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Estimating the Calibration Life of the Measuring Instruments

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Abstract
The paper presents a study aimed at estimating the calibration life of the measuring instruments as a function of the metrological reliability, by considering the internal parameter deviation functions. The study is performed on length measuring instruments, caliper rules and micrometers. The experimental study conducted is aimed at determining the calibration life of external micrometers for 0 - 25 mm and of external caliper rules of 150 mm, with depth rod and with a resolution of 0.1 mm. The experimental data is obtained in laboratory conditions and is represented by the measuring errors, obtained for the same nominal size. Data is grouped in samples produced at a certain interval of time, by measuring the same dimension with a set of caliper rules and a set of micrometers, respectively. By performing an appropriate program, in the case of a set of specific measuring instruments, it is possible to test whether the estimated values obtained for the calibration life in each case considered meet the requirements set in the appropriate standards. The estimated calibration life of the measuring instruments considered was compared to that stated in the appropriate standards. In both cases considered, for the caliper rules and micrometers, the pre-set calibration life proved to be less than the estimated one, such as by considering the proposed method, the costs of the appropriate operation would be reduced.

Keywords
caliper rules, micrometers, calibration life, parameter deviation, metrological reliability

1. Introduction

Each measuring device is characterized by a specific tolerance interval. The measurement errors produced by using a measuring device are located inside the tolerance interval if the measuring device is correctly adjusted. In time, by using the measuring devices, the measurement errors start to grow and, at a certain moment, they might exceed the tolerance interval. In case the probability density function (pdf) for the measurement errors exceeds the tolerance interval with a certain percentage, it is considered that a metrological disturbance has occured. The metrological disturbances cannot be discovered by the time they are produced, they can be discovered only during the periodical checking of the measuring devices or by the negative consequences generated by the use of such measuring devices. As a consequence, it is very important to predict, with a certain precision, the moment when the considered measuring device measures with greater errors than the tolerated ones [1].

Parameter deviation represents a very useful research tool for the estimation of the metrological reliability and for the estimation of the calibration life of the measuring devices, since it helps to predict the moment in time when the probability density function for the measurement errors exceeds the tolerance interval with a certain percentage, corresponding to the chosen level of significance. That moment indicates the stage at which the considered measuring device needs to be checked and, if necessary, calibrated [1, 2]. This experimental research may be added to a former researches performed on different types of measuring instruments [3, 4], in laboratory conditions. In [5] there was presented the estimation of the calibration life of the water meters in an installation consisting of several water meters of different types, while in [6] the calibration life was estimated by using a different method.

The objective of the research performed and presented in the present paper is represented by the estimation of the calibration life of specific measuring devices – external micrometers for 0 - 25 mm and external caliper rules of 150 mm, with depth rod, with a resolution of 0.1 mm.

The experimental study conducted on these measuring instruments consists of the processing of the measuring errors, obtained for the same nominal size, grouped in samples produced at a specific period of time, by measuring in laboratory conditions the same dimension with a set of length measuring instruments of the same type. The contribution of the author in this research is represented by the estimation of the calibration life of the length measuring instruments considered, as a function of the metrological reliability, based on the internal parameter deviation. The results obtained demonstrated that it may be possible to perform the calibration at a longer period than that specified in the appropriate standards [7], being possible to reduce the costs of the operation of calibration.

2. Algorithm for Estimating the Calibration Life of the Measuring Instruments

General metrology uses especially the normal distribution, although positive and asymmetrical distributions (e.g. Weibull distribution) are frequently met in the analysis of the metrological reliability [10].

The following notations are used: α - the level of significance; m - the mean; σ - the standard deviation; n - the volume of the sample; k - the number of samples; x_{ji} - the experimental data, which is assumed to be normally distributed, according to the normal distribution function N(m, σ, t) (j = 1,..., k, i = 1,..., n) having both parameters m and σ variable; m_0 - the initial value of the mean; a - the variation coefficient of the mean; σ_0 - the initial value of the standard deviation; b - the variation coefficient of the standard deviation; T_ε - the tolerance interval for variable ε, as a measurement error; ti - the initial moment; dt- the interval between the collection of the samples (it is considered that dt is constant); t_r - the calibration life.

The case of a normal distribution N(m_0, σ_0, t) is considered. After a period of time, due to the internal parameter deviation, the parameters of the distribution are m and σ, such as the distribution becomes N(m, σ, t). It is considered that the mean m and the standard deviation σ may have a linear or an exponential variation, according to the equations:

$$m = m_0 + a \cdot t \tag{1}$$

$$\sigma = \sigma_0 + b \cdot t \tag{2}$$

$$m = m_0 \cdot exp(a \cdot t) \tag{3}$$

$$\sigma = \sigma_0 \cdot exp(b \cdot t) \tag{4}$$

The algorithm for estimation of the calibration life of the measuring devices as a function of the metrological reliability includes the following steps [2]:

- Data collection; the experimental data is collected from field operation;
- Data outlier tests- Grubbs test [8];
- Distribution assumption - normal distribution, as it is used by general metrology;
- Parameter estimation for the chosen distribution - normal distribution [8];
- Goodness-of-fit tests performance: general goodness-of-fit test (Kolmogorov-Smirnov) and normality goodness-of-fit test (Lilliefors);

The optimum distribution is validated by the values obtained for the statistics of the tests considered: d_j - the value of the statistics of the Kolmogorov-Smirnov goodness-of-fit test; L_j - the value of the statistics of the Lilliefors goodness-of-fit test [9, 10, 11]. These values are compared to the critical values of the tests: $d_{n,\alpha}$ - the critical value of the statistics of the Kolmogorov-Smirnov goodness-of-fit test, $L_{n,\alpha}$ - the critical value of the statistics of the Lilliefors goodness-of-fit test [9].

