

# Calibration and measurement capability (CMC) and customer technical qualification

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**Abstract.** In the context of metrological confirmation, calibration is an essential process in all quality assurance efforts. Several organizations choose to outsource this activity to accredited laboratories in accordance with the requirements set forth in ISO/IEC 17025: 2017. Companies understand that accredited laboratory has formal recognition of its technical competence to perform the services within its scope of accreditation. The document ILAC P14: 2013 sets out guidelines for the presentation of Calibration and Measurement Capability (CMC). However, when analysing the scope of accredited laboratories in some national calibration bodies, it is possible to observe that, for the same instrument and the same measuring range, different values are attributed to CMC. If the CMC should result from normal calibration operations on the best existing device, what causes this dispersion? How can the customer make effective use of the information contained in accreditation scopes? In order to further standardize the presentation of CMC in accreditation scopes, calibration methods adopted by laboratories should be required to meet the maximum permissible errors established by manufacturers or normative documents. Companies can outsource calibration activities. But the selection of service provider and the interpretation of the results remains a customer assignment. The paper presents an analysis of accreditation scopes of different national calibration bodies and discusses the qualification of those in charge of metrology management, regarding the knowledge and skills required for activity.

## 1 Introduction

Conformity assessment based on the product specification and the measurement evaluation is important for the quality assurance of manufactured products and for the stability of production processes [1]. In this sense, providing quality measurements is necessary to ensure that measures can be used to make correct decisions. Among the main factors that impact on the quality of measurements, the measuring instruments have a direct influence on the results obtained. In the latest version of ISO 9001: 2015 [2], the requirement related to the control of measurement resources was divided into two parts: one aimed at the management of measurement processes; and another part directed to the control of the measuring instruments, an activity that ISO 10012: 2003 [3] defines as Metrological Confirmation.

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Metrological Confirmation is the set of operations required to ensure that the measuring equipment conforms to the requirements of its intended use. Required requirements include range, resolution and maximum permissible errors.

ISO 14978: 2018 [4] define the maximum permissible errors for a metrological characteristic (MPE) as the extreme values of a metrological characteristic permitted by specifications, regulations, etc. for measuring equipment. This standard considers that the definition of the maximum permissible errors can be made by the manufacturer or by the user. Therefore, it is possible to observe in several ISO standards related to geometric specification instruments that the MPEs for the metrological characteristics were excluded.

But some countries such as United Kingdom, Germany and Japan have maintained national standards setting the maximum permissible errors for commercially recognized equipment. Table 1 shows the international standards for calipers and micrometers and the respective national standards of the previously mentioned countries.

**Table 1.** Standards for calipers and micrometers.

International Standard	National Standard
ISO 13385-1:2011 Metrological characteristics for Calipers : <ul style="list-style-type: none"> <li>• Partial surface contact error, <math>E</math></li> <li>• Scale shift error, <math>S</math></li> <li>• Line contact error, <math>L</math></li> <li>• Full surface contact error, <math>J</math></li> <li>• Error due to crossed knife-edge distance, <math>K</math></li> <li>• Repeatability of partial surface contact error, <math>R</math></li> </ul>	<ul style="list-style-type: none"> <li>• DIN 862 (2015)</li> <li>• BS 887 (2008)</li> <li>• JIS B 7507 (2016)</li> </ul>
ISO 3611:2010 Metrological characteristics for Micrometers for external measurements : <ul style="list-style-type: none"> <li>• Full surface contact error, <math>J</math></li> <li>• Repeatability, <math>R</math></li> <li>• Partial surface contact error, <math>E</math></li> </ul>	<ul style="list-style-type: none"> <li>• DIN 862 (2015)</li> <li>• BS 887 (2008)</li> <li>• JIS B 7507 (2016)</li> </ul>

In the last revision of ISO/IEC 17025 [5] in 2017 it is possible to show an orientation for calibration laboratories to meet customers' requirements (5.4, 7.1.1.d, 7.2.1.4, 7.2.1.6 e 7.8.12). This could mean that customers could establish abusive MPEs for metrological characteristics of measuring equipment. And consequently, calibration laboratories could be accredited with alternative calibration methods with higher measurement uncertainties.

