

THE CALIBRATION AND MEASUREMENT CAPABILITY AND ITS IMPACT ON METROLOGICAL CONFIRMATION

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Abstract – Calibrations are performed to diagnose the status of equipment and assess their adequacy (or not) to maximum permissible error (MPE). The Calibration and Measurement Capabilities (CMC) established by accredited laboratories should be referenced on valid and updated normative documents where available. Usually, the applied calibration methods should be consistent with the maximum permissible errors for the measuring equipment. This article presents a critical analysis on CMCs provided by accredited laboratories for conventional measuring instruments that have calibration methods defined in recognized standards or documents.

Keywords: CMC, Calibration and Measurement Capability

1. INTRODUCTION

When specifying the requirements for the control of monitoring and measuring equipment, ISO 9001:2008 prioritizes the metrological confirmation of the devices, to address aspects such as calibration, verification, metrological traceability, setting, identification, handling, among others.

As International Vocabulary of Metrology - VIM [1], calibration is a "operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish themselves for the relation obtaining the measurement result from an indication". The holding of periodic calibrations allows to check bias, relevant activity within any quality system applied in the industrial sector. Thus, appropriate calibration procedures should be conducted in order to not compromise the metrological confirmation activity.

The metrological confirmation is defined as set of operations required to ensure that measuring equipment conforms to the requirements for its intended use [2]. The ISO 10012:2003 itself clarifies in notes that the requirements for intended use are related to measuring equipment, with considerations such as measuring range, resolution and maximum permissible errors.

In VIM [1], maximum permissible error (MPE) is an extreme value of measurement error, with respect to a known reference quantity value, permitted by specifications or regulations for a measuring instrument. Measurement error is the sum of systematic error and random error, which are usually estimated by bias and expanded uncertainty

reported in calibration certificate. This standard also makes it clear that metrological confirmation requirements are usually distinct from product requirements.

This article aims to analyze the calibration and measurement capabilities (CMC) presented in the scope of accredited laboratories, and check if they are compatible with the metrological requirements for measuring equipment.

This paper is organized, initially with the theoretical framework of CMCs and MPEs. From a case study, the CMCs published in different national calibration bodies are evaluated by comparing with MPEs. At the end, aspects that should be observed in the CMC specification are presented.

2. CALIBRATION AND MEASUREMENT CAPABILITY

The metrological traceability is widespread in industry by accredited calibration laboratories and by national metrology institutes (NMI). In the past, services of accredited calibration laboratories were related on their accredited service scopes with their "best measurement capability".

The best measurement capability was defined "as the smallest uncertainty of measurement that a laboratory can achieve within its scope of accreditation, when performing more or less routine calibrations of nearly ideal measurement standards intended to define, realize, conserve or reproduce a unit of that quantity or one or more of its values, or when performing more or less routine calibrations of nearly ideal measuring instruments designed for the measurement of that quantity" [3]. The NMIs had a similar description of the services provided, but they used the term calibration and measurement capability.

To harmonize and improve cooperation between communities, the ILAC (International Laboratory Accreditation Cooperation) decided to make a change in the terminology used, after an agreement entered with BIPM (International Bureau of Weights and Measures). In 2009, a circular [4] issued to all ILAC members considered the implementation of Measurement and Calibration Capability term along next two years. In 2013, ILAC issued the document ILAC-P14: 01/2013 [5], in order to ensure proper interpretation of the Guide to the Expression of Uncertainty in Measurement - GUM [6] and the consistent use of CMC by ILAC members.

According to ILAC-P14: 01/2013 [5], a CMC is a calibration and measurement capability available to customers under normal conditions:

- as described in the laboratory's scope of accreditation granted by a signatory to the ILAC Arrangement; or
- as published in the BIPM key comparison database (KCDB) of the CIPM MRA.

Under a CMC, the measurement or calibration should be:

- performed according to a documented procedure and have an established uncertainty budget under the management system of the NMI or the accredited laboratory;
- performed on a regular basis (including on demand or scheduled for convenience at specific times in the year); and
- available to all customers.

ILAC policy states that an estimated measurement uncertainty, and consequently the CMC, should be in accordance with the Guide to the Expression of Uncertainty in Measurement - GUM [6]. CMC should be expressed as an expanded uncertainty having a specific coverage probability of approximately 95%.

