CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY

Large Volume Cone Differential Pressure Meters

Basic Rise Time Measurements

History of Lowry PMEL School

2017
OCTOBER
NOVEMBER
DECEMBER

Electric Current Measurement

DS Series Current Transducers

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

DS200

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

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

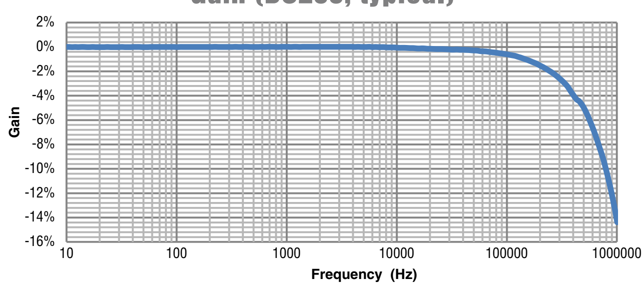
DS2000

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

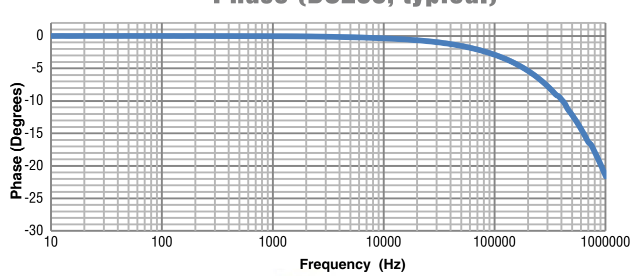
† Voltage Output options available in ±1V and ±10V

Gain / Phase

Gain (DS200, typical)



Phase (DS200, typical)



DSSIU-4 for Multi Channel Systems

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

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

DSSIU-4

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Volume 24, Number 4

FEATURES

DEPARTMENTS

ON THE COVER: Lin Lu, Electronics Calibration Technician, calibrates a TTC6000 at Test Equity in Moorpark, California.

UPCOMING CONFERENCES & MEETINGS

Jan 26-Feb 1, 2018 IMTEX & Tooltech: International Exhibition of Cutting Tools, Tooling Systems, Machine Tool Accessories, Metrology and CAD/CAM. Bengaluru, India. The twin exhibitions will create a platform for exhibitors to showcase their innovations in metal forming technologies, robotics & automation, welding & joining, wire-forming & drawing, and many more. http://imtex.in/imtex2k18/index.php

Mar 8-9, 2018 ICOMA 2018: 20th International Conference on Optical Metrology and Applications. Phuket, Thailand. This conference aims to bring together leading academic scientists, researchers and research scholars to exchange and share their experiences and research results on all aspects of Optical Metrology and Applications. https://www.waset.org/conference/2018/03/phuket/ICOMA

Mar 16, 2018 A2LA Technical Forum and Annual Meeting. Reston, VA. Make plans now to join A2LA and your industry peers in Virginia in March 2018. As an attendee of the A2LA Technical Forum, you will take part in expert-led sessions providing training and education on key topics, and exchange insights during program-specific technical discussions. http://www.a2la.org/tech-forum

Mar 20-23, 2018 MSC Training Symposium. Anaheim, CA. Measurement Science Conference presents the 48th Annual Training Symposium. This year will feature "Innovations in Metrology," along with NIST seminars, tutorial workshops, technical presentation, an exhibit hall, and ASQ-CCT training. http://annualconf.msc-conf.com/

Mar 21-23, 2018 International Symposium on Fluid Flow Measurement (ISFFM). Querétaro City, Mexico. Fluid flow measurement professionals from industrial research laboratories, universities, government laboratories, and industrial field study teams from all over the world will present their latest results in more than 50 technical presentations in parallel sessions. http://www.isffm.org

Mar 21-23, 2018 METROMEET. Bilbao, Spain. METROMEET will show to the experts of the sector the newest working methods and formulas that improve your industrial process and the productivity of your company. During the two days, international leaders in the Industrial Dimensional Metrology sector will show you how to improve the quality of your product and the efficiency of its production. http://www.metromeet.org/

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EDITOR'S DESK

Nostalgia

This past fall, we lost another metrology friend. Bill Berden trained at the Lowry AFB PMEL school during his service in the Air Force. Given his life's passions, his life celebration was held at Wings Over the Rockies Air & Space Museum, in the recently redeveloped Lowry neighborhood in Denver. We appreciate the time we got to spend with Bill and his friends. The level of devotion he received from his friends was testament to his strength of character; it goes without saying that he is greatly missed.

Bill's great love, a 1971 Buick Riviera, was happily accepted into the car collection of the Forney Museum of Transportation at their new location in Denver. The Forney Museum (http://www.forneymuseum.org/) is an exciting collection of planes, trains, and automobiles, while the Wings Over the Rockies Museum (https://wingsmuseum.org/) is a great tribute to our service members and the technology that carried them. If you ever visit the Denver Metro area in Colorado, both museums are well worth planning in extra time to visit.

❧

I'm pleased to present two interesting articles, starting with a Metrology 101 article, contributed by Jerry Eldred of Tescom. Jerry offers practical advice and important considerations for performing "Basic Rise Time Measurements." And this issue's full-length technical article came out of an Appalachian Gas Measurement Short Course from this year, titled "Large Volume Cone DP Meters," by Richard Steven of DP Diagnostics and Joshua Kinney of the Colorado Engineering Experiment Station (CEESI).

CEESI and the Pipeline Research Council host a *large* library of technical papers on their website for those involved in flow measurement. Check it out at: http://www.measurementlibrary.com/.

I've included a short piece towards the end of this issue about the PMEL school at Lowry, which started in the late 1950s and continued until the Air Base's closure in 1994. A great many calibration technicians received their metrology training at Lowry. If you have a PMEL school you would like to write about, please do so and send it to us!

Happy Measuring,

Sita Schwartz
Editor

CALENDAR

Apr 9-11, 2018 FORUMESURE. Marrakesh, Morocco. FORUMESURE is an annual event, for companies and also institutions wishing to present their know-how, new products and services to hundreds of international visitors. This event is organized by The African Committee of Metrology (CAFMET). As the same time as the exhibition, the 7th International Metrology Conference, CAFMET 2018, will take place. http://www.cafmet2018.com

Apr 9-12, 2018 CAFMET. Marrakesh, Morocco. The African Committee of Metrology (CAFMET) is organizing the 7th International Conference of Metrology in Africa – CAFMET 2018, which will be a Metrology forum to share information, ideas and experiences, during conferences, open discussions, technical workshops and exhibition booths. http://www.cafmet2018.com/en

Apr 16-19, 2018 European Flow Measurement Workshop. Barcelona, Spain. CEESI has partnered with VSL, NMi Certin, and Enagás to present the 6th European Flow Measurement Workshop. Each year different specific topics related to custody transfer measurement and ultrasonic meter measurement are discussed. https://efmws.eu/

Apr 17-19, 2018 Expo Control. Moscow, Russia. The most unique and comprehensive trade show in Russia which yearly demonstrates to specialists all the variety of the latest technologies for industrial and scientific quality assurance, measurement and testing. http://expo-control.com/en/

Apr 24-26, 2018 ICEEM. Algiers, Algeria. The Laboratory of Instrumentation at USTHB organizes the International Conference on Electronics, Energy and Measurement (ICEEM). The conference provides opportunity to bring scientists and engineers from academia, research institutes and industrial establishments to present and discuss the latest results in the field of electronics, instrumentation and measurement, sensors and energy. http://easychair.org/cfp/ICEEM-2018

May 2-3, 2018 Metrology Solutions EXPO. Greenville, SC. Manufacturing and Industrial Quality Control managers, engineers, and technical professionals will gather to discover the latest trends in precision measurement gages, instruments and metrology systems technologies. https://www.msiexpo.com/

May 14-17, 2018 I2MTC. Houston, TX. International Instrumentation and Measurement Technology Conference – is the flagship conference of the IEEE Instrumentation and Measurement Society, and is dedicated to advances in measurement methodologies, measurement systems, instrumentation, and sensors in all areas of science and technology. http://imtc.ieee-ims.org/

SEMINARS: Dimensional

Jan 10-11, 2018 Hands-On Gage Calibration and Repair. Chippewa Falls, WI. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Jan 24-25, 2018 Hands-On Gage Calibration and Repair. Chicago, IL. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Feb 1-2, 2018 Hands-On Gage Calibration and Repair. Detroit, MI. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Feb 7-8, 2018 Hands-On Gage Calibration and Repair. Bloomington, MN. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Mar 13-15, 2018 Dimensional Measurement Training: Level 1 - Measurement User. Coventry University, UK. NPL. A three day training course introducing measurement knowledge focusing upon dimensional techniques. http://www.npl.co.uk/training

Mar 19-20, 2018 Hands-On Gage Calibration and Repair. Los Angeles, CA. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Mar 22-23, 2018 Hands-On Gage Calibration and Repair. Las Vegas, NV. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

CALENDAR

Apr 9-12, 2018 Dimensional Measurement Training: Level 2 – Measurement Applier. Telford, UK (Hexagon Metrology). NPL. A four day training course for those who have a good basic understanding of measurement principles gained through the Level 1 training course. http://www.npl.co.uk/training

Apr 18-19, 2018 Hands-On Gage Calibration and Repair. Dallas, TX. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Apr 18-19, 2018 Dimensional Measurement. Port Melbourne, VIC. Australian Government NMI. This two-day course (9 am to 5 pm) presents a comprehensive overview of the fundamental principles in dimensional metrology and geometric dimensioning and tolerancing. http://www.measurement.gov.au/Services/Training/Pages/default.aspx#

May 17-18, 2018 Hands-On Gage Calibration and Repair. Hartford, CT. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

May 21-22, 2018 Hands-On Gage Calibration and Repair. Cleveland, OH. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

SEMINARS: Dosimetry

Jan 16-19, 2018 Practical Course in Reference Dosimetry. NPL, Teddington, UK. Introductory lectures to the course cover basic quantities and units, an overview of dosimetry and evaluation of uncertainties. http://www.npl.co.uk/training

SEMINARS: Electrical

Apr 23-26, 2018 MET-301 Advanced Hands-on Metrology. Everett, WA. Fluke Calibration. This course introduces the student to advanced measurement concepts and math used in standards laboratories. The student will learn how to make various types of measurements using different measurement methods. We will also teach techniques for making good high precision measurements using reference standards. http://us.flukecal.com/training

Apr 30-May 3, 2018 MET-101 Basic Hands-on Metrology. Everett, WA. Fluke Calibration. This course introduces the student to basic measurement concepts, basic electronics related to measurement instruments and math used in calibration. We will also teach various techniques used to make good measurements using calibration equipment. http://us.flukecal.com/training

SEMINARS: Flow / Pressure

Feb 14, 2018 Fundamentals of Flow Measurement Training Course. East Kilbride, UK. NEL. This course will cover the key aspects of flow measurement and will consider all general meter types and their application. Also included is an introduction to the UK National Standards for flow measurement, and open discussion sessions where participants can raise work-place situations for dialogue and advice. http://www.tuvnel.com/site2/subpage/nel_training_courses

Mar 5, 2018 Custody Transfer Measurement Systems Training Course. Aberdeen, UK. NEL. A transaction involving physical transfer of oil and gas from one operator to another is known as Custody Transfer and accurate metering of the fluids being transferred between the two is of vital importance. This course will enable metering engineers to gain a knowledge of how fluids are metered in the oil and gas sector. http://www.tuvnel.com/site2/subpage/nel_training_courses

Apr 11, 2018 Flow Calculations Training Course. East Kilbride, UK. NEL. Accurate measurement of produced hydrocarbons has always been a very high priority for oil and gas operating companies. Stringent requirements are set for the various calculations that define the quantity and quality of the fluids being measured. This course explains the equations and standards which define these parameters. http://www.tuvnel.com/site2/subpage/nel_training_courses

May 8-10, 2018 Principles and Practice of Flow Measurement Training Course. East Kilbride, UK. NEL. This course will enable delegates to understand the issues surrounding flow measurement. It also provides the delegate with an unbiased view of the various technologies available and the basic knowledge required to make informed choices. http://www.tuvnel.com/site2/subpage/nel_training_courses

May 11, 2018 Multiphase & Wet-Gas Flow Measurement Training Course. East Kilbride, UK. NEL. The demand to measure multiphase and wet-gas flows is increasing in the oil and gas industry worldwide. This interactive course will provide an understanding of the complexities of multiphase and wet-gas flows, effective metering techniques, selection and testing of meters and flow assurance strategies. http://www.tuvnel.com/site2/subpage/nel_training_courses

CALENDAR

SEMINARS: General & Management

Jan 24, 2018 Importance of Calibration Training Course. East Kilbride, UK. NEL. Accurate measurement of produced hydrocarbons has always been a very high priority for oil and gas operating companies. Course topics include verification of the equipment and components which constitute the measurement system, the effect of errors caused by calibration and the various techniques used in the industry. http://www.tuvnel.com/site2/subpage/nel_training_courses

Feb 5-9, 2018 Fundamentals of Metrology. Gaithersburg, MD. NIST. The Fundamentals of Metrology seminar will introduce the participant to the concepts of measurement systems, units, measurement uncertainty, measurement assurance, traceability, basic statistics and how they fit into the laboratory Quality Management System. https://www.nist.gov/news-events/events/2018/02/5514-fundamentals-metrology

Feb 5-9, 2018 Fundamentals of Metrology. Gaithersburg, MD. NIST. The Fundamentals of Metrology seminar will introduce the participant to the concepts of measurement systems, units, measurement uncertainty, measurement assurance, traceability, basic statistics and how they fit into the laboratory Quality Management System. https://www.nist.gov/news-events/events/2018/02/5515-fundamentals-metrology

Feb 13-15, 2018 Calibration Test Lab Management Training; Beyond 17025. Fort Meyers, FL. WorkPlace Training. Refresher for experienced lab managers or those who have not had formal lab management training, new or prospective lab managers. Call 612-308-2202 or visit: http://wptraining.com/

Feb 27, 2018 Calibration and Measurement Fundamentals. Port Melbourne, VIC. Australian NMI. This one-day fully interactive course (9 am to 5 pm) covers general metrological terms, definitions and explains practical concept applications involved in calibration and measurements. The course is recommended for technical officers and laboratory technicians working in all industry sectors who are involved in making measurements and calibration process. http://www.measurement.gov.au/Services/Training/Pages/default.aspx#

SEMINARS: Industry Standards

Feb 12-16, 2018 ISO/IEC 17025 Lead Assessor Training. Tampa, FL. ANAB. The 4.5-day ISO/IEC 17025 Lead Assessor training course is designed to further develop your understanding of ISO/IEC 17025 and help you understand how to plan and lead an ISO/IEC 17025 assessment. Attendees will gain an understanding of uncertainty, traceability, and PT/ILC and how they are assessed. This course will prepare you to meet technical demands of the assessor while providing practical exercises to aid comprehension. https://www.anab.org/training/17025/lead-assessor

Mar 26-28, 2018 Internal Auditing to ISO/IEC 17025. Austin, TX. ANAB. The 2.5-day Internal Auditing to ISO/IEC 17025 training course prepares the internal auditor to clearly understand technical issues relating to an audit. Attendees of this course will learn how to coordinate a quality management system audit to ISO/IEC 17025:2005 and collect audit evidence and document observations, including techniques for effective questioning and listening. https://www.anab.org/training/17025/internal-auditing

Apr 9-10, 2018 Introduction to ISO/IEC 17025. San Francisco, CA. ANAB. The 1.5-day Introduction to ISO/IEC 17025 training course will help attendees understand and apply the requirements of ISO/IEC 17025:2005. Attendees will examine the origins of the standard and learn practical concepts such as document control, internal auditing, proficiency testing, traceability, measurement uncertainty, and method witnessing. https://www.anab.org/training/17025/intro

SEMINARS: Mass & Weight

Apr 16-27, 2018 Mass Metrology Seminar. Gaithersburg, MD. NIST. The Mass Metrology Seminar is a 2 week, "hands-on" seminar. It incorporates approximately 30 percent lectures and 70 percent demonstrations and laboratory work in which the trainee performs measurements by applying procedures and equations discussed in the classroom. https://www.nist.gov/news-events/events/2018/04/5516-mass-metrology-seminar

SEMINARS: Measurement Uncertainty

Feb 15, 2018 Introduction to Estimating Measurement Uncertainty. Brisbane, QLD. Australian NMI. This one-day course (9 am to 5 pm) will give you a clear step-by-step approach to uncertainty estimation with practical examples; you will learn techniques covering the whole process from identifying the sources of uncertainty in your measurements right through to completing the uncertainty budget. http://www.measurement.gov.au/Services/Training/Pages/default.aspx#

Mar 9, 2018 Practical Applications of Uncertainty Training Course. Aberdeen, UK. NEL. This course will enable delegates to apply the techniques - developed in NEL's Introduction to Measurement Uncertainty course - to examples tailored to the Oil and Gas sector. Case studies are used to illustrate the application of such calculations in minimizing the impact of measurement uncertainty. http://www.tuvnel.com/site2/subpage/nel_training_courses

SEMINARS: Pressure

Mar 5-9, 2018 Principles of Pressure Calibration. Phoenix, AZ. Fluke Calibration. A five day training course on the principles and practices of pressure calibration using digital pressure calibrators and piston gauges (pressure balances). The class is designed to focus on the practical considerations of pressure calibrations. http://us.flukecal.com/training

Apr 23-27, 2018 Principles of Pressure Calibration. Phoenix, AZ. Fluke Calibration. A five day training course on the principles and practices of pressure calibration using digital pressure calibrators and piston gauges (pressure balances). The class is designed to focus on the practical considerations of pressure calibrations. http://us.flukecal.com/training

SEMINARS: Software

Mar 12-16, 2018 MC-206 Basic MET/CAL® Procedure Writing. Everett, WA. Fluke Calibration. In this five-day basic MET/CAL procedure writing course, you will learn to configure MET/CAL software to create, edit, and maintain calibration solutions, projects and procedures. http://us.flukecal.com/training

Crystal pressure

Every XP2i maintains its accuracy across a wide pressure and temperature range, so using one XP2i is like carrying multiple conventional gauges. The XP2i's case is made from rugged aluminum alloy, and utilizes a gasket to seal the enclosure against dust and water intrusion. Even the RS-232 connector is fully sealed. Configurable with customizable, calibration-due reminders and alerts.

