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Author: G.D. Thilini Asoka Pathiragoda

Industrial Metrology Laboratory, Industrial Technology Institute, Sri Lanka

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METROLOGY FOR INDUSTRIAL DEVELOPMENT AND DIGITAL SYSTEMS IN MASS CALIBRATION

G.D. Thilini Asoka Pathiragoda

Industrial Metrology Laboratory, Industrial Technology Institute,

Sri Lanka

ABSTRACT

International trade can be facilitated through reducing rejects and removing technical barriers to trade(tbt) to resolve the current economic crisis and increasing the production capacity improving quality of export products in developing countries. Therefore, international standards used to improve industrial measurement process through satisfying requirements for measurement processes and measuring equipment metrological characteristic to customer metrological requirement [1]. Mass, dimension, temperature, volume, pressure and flow measurements are critical in manufacturing and production sector for accurate positioning of sensors for transmitting actual data for management systems and making the quality output. It is mandatory to reduce TBT and rejects at international market to resolve current economic crisis and increasing the production capacity improving quality of export products of the local industries. Digital development is a decision not a choice for integrated economic and industrial development for a comprehensive and sustainable development for generations. Internationally traceable metrology facilities provided through accredited calibration certificates according to ISO 17025:2017[2] and focus to develop digital calibration system for mass calibration here.

Digitalization used to fulfill the high demand for calibration in the process from customer request to issuing calibration certificate. Conventional mass value of weights derived using OIML R111-1 standard [4]. Calibration report preparation and reviewing arranged to do in softcopy in MS excel to reduce paperwork/resources using cloud computing facilities. Single page human readable digital calibration certificate was programmed in MS Excel and saved as PDF with electronic signature in mass laboratory to deliver customer in shared folder maintaining data security aspects. This electronic human-readable version reduce handling, storage, retrieval time and more efficient than the analog version in hardcopy. Each Single page auto generated standard weight calibration certificate with unique identification numbers contain conventional mass value with international traceability and uncertainty. Calibration measurement capability (CMC) for E2 class standard weights is 2µg for 1mg standard weight, 0.02 mg for 50g, etc. Calibrated results of weights can be transferred upto 35 weights in one page data analysis form then referred calibration results reported in 2nd Page. If necessary, it has the capacity to extend number of weights received from Customers. Report preparation and reviewing time has reduced significantly. Electronic copies make secure data transmission with loyal customer. Digital calibration certificate in machine readable version is also in experimental basis to convert from excel version. The correction

factors given in report should algebraically added for measurement process or measuring equipment and should confirm it to customer metrological requirement specified in their procedures. If there is deviation customer should correct or replace their equipment. The implementation of DCC is crucial for the quality infrastructure in industrial internet of things (IIOT) and sensor networks to meet the challenges in digital era, going with this year theme for world metrology day 'metrology in digital era', which needs an international effort and coordination to achieve sustainable development.

Keywords: Industrial development, watt balance, Weight calibration, maximum permissible error, Uncertainty, Human readable digital calibration certificate, Digital systems

INTRODUCTION

Metrology is science of measurement and it's application. It has three major streams in scientific metrology, legal metrology and industrial Metrology. The objective is to focus on industrial metrology concerned with application of measurement to manufacturing and other processes and their use in society, ensuring the suitability of measurement instruments, their calibration and quality control. Calibration is the process of comparing the test equipment/instrument or the value of a material measure against reference value of a measurement standard with uncertainties under specified conditions. In the process of calibration of an instrument or material measure, the test item either adjusted or correction factors are determined. It establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding unknown device with associated measurement uncertainties under specified conditions.

Metrological Traceability is the value of a measurement standard or measuring instrument can be determined by an unbroken chain of comparisons with a series of higher-level standards with stated uncertainties. Metrological Traceability guarantees international consistency and comparability, significantly reducing technical barriers to trade (TBT). TBT is mandatory technical regulations and voluntary standards with specific characteristics of a product like size, shape, design, labeling/ marking/ packaging, functionality or performance. It is mandatory to reduce TBT and rejects at international market to resolve current economic crisis and increasing the production capacity improving quality of export products of the local industries. World Trade Organization-TBT Agreement, Article 6: Recognition of Conformity Assessment by Central Government Bodies. by calling on the use of international standards & accreditation, regulators automatically tap into the underpinning metrology base. Adequate metrology infrastructure and adequate engagement with the international organizations is needed for development of trade and industry and to improve industrial measurement process meeting the required specifications and increasing the production capacity with quality of export products in developing countries.

