IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Study on the metrological reliability of the water meters

To cite this article: R Clinciu and M R Clinciu 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **399** 012009

Study on the metrological reliability of the water meters

R Clinciu[1*] **and M R Clinciu**[1]

[1] Department of Manufacturing Engineering, Transilvania University of Brasov, Romania

[*] E-mail: r.clinciu@unitbv.ro

Abstract. The paper presents the results of an experimental study conducted on specific measuring devices - water meters of a certain precision class. The aims of the study are to determine the calibration life of the measuring devices as a function of the metrological reliability and, at the same time, to emphasize the parameter deviation as an important research tool for the quality assurance in metrology. This experimental research may be added to former researches performed on different types of measuring devices. Parameter deviation represents an important research tool for the estimation of the calibration life of the measuring devices. It helps to predict the moment in time when the probability density function for the measurement errors exceeds the tolerance interval by a certain percentage, corresponding to the established level of significance. This moment corresponds to the stage in which the considered measuring device needs to be checked and, if necessary, calibrated. The experimental study conducted is aimed at determining the calibration life of water meters of the same type and of a certain precision class. The research performed on the considered water meters aims to establish which the appropriate moment for performing the calibration is for a specific set of measuring devices, moment which can be estimated by using the parameter deviation functions, these being obtained by means of regression analysis.

1. Introduction

A measuring device is characterized by a specific tolerance interval. In case the measuring device is correctly adjusted, the measurement errors are placed inside the tolerance interval. In time, by using the measuring device, the measurement errors might start to grow such as, at a certain moment, to exceed the tolerance interval. If the probability density function (pdf) for the measurement errors exceeds the tolerance interval by a certain percentage, it is considered that a metrological disturbance has appeared [1]. Metrological disturbances are difficult to discover at the moment they are produced, they can be discovered only during the periodic checking of the measuring device or at encountering the negative consequences of the use of such a measuring device, so that it becomes very important to predict, with a certain precision, the moment when the measuring device starts to measure with greater errors than the tolerated ones [1]. At present, since the quality of any process depends on the measurement information, a remarkable interest is given to the metrological reliability [2, 3].

Parameter deviation represents an important research tool for the estimation of the calibration life of the measuring devices. It helps to predict the moment in time when the probability density function for the measurement errors exceeds the tolerance interval by a certain percentage, corresponding to the established level of significance. This moment corresponds to the stage in which the considered measuring device needs to be checked and, if necessary, calibrated [1, 4]. This experimental research may be added to former researches performed on different types of measuring devices [5-8].

The paper presents the results obtained by performing an experimental study on specific measuring devices - water meters of precision class B, a medium precision for the water meters. The experimental data is obtained in laboratory conditions and it is represented by the measuring errors obtained by measuring the same volume of water by a single person; experimental data is grouped into samples produced at a certain interval of time.

An appropriate algorithm, based on the parameter deviation functions, is used for estimating the calibration life of the water meters considered. The estimated calibration life, obtained as a function of the metrological reliability, is then compared to the requirements set in the appropriate standards, such as to enable the conclusions towards the use of the water meters analysed, from the calibration life point of view.

2. Algorithm for estimating the calibration life of water meters

General metrology uses especially the normal distribution, although positive and asymmetrical distributions, such as Weibull distribution, are frequently met in the analysis of the metrological reliability [9].

2.1. Notations used in the algorithm

The algorithm developed for the estimation of the calibration life of the measuring devices uses the following notations: 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 period of time at which samples are collected (it is considered that dt is constant); t_r - the calibration time [4-6].

The case of a normal distribution N(m_0 , σ_0 , t) is considered. In time, due to the internal parameter deviation, the parameters of the distribution become m and σ and the normal 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:

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

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

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

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

2.2. Presentation of the algorithm

The algorithm for estimating the calibration life of the measuring devices as a function of metrological reliability includes the following steps [4]:

- collecting experimental data, represented by measurement errors;
- performing data outlier tests- Grubbs test [10];
- graphical representation (probability plot), distribution assumption – normal distribution [10, 11];
- parameter estimation for the normal distribution [10];
- goodness-of-fit tests; it is considered a general goodness-of-fit test -Kolmogorov-Smirnov and a normality goodness-of-fit test -Lilliefors. The optimum distribution is chosen by comparing the values obtained for the statistics of the tests considered with the critical values of the tests: d_j - the value of the statistics of the Kolmogorov-Smirnov goodness-of-fit test is to be compared to $d_{n,\alpha}$ - 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 is to be compared to $L_{n,\alpha}$ - the critical value of the statistics of the Lilliefors goodness-of-fit test [9-11];

- parameter deviation functions are determined by using regression analysis and the correlation coefficients for the linear variation, as well as for the exponential variation [10, 11]; the type of the parameter deviation function, linear or exponential, for parameters m and σ, is indicated by the highest value of the two calculated correlation coefficients for each parameter;
- determining the calibration life, by using the parameter deviation functions and the method described in [4]. The period for the metrological control of water meters is set to seven years, as stated in standards [12].

