STUDY ON THE CALIBRATION LIFE OF THE MEASURING DEVICES

Ramona CLINCIU[1]

ABSTRACT: The present paper presents the results obtained by performing experimental studies on specific measuring devices - caliper rules. The study is aimed at the estimation of the calibration life of the measuring devices as a function of the metrological reliability. Parameter deviation is emphasised as a very useful research tool for the estimation of the metrological reliability and for the estimation of the calibration life of the set of the caliper rules considered and in consequence, as an important instrument for the quality assurance in metrology.
KEY WORDS: caliper rules, parameter deviation, metrological reliability.

1 INTRODUCTION

A measuring device is characterized by a specific tolerance interval. The measurement errors are included in 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 are difficult to discover 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 (Wiener & Veres, 1972).

Parameter deviation represents a very useful research tool 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 (Clinciu & Popescu, 1996), (Clinciu, 2000), (Wiener & Veres, 1972).

[1] Universitatea Transilvania din Brasov, Facultatea de Inginerie Tehnologica si Management Industrial, Bd. Eroilor 29, 50036 Brasov, România

E-mail: r.clinciu@unitbv.ro

The objective of the experimental research performed and described by the present paper is represented by the estimation of the calibration life of specific measuring devices, caliper rules. The experimental study conducted on these caliper rules involves the processing of the measuring errors, obtained by measuring the same nominal size with a set of caliper rules, errors grouped in samples produced monthly. Two different nominal sizes were considered and they were measured monthly with the same set of caliper rules. The calibration life of the set of caliper rules was estimated as a function of the metrological reliability, due to the internal parameter deviation, for both nominal sizes considered in the experiment.

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 (Vodă, 1979).

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 time.

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 related 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:

$$m = m_0 + a \cdot t, \quad (1)$$

$$\sigma = \sigma_0 + b \cdot t, \quad (2)$$

$$m = m_0 \cdot \exp(a \cdot t), \quad (3)$$

$$\sigma = \sigma_0 \cdot \exp(b \cdot t). \quad (4)$$

The algorithm for estimation of the calibration life of the measuring devices as a function of the metrological reliability includes the following steps (Clinciu & Popescu, 1996), (Clinciu, 2000):

- Data collection; the experimental data is collected from field operation;

- Data outlier tests- Grubbs test (Martinescu & Popescu, 1995);

- Graphical representation and distribution assumption - normal distribution, as it is used by general metrology;

- Parameter estimation for the chosen distribution - normal distribution (Martinescu & Popescu, 1995);

- 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 (Craiu et al., 1988), (Kececioglu, 1991), (Vodă, 1979). 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 (Craiu et al., 1988).

- Determination of the parameter deviation functions, by means of regression analysis method (m'_0, a', σ'_0, b'- the estimated coefficients of the parameter deviation function) and determination of the correlation coefficients for both the linear variation ($r_{m\text{-}l}$, $r_{\sigma\text{-}l}$) and for the exponential variation ($r_{m\text{-}exp}$, $r_{\sigma\text{-}exp}$) (Kececioglu, 1991), (Martinescu & Popescu, 1995).

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);

- Determination of the calibration life, by means of parameter deviation functions, according to the method described in (Clinciu & Popescu, 1996), (Clinciu, 1999), (Clinciu, 2000).

The pre-set calibration time for caliper rules is set to a year, as stated in the appropriate standards (NTM, 1979).

3 ESTIMATION OF THE STATISTICAL PARAMETERS FOR DATA SAMPLES

3.1 Case I – first nominal size

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 first nominal size measured, the tolerance interval is T_ε = 0.16 mm, while the other values are the following: α = 0.05, n = 16, k = 6, ti = 0 and dt = 1.

Table 1 presents the samples produced by measuring the first nominal size considered with the set of caliper rules.

Table 1. Measuring errors-first nominal size

Sample	Measuring errors – First nominal size
1	0 0 0 0.01 0 -0.01 -0.02 0 0.01 -0.01 -0.01 0 0 -0.01 0 -0.01
2	0 -0.01 0 0 0.01 0 -0.01 -0.02 0 0.01 0.01 -0.01 0 0 0 0
3	-0.02 -0.01 0 0.01 0 0 -0.01 0.01 0.01 0 0 0.01 0.01 0 0.01 0
4	-0.02 -0.01 0 0.01 0 0 -0.01 0.01 0.01 0 0 0.01 0.01 0 0.01 0
5	0 0.01 0 0 -0.02 -0.01 0.01 0 -0.01 0 0.01 0 0.02 0 0.01 0.01
6	-0.02 0.01 0.02 0 0.02 0 0.01 -0.02 0 0 0.01 0.01 0 -0.01 0 0.01

For each sample considered, there will be constructed the appropriate histogram. Also, one will calculate the values of the mean and standard deviation for each sample and then, the values of the statistics of the Kolmogorov-Smirnov and Lilliefors goodness-of-fit tests for each sample, values which will be compared to the appropriate critical values of the tests.

