Using decision rule in calibration of long gauge block on the conformity assessment scheme

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Abstract. Conformity assessment is a process commonly used in calibration activities to ensure the validity of the results of measurements or calibrations which is compared with specific requirements or standards. In this research the use of conformity assessment was carried out on long gauge block calibration activities in National Metrology Institute of Indonesia by determining objective criterion called decision rule. Decision rules are made by referred to JCGM 106:2012 standard that using two-sided acceptance method. In the two-sided acceptance method is used the acceptance/rejection limits such as: tolerance interval, acceptance interval and guard band. Conformity assessment result is stated as “accepted” if the calibration results are within the criteria of the decision rule, and vice versa. From this research, it was found that in the calibration process of long gauge block, the guard band value is obtained from the expanded uncertainty (U) value of the long gauge block (UUT). The conformity assessment results will be “accepted” if the reduced tolerance value (t_r reduced) is greater than the measured deviation value (k_r).

1. Introduction
The conformity assessment are applied to various types of work related to meeting the acceptance criteria of the results. The concept of conformity assessment has also been applied to laboratories that apply the ISO/IEC 17025:2017. To implement the conformity assessment scheme, it is necessary to make technical rules called decision rules. According to ISO/IEC 17025:2017 standard, the decision rule is rule that describes how measurement uncertainty is accounted for when stating conformity with a specified requirement [1]. Specifically, ISO/IEC 17025:2017 standard imposes special requirements regarding the calibration certificate in which contains statement of conformity with certain decision rules. The conformity assessment are needed to see the fulfillment of certain requirements of a calibration result, for example fulfillment of reference standards and fulfillment of legal requirements. In this research, the concept of conformity assessment was applied in the long gauge block calibration activities. This research aims to accommodate the needs of calibration customers who request statement of conformity assessment on calibration certificate from their long gauge block. Statement of conformity assessment can consist of: “accepted/rejected”, “pass/fail”, “in-tolerance/out-tolerance”, and “compliance/uncompliance”. Some research related to decision rule in the conformity assessment scheme have been carried out by Liepina [2] and Pendrill [3].

2. Long Gauge Block Calibration System
According ISO 3650:1998, gauge block is material measure of rectangular section, made of wear-resistant material with one pair of planar mutually parallel measuring faces which can be wrung to the measuring faces of other gauge blocks to make composite assemblies, or to similarly finished surface of
auxiliary plates for length measurements [4]. A set long gauge block consists of several blocks that have a certain nominal value. Generally, a set long gauge block consists of blocks with a nominal length: 125 mm, 150 mm, 175 mm, 200 mm, 250 mm, 300 mm, 400 mm, and 500 mm.

Figure 1. Long gauge block set and its calibration setting in Universal Length Measuring Machine (ULM)

As a measuring instrument, long gauge block needs to be calibrated to determine its deviation. Long gauge block calibration process can be done by the comparison method. The comparison method is done by comparing the calibration results of the reference long gauge block and the calibration results of the calibrated long gauge block (UUT). A long gauge block can be used as a standard if it has a higher grade compared to a calibrated long gauge block (UUT).

In Indonesia, there is a government institution called SNSU-BSN that has the authority as a National Metrology Institute. One of the tasks of SNSU-BSN is to maintain the traceability chain of measurement through the calibration process in the conformity assessment scheme in Indonesia. SNSU-BSN has Length Laboratory that processes the dissemination of the reference standard values for several calibration scopes such as: linear dimensions, angle, complex geometry, form, etc.

In this research, the focus of the discussion is the process of conformity assessment of calibration activities for long gauge block. The long gauge block calibration carried out at the SNSU-BSN laboratory uses a comparison method where the reference long gauge block is compared to the calibrated long gauge block (UUT). The comparator used in the calibration process is the Universal Length Measuring Machine (ULM). The Universal Length Measuring Machine (ULM) is a one-dimensional measuring machine that has a fixed arm and a movable arm that has a tip contact at the end. When calibration process, the calibrated long gauge block (UUT) is placed in the direction of the measurement axis and is lay down at the airy point in order that the measuring surface is parallel. The calibration process of long gauge block with the comparison method carried out by measuring the reference long gauge block and long gauge block (UUT) 10 times. From the calibration process, we can get the difference of length between the standard and the UUT. From equation (1) the measurement deviation ($l_x$) of the calibrated long gauge block (UUT) is obtained.

$$l_x = l_s - l$$

where:

- $l_x$ : measured deviation of long gauge block UUT (mm);
- $l_s$ : length of the reference long gauge block at the reference temperature $t_0 = 20 \, ^\circ\text{C}$ according to its calibration certificate (mm);
- $l$ : length of the long gauge block UUT (mm);
Figure 2. Long gauge block calibration system

After performing the long gauge block calibration process, the next step is to calculate the uncertainty value of the measurement from the long gauge block (UUT). The uncertainty of measurement is something that cannot be separated from calibration process because it determines the traceability of the calibration itself. Figure 2 is a schematic design of long gauge block calibration system.