The International Bureau of Weights and Measures (BIPM) established by Article 1 of the Metre Convention, signed on 20 May 1875 providing the basis for a single, coherent system of measurements and Operates under the authority of the International Committee of Weights and Measures (CIPM). The international system of units in 1960 define 7 base SI units with meter, kilogram. second, Ampere, Kelvin, mole and candela. It's redefined in 2020 to realize by independent nationals and come into inter lab comparisons. It allows use of highly stable natural constants to determined independently, anywhere at any time and easier to make measurement determinations in the national measurement institutes. Then to participate for regional comparison through CIPM MRA signatories. International Organization of Legal metrology OIML is world-wide, inter-governmental organization harmonizing the regulations and metrological controls applied by national metrology services or related organizations of it's member states.

Mass, Dimension, Temperature, volume and flow measurements are critical in manufacturing and production sector for accurate positioning of sensors for transmitting actual data for information management system and for making the required quality output. It is intended to utilize international standards to meet requirements for measurement processes and measuring equipment metrological characteristic (MEMC) to customer metrological requirement (CMR)[1] to improve industrial measurement process since industry and society face issues on traceability and calibration in more broader view metrological confirmation of measuring equipment.

Metrological characteristic is distinguishing feature which influence the results of measurement uncertainty which allows direct comparison with the metrological requirement towards establishing metrological conformation like range, bias, repeatability, stability, hysteresis, drift, resolution, error. Customer metrological requirement is measurement needed for production process, maximum permissible error or operational limits. Metrological confirmation is set of operations required to ensure that measuring equipment conforms to the requirements for its intended use [1]

Conformity assessment is the process used to show that a product, service or system meets specified requirements. Internationally traceable metrology facilities provided through accredited and non-accredited calibration certificates according to ISO 17025:2017[2] to the local and foreign customers. Accredited calibration certificate has third party attestation for technical competency and traceability to ISO 17025: 2017. International laboratory accreditation co-operation (ILAC) providing guidelines for accreditation requirements. ILAC P10 guidelines used to maintain traceability with i) NMI whose services suitable for intended use, covered by CIPM MRA or ii) accredited laboratory [7]. Non-accredited calibration reports given without ILAC MRA logo and accreditation body logo, with traceability to reference standard by direct comparison or with international guidelines.

Digital Transformation is business transformation enabled by digitalization. Difference in Digitization Vs Digitalization is making analog information/physical attributes to digital and use of digital technologies to change enabling/improving process increasing efficiency and productivity and reducing cost. Techniques for Digital Transformation include cloud computing, real time analytics, internet of things, digital twin etc.

Cloud computing provides flexibility, scalability and agility and elevate digital transformation to tools, rebuilding process and experience of a virtual environment accessible from anywhere in the world, with high availability, data protection, storage efficiencies, integration. Main three categories are Infrastructure as a service, platform as a service or software as a service. Real time analytics is the analysis of data and related resources as soon as it enters the system. Real time is ability to act on data in a way that users perceive as instantaneous by robotic process automation or other forms of automated policy enforcement.

Internet of things (IOT) is a system of computing devices, machines or other objects which are connected to the internet and able to transfer data over a network, function independently, without requiring a human or traditional computer system to oversee them. Industrial internet of things (industry 4.0) technology help manufacturers improves operations and increase flexibility, innovation, speed and quality.

Digital twin is the technology that bridge the gap between physical and digital worlds. It's a virtual model designed to accurately reflect physical object with sensors, transducers, transmitters and actuators related to important functional areas. It supports organizations to use virtual model to run simulations, investigate performance issues and make possible improvements to generate valuable insights to applied back to the real physical object. It takes existing environment and overlays new information increasing productivity and superior customer support.

The worldwide national metrology institutes mainly PTB, Germany working with digital transformation in metrology in machine readable version and developed DCC Syntax and Presentations conducted at PTB 2nd International DCC conference [3] to use by other delegates in metrology institutes.

METHODOLOGY

The process from customer request to issuing calibration certificate plans to be digitalized to fulfill the high demand for calibration and issue calibration certificate. Reference standards used for calibration with uncertainty fulfilling the ISO 17025:2017 standard; General requirements for the competence of testing and calibration laboratories ensure the standardized process of operation. When receiving customer request, use of cloud computing facilities, the request form will be shared in separate folder in drive to input the calibration request details, then after preparation of the invoice, it will be shared in drive and after payment, final report will be shared in cloud or drive folder to access by the customer.