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- Absolute, gauge, and differential pressure
- IP66, IP67 Marine grade enclosure resists corrosion
- **NEW!** Low pressure, absolute ranges available now
- Shift everyday wear to replaceable CPF adapter
- Record 32 000 data points with optional DataLoggerXP
- ATEX Zone 0, CSA Class 1, Div 1

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Crystal GaugeCalHP

JOFRA ASC-400

M & G PKII

JOFRA RTC Series

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May 14-18, 2018 MC-207 Advanced MET/CAL Procedure Writing. Everett, WA. This five-day in-depth workshop is for experienced MET/CAL programmers who wish to enhance their procedure writing skills. Students will focus on the use of instrument communication with the IEEE, PORT, VISA, MATH and LIB FSCs, the use of memory registers in procedures, and will create a complex procedure using live instrumentation. http://us.flukecal.com/training

SEMINARS: Temperature

Mar 6-8, 2018 Practical Temperature Calibration Training. American Fork, UT. Fluke Calibration. Three day course loaded with valuable principles and hands-on training designed to help calibration technicians and engineers get a solid base of temperature calibration fundamentals. http://us.flukecal.com/training

Mar 7, 2018 Humidity Measurement. Lindfield, NSW. Australian Government NMI. This one-day course (9 am to 5 pm) provides information about the main concepts and practical techniques involved in measuring humidity in air and explains how to make such measurements accurately and consistently. http://www.measurement.gov.au/Services/Training/Pages/default.aspx#

Mar 20-22, 2018 Temperature Measurement. Lindfield, NSW. Australian Government NMI. This three-day course (9 am to 5 pm) covers the measurement of temperature and the calibration of temperature measuring instruments. It incorporates extensive hands-on practical exercises. http://www.measurement.gov.au/Services/Training/Pages/default.aspx#

Mar 23, 2018 Testing Temperature Controlled Enclosures. Lindfield, NSW. Australian Government NMI. This one day course (9 am to 5 pm) is for people involved in routine performance testing of temperature controlled enclosures (oven, furnace, refrigerator and fluid bath). It incorporates an extensive overview of AS 2853 requirements and common industry practice and it also includes hands-on practical demonstrations. http://www.measurement.gov.au/Services/Training/Pages/default.aspx#

SEMINARS: Volume

Jun 4-8, 2018 Volume Metrology Seminar. Gaithersburg, MD. NIST Office of Weights and Measures. This 5 day volume metrology seminar is designed to enable metrologists to apply fundamental measurement concepts to volume calibrations. https://www.nist.gov/news-events/events/2018/06/5523-volume-metrology-seminar

3D-Lasermeter with Refractive Index Compensation

PTB-News 3.2017 – Within the scope of an international project, PTB has developed the prototype of a 3D-capable interferometer that compensates for the optical refractive index of air intrinsically. This so-called 3D-Lasermeter has been successfully tested in two series of tests under difficult industrial ambient conditions.

The requirements placed on the dimensional accuracy of large-scale components (with dimensions of several meters) are becoming more and more demanding in industry and fundamental research. In the aviation industry, for instance, drill holes in wing segments must be positioned with an accuracy on the order of a few tens of micrometers. Such accuracies can be attained with various optical measurement procedures – in particular interferometry-based ones. For correct measurements, the refractive index of the ambient air must, however, be known with sufficient precision. This, in turn, requires the correct detection of the following ambient parameters: pressure, temperature, relative humidity and CO_2 concentration. If a length is to be determined with micrometer accuracy over a length of 10 m, for example, then the temperature inside the beam must be known with 0.1 K accuracy. For measurements performed outside well-air-conditioned laboratories, this can only be achieved approximatively by means of a very dense and elaborate network of sensors to pick up the ambient parameters.

Within the scope of the international LUMINAR (Large Volume Metrology in Industry) project, an alternative approach has been pursued: the refractive index is determined parallel to the actual length measurement by dispersive refraction compensation. Hereby, the geometrical length is measured by means of two interferometers with optical frequencies (or wavelengths) that are different from each other but very accurately known. By combining the information gained about the path length in this way, it is possible to determine the refractive index – and thus the exact geometrical length – without additional information and with an accuracy of up to $1 \cdot 10^{-7}$.

Within the scope of the LUMINAR project, PTB, together with SIOS Meßtechnik GmbH, has developed the prototype of an auto-tracking interferometer which intrinsically compensates for the refractive index. The probe can automatically follow a measuring reflector in space. To this end, two wavelengths of two NdYAG lasers, which are stabilized against each other, are used.

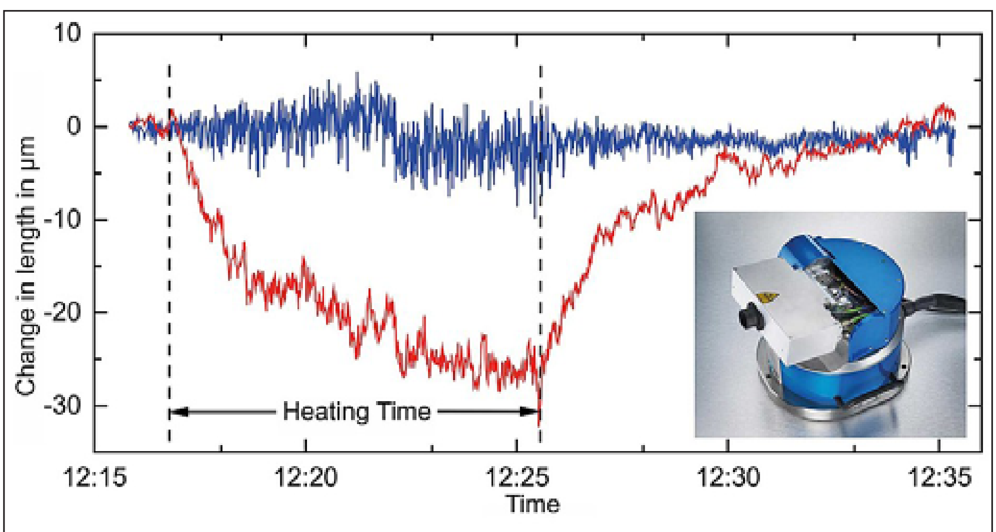
The 3D-Lasermeter was tested within the scope of the same project at the 50 m comparator section of the Polish metrology institute (GUM) under difficult controlled ambient conditions. Moreover, it was also successfully tested under real industrial conditions in an Airbus test hangar in Filton, UK. Thereby, it was possible to demonstrate that the measurement uncertainty of the intrinsically optical refractive index compensation is in the micrometer range.

Two patents have been granted with regard to the procedure. By means of established multilateration procedures, the system can be used to determine the position of points in space – i.e. in the future, it could be used to calibrate large-scale coordinate measuring machines (such as those used to measure the components of wind turbines).

For further information about this research, contact: Florian Pollinger, Department 5.4, Interferometry on Material Measures, Phone: +49 (0)531 592-5420, florian.pollinger(at)ptb.de.

Scientific publication: K. Meiners-Hagen, T. Meyer, G. Prellinger, W. Pöschel, D. Dontsov, F. Pollinger: Overcoming the refractivity limit in manufacturing environment, Opt. Express 24, 25092 (2016)

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



Verification of the 3D-Lasermeter during measurements at the Polish metrology institute (GUM). A constant distance of 19 m was measured with the wavelengths 532 nm and 1064 nm of the 3D-Lasermeter manufactured by SIOS GmbH (small picture). When using a network of temperature sensors to compensate for the refractive index, the distance is allegedly reduced by up to 30 µm (red curve) during the warm-up phase. Contrary to this, the distance from the intrinsically determined correction of the refractive index (blue curve) remains stable (apart from the slightly higher noise). Credit: Physikalisch-Technische Bundesanstalt (PTB)

Bringing the World Closer to Revised Measurement System, Scientists Update Four Key Fundamental Constants

NIST News, October 23, 2017 — Paving the way for transforming the world's measurement system, an international task force has determined updated values for four fundamental constants of nature. The updated values comprise the last scientific piece of the puzzle for redefining the modern metric system, known as the International System of Units (SI) (link is external). If approved by an international body next year, the revised SI will enable authoritative measurements to be made anywhere on the planet.

The adjustments to the constants are small and won't affect everyday life. But a revised SI based fully on accurate values of these constants underpins science and commerce and ensures uniformly precise measurements that scale smoothly from almost infinitesimal to enormous.

Based on state-of-the-art measurements from scientists around the world, the updated values of the constants were prepared by the Committee on Data for Science and Technology (CODATA) Task Group on Fundamental Constants (link is external) (TGFC). A paper containing the new values has been accepted for publication (link is external) in the journal *Metrologia*.

On October 20, the International Committee for Weights and Measures (CIPM) (link is external) submitted a resolution recommending the use of the new values and the redefinition of the SI (link is external) to the General Conference on Weights and Measures (link is external) (CGPM), the official body that makes changes to the SI. In November 2018, the CGPM will formally vote on the adoption of the revised system. The CGPM includes members from dozens of nations, including the U.S. and other signatories of the Convention of the Meter (link is external), the 1875 treaty that standardized measurement units on the international level.

In the world of measurements, an SI based on fundamental constants will bring about a shift. Up until now, the CODATA TGFC updated values of the constants every four years, most recently in 2014, and produced this special update for the four constants this year in anticipation of the updated SI.

"The values of these four constants won't change anymore," said Peter Mohr, a scientist at the National Institute of Standards and Technology (NIST) and a member of the CODATA TGFC. The values will be fixed and stated as exact values, he said, just as the speed of light is currently defined as an exact value. This in turn will allow scientists to focus on measurements that compare other important quantities to the constants.

Redefining the SI

Together with previously accepted constants, the updated values would redefine the SI's seven base units, which include the kilogram (the unit of mass), the kelvin (the unit of temperature), and the ampere (the unit of electrical current).

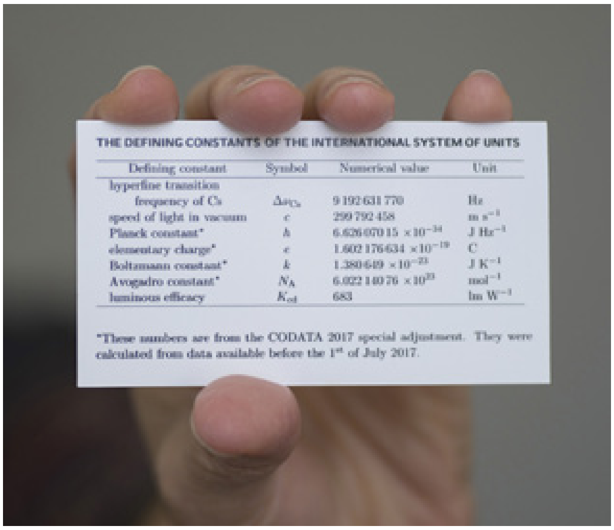
Since 1889, the kilogram has been defined by a platinum-iridium cylinder stored in France, known as the International Prototype of the Kilogram, or, "Le Grand K ." Scientists from around the world have had to travel to France and compare their countries' copies of the kilogram to the original in order to establish accurate mass measurements in their nations.

Meanwhile, temperature has been defined in terms of the "triple point" in a sealed glass cell of water. The triple point is the temperature at which water, ice and water vapor exist in equilibrium. However, the water in these cells can contain chemical impurities that can shift the triple point temperature to inaccurate values. And measurements of temperatures higher or lower than the triple point of water are inherently less precise.

The updated constants include the Boltzmann constant (which relates temperature to energy), and the Planck constant (which can relate mass to electromagnetic energy), the charge of the electron and the Avogadro constant (the quantity that defines one mole of a substance).

"There are no dramatic changes. The Boltzmann constant is very consistent with earlier values," said Mohr. "The temperature experts requested eight digits for the constant and the last digit happened to be 0," he recounted—an amusing situation for metrologists since they can obtain the precision of eight significant digits by only having to use seven.

"There are a variety of ways of determining temperature but the new definition will be very useful for measuring very hot and very cold temperatures far away from the triple point of water," said NIST's David Newell, chair of the CODATA task group.



This wallet card displays the fundamental constants and other physical values that will define a revised international system of units. Credit: Stoughton/NIST

The Planck constant has shifted downward by 15 parts per billion from its earlier value, due to new data collected since 2014. The Planck constant was determined by two experimental techniques, known as the Kibble balance and the Avogadro method. All of the measurements that were used for determining the new Planck value met previously agreed-upon international guidelines for levels of accuracy and consistency with one another.

The Planck constant can be used to define the kilogram, and using a fundamental constant for defining mass will solve many problems, Newell said. Mass must be measured over a very large scale, from an atom to a pharmaceutical to a skyscraper. “At the low end, you currently use one type of physics to determine mass; at the high end, you use another type of physics,” he said.

But the Planck constant will provide a consistent way for defining mass across all of these scales, with whatever laboratory method is used to measure mass.

“It doesn’t matter what method you use. A constant is a constant,” said Mohr.

The dream is to use the Planck constant for mass in the same way that light is used to measure distance. In the SI, the speed of light is already used to define the meter, the unit of length. “You use light to measure the distance to the Moon or the distance between silicon atoms,” he said.

The move to a revised SI is intended to be seamless for just about everyone in the world.

“The whole thing is geared to not have any impact on the average person,” Mohr said.