The first step in calculating measurement uncertainty is determining the form of the mathematical model. With the mathematical model, we can see the factors that influence calibration results. In the long gauge block calibration, measurement uncertainty analysis follows JCGM 100:2008 [5] and the mathematical model can be made as follows:

\[ l_x = l_x + \delta_x + \delta + \delta_C - L(\overline{\alpha} \cdot \delta \theta + \delta \alpha \cdot \overline{\theta}) + \delta_l + \delta_f \]  

(2)

where:
\( \delta_D \): change of the length of the reference gauge block since its last calibration due to drift (mm);
\( \delta \): observed difference in length between the unknown and the reference gauge block (mm);
\( \delta_C \): correction for non-linearity and offset of the comparator (mm);
\( L \): nominal length of the gauge block UUT considered (mm);
\( \overline{\alpha} \): average of the thermal expansion coefficients of the unknown and reference gauge block;
\( \delta \theta \): temperature difference between the unknown and reference gauge block (°C);
\( \delta \alpha \): difference in the thermal expansion coefficients between the unknown and the reference gauge block (°C);
\( \bar{\theta} \) : deviation of the average temperature of the unknown and the reference gauge block from the reference temperature (°C);

\( \Delta V \) : correction for non-central contacting of the measuring faces of the unknown gauge block (mm);

\( \Delta u_f \) : correction for contact deformation (mm).

The next step is to compile the uncertainty budget for the long gauge block calibration by separating the constant factor and the length-dependent factor (L) as shown in table 1.

**Table 1. Uncertainty budget of long gauge block calibration**

| Uncert source       | Unit | Distr. | Symbol | Var. interval | Divisor | Deg. of freedom/\( vi \) | Std. Uncert/\( u_i \) | Sens. Coeff/\( c_i \) | \( (c_iu_i)^2 \) | \( (c_iu_i)^4/vi \) |
|---------------------|------|--------|--------|---------------|---------|---------------------------|------------------------|----------------------|---------------------|---------------------|
| Readability of instrument | µm   | Rect   | \( u(\delta_l) \) | 0.005 | 1.732 | 1E+99 | 0.0029 | 1 | 0.003 | 0.00001 | 6.9E-110 |
| Repeatability of measurement | µm   | Normal | \( u(\delta_l) \) | 0.03 | 3.162 | 14 | 0.0095 | 1 | 0.009 | 0.00009 | 5.8E-10 |
| Comparator uncertainty | µm   | Normal | \( u(\delta_l) \) | 0.18 | 2.000 | 60 | 0.0900 | 1 | 0.090 | 0.00810 | 1.1E-6 |
| Reference block value | µm   | Normal | \( u(l_i) \) | 0.24 | 2.000 | 60 | 0.1200 | 1 | 0.120 | 0.01440 | 3.5E-6 |
| Drift | µm | Triang. | \( u(\delta_l) \) | 0.072 | 2.449 | 1E+99 | 0.0294 | 1 | 0.029 | 0.00086 | 7.5E-106 |
| Var. in length | µm rect | \( u(\delta_l) \) | 0.0067 | 1.732 | 60 | 0.0039 | 1 | 0.004 | 0.00001 | 3.7E-12 |
| Contact deformation | µm rect | \( u(bF_l^2) \) | 0.00 | 1.732 | 60 | 0.0000 | 1 | 0.00 | 0.00000 | 0.0E-0 |
| Sums | | | | | | | | | | 0.02248 | 4.6E-6 |
| Combined uncert, \( u_c \) and effective degree of freedom for constant uncertainty components | | | | | | | | | | 0.1532 | 121 |

