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МЕТРОЛОГИЯ, СТАНДАРТИЗАЦИЯ И СЕРТИФИКАЦИЯ

METROLOGY, STANDARDIZATION AND CERTIFICATION

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Содержит материал для практических занятий по дисциплине «Метрология, стандартизация и сертификация», а также краткие теоретические сведения, методические рекомендации по решению задач и перечень задач для самостоятельного решения.

Может быть использовано при подготовке студентов других специальностей, а также специалистов инженерно-технического профиля.

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CONTENT

INTRODUCTION

Metrology, standardization, certification – these still unfamiliar terms are more often used nowadays in mass media and in the literature devoted to the issues of economy, of manufacture organization, of concrete questions of designing and technology. The concept of quality becomes essential for all people without exception.

It is known that quality is an ability of production, process or service to satisfy requirements of the society or individual. Thus only standardization provides the unique real possibility to establish the necessary requirements meeting which the set degree of quality is provided. Competent and introduced in time standard is a law, a basis of requirements to quality and to its indicators.

In turn, metrology and the measuring technique connected with it are necessary components of any manufacture and scientific researches which allow to receive the objective information on actual values of parameters characterizing quality. Any, even the most important and extremely necessary requirement which has not been supported with possibility of measurements and control, turns into a suggestion.

And, finally, certification is a protection means of a budget and in many cases of health and even of the consumer life from unconscientiousness of the manufacturer of any goods and services. It is practically absolute guarantee of their quality and safety.

It is not mere chance that not certificated production or service cannot be sold at a civilized world market. In turn, certification is impossible without a support of standardization, metrology and computer facilities.

From the told above it becomes clear, that metrology, standardization and certification are those areas which define now and will define the technical policy in the 21st century. They not only absorb all the most advanced things from other sciences and practical experience, but also stimulate and influence them. Modern engineer is certainly inconceivable without serious training in these fields of knowledge.

The manual examines algorithms for processing direct and indirect measurement results, summing of non-excluded systematic errors, estimation of single measurements' errors, calculation rules of instrumental measurement error, measurement of AC voltage, basics of standardization and certification. Each practical lesson consists of brief theoretical information, basic recommendations for solving tasks and tasks for an independent solution.

1 ESTIMATES OF THE DIRECT MULTIPLE MEASUREMENTS' RESULTS ERROR

1.1 Brief theoretical information

Direct is called a measurement in which the desired value of a quantity is obtained directly from the measuring instrument.

Mathematically direct measurements can be expressed by the formula (model)

$$Q = X + \Delta,$$

where Q – the desired (also called true) value of the measured quantity;
X – the measured value of the quantity;
Δ – the measurement error.

The algorithm for processing the results of direct multiple equal corrected measurements can be represented as follows.

Let there be a sample of n measured quantities X_1, X_2, ..., X_n. It is required to find an estimate of the true value of the measured value and the measurement error in this sample. To do this, you must:

1.1.1 Check whether the corrected measured values belong to the normal distribution or accept it as such.

1.1.2 With symmetric laws of probability distribution, the true value of the measured quantity coincides with its mathematical expectation, and the mathematical expectation is the arithmetic mean of the results of individual observations [1]:

$$\bar{X} = m_x = \frac{\sum_{i=1}^{n} X_i}{n}, \tag{1.1}$$

where n – the number of observations;
X_i – i-th measured value or indication in a row of n values.

The arithmetic mean value is taken as the measurement result.

1.1.3 Determine random deviations of the results of individual measured values:

$$V_i = X_i - \bar{X} \,. \tag{1.2}$$

The calculations are correct if $\sum_{i=1}^{n} V_i \approx 0$.

1.1.4 Determine the selective standard deviation, which is an estimate of standard deviation (SD) – a parameter of the distribution function of the measured values or indications characterizing their dispersion and equal to the positive square root of the variance of this distribution:

$$\sigma_x = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} V_i^2}. \quad (1.3)$$

1.1.5 Check the results of observations for a gross error as follows: if $|V_i| \geq 3\sigma$, then this result contains a gross error and should be excluded. In this case, it is necessary to return to paragraph 1.1.2 of the algorithm and repeat the operations in accordance with paragraphs 1.1.2–1.1.4. If every $|V_i|$ turned out to be $< 3\sigma$, go to step 1.1.6 of the algorithm.

1.1.6 Determine the sample standard deviation of the arithmetic mean $\overline{X}$:

$$\sigma_{\overline{x}} = \frac{\sigma_x}{\sqrt{n}}. \quad (1.4)$$

This value characterizes the scattering of the arithmetic mean $\overline{X}$ of the results of n observations of the measured quantity relative to its true value and is a point estimate of the error of the result of direct multiple measurements. The measurement results do not contain any information about the probability of these estimates, although they allow us to estimate the numerical values of the measurement result and its random deviation.

1.1.7 In practice, interval estimates, the so-called confidence intervals, or confidence limits of measurement error are used.

Confidence limits of measurement error are the upper and lower boundaries of the interval within which, with a given probability P_c, is the value of the measurement error, and therefore the true value of the measured quantity. They are related to the sample standard deviation of the arithmetic mean (1.4) by the following relation:

$$\overset{\circ}{\Delta} = t \cdot \sigma_{\overline{x}}, \quad (1.5)$$

where t is a coefficient depending on the type of distribution of random variables, the number of observations and confidence probability.

For the most universal normal probability density distribution of random variables (Gaussian distribution, for $n < 30$ – Student's distribution), the values of t are determined by a numerical solution of the probability integral, tabulated depending on P_c and n and are given in Table 1.1.

In technical measurements, the value $\overset{\circ}{\Delta}$ should be determined for $P_c = 0.95$. In cases where the measurement cannot be repeated, in addition to the boundaries corresponding to $P_c = 0.95$, it is allowed to indicate the boundaries for $P_c = 0.99$.

1.1.8 Record the measurement result in accordance with the rules established in МИ 1317 [2].

The main way of expressing the measurement accuracy is to specify a symmetric interval in which, with a given probability P_c, there is an error $\overset{\circ}{\Delta}$:

$$X = \left(\overline{X} \pm \overset{\circ}{\Delta} \right) \text{ (units of measure)}, P_c = \ldots . \quad (1.6)$$

With an asymmetric confidence interval, the recording form of the measurement result can be as follows:

X; $\overset{\circ}{\Delta}$ from $\overset{\circ}{\Delta}_l$ =... (units of measure) to $\overset{\circ}{\Delta}_h$ = (units of measure);

P_c = ... , where $\overset{\circ}{\Delta}_l$ – lower bound of the interval, $\overset{\circ}{\Delta}_h$ – upper bound of the interval.

Table 1.1 – The values of the coefficient t for Student's distribution with (n – 1) degrees of freedom

$n-1$	$P_c = 0.95$	$P_c = 0.99$	$n-1$	$P_c = 0.95$	$P_c = 0.99$
3	3.182	5.841	16	2.120	2.921
4	2.776	4.604	18	2.101	2.878
5	2.571	4.032	20	2.086	2.845
6	2.447	3.707	22	2.074	2.819
7	2.365	3.499	24	2.064	2.797
8	2.306	3.355	26	2.056	2.779
10	2.228	3.169	28	2.048	2.763
12	2.179	3.055	30	2.043	2.750
14	2.145	2.997	∞	1.960	2.576

1.2 Basic recommendations for solving tasks

1.2.1 Tasks solving should begin with the preparation of the algorithm according to paragraphs 1.1.1–1.1.8, depending on the type of distribution of the measurement results, the number of measurements and the selected confidence probability.

1.2.2 If for the resulting number of degrees of freedom (n – 1) in Table 1.1 there is no Student's coefficient t, it is necessary to carry out interpolation, i. e. the operation of finding intermediate values of a quantity from an available discrete set of known values. In this case, the interpolation will be local.

The simplest and most suitable form of local interpolation in this case is piecewise linear interpolation. It lies in the fact that the relationship between two neighboring known points of the table is a linear function of the form $y = ax + b$. A special case is the situation when the unknown value of the arguments is the average value for the known arguments x_1 and x_2. Then the corresponding x value of the function y will be the arithmetic mean between x_1 and x_2.

1.2.3 Rounding when processing the results of observations and when recording the results of measurements should be carried out, guided by the following rules:

- rounding is done only in the final answer, and all intermediate rounding is carried out with one or two extra digits;
- first, the confidence interval is rounded (measurement error). The error of the measurement result is indicated by two significant digits if the first of them is 1 or 2, and one if 3 or more. Measurement errors are rounded up;
- the measurement result is rounded to the same decimal place, which ends the rounded value of the error. Moreover, if the digit of the oldest of the discarded digits is less than 5, then the remaining digits do not change. If the digit of the eldest of the discarded digits is greater than or equal to 5, and the numbers following it are nonzero, then the last digit left is increased by one. If the discarded digit is 5, and the digits following it are unknown or zeros, then the last stored digit of the number does not change if it is even, and increase by one if it is odd.

1.3 Tasks for an independent solution

1.3.1 In the process of multiple direct measurements of a given value, n results were obtained. Considering them corrected and equal, find the result of multiple direct measurements and evaluate its confidence limits. The value and units of its measurement are given in Table 1.2, and the results of multiple measurements are given in Table 1.3.

Table 1.2 – Measured values and units of measurement

Parameter	Variant									
	1	2	3	4	5	6	7	8	9	10
Value	Amperage	Frequency	Voltage	Resistance	Power	Time	Length	Temperature	Capacitance	Inductance
Units of measurement	mA	GHz	V	kOhm	W	s	m	°C	pF	mH

Table 1.3 – Results of direct multiple measurements

Point number	Variant				
	1	2	3	4	5
1	16.0065	86.0065	11.2345	35.5765	58.0065
2	16.0154	86.0154	12.4894	34.5654	58.0154
3	15.5878	84.5878	12.9605	35.5878	59.5878
4	15.1454	85.1454	12.7684	35.1454	59.1454
5	16.1341	85.1341	11.5679	35.1341	58.1341
6	16.8065	85.8065	11.8134	34.1065	59.8065
7	15.0154	87.0154	12.1564	34.8154	59.0154
8	15.1587	86.1587	12.3750	35.3587	56.1587
9	15.9145	86.9145	11.6783	35.0145	58.9145
10	16.8134	85.8134	12.5672	35.5734	58.8134
Point number	Variant				
	6	7	8	9	10
1	26.9065	6.0065	44.1345	31.5765	158.006
2	26.8154	6.0154	44.1894	32.5654	158.015
3	25.6878	4.5878	45.3605	31.5878	159.587
4	25.5454	5.1454	45.9645	31.1454	159.145
5	26.4441	5.1341	45.5979	31.1341	158.134
6	26.6065	5.8065	45.2334	32.1065	159.806
7	25.0554	7.0154	44.7564	32.8154	159.015
8	25.1697	6.1587	45.3950	32.3587	156.158
9	25.9146	6.9145	44.6783	32.0145	158.914
10	26.8554	5.8134	44.9872	32.1734	158.813

2 ESTIMATED ERRORS OF THE RESULTS OF MULTIPLE INDIRECT MEASUREMENTS

2.1 Brief theoretical information

A measurement is called *indirect* when the desired value of a quantity is determined by the results of direct measurements of other quantities being functionally related to that desired quantity.

Mathematically, the result of indirect measurements can be represented by the following formula [1]:

$$Q = F\left(X_1, X_2, \ldots, X_m\right),$$

where $X_1, X_2, \ldots, X_m$ are the results of direct measurements of the quantities bounded by the known functional dependence F with the desired values of the measured quantity Q.

The errors of indirect measurement results are estimated through the following algorithm:

2.1.1 As the result of indirect measurement, quantity $\bar{Q}$ is taken which is a function from the mean values of the arguments of physical quantities within the formula below

$$\bar{Q} = f\left(\bar{X}_1, \bar{X}_2, \ldots, \bar{X}_m\right), \quad (2.1)$$

where m is the number of variables within the formula.

Variables $\bar{X}_i$ are the mean values of the results of direct multiple measurements.

2.1.2 Components of the error of indirect measurement result are determined – so called *partial random* that take into account the contribution of each variable within the following formula

$$E_{X_i} = \frac{\partial f}{\partial X_i}\sigma_{\bar{X}_i}, \quad (2.2)$$

where $\sigma_{\bar{X}_i}$ are estimated RMS errors of the result of direct measurement of the i-th quantity;

$\frac{\partial f}{\partial X_i}$ are partial derivatives that are calculated at $X_i = \bar{X}_i$ and called weight coefficients.

2.1.3 Sampling standard deviation of indirect measurement result is determined by formula

$$\sigma_{\bar{Q}} = \sqrt{\sum_{i=1}^{m}\left(\frac{\partial f}{\partial X_i}\cdot\sigma_{\bar{X}_i}\right)^2 + \sum_{\substack{i=1\\ i\neq j}}^{m}\sum_{j=1}^{m}\frac{\partial f}{\partial X_i}\cdot\frac{\partial f}{\partial X_j}\cdot\sigma_{\bar{X}_i}\cdot\sigma_{\bar{X}_j}\cdot R_{ij}}\,, \qquad (2.3)$$

where R_{ij} is the correlation coefficient which indicates the level of statistical connection between partial random errors of the measurement result for quantities X_i and X_j. Sometime sit is also called the influence coefficient.

Possible values of the correlation coefficient lie within the interval

$$-1 \leq R_{ij} \leq +1\,. \qquad (2.4)$$

The case of independent partial errors ($R_{ij} = 0$) takes place when X_i and X_j are measured using different Systems of Units at different time, by different operators, etc. In this case, formula (2.3) is simplified to

$$\sigma_{\bar{Q}} = \sqrt{\sum_{i=1}^{m} E_{\bar{X}_i}^2}\,. \qquad (2.5)$$

The case of dependent partial errors ($R_{ij} \neq 0$) takes place when X_i and X_j are measured using same-type System of Units by one operator and at simultaneous change of influencing quantities, etc.

If one of the errors increases with another, then $R_{ij} > 0$ (positive correlation). If one of the errors decreases with another, then $R_{ij} < 0$ (negative correlation).

In the case of dependent partial random errors one should determine the correlation coefficient by formula

$$R_{ij} = \frac{1}{(n-1)\sigma_{X_i}\sigma_{X_j}}\sum_{k=1}^{n}\left(X_{ik} - \bar{X}_i\right)\left(X_{jk} - \bar{X}_j\right), \qquad (2.6)$$

where n – the smallest number of observations for X_{ik} and X_{jk}.

2.1.4 The result is checked for a negligible error.

Taking into account the weight coefficients, not all partial errors of the indirect measurement have the same effect on the total error of the indirect measurement. Some of them may be significantly smaller than others, and since the error value is usually rounded to two significant digits, they will not have a noticeable effect on the value of the final error. Taking into account the rounding rule, a particular error is considered insignificant if it changes the total error by no more than 5 %.

K-th partial error is negligible if

$$E_k < \frac{1}{3}\sigma_{\bar{Q}}. \qquad (2.7)$$

Using the criterion of negligible errors allows you to find those values that, being increased in measurement accuracy, allow reducing the total error of the measurement result, and those whose measurement accuracy does not make sense to increase, since their partial errors are already negligible.

2.1.5 If the number of observations of each quantity $\overline{X}_i$ is above 30, then they use the table to find the Student's coefficient *t*.

2.1.6 If the number of observations of each quantity $\overline{X}_i$ is below 30, then they obtain the number of degrees of freedom:

$$n_{ef} - 1 = \frac{\left(\sum_{i=1}^{m} E_{\overline{X}_i} \delta_{\overline{X}_i} \right)^2}{\sum_{i=1}^{m} \frac{1}{n_i - 1} E_{\overline{X}_i}^2 \delta_{\overline{X}_i}^2}, \quad (2.8)$$

where $\delta_{\overline{X}_i} = \sigma_{\overline{X}_i} / \overline{X}_i$ is the relative RMS deviation of the measurement result;

n_i is the number of observations in case of direct measurements of X_i.

2.1.7 From the tables for the predetermined confidence probability P_c and effective number of degrees of freedom n_{ef} they obtain the Student's coefficient *t*. If the effective number of degrees of freedom is broken, you should apply linear interpolation. The interpolation formula in this case is

$$t = \frac{(t_2 - t_1) n_{ef} + [t_1 \cdot n_2 - t_2 \cdot n_1]}{n_2 - n_1}. \quad (2.9)$$

2.1.8 By multiplying the Student's coefficient *t* to the sampling standard deviation of indirect measurement result for $\sigma_{\overline{Q}}$, we obtain the value of the confidence interval:

$$\overset{\circ}{\Delta} = t \cdot \sigma_{\overline{Q}}. \quad (2.10)$$

2.1.9 The measurement result is written down as per items 1.1.8 and 1.2.3.

2.2 Basic recommendations for solving tasks

2.2.1 Before proceeding with the solution, carefully read the problem condition.

Determine the type of function that links the results of direct measurements with the desired value (expression (2.1)); the number of variables included in the formula; whether or not there is a correlation between partial random errors.