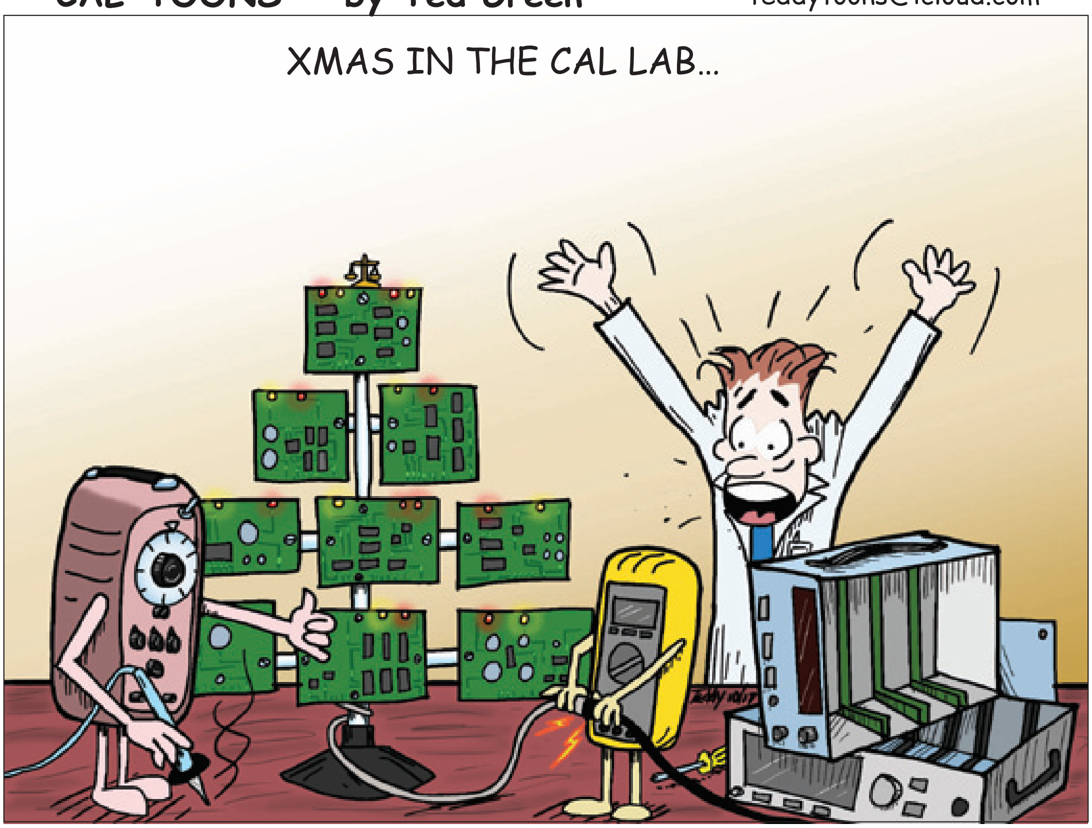
But an SI based fully on the constants is expected to change the world of metrology.

Le Grand K in France will no longer exactly define one kilogram. Instead, it will likely have a mass of slightly less or slightly greater than one kilogram, to within 10 parts per billion in uncertainty.

The volt will change as well, since the Planck constant will also help to define it in the revised SI. A volt based purely on the fundamental constants will be very slightly smaller, about 100 parts per billion, than the current scientific realization of the volt, established in 1990. So, the top-level metrology labs will have to recalibrate their high-precision voltage measurements.

“People doing such high-precision measurements will notice the shift,” Mohr said.

CAL-TOONS by Ted Green teddytoons@icloud.com



That's why the official rollout of the revised SI is slated for May 20, 2019, on World Metrology Day, to give metrologists time to adjust to the new values.

"It's a broader philosophical paradigm shift," Mohr said. "When the speed of light became a fixed number, researchers stopped measuring the speed of light. They focused on realizing the meter. It's the same with the Planck constant. You're not going to be measuring the Planck constant anymore. You're going to be realizing mass and electrical standards more precisely."

Paper: D.B. Newell, F. Cabiati, J. Fischer, K. Fujii, S.G. Karshenboim, H. S Margolis, E. de Mirandes, P.J. Mohr, F. Nez, K. Pachucki,T.J. Quinn, B.N. Taylor, M. Wang, B. Wood and Z. Zhang. The CODATA 2017 Values of h, e, k, and N_A for the Revision of the SI. Metrologia. Accepted for publication 20 October 2017. DOI: 10.1088/1681-7575/aa950a

Source URL: *https://www.nist.gov/news-events/news/2017/10/bringing-world-closer-revised-measurement-system-scientists-update-four-key.*

Basic Rise Time Measurements

Jerry L. Eldred
Tescom, Calibration Services

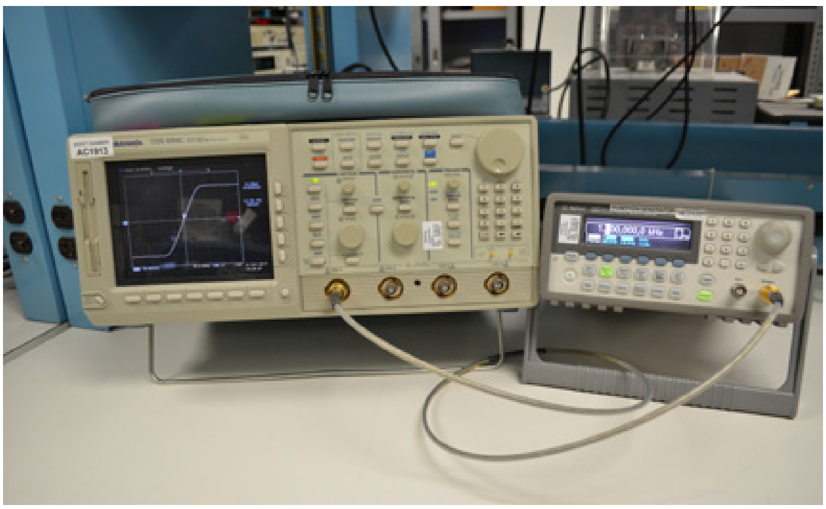


Figure 1. Typical Rise Time Measurement Setup

Introduction

Although rise time is a common calibration measurement in pulse/function generators and some oscilloscopes, it is often not well understood. Making a good rise time measurement is somewhat similar to home stereo equipment, in the regard that it is no better than the weakest component. We will walk through some basics to better understand what Rise Time is, and how to make accurate Rise Time measurements.

Square waves and pulses are important electrical components of systems such as RADARs where timed pulses are an integral part of distance measurement; computers, where they are used as clocks and for transmission of digital information; modern digital cellular networks, to efficiently send voice, text and images; modern internet-based video games, which require the very fast transmission information; and many other applications.

In the high speed transmission of digital information, pulses and square waves have become faster and faster – to transmit more information at a faster rate. This means that to discern faster pulse rates, rise times must be faster as well. And good rise time measurement in calibrations helps ensure the integrity of fast data transmissions in a vast and growing digital world.

What Is Rise Time?

First, let's explore what rise time really is. In a pulse or square wave, the rise time (or 'transition time') is the time required for the leading (or trailing) edge of a square or pulse wave to transition from low to high (or high to low) state; and is normally measured from the 10% to 90% points. The 10% to 90% range is used in the measurement because that is accepted as the most linear part of the transition.

'Fall time' is commonly used to label the negative going transition (as opposed to 'rise time' denoting the positive going transition of a square or pulse wave). So they are really 'two sides of the same coin.' This article then will primarily cover 'rise time,' as the principles of both are the same.

In a time domain, a square wave is simply a DC level that 'abruptly' switches repetitively between a low and a high voltage, with equal time at the low and high levels. In a frequency domain (as in Figure 2), a square wave is comprised of the sinusoidal fundamental frequency of that wave, with all of its odd order harmonics (1st, 3rd, 5th, 7th … etc.) combined algebraically. So a 1 kHz square wave is formed by algebraically adding 1, 3, 5, 7, 9, 11… etc. kHz together. Practically speaking, a square wave does not contain all odd order harmonics, but all of them up to a maximum frequency. That maximum frequency corresponds to both its rise time and its bandwidth. Similarly, a pulse wave in a frequency domain is made up of the sinusoidal frequency of the pulse repetition rate, plus its odd harmonics. For those interested, there is a wealth of information on the complicated Fourier Transform mathematics, and related engineering theories.

This is also a relevant theoretical concept in pulse waves. Just as a square wave is made up of a fundamental sinusoidal frequency (the 1st Harmonic), and its odd order harmonics, the rise time of a pulse wave (see Figure 3) also relates to its bandwidth. This is because the rise time of a pulse wave relates to the rise time of the highest frequency harmonic in the wave.

Some Important Considerations

Bandwidth is commonly used to label the upper frequency response limit of oscilloscopes used in sine wave measurements. For example, an oscilloscope with a 500 MHz bandwidth can accurately measure sinusoidal signals up to 500 MHz; where input signals with frequencies greater than 500 MHz would normally roll off rapidly. This means that since the rise time of a square or pulse wave relates to its bandwidth, an oscilloscope used to measure that rise time must have adequate bandwidth for the measurement.

The accepted mathematical relationship between rise time and bandwidth of a pulse or square wave is the formula [RISE TIME = 0.35 / BANDWIDTH]; and conversely [BANDWIDTH = 0.35 / RISE TIME]. Note that equivalent units must be observed when calculating bandwidth and rise time (such as GHz, MHz, etc., and nS, pS, etc.). The simplest way to accomplish this is by using Hertz and Seconds as units, along with scientific notation for large values.

Engineers debate whether 0.35 should be used as the ratio number in this formula, based on Gaussian or flat response of oscilloscopes, how to derive the ratio using Fourier Transforms, Nyquist Sampling Theorem, etc. Internet searches will yield many articles to explore those details for the curious. For simplicity however, this article will use the accepted Rule of Thumb that [RISE TIME = 0.35 / BANDWIDTH].

To make accurate rise time measurements then, we must consider not only the rise time (or 'bandwidth') of the square or pulse wave, but the bandwidth (or 'rise time') of the oscilloscope making the measurement. Although to understand the underlying theories, it is useful to look at square and pulse waves in a frequency domain (with a Spectrum Analyzer), rise time measurement itself is almost universally performed with an oscilloscope.

A main consideration for accurate rise time measurement is the measurement capability of the system (not just the oscilloscope) where the measurement will be made. Every component, including the source, cabling, adapters, and oscilloscope, must be properly selected.

Since we understand that rise time is related to bandwidth, all cables, adapters, terminations and attenuators used must have adequate bandwidth for the measurement. Their 'bandwidth' then, by rule of thumb, should be at least three times the 'bandwidth' of the rise time to be measured.

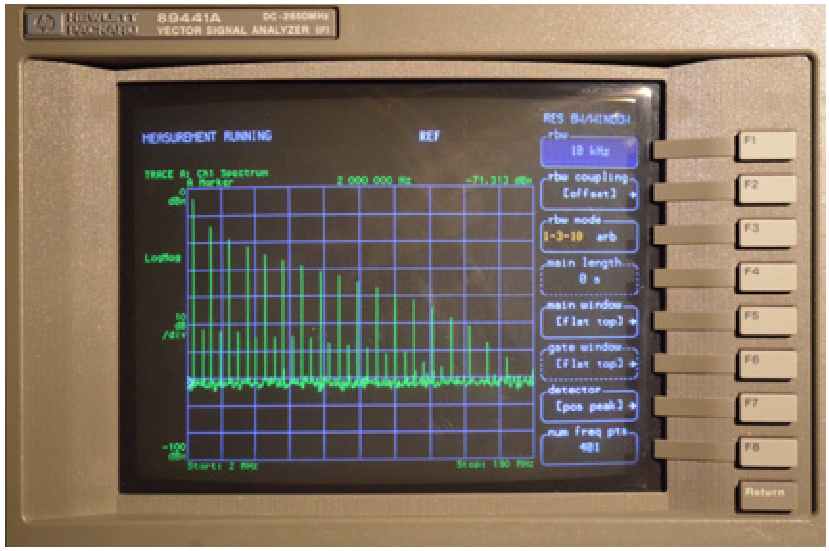


Figure 2. Square Wave in Frequency Domain

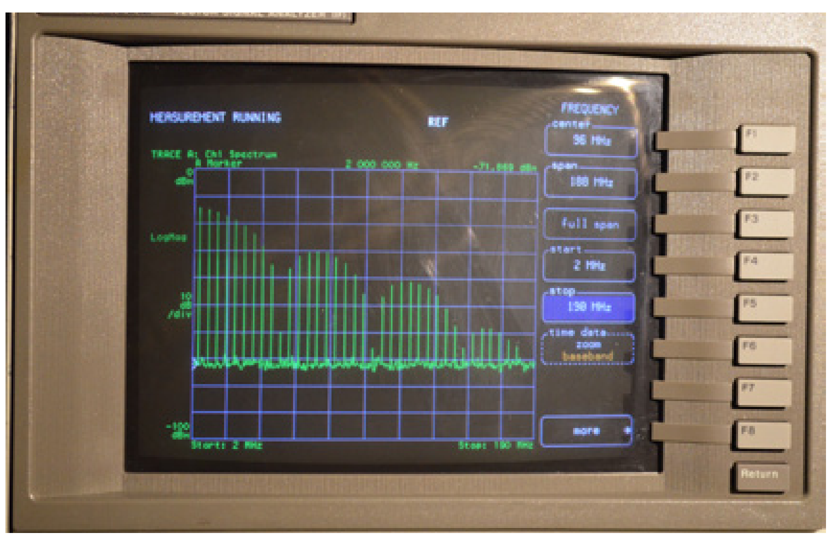


Figure 3. Pulse Wave in Frequency Domain

Matching the impedances of all components is also important. Assure all components of the measurement system are matched, as a mismatch in impedance between the source of the square or pulse wave and the oscilloscope or any cables, adapters or terminations will create errors if not compensated properly. If, for example, the output impedance of the source is 50 ohms, then the input impedance of the oscilloscope (and all cables and adapters) must also be 50 ohms.

The oscilloscope must also have adequate input voltage range for the rise time measurement. Before applying the square or pulse wave to the oscilloscope, verify that its voltage does not exceed the allowable maximum for the oscilloscope's input. Also, assure that the voltage of the square or pulse wave to be measured does not exceed maximum limits of any terminations, attenuators, cables or adapters.

The oscilloscope should have a bandwidth of at least 3 to 5 times that of the measured rise time. To make things more confusing, modern oscilloscopes normally also have a specified digital sampling rate (normally at least 2X the bandwidth). Use the oscilloscope bandwidth, not the digital sampling rate, as the specification to determine adequacy for the rise time measurement.

The input impedance of the oscilloscope used must also match the output impedance of the source. Some oscilloscopes have a single fixed impedance of either 50 ohms or 1 megohm, while others are switchable (most commonly between 50 ohms and 1 megohm).

If the input impedance of the oscilloscope is fixed and matches the output impedance of the source, no feed through termination is needed, and the input impedance of the oscilloscope acts as a match. If the input impedance of the oscilloscope is fixed and doesn't match the output impedance of the source, use a feed through termination with the same impedance as the source, with a bandwidth of at least 3 times that of the rise time being measured. Note that when using a feed through termination, always connects it at the load end of the measurement connection. If the source has a 50 ohm output impedance, and the oscilloscope has a 1 megohm input impedance, place the 50 ohm feed through termination at the oscilloscope end. Also, if an attenuator is to be used, it should normally be connected just before the feed through termination.

If the input impedance of the oscilloscope used is switchable, set the oscilloscope input impedance to match the source, and don't use an external feed through termination. The input impedance of the oscilloscope acts as a match.

Rise time measurements with bandwidths of less than 1 GHz are relatively simple for properly trained technicians. Most errors come from missing one of the above steps. If bandwidth of the oscilloscope, cabling, terminations or adapters is inadequate, measured rise time will read too slowly (slow rise time = lower effective bandwidth). If impedance is not matched, rise time will be incorrect (there may be ringing, what should appear as a normal square wave will look anything but square, and so forth).

So long as all of the considerations above are followed: proper cabling, terminations, attenuators, adapters and an oscilloscope with proper bandwidth; then the rise time measurement will be accurate, and all will be well with the world.

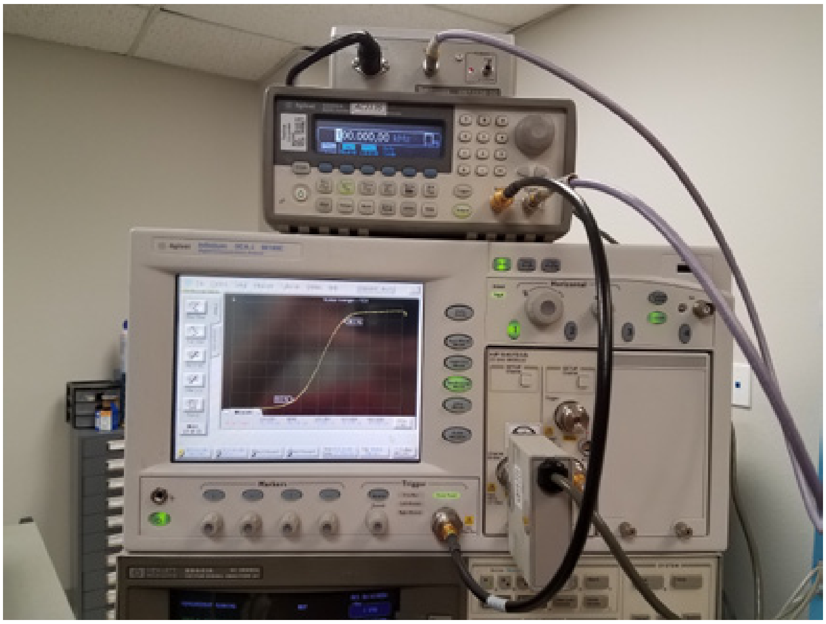


Figure 4. Fast Rise Time Measurement Setup

Making a Measurement

Rise time measurement begins with capturing a stable, continuous square or pulse wave on an oscilloscope. For ease of measurement, peak to peak amplitude should be about 6 major divisions (for an 8 division display), or about 75% of the oscilloscopes vertical display range.