| Uncert source | Unit | Distrib | Symbol | Var. interval | Divisor | Deg. of freedom/\( vi \) | Std. Uncert/\( u_i \) | Sens. Coeff/\( c_i \) | \( (c_iu_i)^2 \) | \( (c_iu_i)^4/vi \) |
|----------------|------|---------|--------|---------------|---------|---------------------------|------------------------|----------------------|---------------------|---------------------|
| Reference block value | µm   | Normal | \( u(l_i) \) | 1.0E-7L | 2 | 60 | 5.0E-8L | 1 | 5.0E-8L | 2.5E-13 | 1.0E-31 |
| Difference between a and a_{\theta} | /°C | Rect | \( u(\delta_{a'} \theta) \) | 1.0E-6 | 4.24264 | 1E+99 | 2.4E-8 | 1L | 2.4E-8 | 5.6E-14 | 3.1E-126 |
| Temperature gradient between blocks | /°C | Rect | \( u(\delta_{\theta}) \) | 0.05 | 1.73205 | 1E+99 | 0.029 | 1.2E-5L | 3.3E-7L | 1.1E-13 | 1.2E-125 |
| Drift | µm Triang. | \( u(\delta_{l_i}) \) | 4.3E-7L | 2.449 | 1E+99 | 1.8E-7L | 1 | 1.8E-7L | 3.1E-14 | 9.8E-127 |
| Sums | Combined uncert, \( u_c \) and effective degree of freedom for length-dependent uncertainty components | | | | | | | | | | 2.0E-13L2 | 1.0E-31 |
| Total combined uncert, \( u_c(L \text{ in mm}) \) | | | | | | | | | | 0.153, 0.000045 L | |
| Effective degree of freedom | | | | | | | | | | > 100 |
| Expanded uncertainty at \( k = 2 \) (L \text{ in mm}) | U = | | | | | | | | | Q(0.31, 0.001 L) |

From table 1, the readability value obtained from the calibration certificate Universal Length Measuring Machine (ULM) as comparator. While the repeatability value is obtained from the results of repeated measurements, which in this case are done 10 times. The reference block value is taken from the long gauge block calibration certificate which is used as the measurement reference. In addition, standard drift values are taken based on ISO 3650:1998 standards and variation in length values taken from EA 4/02 [6]. At the uncertainty budget, the contact deformation value is assumed based on changes in shape due to contact tip deformation while temperature gradient values are taken from the boundary the allowable temperature during calibration. From table 1, regarding the budget uncertainty of the long gauge block, it is obtained that the value of the expanded uncertainty of measurement (\( U \)) for long gauge block method calibration with confidence level 95% and coverage factor k = 2 can be obtained by the following equation:
where:

\( U \) : expanded uncertainty value of the long gauge block UUT at 95% confidence level and coverage factor \( k = 2 \) (\( \mu \)m);

\( L \) : nominal length of the gauge block UUT considered (mm).

3. Decision Rule of Long Gauge Block Calibration

There are several standards that can be used as a reference document in determining the decisions rules of the conformity assessment scheme in calibration results. In this research the JCGM 106:2012 document was used which became the standard in determining decision rules. Based on the JCGM 106:2012, there are several methods that can be used, such as: simple acceptance, guarded acceptance, guarded rejection, and two-sided acceptance [7]. In this research the decision rules used are two-sided acceptance as shown in figure 3.

![Figure 3. Two-sided acceptance decision rules method based on JCGM 106:2012.](image)

In the concept of conformity assessment, the calibration results of long gauge block are used to determine the decision that is in the form of acceptance of the results or rejection of the results. The results will be accepted if they are within the acceptance interval, otherwise the results will be rejected. Acceptance interval value is obtained by calculating the measurement uncertainty value from the long gauge block. The lower limit of the acceptance interval is denoted by the \( A_L \), while the upper limit of the acceptance value interval is denoted by the \( A_U \).

In addition, this research needs to determine the tolerance interval which is defined as the permissible measurement range whose value is determined from the ISO 3650:1998 standard. The tolerance interval value is taken from the interval value of the limit deviation of length (\( \pm t_e \)) from the ISO 3650:1998. The lower limit of interval tolerance is given \( T_L \) notation and the upper limit of interval tolerance is given \( T_U \) notation.

According to JCGM 106:2012, there is the term guard band (\( w \)) which is defined as the interval between tolerance limit and acceptance limit which if written the mathematical relationship is as follows:

\[
 w = T_U - A_U \quad (4)
\]

In two-sided acceptance method, the value of guard band (\( w \)) is obtained by multiplying the value of the expanded uncertainty of the measurement (\( U \)) by a multiplier (\( r \)) according to the following equation:

\[
 w = rU \quad (5)
\]

According to JCGM 106:2012 the value of the multiplier commonly used is \( r = 1 \), so that by using this value then equation 5 can be rewritten to become:

\[
 w = U \quad (6)
\]

\[
 w = U = 2u \quad (7)
\]

where:

\( U \) : expanded uncertainty value of the long gauge block UUT at 95% confidence level and coverage factor \( k = 2 \) (\( \mu \)m);
\(u\) : combined uncertainty value of the long gauge block UUT (µm);
\(w\) : guard band (µm).