3. Experimental study

The experimental study is conducted on water meters of the same type, of precision class B, a medium precision for the water meters, connected in series arrangement, to a water source. The water meters considered are of a different type than those considered in a former study [8]. At the time the experimental study was conducted, all water meters were in their specified working period, they had been used in the installations in the apartments in a block of flats, for a specific period of time, 36 months, and were still in their working period according to the standards prescriptions [12].

The considered level of significance is $\alpha = 0.05$, the volume of a sample is $n = 18$, the number of samples $k = 6$, initial moment $ti = 0$ and the interval between the moments at which samples are collected $dt = 1$.

The experimental data, x_{ji}, is represented by the measuring errors, obtained by measuring a certain volume of water, 0.01 m^3, the measuring errors being obtained as the difference between the indications of each water meter used and the true value of the volume of water (0.01 m^3). Data is grouped in six samples produced at a certain period of time (one month), by measuring the same volume of water with the group of water meters, in laboratory conditions. Table 1 presents the measuring errors x_{ji}, obtained by measuring the same volume of water with the water meters considered; they are all located within the appropriate tolerance interval $T_\varepsilon = 0.0004$ m^3. The tolerated maximum measuring errors are ±2% for cold water (if water temperature <= 30°C) [12], such as for the considered case, the tolerance interval is $T_\varepsilon = 0.0004$ m^3.

Table 1. Measuring errors.

Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
-0.00007	0.00007	0.00005	0.00007	0.00017	0.00017
-0.00011	-0.00011	-0.00010	-0.00010	0.00011	0.00011
-0.00006	-0.00006	-0.00006	-0.00006	-0.00006	-0.00006
-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002
-0.00011	-0.00011	-0.00011	-0.00011	-0.00011	-0.00011
-0.00004	-0.00004	-0.00004	-0.00004	0.00004	0.00004
-0.00016	-0.00016	0.00016	0.00016	0.00019	0.00019
0.00008	0.00008	0.00008	0.00008	0.00008	0.00008
-0.00001	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001
-0.00011	-0.00011	-0.00011	-0.00011	0.00011	0.00011
-0.00002	-0.00002	0.00002	0.00002	-0.00002	-0.00002
0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
-0.00007	-0.00007	0.00007	0.00007	-0.00007	-0.00007
-0.00012	-0.00012	0.00012	0.00012	-0.00012	-0.00012
-0.00003	-0.00003	0.00003	0.00003	-0.00003	-0.00004
-0.00002	-0.00002	0.00002	0.00002	0.00002	-0.00002
0.00002	0.00002	0.00002	0.00002	0.00002	0.00003
0.00001	0.00001	-0.00001	0.00001	0.00002	0.00012

The results of the application of the data outlier test, the Grubbs test, are presented in figures 1 to 6. The conclusions of the applications of this test to the six samples considered are that there is no outlier at 5% level of significance in any of the samples considered.

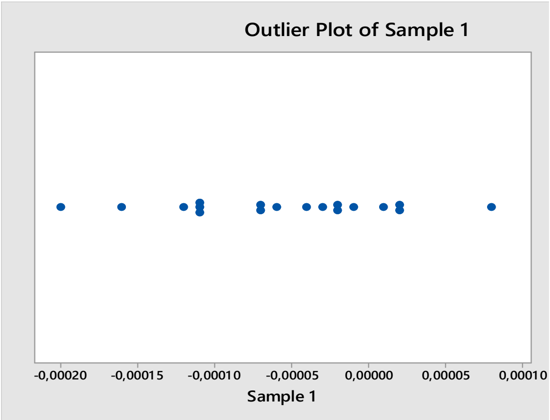

Figure 1. Outlier plot of sample 1.

