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A. Tkachuk (ORCID 0000-0001-9085-7777) **T. Terlets'kyy V. Krasovsky**
Lutsk national technical university

STUDY OF APPOINTMENT CALIBRATION INTERVALS FOR THE WATER METER DEPENDING ON THEIR OPERATION

The article analyzes the recalibration interval appointment procedures for cold water meters КВ-1,5. It was found that generally in the appointment of this period are guided only by the results of bench tests, it means that this case does not take into account indicators of metrological reliability and the average operation time measuring means in the real world. Recommendations for further recalibration interval, based on the results of experimental studies and supported by appropriate calculations.

Keywords: *counter, error, testing, trouble-free operation, calibration interval.*

Formulation of the problem. Calibration interval is called a calendar period of time, after which the means of measurement need to send verification regardless of its technical condition [1]. Calibration interval for the measuring instruments in accordance with existing procedures adopted by the State Standard of Ukraine to the type approval of measuring the results of the tests, along with the results of the tests may be used as the recommendations contained in the specifications and technical documentation for this type of measurement tool (specifications, technical description and passport). If the calibration interval is intended only for the test results, in this case captured metrological reliability indices and average time of operation measuring tools in normal conditions. Today, in connection with the housing reform has increased dramatically the volume of production of water meters and the cost of the respective control operations (calibration), so quite sharply raises the question of the validity of the appointment of the current practice inter-verification interval for such meters.

Analysis of recent research. This problem is analyzed on the example of the appointment calibration period for cold water meter type КВ-1,5. It is known that these meters calibration interval is 3 years. Their passport is given the dependence of average relative error ∂ time of operation:

$$\partial=(1{,}80+0{,}17\cdot t)\%, \tag{1}$$

where t – operation in thousands of hours.

This limit is set equal to the maximum permissible error ±3,5%. If the error count is beyond these limits, it is removed from service. However, the application of the linear model, depending on the time of the error, the period of validity of the metrological device is from 1,5 to 2 years, which is consistent with the bad calibration intervals equal to 3 years. To the average time of the metrological refusal to agree with the value of calibration period, it is necessary that in equation (1) the rate of change of error ∂ value does not exceed 0,03 %÷thousand hours at a positive value and the initial error 0,1 %÷thousand hours - in the negative.

Formation of research objectives. These estimates are conditional, because according to (1) the unknown costs when employing water meters. Technical documentation is usually specified only approved expenses, which are water meters for КВ-1,5 orifice diameter of 15 mm should not exceed 0,375 m^3/h. A more correct for the right producer and user ratings calibration period is the use of error depending on the values of the measured meter of the water that passes through it, because in this case it is possible to consider modes of consumption at which the meter operates. Thus, the question arises as estimates and values given in equation (1), consistent with the criteria metrological reliability of measurement.

Presenting main material. At the same time, the use of these methods to assign calibration period requires statistical tests metrological characteristics of measuring instruments, and their treatment is associated with methodological and mathematical problems that are often not satisfied manufacturers of meters and employees of the metrological services. Currently one of the main normative documents regulating the procedure for establishing and adjusting the calibration period, GOST 8.565-99 is [2], which states that the materials developers of measuring instruments submitted for testing for type approval purposes often no reliable about their instability, that is to change the error for a specified length of time necessary for a reasonable purpose of initial calibration period. In these cases it is possible to use approximate estimates normalized values of reliability indicators specified in the technical documentation on the counter. On the basis of GOST developed a method [3], which are ways appointment calibration period based on the normalization of various indicators of reliability, in including the normalization of the probability of failure of means of measurements, the average time between the time metrological refusal, performance reliability components elements. Evaluation determining calibration period should be based on the methods of reliability theory, this approach is as follows:

- probability measuring means $P(t)$, ie the probability that during time t normalized metrological characteristics of error means go out on a regulated limits;
- failure rate $\lambda(t)$, he probability that the measuring device, having worked flawlessly during the time t refuse the next time interval Δt, is $\lambda(t)\cdot\Delta t$;
- uptime average time (time between metrological refusal) $T_м$.