- Determining the parameter deviation functions by means of regression analysis (m'_0, a', σ'_0, b' - the estimated coefficients of the parameter deviation function) and the correlation coefficients for the linear variation ($r_{m\text{-}l}$, $r_{\sigma\text{-}l}$) and for the exponential variation ($r_{m\text{-}exp}$, $r_{\sigma\text{-}exp}$) [8, 11]. The type of the parameter deviation function (linear or exponential) for each parameter – m and σ, is indicated by the highest value of the two calculated correlation coefficients for each parameter ($r_{m\text{-}l}$ or $r_{m\text{-}exp}$ and $r_{\sigma\text{-}l}$ or $r_{\sigma\text{-}exp}$, respectively);
- Determining the calibration life, by means of parameter deviation functions, according to the method described in [2].

The pre-set calibration time for length measuring instruments is set to two years, as stated in the appropriate standards [7].

3. Estimating the Calibration Life of the Micrometers

The experimental study is conducted on a set of micrometers for 0 - 25 mm. Experimental data is represented by the measuring errors, obtained by measuring a certain nominal size. Data is grouped in six samples produced at a certain period of time (a month), by measuring the same dimension with the set of micrometers, in laboratory conditions. The tolerance interval is T_ε = 0.016 mm, the level of significance is α = 0.05, the volume of the sample is n = 17, the number of samples k = 6, initial moment ti = 0 and the interval between the moments at which samples are collected dt = 1. Table 1 presents the measuring errors, obtained by measuring the same nominal size with the set of micrometers considered.

Table 1. Measuring errors obtained by using the set of micrometers

Sample	Measuring errors
1	-0.001 -0.002 0 0.001 0 -0.001 0 -0.002 0 0.001 0.001 -0.001 0.001 -0.001 0 0 -0.001
2	-0.001 -0.002 0 0.001 0 -0.001 0 -0.002 0 0.001 0.002 0 -0.001 -0.001 0 0 0.001
3	-0.001 -0.002 0 0.001 0 -0.002 0 -0.002 0 0.001 0.001 0 -0.001 -0.001 0 0.001 0.001
4	-0.001 -0.002 0 0.001 0 -0.001 0 -0.002 0 0.001 0.002 0.001 0.002 -0.001 0 0.001 0.002
5	-0.001 -0.002 0 0.001 0 -0.001 0 0 0.001 0.001 0.002 0.002 0.002 -0.001 0.001 0.002 0
6	-0.001-0.002 0 0.001 0 -0.001 0.001 -0.002 0 0.001 0.002 0.002 0.002 -0.001 0.001 0.001 0.002

Table 2 presents the values of the statistics of both Kolmogorov-Smirnov and Lilliefors goodness-of-fit tests for each sample. These values are according to both conditions: $d_j \le d_{n,\alpha}$ = 0.318, for Kolmogorov-Smirnov goodness-of-fit test and respectively $L_j \le L_{n,\alpha}$ = 0.206 for Lilliefors goodness-of-fit and this indicates normal distributions [10, 11]. The critical value of the statistics of the Kolmogorov-Smirnov goodness-of-fit tests for the sample size is $d_{n,\alpha}$ = 0.318 and the critical value of the statistics of the Lilliefors goodness-of-fit tests for the sample size is $L_{n,\alpha}$ = 0.206 [8, 10, 11].

Table 2. Values of the statistics of the Goodness-of-fit Tests

Sample	1	2	3	4	5	6
d_j	Kolmogorov-Smirnov Goodness-of-fit Tests					
	0.2056	0.2123	0.2324	0.1513	0.1607	0.2115
L_j	Lilliefors Goodness-of-fit Tests					
	0.1749	0.1995	0.1736	0.1428	0.1607	0.1527

The values of the estimated parameters m and σ for each sample are given in Table 3.