2.2.2 Determine the partial random errors of the indirect measurement result using formula (2.2). Partial random errors for each variable are assumed that all other values included in the formula are constant.

2.2.3 If the correlation coefficients are not specified in the condition, calculate them by formula (2.6).

2.2.4 Determine the sampling standard deviation of the indirect measurement result using formula (2.3), assuming that the influence of the *i*-th and *j*-th variables on each other is symmetrical.

2.2.5 Check the measurement results for insignificant errors according to criterion (2.7) and make a conclusion about the need to improve the accuracy of the measurement of the *i*-th variable. *Insignificant errors are not excluded from consideration!*

2.2.6 Calculate the relative standard deviations of direct measurement results using formula $\delta_{\bar{X}_i} = \sigma_{\bar{X}_i} / \bar{X}_i$.

2.2.7 Determine the effective number of degrees of freedom (n_{ef} – 1) by formula (2.8). Remember that the calculation result for (n_{ef} – 1) is not rounded.

2.2.8 Use the interpolation formula for linear interpolation (2.9) to determine the value of the Student's coefficient for (n_{ef} – 1). To this end, you should first determine the interval between n_1 and n_2 which includes (n_{ef} – 1), and then substitute the values of n_1 and n_2 and of corresponding t_1 and t_2.

2.2.9 Use formula (2.10) to calculate the confidence boundaries of the random error of indirect measurement and write down the result in standard form (see items 1.1.8, 1.2.3).

2.3 Tasks for an independent solution

2.3.1 The voltage in an electrical circuit U is determined through multiple measurements of voltages U_1, U_2, U_3 at the sections of this circuit with further calculation by formula $U = U_1 + U_2 + U_3$.

By the results of processing *n* direct measurements of the voltages we know the mean values of voltages $\bar{U}_1, \bar{U}_2, \bar{U}_3$ and RMS deviations of the measurement results for voltages $\sigma_{\bar{U}_1}, \sigma_{\bar{U}_2}, \sigma_{\bar{U}_3}$ (Table 2.1). We also know the correlation coefficients $R_{\bar{U}_1\bar{U}_2}, R_{\bar{U}_1\bar{U}_3}, R_{\bar{U}_2\bar{U}_3}$ (see Table 2.1).

Estimate the confidence boundaries of the result of indirect measurement of voltage and write down the measurement results. The results of measurements are given in Table 2.1. The values of Student's coefficient *t* are outlined in Table 1.1.

2.3.2 Resistance of R_X was obtained through multiple measurements of voltage U_x drop on it and of voltage U_0 drop on the serially connected etalon resistor with resistance R_0 followed by the calculation through formula $R_X = R_0 \cdot \frac{U_X}{U_0}$.

The results of direct measurements of voltages and sampling standard deviation of arithmetic mean measurement of voltages are given in Table 2.2. The error of measuring the resistance of resistor R_0 should be neglected. Partial random errors are not correlated; the number of observations is n = 45. The values of Student's coefficient t are listed in Table 1.1.

Estimate the confidence boundaries of the result of indirect measurement of resistance and write down the result.

Table 2.1 – Measurement results for task 2.3.1

Variant	n	$\bar{U}_1$, V	$\bar{U}_2$, V	$\bar{U}_3$, V	$\sigma_{\bar{U}_1}$, V	$\sigma_{\bar{U}_2}$, V	$\sigma_{\bar{U}_3}$, V	$R_{\bar{U}_1\bar{U}_2}$	$R_{\bar{U}_1\bar{U}_3}$	$R_{\bar{U}_2\bar{U}_3}$
1	12	12.45	8.46	7.54	0.22	0.02	0.14	0	0,1	–0.8
2	13	43.66	12.35	5.13	0.91	0.12	0.04	–0.1	0	0.7
3	14	28.44	25.61	29.01	0.16	0.35	0.25	0.9	0.1	–0.5
4	15	7.38	8.14	10.94	0.45	0.14	0.93	0.1	0.6	0.9
5	16	2.45	18.46	27.54	0.22	0.22	1.14	0.5	–0.1	0
6	17	4.68	2.35	15.13	0.01	0.02	0.14	–0.1	0.3	0.7
7	18	8.48	5.61	9.91	0.06	0.15	0.25	–0.9	0.8	–0.5
8	19	17.38	18.14	0.94	0.45	0.14	0.03	0.1	0	0.9
9	20	12.45	18.46	17.54	0.22	0.02	0.14	0.2	0.1	–0.3
10	21	3.66	2.35	5.13	0.91	0.12	0.04	0.1	–0.4	0.7

Table 2.2 – Measurement results for task 2.3.2

Variant	$\bar{U}_x$, V	$\bar{U}_0$, V	R_0, kOhm	$\sigma_{\bar{U}_x}$, V	$\sigma_{\bar{U}_0}$, V
1	26	48.48	9.14	0.01	0.02
2	28	11.38	48.46	0.06	0.15
3	27	43.66	7.35	0.45	0.14
4	21	28.44	55.61	0.22	0.02
5	19	6.68	11.14	0.91	0.12
6	18	12.45	12.35	0.16	0.35
7	17	3.66	25.61	0.45	0.14
8	16	48.45	7.35	0.22	0.22
9	15	3.38	18.46	0.01	0.02
10	25	42.45	2.35	0.06	0.15

3 SUMMING OF NON-EXCLUDED SYSTEMATIC ERRORS

3.1 Brief theoretical information

3.1.1 *Summation of non-excluded residuals of systematic errors*

Systematic errors that remain in the measurement results after the operations of detection, evaluation and exclusion are called non-excluded systematic errors (NSE).

They are formed from many components (measurement method errors, measuring instruments errors, other sources errors). Individual NSE should be summarized among themselves to assess the confidence limits of the total NSE of the measurement result.

The following is an algorithm for estimating the boundaries of non-excluded systematic errors:

3.1.1.1 When determining the boundary of the resulting NSE, its individual components are considered as random variables.

3.1.1.2 If it is known that the distribution of components corresponds to the normal law, then Δ_S is calculated in direct measurements by the formula [1]:

$$\Delta_S = \sqrt{\sum_{i=1}^{m} \Delta_{S_i}^2}, \tag{3.1}$$

where Δ_{S_i} – the boundary of the i^{th} NSE;

m – the number of summed NSE.

3.1.1.3 If there is no data on the type of distribution, it is considered uniform, and the boundaries of the total non-excluded systematic error in direct measurements are calculated as follows:

$$\Delta_S = k\sqrt{\sum_{i=1}^{m} \Delta_{S_i}^2}, \tag{3.2}$$

where k – coefficient determined by accepted confidence.

With a confidence probability $P_c = 0.95$ $k = 1.1$.

With a confidence probability $P_c = 0.99$ $k = 1.4$ if $m > 4$.

With a confidence probability $P_c = 0.99$ and $m < 4$, the coefficient k is determined from the dependence graph $k = f(m, l)$ (Figure 3.1), where $l = \Delta_{S_i} / \Delta_{S_j}$, Δ_{S_i} is the component of the NSE that is most different from others, Δ_{S_j} is the component closest to Δ_{S_i}.

In Figure 3.1, curve 1 is shown for the number of NSE $m = 2$, curve 2 for $m = 3$, curve 3 for $m = 4$.

3.1.1.4 In indirect measurements, the NSE that occur when measuring the arguments X_i, are private NSE of the result of an indirect measurement:

$$\Delta_{S_{\bar{Q}}} = \frac{\partial F}{\partial X_i} \Delta_{S_{X_i}}. \quad (3.3)$$

They are then summarized in the same way as in direct measurements (see paragraphs 3.1.1.2–3.1.1.5), i. e., in order to determine Δ_S the result of an indirect measurement in formulas (3.1) or (3.2), it is necessary to substitute the values Δ_{S_i} instead of $\Delta_{S_{X_i}}$ calculated by formula (3.3).

The confidence probability for calculating Δ_S is taken to be the same as for calculating the confidence limits of the random error of the measurement result.

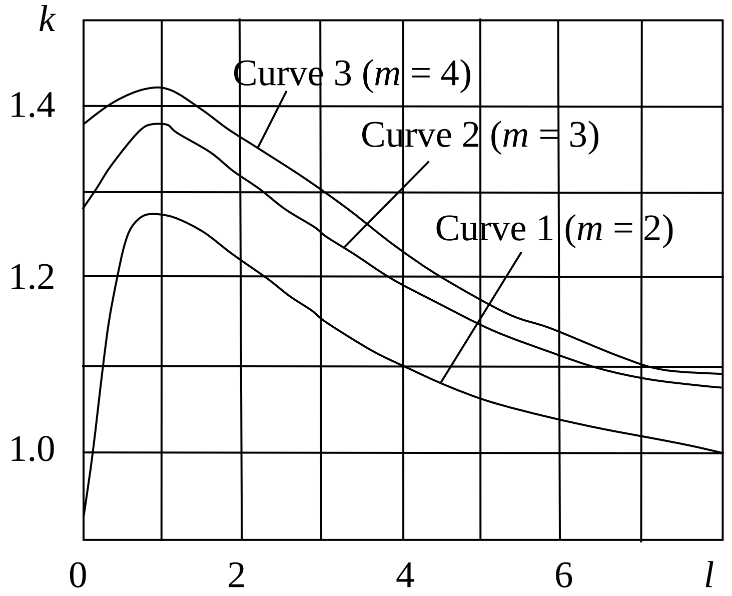


Figure 3.1 – Graph for finding the coefficient *k*

3.1.2 *Determining the confidence limits of the resulting measurement error*

To determine the boundaries of the resulting measurement error, it is necessary to summarize the confidence boundaries of the random and systematic components in the following sequence:

3.1.2.1 Find a ratio

$$R = \frac{\Delta_S}{\sigma_{\bar{X}(\bar{Q})}}. \quad (3.4)$$

If $R < 0.8$, then non-excluded systematic errors are neglected, and the total error in this case is equal to the boundaries of the random measurement errors $\mathring{\Delta}$ calculated by formula (1.5) for direct measurements and by formulas (2.8)–(2.10) for indirect measurements.

If $R > 8$, then the random component of the error is neglected, and $\Delta = \Delta_S$.

If $0.8 \le R \le 8$ then it is impossible to neglect any component, and then the boundaries of the summary measurement error are found by the formula

$$\Delta = K \cdot S_\Sigma, \tag{3.5}$$

where K is a coefficient depending on the ratio of random non-excluded systematic error and determined by the formula

$$K = \frac{\overset{\circ}{\Delta} + \Delta_S}{\sigma_{\bar{X}(\bar{Q})} + \sqrt{\frac{1}{3}\sum_{i=1}^{m}\Delta_{S_i}^2}}, \tag{3.6}$$

where S_Σ is the estimate of the summary standard deviation of the measurement result, determined by the formula

$$S_\Sigma = \sqrt{\sum_{i=1}^{m}\frac{\Delta_{S_i}^2}{3} + \sigma_{\bar{X}(\bar{Q})}^2}. \tag{3.7}$$

3.1.2.2 Write down the final measurement result in one of the standard forms (see paragraphs 1.1.8 and 1.2.3).

3.2 Basic recommendations for solving tasks

3.2.1 Before starting to solve the task, determine the type of measurement by the method of obtaining the result (direct or indirect). For indirect measurements, calculate the measurement result according to the given functional relationship.

For direct measurements, values $\sigma_{\bar{X}}$ are substituted into formulas (3.4), (3.6), and (3.7), and $\sigma_{\bar{Q}}$ for indirect measurements.

3.2.2 Determine negligible measurement errors. To do this, find the relation R by the formula (3.5).

If $R < 0.8$, then the resulting error is equal to the boundaries of the random measurement error determined by formulas (1.5) for direct measurements depending on the number of measurements n and (2.10) for indirect measurements depending on the effective number of degrees of freedom (formulas (2.8) , (2.9)) and the accepted confidence probability P_c.

If $R > 8$ the resulting error is equal to the boundaries of the NSE: $\Delta = \Delta_S$.

3.2.3 If $0.8 \le R \le 8$ the resulting error is calculated according to formulas (3.5)–(3.7).

The values of the Student's coefficient are given in Table 1.1.

3.3 Tasks for an independent solution

3.3.1. In the process of processing the results of direct voltage measurements, the arithmetic mean value of the voltage $\bar{U}$, the standard deviation of the measurement result $\sigma_{\bar{U}}$, the boundaries of the non-excluded residues of the three components of the systematic voltage measurement error $\Delta_{S_{U1}}$, $\Delta_{S_{U2}}$ and $\Delta_{S_{U3}}$ (Table 3.1) are determined. The number of observations is significantly greater than 30. The confidence probability is 0.99. Determine the confidence limits of the summary error of the measurement result. In the calculations, it is assumed that there is no data on the type of distribution of systematic errors.

Table 3.1 – Measurement results for task 3.3.1

Parameter	Variant									
	1	2	3	4	5	6	7	8	9	10
$\bar{U}$, V	5.75	1.246	18.31	25.43	8.49	4.38	20.92	9.48	53.79	16.48
$\sigma_{\bar{U}}$, V	0.08	0.037	0.52	0.23	0.20	0.60	1.20	0.45	0.45	0.51
$\Delta_{S_{U1}}$, V	0.32	0.45	1.30	0.92	0.56	0.14	1.56	0.35	2.30	0.83
$\Delta_{S_{U2}}$, V	0.15	0.023	0.49	0.87	0.35	0.48	0.62	0.46	0.82	0.87
$\Delta_{S_{U3}}$, V	0.21	0.012	0.16	0.29	0.20	0.12	0.47	0.23	0.63	0.39

3.3.2 Determine the resistance of the circuit, consisting of 12 resistors of two different ratings, with $R = 4R_1 + 8R_2$. For the resistor of each value, the sample standard deviations of the measurement of the resistances σ_{R_1}, σ_{R_2}. The resistance values were determined by the results of 12 measurements. Private random errors are uncorrelated. Also known are the boundaries of the NSE of resistance measurement Δ_{S_R} (Table 3.2). Estimate the resulting error of resistance measurement with a confidence probability of 0.95.

Table 3.2 – Measurement results for task 3.3.2

Parameter	Variant									
	1	2	3	4	5	6	7	8	9	10
R_1, Ohm	3.48	28.35	11.35	45.14	8.44	38.44	8.85	14.57	28.15	5.78
R_2, Ohm	8.14	10.94	7.38	30.14	57.03	18.14	40.94	7.26	45.14	69.03
Δ_{S_R}, Ohm	0.13	0.41	0.45	0.13	0.41	0.45	0.13	0.41	0.45	0.34
σ_{R_1}, Ohm	0.54	1.55	0.81	0.98	0.06	1.34	0.98	0.51	1.98	0.034
σ_{R_2}, Ohm	0.08	0.01	0.33	1.45	0.13	0.82	0.71	0.36	1.14	0.084

4 ESTIMATION OF SINGLE MEASUREMENTS' ERRORS

4.1 Brief theoretical information

For single measurements, no statistical processing of the measured value or indication is required.

During technical measurements, a procedure must be established in advance, the observance of which ensures that the measurement result is obtained with an error not exceeding the allowable one. The expected error of the measurement result is estimated before measurement (a priori estimate), using preliminary data on the measured value, the applied measurement method and measuring instrument, as well as on the measurement conditions. It is this a priori information that makes it possible to carry out single measurements and ensures their *convergence* (proximity to each other of measurement results performed under the same conditions) and *reproducibility* (proximity to each other of measurement results reduced to the same conditions).

For a priori estimation of the expected error of a single measurement, the following algorithm is recommended.

4.1.1 The analysis of the components of the measurement result error by sources of occurrence is carried out. Methodological errors are estimated either on the basis of a study of theoretical dependencies describing the object under study and the measurement method, or experimentally when measuring the same quantity by different methods. To assess the instrumental and external errors, data on the main and additional errors of the applied measuring instruments are used. Finally, subjective errors are usually estimated experimentally. In this case, the assessment of systematic errors is given by their boundaries (limits), and random ones – by the values of estimates of sample standard deviations.

4.1.2 Exclusion of systematic errors is carried out, and non-excluded errors are summed up to determine Δ_s.

4.1.3 The sample standard deviation of the measured value is estimated (it is assumed that the detected random errors are independent). Therefore, for the estimate we use formula (1.4), and for the estimate $\sigma_{\bar{Q}}$ – (2.5).

4.1.4 Using the Student's coefficient, the confidence limits of the random error $\dot{\Delta}$ are found. For single measurements, the following values of the Student's coefficient t are taken:

- with P_c = 0.95 t = 2;
- with P_c = = 0.99 t = 2.6.