The appropriate histograms for the samples obtained are presented in Figures 1…6.

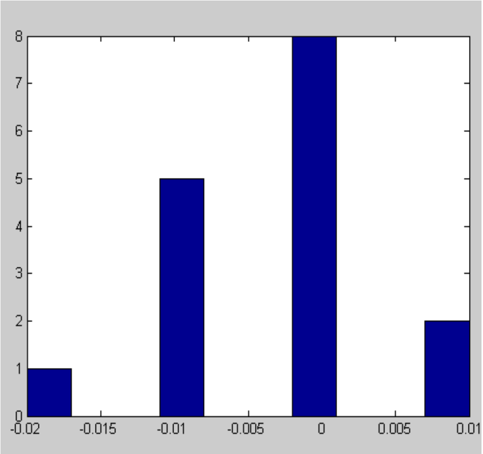

Figure 1. Histogram for Sample 1

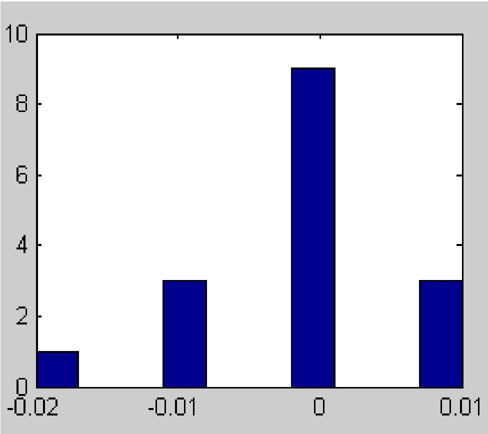

Figure 2. Histogram for Sample 2

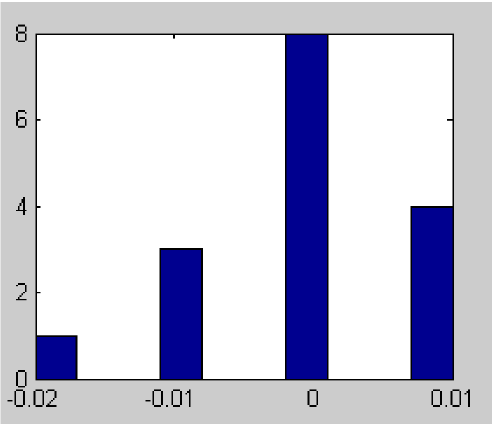

Figure 3. Histogram for Sample 3

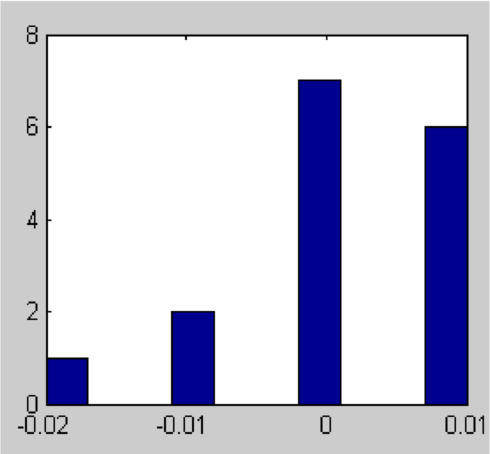

Figure 4. Histogram for Sample 4

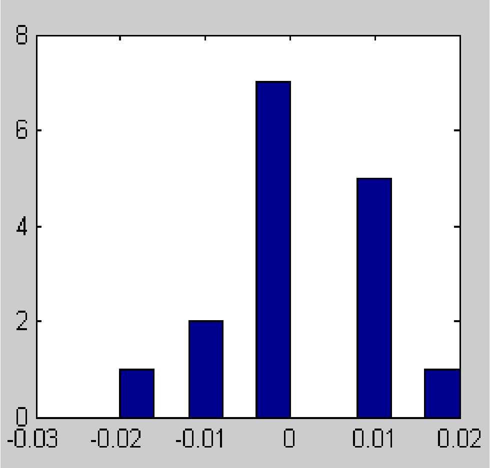

Figure 5. Histogram for Sample 5

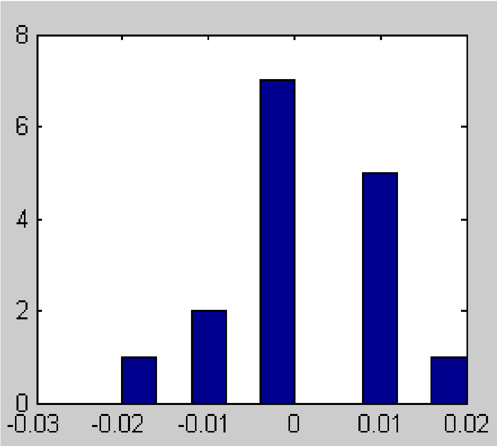

Figure 6. Histogram for Sample 6

Table 2 presents the values of the estimated parameters for the considered samples, obtained by measuring the first nominal size.