To ensure appropriate estimation of measurement uncertainty, the accreditation bodies and recognized institutions have developed own documents containing guidelines and requirements to be followed by calibration laboratories. For example, in Europe, EA-4/02 M:2013 [7] is a reference publication for evaluation of uncertainty of measurement in calibration. The American Association for Laboratory Accreditation - A2LA, through the document P-110: 2011 [8], sets out the policy on measurement uncertainty in calibration. M 3003: 2015 [9] is a United Kingdom Accreditation Service (UKAS) document with guidelines to provide policy on the evaluation and reporting of measurement uncertainty for testing and calibration laboratories. All these documents has been amended to address the replacement of the term "Best Measurement Capability" (BMC) with "Calibration and Measurement Capability" (CMC).

Accordingly with the ISO/IEC 17025:2005 [10], the laboratory should use appropriate calibration methods and that meet customer needs. Methods published in international, regional or national standards in their latest valid edition are recommended to use. It is possible to select methods that have been published by reputable organizations or specified by the manufacturer.

In the Guide for the application of ISO/IEC 17025:2005 issued by Portuguese Institute for Accreditation (IPAC) [11] is established that, in general, cannot be considered for accreditation methods carried out to obsolete standard methods. The Canadian Association for Laboratory Accreditation (CALA) [12] follows similar rule. For these organizations, the use of obsolete methods is restricted to legal provisions and for a specified time. For American Association for Accredited Laboratories (A2LA) [13], the application of internal methods is not appropriate upon the existence of standardized methods. And for cases of application of own methods, they need to be validated.

ISO 9001: 2008 [14] sets the calibration and verification requirement of measuring instruments, when they should ensure valid results. In general, the limit of error should be specified according to device characteristics, taking into account their normative aspects or manufacturer specifications. It is not appropriate to confuse the maximum permissible errors for a measuring instrument with the suitability criteria to use.

In this sense, for metrological confirmation is important that CMCs provided by accredited laboratories should be compatible to MPEs of the measuring instruments.

Some accreditation bodies have provided additional calibration guidelines for different types of measuring instruments. National Body of Germany Accreditation - DAkkS [15] provides a set of guidelines to be observed in conventional calibration instruments from different areas, including a list of contributions to calculate the expanded uncertainty. Also, National Physical Laboratory (NPL) [16] has published guides to improve measurement understanding and technical abilities, and many are available for public consultation.

However, standards and guidelines have contributed to causing convergence in the estimation of CMC?

3. CASE STUDY

It is important that metrological confirmation needs of a measuring instrument should be observed during a calibration. For this, the use of standard methods is relevant and it allows performing calibrations compatible to the intended use of the measuring instrument. For lack of standardized methods or recognized publications, the laboratory should apply consistent calibration methods.

So that metrological traceability rules are maintained, one important point is the selection of measurement standards (etalons). It is necessary that their uncertainties are appropriate, preferably in a ratio of 3 to 10 times more precise than the results needed for instrument under calibration [17-18]. A common application is the rule 4: 1 ratio, that is, it is desirable that the measurement standards are at least 4 times more precise than the maximum permissible errors for the instrument [19].

The analog external micrometer is used in this paper to demonstrate differences in the CMCs statements of various accredited laboratories in different national bodies, despite the calibration methods are defined on normative or recognized documents.

The updated version of ISO 3611: 2010 [20] considers that error of indication can be tested with instruments or material measures with appropriate uncertainties. For DAkkS-DKD-R 4-3 Blatt 10.1 guideline [21], for external micrometers with larger measuring ranges, the use of longitudinal measuring machine is convenient. In this guideline, are listed as sources of variation: measurement uncertainties from the standard used, environmental conditions (especially temperature) and the micrometer itself.

The A2LA exemplifies how measurement uncertainty sources for the calibration of a micrometer in the range 0-1"[22]: standard block, resolution of measuring instrument,

linear coefficient of expansion and the temperature difference between standard and measuring instrument. Flack [23] also considers as measurement uncertainty sources: uncorrected bias of measure standards and repeatability.

The maximum permissible errors for analog external micrometer were consulted in two different manufacturers catalogs: Mitutoyo and Starrett, presented in Table 1.

Table 1. Maximum permissible errors for micrometer (MPE).

Manufacturer	Graduation: 0,001 mm		Graduation: 0,01 mm	
	Length (mm)	MPE (μm)	Length (mm)	MPE (μm)
Mitutoyo [24]	25	0,002	25	0,002
			300	0,005
Starrett [25]	25	0,001	25	0,002
			300	0,007

In DIN 863-1: 1999 [26], the maximum permissible error for micrometers with measuring range 0-25 mm is $4\mu\text{m}$. And for measuring range 275-300 mm, MEP for indication error is $9\mu\text{m}$.