For our example, we will use a 600 mV peak to peak wave (with oscilloscope set to 100 mV/Div), which will occupy 6 of 8 vertical divisions. Time base should first be set to display about one cycle of the wave. Then increment the time base until the leading edge of the wave covers about two or three horizontal divisions. Setting the time base too slow (less than about two divisions) will reduce measurement resolution and cause errors in the measurement. Setting the time base too fast (more than about four divisions) can exclude the beginning and end of the transition, and cause errors as well.

Adjust oscilloscope vertical position (or offset) until the bottom and top of the wave are positioned at the 2nd to 7th divisions. Then, if possible, adjust the oscilloscope horizontal position until the middle of the leading edge crosses the vertical and horizontal center of the oscilloscope display. If making the measurement visually, adjust the horizontal position of the wave until the 10% point of the leading edge (60 mV = 0.60 vertical divisions from the bottom of the wave) is positioned at a major horizontal division (this will be a reference point for the measurement).

Locate the 90% point of the leading edge (540 mV = 5.40 vertical divisions from the bottom of the wave). Observe the horizontal position of that 90% point and calculate the exact number of horizontal divisions between the 10% and 90% point of the wave. That number of major horizontal divisions (including decimal portions), divided by the oscilloscope time/div setting, is the measured rise time.

Many modern oscilloscopes have a built in rise time measurement function which, if available, may be used for the measurement. A combination of vertical and horizontal cursors when available, may also improve rise time measurement accuracy. Many oscilloscopes also have an available "averaging" function which often improves accuracy of rise time measurements.

Rise time measurements with bandwidths of greater than 1 GHz, although connections and principles are essentially the same, can be more challenging. As the measured rise time and related bandwidth increases, proper cabling, adapters, and measurement system components become increasingly important.

For rise time measurement bandwidths above 1 GHz, assure that every component of the measurement system meets the rules detailed above, including use of metrology grade cables and adapters, and proper torquing of RF and microwave connections.

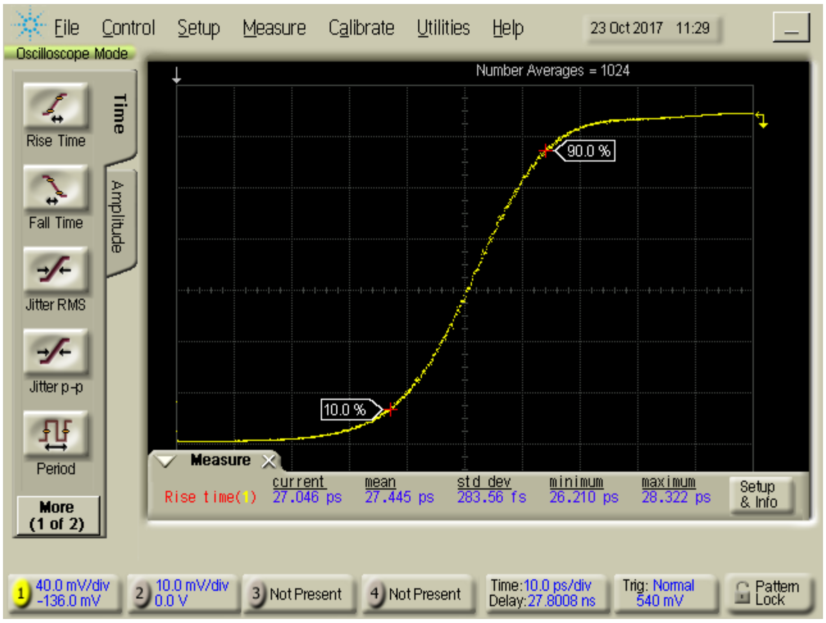


Figure 5. Fast Rise Time Measurement

In Conclusion

For very high rise time measurement bandwidths, limitations of technology may make it impractical to meet all of the bandwidth rules above when measuring some of the fastest rise times. In those cases, cabling, adapters, feed through terminations, and the oscilloscope used must still exceed the bandwidth of the measurement. However, the compromised rules in the measurement system will produce erroneously slower rise time readings. That is, the measured rise time will be a slower value than the actual rise time.

There are many opinions as to what calculations to use when performing these fast rise time measurements that are beyond the scope of this article. The important detail is that the technician performing any rise time measurement must adhere to correct rules above for an accurate rise time measurement. And in circumstances where it is not practical to follow those rules: first, know that measured rise time will be slower than the actual, and second, use an accepted mathematical technique to correct the error.

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[1] Eric Bogatin, *Signal and Power Integrity – Simplified*, 2nd Ed., Prentice Hall.

[2] "Understanding Oscilloscope Frequency Response and Its Effect on Rise-Time Accuracy" Keysight App. Note p/n: 5988-8008EN.

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Large Volume Cone Differential Pressure Meters

Richard Steven
DP Diagnostics LLC

Joshua Kinney
Colorado Engineering Experiment Station, Inc. (CEESI)

Cone DP meters are a member of the generic DP flow meter family. Used extensively throughout different industries for quarter of a century, the cone meter is now a mature technology with multiple manufacturers throughout the world. There is now a cone meter international standard, ISO 5167-5. The cone meter has distinct pros and cons when compared to other DP meter designs. This article describes the cone meter operating principle and the associated pros and cons compared to other DP meters. Particular attention is paid to cone meter calibration requirements, cone meter resistance to disturbed inlet flow, and the cone meter internal verification system.

1. Introduction

Differential Pressure (DP) meters have been used extensively since Herschel developed a commercial Venturi meter in the 1880s. Since then, many different variants of DP meters have been developed. One of the most recent is the cone meter. The cone meter is a generic DP meter. It uses the same generic DP meter flow equation as all other standard DP meters. All DP meter types exist on the market as they offer some particular advantage over the others. If a meter does not have some niche, whether it be reduced flow rate prediction uncertainty, lower pressure loss, no requirement for calibration, more robust, wider range ability, resistance to flow disturbances, self-verification capable, or simply an attractive price, it would not be successful on the market. The cone meter has been steadily growing in market share for twenty-five years. Originally a patented device, the patent expired in 2004 and now the meter is a generic type offered by multiple suppliers.

The cone meter has some particular advantages over other meters. While giving the same flow rate uncertainty as other generic DP meters, the cone meter has the unusual characteristic of being extremely resistant to upstream disturbances. That is, compared to other flow meters, the cone meter has a small bias induced on its flow rate prediction by various pipe component induced flow disturbances. The cone meter is not completely immune to flow disturbances, but it is far less sensitive to flow disturbances than most other DP and non-DP meter designs. Therefore, the cone meter typically requires no flow conditioner and less upstream straight inlet run length than most other meters. The cone meter is therefore attractive to the many applications where significant straight pipe inlet runs are not available. Furthermore, as a generic DP flow meter, the cone meter can use the generic DP meter verification system (Prognosis™).

Cone meters can also be attractive as standard generic DP meters when there is plenty upstream straight inlet run. Venturi meters are very sturdy and offer minimal total pressure loss. (For example, Venturi meters tend to have less permanent pressure loss than flow conditioners used by ultrasonic or orifice meters.) However, Venturi meters are relatively expensive and (for low flow rate prediction uncertainty) require calibration. Therefore, amongst the DP meter family, Venturi meters have a relatively high CAPEX but relatively low OPEX. Orifice plate meters are less sturdy than Venturi meters and create significant permanent pressure loss. However, orifice meters do not require calibration. Orifice meters can have a relatively low CAPEX but a relatively high OPEX. However, the cone meter falls between the Venturi and orifice meters in most of these specifications. The cone element tends to be sturdier than the orifice plate although not as sturdy as the Venturi tube. The permanent pressure loss of a cone meter is more than a Venturi and similar to an orifice meter. A cone meter tends to be reasonably priced compared to a Venturi meter but (unless a dual chamber orifice meter is used) tends to be more expensive than the orifice meter.

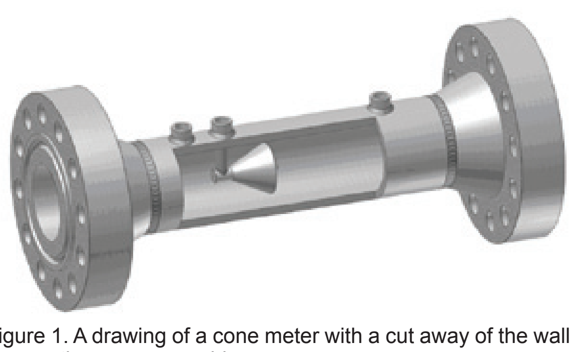

Figure 1. A drawing of a cone meter with a cut away of the wall to expose the cone assembly.

For low flow rate prediction uncertainty, ISO 5167-5 [1] states cone meters must be calibrated like the Venturi meter. Therefore, along with high resistance to flow disturbances, the cone meter can be a compromise to the pros and cons of Venturi and orifice meters.

The cone meter has become a mature metering technology. In 2016, ISO released a cone meter standard [1] formalizing the cone meter geometry and the stated performance.

2. The Operating Principles of Cone Meters

A cone meter is a generic DP meter. The cone meter gets its name from the shape of the primary element. The primary element is the physical obstruction that produces the differential pressure. The primary element design is differentiator between DP meter designs. Figure 1 shows a typical cone meter geometry. A cone meter has a cone installed in line with the pipe center line with the cone pointing upstream and attached at the cone apex by a circular support bar. There is an inlet static pressure port upstream of this cone assembly. Most cone meters have the low pressure port running from the center of the back face of the cone through the cone's center line and up through the center of the support bar. (A few cone meters read the low pressure at the wall immediately behind the cone. These are relatively rare and this paper does not discuss this design.) Traditionally, the distance between the inlet and low pressure port couplings is 2 1/8" to couple directly to a DP transmitter.

Figure 2 shows a sketch of a cone meter with named components and an indication of the flow profile. With the low pressure port located at the back of the cone the low pressure is the pressure in the cones "wake." A wake is a highly turbulent area of flow directly behind bodies immersed in a fluid flow. It is characterized by having strong vortices and low pressures. The faster the flow past a body, the stronger the wake is, i.e., the lower the pressure in the wake. The cone meter's use of a pressure reading away from the fluid stream can cause confusion but it should not. The cone meter is not the first DP meter to read at least one of the two pressures in a re-circulating section of the flow. The orifice meter also does this by reading inlet and low pressures in the re-circulation zones upstream and downstream of the plate.

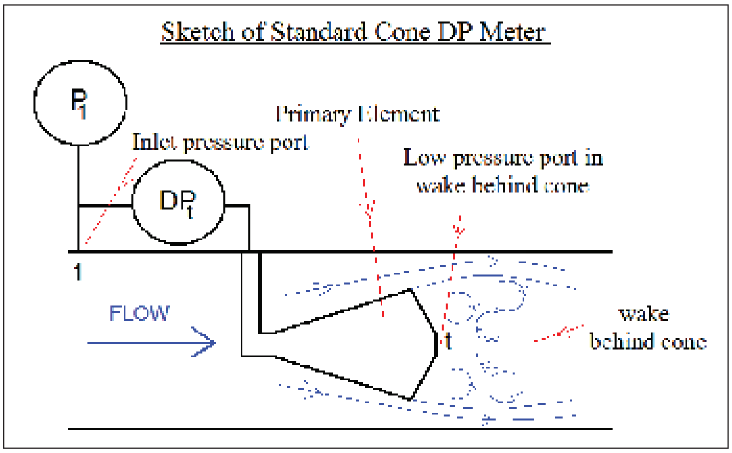

Figure 2. A sketch of flow past a cone meter.

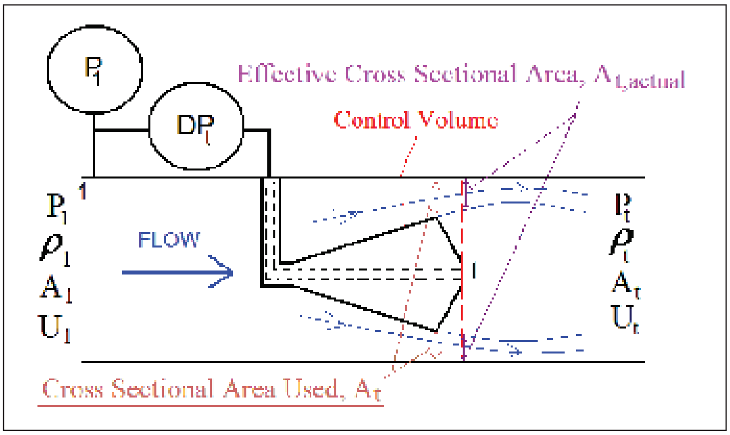

Figure 3. A sketch of a cone meter with a control volume drawn around the system.

The cone meter uses the same generic DP meter flow equation as other DP meters, such as the Venturi, nozzle, wedge, and orifice meters. Figure 3 shows a sketch of a cone meter with local conditions and some geometry noted. Here '*P*' is the pressure, '*U*' represents fluid velocity, while 'ρ' represents fluid density, and '*A*' represents cross sectional area. The subscript '1' represents inlet conditions (where the upstream pressure port is located). The subscript 't' represents conditions at the low pressure port. Consider incompressible flow (flow where the fluid density is constant) between the meter inlet (say section '1') and the cross sectional plane where the low pressure is read from (section 't'). Conservation of mass and energy exists across these planes, if we make the simplifying assumption of there being no energy losses. As the fluid passes the edge of the cone (often called the 'beta edge'), it detaches from the cone and forms an annular jet downstream with a wake at the center driven by the shear from the annular jet. The effective cross sectional area of this jet at the low pressure port is denoted in Figure 3 as $A_{t,actual}$. The correct downstream cross sectional area to use in the flow calculation is the effective cross sectional area, $A_{t,actual}$. However, as this area is not known in practice (and varies with flow rate), the known annular area between the cone edge and the wall (denoted as A_t) is used.

The mass and energy conservation equations can be applied for a horizontal incompressible flow (Equations 1 and 2). Note that *m* is the mass flow rate. Equations 1 and 2 can be re-arranged into Equations 1a and 2a respectively.

$$m = \rho A_1 U_1 = \rho A_t U_t \tag{1}$$

$$\frac{A_t}{A_1} = \frac{U_1}{U_t} \tag{1a}$$

$$\frac{P_1}{\rho} + \frac{U_1^2}{2} = \frac{P_t}{\rho} + \frac{U_t^2}{2} \tag{2}$$

$$\frac{\Delta P}{\rho} = \frac{P_1 - P_t}{\rho} = \frac{U_t^2}{2}\left(1 - \left(\frac{U_1}{U_1}\right)^2\right) \tag{2a}$$

Therefore, substituting Equation 1a into Equation 2a gives Equation 3 which can be rearranged to give Equation 3a:

$$\frac{\Delta P}{\rho} = \frac{U_t^2}{2}\left(1 - \left(\frac{A_t}{A_1}\right)^2\right) \tag{3}$$

$$U_t = \frac{1}{\sqrt{1-(A_t/A_1)^2}}\sqrt{\frac{2\Delta P}{\rho}} \tag{3a}$$

Substituting Equation 3a into the Equation 1 where the beta (β) is defined as Equation 5:

$$m = \frac{\rho A_t}{\sqrt{1-(A_t/A_1)^2}}\sqrt{\frac{2\Delta P}{\rho}} = \frac{A_t}{\sqrt{1-\beta^4}}\sqrt{2\rho\Delta P} \tag{4}$$

$$\beta = \sqrt{\frac{A_t}{A_1}} \tag{5}$$

It is convention with DP meters to let the geometric constant "velocity of approach," *E*, be defined as Equation 6. Therefore, Equation 4 can be expressed as Equation 4a.

$$E = 1/\sqrt{1-\beta^4} \tag{6}$$

$$m = EA_t\sqrt{2\rho\Delta P} \tag{4a}$$

Equation 4a is the theoretical mass flow equation of all DP meters, not just the cone meter. The same equation can be derived regardless of the primary element design. This is not a unique special cone DP meter equation. The cone just uses the generic DP meter equation.

