GLOBAL ACADEMIC RESEARCH INSTITUTE

COLOMBO, SRI LANKA

GARI International Journal of Multidisciplinary Research

ISSN 2659-2193

Volume: 09 | Issue: 01

On 31st March 2023

http://www.research.lk

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GARI Publisher | Metrology | Volume: 09 | Issue: 01

Article ID: IN/GARI/SL/ICEST/2022/111B | Pages: 90-99 (10)

ISSN 2659-2193 | Edit: GARI Editorial Team

Received: 23.11.2022 | Publish: 31.03.2023

REMOTE CALIBRATION MODEL FOR TEMPERATURE AND ELECTRICAL INSTRUMENTS IN INDUSTRY THROUGH EMERGING TECHNOLOGIES

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ABSTRACT

Internationally competitive calibration services with traceability provided to local and foreign customers through analog calibration certificates but need arise in digital era to do it remotely as an example for industrial internet of things sensors (IIOT). Electrical and temperature metrology guidelines used for calibration of equipment in industry to meet requirements for measuring equipment characteristic to customer metrological requirement (CMR) [1] to improve industrial measurement process. Temperature indicator/simulator calibrated according to EURAMET cg-11[2], where the electrical stimuli used for the temperature indicator or simulator calibration. Instrument accuracy stay within specification with traceability only if calibration/adjustment performed at regular interval or at extended interval by analyzing previous calibration data according to OIML D10 guideline [3]. Multimeters and electrical measuring devices calibrated according to EURAMET cg-15 [4] where test meter value directly compare with the reference standard values at defined percentages to cover the range of operation. It also has provision for capacitance, frequency, etc measuring instrument calibration by direct comparison with the appropriate reference standard with traceability certificates.

Calibration devices taken to calibration laboratory or onsite calibration will not be feasible in industry 4.0 environment. Developing remote calibration applications, virtual measurements and simulations are crucial to survive in digital era and need to be sustainably strengthen. Recalibration of measuring instrument modelled using remote interfaces, cloud computing and data communication methods and international/EURAMET guidelines. RS232 remote interface, wireless sensor networks and software application separately purchased from manufacture or calibration provider used for the purpose. The user plug in the device and remote program directs to apply a series of shorts, opens, voltage, current, and resistance to input the test calibration equipment/device. Then software obtains the test meter reading reducing cost, time, human error and energy. Temperature sensors, dry well, ESP 8266 wifi device and 'Thingspeak.com' IOT platform used data acquisition to IOT to view from remote location. The correction factors in calibration certificates used for measuring equipment and should confirm it to customer metrological requirement specified in their procedures. If there is deviation customer should correct/ replace their equipment to ensure the quality of their products to compete in international trade and achieve sustainable development goals.

Remote calibration model for direct comparison shall be implemented with metrological digital twins and digital calibration certificate, mathematical-

physical simulation methods with measurement uncertainties.

Customer shall extend or reduce recalibration interval over time with trend analysis, statistical process or other methods analyzing the previous data using En ratio. If En ratio was within ±1, calibration interval can be extended. Similarly, for quality assurance of the degree of equivalence shall be evaluated by En number statistical formula for measurement results management within entities, calibration providers or several manufacturing plants. Developing digital reference system for digital SI units also shall be modelled using statistical evaluation. Finally, the development in metrology is crucial for integrated economic and industrial development for a comprehensive and sustainable development for generations.

Keywords: SI units, Temperature or Electrical measuring devices, digital/remote calibration, uncertainty, calibration interval, measurement management system, Inter comparison, industrial process improvement.

INTRODUCTION

The International Bureau of Weights and Measures (BIPM) established by Article 1 of the Metre Convention, signed on 20 May 1875 provide the basis for a single, coherent system of measurements and Operates under the authority of the International Committee of Weights and Measures (CIPM). BIPM is the intergovernmental organization through which Member States act together on matters related to measurement science and measurement standards. CIPM MRA; International Committee for Weight and Measures Mutual Recognition Arrangement is an arrangement between National Metrology Institutes which provides the technical framework to assure the mutual recognition of national measurement standards and for recognition of the validity of calibration and measurement certificates issued by National Metrology Institutes. The international system of units consists of 7 base SI units with meter, kilogram, second, Ampere, Kelvin, mole and candela in 1960. It's redefined in 2020 related to known constants like Avogadro number, plank constant, electronic charge etc to realize by independent nationals and then participate in regional inter lab comparisons. It’s purely high-end scientific research and falls under scientific metrology

.