These indicators are linked following equation:

$$P(t) = e^{-\int_0^t \lambda(t)dt'}, \tag{2}$$

with:

$$\lambda(t) = -\frac{1}{P(t)} \cdot \frac{dP(t)}{dt}, \tag{3}$$

$$T_м = \int_0^\infty P(t)dt. \tag{4}$$

Metrological failure can be gradual and sudden, while phasing associated with wear and tear, aging elements measuring tool in the gradual release of error the permissible limits, while rejection is caused by a sudden accidental error or failure of any which means measuring element. The peculiarity of sudden failures have sustainability over time their intensity:

$$\lambda(t) = \lambda = const. \tag{5}$$

If the phase-out rate of change of error is not enough, we can assume that the condition (5) holds for these failures with high accuracy. In this case, between the failure rate λ and best practices on metrological refusal $T_м$ exists following link:

$$\lambda = \frac{1}{T_м}. \tag{6}$$

Substituting permissible value of the probability $P(t)$ obtained the results of tests for the duration of the calibration period τ_{ci} with (6) takes the form:

$$\tau_{ci} = T_м \cdot \ell n P(t). \tag{7}$$

Since the counter almost never work continuously, then (7) should be adjusted using a coefficient k_1, equal to the ratio that the duration of use of means of measurement in hours for the duration of one year (8760 h). Given this formula for assessing the maximum duration T_{ci} calibration period takes the form:

$$T_{ci} = T_P \cdot \ln P(t), \tag{8}$$

where working means of measurement in measurement mode is defined as T_p,

$$T_p = \frac{T_м}{k}. \tag{9}$$

From formulas (8) and (9) shows that the definition of calibration period at a given probability of failure-free operation is primarily determined by parameters such as time between metrology and refuse to use the coefficient measurements. For water meters КВ-1,5 mean time to failure is 100,000 h, ie 11.4 years. As for the utilization of k, then the water meter any type of assessment of its value requires research, because after the installation of the meter in the pipeline it is in Standby inclusion, but in the absence of technological flow meters for the measurement mode is not non-stop.

To understand the dependence of the probability of failure of water meters on their utilization rate calculation was made according to the formula (2) results are presented in Fig. 1. It appears that for the time water meters for about 10,000 h probability close to unity (0,95...0,99) and almost unchanged compared with the start of operation and is independent of the utilization of means of measurement. When the coefficient of k=0,66 for 3 years life (35,040 h), the probability of changing from one to 0,8, and for 6 years (52,560 h) – 0,7 (see the curve 2 in Fig. 1). This change in the coefficient of 10 ... 11 times (ie the order of magnitude) leads to a change in the probability of 6 years of operation only 1,4 times. This means that the variation in the assessment of the utilization rate of 10% leads to errors in assessing the probability of around 4% and the selected level of accuracy (three decimal places) does not affect the assessment value calibration period. The results of this assessment are presented in Fig. 1.

Assessing calibration period for determining the normalized intensity of failures λ, metrology, metrological allowable probability of failure q for domestic counter should not be more than 0,3. The calculation of the formula (8) on the basis of the formula (6) and that the probability P and q related to the ratio $P=1-q$, for $T_{\text{м}}=100\,000$ h and $k=0{,}66$ і 1,00 leads to value $T_{ci}=6$ (6,17) years and 4 (4,07) years, respectively.

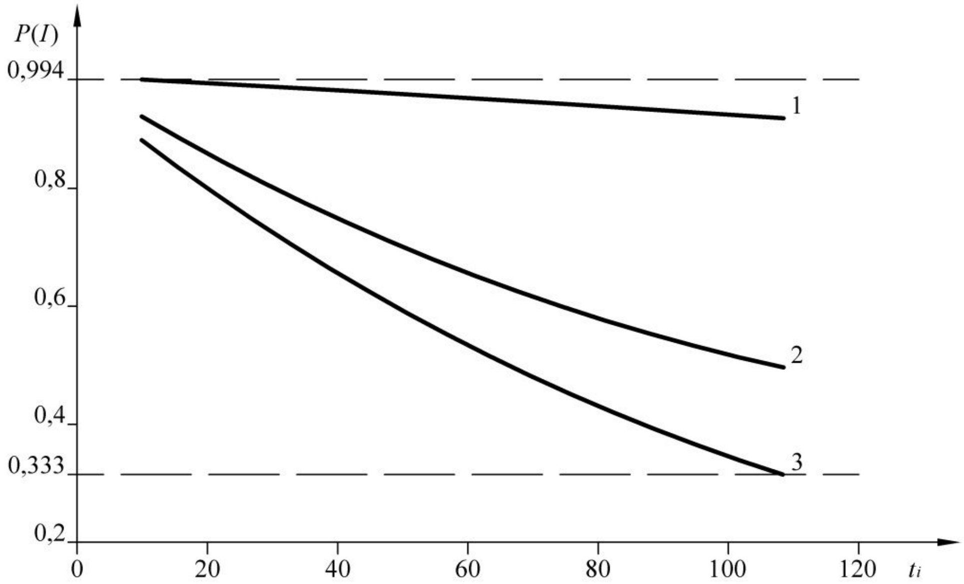

Fig. 1. The dependence of the probability of failure of water meters on the time of use (thousands of hours) in metrological practices $T_{\text{м}}=102\,000$ h and various utilization rate (curve 1 – $k=0{,}06$ (normal), curve 2 – $k=0{,}66$ (meter work 18 hours a day), curve 3 – $k=1{,}00$ (counter clockwork))