In reality, the theoretical flow equation is not applicable for any real DP meter, including the cone meter. The simplifying assumptions in the theoretical flow equations development need to be corrected for. These corrections are individual DP meter designs dependent. Cone meters require three modifications to the theoretical Equation 4a. The first is a correction to account for the known geometric minimum cross sectional flow area (A_t) being used in the flow rate equation instead of the unknown actual flow area ($A_{t,actual}$). Secondly, the assumption of no energy losses is obviously incorrect. Thirdly, the assumption of incompressibility is only valid for liquids; gas flows will change density with changing pressure. Therefore, gas flow applications require a gas density correction (whereas liquid flow applications do not).

None of the three required correction factors can be theoretically derived. Hence, they can be combined to create a single correction factor or "flow coefficient," denoted by '*K*.' However, if the flow is a gas, the correction factor component for gas density fluctuations through the meter, called an expansion factor (denoted by '*Y*'), can be separated out. The combined correction for the flow area and energy loss assumptions only is called the discharge coefficient and denoted by 'C_d.' As liquid is incompressible, the expansion factor (*Y*) for liquid is unity, and for liquid flows, the flow coefficient and discharge coefficient are equivalent. The flow coefficient and the discharge coefficient for cone meters have the same definition as all DP meters. They are defined by Equation 7, where m_{actual} and m_{theory} represent the actual mass flow and the mass flow rate being predicted by the theoretical Equation 4a. The cone meter expansion factor is shown as Equation 8. The derivation of this equation is well beyond the scope of this paper but interested readers will find the derivation published by Stewart [2]. This specific cone meter expansion factor is unique to the cone meter. In Equation 8, κ is the isentropic exponent for gas. This is available from look up tables for most common fluids. Equations 9 and 9a show the actual cone meter gas and liquid flow rate equations respectively. The subscript *actual* has been dropped in Equations 9 and 9a and replaced with *g* and *l* respectively to denote the predicted gas and predicted liquid flows.

$$K = YC_d = m_{actual}/m_{theory} \tag{7}$$

$$Y = 1 - \left((0.649 + (0.696\beta^4))(\Delta P/\kappa P)\right) \tag{8}$$

$$\text{For gas:}\quad m_g = EA_tYC_d\sqrt{2\rho\Delta P} \tag{9}$$

$$\text{For liquid:}\quad m_1 = EA_tC_d\sqrt{2\rho\Delta P} \tag{9a}$$

The difference between the DP meter flow rate equations of orifice, Venturi, cone meters, etc. is what values or equations are used for the discharge coefficient and expansion factor. The expansion factor for cone meters is known (Equation 8). ISO 5167-5 states this expansibility equation and that a cone meter's discharge coefficient is 0.82 ± 5% to 95% confidence. For allocation, custody transfer, or fiscal metering, a 5% flow rate prediction uncertainty is high, and this is why ISO states cone meters should be calibrated to achieve low flow rate prediction uncertainty. Calibration should produce a discharge coefficient uncertainty of < 0.5%.

The cone meter's ***pre-calibration*** relatively high discharge coefficient uncertainty is due to issues such as varying upstream inlet pressure port locations, different support bar sizes, varying cone/support bar junction geometry, and the manufacturing process. Unlike orifice and Venturi meters, the primary element (i.e., the cone assembly) is welded into place. Welding by nature does not produce precisely reproducible meters. A batch of nominally identical cone meters built to the same drawing tend to not be truly identical in practice due to the cone assembly welding process. Different meters can have slight differences in the cone positioning due to slight welding distortions. Although slight, these differences are enough to shift discharge coefficient values between meters. Each individual cone meter can be calibrated to find its particular, very repeatable low uncertainty discharge coefficient. Cone meter manufacturers could tighten the manufacturing process to reduce the discharge coefficient variation between cone meters, but they tend to keep deliberately liberal manufacturing tolerances to ease manufacturing time, cost, and complexity. That is, for economic reasons, industry has always defaulted to keeping cone meter manufacturing costs down and calibrating each cone meter instead.

3. Cone Meter Calibration

Cone meters are typically calibrated. This is similar to Venturi meters (for high end applications), ultrasonic meters, turbine meters, etc. Cone meters should be calibrated in a calibration facility where the mass flow rate ($m_{reference}$) is recorded by a reference meter (of stated low uncertainty) across the full flow rate range of the application. The flow coefficient can be found by Equation 10.

$$C_d = \frac{m_{reference}}{EA_t Y\sqrt{2\rho\Delta P}} \tag{10}$$

$$\mathrm{Re} = \frac{\rho U D}{\mu} = \frac{4m}{\pi\mu D} \tag{11}$$

More precisely, cone meters (like all flow meters) should be calibrated across the applications Reynolds number range. For a given pipe size and fluid viscosity, Reynolds number can be thought of as a non-dimensional flow rate. Equation 11 shows how to calculate the Reynolds number, where μ is the fluid viscosity, U is the average fluid velocity, and D is the pipe diameter. The cone meter's discharge coefficient is not always constant across a Reynolds number range. (This is not a unique cone meter phenomenon. Generic flow meter flow coefficients usually vary with Reynolds number. This is true of turbine, ultrasonic, Venturi, orifice meters, etc.).

Figure 4 shows a real CEESI gas flow rate calibration of a 4", 0.75 beta ratio cone meter. Note that the calibration procedure is to plot the discharge coefficient vs. Reynolds number and then fit an equation relating the two parameters. In this case, the equation was a linear line and the discharge coefficient is predicted to within ±0.5% across the Reynolds number range tested. This is the typical

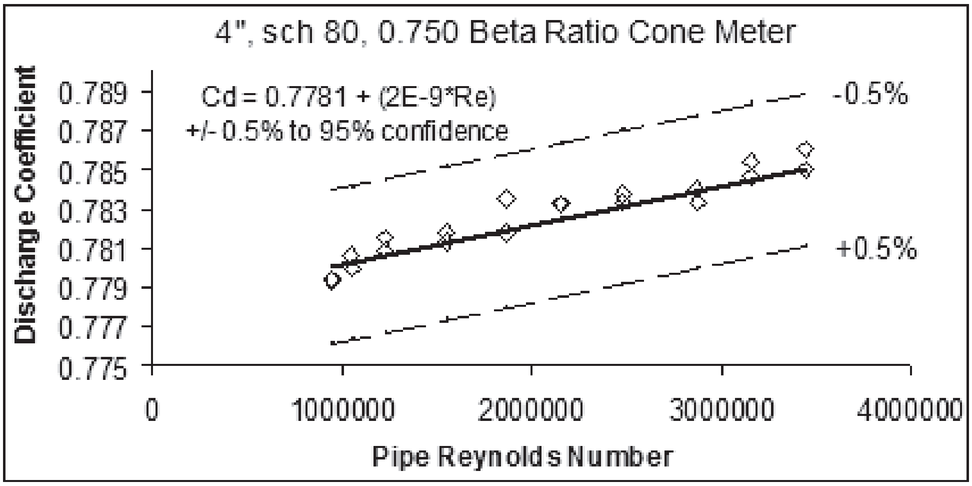

Figure 4. A gas flow calibration result for a 4", 0.75 beta ratio cone meter.

uncertainty of a **calibrated** cone meter.

$$C_d = f(\mathrm{Re}) = f(m/\pi\mu D) \tag{12}$$

$$m - \left\{ EA_t Y * f(m/\pi\mu D) * \sqrt{2\rho\Delta P} \right\} = 0 \tag{9b}$$

Equation 12 shows the generic form of the discharge coefficient to Reynolds number fit. It should be noted that there is no restriction on the form of the function 'f,' i.e., the type of equation used to fit the data. Occasionally, the discharge coefficient is insensitive enough to the Reynolds number to allow a constant discharge coefficient to be used. However, more complicated equations generally give lower flow rate uncertainty results. Many cone meter operators default to using the generic flow computer 'piece wise linear interpolation' data fit. As the Reynolds number is mass flow rate dependent (i.e., the Reynolds number is dependent on the parameter being derived), the cone meter flow rate calculation method is an iteration routine, as indicated by Equation 9b. Modern flow computers perform such iterations (even with complex data fits) with ease.

4. Cone DP Meter Performance and Calibration Issues

A typical properly calibrated cone meter has a discharge coefficient known across a Reynolds number range to < 0.5% uncertainty. It does not matter what fluid is used to calibrate the meter, as long as the Reynolds number range of the application is matched. However, there are a few caveats to that general statement. These are:

- the fluid must be Newtonian,
- expansibility of gas needs to be accounted for; and,
- if using water, cavitation must be avoided.

A rule of cone meter (and all flow meter) calibrations is that the Reynolds number range of the application must be covered. If this stipulation is met, a cone meter calibration carried out with one fluid is applicable to when the meter is in use with any other fluid.

Water flow meter calibration facilities are simpler and less expensive to operate than gas flow meter calibration facilities. Therefore, calibrating a cone meter with a water flow can be attractive to both manufacturers and meter users. However, there can be a significant potential problem with this approach. This problem hinges on the requirement that the Reynolds number range of the application has to be matched. Equation 11 shows that the Reynolds number is a function of the fluid density, average fluid velocity, the inlet diameter, and the fluid viscosity. For a given meter, the inlet diameter is of course set. However, if we consider a set velocity value, we see that the Reynolds number is a function of the fluid density and viscosity. Liquids are considerably denser than gases (even at extremely high pressures) but gas is typically a couple of orders of magnitude less viscous than liquids. Hence, water flows tend to have far lower Reynolds numbers than gas flows. The effect this has on cone meter calibration is that ***it is unlikely that a water calibration facility can reach the upper Reynolds number values required for most gas flow metering applications***. That is, water calibration facilities more often than not cannot properly calibrate a cone meter for gas applications as they cannot calibrate across the applications Reynolds number range. As we will see, cone meters often have a non-linear discharge coefficient vs. Reynolds number relationship, and hence it is not appropriate to extrapolate water flow low Reynolds number range data to gas flow high Reynolds number ranges. To do so can, and does, lead to significant flow rate prediction biases.

If a cone meter is calibrated across the applications full Reynolds number range then the cone meter will be a reliable flow meter giving a competitive flow rate uncertainty across a > 10:1 turndown[1]. The cone meter has no moving parts and therefore if properly calibrated and installed, and if it receives no damage, wear, trapped foreign objects or contamination issues, then the calibration result will remain constant. However, as with all flow meters, failure to calibrate the cone meter correctly can lead to significant bias on the flow rate measurement. The following discussion discusses potential calibration issues with cone meters.

4a. The Necessity for Calibration Across the Application's Full Reynolds Number Range

If a cone meter is calibrated across a relatively low Reynolds number range (e.g., with water flow calibration facility), it is not possible to predict any discharge coefficient relationship with the Reynolds number over a wider range. A low Reynolds number range/water calibration can give the illusion that the meter's discharge coefficient is constant, and/or can suggest the performance at higher Reynolds numbers is different to what it actually is. Often calibration across a larger turndown (usually by means of gas flow tests) shows extrapolation of lower Reynolds number data to be incorrect. Hence, a cone DP meter's uncertainty rating is only applicable within the Reynolds number range of its calibration. Extrapolating

1 There is a debate about the flow rate turndown capability of DP meters. A traditional limit is a very conservative 3:1. Due to the parabolic relationship between flow rate and DP this corresponds to an approximate DP reading turndown of 9:1 (see equation 9). However, this 9:1 DP turndown is based on traditional manometer technology. Modern DP meters have the DP read by stacked digital DP transmitters and can easily give DP turndowns > 100:1 making the associate flow rate turndown > 10:1 and competitive with all other modern flow meter designs.

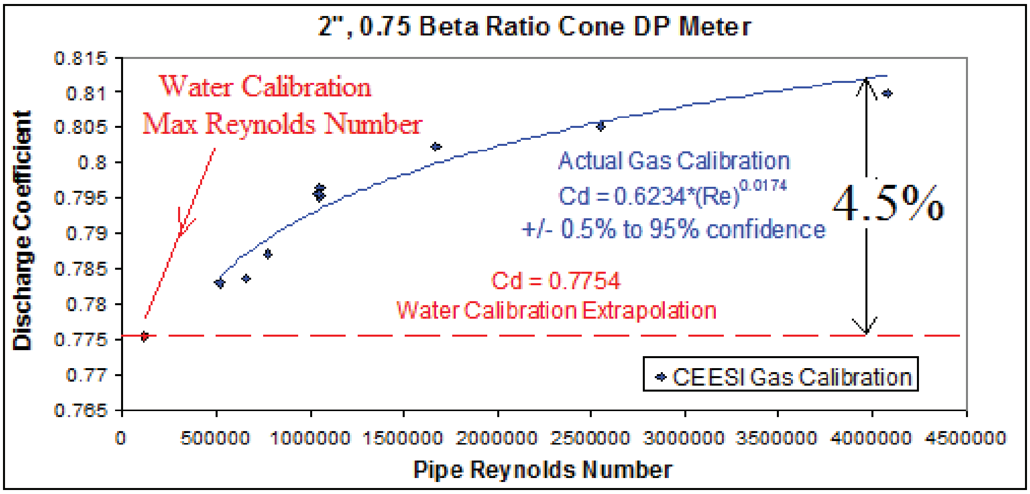

Figure 5. 2", 0.75 beta ratio cone meter water and gas calibration results.

a low Reynolds number calibration for use with high Reynolds number flows invalidates the uncertainty rating and may lead to significant bias in the flow measurement. An example is now given.

A 2", 0.75 beta ratio cone meter was supplied to a gas flow application with a water calibration. The discharge coefficient based on a water flow calibration with a maximum Reynolds number of 114,606 was stated to be a set value of 0.7754. During use at considerably higher Reynolds numbers, a potential performance problem was noted. By plotting subsequent gas flow calibration data at Reynolds numbers up to 4e6, it was found that extrapolation of the water calibration data was causing a 4.5% under-reading of the gas flow rate. Data fitting all the data across the full Reynolds number range gave a discharge coefficient uncertainty of 0.5% as required. Figure 5 shows these results. Hence, it is not good practice to extrapolate cone meter calibrations to higher Reynolds numbers. Such practice can induce significant measurement biases. Only when a cone meter is calibrated across the full Reynolds number range is the meter's uncertainty statement valid. Operation outside the calibrated Reynolds number range gives an unknown cone meter performance. Note that the gas calibration can be done at any pressure. When calibrating a cone meter the Reynolds number range is the parameter range that matters, as long as the Reynolds number range is met the gas pressure/density does not matter.

4b. The Necessity to Calibrate Each Individual Cone DP Meter

Many flow meter applications are in systems where multiple, identical meters are required. If multiple meters

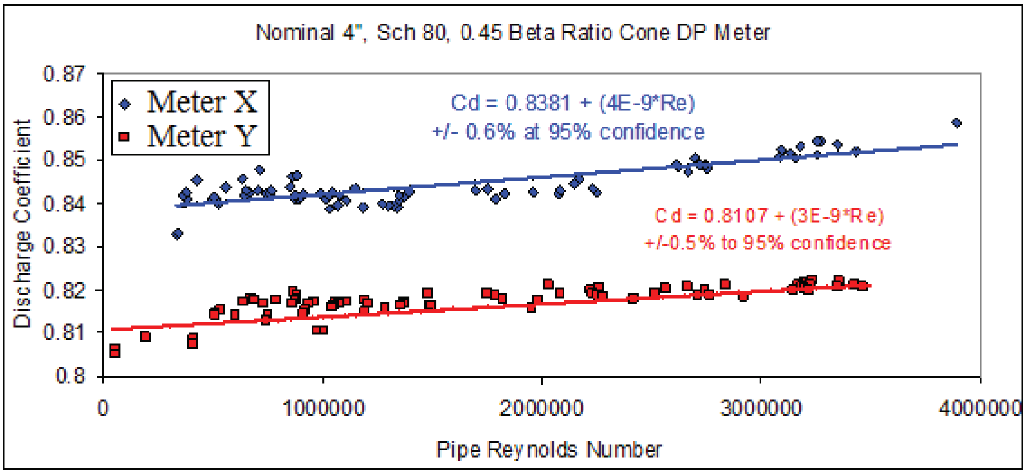

Figure 6. Comparison of two nominally identical cone DP meter calibrations.