Table 3. Values of the estimated parameters of the samples

	Sample					
	1	2	3	4	5	6
m	-0.0003	-0.0002	-0.0002	0.0002	0.0004	0.0004
σ	0.0010	0.0010	0.0011	0.0012	0.0012	0.0013

By using the values of the means and standard deviations of the samples, presented in Table 3, one can find the parameter deviation functions, by means of regression analysis [8, 11]. The correlation coefficients for linear variation of the parameters are $r_{m\text{-}l}$ = 0.9493 and $r_{\sigma\text{-}l}$ = 0.9710 and the correlation coefficients for exponential variation of the parameters are $r_{m\text{-}exp}$ = 0.8130 and $r_{\sigma\text{-}exp}$ = 0.9703; these values indicate a linear variation for both parameters, according to the equations:

$$m = -0.0005 + 0.0002 \cdot t \quad (5)$$

$$\sigma = 0.0009 + 0.00001 \cdot t \quad (6)$$

The calibration life, for the considered case, is calculated by means of parameter deviation functions (5) and (6), according to the method described in [2]. The value which is obtained for the calibration time is t_r = 24.4034 time units (months), value which is almost equal to the pre-set calibration time for micrometers which is set to a two years (24 months) in the standards [7].

4. Estimating the Calibration Life of the Caliper Rules

The experimental study conducted is aimed on the estimation of the calibration life of external caliper rules of 150 mm, with depth rod, with a resolution of 0.1 mm. The experimental data is represented by the measuring errors, obtained by measuring the same nominal size with a set of caliper rules and is grouped in samples produced monthly. For the nominal size measured, the tolerance interval is $T_ε$ = 0.16 mm, while the other values are the following: α = 0.05, n = 17, k = 6, ti = 0 and dt = 1.

Table 4 presents the samples produced by measuring the same nominal size with the set of caliper rules considered.

Table 4. Measuring errors obtained by using the set of caliper rules

Sample	Measuring errors
1	0 0 0 0.01 0 -0.01 -0.02 0 0.01 -0.01 -0.01 0.01 0 -0.01 0 0.01 -0.02
2	0 0 -0.01 0 0 0.01 0 -0.01 -0.02 0 0.01 0.01 -0.01 0 0.01 -0.02 0.01
3	0 0.01 -0.01 0 0.01 0.01 0 -0.01 -0.02 0 0.01 0.01 -0.01 0 0.01 -0.02 0.01
4	-0.02 0.01 0.02 0 0.02 0 0.01 -0.02 0 0 0.01 0.01 0 -0.01 0 0 0.01
5	-0.02 0.01 0.02 0 0.02 0 0.01 -0.02 0 0 0.01 0.01 0 -0.01 0 0.01 0.01
6	-0.02 0.01 0.02 0 0.02 0 0.01 -0.02 0 0 0.01 0.02 0 -0.01 0 0.01 0.01

Table 5 presents the values of the statistics of both Kolmogorov-Smirnov and Lilliefors goodness-of-fit tests for each sample. These values are according to both conditions: $d_j \le d_{n,\alpha}$ = 0.318, for Kolmogorov-Smirnov goodness-of-fit test and respectively $L_j \le L_{n,\alpha}$ = 0.206 for Lilliefors goodness-of-fit and this indicates normal distributions [10, 11].

Table 5. Values of the statistics of the Goodness-of-fit Tests

Sample	1	2	3	4	5	6
d_j	Kolmogorov-Smirnov Goodness-of-fit Tests					
	0.2429	0.2531	0.2389	0.2423	0.2235	0.2099
L_j	Lilliefors Goodness-of-fit Tests					
	0.1841	0.1942	0.1801	0.1835	0.1646	0.1510

The values of the estimated parameters m and σ for each sample are given in Table 6.

Table 6. Values of the estimated parameters of the samples

	Sample					
	1	2	3	4	5	6
m	-0.0024	-0.0012	0	0.0024	0.0029	0.0035
σ	0.0094	0.0096	0.0103	0.0111	0.0113	0.0119

By using the values of the means and standard deviations of the samples, presented in Table 3, one can find the parameter deviation functions, by means of regression analysis [8, 11]. The correlation coefficients for linear variation of the parameters are $r_{m\text{-l}}$ = 0.9791 and $r_{\sigma\text{-l}}$ = 0.9875 and the correlation coefficients for exponential variation of the parameters are $r_{m\text{-exp}}$ = 0.4044 and $r_{\sigma\text{-exp}}$ = 0.9866; these values indicate a linear variation for both parameters, according to the equations:

$$m = -0.0036 + 0.0013 \cdot t \quad (7)$$

$$\sigma = 0.0088 + 0.0005 \cdot t \quad (8)$$

The calibration life, for the considered case, is calculated by means of parameter deviation functions (7) and (8), according to the method described in [2]. The value which is obtained for the calibration time is t_r = 30.8273 time units (months), value which exceeds the pre-set calibration time for caliper rules which is set to a two years (24 months) in the standards [7].

5. Conclusions

The conclusion which can be drawn from the research performed on the considered sets of measuring instruments is that the method for determining the calibration life based on parameter deviation can be used for establishing the right moment for performing the calibration for a specific set of measuring devices.

The paper points out the fact that the calibration life of the measuring devices can be calculated by means of the parameter deviation functions. By performing the appropriate program in the case of a set of specific measuring devices, it is possible to test whether the values estimated for the calibration life for each case considered meet the requirements set in the appropriate standards.

The method for calculation of the calibration life can be used in the analysis of the metrological reliability, for the determination of the calibration life of the measuring devices, in order to meet the requirements of the quality assurance in metrology. The method is intended to be applied to other types of metrological devices.

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