4.1.5 An assessment of the confidence limits of the expected error of the measurement result is carried out. For direct single measurements, it is recommended to calculate the ratio $\mu = \Delta_s / \sigma_{\bar{Q}}$ (by analogy with multiple measurements). If it is less than 0.5, you can take $\Delta = \overset{\circ}{\Delta}$, and for μ > 8 take $\Delta = \Delta_s$. If 0.5 ≤ μ ≤ 8, the value of Δ for direct measurements can be calculated by the formula [1]:

$$\Delta = 0.8\left(\Delta_s + \overset{\circ}{\Delta}\right), \quad (4.1)$$

and for indirect measurements by the formula

$$\Delta = \sqrt{\Delta_s^2 + \overset{\circ}{\Delta}{}^2}. \quad (4.2)$$

The coefficient 0.8 takes into account the low probability that Δ_s and $\dot{\Delta}$ will simultaneously have their boundary values.

If the obtained value of Δ turned out to be greater than the permissible error Δ_p, it is necessary either to turn to another measurement method, or to replace the measuring instruments (or to clarify their metrological characteristics), or, finally, to change the measurement conditions in a certain way. If $\Delta < \Delta_p$, then the established procedure ensures that the measurement result is obtained with the required accuracy.

4.1.6 Record the final measurement result in one of the standard forms (see paragraphs 1.1.8 and 1.2.3).

4.2 Basic recommendations for solving tasks

4.2.1 When starting to solve a task, carefully read the condition and determine the type of measurements depending on the method of obtaining the result. For indirect measurements, calculate the result of the indirect measurement according to the given functional relationship.

4.2.2 If possible, eliminate systematic components of the measurement error.

4.2.3 Determine the sample standard deviations of the result by formula (1.4) or (2.5) depending on the type of measurement.

4.2.4 Determine the confidence limits of the measurement result according to the formula (1.5) for direct measurements or (2.10) for indirect measurements, taking the Student's coefficients in accordance with paragraph 4.1.4.

4.2.5 Determine the boundaries of non-excluded systematic measurement errors using the formula (4.1) for direct measurements and (4.2) for indirect ones.

4.2.6 Determine the value of μ and the limits of the resulting measurement error Δ according to paragraph 4.1.5.

4.2.7 Record the measurement result in standard form (see paragraphs 1.1.8, 1.2.3).

4.3 Tasks for an independent solution

4.3.1 To measure the energy consumed by the load at a constant current for time t, an indirect method was used and the expression $E = \frac{U^2}{R}t$. In this case, as a result of single measurements, the values of the voltage U, resistance R, time t, standard deviation of the results of direct measurements of voltage $\sigma_{\bar{U}}$, resistance

$\sigma_{\bar{R}}$, time $\sigma_{\bar{t}}$, boundaries of non-excluded residuals of three components of the systematic error in measuring voltage $\Delta_{s_{\bar{U}}}$, resistance $\Delta_{s_{\bar{R}}}$, time $\Delta_{s_{\bar{t}}}$ were received (Table 4.1). Estimate the total error of energy measurement and write the result with a confidence probability 0.99.

Table 4.1 – Measurement results for task 4.3.1

Variant	*U*, V	$\sigma_{\bar{U}}$, V	*R*, Ohm	$\sigma_{\bar{R}}$, Ohm	*t*, s	$\sigma_{\bar{t}}$, s	$\Delta_{s_{\bar{U}}}$, V	$\Delta_{s_{\bar{R}}}$, Ohm	$\Delta_{s_{\bar{t}}}$, s
1	146	20	415	5	15	0.04	0.44	0.15	0.48
2	15	0.45	104	1.2	20	0.15	0.18	0.35	0.02
3	35	0.13	54	0.08	10	0.09	0.35	0.18	0.3
4	250	1.34	550	3.4	21	0.35	0.18	0.55	0.91
5	220	0.95	280	1.35	19	0.85	1.13	0.81	0.15
6	150	12	38	0.45	19	0.13	1.15	0.83	0.05
7	88	0.9	154	1.38	10	0.05	0.38	3.14	0.71
8	280	15	1450	80	15	0.8	0.8	0.3	0.45
9	560	25	930	1.45	10	0.03	0.03	1.13	0.81
10	340	1.50	200	8.35	25	0.8	1.52	1.18	0.81

4.3.2 The current strength *I*, flowing through the resistor with resistance *R*, is known; sample standard deviation of current measurement $\sigma_{\bar{I}}$; trust limits of resistance measurement $\overset{\circ}{\Delta}_{\bar{R}}$; the boundaries of the non-excluded systematic component of measuring the current strength $\Delta_{s_{\bar{I}}}$ (Table 4.2). Estimate the voltage drop across the resistor and the resulting limits of its measurement error with a confidence probability of 0.95 for single measurements of the current strength and resistance of the resistor.

Table 4.2 – Measurement results for task 4.3.2

Variant	*I*, mA	$\sigma_{\bar{I}}$, mA	*R*, Ohm	$\overset{\circ}{\Delta}_{\bar{R}}$, Ohm	$\Delta_{s_{\bar{I}}}$, mA
1	340	1.34	308	4.5	0.35
2	35	0.95	147	1.38	3.42
3	84	0.12	1468	87	0.01
4	173	2.9	330	10.45	0.19
5	354	15	20	0.35	4.81
6	98	5	18	0.44	0.15
7	16	1.50	40	0.38	0.35
8	150	5.2	38	0.5	0.18
9	351	37.03	177	1.34	0.55
10	20	0.4	130	8.3	0.81

5 INSTRUMENTAL ERROR OF MEASUREMENT

5.1 Brief theoretical information

Each measurement result contains errors due to different sources of occurrence:

- the error of the measuring instrument (MI) – *instrumental*;
- measurement method error – *methodical*;
- the error due to the individual characteristics of the experimenter – *subjective*;
- *external* errors caused by going beyond the range of normal values that affect the measurement result of quantities (humidity, temperature, pressure, etc.).

The main metrological task of any experimenter is to correctly plan a measurement experiment, that is, to obtain a reliable measurement result with a minimum error.

The instrumental error is due to the characteristics of the MI, and it cannot be excluded from the measurement result. It should be estimated and, if possible, minimized using a more accurate MI. The main instrumental error is established for the normal operating conditions of the measuring instrument. An additional instrumental error is set for the operating conditions of the MI. If the conditions of the experiment are in the range of operating values, then in addition to the main one, it is necessary to assess the additional error of the measurement result.

Methodological error can be eliminated by introducing a correction into the measurement result. Using standard measurement methods, the methodical error can be made negligible in comparison with the instrumental error and not taken into account as a result of measurements.

Subjective errors are caused by the state and errors of the experimenter when taking readings from the MI. These errors are caused by parallax (the wrong direction of the experimenter's gaze when taking readings of the pointer MI), interpolation when taking readings, from negligence, inattention, lack of thoroughness, due to the observer's tendency to overestimate or underestimate the results and other reasons. Such errors are eliminated by the increased responsibility of the experimenter and the use of digital MI.

External errors can be eliminated by eliminating the causes of their occurrence, i. e. carefully prepare the experiment and control interference, noise, electromagnetic fields and other factors affecting the measurement result.

Thus, if it is possible to exclude or minimize the methodological, subjective and external errors, then it will be necessary to estimate only the instrumental error of the measurement result.

The main instrumental error is assessed by the metrological characteristics of the measuring instrument given in the instructions for its operation, or by the accuracy class. The accuracy class is one of the main characteristics of the MI.

Accuracy class is a generalized characteristic of the MI, determined by the limits of the permissible basic and additional instrumental errors, as well as the properties of the MI that affect the accuracy.

MI errors are normalized by determining the limits of permissible basic and additional errors. Methods of normalization and representation forms of these limits are defined in the standards and (or) Technical Specifications for specific MI and must correspond to requirements of ГОСТ 8.009 [3] and ГОСТ 8.401 [4].

The designation of the accuracy class is given in the operating instructions and is applied to the MI dials with the accepted conventions depending on the form of expression of the basic MI error. Construction rules and examples of designation of accuracy classes are given in Table 5.1. Moreover, the closer to the beginning of the Latin alphabet the letter and the smaller the number in the designation of the accuracy class (columns 3, 4 of Table 5.1), the more accurate the MI and the smaller its error.

The rules for choosing X_N are determined by the features of the MI scale calibration, according to which the measured value is read. For MI with a uniform, practically uniform or power-law scale, as well as for measuring transducers, X_N is chosen as follows:

- if the zero value of the scale is at the edge of the measurement range, X_N is set equal to the larger of the measurement range;
- if the zero value is within the measurement range, then X_N is equal to the largest of the modules of the measurement limits.

In the particular case for electrical measuring instruments, if the zero is within the measurement range, X_N is set equal to the sum of the modules of the measurement limits.

For MI, which adopted a scale with a conditional zero (located outside the scale), X_N is set equal to the modulus of the difference of the measurement limits. For example, for a thermoelectric thermometer with measurement ranges of 200 and 600 °C, X_N = 400 °C. For MI with a fixed nominal value, X_N is taken equal to this nominal value. For example, for a frequency meter with a measurement range of 45 to 55 Hz and a nominal frequency of 50 Hz, X_N = 50 Hz. For MI with a substantially uneven scale, X_N is set equal to the length of the entire scale or its part corresponding to the measurement range (in units of the scale length). For example, for an ohmmeter in the measurement range from 0 to 300 Ohm, X_N = 62 mm, and in the measurement ranges of kOhm and MOhm – X_N = 58 mm.

Knowing the methods of designating the accuracy classes given in Table 5.1, it is possible to estimate the basic instrumental error of the measurement result, which is necessary when performing any measurements.

5.2 Basic recommendations for solving tasks

5.2.1 Analyze the task condition.

5.2.2 Knowing the designation of the accuracy class, determine the form of the basic instrumental error (see Table 5.1).

5.2.3 In accordance with the condition of the problem, draw the MI scale, mark on the scale and determine the values X_N or X_K, the length of the scale L, corresponding to X_N, and the length of the scale l_X, corresponding to the reading on the scale.

5.2.4 Estimate the basic instrumental error according to Table 5.1.

5.2.5 Knowing the form of the basic error and the features of the calibration of the scale of the indicated MI, evaluate the remaining forms of the instrumental error using the formulas given in Table 5.1, and compare them in magnitude.

Table 5.1 – Designation of MI accuracy classes

Form of error expression	Method of standardizing the basic error	Examples of designation of the accuracy class, in the documentation	Examples of designation of the accuracy class, on MI	Basic permissible error limit, %
Absolute	According to the formulas: $\Delta = \pm a = \text{const}$; $\Delta = \pm(a + bX)$. In the form of graphs, tables, etc.	Accuracy class C Accuracy class IV Accuracy class A_2	C IV A_2	Specified in technical regulatory legal acts
Reduced	According to the formula $\gamma = \frac{\Delta}{X_N} 100\,\% = \pm p$ p = (1; 1.5; 2; 2.5; 3; 4; 5; 6) 10^n; n = 1; 0; –1; –2;... X_N is expressed in units of the measured value	Accuracy class 2.5 1.0 (scale with conditional zero)	2.5 |1|	$\gamma = \pm 2.5$ $\gamma = \pm 1.0$
	X_N is expressed in the length of the working section of scale	Accuracy class 0.5	0.5	$\gamma = \pm 0.5$
Relative	According to the formula $\delta = \frac{\Delta}{X} 100\,\% = \pm p$	Accuracy class 2.0	2.0	$\delta = \pm 2.0$
	According to the formula $\delta = \frac{\Delta}{X} 100\,\% = \pm\left[c + d\left(\left\|\frac{X_K}{X}\right\| - 1\right)\right]$, c, d = (1; 1.5; 2; 2.5; 3; 4; 5; 6) 10^n; n = 1; 0; –1; –2;... $c = b + d$, $d = a / X_K$	Accuracy class 0.02/0.01	0.02/ 0.01	$\delta = \pm\left[0.02 + 0.01\left(\left\|\frac{X_K}{X}\right\| - 1\right)\right]$, where 0.02 = c, 0.01 = d
	In the form of tables, graphs, etc.	Accuracy class D Accuracy class G_1 Accuracy class III	D G_1 III	Specified in technical regulatory legal acts
Note: X is the measured value of the quantity; X_N – normalizing value; X_K – the largest (modulo) from the measurement limits.				

5.3 Tasks for independent solution

In tasks 5.3.1–5.3.4, it is necessary to determine the limit of the absolute, relative and reduced instrumental error in measuring current and voltage, if the measurements were carried out by magnetoelectric devices with accuracy classes *K* and measurement limits *A* (Table 5.2).

Table 5.2 – Initial data for tasks 5.3.1–5.3.5

Parameter	Variant									
	1	2	3	4	5	6	7	8	9	10
A_1	250	25	150	75	50	300	80	30	60	100
A_2	200	10	75	25	20	500	100	15	30	150
K_1	(1.0)	(2.5)	4.0/0.001	0.2/0.003	(0.5)	2.5	1.5	0.1/0.004	(2.0)	2.5
K_2	0.5	4.0	5.0	(1.5)	1.0	(1.5)	(2.0)	0.25	4.0	(2.0)
K_3	1.0 ∨	2.0 ∨	0.5 ∨	0.4 ∨	1.5 ∨	1.0 ∨	2.0 ∨	0.5 ∨	0.4 ∨	1.5 ∨
X_1	185	7.8	76	21.5	19	282	65	12.8	27.5	72
X_2	180	8.6	70	20.1	18.2	270	63	12.7	25.8	79
l_X	70	15	60	40	35	75	50	20	40	55

5.3.1 Measurement result $I = X_1$ (mA), milliammeter with zero at the beginning of the scale, accuracy class K_1, measurement limit A_1 (mA).

5.3.2 Measurement result $I = X_1$ (mA), milliammeter with zero in the middle of the scale, accuracy class K_2, measurement limit $\pm A_1$ (mA).

5.3.3 Measurement result $U = X_2$ (V), voltmeter with zero at the beginning of the scale, accuracy class K_1, limit A_2 (V).

5.3.4 Measurement result $U = X_2$ (V), voltmeter with zero in the middle of the scale, accuracy class K_2, limit $\pm A_2$ (V).

5.3.5 Determine the absolute, relative and reduced instrumental errors in measuring the active resistance $R_X = X_1$ (kOhm) by a combined device, if it has an accuracy class K_3, the length of the working part of the scale L = 80 mm, the mark R_X corresponds to the length of the part of the scale l_X (mm) (see table 5.2).

6 METHODOLOGICAL MEASUREMENT ERROR

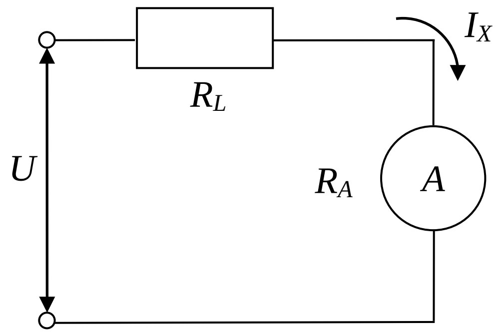
6.1 Brief theoretical information

Methodological error is one of the components of the error of the measurement result and arises due to the imperfection of the measurement method. It depends only on the method used and does not depend on the error of the MI itself. Using standard measurement methods and recommended measuring instruments for specific measurement experiments, the results obtained will contain a small methodological error compared to the instrumental one. If the measurement experiment is not planned correctly, the methodological error can be significant, and it must be assessed and, if possible, excluded from the measurement result.

Let's consider the features of finding and eliminating methodological errors using the example of measuring direct current and voltage.

6.1.1 *Methodological error when measuring current*

A simplified circuit for measuring direct current is shown in Figure 6.1.



R_A – the internal resistance of the ammeter; R_L – the load resistance

Figure 6.1 – DC current measurement

From a physical point of view, when an ammeter is connected to the circuit under study, the electrical mode of its operation changes, since the ammeter consumes some power, which leads to the appearance of a methodological error.

Let current I (actual current value) flow in the measuring circuit before the ammeter was turned on, the value of which can be determined by the formula [1]:

$$I = \frac{U}{R_L}, \tag{6.1}$$

where U – the voltage drop across the load;
R_L – load resistance.

After turning on the ammeter, the current in the circuit will be equal to the measured value:

$$I_X = \frac{U}{R_L + R_A}, \tag{6.2}$$

where R_A – the internal resistance of the ammeter.

Knowing the actual I and measured I_X current values, you can find the relative methodological measurement error using the formula

$$\delta_{MI} = \frac{I_X - I}{I} \cdot 100\,\% = -\frac{1}{1 + \dfrac{R_L}{R_A}} \cdot 100\,\%. \qquad (6.3)$$

Analyzing formula (6.3), we can draw the following conclusions:

- knowing the values of R_A (according to the characteristics of the ammeter) and R_L, you can estimate the methodological error δ_{MI} a priori (before the experiment);
- reducing δ_{MI} is possible if the condition $R_A << R_L$ is met, i. e. it is necessary to choose an ammeter with the smallest possible R_A;
- when designing ammeters, it is necessary to reduce the internal resistance of the R_A ammeter;
- the “minus” sign indicates that the measured current value I_X is always less than the actual I;
- in the ideal case δ_{MI} will tend to zero if R_A tends to zero.