By using the values of the means and standard deviations of the samples considered, it is possible to obtain the parameter deviation functions.

Table 2. Estimated parameters – first nominal size

Sample	Estimated parameters – first nominal size	
	m	σ
1	-0.0019	0.0077
2	-0.0012	0.0078
3	-0.0006	0.0083
4	0.0013	0.0086
5	0.0019	0.0095
6	0.0025	0.0115

Table 3 presents the the values of the statistics of the Kolmogorov-Smirnov and Lilliefors goodness-of-fit tests for each sample; they are compared to the appropriate critical values of the tests.

Table 3. Goodness-of-fit Tests – first nominal size

Sample (j)	Kolmogorov-Smirnov Test	Lilliefors goodness-of-fit tests
	$d_j \leq d_{n,\alpha} = 0.328 \Rightarrow$ normal distribution	$L_j \leq L_{n,\alpha} = 0.213 \Rightarrow$ normal distribution
1	0. 2782	0. 2218
2	0. 3116	0. 2509
3	0. 2833	0. 2208
4	0. 2563	0. 1938
5	0. 2367	0. 2008
6	0. 2288	0. 1663

Parameter deviation functions are obtained by means of regression analysis (Martinescu & Popescu, 1995).

The correlation coefficients calculated for the linear variation of the parameters are $r_{m\text{-}l} = 0.9793$ and $r_{\sigma\text{-}l} = 0.9123$ and for the exponential variation of the parameters are $r_{m\text{-}exp} = 0.9777$ and $r_{\sigma\text{-}exp} = 0.7994$.

The values of the correlation coefficients indicate a linear variation of the parameters, according to the following equations:

$$m = -0.0027 + 0.0009 \cdot t, \quad (5)$$

$$\sigma = 0.0065 + 0.0007 \cdot t. \quad (6)$$

The calibration life, for the considered case is calculated by means of parameter deviation functions (5) and (6), according to the method described in (Clinciu & Popescu, 1996), (Clinciu, 2000). The value which is obtained for the calibration time is $t_r = 33.6586$ time units/months, value which exceeds the pre-set calibration time for caliper rules which is set to a year (12 months), as stated in the appropriate standards (NTM, 1979).

3.2 Case II – second nominal size

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.

In the second case considered, the experimental data is represented by the measuring errors obtained by measuring a second nominal size with a set of caliper rules of 150 mm, with depth rod and with a resolution of 0.1 mm, data being grouped in samples produced monthly. For the second nominal size measured, the tolerance interval is $T_\varepsilon = 0.14$ mm and the other values are the following: $\alpha = 0.05$, n = 16, k = 6, ti = 0 and dt = 1.

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

Table 4. Measuring errors-second nominal size

Sample	Measuring errors – second nominal size
1’	0 0 0 0.01 0 0 -0.01 0 0.02 -0.01 -0.01 0 0 -0.01 0 -0.01
2’	0 -0.01 0 0 0.01 0 -0.01 -0.02 0.01 0.01 -0.01 0.01 0 0 0 0
3’	0.01 0.01 0 -0.01 0.01 0 -0.01 0.01 -0.02 0.01 0 0.01 0 0 0 0
4’	-0.01 0.01 0 -0.01 0.01 0 0.01 0.01 -0.01 0.02 0 0.01 0 0 -0.01 0
5’	-0.01 0.01 0.01 -0.01 0.01 0 0.01 0.01 -0.01 0.02 0 0.01 0 0 -0.01 0
6’	-0.02 0.01 0 0 0.01 0 0.01 0.02 0.01 0.02 -0.01 0.01 0 0 0 0

The appropriate histograms for the samples obtained are presented in Figures 7…12.