In most cases, to assess the impact of failures on the meteorological characteristics of a measurement error using a linear model, which assumes that the error dependence on time can be written as:

$$\sigma(t)=\sigma_0+a\cdot t, \tag{10}$$

where σ_0 – the initial meter error; a – the rate of change of error is constant for each measurement, which varies randomly; t – meter operation.

Note that the model (10) describes the systematic error component meter. An example of the linear model error related to water meters, a formula (1). Practical experience shows that these means of measuring the deviation from the linear model error occurs only at the final stage of the operation, which averages a fraction of the total time use. So, we can assume that the linear model (10) adequately describes the behavior of water meters, depending errors from time to time. Introduce the assumption that the function $\delta(t)$ is a non-stationary normal process with a density of probability distribution:

$$\phi[\delta(t)]=\frac{1}{\sqrt{2\pi D}_t}e^{-\frac{\{\delta(t)-m_t\}^2}{2D_t}}. \tag{11}$$

where m_t – expectation function (10), which is defined as:

$$m_t=m_{\delta 0}+t\cdot m_a, \tag{12}$$

D_t – variance, which is calculated by the formula:

$$D_t=D_{\delta 0}+t^2\cdot D_a. \tag{13}$$

In turn $m_{\delta 0}$ and m_a – primary expectation error and rate of change of error, $D_{\delta 0}$ and D_a – dispersion of these values. Formulas (12) and (13) are valid only if the value of δ_0 and a statistically independent. Next possible to calculate the probability $P_n(t)$ of vehicle uptime metrological measurement corresponds to the probability of the inequality:

$$-\delta_p\le\delta(t)\le\delta_p, \tag{14}$$

that

$$P_n(t)=P\{-\delta_p\le\delta(t)\le\delta_p\}=\int_{-\delta_p}^{\delta_p}\varphi[\delta(t)]dt, \tag{15}$$

where δ_p – symmetrical tolerance limit errors. For water meters КВ-1,5 value δ_p=3,5%.

The result is a relationship:

$$P_n(t) = C \cdot \{\Phi(\frac{\delta_p + m_t}{\sqrt{D_t}}) - \Phi(\frac{-\delta_p + m_t}{\sqrt{D_t}})\}, \tag{16}$$

where $\Phi(Z) = \frac{1}{\sqrt{2\pi}} \cdot \int_{-\infty}^{Z} e^{\frac{u^2}{2}} du$ – Laplace function; C – normalizing factor, determined from the condition that the initial time (at t=0) probability equal to unity, and the initial meter error satisfies the condition:

$$-\delta_p \le \delta(t) \le \delta_p. \tag{17}$$

This means that:

$$C = 1/\Phi(\frac{\delta_p + m_t}{\sqrt{D_t}}) - \Phi(\frac{-\delta_p + m_t}{\sqrt{D_t}}). \tag{18}$$

In the above formulas, including (8) for the purpose calibration period, depending on the studied variables appear occasionally. Methods of verification of water meters [4] recommends this procedure for the following values of: Q_n=1,50 m^3/h; Q_t=0,12 m^3/h and $Q_{\min}$=0,03 m^3/h (nominal, transient and minimal costs respectively). Measurement error analysis of water during initial verification conducted 100 water meters for КВ-1,5 showed that the cost of these error counters are characterized by different standard deviations, so in this case we have to deal with asymmetric measurements. This raises the problem of the weighting coefficients ρ_t, necessary to calculate the statistical characteristics of measurement. In the case of symmetrical measuring the weights are set inversely proportional to the variance measurement results in an appropriate range and are determined using the following formula:

$$\rho_t = \frac{1/S^2(Q_i)}{\sum_{i=1}^{3} 1/S^2(Qi)}, \tag{19}$$

where $S(Q_i)$ – assessment standard deviation obtained for the i-th costs. At the initial verification of water meters КВ-1,5 received the following assessment of the average quadratic deviation (in percent):

$$\begin{aligned} S(Q_n) &= 0,56; \\ S(Q_t) &= 0,65; \\ S(Q_{\min}) &= 1,56. \end{aligned} \tag{20}$$

With these values the formula (19) the values of weighting coefficients presented in Table 1, here $\sum_{i=1}^{3} \rho_t = 1$.