A methodological error is always present as a result of measuring current strength and is systematic. If the condition $R_A << R_L$ is not satisfied, then δ_{MI} must be assessed and excluded from the measurement result by introducing a correction q_I using the formula

$$I = I_X + q_I\,, \qquad (6.4)$$

where

$$q_I = -\frac{\delta_{MI}}{100 + \delta_{MI}} \cdot I_X\,. \qquad (6.5)$$

After introducing a correction, the measurement result is called corrected, i. e. it does not contain a methodological error.

6.1.2 *Methodological error when measuring voltage*

A simplified circuit for measuring DC voltage is shown in Figure 6.2.

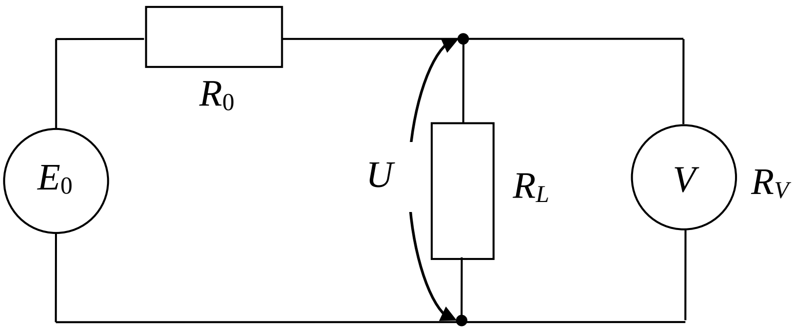
From a physical point of view, when making measurements, the voltmeter consumes some power from the circuit under study, which leads to a change in the electrical mode of its operation and the appearance of a methodological error.

Before connecting the voltmeter to the measuring circuit, the voltage U (real voltage value) at the load R_L can be determined by the formula

$$U = \frac{E_0 \cdot R_L}{R_0 + R_L}. \qquad (6.6)$$

After connecting the voltmeter, the voltage U_X (measured voltage value) on the load R_L is determined by the formula

$$U_X = \frac{E_0}{R_0 + \frac{R_L \cdot R_V}{R_L + R_V}} \cdot \frac{E_L \cdot R_V}{R_L + R_V}. \quad (6.7)$$



E_0 – EMF of the power source; R_0 – internal resistance of power supply; R_V – the input resistance of the voltmeter; R_L – load resistance

Figure 6.2 – DC voltage measurement

Knowing the actual U and measured U_X values, the relative methodological error in voltage measurement is determined by the formula

$$\delta_{MU} = \frac{U_X - U}{U} \cdot 100\,\% = -\frac{1}{1 + \frac{R_V}{R_L} + \frac{R_V}{R_0}} \cdot 100\,\%. \quad (6.8)$$

Analyzing formula (6.8), we can draw the following conclusions:

- knowing the values of R_V (according to the characteristics of the voltmeter), R_L and R_0, it is possible to estimate the methodological error δ_{MU} a priori (before the experiment);

- decreasing δ_{MU} is possible if the conditions $R_V >> R_L$ and $R_V >> R_0$ are met, i. e. it is necessary to select a voltmeter with the highest possible input resistance R_V;

- when designing voltmeters, it is necessary to increase the input resistance R_V;

- in the ideal case δ_{MU} will tend to zero if R_V tends to infinity;

- the “minus” sign indicates that the measured voltage U_X is always less than the actual U.

This error is always present as a result of measuring DC voltage and is systematic. If the conditions $R_V >> R_L$ and $R_V >> R_0$ are not met, then δ_{MU} must be assessed and excluded from the measurement result by introducing the correction q_U, according to the formula

$$U = U_X + q_U, \quad (6.9)$$

where

$$q_U = -\frac{\delta_{MU}}{100 + \delta_{MU}} \cdot U_X. \quad (6.10)$$

After introducing a correction, the voltage measurement result is called corrected, i. e., it does not contain a methodological error.

6.2 Basic recommendations for solving tasks

6.2.1 Reasoning in a similar way (see subsection 6.1), one can find the methodological error of any methods of measuring other physical quantities.

6.2.2 After analyzing the problem conditions, draw a simplified diagram of the measurement experiment.

6.2.3 Derive a formula for the measured value of a quantity.

6.2.4 Derive a formula for the corrected value of the measured quantity.

6.2.5 Assess the relative methodological error of the measurement result.

6.2.6 Analyze the methodological error formula and draw conclusions:

- what does the methodological error depend on;
- what conditions must be met for it to tend to zero;
- if these conditions are not met, then find the correction and estimate the corrected value of the measured value;
- draw a conclusion about the value of the measurement result in comparison with the corrected value of the measured value.

6.3 Tasks for independent solution

6.3.1 Construct a circuit for measuring active resistance (R_X) using the indirect ammeter-voltmeter method. The current measured by the ammeter is equal to I_X, the voltage measured by the voltmeter is equal to U_X. The internal resistance of the ammeter is R_A, and the input resistance of the voltmeter is R_V. Derive a formula for the methodological error in measuring R_X and draw a conclusion on its reduction. Find the corrected value of the measured resistance. The decision process should be carried out in accordance with subsection 6.2. Evaluate the quantitative value of the measurement result R_X, the methodological error δ_{MR}, the correction q_R and the corrected value of the measurement result R_{xd}. The initial numerical values of I_X, U_X, R_A and R_V are given in Table 6.1.

Table 6.1 – Initial data for task 6.3.1

Parameter	Variant									
	1	2	3	4	5	6	7	8	9	10
I_X, mA	0.08	0.4	2.5	9.6	51	0.15	1.7	17.3	167.7	1.2
U_X, V	1.4	2.8	10.5	15.8	0.15	1.6	13.8	11.4	1.9	130.5
R_A, kOhm	1.133	0.285	0.06	0.016	0.004	1.01	0.104	0.015	0.006	0.06
R_V, kOhm	30	60	240	600	10000	10000	10000	10000	10000	10000

7 MEASUREMENT OF AC VOLTAGE

7.1 Brief theoretical information

Electrical voltage that changes its value over time is called *alternating*, in contrast to direct voltage, which does not change its value over time.

Alternating voltage can be characterized by the following main parameters: instantaneous, average rectified, root mean square, maximum, minimum, average value and voltage swing. Let's look at these concepts from a mathematical point of view.

The *instantaneous* value of alternating voltage in general depends on time:

$$u = f(t). \tag{7.1}$$

In a particular case, the sinusoidal shape of the instantaneous voltage value has a mathematical description [1]:

$$u = U_m \cdot \sin(\omega t + \varphi), \tag{7.2}$$

where U_m – the *maximum* (*peak*) voltage value of all instantaneous values for the period;

ωt – the voltage phase at different times;

φ – initial phase of sinusoidal voltage at time $t = 0$.

The *average rectified* voltage value is the arithmetic mean of the modules of instantaneous values in a given time interval (for periodic signals – for a period):

$$U_{AR} = \frac{1}{T} \cdot \int_0^T |u|\, dt, \tag{7.3}$$

where T – the period of the measured voltage.

The *root mean square* voltage value is determined by the formula

$$U_{RMS} = \sqrt{\frac{1}{T} \cdot \int_0^T u^2\, dt}. \tag{7.4}$$

The *average* value (constant component) of voltage is determined by the formula

$$U_0 = \frac{1}{T} \cdot \int_0^T u\, dt. \tag{7.5}$$

In addition to the listed parameters, it is convenient to characterize the shape of the alternating voltage by the maximum $U_{\max}$, minimum $U_{\min}$ and swing U_s voltage Knowing $U_{\max}$ and $U_{\min}$ we can determine the voltage range using the formula

$$U_s = U_{\max} - U_{\min}. \quad (7.6)$$

The relationship between peak U_m and root-mean-square U_{RMS} values is established by the *amplitude coefficient*:

$$k_A = U_m / U_{RMS}. \quad (7.7)$$

The relationship between the root-mean-square (U_{RMS}) and average-rectified (U_{AR}) voltage values is determined by the *form factor*:

$$k_F = U_{RMS} / U_{AR}. \quad (7.8)$$

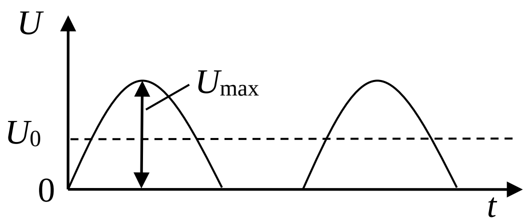
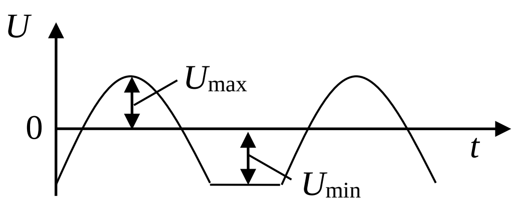
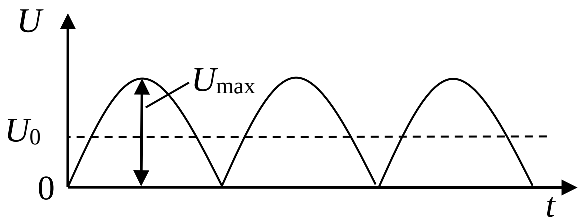
Sometimes, for the convenience of calculations, an *averaging coefficient* is used:

$$k_{AV} = k_A \cdot k_F = U_m / U_{AR}. \quad (7.9)$$

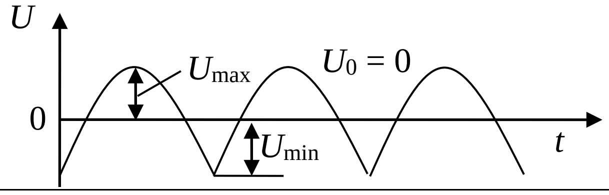
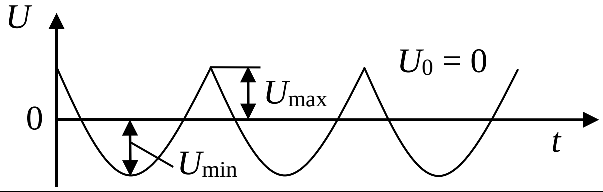
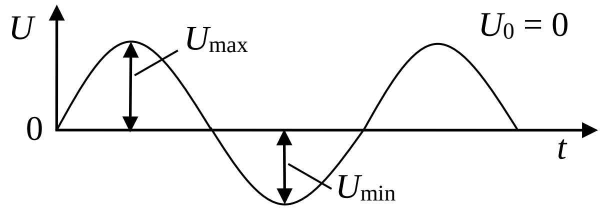
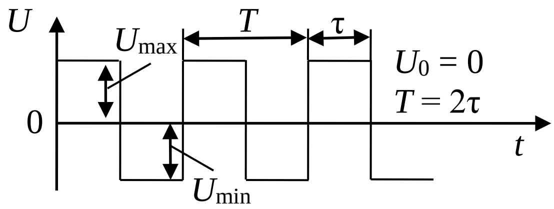
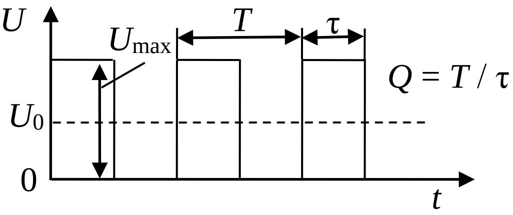
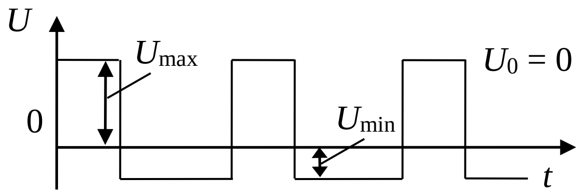
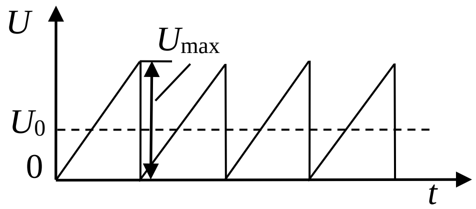
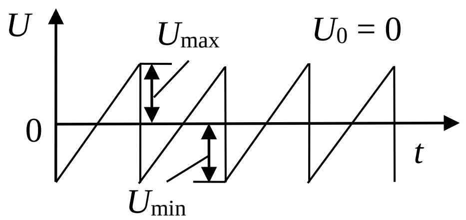
These coefficients make it possible to determine any variable voltage parameter if one of its parameters and the voltage shape are known.

In addition to sinusoidal signals, non-sinusoidal signals are widely used in radio electronics. The values of k_A, k_F, k_{AV} for different voltage forms are given in Table 7.1.

Table 7.1 – Values of k_A, k_F, k_{AV}

<table>
<tr><td>Voltage form, $U = f(t)$</td><td>k_A</td><td>k_F</td><td>k_{AV}</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td>
</td><td>2</td><td>1.57</td><td>3.14</td></tr>
<tr><td>
</td><td>1.77</td><td>1.1</td><td>1.94</td></tr>
<tr><td>
</td><td>1.41</td><td>1.11</td><td>1.57</td></tr>
</table>

Continuation of the Table 7.1

1	2	3	4
	1.18	1.15	1.36
	2.07	1.15	2.375
	1.41	1.11	1.57
	1	1	1
	$\sqrt{Q}$	$\sqrt{Q}$	Q
	$\sqrt{Q-1}$	$\dfrac{Q}{2\sqrt{Q-1}}$	$Q/2$
	1.73	1.16	2
	1.73	1.16	2

A generalized block diagram of an analog voltmeter is presented in Figure 7.1.

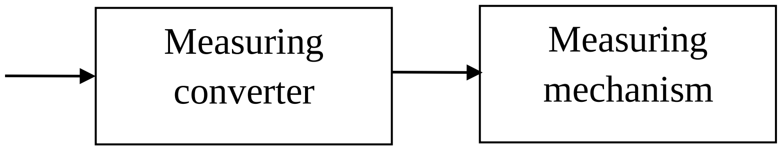
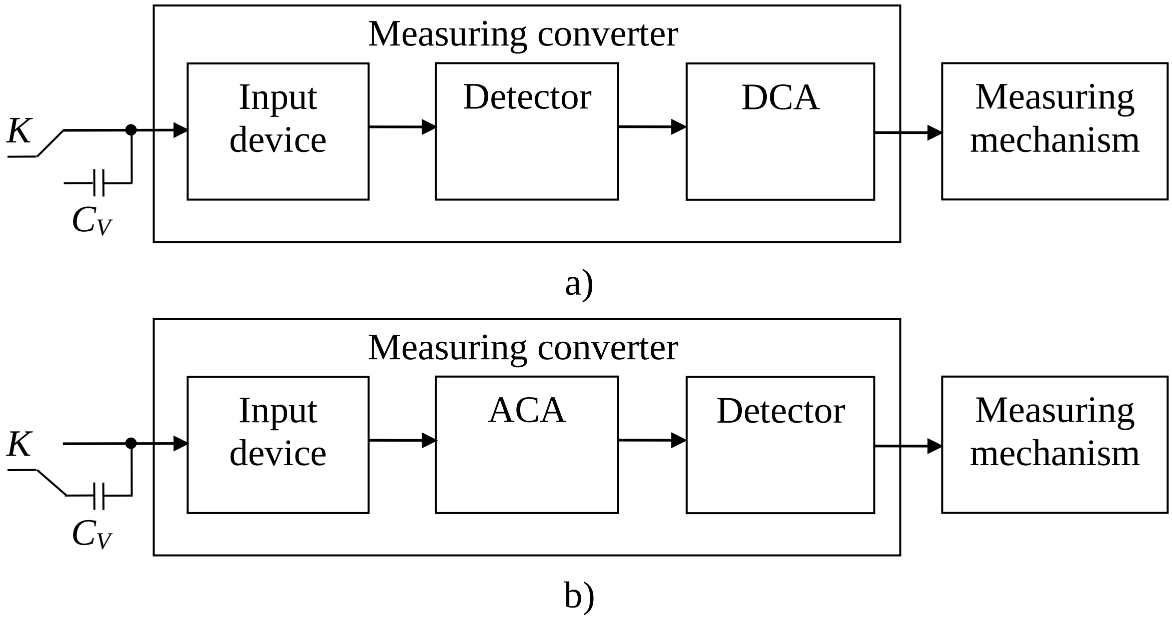


Figure 7.1 – Generalized block diagram of an analog voltmeter

The main purpose of the measuring converter is to convert the measured voltage into a proportional value of direct current, capable of deflecting the arrow of the measuring mechanism at an angle corresponding to the input voltage level.

In DC voltmeters (type B2 voltmeters), the measuring transducer is an input device and a DC amplifier. In AC voltmeters (voltmeters of type B3, B4) – an input device, a detector in combination with an AC or DC amplifier. Figure 7.2 shows block diagrams of AC voltmeters.



DCA – direct current amplifier; ACA – alternating current amplifier
a) with a detector at the entrance; b) with a detector at the output

Figure 7.2 – Block diagrams of AC voltmeters

A voltage divider or attenuator is usually used as an input device, expanding the measurement limits.