It seems, at first, that calibration laboratories, even accredited, would be allowed to use inappropriate methods, as long as those accepted by customers.

This paper aims to perform an analysis of the accreditation scopes available in different accreditation bodies and to provide guidelines for users of calibration services performed by external providers to make appropriate requests. For this, calibration activity of calipers and micrometers were used as a case study.

## 2 Analyses of Accreditation Scopes

Document P14: 2013 [6], issued by the International Laboratory Accreditation Cooperation (ILAC) is a policy that sets out the requirements and guidelines for the estimation and statement of uncertainty, in order to ensure a harmonised interpretation of the GUM and the consistent use of CMC.

CMC is a calibration and measurement capability available to customers under normal conditions as described in the laboratory's scope of accreditation. Also, according to ILAC P14: 2013, there shall be no ambiguity on the expression of the CMC on the scopes of accreditation and, consequently, on the smallest uncertainty of measurement that can be expected to be achieved by a laboratory during a calibration or a measurement.

Several accreditation bodies have developed complementary normative documents to ILAC P14: 2013 to guide calibration laboratories in presenting their Measurement and Calibration Capabilities. Among them: R205 issued by A2LA [7], M3003 issued by UKAS [8] and NIT-DICLA-021 issued by CGCRE [9]. The European Community uses EA 4/02 M: 2013 [10] as a reference for the measurement uncertainty evaluation and consequently also for CMC.

SAC-SINGLAS in 2019 [11] considers that CMC is one of the essential pieces of information to be used by potential customers to judge the suitability of a laboratory to carry out particular calibration work at the laboratory or on-site.

To evaluate the form and declared values of CMCs in the accreditation scopes, four accreditation bodies were consulted. The data collection of CMCs from the accreditation scopes focused on the dimensional area. More specifically, the calibration and measurement capabilities for micrometers and calipers were analysed. For external micrometers, lengths of 25 mm and 300 mm were considered. As for calipers, evaluated lengths were 150 mm and 600 mm.

The query was performed in the databases provided by A2LA [12] RBC [13] UKAS [14] and DAKKS [15] and the total of laboratories evaluated is presented in Table 2.

**Table 2.** Accreditation bodies consulted on the presentation of the CMC.

Measuring instrument	Accreditation body	Total laboratories evaluated
Micrometer	Association for Laboratory Accreditation (A2LA)	174
	Rede Brasileira de Calibração (RBC)	75
	United Kingdom Accreditation Service (UKAS)	57
	Deutsche Akkreditierungsstelle GmbH (Dakks)	25
Caliper	Association for Laboratory Accreditation (A2LA)	54
	Rede Brasileira de Calibração (RBC)	46
	United Kingdom Accreditation Service (UKAS)	34
	Deutsche Akkreditierungsstelle GmbH (Dakks)	19

It was evidenced that the forms of presentation of CMC follow the models suggested in document ILAC P14: 2013 (Table 3), being the most common:

- A single value, which is valid throughout the measurement range;
- A range. In this case a calibration laboratory should have proper assumption for the interpolation to find the uncertainty at intermediate values;
- An explicit function of the measurand or a parameter.

**Table 3.** Forms of CMC presentation in accreditation scopes.

Format	Example
A single value	1,0 $\mu\text{m}$ 0,008 mm
A range	0,8 $\mu\text{m}$ até 2 $\mu\text{m}$ 0,01 mm até 0,06 mm
An explicit function	$[10 + (L/50)] \mu\text{m}$ , L em m (0.6R + 13L) $\mu\text{m}$ , R e L em in

In the verified accreditation bodies, it was observed that only A2LA presented the CMC in function of resolution, which was not observed in the other networks. On the other hand, DAKKS and UKAS present greater uniformity in form and declared CMC values.

Tables 4 and 5 present the minimum and maximum values shown in the accreditation scopes consulted.