In the survey to scopes of accredited laboratories in different accreditation bodies, discrepancies were observed for CMCs of external micrometer, presented in Table 2.

Table 2. CMC for micrometer.

Accreditation body	Length (mm)	CMC (μm)
UKAS [27]	25	0,7 a 2,0
	300	1,5 a 3,4
DAkkS [28]	25	3,3
	300	5,0
CGCRE [29]	25	0,4 a 3,0
	300	0,5 a 10,0
A2LA [30]	25	0,3 a 4,0
	300	1,0 a 10,0

In analysis of the CMCs of laboratories accredited by A2LA [30], variability was observed between the values

Table 3. Measurement uncertainty balance for external micrometer with measuring range 275-300 mm

Source of uncertainty (x_i)	Value	Divider	$u(x_i)$	Distribution	c_i	$u_i(y)$ (μm)	ν_i
repeatability (x_1)	0,58 μm	$\sqrt{3}$	0,33 μm	t	1	0,33	2
Resolução adotada (x_2)	1,0 μm	$\sqrt{3}$	0,58 μm	Rectangular	1	0,58	∞
MPE of gauge block – 300 mm(x_3)	1,4 μm	$\sqrt{3}$	0,03 μm	Rectangular	1	0,81	∞
Temperature difference between standard and measurand (x_4)	0,3 $^{\circ}\text{C}$	$\sqrt{3}$	0,17 $^{\circ}\text{C}$	Rectangular	300 mm*1000 *11,5x10 ⁻⁶ $^{\circ}\text{C}^{-1}$	0,59	∞
Doubt of linear expansion coefficient (x_5)	$\pm 2,0 \times 10^{-6} \text{ } ^{\circ}\text{C}^{-1} \times 2 \text{ } ^{\circ}\text{C}$	$\sqrt{3} \times \sqrt{6}$	$9,4 \times 10^{-7}$	-----	300 mm*1000	0,28	∞
Combined uncertainty $u(y)$						1,24	$\nu_{\text{eff}} > 50$
Expanded uncertainty U						2,5	k = 2,00

shown, but also in form. That is, in some laboratories the presentation of CMC is based on the micrometer resolution. In other laboratories, CMC is declared for the metrological parameters (indication, flatness and parallelism). Yet others show the CMC depending on the type of indication, analog or digital.

In the measurement uncertainty calculation using the standard methods of calibration, it is common the expanded uncertainty present values close to 1 μm or 2 μm for measuring range of 25 mm.

In this sense, consulting calibration scopes of accredited laboratories can become an arduous task for users, since they cannot identify the covered sources of uncertainty and how this can be significant for their instruments. For example, it is not possible getting a expanded uncertainty of 0,6 μm on a centesimal micrometer, which is applied a resolution of 0,001 mm or 0,002 mm when calibrating. Contrary to what is proposed in ILAC-P14: 01/2013 [5], the recommendation is the presentation of CMC for different resolutions commercially available in the market.

Table 3 shows the balance of measurement uncertainty to the error of indication of an external micrometer adopted resolution with 0,001 mm and measuring range 275-300 mm is exemplified, for which we considered the following sources of uncertainty: repeatability, adopted resolution measuring instrument: 0,001 mm; MPE of gauge block, temperature difference between gauge block and measuring instrument, doubt of linear expansion coefficient attributed to gauge block and measuring instrument.

According to Table 2, it is found that expanded uncertainty of measurement obtained in the calibration was $U = 2,5 \text{ } \mu\text{m}$ $k = 2,00$.

The scope of accredited laboratories should assist in the correct interpretation of informed CMC. Once the laboratory follows calibration guidelines established in valid and updated guidelines, sources of uncertainty from methods, standards and environmental conditions have limited variations. This should result in lower variability in CMCs obtained between laboratories. Finally, the laboratory should establish their practices in accordance with valid documents that meet the specifications given for the measuring instruments, regardless of the calibration method become more expensive. It is worth repeating that calibrations are performed to assess whether the metrological characteristics, for which the instrument was developed, are still detained.

4. CONCLUSION

The precision effect of the calibration results should be as small as possible. The sources of uncertainty coming from measurement standards, environment, method, repeatability and subject to calibration instrument, should be minimized and follow the guidelines given in valid and updated documents. This ensures the customer a consistent calibration method and allows the comparison of calibration results with the maximum permissible error. Thus, the CMCs provided by accredited laboratories will be consistent and more convergent.

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