Base quantity	Base unit	Symbol	Reference constant used to define SI	New reference constant to define SI
Time	second	s	Hyperfine splitting in Cs-133	Hyperfine splitting in Cs -133
Length	meter	m	Speed of light in a vacuum c	Speed of light in a vacuum, c

Mass	kilogram	kg	Mass of international prototype kilogram	Plank constant, h
Electric current	ampere	A	Permeability of free space	Elementary charge, e
Thermodynamic temperature	kelvin	K	Triple point of water	Boltzmann constant, k
Amount of Substance	mole	Mol	Molar mass of carbon -12	Avogadro constant, N_A
Luminous intensity	candela	cd	Luminous efficacy of a 540 THz radiation source	Luminous efficacy of a 540 THz radiation

Table 1: Definition of basic measurement quantities for the current SI units and the proposed new SI units[1]

National metrology institute world-wide aim to realize the SI units and participate for regional comparison or claim calibration measurement capability values in key comparison database (KCDB) in BIPM to maintain external traceability. The KCDB is a publicly available, free web resource related to the CIPM MRA. It contains information on participants of the CIPM MRA, results of key and supplementary comparisons and peer reviewed Calibration and Measurement Capabilities (CMCs). NMI's disseminate their traceability internally to other local calibration laboratories and industries as shown in figure 1. Number of calibration and measurement uncertainty increase down the line like pyramid to consumer measuring processes.

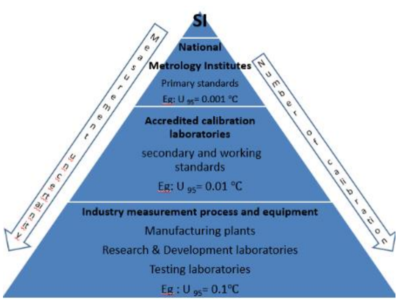

Figure 1: Measurement traceability hierarchy

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. Metrological Traceability gives the value of a measurement standard 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).

Electrical and temperature metrology international guidelines used to meet requirements for measurement processes and measuring equipment metrological characteristic (MEMC) to customer metrological requirement (CMR) [2] to ensures that measuring equipment and measurement processes are fit for their intended use and is important in achieving product quality objectives and managing the risk of incorrect measurement results. Metrological characteristic is distinguishing feature which can influence the results of measurement. Metrological confirmation is set of operations required to ensure that measuring equipment conforms to the requirements for its intended use [2]. Self-calibration/ auto-calibration is internal calibration process of an instrument, with the aim of improving its accuracy. Adjustment of a measuring system is set of operations carried out on a measuring system to provide prescribed indications corresponding to given quantity to be measured. Depending on the instrument, the adjustment can be performed by physical adjustment of internal components or via the instrument's firmware. Accredited calibration services have third party attestation for technical competency and traceability to ISO 17025:2017 standard; General requirements for the competence of testing and calibration laboratories ensure the standardized process of operation. Non-accredited calibration does not have third part attestation and reports given without ILAC MRA and accreditation body logo, with traceability to reference standard by direct comparison.

Temperature indicator operates by converting the electrical signal received from a sensor in to an equivalent readout in temperature units. The calibration principle is based on the verification of this conversion process by simulation/replacement of the output of the sensor by appropriate electrical stimuli and calibrated according to EURAMET cg-11[3]. (European national metrology institute guidelines) Fluke bench type digital multimeter available with remote interface for calibration. It is user friendly to field precision measurements in automation systems and portable for adjustment or calibration required to maintain traceability and accuracy at desired interval or when meter verification test indicate it is out of tolerance. Instrument accuracy stay within specification only if adjustment performed at regular interval [4]. Electrical measuring equipment can be calibrated at laboratory according to EURAMET cg-15 [5] for that it needs to be taken to calibration laboratory. To survive in the business, developing remote calibration applications is a must using remote data communication methods, wireless networks to work from remote desktop to give required reference values and obtain the test meter reading with in short period of time reducing cost, time and energy.

The International System of Units (SI) providing confidence in the accuracy and global comparability of measurements needed for international trade, manufacturing, human health and safety, protection of the environment, global climate studies and scientific research through the international quality infrastructure. Maintaining this confidence in the accuracy and global comparability of measurements will require the creation and adoption of a full digital representation of the SI, including robust, unambiguous, and machine-actionable digital representations of units of measurement and of measurement results and uncertainties [6]. Machine-actionable information allow the provenance, traceability and fitness-for-purpose of datasets and enable the application of knowledge reasoning, machine learning and artificial intelligence tools to be applied to create new knowledge.[6]

METHODOLOGY

Transducers available for conversion of physical quantities and electrical signal and vise-versa in wireless sensor networks. Intelligent measuring systems equipped with software generate results automatically or partly autonomously, will interact with other sensors and facilities to purchase measurement values rather than measuring instruments in future. The concept of "predictive maintenance" developed applied to increase efficiency in the fields of metrology, verification and calibration. By developing appropriate modelling methods, it would be possible to establish continuous prognostics and to guarantee the quality of the measurement accuracy of the entire measurement infrastructure.