**Table 4.** Extreme values of CMC extracted from the accreditation scopes for micrometer.

Length	CMC	CGCRE	A2LA	UKAS	DAKKS
25 mm	Lowest value ( $\mu\text{m}$ )	0,3	0,2	0,9	1,4
	Highest value ( $\mu\text{m}$ )	3,0	14	1,6	3,8
300 mm	Lowest value ( $\mu\text{m}$ )	0,8	0,3	1,7	6,0
	Highest value ( $\mu\text{m}$ )	14	22	3,4	12

**Table 5.** Extreme values of CMC extracted from the accreditation scopes for calipers.

Length	CMC	CGCRE	A2LA	UKAS	DAKKS
150 mm	Lowest value ( $\mu\text{m}$ )	1,0	1,6	11	34
	Highest value ( $\mu\text{m}$ )	30	29	19	34
600 mm	Lowest value ( $\mu\text{m}$ )	4,0	2,50	14	48
	Highest value ( $\mu\text{m}$ )	37	33	33	78

The variation detected in the accreditation scopes requires that the user of the calibration services pay attention to their real needs and make the appropriate choice of the external provider. It should be noted that CMC represents the lowest uncertainty the laboratory can obtain, considering the best equipment available. Therefore, depending on the measuring instrument that will be subject to calibration, the measurement uncertainty obtained may be different from that established for CMC. This implies that there may still be an increase in the expanded uncertainty presented in the calibration certificate because the resolution directly impacts the measurement uncertainty. It is also important to note that the CMC declared is for the best method that laboratory performs. If there are more calibration methods, there may be an increase in uncertainty.

In a careful analysis, uniformity in the presentation of CMCs was expected, especially when it comes to measuring instruments used on a large scale. It is a fact that ISO standards tend not to establish the maximum permissible errors for geometric specification equipment. But several countries have specific standards setting these limits. It is also observed homogeneity in MPEs established by different manufacturers for the same type of measuring instrument.

Although some ISO standards do not specify MPEs, they relate the metrological characteristics to be evaluated in the instruments and suggest the standards to be used. Thus, if the laboratories were using normative documents and observed the maximum permissible errors established by the manufacturers or standards, greater uniformity in CMCs could be obtained.

Table 6 presents an example of measurement uncertainty balance for the metrological characteristic full surface contact error, evaluated in a micrometer at 25 mm, considering normal calibration conditions and main sources of uncertainties. For this evaluation, 3 measurement cycles were considered.

**Table 6.** Measurement Uncertainty Balance for Micrometer

Source of uncertainty	Value	Divisor	$u(x_i)$	Probability distribution	$c_i$	$u_i(y)$ ( $\mu\text{m}$ )	$v_i/v_{\text{eff}}$
Repeatability	$s_{\text{REP}} = 0 \mu\text{m}$	$\sqrt{3}$	0	T	1	0	2
Calibration of the reference standard (gauge block)	$U_{\text{GB}} = 0,2 \mu\text{m}$	2	0,1	N	1	0,1	$\infty$
Length variation of gauge block	$E_{\text{GB}} = 0,2 \mu\text{m}$	$\sqrt{3}$	0,12	R	1	0,12	$\infty$
Micrometer resolution	$\text{Res} = 0,5 \mu\text{m}$	$\sqrt{3}$	0,29	R	1	0,29	$\infty$
Temperature difference between micrometer and gauge block	$\delta\text{Temp} = 0,2^\circ\text{C}$	$\sqrt{3}$	0,12	R	$25000 \mu\text{m} \times 11,5 \times 10^{-6} \text{C}^{-1}$	0,12	$\infty$
Temperature other than $20^\circ\text{C}$ degrees	$\Delta\text{Temp} \times \delta\alpha = 1^\circ\text{C} \times 2 \times 10^{-6} \text{C}^{-1}$	$\sqrt{3} \times \sqrt{6}$	$0,47 \times 10^{-6} \text{C}^{-1}$	---	25000 $\mu\text{m}$		$\infty$
Combined uncertainty $u(y)$						0,33	$>50$
Expanded Uncertainty $U$						0,7	$k = 2,00$

Based on Table 6, some simulations were made for different measurement conditions. The results are shown in Table 7.

