018
[2] Jones, K. & Stewart, T., Indirect Transformer Calibration, Measurement Standards Laboratory of New Zealand, presented at the Metrology Society of Australasia Conference MSA2015, Queenstown, 2015
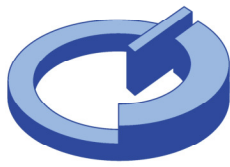
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