Companies use virtual images and simulations for design process for planning and quality assurance. So need to secure confidence in simulated results. Figure 2 elaborates the connection between industrial real world production optimization and virtual optimization plan. It was evolved with sensor data, central database cloud computing, digital twin to facilitate industry 4.0.

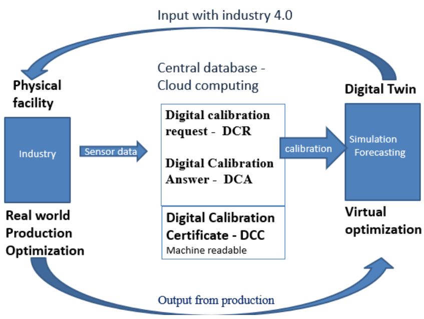

Figure 2

Main focus is to develop model to provide calibration answer remotely. EURAMET guidelines and fluke multi product calibrator used as reference for calibration fulfilling the ISO 17025:2017 standard. Temperature indicator/simulator calibration done according to EURAMET cg-11[3], where the electrical simulation used for the temperature calibration. Model for temperature indicator calibration is through providing reference temperature setting, reference voltages and resistances to remote interface to the temperature device and output is taken from software and transfer to certificate. The calibration principle is based on the verification of the conversion (electrical signal in to equivalent temperature) process by simulation or replacement of the output of the sensor by appropriate electrical stimuli. Digital thermometer calibration system for remote data acquisition of calibration data through ESP 8266 and updated to thingspeak.com. Internet of things (IOT) platform or additional software will be developed using remote panels in Lab view. Calibration report preparation and reviewing arranged to do in softcopy to reduce paperwork and resources. Even handling, storage, retrieval is efficient with digital systems than the analog version in hardcopy.

Investigate to find suitable methods to revise the calibration interval considering other factors influencing the measuring equipment.

Process requirements of ISO 17025:2017 followed and to ensure validity of results degree of equivalence calculated with En ratio for different measurement parameters.

DATA ANALYSIS

Calibration correction for temperature indicators/controllers given by the following equation,

$$C = (T_0 - T) + (Z_f - Z_i), \text{ ------------------------------------ } 1$$

Where, T_0 = Temperature indicated in the Reference Standard

T = Temperature of the test controller/indicator,

Z_f = Final zero point,

Z_i = Initial zero point

Nominal value ºC	Reference value ºC	Test value ºC	Correction ºC	Uncertainty, k=2 ºC
0	0.02	0.0	0	0.1
20	20.02	20.0	0	0.1
40	40.06	40.1	0	0.1
60	60.07	60.1	0	0.1
80	80.08	80.1	0	0.1
100	100.10	100.1	0	0.1

Table 2: calibration results of temperature indicator/controller

Uncertainty evaluation

Uncertainties are calculated in accordance with the methods laid down in "Guide to Expression of uncertainty in measurement (GUM) JCGM 100:2008".

Type A evaluation (statistical) through uncertainty component U7,

Type B evaluation (calibration certificates, Instrument specifications, manuals) through uncertainty components from U1 to U6

U1 - Reference thermometer Calibration uncertainty. Take the value given in the calibration certificate and divide it by the appropriate factor (if k=2 is given, then divide by 2).

U2 - Resolution of the Reference thermometer display value divided by 2

U3 - Accuracy of the reference thermometer (selected from values given in simulator 741B as the reference) divided by

U4 - Probe calibration uncertainty as given in the calibration certificate divided by the appropriate factor (if k=2 is given, then divide by 2).

U5 - Drift of the thermocouple divided by

U6 - Resolution of the test temperature controller. Consider it as a rectangular distribution

U7 - Scatter of results (type A): Take the highest standard deviation of the mean divided by

Combined uncertainty

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

Selection of Coverage factor k on the basis of desired level of confidence to be associated with the interval defined by U = k *U_c.

Expanded uncertainty, U_{95} = 2 * U_c, for Coverage factor k = 2 --------- 3

Calibration measurement capability or the realizable best measurement uncertainty get from those expanded uncertainty values. For calibration of temperature indicator/controller, simulator CMC is 0.01 ℃, 1.6µV, 1.2 MΩ, 1µA. 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).