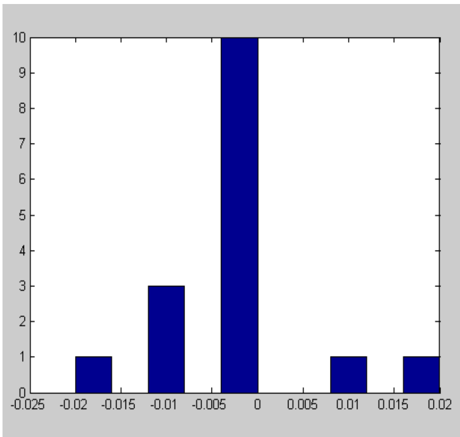

Figure 7. Histogram for Sample 1’

Table 5 presents the values of the estimated parameters for the considered samples, obtained by measuring the second nominal size.

Table 6 presents the the values of the statistics of the Kolmogorov-Smirnov and Lilliefors goodness-of-fit tests for each sample; they are compared to the appropriate critical values of the tests.

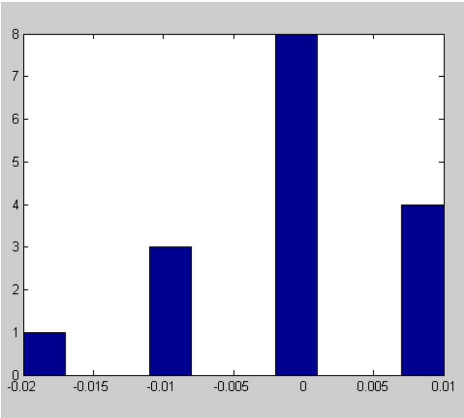

Figure 8. Histogram for Sample 2'

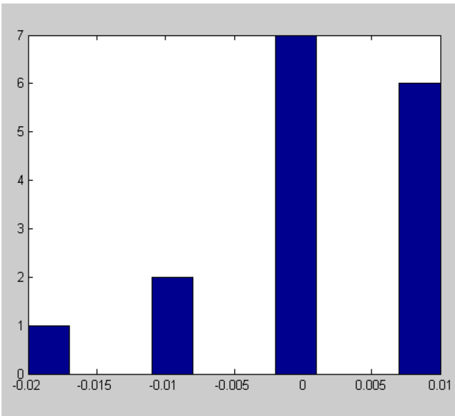

Figure 9. Histogram for Sample 3'

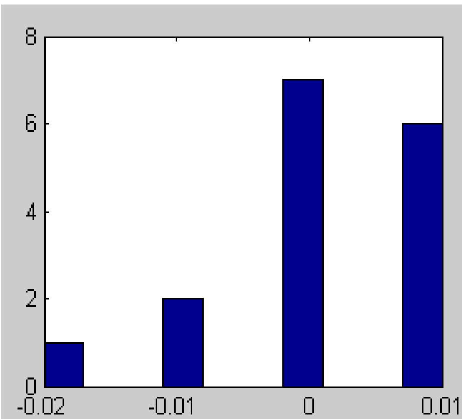

Figure 10. Histogram for Sample 4'

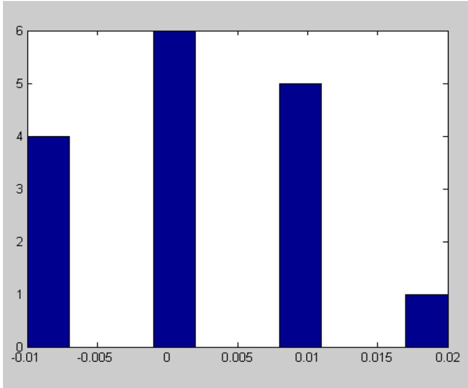

Figure 11. Histogram for Sample 5'

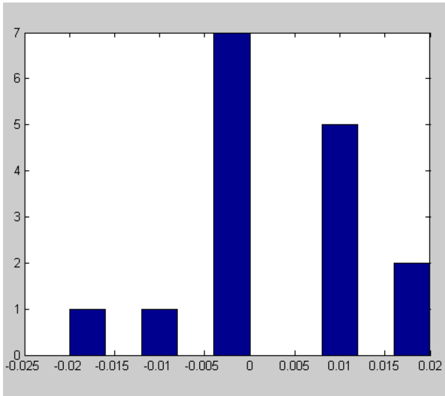

Figure 12. Histogram for Sample 6'

Table 5. Estimated parameters – second nominal size

Sample	Estimated parameters – second nominal size	
	m	σ
1	-0.0013	0.0078
2	-0.0006	0.0083
3	-0.0013	0.0086
4	0.0019	0.0088
5	0.0025	0.0090
6	0.0037	0.0099

By using the values of the means and standard deviations of the samples considered, it is possible to obtain the parameter deviation functions. Parameter deviation functions are obtained by means of regression analysis (Martinescu & Popescu, 1995).