The measurement result is influenced by the voltmeter input parameters. If the input is open when key *K* is in the upper position (see Figure 7.2, a), the entire measured voltage is supplied to the input device. If the input is closed when key *K* is in the lower position (see Figure 7.2, b) and connects capacitance C_V to the input connector of the voltmeter, only the alternating component of the measured voltage is supplied to the input device, i. e., without the direct component.

The circuit with a detector at the input (see Figure 7.2, a) has a wide frequency range of measured voltages (from 20 Hz to 3000 MHz), but has low sensitivity (several divisions per millivolt).

The circuit with a detector at the output (see Figure 7.2, b) is limited by the frequency bandwidth of the ACA (up to 50 MHz), but thanks to it has higher sensitivity.

The main converting element of alternating voltage into direct voltage in the circuits under consideration is the detector. The type of detector determines the type of voltage being measured. If the detector is peak, then the voltmeter measures the voltage proportional to U_m, if the detector is a mean-rectified value – U_{AR}, if the detector is root-mean-square – U_{RMS}. The result of measurements with a voltmeter depends not only on the type of detector, but also on the calibration of the scale of the measuring mechanism.

During the manufacturing process, voltmeters are calibrated according to a reference sinusoidal voltage. For various types of detectors, the rms or peak values of the sinusoidal voltage are usually marked on the scales, since the main purpose of these voltmeters is to measure sinusoidal voltages, despite the fact that the deviation of the measuring mechanism pointer may be proportional to U_m, U_{RMS} or U_{AR} depending on the electrical circuit of the detector. Let us explain this with an example.

Let us assume that the same reference sinusoidal voltage with an amplitude of 141 mV is simultaneously applied to the inputs of four calibrated voltmeters. The first and fourth voltmeters have peak detectors, the second has an rms detector, and the third has a mean-rectified value detector. The first, second and third voltmeters are designed to measure harmonic voltage and their scales are calibrated in rms values of this voltage, the fourth device is a pulse voltmeter and its scale is calibrated in peak values. After the arrows of all four instruments deviate, the following inscriptions will be made at the marks of their scales, against which the arrows of the measuring mechanisms are installed: for the first three voltmeters – 100, for the fourth – 141. Thus, it is clear that not all voltmeters have scale graduations corresponds to the actual measured voltage parameter. In the case considered, only the second and fourth voltmeters have a correspondence; the first and third voltmeters do not have a correspondence.

This scale graduation complicates measurements of non-sinusoidal voltages and creates difficulties when comparing measurement results obtained with different voltmeters. Therefore, it is necessary to be able to correctly determine the readings of voltmeters, compare the readings of different types of voltmeters with each other, and clearly understand the dependence of the voltmeter readings on the shape of the measured voltage curve.

Knowing the type of detector and the type of scale graduation, you can determine the measurement result. All other parameters of the measured voltage (Table 7.2) are found by knowing k_A, k_F and k_{AV}, i. e. the form of alternating voltage (see Table 7.1).

Table 7.2 – Dependence of the measurement result on the type of detector, voltmeter readings, scale graduation and alternating voltage shape

Detector type	Scale graduation	Measured parameter	Other parameters of the measured voltage
Peak	Peak	$U_m = 1 \cdot U_V$	$U_{RMS} = U_V / k_A$; $U_{AR} = U_V / k_{AV}$
Peak	RMS	$U_m = 1{,}41 \cdot U_V$	$U_{RMS} = 1{,}41 \cdot U_V / k_A$; $U_{AR} = 1{,}41 \cdot U_V / k_{AV}$
RMS value	RMS	$U_{RMS} = 1 \cdot U_V$	$\mathrm{U_m} = k_A \cdot U_V$; $U_{AR} = U_V / k_F$
Average rectified value	RMS	$U_{AR} = 0{,}9 \cdot U_V$	$\mathrm{U_m} = 0{,}9 \cdot U_V \cdot k_{AV}$; $U_{RMS} = 0{,}9 \cdot U_V \cdot k_F$
Note: U_V – reading on the scale of the voltmeter measuring mechanism			

7.2 Basic recommendations for solving tasks

7.2.1 Problems related to measuring alternating voltage are solved using the block diagram of a voltmeter. The main functional units that directly influence the progress of the solution are the elements that determine the input (key position *K*, see Figure 7.2), the type of detector and the measuring mechanism (type of scale graduation).

7.2.2 Using tables 7.1 and 7.2 for a given voltage waveform, detector type, scale graduation type and voltmeter reading, find the measurement result and determine all other alternating voltage parameters.

7.3 Tasks for an independent solution

7.3.1 The sawtooth voltage (Figure 7.3) was measured with five voltmeters. Basic technical data and voltmeter readings are given in Table 7.3. Find the maximum value of the measured voltage U_m according to the readings of each of the voltmeters. Find the reading of each voltmeter.

Table 7.3 – Initial data for task 7.3.1

Voltmeter number	1	2	3	4	5
Detector	Average rectified value	RMS value	Peak	Average rectified value	Peak
Scale graduation	RMS	RMS	Peak	RMS	Peak
Entrance	Closed	Closed	Closed	Open	Open
Voltmeter reading	A	B	C	D	E

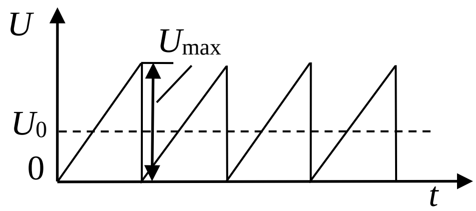


Figure 7.3 – Voltage waveform

8 BASICS OF STANDARDIZATION

8.1 Brief theoretical information

Standardization – an activity to establish rules and characteristics for their voluntary and repeated use, aimed at the achievement of order in the sphere of production and circulation, and enhance the competitiveness of products, works and services.

Standardization should be regarded as a practical activity as management and as a science.

Standardization as a practical activity is to establish regulations on standardization and application of rules, regulations and requirements, providing an optimal solution repetitive tasks in the areas of social production and social life.

Standardization as a practice management system is carried out on the basis of the State standardization system, a system of planned management practice standardization activities. It is based on a set of normative and technical documents establishing interrelated demands on the organization and method of implementation of practical work on standardization.

Standardization as a science about the methods and means of standardization identifies, summarizes and formulates the laws on standardization activities in general and its individual areas. Development of standardization as a science helps to improve the system of organization of these activities and contributes to the improvement of practical work in this field.

Standardization objects: common consumption goods; technological processes; forms and methods of work organization and production; rules for execution of production and control operations; terms of transportation and storage of goods; labor safety and health of population; rational use of natural resources; protection and improvement of the natural human environment; efficient use of information and understanding of people and etc.

Objectives of standardization:

- increase the level of safety of life and health of citizens, property of individuals and legal entities, state or municipal property, environmental safety, animal and plant life and health safety and facilitating compliance with the requirements of technical regulations;
- improve safety facilities, taking into account the risk of emergency situations of natural and technogenic character;
- providing scientific and technical progress;
- improving the competitiveness of products, works and services;
- rational use of resources;
- technical and information compatibility;
- comparability of results of researches (tests) and measurements, technical, economic and statistical data;
- interchangeability of products.

Types of standards: regulation; interstate standards; state standard; branch standard; the enterprise standard; standards of scientific, technical and engineering societies; technical conditions; rules; recommendations.

The main international organization engaged in standardization activities is the International Standards Organization (ISO). Standards adopted by this organization receive the abbreviation ISO and have the rank of international.

The fields of electrical engineering, electronics, radio communications, instrumentation are not within the competence of ISO. Standardization in these areas is carried out by the International Electrotechnical Commission (IEC). In the field of information technology standardization, ISO and IEC have combined their activities, creating Joint Technical Committee 1 (JTC1).

The following designations of standards are accepted abroad and in Belarus:

- the category of the standard is written first; for example, СТБ is the standard of Belarus, ГОСТ Р is the state standard of Russia, ГОСТ is an interstate standard for a number of CIS countries, before the collapse of the USSR the abbreviation ГОСТ denoted the state standard of the USSR, ISO/IEC is the international standard of the ISO and IEC organizations;
- if the standard was developed by the method of direct application (for example, it is an authentic translation of an international standard), then the category of the standard is followed by the designation of the category of the basic standard;
- then comes the standard number; in this case, if the standard was developed by the method of direct application, its number coincides with the number of the basic standard;
- if the standard consists of several parts, then the number of its part is written after the standard number; for example, ISO/IEC 14598–1;
- after the number of the standard (or its part), the year of its approval is written; for example, ISO/IEC 9126:1991;
- if the standard is still under development, but there is a need to publish its materials, then in the designation of ISO/IEC standards after the category, the abbreviation TR (Technical Report) is written; for example, ISO/IEC TR 15271:1998.

Existing standards can be divided into two main types: product standards, which define their characteristics and requirements; process standards, which define specific methods for creating products.

8.1.1 *Basic methods of standardization*

Basic methods of standardization are: limitation method, typification method, unitization method, unification method and method of preferred numbers. All these methods find wide application in radio electronics as a branch of the national economy which has a big variety and nomenclature of componentry and materials used.

Limitation (simplification) is the standardization method consisting in selection from the existing set and in rational limitation of objects nomenclature, allowed for application in the given branch at the given factory or in any object (product). Application of the limitation method maintains a certain number of already existing objects and sharply reduces the total number of their types. For example, the state standards (SS) can be restricted by the branch standards, and the branch standards by the factories standards.

Typification is the standardization method consisting in rational reducing of objects types by determining some typical objects carrying out the functions of the majority of objects of the given set and applied as basis (foundation) for creation of other objects, analogue or close in functionality. This method is often called the method of “basic construction”.

Efficiency of the method consists in the following:

- while designing a new product a reliable way, method, construction or basic model eliminating searches and possible errors is used;
- major continuity in manufacture is provided while changing the devices models created on one basis; production preparation is considerably sped up and its performance charges are reduced;
- service conditions and repairing of equipment having many common constructive elements or operating principles are considerably facilitated;
- different modifications (dimension-type lines) can be easily created on the basis of typical (basic) products.

Unitization and unification methods are the basic standardization methods which are used while designing new products and are recommended for further wide use. These methods have much in common and at the same time they differ in essence from each other.

Unitization is the standardization method consisting in creation of objects of special functional purpose on the basis of functional interchangeability of their components. This method is one of difficult standardization methods. Its characteristic features are: selection and creation of many objects of special functional purpose on the basis of various combinations, a certain set of objects with special functions having dimensional functional interchangeability and normalized parameters.

Application of the unitization method is completed with the development of standards of the corresponding level regulating in some cases the complete characteristics of the standardization object.

Unitization indications:

- functional completeness of components (units, mechanisms, finishing parts, etc.);
- constructive reversibility, i. e. a possibility of a reuse of components (units);
- change of the product functional properties with components shift in it.

Unification is the standardization method consisting in rational reduction of the existing objects nomenclature by selection or creation of new objects of general application, carrying out the majority of objects functions of the given set, but not excluding the usage of other objects with an analogue purpose.

The unification method has the following indications:

- uniformity in constructive design of products;
- functional completeness of products;
- conformity of the main products parameters to the general requirements or conformity of the main line parameters to a certain law;

- possibility of usage of the unified products as a part of various devices or systems of various functional purposes, i. e. certain universality.

Unification leads to quantity reduction of products kinds within the device, the device class or the whole groups. This method is aimed at rational reduction of the existing objects nomenclature.

Thus, if unitization is creation of objects of special functional purpose, the unification method is aimed at creation of multipurpose objects on the basis of original components or objects with special functions.

8.1.2 *Types of standardization and system of preferred numbers*

Standardization types. Depending on the subsequent influence on manufacture development it is possible to single out three types of standardization different in essence by approaches to determination of the corresponding norms in standards: standardization with respect to the achieved level; advanced standardization; integrated standardization.

Standardization with respect to the achieved level is the standardization setting up the parameters, reflecting properties of the existing and mastered product in production and thus fixing the achieved level of production. Such approach is characteristic with standardization of product-quality indexes of mass production of interbranch application (radio components, relays, fastening products, some kinds of raw materials and materials).

Advanced standardization consists in determination of the increased in relation to the already achieved in practice level of norms, requirements to the standardization objects which according to predictions will be optimum in the subsequent time. Thus, depending on real conditions, the stages of quality having differential parameters, norms, characteristics and terms of their introduction can be defined in standards. Thus, the advanced standardization puts certain tasks before the developer and manufacturer of products, encouraging them to improve the standardization objects, to increase their safety and quality.

Integrated standardization is the standardization where for the optimum solution of a specific problem a goal-oriented and systematic determination and application of the interconnected requirements system to the standardization object as a whole and to its basic elements are carried out. Thus the purpose of the integrated standardization is to provide development and introduction of complexes of interconnected and coordinated standards covering totality of requirements to standardization objects: products in whole, their components, raw materials, materials, purchased products, manufacturing method, packaging, transportation and storage, maintenance and repair.

System of preferred numbers

Preference principle is a theoretical base of modern standardization and is used while doing unification, typification and development of standards for products of general application, while solving problems of rational choice and graduation determination of quantitative values of products parameters. This principle is based on the usage of the preferred numbers sequences which are used to choose dimenssion types of details and typical joint units, tolerances sequences, fits and other parameters standardized simultaneously for many industries.

The main properties of the preferred numbers sequences

1. Preferred numbers are calculated according to geometrical progression the i^{th} member of which is equal to $g = \pm 10^{i/R}$ (progression denominator is $\sqrt[R]{10}$), where R = 5, 10, 20, 40, 80, 160, and i is an integral value in the range from 0 to R.

Value R defines the number of the progression members in one decimal interval. Preferred numbers are the rounded values of members of the given progression sequence. The sequence members in the range from 1 to 10 make the initial sequence.

2. Preferred numbers sequences are not restricted in both directions, thus preferred numbers less than 1 and more than 10 are calculated by division or multiplication of members of the initial sequence by 10, 100, 1000, etc.

3. Preferred numbers of the same sequence can be either only positive, or only negative.

4. Product or quotient of two preferred numbers, and also positive or negative orders of the sequence numbers give a preferred number of the same sequence with the relative error from –1.01 % to +1.26 %.

5. Cube of any number of *R*10 sequence is two times more than the cube of the previous number, and the square is 1.6 times more than the square of the previous number with the relative error up to 0.1 %.

6. *R*10 sequence members double after each 3 numbers, *R*20 sequence members – after each 6 numbers, *R*40 sequence members – after each 12 numbers, etc.

7. In sequences, beginning with *R*10, there is number 3.15 which is ≈π, i. e. circumferences lengths and circle squares are approximately equal to preferred numbers if the diameter is a preferred number.

8. *R*40 sequence includes preferred numbers 3000, 1500, 750 and 375, which are synchronous rotational frequencies of motors shafts (rotation/min).

9. Main and additional preferred numbers sequences contain all whole orders of ten.

Main sequences of preferred numbers

Designation and denominators of preferred numbers are given in Table 8.1.

Table 8.1 – Designation and denominators of preferred numbers

Designation of the main sequence	Sequence denominator	
	Rounded value Q_R	Exact value Q_E
*R*5	1.6	$\sqrt[5]{10}$
*R*10	1.25	$\sqrt[10]{10}$
*R*20	1.12	$\sqrt[20]{10}$
*R*40	1.06	$\sqrt[40]{10}$

The main sequences of preferred numbers and their members in the range from 1 to 10 are presented in Table 8.2.

Table 8.2 – The main sequences of preferred numbers and their members

*R*5	*R*10	*R*20	*R*40	Number of the preferred number	Calculated value of the preferred number
1.00	1.00	1.00	1.00	0	1.0000
			1.06	1	1.0593
		1.12	1.12	2	1.1220
			1.18	3	1.1885
	1.25	1.25	1.25	4	1.2589
			1.32	5	1.3335
		1.40	1.40	6	1.4125
			1.50	7	1.4962
1.60	1.60	1.60	1.60	8	1.5849
			1.70	9	1.6788
		1.80	1.80	10	1.7783
			1.90	11	1.8836
	2.00	2.00	2.00	12	1.9953
			2.12	13	2.1135
		2.24	2.24	14	2.2387
			2.36	15	2.3714
2.50	2.50	2.50	2.50	16	2.5119
			2.65	17	2.6607
		2.80	2.80	18	2.8184
			3.00	19	2.9854
	3.15	3.15	3.15	20	3.1623
			3.35	21	3.4394
		3.55	3.55	22	3.5481
			3.75	23	3.7584
4.00	4.00	4.00	4.00	24	3.9811
			4.25	25	4.2170
		4.50	4.50	26	4.4668
			4.75	27	4.7315
	5.00	5.00	5.00	28	5.0119
			5.30	29	5.3088
		5.60	5.60	30	5.6234
			6.00	31	5.9566
6.30	6.30	6.30	6.30	32	6.3096
			6.70	33	6.6834
		7.10	7.10	34	7.0795
			7.50	35	7.4989
	8.00	8.00	8.00	36	7.9433
			8.50	37	8.4140
		9.00	9.00	38	8.9125
			9.50	39	9.4406
10.00	10.00	10.00	10.00	40	10.0000

When it is necessary to restrict the main sequences, the maximum (limiting) members which are always included into restricted sequences are specified in their designations. For example:

- *R*10 (1.25...) is *R*10 sequence restricted by the member 1.25 (inclusive) as the bottom limit;
- *R*20 (...45) is *R*20 sequence restricted by the number 45 (inclusive) as the top limit;
- *R*40 (75...300) is *R*40 sequence restricted by the members 75 and 300, both members inclusive.