Hence, methods of verification, in terms of the discussed aspect cannot be universal and should be developed for each type of meters apart based on their design and metrological characteristics. As mentioned weighting coefficients are known, it is now possible for the formula (21), (22) to calculate average values and the corresponding mean-square deviation for water meters КВ-1,5 [5].

$$m(Q) = \frac{\sum_{i-1}^{3} \rho_i \cdot m_t}{\sum_{i=1}^{3} \rho_i}, \tag{21}$$

$$S(Q) = \sqrt{\frac{\sum_{i=1}^{3} \rho_i \cdot (m_i - m(Q))^2}{2 \cdot (\sum_{i=1}^{3} \rho_i)^2}}. \tag{22}$$

As a result, the following values:

- average costs Q=0,85 m^3/h;

- the average relative error of the primary calibration (initial error) δ_0=0,48%;
- the standard deviation of the average primary error $S(\delta_0)$=0,67%.

Table 1

The value of weighting coefficients

Costs (m^3/h)	Q_n=1,5	Q_t=0,12	$Q_{\min}$=0,03
ρ_i	0,535	0,397	0,068

The relatively large standard deviation value due to the fact that the variance measurement with minimal despite its light weight, is much (on average 4...9 times) compared to the variance in other costs. Using Table 1 you can determine the relationship between the total volume V, passed through the water meter and the time t it work. Since the set statistics time on each of expenses is not fixed, it will continue to convert the time of the count will be used the following formula:

$$V = Q \cdot t, \tag{23}$$

where Q – average costs; t – full time work at all costs.

Based on statistical data of testing results was obtained following linear model based on measured meter volume (in m^3):

$$\delta = \pm(0{,}72 + 2{,}26 \cdot 10^{-4} \cdot V)\%, \tag{24}$$

with $S(\delta_0)$=0,04%=0,02$\Delta_н$, where $\Delta_н$=1,80% – normalized limit permissible error counter during the release of the production (primary calibration error limit). The initial error and its standard deviation appearing in equation (24), differ from values that were given the results of the initial check of 100 meters. These differences are related to insufficient sample, but with an average error does not exceed the maximum permissible error primary check equal to ±1,8%. If we consider that the utilization counters in operation close to 0,66, the average time-error of a meter outside the operating clearance for its work with the recommended consumption will be about 4 years. In this situation, you can use the guidelines [2] and to assess inter-verification interval by formulas:

$$T_1 = t \cdot \frac{\ln\left(\dfrac{\Delta_e}{\chi_P S(\delta_0)}\right)}{\ln\left(\dfrac{\Delta_н}{\chi_P S(\delta_0)}\right)}, \tag{25}$$

$$T_2 = t \cdot \frac{\Delta_e \cdot \chi_P \cdot S(\delta_0)}{\Delta_н - \chi_P \cdot S(\delta_0)}, \tag{26}$$

where χ_P – normal distribution corresponding to the probability P; t – time between probability P.

Thus (25) is a generalization of the formula (8) to account for the current tolerances, and (26) corresponding generalization of linear model (10). Given that the probability P=0,7 normal distribution is 0,53, and the time between this probability is 52,560 h (25) implies that T_1=8,5 years, T_2=11 years. Thus, the assessment of inter-verification interval for such meters which follows from formulas (25) and (26) the methodology [2] is 8.5 years. Note that the calibration interval equal to 3 years, exceeds this criterion is almost 3 times. These estimates are too high for several reasons:

- first, all of the estimates have been made assuming that the metrological failure is gradual, sudden failure were not considered;
- secondly, it introduced the assumption that the work meters is under ideal conditions when water no mechanical and other impurities that can lead to distortion of results, and even to the failure of most devices, and their operation is under constant normal temperature and economical costs. However, their indirect influence is reflected in the specific sense of a coefficient obtained based on experimental research. As for water meters, depending errors КВ-1,5 since their operation, then the normalized level of accuracy of initial calibration in ±1,8% is more correct dependence that follows from (24) and has the form:

$$\delta = \pm(1{,}8 + a \cdot Q \cdot t)\%, \tag{27}$$

where a – the rate of change of error that has the dimension of %÷m^3; Q – the recommended water intake per unit time, namely, the a=2,26·10^{-4} %÷m^3 (24) coefficient t, equal to 0,17 %÷thousand hours in (1), out at the rate Q=0,75 m^3/h. This value is close to the average cost, and is used for verification of meters is between nominal and transition costs and 2 times the recommended charges. This mode counters in operation can lead to premature meters down.