Coverage factor selected from the confidence level required for application from student's t distribution. For 95% confidence interval, k=1.96 and for 99% confidence interval, k=2.58. In metrology industry and ISO 17025 accreditation, we use k=2 then actually we estimate uncertainty to 95.45% confidence. In manufacturing industry, to reduce failure rate choose k= 3.89 for 99.99 confidence, or k =3 has 99.73% confidence from student's T distribution table. Confidence interval can be greater or smaller depending on acceptable failure rate. The focus was on ensuring reliability and trust in results by consistently incorporating measurement uncertainties and data quality.

The human-readable version or electronic copies make secure data transmission and increase process efficiency. Correction values given in calibration certificates should apply for measurement process in measuring equipment. After the calibration, the MEMC are compared to the CMR before confirming the equipment for its intended use. the reported error of indication of the measuring equipment would be compared to the maximum permissible error specified as a CMR. If the error is smaller than the maximum permissible error, then the equipment complies and confirmed for use. If the error is greater, action should be taken to remove the nonconformity or the customer should be informed that the equipment cannot be confirmed.

EURAMET cg-15 guideline used with multifunctional measuring instruments with digital reading for the measurement of the quantities: DC voltage, AC voltage (low frequency), DC current, AC current (low frequency), resistance, Capacitance, Frequency. The guidelines also be applicable to digital instruments that are able to measure only some of the quantities mentioned above [5] through direct comparison with the reference standard values at appropriate percentages to cover the range of operation. Therefore, we could extend method for inductance also if we have the appropriate reference standard to be used during calibration. The automatic calibration facility modeled to provide using RS 232 remote interface, the user plug in the device and remote program directs to apply a series of shorts, opens, voltage, current, and resistance to input the test calibration equipment/device. At each step software makes necessary calculation to bring meter into specification and record in calibration certificate. Calibration Measurement Capability for calibration of electrical measuring instruments DC and AC voltage upto 1000V is 4µV/V and 0.1mV/V, For AC current 20A CMC uncertainty is 0.8mA/A.

Revision of calibration intervals

Factors influence the time interval allowed between calibrations are uncertainty of measurement required or declared by the laboratory, risk of a measuring instrument exceeding the limits of the maximum permissible error when in use, cost of necessary correction measures when it is found that the instrument was not appropriate over a long period of time, type of instrument and tendency to wear and drift, manufacturer's recommendation, and severity of use, environmental conditions, trend data obtained from previous calibration records, recorded history of maintenance and servicing, frequency of cross-checking against other reference standards or measuring devices, frequency and quality of intermediate checks in the meantime and transportation arrangements and risk. Calibration intervals of measuring equipment vary depending on the application of use. Therefore, investigated the methods of revising the calibration interval given in OIML D10[4]

Method 1: staircase (calendar-time); Each time an instrument is calibrated on a routine basis, the subsequent interval is extended if it is found to be within % of maximum permissible error that is required for measurement, or reduced if it is found to be outside this maximum permissible error.

Method 2: Control chart (calendar-time); In principle, Significant calibration points are chosen and the results are plotted against time. then both dispersion of results and drift are calculated, the optimum interval calculated.

Method 3: “In-use” time; the calibration interval is expressed in hours of use, rather than calendar months. The instrument is fitted with an elapsed time indicator and is returned for calibration when the indicator reaches a specified value.

Method 4: In service checking, or “black-box” testing; suitable for complex instruments. Critical parameters are checked frequently (once a day or even more often), If the instrument is found to be outside the maximum permissible error by the “black box”, it is returned for a full calibration.

Method 5: Other statistical approaches Methods based on statistical analysis of an individual instrument or instrument type, especially when used in combination with software tools.

Use of past calibration data for evaluation of E_n ratio also used in extending the calibration interval. Reference value will be considered as previous year calibration certificate value and new calibration certificate figures will be used as test value in calculating equivalence ratio. If $E_n < 1$, we can extend the calibration interval otherwise need to reduce the calibration interval.

Ensure validity of results

ISO 17025:2017 Process requirements followed and to ensure validity of results degree of equivalence calculated with E_n ratio for different measurement parameters for quality assurance.

Inter comparison organize to coordinate and assure the consistency of measurements used by monitoring the measurement capabilities of laboratories or individual entity. This concept extended to use with different entities, factories, manufactures, customers to accept their results in achieving product quality objectives and managing the risk of incorrect measurement results. As an example food and beverage manufacturing process need to maintain temperature in production line to 20 ℃, therefore process management uses temperature indicators/controllers to manage the production process requirements within allowable limits, and it’s crucial to manage the suitability of the measuring device through proper evaluation with the international Inter Laboratory Comparison practice, the measurement performance of a entity may assessed on the basis of E_n numbers for each measurement in Industry in temperature parameters, Otherwise quality of products manufactured will deviate from required standards.