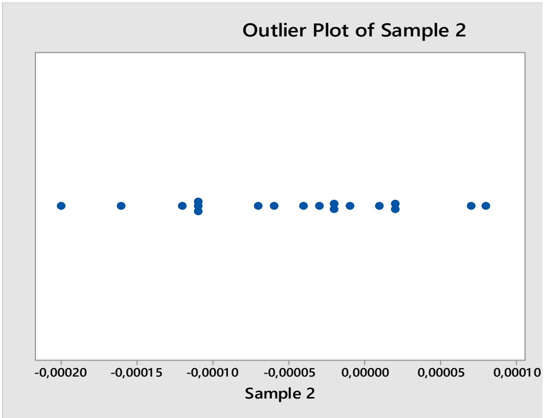

Figure 2. Outlier plot of sample 2.

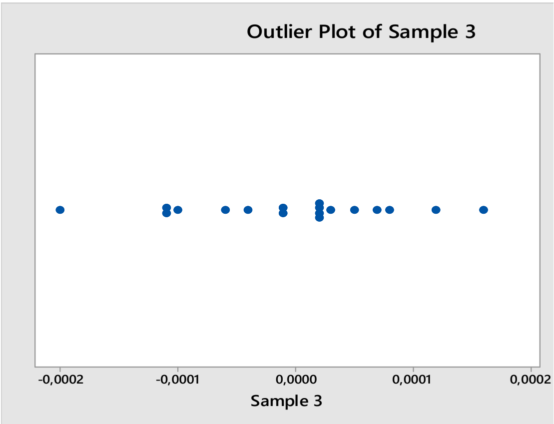

Figure 3. Outlier plot of sample 3.

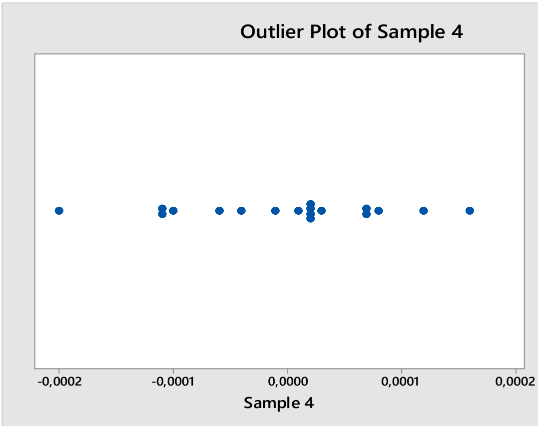

Figure 4. Outlier plot of sample 4.

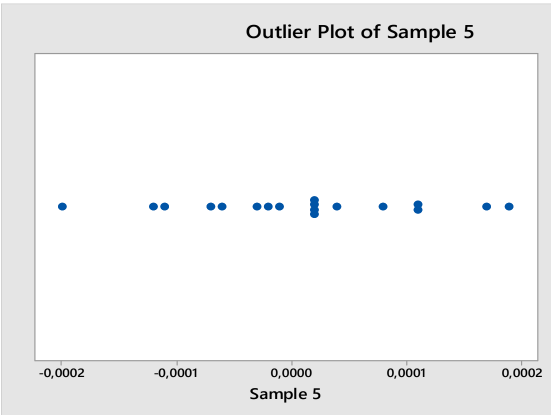

Figure 5. Outlier plot of sample 5.

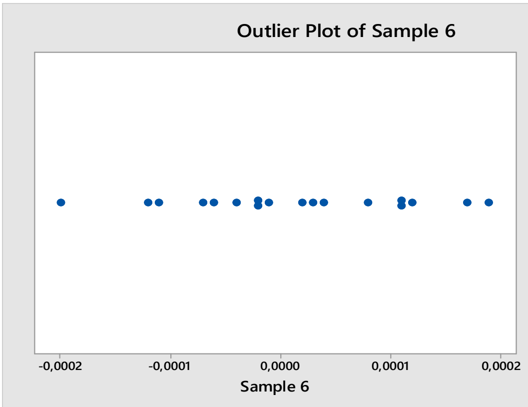

Figure 6. Outlier plot of sample 6.

IOP Conf. Series: Materials Science and Engineering **399** (2018) 012009 doi:10.1088/1757-899X/399/1/012009

The probability plots of the six samples considered are presented in figures 7 to 12. By analyzing the probability plots, one can assume that the appropriate distribution is the normal distribution and this is to be tested by using the goodness-of-fit tests.

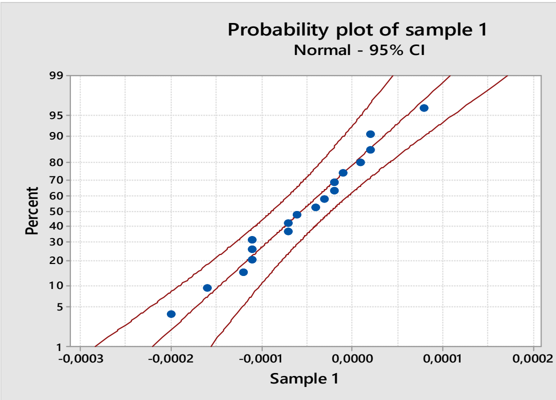

Figure 7. Probability plot of sample 1.