**Table 7.** Expanded uncertainty for different measurement conditions (micrometer)

Length (mm)	$s_{\text{REP}}$ ( $\mu\text{m}$ )	$U_{\text{GB}} (k = 2)$ ( $\mu\text{m}$ )	$E_{\text{GB}}$ ( $\mu\text{m}$ )	Res ( $\mu\text{m}$ )	$\delta\text{Temp}$ ( $^\circ\text{C}$ )	$\Delta\text{Temp} \neq 20^\circ\text{C}$ ( $^\circ\text{C}$ )	U ( $\mu\text{m}$ )	k
25	0	0,2	0,2	0,5	0,2	1	0,7	2,00
	1	0,5	1	0,5	1	3	2,0	2,23
	0	0,2	0,2	1	0,2	1	1,2	2,00
	1	0,5	1	1	1	3	2,2	2,13
	0	0,2	0,2	2	0,2	1	2,3	2,00
	1	0,5	1	2	1	3	2,9	2,00
300	0	0,2	0,9	0,5	0,2	1	1,5	2,00
	1	0,5	3	0,5	1	3	5,5	2,01
	0	0,2	0,9	1	0,2	1	1,8	2,00
	1	0,5	3	1	1	3	5,6	2,01
	0	0,2	0,9	2	0,2	1	2,7	2,00
	1	0,5	3	2	1	3	6,0	2,00

In comparison with the CMCs declared in the calibration scopes (Table 4), it is clear that there is a real possibility of minimizing the existing variations.

Simulations were also carried out to evaluate the expanded uncertainty of the metrological characteristic partial surface contact error in calibration of calipers. The results are shown in Table 8.

**Table 8.** Expanded uncertainty for different measurement conditions (caliper)

Length (mm)	S <sub>REP</sub> (mm)	U <sub>GB</sub> (k = 2) (μm)	E <sub>GB</sub> (μm)	Res (mm)	δ <sub>Temp</sub> (°C)	Δ <sub>Temp</sub> ±20°C (°C)	U (mm)	k
150	0	0,2	0,8	0,005	0,2	1	0,01	2,00
	0,01	2	5	0,005	1	3	0,02	2,87
	0	0,2	0,8	0,01	0,2	1	0,02	2,00
	0,01	2	5	0,01	1	3	0,02	2,28
	0	0,2	0,8	0,025	0,2	1	0,03	2,00
	0,01	2	5	0,025	1	3	0,04	2,02
600	0	0,3	1,3	0,005	0,2	1	0,01	2,00
	0,01	2	8	0,005	1	3	0,02	2,25
	0	0,3	1,3	0,01	0,2	1	0,02	2,00
	0,01	2	8	0,01	1	3	0,03	2,13
	0	0,3	1,3	0,025	0,2	1	0,03	2,00
	0,01	2	8	0,025	1	3	0,04	2,00

A survey was conducted with a group of 30 companies that operate in the Brazilian market and use calibration services performed by accredited laboratories. The objective was to identify the perception that these companies have when they hire a calibration service. Questioned about the criteria used to select the external provider, the most frequent answers were: Calibration and Measurement Capability, Customer Support, Laboratory credibility and price. In order to verify the calibration results, most of the participating companies use the algebraic sum of indication error (or deviation) and measurement uncertainty in comparison with MPE as acceptance criterion. Specific cases pointed to the use of quadratic sum of indication error with measurement uncertainty, or only the indication error as value to be compared with MPE. Asked how the maximum permissible errors are defined, responses were divided between using percent tolerance of the product to be controlled or errors defined in technical standards (or manufacturer specifications).

Since the accreditation process of calibration laboratories is voluntary, CMC is an agreement between the laboratory and the accreditation body. In view of the flexibility of ISO/IEC 17025 in laboratory to develop its own procedures, it is responsibility of customer to critically evaluate the accreditation scopes and, in particular, to agree with the laboratory the methods that meet their needs, so that the measurement uncertainty is compatible with the measurement requirements.

### 3 Qualification of the metrological function

ISO 10012: 2003 (and also ISO 9000: 2015 [16]) defines the metrological function as the functional unit with technical and administrative responsibility to define and implement the measurement management system, which is a set of interrelated or interactive elements necessary for the metrological conformation and control of measurement processes.