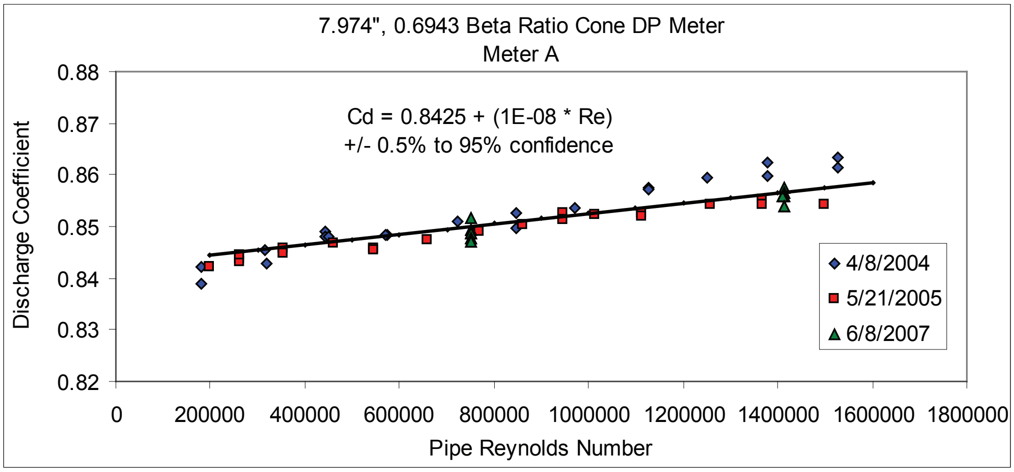

Figure 7. The repeat calibration results of one cone meter.

are ordered, which are on paper said to be identical, there is a temptation to calibrate one meter only and apply that calibration to all meters of that specification. The rational of this proposed approach is based on the assumption that because the meters are said to be identical, their performance under the same flow conditions should also be identical. Therefore, this common argument is wholly based on the assumption that because the meters are identical on paper they are also identical in reality. However, in reality as already discussed, there are manufacturing tolerances. No two cone meters are truly identical. With the current typical cone meter manufacturing tolerances, although meters are identical on paper, they can be subtly different in practice. Let us consider an example.

Figure 6 shows the calibration results from two 4”, schedule 80, 0.45 beta ratio cone meters that are identical on paper. They were built by the same manufacturer, at the same fabrication shop, from the same drawing. The first meter (Meter X) had an ID of 3.812” and a beta of 0.4512, whereas, the second meter (Meter Y) had an ID bore of 3.823” and a beta of 0.4500. When the two meter calibrations were compared, it was found that there was approximately 4% difference between the meters discharge coefficients. If only one of the meters was calibrated, and the result assumed to be valid for the other, the un-calibrated meter would have a flow rate prediction bias of 4%. Therefore, it is not advisable to assign the result of one cone meter calibration to another cone meter even if the meters are nominally identical. It is possible, depending on chance, that two nominally identical cone meters may have very similar performances. The chance of this seems to increase with larger meters. However, it can’t be guaranteed that any two nominally identical meters have a similar performance until they are both calibrated.

4c. A Discussion on the Requirement for Periodic Re-Calibration

For any given cone meter, as long as the geometry remains constant (i.e., there is no wear, contamination, cone deflection, etc.), then the performance—the relationship between the Reynolds number and the discharge coefficient—is set. Proof of this statement is given in Figure 7. Here three separate calibrations of the same cone meter over several years are shown. The meter was periodically sent for re-calibration by the operator. Clearly, no significant difference is seen between the calibration results. The original 2004 calibration result is still valid in 2007. The only time a cone meter’s calibration changes is when there is a physical change to the meter, such as wear, contamination, cone deflection, etc. However, it is recognized here that without the installation of the DP meter verification system, Prognosis™, it is difficult for the operator to be sure if there has been such a change. As with all flow meters, one confirmed way to guarantee a previous calibration is still valid is to recalibrate.

5. The Cone Meters High Resistance to Disturbed Inlet Flow

The cone meter is renowned for being extremely resistant to disturbed inlet flow. Most flow meters are sensitive to flow disturbances and require a fully developed symmetric flow profile at the meter inlet. This is achieved by setting the meter’s location at various distances downstream from various obstructions and/or including a flow conditioner. The cone meter is not completely immune to upstream flow disturbances but it has been proven to be considerably less sensitive to most flow disturbances than other meters.

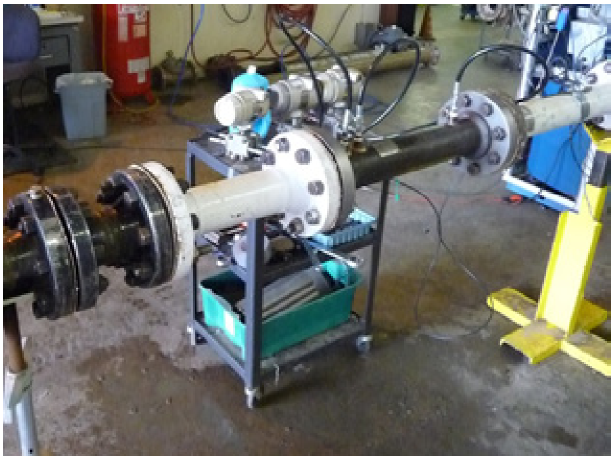

Figure 8. Baseline Installation.

Figure 11. DOPB 0D up & TOPB down.

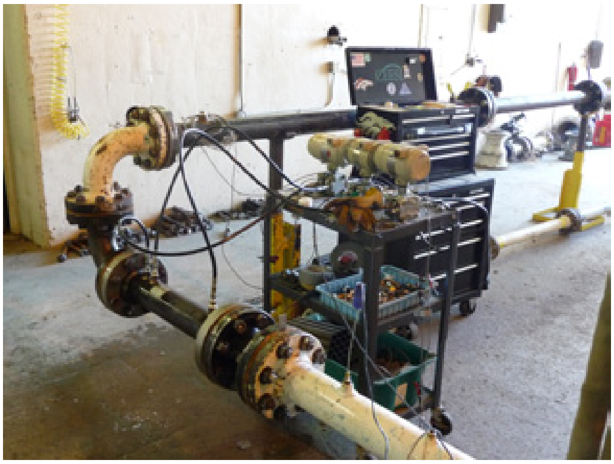

Figure 9. DOPB, 0D up.

Figure 12. HMOP 6.7D up.

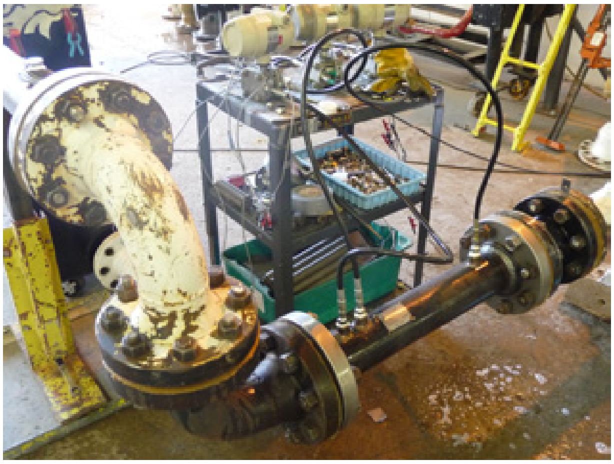

Figure 10. DOPB 0D up & HMOP 2D down.

Figure 13. HMOP 8.7D up.

Figure 14. HMOP 2D down.

Figure 15. 3" Swirl Generator + Expansion 9D up.

Hence, the cone meter can be used in applications where long straight pipe work is not available and other meters cannot be applied.

Cone meter insensitivity to flow disturbances has been shown in API 22.2 test reports (see Peters [3]). This API test protocol allows a neutral test laboratory to test a DP meter's sensitivity to select upstream (and downstream) disturbances. Other neutral tests have also confirmed the cone meter's remarkably low sensitivity to upstream flow disturbances. Figures 8 thru 15 show testing done at CEESI in 2009 (see Steven [4]) to find the flow disturbance sensitivity of a 4", 0.63β cone meter. Figure 8 shows the baseline. Figure 9 shows a Double Out of Plane Bend (DOPB) at 0D upstream of the meter. Figure 10 shows a DOPB at 0D upstream of the meter and a Half Moon Orifice Plate (HMOP) at 2D downstream of the meter. (A HMOP models the effect of a half open gate valve.) Figure 11 shows a DOPB at 0D upstream of the meter and a triple out of bend at 0D downstream of the meter. Figures 12 and 13 show a HMOP at 6.7D and 8.7D upstream of the meter respectively. Figure 14 shows a HMOP 2D downstream of the meter. Figure 15 shows a swirl generator generating extreme swirl before a 3" to 4" expansion at 9D upstream of the meter. Some of these flow disturbance tests are the most extreme ever tested on a cone meter.

The results are shown in Figure 16. Note that the baseline calibration shows a discharge coefficient fitted across the Reynolds Number range to ±0.5%. Of the nine different disturbances—more are listed than pictures shown—six of them did not shift the baseline calibration results more than the uncertainty of the baseline, i.e. the meter's discharge coefficient remained within 0.5% of the baseline. Of the other three, the discharge coefficient bias induced is still < 1%. Other meters on the market tend to be more sensitive to such disturbances. Of course like other flow meters, any bias due to the flow disturbance can be removed by calibrating the meter in the pipe configuration for which it is to be used. Similar results were shown by Stobie [5] for a 4", 0.75β cone meter.

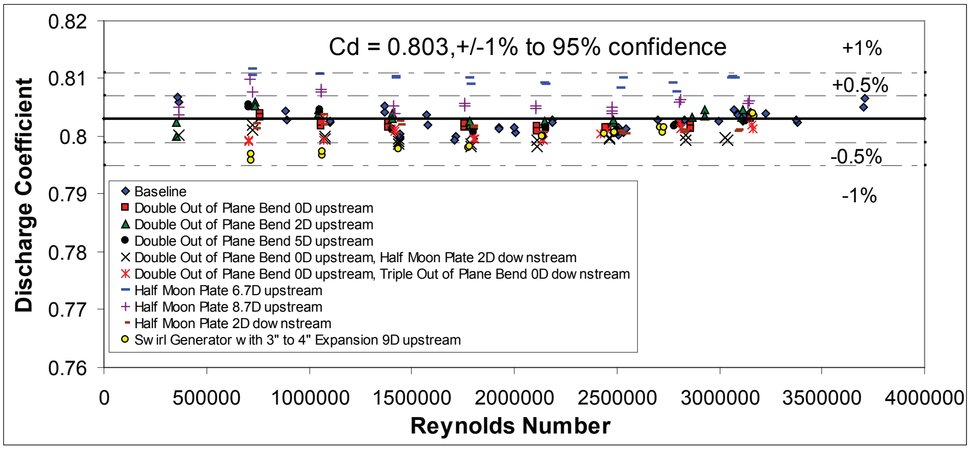

Figure 16. Complete Results of Cone Meter Performance with Flow Disturbances.

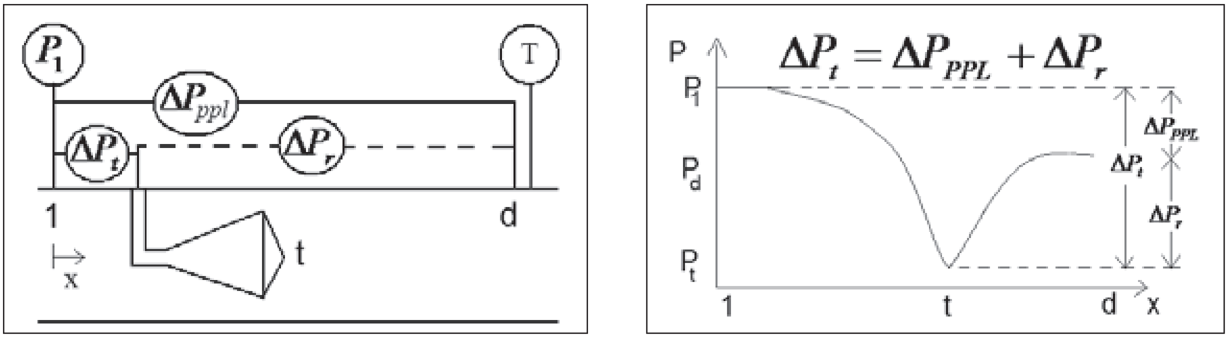

Figure 17. Cone Meter Sketch with Instrumentation and Pressure Fluctuation Graph.

6. A Cone Meter Verification System

The cone meter has an optional verification system developed by DP Diagnostics for generic DP meters (called Prognosis™). Figure 17 shows a sketch of a cone meter with the required instrumentation. A graph depicting the (simplified) pressure fluctuation through the meter is also presented. There is an extra pressure tap downstream of the cone. The three pressure ports allow the reading of the traditional (ΔP_t), recovered (ΔP_r), and permanent pressure loss (ΔP_{PPL}) DPs. The sum of the permanent pressure loss and recovered DP equals the traditional DP. This gives a DP reading integrity check.

Each of these individual DPs can be used to predict the flow rate (see Stobie [5]). The resulting three flow rate equations are Equations 13, 14 and 15:

Traditional Flow Equation:	$m_t = f(\Delta P_t)$, uncertainty ± x%	(13)
Expansion Flow Equation:	$m_r = f(\Delta P_r)$, uncertainty ± y%	(14)
PPL Flow Equation:	$m_{PPL} = f(\Delta P_{PPL})$, uncertainty ± z%	(15)

Note m_t, m_r, and m_{PPL} represent the traditional, expansion, and PPL mass flow rate equation predictions of the actual mass flow rate (m) respectively. The extra downstream pressure tap turns the single meter effectively into a flow meter with two check meter is series. These two extra flow meters can be calibrated by the standard cone meter calibration. Three flow rate predictions give three pairs of flow rate predictions to compare, i.e., three diagnostic checks. Three read DPs gives three pairs of DPs, i.e., three DP ratios. These ratios are characteristics of the cone meter and remain constant throughout the meter's correct operation. Again, these DP ratios can be characterized by the standard cone meter calibration. The three DP ratios found in the field can be compared to the calibrated values giving three further diagnostic checks. Therefore, there are seven cone meter diagnostic checks, the DP integrity check, the three flow rate prediction comparisons, and the three DP ratio checks.

Figure 18 shows a ConocoPhilips McCrometer 14", 0.556β cone meter under calibration at GLIS. The cone meter has the verification system (note the downstream pressure port). The seven diagnostic checks can be plotted on a simple display as shown in Figure 18 (right hand graph) for ease of use by technicians. Each DP pair produces two flow rate predictions to check against each other (the x-coordinate), and a read to baseline DP ratio comparison (the y-coordinate). Hence, three points representing six diagnostic checks are plotted on a graph. The fourth point only has an x-coordinate and represents the DP integrity check. A normalized box is drawn around the graph origin representing the maximum allowable variation between

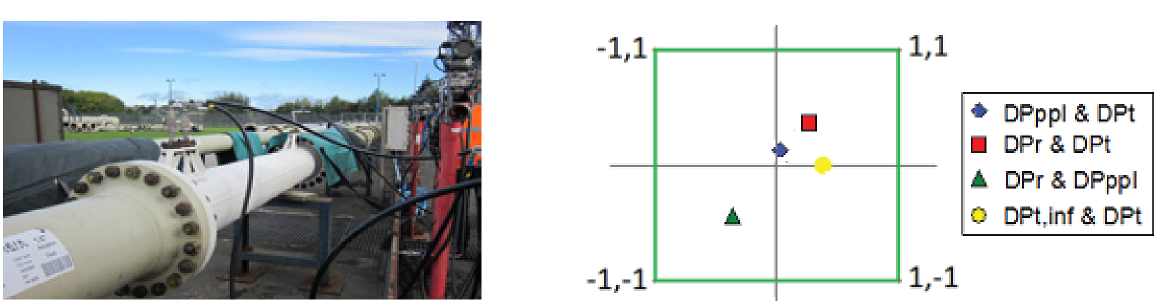

Figure 18. 14", 0.556β cone meter with verification system and verification system display.