In the calibration laboratory providing digital calibration answer is planned for last phase due to limited resources. Primary method to realize 1kg is Kibble Balance (KB)/ Watt Balance uses current and voltage to realize weight standard in vacuum. (6)

Weighing mode: upward force on the coil is the product of the current I, magnetic field strength B and length of wire in coil which is equal to mg

$I*B*L= mg$ -------------------------- 1

Moving / velocity mode: Voltage induced in coil as it moves equals velocity, u into BL

$V = u*B*L$ --------------------------- 2

Equating B*L in both equations we get electric power in watts, I*V = m*g*u mechanical power

$M = I*V/ g*u$ ------------------------ 3

Best model for providing digital calibration answer would be to use watt balance method for remote calibration of industry weights, it will compare the voltage and current measurements instead of gram in future. It was not experimented due to the complex nature to realize in vacuum.

Experimented the possibility of Calibration of weights with automated systems for direct comparison with programmed logic for selection of weights and pick and drop function using sensors for location identification. Lynx motion combo kit used to experiment the system in 2013 with the TG project Preliminary study for developing automated mass calibration system. Programmed the weight handling system using computer to handle Stainless steel cylindrical weight of 10g. The robot arm had 5 servo motors; for rotation in the base, motion in the shoulder, elbow, wrist, and in the gripper. SSC-32 Servo sequencer utility program enables to easily move servo motors, store and playback motion sequences. Gripper opens to 1.3” and has the capacity to pick upto100g and rotates 180°. Set of instruction lists prepared to feed into the program for selection of reference weights, test weight and sensitivity weight & Pick and drop weights with location identification. Comparator balance are highly sensitive for electrical and magnetic interference, vibration on level Matic weighing pan, external disturbances. We shall place the weights smoothly to avoid vibrations and opening and closing door of the balance also should be done very carefully. Gripper designed to support for heavy weights/low accuracy weights, precision balance without doors used to reduce handling difficulty of weights. Constraints encountered with lynx motion robot arm are Robot vibrations on the placement (impact load) stability of weighing pan, Insert the gripper arm into the balance without disturbing the process, Precise location identification, minimize interference in repetitive movements, Optimizing arm speed. The absence of any manual intervention during the measurements improves the quality, accuracy & productivity of comparative weighing. It helps to determine the mass of an object with maximum accuracy to produce more accurate & reliable calibration.

Direct comparison Calibration procedure

Reference weights, comparator balances and OIML 111 - part 1 international recommendation [4] and Direct comparison double substitution method given in [5] using sensitivity weight used for standard/industrial weights calibration to determine conventional mass value. Conventional mass value is mass of a reference weight of density of 8000 kgm-3 which it balances in air of a reference density of 1.2 kgm-3 Weight taken at reference temperature 20 °C.

The test weight compared against one or more reference weights of nominally equal value and the following cycle of weighing is performed: Load the reference weight® and obtain reading r1, replace ® by the test weight and obtain reading t1, add a sensitivity weight and obtain reading t2, Replace T by R and obtain reading r2.

DATA ANALYSIS

Calculated the conventional mass(m_{ct}) of the test weight using the equation;

$$m_{ct} = m_{cr} + \frac{m_{cs}(t_1 + t_2 - r_1 - r_2)}{2(r_2 - r_1)} + m_{cr}C$$

, where $C = (\rho_a - 1.2)\left[\frac{1}{\rho_t} - \frac{1}{\rho_r}\right]$ ----- 4

The term C in equation (1) represents the buoyancy correction.

if $|C| \leq \frac{1}{3}\frac{U}{m_o}$

the term $m_{cr}C$ can be omitted. U - Expanded uncertainty of the test weight, m_o - Nominal mass of the test weight

Repeated the above cycle several times and recorded the data

Average conventional mass for n cycles (m_{ct}) =

$$\overline{m}_{ct} = \frac{\sum m_{ct}}{n} \quad \text{--- 5}$$

mct - Conventional mass of the test weight,

mcr - Conventional mass of the reference weight,

mcs - Conventional mass of the sensitivity weight,

ρt - Density of the test weight, ρr - Density of the reference weight, ρa - Air density

Calibration report prepared through transferring calculated data values from data sheets to autogenerated final data sheet in MS excel and reviewed in softcopy to reduce paperwork and resources and auto generated human readable digital calibration certificate. It saved in cloud or drive folder for easy access to work from home. Even handling, storage, retrieval is efficient with digital systems than the analog version in hardcopy. Number of weights can be combined upto 35 weights in single report then calibration results report in 2nd Page, Report preparation and reviewing time has reduced significantly. If necessary, it has the capacity to extend even more. Finally, after reviewing saved as PDF with electronic signature or take print in security papers, when necessary, maintaining data security aspects in mass laboratory to deliver customer. Auto generated calibration certificate issued with unique identification number and contain conventional mass value with international traceability and uncertainty as given in annexure 1.