Additional sequences of preferred numbers

Designations and denominators of additional sequences are given in Table 8.3.

Table 8.3 – Designations and denominators of additional sequences

Additional sequence designation	Denominator	
	Q_R	Q_E
*R*80	1.03	$\sqrt[80]{10}$
*R*160	1.015	$\sqrt[160]{10}$

Designation of restricted additional sequences is similarly to designation of restricted main sequences.

Selective sequences of preferred numbers

Selective sequences of preferred numbers are received by selection of every second, third, fourth, …, n^{th} member of the main or additional sequence beginning with any number of the sequence.

Designation of the selective sequence consists of the designation of the initial main sequence after which a slash and number 2, 3, 4, *n* is put respectively. If the sequence is restricted, the designation should contain members which restrict the sequence. If the sequence is not restricted, at least its one member should be specified. For example:

- *R*5/2 (1…1000000) is a selective sequence consisting of every second member of the main *R*5 sequence, restricted by the members 1 and 1000000;
- *R*10/3 (…80…) is a selective sequence consisting of every third member of the main *R*10 sequence, including member 80 and unlimited in both directions;
- *R*20/4 (112…) is a selective sequence consisting of every fourth member of the main *R*20 sequence, restricted on the bottom limit by member 112;
- *R*40/5 (…60) is a selective sequence consisting of every fifth member of the main *R*40 sequence and restricted on the top limit by member 60.

Selective sequences of preferred numbers should be applied when graduation numbers decrease, an additional effect in comparison with the usage of complete sequence is created, thus it is necessary to give preference to the sequences given in Table 8.4.

Table 8.4

Selective sequences	Q_R	Main sequences with the same denominator
*R*5/3	4.0	
*R*5/2	2.5	
*R*10/3	2.0	
*R*10/2	1.6	*R*5
*R*40/8	1.6	*R*5
*R*20/3	1.4	
*R*20/2	1.25	*R*10
*R*40/4	1.25	*R*10
*R*40/3	1.18	
*R*40/2	1.12	*R*20
*R*80/3	1.09	

The used selective sequence, denominators of which are equal to denominators of the main sequence, is permitted only for the found values of dependent parameters. For selective sequences with equal denominators preference should be given to the sequence containing unity (one) or number the only significant digit of which is 1. For example: 0.01; 0.1; 10; 100, etc.

Compound sequences of preferred numbers

Compound sequences of preferred numbers are received by combination, expansion of the main and (or) selective sequences. Thus the compound sequence has not the same denominator in different intervals. Quantity of the main and selective sequences used to obtain a compound sequence should be minimum. Final and initial members of the adjacent sequences forming the compound sequence should be identical. For example: *R*20 (1…2) *R*10 (2…10) *R*5/2 (10…1000).

Compound sequences of preferred numbers should be applied, if the desired density of parameter values is not equal in the interval under study.

Approximate preferred numbers

In the justified cases instead of the main sequences of preferred numbers R and individual numbers of these sequences it is possible to apply sequences of approximate preferred numbers, and also individual approximate preferred numbers *R′* and *R″*, given in table 5 of ГОСТ 8032 [5].

Derived preferred numbers sequences

Derived preferred numbers sequences are set for cases in which because of the natural regularity geometric sequences cannot be applied. Derived sequences are received by transformation of the main and additional sequences of preferred numbers, and according to this the derived sequences of preferred numbers are also divided into main and additional.

Derived sequences of preferred numbers can be: decreasing; complementary; arithmetical.

Decreasing sequences of positive preferred numbers

Decreasing sequences of positive preferred numbers are received on the basis of decreasing geometrical progression i^{th} member of which is equal to:

$$\downarrow g_i = \frac{1}{g_i} = 10^{-\frac{i}{R}}.$$

These number sequences are used to determine parameters values of asymptotically approaching 0 (for example, pollution of substances). Decreasing sequences of positive preferred numbers contain numbers given in tables (given above). Designation of a decreasing sequence of positive preferred numbers is received by addition to the designation of each main or additional sequence of preferred numbers of the sign down arrow ↓. For example: ↓*R*5, ↓*R*10 (…1,25), ↓*R*20 (45…), ↓*R*40 (300…75). Designation rules of compound and selective sequences are valid for decreasing sequences of positive preferred numbers.

Complementary preferred sequences

Complementary preferred sequences are received on the basis of the decreasing geometrical progression. Expression for i^{th} member of complementary sequence looks like the following:

$$\overline{g}_i = 10^m - \downarrow g_i .$$

where *m* – an integer number or 0.

To form complementary sequences it is necessary to take preferred numbers and to subtract them from 10^m. Complementary preferred number sequences should be used to find parameters values of asymptotically approaching to 10^m (for example: purity of substance, efficiency, probability of no-failure operation). Members of complementary sequence, except for some, are not preferred numbers.

Designation of a complementary number:

$$\overline{R}5,\ \overline{R}10,\ \overline{R}10(0.845...),\ \overline{R}20(...0.99955),\ \overline{R}40(0.700...0.925) .$$

Formation rules of complementary preferred sequences are similar for selective and compound sequences of preferred numbers.

Arithmetical preferred numbers sequences

Arithmetical preferred numbers sequences are received on the basis of the arithmetic progression i^{th} member of which is defined by expression:

$$a_i = a_0 \pm 10^m \cdot l_0 \cdot g_i = a_0 \pm \frac{10^m}{R} \cdot i .$$

This expression is true when a_0 is multiple of $\frac{10^m}{R}$ or $\left| a_i \cdot \frac{10^m}{R} \right| \le 100$, where *m* is an integer or 0. Therefore arithmetical preferred numbers sequences are restricted in both directions.

Arithmetical preferred numbers sequences are the arithmetic progression with difference D = 10^m / *R*, and this difference and sequence members have precise values. The condition that a_0 should be multiple of $10^m / R$, is possible to formulate in the following way: in the absence of restrictions the arithmetical preferred numbers sequence should contain 0 as one member.

Arithmetic preferred numbers sequences should be used when we determine the following parameters:

- the sum and difference of which should belong to the same sequence (for example, at block designing and modular coordination of dimensions);
- situated within the restricted limits where linearization is reasonable (for example, air temperature intervals, defining norms, shoes and clothes sizes);
- when the uniform gradation is stipulated by the usage convenience (for example, arguments values in tables, devices scales gradation);
- when precise whole values are necessary (for example, reference values of parameters);
- expressed in logarithms values or dB, for example, noise level norms.

Preferred arithmetic sequences can be positive and negative or can pass through 0. With addition and subtraction the numbers of the preferred arithmetic sequence give a number of the same sequence if it does not go beyond its limits. Designations and differences of the main and additional arithmetic sequences of preferred numbers are given in Table 8.5.

Table 8.5 – Designations and differences of the main and additional arithmetic sequences of preferred numbers

Designation		Significant digits of the difference (precise values)
of the initial geometrical sequence	of the derived arithmetical sequence	
Main sequences		
*R*5	*A*20	2
*R*10	*A*10	1
*R*20	*A*5	5
*R*40	*A*2.5	25
Additional sequences		
*R*80	*A*1.25	125
*R*160	*A*0.625	625

In designations of the arithmetical preferred numbers sequences their difference and the numbers restricting the sequence should be specified.

For example: $A2(-10 \ldots 10)$, $A0.5(0 \ldots 40)$, $A1250(5 \cdot 10^3 \ldots 2 \cdot 10^4)$. Regulations of selective arithmetic sequences are preserved for the arithmetical preferred sequences. In cases when the numbers sequences examined earlier, are used because of natural regularity of parameters value change, special numbers sequences are used.

Special numbers sequences

Let’s examine some special numbers sequences given in ГОСТ 8032.

1. The binary numbers sequence is the sequence the i^{th} member of which is found with the help of expression $f_i = 2^i$. It is used in computer engineering.

2. Arithmetic sequence of time and angular size. When for time measuring seconds and minutes or minutes and hours are used, and for angular sizes measurement they use angular degrees, minutes and seconds, so the preferred special arithmetic sequences having differences of 3 and 1.5 may be used.

3. Standard sequences of nominal capacity of electric capacitors and nominal resistance of resistors are given in Table 8.6.

Table 8.6 – Standard sequences of nominal capacity of electric capacitors and nominal resistance of resistors

Sequence designation	Precise value of the sequence denominator	Approximate value of the sequence denominator
*E*6	$\sqrt[6]{10}$	1.5
*E*12	$\sqrt[12]{10}$	1.2
*E*24	$\sqrt[24]{10}$	1.1
*E*48	$\sqrt[48]{10}$	1.05
*E*96	$\sqrt[96]{10}$	1.02
*E*192	$\sqrt[192]{10}$	1.01

Sequences members of nominal capacity of electric capacitors and nominal resistance of resistors are given in Table 8.7.

Table 8.7 – Sequences members of nominal capacity of electric capacitors and nominal resistance of resistors

Parameter tolerance							
–	± 20 %	±10 %	±5 %	–	±20 %	±10 %	±5 %
*E*3	*E*6	*E*12	*E*24	*E*3	*E*6	*E*12	*E*24
1.0	1.0	1.0	1.0		3.3	3.3	3.3
			1.1				3.6
		1.2	1.2			3.9	3.9
			1.3				4.3
	1.5	1.5	1.5	4.7	4.7	4.7	4.7
			1.6				5.1
		1.8	1.8			5.6	5.6
			2.0				6.2
2.2	2.2	2.2	2.2		6.8	6.8	6.8
			2.4				7.5
		2.7	2.7			8.2	8.2
			3.0				9.1
				10.0	10.0	10.0	10.0

Identical, investigatory, selective sequences: R20/5 ≡ E12/3; R80/5 ≡ *E*48/3; *R*40/3 ≡ *E*24/3; *R*160/5 ≡ *E*96/3.

General rules of application of the preferred numbers sequences

Preferred sequences and their numbers should be used in the following cases.

1) When determining standard values and standard values sequences of quantities.

2) When normalizing values of the products initial parameters, condition of its existence and processes, and also allowing and admitting their deviations.

3) When normalizing values of the products parameters connected by logarithmic dependence with the initial parameters the values of which are normalized with the help of the preferred numbers.

4) When giving parameters values of subjects and processes (including natural constants) if the usage of preferred numbers does not lead to overrunning of admissible deviation limits.

5) It is allowed to use derived and special numbers sequences only if the usage of preferred numbers sequences is not possible or not reasonable.

6) In case of alternative variants it is necessary to give preference to the sequence with a smaller number of gradations.

7) In case of alternative variants it is necessary to give preference to the main sequence before selective or compound one.

8) Usage of additional sequences of preferred numbers and preferred numbers sequences is allowed only if the sequence *R*40 or any random numbers sequence created on its basis does not provide the desired number of gradations. Usage of an additional sequence should be accompanied by a detailed substantiation.

9) It is not allowed to form compound sequences by joining the preferred sequences of different kinds.

For example, geometrical and arithmetical, complementary and geometrical, etc.

8.2 Basic recommendations for solving tasks

8.2.1 Based on the problem conditions and range display, select a table of working number series.

8.2.2 The designation of the series corresponds to a limited series, i. e., starting with the first element (the first number in brackets), write out all the other elements of the series from the required table, including the last element (the second number in brackets). For example, *R*40(1.32...8.5) – from Table 8.2, select the original series *R*40 and write out all its elements, starting with the numbers from 1.32 till 8.5.

8.2.3 If the designation of the series (the numbers in brackets) contains numbers less than 1 and (or) greater than 10, then the elements of the original series (see Tables 8.2, 8.7) must be multiplied or divided by 10^n, where *n* is any integer. For example, *R*40(0.132...85) – from Table 8.2 we select the original series *R*40 and write out all its elements, starting with the number 1.32 to 9.5. We multiply all the numbers in this interval by 10^{-1}, obtaining the first sequence of numbers from 0.132 to 0.95.

The second sequence corresponds to the original series in the interval from 1.0 to 9.5. The third sequence corresponds to the original series of numbers in the interval from 1.0 to 8.5, multiplied by 10^1. Thus, putting these three sequences of numbers together, we get the answer to the task.

8.2.4 If the series is selective and limited, then, starting with the first element of the series (the first number in brackets), select from the table and write down all the other elements of the series corresponding to the designation (the number after the slash), including the last number in brackets of the series designation. For example: *R*40/3(0.132...85) – from Table 8.2, select the original series *R*40, starting with the element 0.132, write down every third element of the series *R*40, including the number 85.

8.2.5 If the series is composite, then, if necessary, using the examples considered in paragraphs 8.2.3 and 8.2.4, write down the sequences of numbers of each series included in the designation of the composite, taking into account the final and initial elements of adjacent series once.

8.3 Tasks for independent solution

8.3.1 Solve the crossword puzzle (Figure 8.1). **Horizontally:** 1. An activity to establish rules and characteristics for their voluntary and repeated use, aimed at the achievement of order in the sphere of production and circulation, and enhance the competitiveness of products, works and services. 4. Which standardization consists in determination of the increased in relation to the already achieved in practice level of norms, requirements to the standardization objects which according to predictions will be optimum in the subsequent time? 6. One of the objectives of standardization is technical and information… 8. Name the main international organization engaged in standardization activities. 9. One of the standards' types. 12. Which standardization is the standardization where for the optimum solution of a specific problem a goal-oriented and systematic determination and application of the interconnected requirements system to the standardization object as a whole and to its basic elements are carried out. **Vertically:** 2. Standardization method consisting in rational reduction of the existing objects nomenclature by selection or creation of new objects of general application, carrying out the majority of objects functions of the given set, but not excluding the usage of other objects with an analogue purpose. 3. Standardization method consisting in creation of objects of special functional purpose on the basis of functional interchangeability of their components. 5. Organization in the field of information technology standardization. 7. Standardization method consisting in selection from the existing set and in rational limitation of objects nomenclature, allowed for application in the given branch at the given factory or in any object. 10. Which organization works in the fields of electrical engineering, electronics, radio communications, instrumentation standardization. 11. Standardization method consisting in rational reducing of objects types by determining some typical objects carrying out the functions of the majority of objects of the given set and applied as basis (foundation) for creation of other objects, analogue or close in functionality.

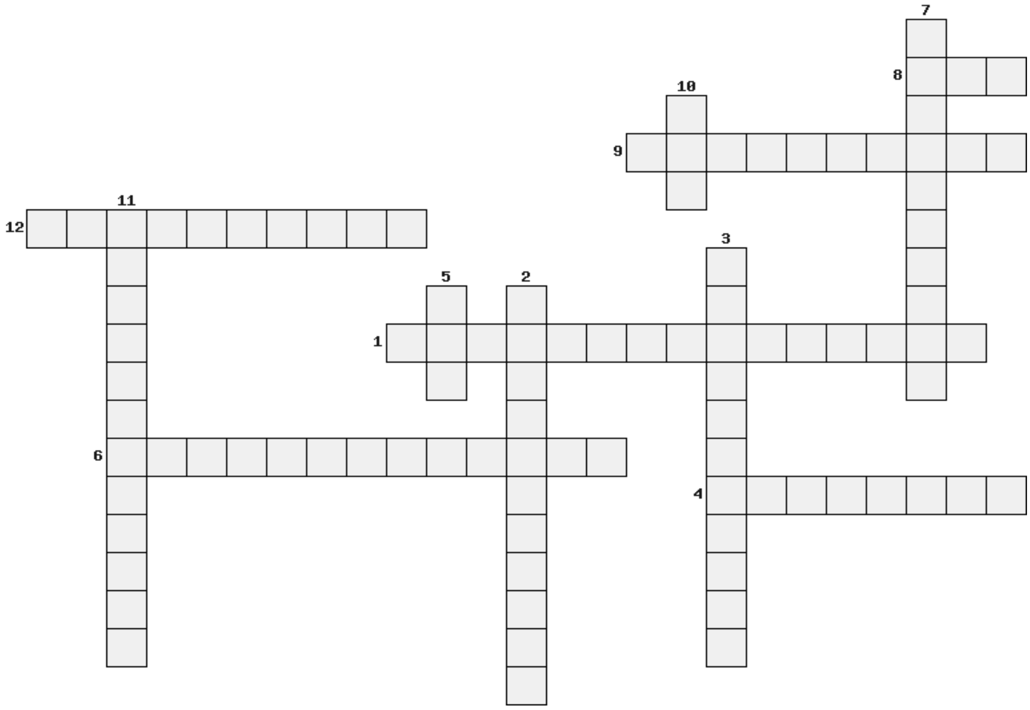


Figure 8.1 – Crossword puzzle

8.3.2 Write down the series of preferred numbers, designated *R*20/4(0.1...39...160).

8.3.3 Write down the series of preferred numbers, designated *R*40/5(0.1...7.6...160).

8.3.4 Write down the series of preferred numbers, designated *R*10/4(0.1...33...160).

8.3.5 Write down the series of preferred numbers, designated *R*20/4(0.1...5.2...160).

8.3.6 Write down in accordance with ГОСТ 8032 the designation of the series (1; 1.5; 2; 3; 5)$\cdot 10^{-n}$, where n = 3, 2, 1, 0, –1, –2, ..., from which the upper values of the limits of the measuring instruments are selected.