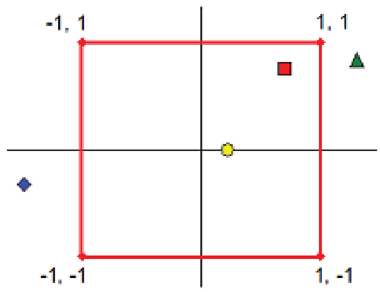

Figure 19. Incorrect Cone Diameter Entered.

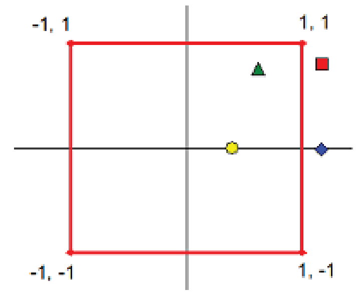

Figure 20. Incorrect C_d Value Entered.

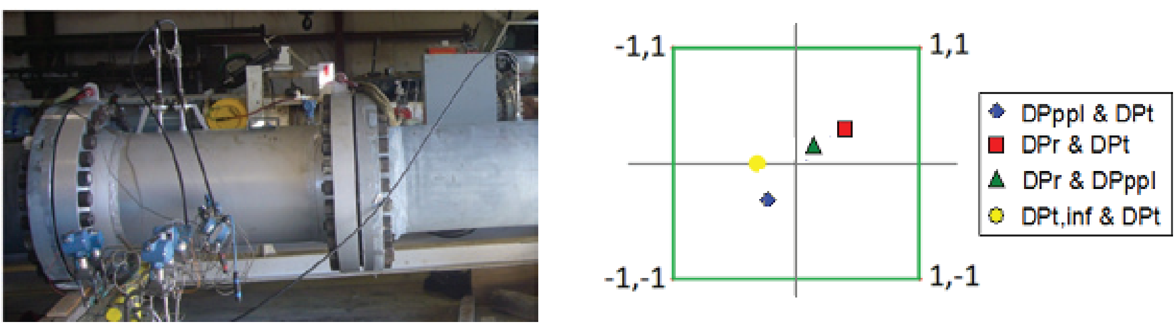

Figure 21. 26", 0.669β cone meter at CEESI with verification system and verification system display.

expected and actual results. All points inside the box means a fully serviceable cone meter. One or more points outside the box represents an unserviceable cone meter.

Not all problems create the same diagnostic pattern; there is information about the source of the problem within the diagnostic result. Figure 18 shows the verification system showing the cone meter operating correctly. The primary job of a flow meter verification system is to reassure the end user that the meter is indeed operating correctly. However, the following is a small selection of examples if the cone meter has a problem.

Figures 19 and 20 manipulate the data logged at GLIS for the 14", 0.556β cone meter. Figure 19 shows the verification response if an incorrect cone geometry of 0.279m instead of 0.280m is keypad entered into the flow computer (producing a +1.7% flow rate prediction bias). Figure 20 shows the verification response if an erroneously keypad entered discharge coefficient vs. Reynolds number data fit gave a discharge coefficent of 0.841 instead of the correct 0.851 (producing a -1.2% flow rate prediction bias).

Figure 21 (left side photograph) shows a Dermaga/DP Diagnostics 26", 0.556β cone meter under calibration at CEESI Iowa. The verification system shows the cone meter operating correctly (Figure 21 - right hand graph). Figure 22 shows the verification response of this meter if the traditional DP (used for the primary flow rate calculation) is in error due to a DP transmitter drift. In this case, the correct DP of 26.6"WC was (deliberately in order to prove the verification system) incorrectly read as 25.8"WC causing a -1.4% flow rate prediction bias.

Figure 23 (left side photograph) shows a DP Diagnostics 4", 0.63β cone meter under test at CEESI where a foreign

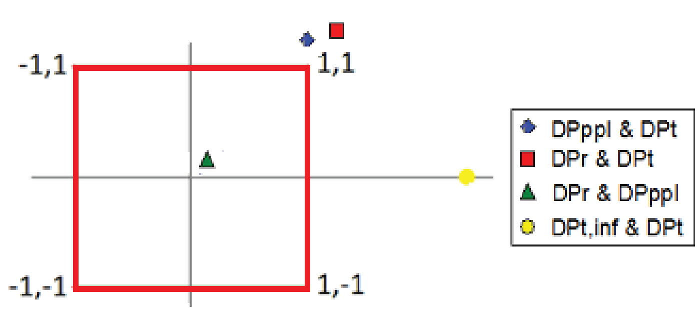

Figure 22. 26", 0.669β cone meter with drifted DP transmitter.

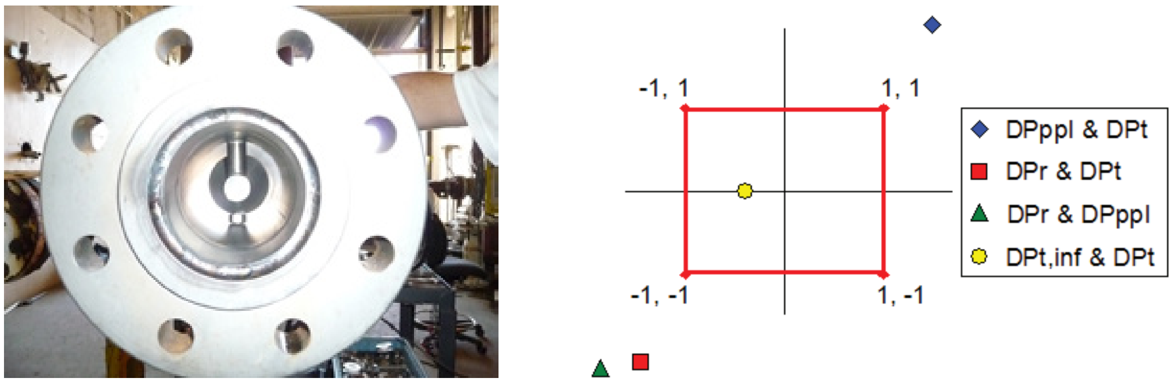

Figure 23. 4”, 0.63β cone meter with trapped nut and verification result.

object (in this case a nut) is deliberately trapped at the cone element. This cone meter was pre-calibrated to have the Prognosis™ verification system. Figure 23 shows the verification response to the foreign object’s presence. The flow bias was recorded as +5%.

Figure 24 shows drawings of a DP Diagnostics 4”, 0.75β cone meter as manufactured (left hand drawing) and after damage to the cone element (right had drawing). The meter was calibrated before being damaged. The damage, i.e. a modest cone deflection of approximately 1.9^0, produced a flow rate prediction bias of +1.2%. Figure 25 shows the verification result before and after the damage occurred.

These cone meter verification system examples are a random selection. The Prognosis™ verification system has been shown to be sensitive to many common cone meter problems, such as incorrect keypad entry of meter geometry or discharge coefficient, cone element damage, contamination, a partial blockage at the cone, wet gas flow, DP reading errors, etc. This verification system is external to the standard cone meter but is available from various independent outlets as a supplementary system (e.g., Emerson RAS ROC flow computer, Swinton Technology Prognosis Micro, etc.).

7. Conclusions

Cone meters are generic DP meters. They operate according to the same physical principles as the other DP meters. Cone meters have pros and cons when being compared to other DP meters.

The ISO 5167-5 [1] uncalibrated cone meter’s predicted discharge coefficient has an uncertainty of 5%. For lower uncertainty, each cone meter must be individually calibrated. Like many other meters, cone meters must be calibrated across the application’s full Reynolds number range. A manufacturer’s water flow calibration range often does not cover a gas flow applications full Reynolds number range. Cone meters built to a nominally identical design can have small but significant geometric differences due to manufacturing tolerances, and hence each cone meter’s calibration data is unique. That is, no cone meter’s calibration result should be transferred to another nominally identical cone meter. However, when properly calibrated, each cone meter can have a discharge coefficient ±0.5% uncertainty across a > 10:1 turndown.

A calibrated cone meter is resistant to many flow disturbances. The meter continues to correctly measure the

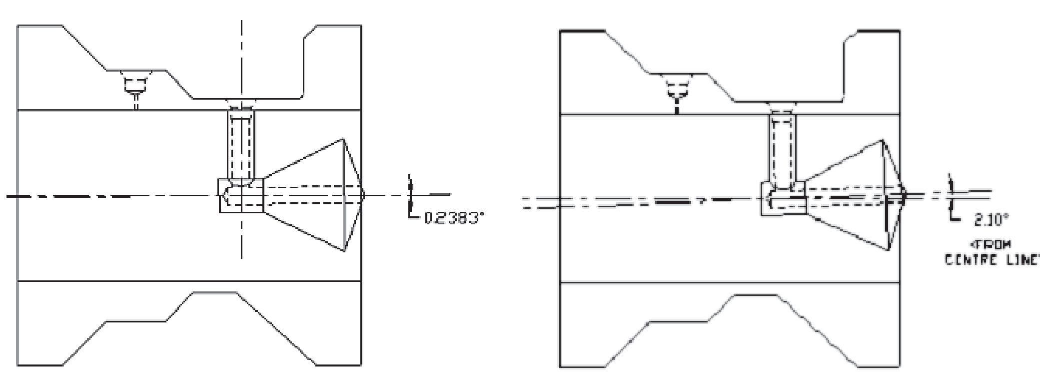

Figure 24. 4”, 0.75 β cone meter before and after cone element damage.

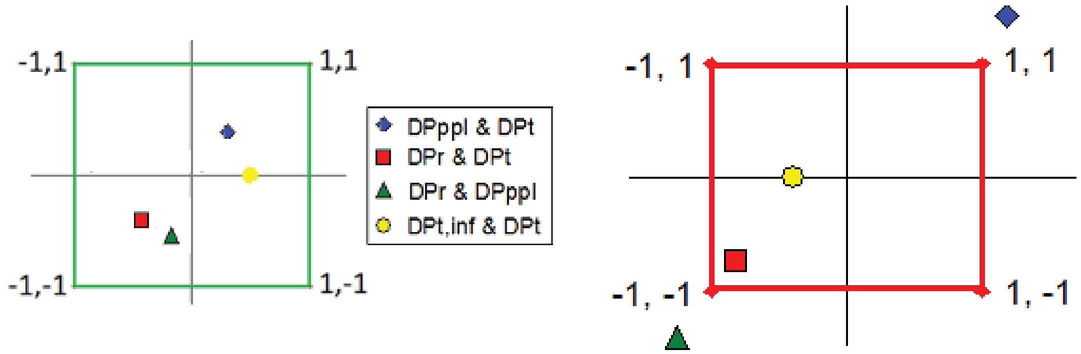

Figure 25. 4", 0.75 β cone meter verification results before and after cone element damage.

fluid flow rate even with extreme flow disturbances that would make many other meter designs have significant flow rate prediction biases. Finally, it should be noted that the cone meter now has a comprehensive verification system available (Prognosis™), thereby giving assurance to the operator that the cone meter is functioning correctly.

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History of Lowry PMEL School

Sita Schwartz
Editor

Wings Over the Rockies Air & Space Museum, located in Building 401, Hanger 1 of the decommissioned Lowry AFB.

Timeline

- **1918** – Namesake, Lt. Francis B. Lowry (aerial observer), was shot down and killed during aerial combat along with his pilot, Lt. Asher Kelty, in the Meuse-Argonne offensive.
- **1926** – Lowry Field, established in Denver, Colorado.
- **1938** – Lowry AFB became activated, built just east of the original airfield.
- **1950** – A need for standardized maintenance procedures within the United States Air Force prompted creation of PMELs.
- **1959** – PMEL metrology training courses begin at Lowry AFB.
- **1974** – Calibrations Specialist course moved to Lowry from the Aberdeen Proving Ground, MD. Multi-service enrollment to include: Marine Corps, Army, and Navy.
- **1994** – Decommission of Lowry AFB.
- **2011** – Wings over the Rockies Air & Space Museum opens in Building 401, Hangar 1.

For an industry outsider looking in, an awful lot of metrology technicians and metrologists have their background in the military. There's a reason for that: Precision Measurement Equipment Laboratories (PMEL) schools all over the world churned out multiple generations of skilled technicians during the last century. Lowry Air Force Base, in Denver, Colorado, was a particularly active training ground for United States Air Force members, as well as other branches of the military. US service members trained at Lowry schools during WWII for photography, armaments, and B-29 crew training. Training at Lowry expanded to rocket propulsion, missile guidance, and Undergraduate Space Training, as well as "other logistical services required by the military," including precision measurement [1].

Prompted by a 1958 inspection of Russian military training facilities by General Doolittle, the Pentagon solicited bids for creating a program similar to the Russians' calibration course. Henry May, of Lowry's Photo school, submitted materials for consideration, and so began Lowry's history of formal metrology training.

Ten specialists from different technical backgrounds went through six weeks of training at Gentile Air Depot, Ohio, where "They were introduced to the theory and practical application of basic standards of precision measurement, primarily of electronic instrumentation" [2]. These specialists put together training material from what they learned and class started on April 1, 1959 on the top floor of the Photo school. Eventually, the PMEL school was moved into its own building (375A) and the course was expanded to 35 weeks in order to cover added material. In 1968, school length was expanded to 46 weeks. The school continued to go through changes, including a name change to "Metrology" and cutting back the Basic Course to 32 weeks by dropping Microwave and Physical/Dimensional.

The bar was set high for entering students. "The original students selected for PMEL/Metrology training had to be first three graders and must have at least three years left on their current enlistments." And until 1968, students "had to be on at least their second enlistment, have been in an electronics field and got 90 or more of the 130 questions correct on the Pre-Entrance Examination" [2].

> The PMEL course was originally set up for AF personnel only. Not long after the course was established, other military branches recognized the importance of having men trained in this specialty. The Navy was the first to send men to Lowry. And then came selected military members of allied nations. One shift and building 375A weren't enough. Building 1433 and several others became the next homes for the PMEL school. The school added one shift after another until the course was in session for four six-hour shifts a day…
>
> More than 50,000 students graduated from the basic Metrology course at Lowry AFB including those from all branches of service as well as services of 21 foreign countries under the MAP program…
>
> This [was] perhaps the only complete school where calibration [was] taught in electronics, physical, dimensional, optical, chemical, mechanical, radiac, or combinations of these disciplines. The school was capable of meeting any and all necessary requirements that would keep our military equipment in the most dependable and reliable condition for the defense of this country.
>
> The last class graduated from Lowry's PMEL/Metrology School on 18 March 1994, 35 years after the first class started. The last class had 3 US Airmen and 4 foreign nationals in attendance.
>
> The USAF Metrology Program began transitioning to Keesler AFB, Mississippi during the 1992-1993 time-frame where Metrology Training is currently being offered, the result of the [Base Realignment and Closure] BRAC decision to close Lowry AFB, Colorado in 1994. [2]

PMEL metrology schools offer an opportunity for smart young men and women to acquire vital skills in order to serve their country. Not only does metrology and calibration training *not* require a college degree, but also prepares members of the military for a career in the civilian world. Lowry was just one of many military bases with a PMEL that contributed to a skilled workforce now retiring in numbers quicker than can be replaced. As US military bases consolidate and outsource services, metrology training schools such as Lowry's PMEL have dwindled.

References

[1] http://www.lowryfoundation.org/

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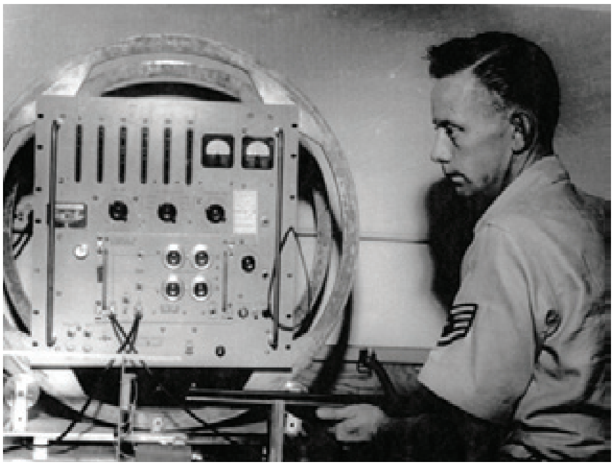
The last building to house the calibration school at Lowry is now utilized by the Community College of Aurora.