Uncertainty evaluation

Combined uncertainty,

$$U_C = \sqrt{\sum_{i=1}^{7} U_i^2} \qquad \text{----------- 6}$$

Coverage factor selected as k=2 at approximately 95% confidence level .

Expanded uncertainty, U95 = 2 * Uc , for Coverage factor k = 2 ------------ 7

The reported expanded uncertainty of measurement is based as the standard uncertainty of measurement multiplied by a coverage factor k=2, corresponding to a coverage probability of approximately 95%. The standard uncertainty of measurement has been determined in accordance with Guide to the expression of uncertainty in measurement (GUM-JCGM 100: 2008)=

For each weight, expanded uncertainty of the conventional mass should be less than one third of the maximum permissible error given in table 1. Maximum permissible error defined in OIML as Maximum absolute value of the difference allowed by the national regulations between the measured conventional mass and the nominal value as determined by corresponding reference weights. Conventional mass shall not differ from nominal value of weight by more than the maximum permissible error given in table 1[page 11 of OIML R 111-1]

Table 1 Maximum permissible errors for weights (± δm in mg)

Nominal value*	Class E_1	Class E_2	Class F_1	Class F_2	Class M_1	Class M_{1-2}	Class M_2	Class M_{2-3}	Class M_3
5 000 kg			25 000	80 000	250 000	500 000	800 000	1 600 000	2 500 000
2 000 kg			10 000	30 000	100 000	200 000	300 000	600 000	1 000 000
1 000 kg		1 600	5 000	16 000	50 000	100 000	160 000	300 000	500 000
500 kg		800	2 500	8 000	25 000	50 000	80 000	160 000	250 000
200 kg		300	1 000	3 000	10 000	20 000	30 000	60 000	100 000
100 kg		160	500	1 600	5 000	10 000	16 000	30 000	50 000
50 kg	25	80	250	800	2 500	5 000	8 000	16 000	25 000
20 kg	10	30	100	300	1 000		3 000		10 000
10 kg	5.0	16	50	160	500		1 600		5 000
5 kg	2.5	8.0	25	80	250		800		2 500
2 kg	1.0	3.0	10	30	100		300		1 000
1 kg	0.5	1.6	5.0	16	50		160		500
500 g	0.25	0.8	2.5	8.0	25		80		250
200 g	0.10	0.3	1.0	3.0	10		30		100
100 g	0.05	0.16	0.5	1.6	5.0		16		50
50 g	0.03	0.10	0.3	1.0	3.0		10		30
20 g	0.025	0.08	0.25	0.8	2.5		8.0		25
10 g	0.020	0.06	0.20	0.6	2.0		6.0		20
5 g	0.016	0.05	0.16	0.5	1.6		5.0		16
2 g	0.012	0.04	0.12	0.4	1.2		4.0		12
1 g	0.010	0.03	0.10	0.3	1.0		3.0		10
500 mg	0.008	0.025	0.08	0.25	0.8		2.5		
200 mg	0.006	0.020	0.06	0.20	0.6		2.0		
100 mg	0.005	0.016	0.05	0.16	0.5		1.6		
50 mg	0.004	0.012	0.04	0.12	0.4				
20 mg	0.003	0.010	0.03	0.10	0.3				
10 mg	0.003	0.008	0.025	0.08	0.25				
5 mg	0.003	0.006	0.020	0.06	0.20				
2 mg	0.003	0.006	0.020	0.06	0.20				
1 mg	0.003	0.006	0.020	0.06	0.20				

This human-readable version is similar to the current (non-digitalized) calibration certificate. Correction values given in calibration certificates should apply for measurement process in measuring equipment. If not algebraically add the correction to the process purpose of calibration will be lost, end product will deviate from required quality standards and face their products reject at the international market. So, it's mandatory to use calibration certificates for industrial process development and reduce technical barriers to trade. Example from industry application is check weights are used for intermediate checks of balances, when any deviation occurs recalibration is required. If the production process requires weighing accuracy of 0.01g, balance accuracy should be maintained to satisfy it. Otherwise, the deviation reflects on the product manufactured. For Industry 4.0 manufacturing environment or programable logic controller production lines, input of calibration results to machine through programming the software is necessary. Electronic copies make secure data transmission with loyal customer, so converting this human readable calibration certificate to machine readable version in Excel is in progress using 'python', but still no customer requirement for the machine-readable version certificate.