E_n is the number defining the status of the laboratory showing the equivalence in the comparison. For the evaluation of the results the normalized error E_n was determined. The E_n value evaluates the deviation of the individual laboratory’s value from the reference value relative to the combined uncertainties of the values according to the following equation:

$$E_n = \frac{b - a}{\sqrt{Ua^2 + Ub^2}} \qquad \text{------- 4}$$

a - Result of the reference laboratory or coordinating entity (taken from calibration certificate)

b - Result reported by the participating laboratory/entity

Ua- Expanded uncertainty of the reference Laboratory’s Result (from calibration certificate)

Ub - Expanded uncertainty stated by the participating laboratory

The Expanded Uncertainty of Measurement evaluated at a Confidence-Level of approx. 95 % with Coverage-factor, k=2 for a normal probability distribution.

Reference values provided by coordinating entity a and measurement results of three participating institutes/companies/manufacturing plants b, c, d sample data as follows,

Lab code	Measurement results ºC	Measurement Uncertainty ºC	E_n number	Remarks
Ref lab/coordinator- a	20.01	0.01		
Participant – b	19.9	0.1	1.09	In doubt, unsatisfactory
Participant – c	20.1	0.1	0.9	Pass
Participant – d	20.3	0.1	2.89	Fail

Table 3: ILC evaluation for temperature set point 20 ºC

The degree of equivalence shall be evaluated in terms of En numbers of participants and following criteria apply for the evaluation:

En < ±1, Intercomparison passed,

En > ±1, Intercomparison failed (measurement agreement is in doubt or very unlikely if >2)

The En value serves as acceptance criterium. Participant b results are in doubt, not satisfactory and need to take actions for measurement improvement. Participant C results are acceptable and can proceed with measurement process. Participant D failed the intercomparison and Results not acceptable for comparison, need to implement major corrective actions in measurement management process. For the results to be internationally accepted, values of En should lie between -1 and +1. It indicates an acceptable degree of compatibility between individual measurement result and the reference value when the quoted uncertainties are taken into account. Likewise for all measurement processes and parameters this analysis shall be done to ensure the validity of results and assure the quality of output produced. Therefore, Industries benefit in achieving product quality objectives and managing the risk of incorrect measurement results.

CONCLUSION AND RECOMMENDATION

Industrial temperature indicator/controller/simulator or electrical devices calibration model can be concluded to provide reference voltages, resistances through remote interface to the temperature indicator/controller or the electrical device and output is taken from software and type A and type B uncertainty evaluated separately, then calculate the expanded uncertainty and prepare the calibration report in softcopy which can reduce report preparation and reviewing time and human errors. For calibrating electrical measuring devices, Euramet cg 15 guideline [5] has provision for capacitance, frequency, etc measuring instrument calibration by direct comparison with the appropriate reference standard with traceability certificates. Human readable calibration certificate in electronic or digital form is far beyond a just calibration report of measuring instruments in the industry, 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 their procedures. If there is deviation customer should correct/ replace their equipment. Customer shall decide on recalibration interval over time with trend analysis, statistical process analyzing the previous data using En ratio or other methods. Calibration interval can be extended, if En ratio was within ±1, otherwise interval should reduce. Similarly, for quality assurance the degree of equivalence shall be evaluated in terms of En numbers given by the statistical formula for measurement results management within calibration providers, companies or several manufacturing plants since they benefit in achieving product quality objectives and managing the risk of incorrect measurement results.

Large number of sensors developing and their use increase in sensor networks, therefore quality assurance in digital process is needed and Confidence in digital innovation achieved through reliability in data and algorithms used. It is prerequisite for their sustainable application to the process of machine learning in artificial intelligence. Digital transformation with techniques for statistical approach in metrology to ensure reliability in industrial internet of things (IIOT) and sensor networks to achieve sustainable development goals. Developing digital reference system for digital SI units will also base on statistical evaluation methods and machine learning practices. In future task of metrology laboratories would be to provide reference methods and reference data sets, to be investigated and analyzed for different measuring instruments by consistently incorporating measurement uncertainties to accompany practical suitability of mathematical methods for industry related applications.

Acknowledgement

I acknowledge Director General and Additional Director Generals of Industrial Technology Institute. Special acknowledgement to PTB Strengthening quality infrastructure project 2018-22. Also, I forward my heartfelt gratitude to my parents, relatives, friends, colleagues and GARI team, who supported my endeavors.

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