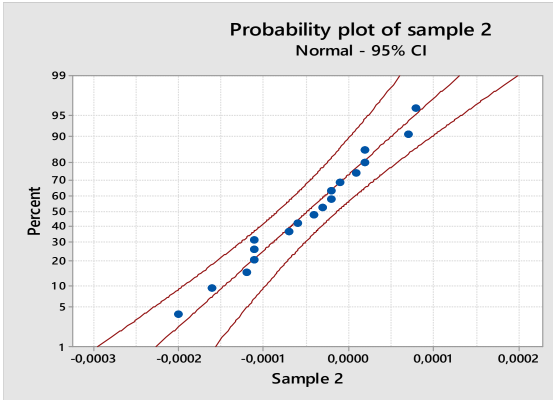

Figure 8. Probability plot of sample 2.

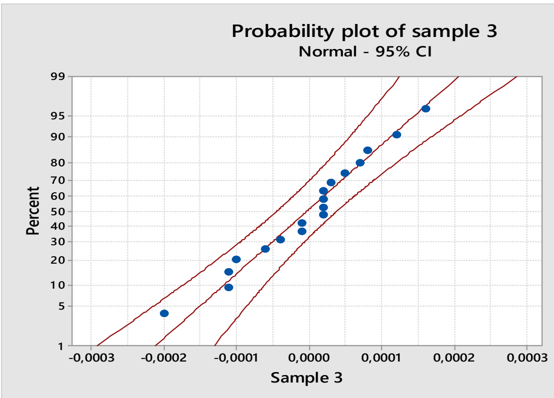

Figure 9. Probability plot of sample 3.

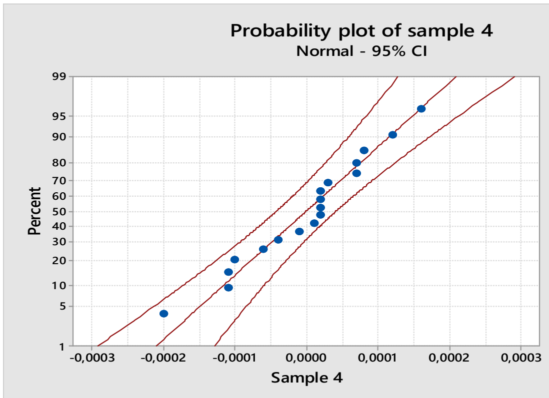

Figure 10. Probability plot of sample 4.

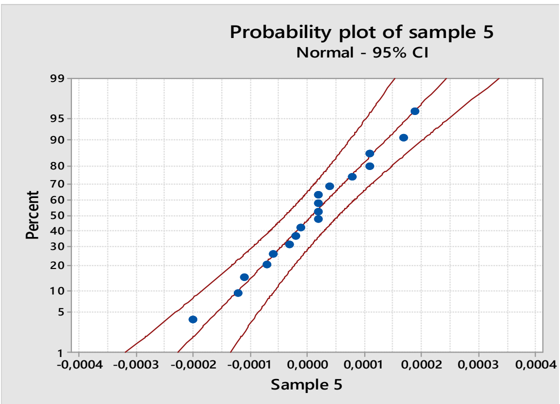

Figure 11. Probability plot of sample 5.

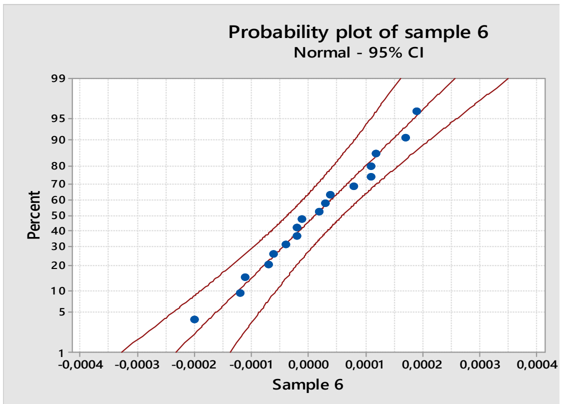

Figure 12. Probability plot of sample 6.

