Methods and Means of Automatic Statistical Assessment of Information Measuring Systems

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Abstract

The method of assessing the accuracy of information and measurement systems is considered, using the example of the system of the oil refining industry. In particular, indicators of temperature, pressure and product level sensors in the tank to optimize the process of transmitting information over significant distances. And formation based on measurement of certain conclusions and implementation of controlling influences on the object. A metrological analysis of the created information and measurement complex was carried out based on this concept of uncertainty. The obtained results were compared with the result of calculating the total error of the channel using the entropy coefficient

Keywords

Mathematical support, information measuring system, metrological analysis, measurement uncertainty, error, imprecise value, inadequate knowledge, subjective error.

1. Introduction

Problems of measurement accuracy accompany experimental research in many fields. In addition to the fact of having information about a certain parameter, it is important to be able to process and use this information at further stages of the product's operation.

Along with the concept of "error", the concept of "uncertainty of measurement" is becoming widespread. The term "uncertainty", which means doubt about the reliability of the measurement result, lack of accurate information about the actual value of the measured value, is embodied in certain quantitative characteristics. On their basis, a metrological analysis of the created information and measurement complex is carried out.

The problems of the measurement process and accuracy are described in a number of works by well-known scientists of Ukraine and foreign authors such as V. O. Yatsuk, T. Z. Bubela, M. M. Mykiychuk, E. V. Pokhodylo, B. Schweber, [1], [2], [3], [4]. It is also reflected in the works of other authors [5], [6] and other outstanding scientists of the technical direction.

2. Metrological analysis of the information and measurement system according to the concept of "uncertainty"

Measurement uncertainty is a parameter related to the measurement result and characterizes the dispersion of values that could reasonably be attributed to the measured value [7].

Proceedings ITTAP'2023: 3rd International Workshop on Information Technologies: Theoretical and Applied Problems, November 22–24, 2023, Ternopil, Ukraine, Opole, Poland
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Uncertainty of measurement expresses the fact that for a given measured value and for a given result of its measurement there is no single exact value, but there is an infinite number of values scattered around the result, which are consistent with all observations and data, as well as with knowledge of the physical world, and which with varying degrees of confidence can be attributed to the measured quantity [8].

In practice, there are many possible sources of measurement uncertainty, including:

- incomplete definition (specification) of the measured quantity;
- imperfect realization of the definition of the measured quantity;
- inadequate knowledge about the possible effects of influencing quantities or their imperfect measurement;
- subjective error of the operator when reading displays of analog devices;
- finite resolution of measuring devices or sensitivity threshold;
- inaccurate value attributed to standards or measures of physical quantities;
- inaccurate value of constants and other parameters obtained from external sources used in the data processing algorithm;
- approximations and assumptions used in the measurement method and in the measurement procedure, including approximate calculations using personal computers;
- random changes in external influencing variables during repeated observations.

Uncertainty is classified according to assessment methods and the way they are expressed. All uncertainties according to assessment methods are divided into two categories: A and B. Category A includes components that are assessed using statistical methods, i.e., those about which there is a posteriori information. Category B includes components that are evaluated by other methods. According to the method of expression, standard, total, extended and relative uncertainty are distinguished. Standard uncertainty - the uncertainty of the measurement result, expressed as a standard deviation [9].

The total uncertainty is the standard uncertainty of the measurement result obtained from the values of other quantities associated with the measured quantity. Expanded uncertainty is an interval estimate of measurement uncertainty, which is the product of the standard uncertainty by the coverage coefficient, which depends on the type of distribution and the level of confidence (probability of coverage). Relative uncertainty is the ratio of standard, total or expanded uncertainty to the estimate of the measured quantity. Estimates of uncertainty components can be obtained a posteriori or a priori [10].