It is true that metrological confirmation is directly related to the control of measurement processes, since instruments are devices used to monitor and measure the manufacturing processes and products, respectively. In this sense, it is common for companies to apply product tolerance to establish MPEs for measuring instruments. However, this should not be the order of the activity's execution. And yes, from the metrological confirmation, the equipment should be selected for the measurement tasks. Even because the measurement processes are subject to other sources of variation, such as the measurand itself, operator, environmental conditions, etc. To analyse the quality of measurement processes, statistical

methods as set out in MSA [17] or VDA 5 [18] manuals are widely used. And for application of these methods, verified measuring instruments should be selected. More advanced studies also operate with probabilistic calculations to estimate the risks of incorrect inspections [1] [19,20].

In metrological confirmation activities, the calibration and verification of the measuring instruments are fundamental. Verification is defined in VIM [21] and ISO 9001 as the objective proof that a given item satisfies the specified requirements. Verification after calibration compares calibration results with established MPEs for metrological characteristics. In an internal process, it is up to the metrological function to define these limits [4]. For definition of MPEs, the specifications given by manufacturers and normative documents should be considered. This is because the design characteristics are set to meet a certain level of accuracy of the equipment. Applications of measuring instruments should be taken into account in the MPEs definition, allowing longer equipment life and less intervention for adjustments. But care should be taken in adopting larger MPEs. Values well beyond those specified by manufacturers may lead the instrument to operate at levels for which it was not built, and may also compromise the organization's metrological culture.

In order to define the maximum permissible errors, the following qualifications of the metrological function are required: to know principles of operation of measuring system and the measurement processes in which it will be used.

Once the maximum permissible errors are defined, the next step is to evaluate how they should be compared to the calibration results.

The complete result of a calibration displays values obtained for the metrological characteristics together with the measurement uncertainty. The measurement uncertainty corresponds to the confidence interval within true value can be assigned, with a confidence level of approximately 95%. Higher uncertainty values can make metrological verification process unfeasible if the main sources of variation are due to the calibration process itself and not to the equipment being evaluated.

In this step, a fundamental requirement in metrological verification should be considered: the selection of external provider to carry out the calibration. Unless the company has technical support of its supplier and has credibility in the information passed by him, the metrological function shall be technically qualified in terms of calibration methods and measurement uncertainty. Then, the metrological function may perform a critical analysis of the CMCs declared by the calibration laboratories. Typical sources of measurement uncertainty in calibration are repeatability, the uncertainty of the gauge used and the measuring instrument resolution. In dimensional area, uncertainty sources of temperature variation may also impact the calibration results, especially when it comes to longer lengths. It is important to note that CMCs declared in accreditation scopes usually have been calculated considering the best existing equipment, unless the reference gauge fails to meet this condition.

In practical terms, the company can estimate the expected measurement uncertainty for a given equipment from the declared CMC. Two sources of uncertainty that can directly impact on the expanded uncertainty are repeatability and resolution. Equation (1) presents a directive for the minimum measurement uncertainty expected for a measuring instrument.

$$U = 2 \cdot \sqrt{\left(\frac{CMC}{2}\right)^2 + \left(\frac{RES}{\sqrt{3}}\right)^2 + (S_{REP})^2} \quad (1)$$

where :  $RES$  is the resolution of the measuring instrument, adopted during calibration  
 $S_{REP}$  is the repeatability standard deviation.

Another way to obtain consistent information is to request the external supplier to discriminate in a tender the least possible uncertainty to be obtained, considering the specific

metrological characteristics of the measuring instrument and the procedure that will effectively be used in the calibration.

Having clarity about the information passed on by the external provider, it is possible to compare them with the company-defined MPEs and thus to be able to select the calibration service provider appropriately.

## 4 Conclusion

This paper sought to contextualize the variations existing in the presentations of accreditation scopes. In order to promote greater homogeneity among laboratories, it is important that customers request calibration procedures compatible with the functional and metrological characteristics of measuring instruments, established in standards or by manufacturers.

In this sense, it is necessary for the metrological function in companies to have technical knowledge about the functionality of the measuring instruments, the metrological characteristics that need to be checked, the definition of maximum permissible errors, calibration method and associated uncertainties, interpretation of accreditation scopes and calibration certificates.

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