8.3.7 Write down the designation of the series in accordance with ГОСТ 8032 from which the final values of the measurement ranges of analog voltmeters are selected (1; 1.2; 1.5; 2; 2.5; 3; 4; 5; 6; 7.5; 8)$\cdot 10^{-n}$, where n = 3, 2, 1, 0, –1, –2.

8.3.8 Write down the values of the nominal resistances of precision resistors corresponding to the series of preferred numbers designated *E*192(1...10).

8.3.9 Write down the designation of the series of nominal voltages of capacitors in accordance with ГОСТ 8032: 1.0; 1.6; 2.5; 3.2; 4.0; 6.3; 10; 16; 20; 25; 32; 40: 50; 63: 80; 100; 125; 160; 200; 250.

9 BASICS OF CERTIFICATION

9.1 Brief theoretical information

Certification is a form of acknowledgment of conformity of objects to the requirements of technical regulations, provisions of standards or conditions of contracts carried out by the certification body.

Certification objects: products; works; services; quality systems; staff; workplaces and etc.

The certification of products, works and services and other objects have 3 sides. *The first side* – the manufacturer or seller. *The second side* – the consumer or buyer. *The third side* – a person or body is recognized like an independent from the parties involved in the matter

The applicant shall submit an application to the certification body, where the identification of product and assessment of conformity are performed and if a positive decision is issued a certificate of conformity.

Certification types: mandatory certification (MC); voluntary certification (VC).

Special features of the MC and VC:

The purpose of the performing: MC – security and environmental goods; VC – ensuring the competitiveness of the commodity, product advertising that it meets not only the security, but also increased quality.

Grounds for certification: MC – the laws of the state; VC – on the initiative of individuals or legal entities on contractual terms between the applicant and the body VC.

The object of certification: MC – lists of goods and services approved by the government; VC – any objects to the applicant's discretion.

The essence of the conformity assessment: MC – assessment of compliance with mandatory requirements stipulated by applicable law; VC – conformity assessment of the applicant's requirements, consistent with the Standards Department as additional requirements for the mandatory.

Regulatory certification database: MC – state standards, technical regulations, sanitary norms and rules, i. e. approved by the state standard documents establishing mandatory requirements for the product; VC – standards of all categories, including foreign and recognized national standard, proposed by the applicant.

9.1.1 *International standards of ISO 9000 series*

Quality of products, processes or services is a sum total of products properties stipulating its suitability to satisfy certain needs according to its purpose.

Quality cannot be ensured only by finished product control. It should be ensured already in the process of the market requirements study, at the stage of design and engineering developments, while choosing the raw material suppliers, materials and componentry, at all stages of manufacture and sales of products, their servicing in operational process by the user and recycling after usage.

Now the most effective quality model is the model of Total Quality Management (TQM). The following main ideas of TQM can be singled out: factory activity is oriented only on satisfying the user requirements; continuous improvement of all spheres of the factory activity in the field of quality; participation of all factory workers in solving quality problems; emphasis is on inadequacy prevention; quality of final object – is the consequence of quality achievement at all previous stages. Thus efficiency of the total quality control depends on personal participation of the factory top management in the problems connected with quality, displacement of the center of gravity of efforts in the problem of quality towards human resources and transformation of organizational structure according to the universal quality management.

To develop the uniform approach to the solution of quality management problems, to eliminate differences and to harmonize requirements at the international level the committee TK 176 “Quality management and quality ensuring” was created as a part of ISO, its activity result was appearance of five standards of ISO 9000 series dedicated to the activity regulation in the field of quality management, and also the trilingual dictionary of terms and definitions in the field of quality.

The main requirements on creation of the general programs of quality control in industry and service industry (banking, hospitals, hotels, restaurants etc.) are established in ISO 9000 series standards. Having established the specific requirements to the quality ensuring systems, they initiated procedures of development, introduction and certification of quality systems, and as a result a new independent direction of management – **quality management** – activity of the administration of an enterprise or organization, directed at creation of such conditions of manufacture, which are necessary and sufficient to make quality products, appeared. In turn **quality management system (QMS)** – a management system to administer and control the organization with regard to quality. General quality management is carried out with the help of **quality system,** which is a sum total of organizational structure, procedures, processes and resources necessary for realization of the quality management.

International standard **ISO 9000** “Quality management systems – Fundamentals and vocabulary” is the fundamental standard in the series of specified standards. This International Standard provides the fundamental concepts, principles and vocabulary for quality management systems (QMS) and provides the foundation for other QMS standards. This International Standard is intended to help the user to understand the fundamental concepts, principles and vocabulary of quality management, in order to be able to effectively and efficiently implement a QMS and realize value from other QMS standards. This International Standard proposes a well-defined QMS, based on a framework that integrates established fundamental concepts, principles, processes and resources related to quality, in order to help organizations realize their objectives. It is applicable to all organizations, regardless of size, complexity or business model. Its aim is to increase an organization’s awareness of its duties and commitment in fulfilling the needs and expectations of its customers and interested parties, and in achieving satisfaction with its products and services.

International standard **ISO 9001** “Quality management systems – Requirements” specifies requirements for a quality management system when an organization: a) needs to demonstrate its ability to consistently provide products and services that meet customer and applicable statutory and regulatory requirements, and b) aims to enhance customer satisfaction through the effective application of the system, including processes for improvement of the system and the assurance of conformity to customer and applicable statutory and regulatory requirements.

Initial stage at QMS creation at the factory is formulation and documentary registration **of policy in the field of quality** by the administration – the main areas and purposes of the factory in the field of quality, officially formulated by the administration. Policy in the field of quality is formulated in the form of activity areas or strategic aims and stipulates improvement of the factory economic condition; expansion of product markets; achievement of a new technological products level; orientation onto meeting users requirements; adoption of new products in essence; improvement of product-quality indexes; decrease of products defectiveness level; increase of products guarantee periods; service development.

Quality system is developed taking into account the specific factory activity, but in any case it should cover all stages of products life cycle – the so-called “quality loops” (Figure 9.1).

QMS should ensure quality management at all stages of products life cycle; ensure participation of all factory workers in the quality management; establish responsibility of the management; ensure continuity of quality activity and costs reduction activity; ensure conducting of preventive inspections to prevent discrepancies and defects; ensure obligatory localization of defects and preventing their appearance in manufacture and in sale; establish order of periodic checks conducting, analysis and system perfection; establish and ensure order of documentary registration of all system procedures.

9.1.2 *Elements of a complete quality system*

The structure of a complete quality system is given in Table 9.1.

ISO 9000 [6] contains recommendations for the most rational choice of the quality system model or its separate elements (proceeding from manufacture needs or contract terms).

Quality system created should consider the factory specific character, its size, production organization structure. Besides, it should be flexible, allowing to make quick modifications.

The qualities system elements given in table 6.1 can be divided into 3 groups.

1. Elements which should be defined or determined by the administration (elements 1, 18).

2. Elements covering several phases or subdivisions, connected with the quality system itself, with company-wide problems and with problems of products (services) (elements 2, 5, 8, 11, 13, 15, 16, 17, 20).

3. Elements of the quality system specific to certain stages (elements 3, and also quality ensuring at different stages of the products life cycle).

The main document describing the quality system is **the quality manual** in which are specified those its elements which characterize the activity areas of the factory administration on ensuring quality of the manufactured products.

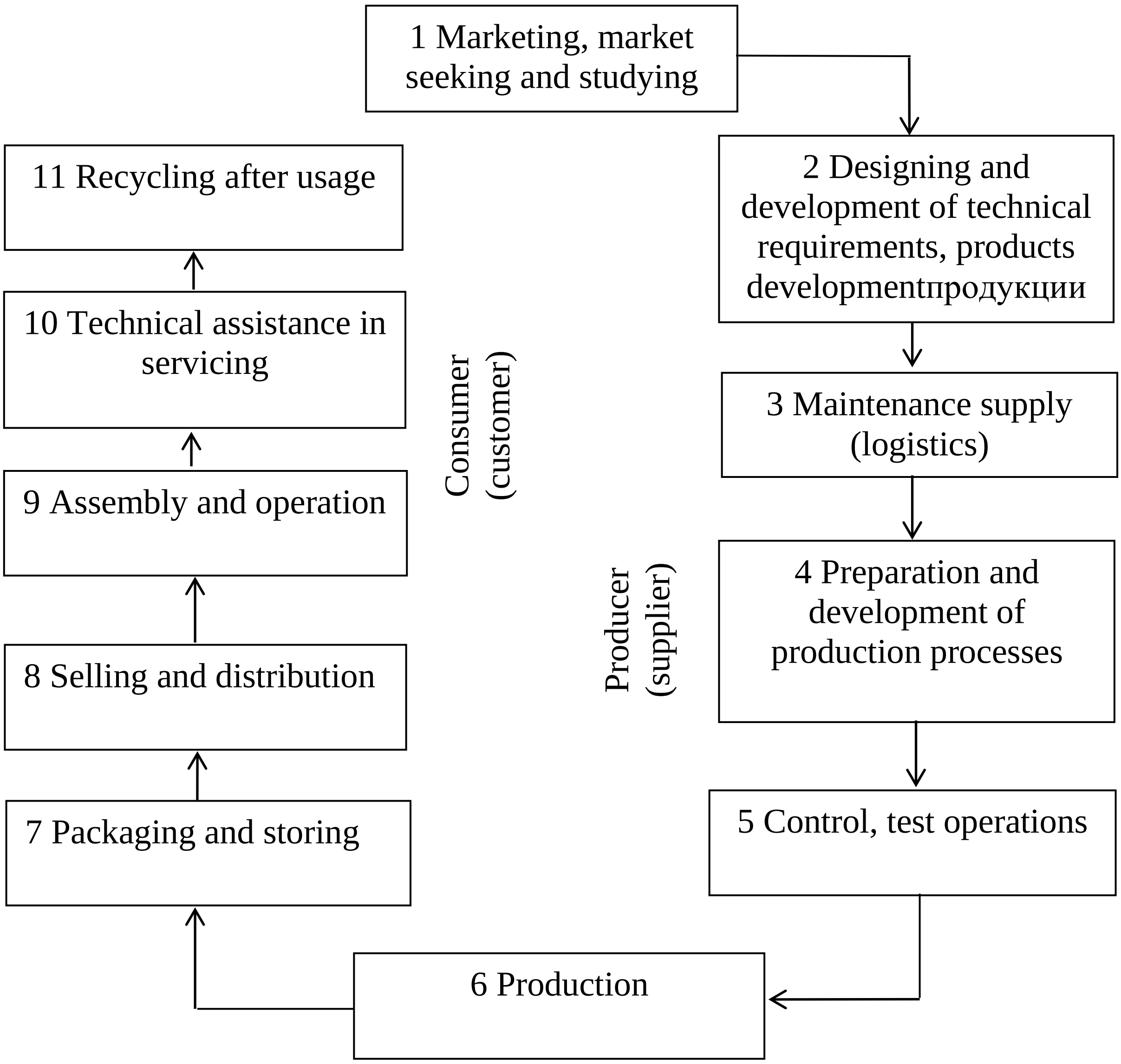


Figure 9.1 – Typical stages of products life cycle (quality loop)

Table 9.1 – Structure of a complete quality system

Elements	Contents
1	2
1 Management responsibility	- policy development in the field of quality; - creation and approval of works structure and organization; - responsibility definition of officials and their powers; - presentation of means and resources, definition and assigning of the necessary personnel; - assigning of the person responsible for all work on quality; - estimation of the quality system by the management
2 Quality system	- methods applied should be written down and updated; - the requirements established should be described explicitly in methodical instructions concerning quality ensuring, in working instructions, tests instructions
3 Periodic analysis of contracts	Development and maintenance in working order of the following procedures: - requirements specification (technical task) formulation; - offers and orders conformance testing; - checking of ability and possibility of the manufacturer to implement the requirements specification; - concordance with the customer
4 Project management	- planning of development engineering activity (DEA); - establishment of DEA aims; - description of DEA results; - checking of DEA results; - establishment and maintenance in working conditions of procedure of definition, documentary registration, checking and approval of all project changes and modifications
5 Documents management	- documentation checking; - permission of the documentation application; - documentation distribution; - rules of the documentation arrangement; - elimination of the out-dated documentation; - modifications documenting
6 Products purchase	- estimation, choice and allowance of sub-suppliers; - documentation checking of maintenance supply (logistics) concerning clarity of the product description and reflection of technical requirements; - acceptance inspection of products bought
7 Products supplied by a consumer (it concerns the products which are supplied by the consumer to be part of the final delivery)	- inspection; - storage; - maintenance; - informing the customer about losses, damages and defects

Continuation of the Table 9.1

1	2
8 Products identifications and traceability	Products identification should have uniform character and be properly registered
9 Technological processes management	Documentary securing of requirements to the method, equipment and their constant control
10 Control and inspection	- incoming inspection; - intermediate inspection; - final inspection; - control and inspection reports
11 Control, measuring and test equipment	Ensuring suitability of the measuring means and test methods
12 Control and tests status (conditions of completion and official registration of control)	Delivery ensuring of products and materials which were tested and received only positive estimation
13 Actions with unsuitable products	Elimination of unintentional usage of defective units. For products of improper quality: - correction to meet the requirements: - acceptance with deviation from the contract; - transfer to another class for usage in other purposes; - penalization and sending to waste products
14 Corrective actions	- elimination of the defects reason; - taking measures to eliminate the defects repetition
15 Handling operations, storage, packaging, delivery	- prevention of damages and reduction of the products quality; - making instructions to conduct this type of work
16 Quality data registration	- correspondence of the quality records of the given product; - deliveries quality records of sub-suppliers; - keeping records of all quality data
17 Administrative (inner) quality inspection	- scheduled and documentary inner quality inspections to prove QMS efficiency; - development of corrective actions to eliminate defects
18 Professional training	- improvement of professional skills of the personnel, responsible for quality
19 Maintenance service (for products delivered to the customer)	- develop and maintain in working conditions the procedures of maintenance service conducting and products inspection for correspondence to the established requirements (if it is mentioned in the contract)
20 Statistical methods	- introduction of suitable statistical methods of quality estimation at all stages of the product life cycle

9.1.3 *Conformity assessment*

Conformity assessment is the demonstration that specified requirements relating to a product, process, system, person or body are fulfilled.

Conformity assessment activities:

1) *Testing* is a determination of one or more characteristics of an object of conformity assessment.

2) *Certification* is a third party assurance that: product (services), process, personnel, organization or management system conforms to specific requirements.

3) *Inspection* is examination of a product design, product, process or installation and determination of its conformity with specific requirements or, on the basis of professional judgement, with general requirements.

4) *Supplier's declaration of conformity* is a first-party attestation.

5) *Accreditation* is a third-party attestation related to a conformity assessment body conveying formal demonstration of its competence.

6) *Mutual recognition & Peer assessment* is an arrangement whereby more than two parties recognize or accept one another's conformity assessment results and assessment of a body against specified requirements by representatives of other bodies in, or candidates for, an agreement.

9.1.3.1 Certification of products

Product certification is the provision of impartial third-party attestation that fulfilment of specified requirements has been demonstrated. Product certification is carried out by product certification bodies which should conform to ISO/IEC 17065. Specified requirements for products are generally contained in standards or other normative documents.

Product certification is an established conformity assessment activity that provides assurance to consumers, regulators, industry and other interested parties that products conform to specified requirements, including for example product performance, safety, interoperability and sustainability.

Product certification can facilitate trade, market access, fair competition and consumer acceptance of products on a national, regional and international level.

The fundamental objectives of product certification are to:

a) address the needs of consumers, users and, more generally, all interested parties by giving confidence regarding fulfilment of specified requirements;

b) allow suppliers to demonstrate to the market that their product has been attested to fulfil specified requirements by an impartial third party body.

Product certification should provide confidence for those with an interest in fulfilment of requirements and product certification should provide sufficient value so that suppliers can effectively market products. Product certification is most successful when it delivers the required confidence while utilizing the fewest possible resources thereby maximizing value.

Whenever product certification is performed a certification scheme is in place.

Product certification schemes should implement the functional. The functions are:

- selection which includes planning and preparation activities in order to collect or produce all the information and input needed for the subsequent determination function;

- determination which may include assessment activities such as testing, measuring, inspection, design appraisal, assessment of services, and auditing to provide information regarding the product requirements as input to the review and attestation functions;

- review which means verification of the suitability, adequacy and effectiveness of selection and determination activities, and the results of these activities, with regard to fulfilment of specified requirements;

- decision on certification;

- attestation which means issue of a statement of conformity, based on a decision following review, that fulfilment of specified requirements has been demonstrated;

- surveillance (where needed) which means systematic iteration of conformity assessment activities as a basis for maintaining the validity of the statement of conformity.