CONCLUSION AND RECOMMENDATION

The new defined methods of realizing SI units open up the possibilities for enhancing the accuracy level of realization by introducing new methods with future development in science and technology, though the values of universal constants remain unchanged. Therefore, theoretical study conducted to simplify a model to measure voltage and current to realize mass utilizing kibble balance technique, which could be used for industrial weight calibration. Human readable calibration certificate in electronic or digital form is successfully automated from data entry point to any number of weights to produce the calibration certificate with minimum time. Maximum permissible error for E2 weights for 1mg is 0.006mg, 50g is 0.10mg. Calibration measurement capability or the realizable best measurement capability achieved to E2 class standard weights was 2μg for 1mg standard weight, 0.02 mg for 50g, etc. The standard weight calibrated, satisfy the requirement of MPE for the accuracy class. Also check the uncertainty requirement to be in E2 class of weights ie is less than one thired of MPE also satisfied.

Calibration is far beyond obtaining calibration report for audits, The correction factors given in report should be used for measurement process or measuring equipment and should confirm it to customer metrological requirement specified in standard procedures. If there is deviation customer should correct or replace their equipment, otherwise end product will deviate from required quality standards and face their products reject at the international market. So, it's mandatory to use calibration certificates for industrial process development and reduce technical barriers to trade. Development in industrial sector can be catalyzed by introducing digital calibration certificate, since calibration laboratory will transfer the calibrated data directly to the machines to improve the efficiency and effectiveness of the measurement processes. Metrological confirmation of measuring equipment satisfying customer metrological requirement in industrial processes, will help to minimize rejects and remove technical barriers to trade facilitating international trade in developing countries.

It's very important to come together and discuss how to implement digitalization tools, since it's crucial for the quality infrastructure in digital environment. It's a pleasure to take initiating steps to introduce digital calibration systems to meet the challenges in digital era, going with this year theme for world metrology day 'metrology in digital era'. Finally, lot more to do for implementation of digital transformation with traceability in metrology in industrial internet of things (IIOT) and sensor networks. This needs an international effort and coordination to achieve sustainable development goals.

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ANNEXURE 1

Calibration Certificate of Standard Weights

Issued by ....

	Certificate No:	-	
Reference No:	xxxxxx-1		
Customer:	XXXXXXX		
Address:	XXXXXXXXXXX		
Description:	Standard Weight set	Accuracy class:	E2
Capacity/Range:	1mg and 50g	No of weights:	2
Serial No:	xxxx	ID No:	WS-001
Manufacture:	Ohaus		
Received Condition:	No visual damage		
Request Date:	2022 August 20	Calibration Date:	2022 September 15
Location of calibration:	Mass Laboratory		
Temperature:	23 ± 0.5 ˚ C	Relative Humidity:	50 ± 10%

Reference standards and Traceability

Set of weights of accuracy class E2 (Eqp No MA00X) traceable to Primary standards maintained at DKD, Germany to the International system of units (our reference xxxx)

Auxiliary Equipment used

Comparator	Mettler AT1005	1000 g	0.01 mg
Comparator	Mettler AX 26	22 g	0.001 mg

Calibration Results

Nominal value	Conventional mass value (g)	Deviation (g)	Expanded Uncertainty *U* (g)
1 mg	0.000999	0.000001	0.000002
50 g	50.000013	0.000013	0.000021

The measurement results can be varied ± *U*

UNCERTAINTY:

The reported expanded uncertainty of measurement is based as the standard uncertainty of measurement multiplied by a coverage factor k=2, corresponding to a coverage probability of approximately 95%. The standard uncertainty of measurement has been determined in accordance with Guide to the expression of uncertainty in measurement (GUM-JCGM 100: 2008)

Customer obliged to recalibrate the weights at appropriate intervals

Authorized by

xxxxxx

Authorized Signatory

Senior Research Scientist

2022 October 5

Test Performed by

xxxx

Research Scientist

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