In determining the suitability of metrology meters will use a fair value (27) rather than (1), because the formula is not specified costs for which work counters. This means that for each type of dependence meters (27) must be determined individually or in the process of testing for metrological stability. For water meters, КВ-1,5 output error over time beyond the tolerance of 3 years, with operating costs 0,375 m^3/h and the coefficient of 0,66 meter rate of change of error shall not exceed $1{,}3\cdot10^{-4}$ %÷m^3, and dependence on the time of operation error is defined as follows:

$$\delta = \pm(1{,}8 + 0{,}05t)\,\%. \qquad (28)$$

Conclusions. In order calibration period for the purpose of water meters is proposed an integrated approach based on volatility statistics metrological characteristics and on the use of reliable data on the time between metrological refusal derived from the operation of measuring instruments. Also, instead of commonly used depending on the dynamic component error means measurement of time of operation proposed to use the dependence of this error on the amount of water passing through the meter. What is more correctly takes into account the dependence of the operating conditions of the meter because it allows you to enter in these modes expenses, while employing the means of water.

Інформаційні джерела

1. Андронов И.В. Измерение расхода жидкостей и газов. – М.; Энергоиздат, 1981. - 86 с.
2. ГОСТ 8.565-99 «ГСИ. Порядок установления и корректировки межповерочных интервалов эталонов».
3. МИ1592 - 99 «ГСИ. Счетчики воды крыльчатые. Методика поверки».
4. МИ 1832-88. «ГСИ. Сличения груп средств поверки одинакового уровня точности. Основные правила».
5. Ткачук А.А. Дослідження методів контролю метрологічних характеристик лічильників води під час їх експлуатації /Т.В. Дуляницька, А.А. Ткачук // Перспективні технології та прилади. Збірник наукових праць. – Луцьк: Луцький НТУ, 2015. – №7 (2). - С. 38-42.

Ткачук А.А. (ORCID 0000-0001-9085-7777) **Терлецький Т.В. Красовський В.В.**
Луцький національний технічний університет

ДОСЛІДЖЕННЯ СПОСОБУ ПРИЗНАЧЕННЯ МІЖПОВІРОЧНОГО ІНТЕРВАЛУ ДЛЯ ЛІЧИЛЬНИКІВ ВОДИ В ЗАЛЕЖНОСТІ ВІД ІНТЕНСИВНОСТІ ЇХ ЕКСПЛУАТАЦІЇ

В статті проведено аналіз процедури призначення міжповірочного інтервалу для лічильників холодної води типу КВ-1,5. Виявлено, що зазвичай під час призначення цього періоду керуються тільки результатами стендових випробувань, отже в цьому випадку не враховуються показники метрологічної безвідмовності та середнє значення часу експлуатації вимірювального засобу в реальних умовах. Запропоновано рекомендації для уточнення міжповірочного інтервалу, які ґрунтуються на результатах експериментальних досліджень та підтверджені відповідними розрахунками.

Ключові слова: *лічильник, похибка, випробування, безвідмовна робота, міжповірочний інтервал.*

Ткачук А.А. (ORCID 0000-0001-9085-7777) **Терлецкий Т.В. Красовский В.В.**
Луцкий национальный технический университет

ИССЛЕДОВАНИЕ ОБРАЗА НАЗНАЧЕНИЕ МЕЖПОВЕРОЧНОГО ИНТЕРВАЛА ДЛЯ СЧЕТЧИКОВ ВОДЫ В ЗАВИСИМОСТИ ОТ ИНТЕНСИВНОСТИ ИХ ЭКСПЛУАТАЦИИ

В статье проведен анализ процедуры назначения межповерочного интервала для счетчиков холодной воды типа КВ-1,5. Выявлено, что обычно при назначении этого периода руководствуются только результатами стендовых испытаний, так что в этом случае не учитываются показатели метрологической безотказности и среднее значение времени эксплуатации измерительного средства в реальных условиях. Предложены рекомендации для уточнения межповерочного интервала, основанные на результатах экспериментальных исследований и подтверждены соответствующими расчетами.

Ключевые слова: *счетчик, погрешность испытания, безотказная работа, межповерочный интервал.*