Lowry AFB PMEL School, 1963: Andre Grabel Measuring Pellet Speed. Credit: George Blood

Beamex Introduces LOGiCAL - Free, Cloud-based Calibration Software

PIETARSAARI, Finland, Nov. 13, 2017 /PRNewswire/ -- Beamex introduces a free of charge, cloud-based calibration certificate generation software called LOGiCAL. It was developed to offer an easy-to-use, modern, cloud-based software for documenting calibration results. Beamex has been producing and developing calibration equipment for more than 40 years, and calibration software for over 20 years.

In the process industry, most calibrations performed need to be documented in a calibration certificate. It is notable that many sites manually document calibrations using paper and pen, making it an inefficient process that is prone to errors.

As a solution to the industry's needs, Beamex has launched a new calibration software product called LOGiCAL.

"LOGiCAL reads the calibration results from Beamex documenting calibrators, such as the Beamex MC6 or Beamex MC4, and hence does not store any critical data in the cloud. When you perform calibrations using these calibrators, they automatically store the calibration results in their memory. LOGiCAL software can read these results and convert them into a PDF calibration certificate that you can either store or print," Product Manager Antti Mäkynen describes.

The LOGiCAL cloud communicates with the calibrators using a web service technology, meaning that the calibration certificate can be generated using any device connected to the internet and a web browser, given that the calibrator is connected to the computer and running LOGiCAL. It is compatible with most browsers, such as Chrome, Internet Explorer or Safari.

"To start using LOGiCAL, all you need to do is to visit the Beamex LOGiCAL product page (https://www.beamex.com/software/logical-calibration-software/) and navigate from there to register. After the registration, you can start using it right away. You will need to have a Beamex MC6 or Beamex MC4 calibrator with the Documenting Calibrator option to utilize LOGiCAL," Antti Mäkynen continues.

The initial use of LOGiCAL will be available at no cost while further capabilities will become available as chargeable options. Beamex is committed to developing additional functionality in LOGiCAL based on user feedback and market requirements.

Beamex continues to develop its market leading CMX calibration software; an excellent choice for even the most demanding and regulated companies.

Starrett Benchtop Vision System

ATHOL, MA U.S.A. (October 27, 2017) – Today The L.S. Starrett Company (www.starrett.com) has announced the introduction of the HVR100-FLIP, an innovative new large field-of-vision (FOV) Benchtop Vision Measurement System that is capable of being used in either a vertical or horizontal orientation, features a high-resolution digital video camera and minimal optical distortion for accurate FOV measurements of up to 90mm (3.65"). The "FLIP", developed by Starrett Kinemetric Engineering Inc., a subsidiary of The L.S. Starrett Company, made its North American debut at The Quality Show in Chicago, October 24th, 2017. A video on the new FLIP system and product brochure can be viewed at http://starrett.co/2gCZAyw.

The FLIP horizontal or vertical orientation feature lends itself to an extremely wide array of applications from flat parts such as gaskets and seals, to turned and threaded parts. The system can be easily changed over from vertical to horizontal and back within minutes, and can be placed on most sturdy workbenches.

The compact Starrett HVR100-FLIP has a 24" LCD touch-screen monitor, a 348mm x 165mm (13.7" x 6.5") stationary top plate and 165mm (6.5") optics travel with a motorized power drive for accommodating various part sizes and enhanced performance. An LED ring light provides surface illumination and LED backlight offers transmitted illumination.

The main operator interface of the FLIP displays a live video image with software measurement tools and graphical digital reading of measurements. A part image can be resized using pan, zoom and measurements by simply tapping a feature on the monitor screen. A wireless keyboard and pointing device are also provided for entering file names and targeting key functions. MetLogix M3 software includes 2D geometric functions such as points, lines, circles, arcs, rectangles, distances, slots, angles and skew, and utilizing the part design DXF/ CAD file digital overlay makes part inspection simple.

Additional features and options that offer enhanced measurement capability and increased throughput include:

- "Auto Part Recognition"
- "Digital Comparator-DXF overlay"
- "Profile Fitting"
- "Thread Measurement"

"The HVR100-FLIP video based measurement system is rugged and innovative, as equally effective on the manufacturing floor as it is in the Quality lab. The design structure allows for work handling and part fixturing and an operator interface typical of an Optical Comparator and Vision Metrology system, to measure parts in a progressive, efficient and practical way," said Mark Arenal, General Manager at Starrett Kinemetric Engineering.

Rohde & Schwarz ZN-Z32/33 VNA Calibration Solution

Munich, October 12, 2017 – Unlike conventional automatic network analyzer calibration units, the new R&S ZN-Z32/33 inline calibration units from Rohde & Schwarz are permanently connected to the test setup. This makes them an ideal solution for test setups that require frequent recalibration, especially where the test setup is inaccessible.

The new inline calibration units are the only solution available for testing in TVAC chambers where it is not possible to access the test set under vacuum conditions. After a basic calibration, carried out under ambient environmental conditions, the test set components are brought inside the TVAC before the vacuum is applied and testing starts. Once the vacuum is applied, recalibration is required after every temperature change due to thermal drift effects. With the calibration units in place and linked by a CAN bus, this recalibration can be easily performed.

For multiport applications that are typical in production testing, accuracy and reproducibility suffer due to limited phase stability when cables are moved. Repeated calibration with conventional equipment involves extra effort and wastes test time. In contrast, the R&S ZN-Z32/33 units allow calibration of a high number of test ports via a single keystroke in the control software tool, cutting recalibration time down to seconds. Users benefit from dramatically increased efficiency on the production line.

The R&S ZN-Z32 covers the frequency range from 10 MHz to 8.5 GHz and can be used in ambient conditions from +5 °C to +40 °C. The R&S ZN-Z33 covers the 10 MHz to 40 GHz range in ambient conditions from +5 °C to +40 °C or in TVAC conditions from –30 °C to +80 °C. The calibration units are controlled by an R&S ZN-Z30 CAN bus controller, which supports up to 48 units. With multiple controllers, a virtually unlimited number of inline calibration units, and therefore test ports, are supported. The R&S ZN-Z3ASW application software guides the operator through the system configuration and the calibration process.

The new R&S ZV-Z32/-Z33 inline calibration units, R&S ZN-Z30 CAN bus controller and R&S ZN-Z3ASW software are now available from Rohde & Schwarz and can be used with every R&S ZNB(T), R&S ZVA and R&S ZVT vector network analyzer.

Asterion™ 3kVA High-Power AC Sources

SAN DIEGO, September 19, 2017 – AMETEK Programmable Power, the global leader in programmable AC and DC power test solutions manufacturing such brands as California Instruments™, Sorensen™ and Elgar™ (www.programmablepower.com), has added three new models to its Asterion™ line of AC/DC power sources.

The Asterion 1503 supplies up to 1,500 VA or 1,500 W; the Asterion 2253 supplies up to 2,250 VA or 2,250 W; and the Asterion 3003 supplies up to 3,000 VA or 3,000 W. All three units come in a 2U enclosure, and in both single and three phase models.

Like the lower-power 1U Asterion AC units, the Asterion Models 1503, 2253, and 3003 offer users a compelling combination of intelligence, performance, and modularity that make them the most adaptable and affordable platform available today.

The key to Asterion's outstanding performance is AMETEK's iX2™ current-doubling technology. With iX2, as the output voltage decreases from the maximum value to one-half the maximum value, the available output current increases up to two times the rated output current.

This allows Asterion to maintain maximum power through the widest range of voltages. As a result, iX2 current-doubling technology eliminates the need to buy multiple sources or overpowered sources to run tests at different voltage levels, such as when performing low line voltage testing.

Other unique Asterion benefits include Auto-Paralleling and Clock/Lock. With auto-paralleling, users can combine up to six units to achieve 18,000 VA of output power. One unit becomes the master while the rest serve as auxiliary units. The clock/lock feature allows users to easily configure multi-phase systems, such as split-phase, three-phase, or even higher phase count systems.

This allows users to purchase only the power they need today and then easily add more power and/or phases later as required. That scalability, along with the ability to expand easily as required, helps protect the value of the user's initial investment and allows additional capital spending to be deferred until needed.

While these features are impressive, equally impressive are Asterion's analog specifications. Asterion offers wide AC and DC output voltage ranges up to 400 Vac and 500 Vdc. Load and line regulation are +/-0.025% and +/-0.015%, respectively. This makes the Asterion more versatile and accurate than most other AC power sources available today.

In addition, test engineers will appreciate the Asterion AC source's ease of use. AMETEK developed an entirely new user interface for this platform. The intuitive, touch-screen interface, not found on other AC sources, allows users to quickly and easily set up the source and run tests. The Asterion offers a complete avionics test suite as an option, with a programmable frequency between 16Hz and 5,500Hz.

This powerful set of features allows Asterion to be used in both the lab and in ATE systems. If the Asterion is used as part of an ATE system, test engineers can order it without a front panel, which offers significant savings.

Asterion comes with standard LAN, USB, and RS-232 interfaces, and an optional GPIB interface is also available. Intuitive Virtual Panels control GUI software comes bundled with the instrument for easy remote control from a computer. Included drivers allow test engineers to quickly integrate the unit into ATE systems.

To learn more about AMETEK programmable power supplies and programmable electronic loads, contact AMETEK Programmable Power Sales toll free at 800-733-5427, or 858-458-0223, or by email at sales.ppd@ametek.com. Information also is available from an authorized AMETEK Programmable Power sales representatives, who can be located by visiting http://www.programmablepower.com/contact.

Modular vs. Monolithic Automation

Michael Schwartz
Cal Lab Solutions, Inc.

Over the past 30 years of my software and automation career, I have migrated to a modular approach to software design. I come from an Object Oriented Programming (OOP) background and I am a firmly in the camp of agile/lean software development. That means I have an inclination to dislike monolithic software designs. It is not just me; the other software engineers I know--people who do nothing but write code all day--they also prefer a flexible, reusable and modular design. So I was surprised to discover the next release of MET/CAL® will only support PXEs.

This got me to thinking, is metrology better off with larger monolithic calibration procedures or with smaller, well architected and interchangeable parts? At first glance, one would think it is easier to QA procedures in one single pass: run it start to finish, QA the results, and then put your quality stamp on the procedure.

The problem with a monolithic automation is the long-term costs! First of all, there is the cost of creating the QA process and documentation! The more you have to check, the longer the QA process needs to be and the easier it is to miss something or skip a step.

Now you have to multiply the QA costs every time you make a change to the procedure. It could be a simple change to the pass fail limits on a test point or something as complex like a complete change of the standards being used and uncertainty calculations. If your process is a full QA check with every change, and there are no shortcuts allowed, each change will be a timely process costing time and money.

There is a much better way! It's called modular programming, which is a software design technique that emphasizes breaking the program up into independent, interchangeable modules. Each module can then be tested, validated, and QA-ed independently.

The total QA process times between the two would be equivalent the first time. However, with modular software design comes a modular QA system; just like how the modular software is compiled into a single application, the sum of the QA process is the sum of the QA modules.

This saves time and money in both the development and the QA side! Modular object oriented programming is a time tested, better way to develop and support software. Now QAs can be done with a unit testing approach where each component of the software can be individually and thoroughly tested. Much of these QA processes can be run automatically using unit testing tools. It is important to note, just about all modern software development tools today have a unit testing package and revision control tools where they can be configured in such a way that the QA processes are run before any changes are checked in.

The bigger question seems to be "Why do people trust a monolithic QA procedure more than a more modular one?" My guess is because people poorly execute their monolithic QA processes. Because people short cut the larger QA thinking or underestimate all the ramifications of a simple change, errors appear in production. I have seen this first hand, back in my early programming days. I had one developer on my team, my boss, who would always be coming up with a better way to do something. So he would code it and check it in. Often, those better ways were not better. They seemed to work better with that UUT and that set of standards, but all too often they broke more things than they fixed.

When the UUT and standard code is so tightly integrated into one monolithic program, it is very difficult to isolate and resolve the problems. And if you do manage to find and fix a problem with the standard, now you have several UUT procedures with which you have to find and fix the same problem… and then QA!

Modular programming does require a little more forethought! When you are working on the UUT code, you are not thinking about the standards or any idiosyncrasies related to the standards that will be used. Your focus has to be solely on the UUT code, test points, test limits, and setting. And when you are working on standard code, drivers, and uncertainties, you shouldn't be thinking of a specific UUT's idiosyncrasies.

When it comes to testing and QA-ing the UUT code module with multiple standards, your end result is more reliability and repeatability in the code. You can even QA the test limits and verify what test points will be executed on a specific make model option configuration. The same is true for the standards and drivers; the more UUTs using them, the better the reliability of that driver's operations.

So, I am always going to be a modular code kind of guy, and so will my company. The challenge is going to be getting the auditors and QA guys of the world to see they actually have less work and a better quality system with modular software and a modular QA system. ❧

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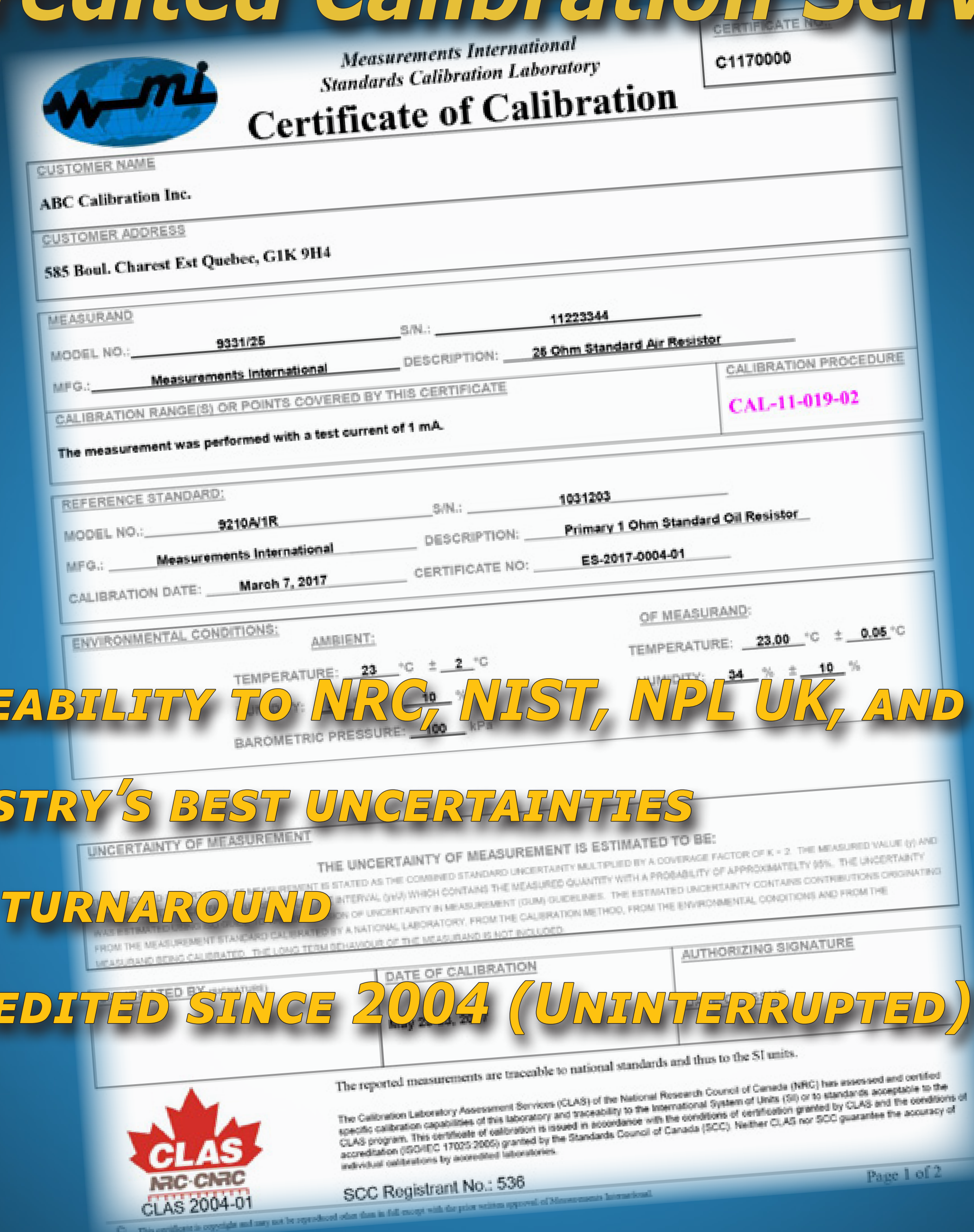

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