From equation 7, the relationship between guard band \((w)\) and expanded uncertainty of measurement \((U)\) is obtained from the long gauge block calibration results. By using guard band \((w)\), the measurement tolerance value \((t_e)\) will reduced by the expanded uncertainty of measurement value \((U)\). Reducing the tolerance value \((t_e)\) due to guard band \((w)\) is called reduced tolerance \((t_{e \text{ reduced}})\) as in the following equation:

\[
t_{e \text{ reduced}} = t_e - U
\]  

where:
\(t_e\) : measurement tolerance (µm), taken from ISO 3650:1998
\(t_{e \text{ reduced}}\) : reduced tolerance of measurement (µm)

The calibration results will be at the acceptance interval based on the two-sided acceptance method if the reduced tolerance value \((t_{e \text{ reduced}})\) is greater than the measured deviation value \((lx)\) of the long gauge block UUT. On the other hand, the calibration results will be rejected if the reduced tolerance value \((t_{e \text{ reduced}})\) is less than or equal to the measured deviation value \((lx)\) of the long gauge block UUT. The decision rules used in this research are as follows:

\[
\begin{align*}
    t_{e \text{ reduced}} &> lx, \text{ (accepted)} \quad (9) \\
    t_{e \text{ reduced}} &\leq lx, \text{ (rejected)} \quad (10)
\end{align*}
\]

4. Results
Based on the decision rules discussed above, the rules are used in the conformity assessment process for calibration of long gauge block (UUT) process. In this research, we are using two calibration results data of the long gauge block (UUT) where the decision rule was used. The nominal length and grade of the two long gauge blocks (UUT) are the same which has a nominal length of 400 mm and grade 0. The first calibration result data we call long gauge block A, and the others are named long gauge block B. The following table are the long gauge block calibration results data:

| Identity of UUT      | Grade of UUT | Nominal Length (L) in mm | Measured Deviation (lx) in µm | Expanded Uncertainty (U) in µm |
|----------------------|--------------|--------------------------|-------------------------------|-------------------------------|
| Long Gauge Block A   | 0            | 400                      | 0.07                          | 0.51                          |
| Long Gauge Block B   | 0            | 400                      | 2.58                          | 0.51                          |

From table 2, we get data for long gauge block A that measured deviation \((lx)\) is 0.07 µm while the expanded uncertainty value \((U)\) is ±0.51 µm. By using the measurement tolerance value \((t_e)\) of 0.9 µm obtained from ISO 3650:1998 we can determine the value of reduced tolerance \((t_{e \text{ reduced}})\) using equation 8. From this calculation, the value of \(t_{e \text{ reduced}}\) obtained for long gauge block A is ±0.39 µm.

By using the decision rules from equations 9 and 10, it can be concluded that the calibration results of the Long Gauge Block A are stated as “accepted” because it is comply with equation 9.

As for the calibration results of the long gauge block B, the results of the measured deviation \((lx)\) are obtained is 2.58 µm and expanded uncertainty measurement value \((U)\) is ±0.51 µm. By using \(t_e = 0.9\) µm obtained from ISO 3650:1998, the \(t_{e \text{ reduced}}\) value obtained using equation 8. The reduced tolerance \((t_{e \text{ reduced}})\) value for long gauge block B is ±0.39 µm. By using decision rules from equations 9 and 10,
it can be concluded that the calibration results from long gauge block B are expressed as “rejected” because it is comply with equation 10.

5. Conclusions
From the results of this research, the decision rule for long gauge block calibration on the conformity assessment scheme has been formulated. The decision rule method used in this research is a two-sided acceptance which refer to JCGM 106:2012. In the two-sided acceptance method, tolerance interval (\(t_e\)) is used taken from ISO 3650:1998 which is define as the range of measurement results that are permitted. While acceptance intervals is measurement range of acceptable measurement results. In this method the guard band (\(w\)) is used which is the expanded uncertainty of measurement (\(U\)) value of the long gauge block (UUT) calibration results. From the relationship between tolerance interval (\(t_e\)), expanded uncertainty of measurements (\(U\)) and measured deviation (\(lx\)), the decision rule is formulated to determine the acceptability of the calibration results. The statement of conformity assessment the calibration results is in the form of “accepted” or “rejected”. The calibration results are stated “accepted” when at acceptance interval, otherwise the calibration result is stated “rejected” if it is outside the acceptance interval. The decision rules that formulated from this research were used for the conformity assessment in the calibration of long gauge blocks (UUT). The results are there is long gauge block (UUT) which is stated “accepted” and the other long gauge block (UUT) which is stated “rejected”.

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