The critical value of the statistic of the Kolmogorov-Smirnov goodness-of-fit test for the considered sample size is $d_{n,\alpha} = 0.309$ and the critical value of the statistic of the Lilliefors goodness-of-fit test for the considered sample size is $L_{n,\alpha} = 0.200$ [9-11].

Table 2 presents the values obtained for the statistics of both Kolmogorov-Smirnov and Lilliefors goodness-of-fit tests, for each sample. These values are according to both conditions: $d_j \leq d_{n,\alpha} = 0.309$, for Kolmogorov-Smirnov goodness-of-fit test and respectively $L_j \leq L_{n,\alpha} = 0.200$ for Lilliefors goodness-of-fit and this indicates normal distributions [9-11].

Table 2. Values of the statistics of the goodness-of-fit tests.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
d_j	0.1129	0.1255	0.1562	0.1577	0.1229	0.1017
L_j	0.1129	0.1255	0.1006	0.1021	0.1229	0.0837

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	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
m	-0.000056	-0.000048	-0.00003	-0.00001	0.00009	0.00012
σ	0.000068	0.000074	0.000087	0.000088	0.000098	0.000102

By using the values of the means and standard deviations of the samples, presented in table 3, one can obtain the parameter deviation functions, by means of regression analysis [10, 11]. The correlation coefficients for linear variation of the parameters are $r_{m\text{-}l} = 0.9350$ and $r_{\sigma\text{-}l} = 0.9831$ and the correlation coefficients for exponential variation of the parameters are $r_{m\text{-}exp} = 0.8184$ and $r_{\sigma\text{-}exp} = 0.9774$; these values indicate a linear variation for both parameters, m and σ, according to the equations presented below:

$$m = -0.00012+0.000038 \cdot t. \quad (5)$$

$$\sigma = 0.000062+0.000007 \cdot t. \quad (6)$$

The calibration life for the considered case is calculated by means of parameter deviation functions presented in equations (5) and (6), according to the method described in [4]. The value which is obtained for the calibration time for the case considered is $t_r = 38.768$ time units (months), value which is less than the remaining period for the use of the water meters (water meters had been used for 36 months before the experiment), according to the pre-set period for the metrological control of the water meters, which is set to 7 years/84 months in the appropriate standards [12].

The estimated calibration life in this case is close to the pre-set period for the metrological control of the water meters, which proves the fact that the type of water meters analysed in this research is better than other types analysed [8]. Still, the estimated calibration life is less than the remaining period for the use of the water meters, till the pre-set period for the metrological control. This means that the use of the respective water meters, more than the period indicated by the value t_r, might produce errors in metering.

4. Conclusions

The method for determining the calibration life based on parameter deviation functions can be used for estimating the right moment for performing the metrological control/calibration for a specific set of measuring devices. This moment might be later than the pre-set one, and in this case financial costs with the metrological control are diminished, or earlier than the pre-set calibration time, and in this case greater errors than the tolerated ones are prevented. As further work, it is necessary to perform a study on the metrological reliability of different types of water meters which are being used at present such as to provide information on the calibration life of the types of water meters considered.

By estimating the calibration life of the measuring devices as a function of metrological reliability, based on parameter deviation functions, it might be possible to test whether, for a certain type of measuring devices, the values obtained for the calibration life t_r are according to the requirements set in the appropriate standards. As future research, it is intended to consider other types of metrological devices, to test whether the values obtained for the calibration life meet the requirements set in the appropriate standards.

References

[1] Wiener U and Veres F 1972 *Qual. Prod. Metr. J.* **5** 265
[2] Toteva P, Slavov S and Vasileva D 2017 *Matec Web Conf.* **94** 04012
[3] Arregui F J, Pardo M A, Parra J C and Soriano J 2007 *IWA Water Loss Conf.* Sept 2007 Bucharest
[4] Clinciu R 2000 *Bulletin.of Transilvania Univ. of Brașov* **7(42)** 65
[5] Clinciu R 2013 *Applied Mech. Mat.* **371** 695
[6] Clinciu R 2014 *Applied Mech. Mat.* **657** 694
[7] Clinciu R 2014 *Academic J. of Manuf. Eng.* **12/1** 76
[8] Clinciu M R and Clinciu R 2017 *Matec Web Conf.* **94** 04003
[9] Vodă V G 1979 *Applied metrology* **XXVI(1)** 11
[10] Martinescu I and Popescu I 1995 *Reliability* (Brasov: Gryphon)
[11] Kececioglu D 1991 *Reliability Engineering Handbook* (N J: Prentice Hall, Englewood Cliffs)
[12] NML 003-05 2005 *Water meters* (Bucuresti: Monitorul Oficial al Romaniei)