Product certification schemes are developed by defining specific activities for each of the applicable functions described above. The following Table 9.2 specifies how to build a product certification scheme by using these functions and outlines some of the combinations of activities in use in the wide range of fields where product certification is employed.

The following examples do not represent all possible types of product certification schemes. They may be used with many types of requirements and may utilize a wide variety of statements of. All types of product certification scheme involve selection, determination, review, decision and attestation. One or more determination activities should be selected from among those in Table 6.2 considering the product and the specified requirements. The types of schemes referred to in Table 6.2 differ according to which surveillance activities (if applicable) are carried out. For scheme types 1a and 1b, no surveillance is required since the attestation relates only to the product items which have been subjected to the determination activities. For the other scheme types outline the way in which the different surveillance activities can be used and the circumstances to which they could be applicable.

Scheme Type 1a

In this scheme, one or more samples of the product are subjected to the determination activities. The samples are representative of subsequent production items but these items are not covered by the attestation of conformity. A certificate of conformity or other statement of conformity (e. g. a letter) is issued for the product type, the characteristics of which are detailed in the certificate or a document referred to in the certificate. Subsequent production items cannot be described as “certified” but could be referred to as being manufactured in accordance with the certified type.

Table 9.2 – Building a product certification scheme

Conformity assessment functions and activities [a] within product certification schemes	**Types of product certification schemes [b, c]**							
	1a	**1b**	**2**	**3**	**4**	**5**	**6**	**N [d]**
1) **Selection**, including planning and preparation activities, specification of requirements e. g. normative documents, and sampling as applicable	x	x	x	x	x	x	x	
2) **Determination of characteristics**, as applicable, by: a) testing b) inspection c) design appraisal d) assessment of services or processes e) other determination activities, e. g. verification	x	x	x	x	x	x	x	
3) **Review** Examining the evidence of conformity obtained during the determination stage to establish whether the specified requirements have been met	x	x	x	x	x	x	x	
4) **Decision on certification** Granting, maintaining, extending, reducing, suspending, withdrawing certification	x	x	x	x	x	x	x	
5) **Attestation, licensing** a) issuing a statement of conformity (attestation)	x	x	x	x	x	x	x	
b) Granting the right to use certificates, marks or other statements of conformity on products conforming to the specified requirements (licensing)		x	x	x	x	x	x	
6) **Surveillance**, as applicable, by: a) testing or inspection of samples from the open			x		x	x		
b) testing or inspection of samples from the factory				x	x	x		
c) assessment of the production, the delivery of the service or the operation of the process				x	x	x	x	
d) management system audits combined with random tests or inspections						x	x	

[a] Where applicable, the activities can be coupled with initial audit and surveillance audit of the applicant's management system or initial assessment of the production process. The order in which the assessments are performed may vary and will be defined within the scheme.
[b] A product certification scheme includes at least the activities 1), 2), 3) 4) and 5a).
[c] An often used and well-tried model for a product certification scheme is described in ISO/IEC Guide 28; it is a product certification scheme corresponding to scheme type 5.
[d] The symbol N has been added to show an undefined number of possible other schemes, that can be based on different activities.

Scheme Type 1b

This scheme type involves the certification of a whole batch of products following selection and determination as specified in the scheme. The proportion to be tested would be based, for example, on the homogeneity of the items in the batch and the application of a sampling plan where appropriate. If the outcome of the determination is positive, all items in the batch may be described as certified and may have a mark of conformity affixed if that is included in the scheme.

Scheme Type 2

The surveillance part of this scheme involves periodically taking samples of the product from the market and subjecting them to determination activities to check that items produced subsequent to the initial attestation fulfil the specified requirements. While this scheme may identify the impact of the distribution channel on conformity, the resources it requires can be extensive. Also, when significant nonconformities are found, effective corrective measures may be limited since the product has already been distributed to the market.

Scheme Type 3

The surveillance part of this scheme involves periodically taking samples of the product from the point of production and subjecting them to determination activities to check that items produced subsequent to the initial attestation fulfil the specified requirements. The surveillance includes periodic assessment of the production process. This scheme does not provide any indication of the impact the distribution channel plays on conformity. When serious nonconformities are found, the opportunity may exist to resolve them before widespread market distribution.

Scheme Type 4

The surveillance part of this scheme allows for the choice between periodically taking samples of the product from the point of production or from the market or both and subjecting them to determination activities to check that items produced subsequent to the initial attestation fulfil the specified requirements. The surveillance includes periodic assessment of the production process. This scheme can both indicate the impact of the distribution channel on conformity and provide a pre-market mechanism to identify and resolve serious nonconformities. Significant duplication of effort may take place for those products whose conformity is not affected during the distribution process.

Scheme Type 5

The surveillance part of this scheme allows for the choice between periodically taking samples of the product either from the point of production or from the market, or both, and subjecting them to determination activities to check that items produced subsequent to the initial attestation fulfil the specified requirements. The surveillance includes periodic assessment of the production process or audit of the management system or both. The extent to which the four surveillance activities are conducted may be varied for a given situation as defined in the scheme. In the case where the surveillance includes audit of the management system, an initial audit of the management system will be needed.

Scheme Type 6

This scheme is mainly applicable to certification of services and processes. Although services are considered as being generally intangible, the determination activities are not limited to the evaluation of intangible elements (for instance effectiveness of an organization's procedures, delays and responsiveness of the management). In some situations the tangible elements of a service can support the evidence of conformity indicated by the assessment of processes, resources and controls involved. For example inspection of the cleanliness of vehicles for the quality of public transportation. As far as processes are concerned, the situation is very similar. For example, the determination activities for welding processes can include testing and inspection of samples of the resultant welds, if applicable. . For both services and processes, the surveillance part of this scheme should include periodic audits of the management system and periodic assessment of the service or process.

9.1.3.2 Declaration of conformity

The purpose of the declaration is to give assurance of conformity of the identified object to specified requirements to which the declaration refers, and to make clear who is responsible for that conformity and declaration. A supplier's declaration of conformity may be used alone or in conjunction with another conformity assessment procedure for regulatory or non-regulatory purposes.

The issuer (issuing organization or person) of a declaration of conformity shall be responsible for issuing, maintaining, extending, reducing, suspending or withdrawing the declaration and the conformity of the object to the specified requirements.

The declaration of conformity shall be based on results of an appropriate type of conformity assessment activity (e. g. testing, measurement, auditing, inspection or examination) carried out by one or more first, second or third parties. Conformity assessment bodies involved, where applicable, should consult relevant International Standards, Guides and other normative documents.

Where a declaration of conformity is for a group of products of a similar type, it shall cover each individual product of the group. Where a declaration of conformity is for similar products delivered over a period of time, it shall cover each product as delivered or accepted.

It is recommended, as good conformity assessment practice, that the person reviewing the conformity assessment results be different from the signatory.

The issuer of the declaration of conformity shall ensure that the declaration contains sufficient information to enable the recipient of the declaration of conformity to identify the issuer of the declaration, the object of the declaration, the standards or other specified requirements with which conformity is declared, and the person signing for and on behalf of the issuer of the declaration of conformity.

As a minimum, the declaration of conformity shall contain the following:

a) unique identification of the declaration of conformity;

b) the name and contact address of the issuer of the declaration of conformity;

c) the identification of the object of the declaration of conformity (e. g. name, type, date of production or model number of a product, description of a process, management system, person or body, and/or other relevant supplementary information);

d) the statement of conformity;

e) a complete and clear list of standards or other specified requirements, as well as the selected options, if any;

f) the date and place of issue of the declaration of conformity;

g) the signature (or equivalent sign of validation), name and function of the authorized person(s) acting on behalf of the issuer;

h) any limitation on the validity of the declaration of conformity.

Additional supporting information may be provided to relate the declaration to the conformity assessment results on which it is based, for example:

a) the name and address of any conformity assessment body involved (e. g. testing or calibration laboratory, inspection body, certification body);

b) reference to relevant conformity assessment reports, and the date of the reports;

c) reference to any management systems involved;

d) reference to the accreditation documents of conformity assessment bodies involved where the scope of accreditation is relevant to the declaration of conformity;

e) reference to the existence of associated supporting documentation, such as that described in ISO/IEC 17050-2;

f) additional information regarding certificates, registrations or marks that have been obtained;

g) other activities or programs of the conformity assessment body (e. g. membership in an agreement group).

References in the documentation to conformity assessment results shall not misrepresent their applicability nor mislead the recipient of the declaration of conformity.

See Figure 9.2 for an example of form of declaration of conformity. The declaration of conformity may be in hardcopy, electronic media, or any other suitable medium.

Guidance to complete the form of declaration of conformity (numbers 1 to 7 refer to the form shown in Figure 9.2):

1) Every declaration of conformity should be uniquely identified.

2) The responsible issuer should be unequivocally specified. For large organizations, it may be necessary to specify operational groups or departments.

3) The «object» should be unequivocally described so that the declaration of conformity may be related to the object in question. For mass-produced products, it is not necessary to give individual serial numbers. In such cases it is sufficient to give the name, type, model number, etc.

4) For products, an alternative conformity statement may be: “As delivered, the object of the declaration described above is in conformity with the requirements of the following documents”.

5) Requirements documents should be listed with their identification numbers, titles and dates of issue.

6) Text should appear here only if any limitation on the validity of the declaration of conformity and/or any additional information are given.

7) Full name and function of the signing person(s) authorized by the issuers management to sign on its behalf should be given. The number of signatures, or equivalent, included will be the minimum determined by the legal form of the issuer's organization.

Supplier's declaration of conformity (in accordance with ISO/IEC 17050-1)

1) **No.** ....

2) **Issuer's name:** ....

Issuer's address: ....

....

3) **Object of the declaration:** ....

....

....

4) **The object of the declaration described above is in conformity with the requirements of the following documents:**

Documents No.	Title	Edition/Date of issue
5)	....	....
....	....	....
....	....	....

Additional information:

6) ....

....

....

Signed for and on behalf of:

....

....

(Place and date of issue)

7) ....

(Name, function) (Signature or equivalent authorized by the issuer)

Figure 9.2 – Example of form of declaration of conformity

A copy of the declaration of conformity may be included in other documentation, such as a statement, catalogue, invoice, users instructions or website, relevant to the object of the declaration of conformity.

If any marking is placed on the product to indicate the existence of a declaration of conformity, such marking shall be in such a format that it will not be confused with any certification mark. Such marking shall be traceable to the declaration of conformity.

The issuer of the declaration of conformity shall have procedures in place to ensure the continued conformity of the object, as delivered or accepted, with the stated requirements of the declaration of conformity.

The issuer of the declaration of conformity shall have procedures in place to re-evaluate the validity of the declaration of conformity, in the event of

a) changes significantly affecting the object's design or specification,

b) changes in the standards to which conformity of the object is stated,

c) changes in the ownership or structure of management of the supplier, if relevant, or

d) relevant information indicating that the object may no longer conform to the specified requirements.

9.1.3.3 Certification of services

Certification of services is carried out according to patterns including the services executor (personnel) estimation, the process estimation of services rendering, the quality control systems certification of the services executor, random inspection of the services results and inspection checkup of the certified services and quality control systems.

Process estimation of services rendering generally includes checking of presence and conditions of TNLA, of technological documentation necessary for services rendering; presence and testing of the technological equipment used, means of control and measurements, materials; conditions and correspondences of the facilities and equipment to TNLA requirements, to electric, fire and explosion safety, to sanitary rules and norms; presence of the control and estimation system of safety and quality of services; presence and conditions of the registration and account system of information about safety and quality of services; observance of security requirements for safety of life, health and heredity of people, and also preservation of property and environment protection while rendering services; presence of qualified personnel and of information about the services rendered; organization of cooperation with the services user; ensuring conditions of users servicing, etc.

9.1.3.4 Certification of personnel competence

While certifying personnel their qualification correspondence is determined to the requirements established in TNLA for a certain sphere of activity. Qualification and qualification level are determined according to the qualification examination results conducted by the certification body. Personnel certification is possible within the limits of international and regional systems with which the agreement about mutual recognition of the certification results is concluded.

9.1.3.5 Certification of quality management systems

Certification of QMS is organized and conducted to ensure confidence of products users, of factories management, of organizations and other interested parties that the organization has conditions and takes measures to produce goods corresponding to the requirements of users and to the obligatory requirements, and also to increase users satisfaction by means of effective application of QMS, including processes of its constant improvement. QMS certification is carried out if it is provided for by the pattern of obligatory certification or products correspondence declaring or according to the organization initiative. It includes submission of the certification application, documents analysis and QMS audit, inspection control of the certified QMS.

While conducting the certification the group audit or expert-auditor examines and analyses all presented documents, namely: the application, the initial information, the questionnaire, the quality manual and the obligatory documentary procedures necessary for processes control. The initial information analysis is done taking into account the requirements of TNLA to QMS and products, and also information about the product quality, received from independent sources.

With positive estimation results of QMS documents its audit is carried out. The opinion letter is prepared and the final meeting is held according to the audit results.

Data gathering is carried out by interrogation methods of the organization workers, by observation of activity and processes and analysis of documents. The information received is verified by comparison with the information from the test certificates, reports, etc. Audit certificates are compared with the audit criteria and on their basis nonconformance and its significance are determined. **Essential and insignificant cases of nonconformance** are singled out in the process**.**

Essential nonconformance is absence, non-use or complete violation of any requirement (criterion) of QMS or another deviation from QMS normative requirement the elimination of which will require modification of the factory organizational structure, heavy material expenditure, long period of time or it will essentially affect the product quality.

Insignificant nonconformance is neglect in carrying out the established requirements (criteria) or another deviation from QMS normative requirement the elimination of which is not connected with modification of the factory organizational structure, heavy material expenditure and which can be eliminated in the process of work of the audit group or within one month from the moment of detection.

QMS is recognized as corresponding to TNLA if there is no nonconformance; if there is insignificant nonconformance; if two or less essential and insignificant cases of nonconformance are detected. In this case nonconformance elimination terms in QMS (not more than 6 months) are determined.

QMS is recognized as non-corresponding to TNLA if it contains three and more essential and insignificant cases of nonconformance. In this case the organization QMS estimation is carried out after elimination of all cases of nonconformance (not earlier than in 6 months).

According to the audit results after regulation procedures conducting the Certification council makes a decision to issue the correspondence certificate for a period of 3 years. In justified cases a smaller period of the correspondence certificate validity can be established but not less than 2 years.

The certification body carries out the planned and unplanned inspection control of the certified QMS during the whole period of the certificate validity.

9.2 Basic recommendations for solving tasks

When studying the topic, you should pay attention to the following issues:
- general provisions of product certification;
- product certification schemes, conditions of their application;
- stages of product certification;
- general provisions of declaration of conformity;
- procedure for declaration of conformity;
- information provided in the declaration of conformity;
- general provisions of certification of performance of work, provision of services;
- general provisions and procedure for personnel certification;
- general provisions of QMS certification.

9.3 Tasks for an independent solution

9.3.1 Develop a flow chart for conducting product certification according to one of the charts in Table 9.2. When constructing the algorithm, use the elements of the graphical description of the process presented in Figure 9.3.

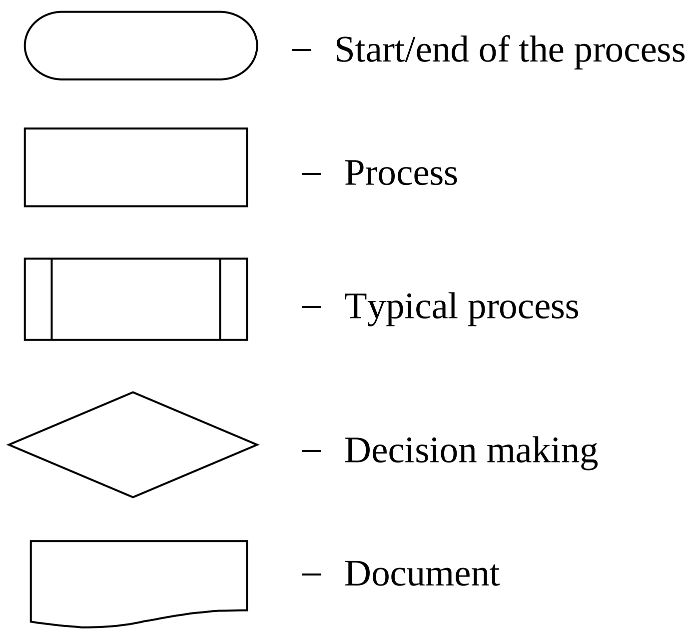


Figure 9.3 – Elements of a graphical description of a process

9.3.2 Develop a declaration of conformity for the product in accordance with Figure 9.2.

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METROLOGY, STANDARDIZATION AND CERTIFICATION

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