The correlation coefficients calculated for the linear variation of the parameters are $r_{m\text{-}l} = 0.9855$ and $r_{\sigma\text{-}l} = 0.9650$ and for the exponential variation of the parameters are $r_{m\text{-}exp} = 0.9687$ and $r_{\sigma\text{-}exp} = 0.9217$. The values of the correlation coefficients indicate a linear variation of the parameters, according to the following equations:

$$m = -0.0022 + 0.0010 \cdot t, \quad (7)$$

$$\sigma = 0.0075 + 0.0004 \cdot t. \quad (8)$$

Table 6. Goodness-of-fit Tests – second nominal size

Sample (j)	Kolmogorov-Smirnov Test	Lilliefors goodness-of-fit tests
	$d_j \leq d_{n,\alpha} = 0.328$ $\Rightarrow$ normal distribution	$L_j \leq L_{n,\alpha} = 0.213$ $\Rightarrow$ normal distribution
1	0.3134	0.3134
2	0.2792	0.2208
3	0.2563	0.1938
4	0.2066	0.2066
5	0.2273	0.1684
6	0.2322	0.2053

The calibration life for the case presented above is calculated by means of parameter deviation functions (7) and (8), according to the method described in (Clinciu & Popescu, 1996), (Clinciu, 2000). The value which is obtained for the calibration time is t_r = 36.1154 time units/months, value which exceeds the pre-set calibration time for caliper rules which is set to a year (12 months), as stated in the appropriate standards (NTM, 1979).

One can notice that the values obtained for the calibration life, for the considered set of caliper rules, in both cases, are very close. The value obtained by measuring the first nominal size is t_r = 33.6586 time units/months and for the second nominal size is t_r = 36.1154 time units/months, values which are greater than the preset calibration time.

4 CONCLUDING REMARKS

An important conclusion drawn from the research performed on the considered set of caliper rules is that the method for determining the calibration life based on parameter deviation can be used for determining the right moment for performing the calibration for a specific set of measuring devices.

The paper emphasizes 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 obtained for the calibration life t_r in 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 estimation of the calibration life of the measuring devices. This method is intended to be applied to other types of metrological devices, in order to estimate the calibration life and to compare it with the standards prescriptions.

5 REFERENCES

►Clinciu, R., Popescu, I.(1996). *Parameter Deviation-A Research Tool for the Analysis of the Metrological Reliability.* Bulletin of the Satellite Conference of ECM'96 - Symmetry and Antisymmetry in Mathematics, Formal Languages and Computer Science, Braşov, p. 31-34.

►Clinciu, R.(2000). *Algorithm for Simulation of the Parameter Deviation.* Bulletin of the Transilvania University of Braşov, vol. 7(42) – New Series, Series A, p. 65-68.

►Clinciu, R.(1999). *Studiu privind determinarea perioadei de verificare/calibrare a mijloacelor de măsurare pe baza derivei parametrilor interni.* Buletinul Conferinţei internaţionale TMCR'99, Chişinău, Republica Moldova, p. 259-262.

►Craiu, V., Enache, R., Bâscă, O.(1988). *Teste de concordanţă cu programe în FORTRAN*, Ed. ştiinţifică şi enciclopedică, Bucureşti.

►Kececioglu, D.(1991). *Reliability Engineering Handbook.* Dpt. of Aerospace and Mechanical Engineering, The University of Arizona, Prentice Hall, Englewood Cliffs, N.J.

►Martinescu, I., Popescu, I. (1995). *Fiabilitate*. Ed. Gryphon. ISBN 973-604-007-0, Brasov.

►Vodă, V. Gh.(1979). *Metode de verificare a normalităţii datelor de măsurare*. Metrologia aplicată, vol. XXVI, nr.1, p. 11-14, Bucureşti.

►Wiener, U., Vereş, F. (1972). *Cu privire la fiabilitatea metrologică. Modele şi metode.* Calitatea produselor şi metrologie 5/1972, p. 265-271, Bucureşti.

►NTM 0-1-79. (1979). *Lista oficială a principalelor mijloace de măsurare supuse obligatoriu etalonării sau verificării metrologice. Termene şi tarife*. Ed. Tehnica, Bucuresti.

6 NOTATION

The following symbols are used in this paper:

m - the mean;

σ - the standard deviation;

d_j - the value of the statistics of the Kolmogorov-Smirnov goodness-of-fit test;

$d_{n,\alpha}$ - the critical 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;

$L_{n,\alpha}$ - the critical value of the statistics of the Lilliefors goodness-of-fit test;

T_ε - the tolerance interval for variable ε;

ε - the measurement error;

t_r - the calibration time.