The first case (a posteriori evaluation) is based on the results of a specific measurement and evaluates its uncertainty. It is possible only when conducting repeated observations of the measured quantity. These measurements can be carried out in two ways:

- in the conditions of repeatability (to assess and minimize the uncertainty component of measurements due to random effects);
- when changing one of the observation conditions in such a way as to obtain the variability of the observed results (to estimate and minimize the uncertainty component of the measurement results due to the variable part of the non-excluded component of the known systematic effect).

As a result of processing multiple observations using methods of mathematical statistics, it is possible to obtain a measure of their dispersion around the estimate of the expected value taken as the result of the measurement. The experimental standard deviation, called the standard uncertainty of type A, is taken as an estimate of the dispersion of the observation results.

An a priori assessment of the uncertainty components of measurement results must be made when multiple observations for the studied random or systematic effect in this measurement are not conducted. In this case, it is worth relying on information obtained from previously conducted measurements, physical properties of the measured quantity, and passport data for the device or reference books. The dispersion of the measurement results obtained in this case is characterized by the estimated standard deviation and is called the standard uncertainty of type B.

In most cases, the best available estimate of the mathematical expectation or expected value Mq of the quantity q_i, for which n independent values were obtained during observations under the same measurement conditions, is the arithmetic mean:

$$\overline{q} = \frac{1}{n}\sum_{i=1}^{n} q_i \tag{1}$$

The experimental variance of observations, which is a static estimate of the variance of the probability $\sigma^2(q)$ distribution of the quantity *q*, is obtained as:

$$s^2(q_i) = \frac{1}{n-1}\sum_{i=1}^{n}(q_i - \overline{q})^2 \tag{2}$$

The positive square root $s(q_i)$ of the variance is called the experimental standard deviation.

The best estimate of the variance of the mean value is:

$$s^2(\overline{q}) = \frac{s^2(q_i)}{n} \tag{3}$$

The corresponding root mean square deviation of the mean value:

$$s(\overline{q}) = \frac{s(q_i)}{\sqrt{n}} \tag{4}$$

Thus, the standard uncertainty, estimated according to type *A*, for the measurement result, for which the average value is taken, is:

$$u_A(\overline{q}) = s(\overline{q}) = \sqrt{\frac{\sum_{i=1}^{n}(q_i - \overline{q})^2}{n(n-1)}} \tag{5}$$

However, estimates of uncertainty components using the method based on type *A* calculations are based on information, the accumulation of which requires unlimited resources of the measuring laboratory.

The calculation of uncertainty according to type *B* is based on a scientific judgment about the possible variability of the quantity q using all available information, and consists, as a rule, in the use of a priori knowledge of the probability distribution.

The source of information can be:

- data of previous measurements;
- data obtained as a result of the experiment, or general values about the behavior and properties of the relevant substances and devices;
- manufacturer's specifications;
- data given in calibration, verification and other certificates;
- uncertainties attributed to reference data taken from reference books.

When the uncertainty of the quantity *q* cannot be estimated by analyzing the results of repeated observations, it is necessary to use an a priori probability distribution, which is based on the degree of confidence that a certain event will occur and relies on knowledge, which is always limited. However, this does not make the distribution unsuitable or unrealistic. Like all distributions, it is an expression of the knowledge that exists at a given moment in time.

Often there is a situation when for the quantity *q* there is an estimate of the limits a^+ and a^- (upper and lower limits) of the interval within which its possible values are located. If there are no specific data on the possible values of the quantity q in the middle of the interval, then it can only be assumed that with equal probability the quantity q can acquire any value within its limits (uniform distribution). In this case, the expected value will be the midpoint of the interval with the corresponding variance:

$$u^2(q) = \frac{(a^+ - a^-)^2}{12} \tag{6}$$

or the mean square deviation:

$$u(q) = \frac{a^+ - a^-}{2\sqrt{3}} \tag{7}$$

A uniform distribution should not be assumed if it is known that values near the boundaries of the interval are more likely than those that lie closer to the center of the interval. In this case, often, based on the central limit theorem of probability theory, it is possible to make an assumption that the distribution is approximately normal. In the case of a normal distribution, the interval $\mu_q \pm 3\sigma(q)$ covers approximately 99.73% of the distribution. In this case, it can be considered:

$$u^2(q) = \frac{(a^+ - a^-)^2}{36} \tag{8}$$

or

$$u(q) = \frac{(a^+ - a^-)}{6} \tag{9}$$

In the absence of reliable information about the normality of the distribution, it is advisable to accept a compromise between the uniform and normal distribution, allowing, for example, the Simpson (triangular) distribution. Then

$$u^2(q) = \frac{(a^+ - a^-)^2}{24} \tag{10}$$

or

$$u(q) = \frac{(a^+ - a^-)}{2\sqrt{6}} \tag{11}$$

The total standard uncertainty is the uncertainty of the measurement result obtained from the set of values of other quantities. It is the square root of the sum of variances or correlation moments of these quantities.

$$u_c(y) = \sum_{i=1}^{N} \sqrt{u^2(X_i)} \tag{12}$$

The total standard uncertainty $u_c(y)$ is also an estimate of the root mean square deviation and characterizes the spread of values that could reasonably be attributed to the measured quantity. It is determined by the formula:

$$u_c^2(y) = \sum_{i=1}^{N} u^2(X_i) \tag{13}$$

or

$$u_c(y) = \sum_{i=1}^{N} \sqrt{u^2(X_i)} \tag{14}$$

Therefore, the standard uncertainty is the uncertainty of the direct measurement, and the total standard uncertainty is the uncertainty of the indirect measurement. The standard uncertainty can also be cumulative in the case of a direct measurement with several sources of error.

Expanded uncertainty U is a value that defines the interval around the measurement result, within which, as can be expected; most of the distribution of values that could reasonably be attributed to the measured value is located.

The number p, which shows how much of the distribution of values lies within the interval defined by the expanded uncertainty, is called the coverage probability or confidence level of the interval.

The extended probability is calculated according to the formula:

$$U = k \cdot u_c, \tag{15}$$

where k is a numerical coefficient used as a multiplier of the total standard uncertainty to obtain the expanded. It is called the coverage ratio or coverage ratio.

If the expanded uncertainty is calculated, then the result of the measurement can be given as $Y = y \pm U$, it means that the best estimate of the value attributed to the measured quantity Y is y, and that the interval from $y - U$ to $y + U$ contains, as might be expected, most of the distribution probabilities of values that can be attributed to the measured value with sufficient justification.

The value of the coverage coefficient k is chosen based on the confidence level. Establishing the relationship between the interval defined by the expanded uncertainty and the confidence equation requires explicit and implicit assumptions about the probability distribution that characterizes the result of the measurement and its total uncertainty. The level of confidence that can be attributed to this interval can only be known to the extent that such assumptions are justified. In most practical situations when measuring, the calculation of an interval that has a given confidence level is approximate:

Relative uncertainty is the ratio of the standard total or expanded uncertainty to the estimate of the measured value:

- relative standard uncertainty of type A, $u_A(x)/|x|$, $|x| \neq 0$;
- relative standard uncertainty of type B, $u_B(x)/|x|$, $|x| \neq 0$;
- relative total uncertainty $u_C(y)/|y|$, $|y| \neq 0$;
- relative expanded uncertainty $U/|y|$.

3. Uncertainty assessment of individual components using the example of pressure and level sensors

As the primary transducer for the pressure measurement channel, a differential pressure gauge is used, the sensitive element of which is a membrane. A significant part of the uncertainty components of this transducer is a consequence of the non-ideality of the membrane.

The elastic surface of the membrane is defined as

$$\lambda = \lambda_0[1-(\frac{r}{R})^2]^2 \tag{16}$$

where $1 < \lambda_0 / h \leq 7$. There is a non-linear relationship between λ_0 i P

$$\frac{PR^4}{Eh^3} = 5.86\lambda_0 + 3.58\frac{\lambda_0^3}{h^2} \tag{17}$$

and the equation of the elastic surface is described by the following relationship

$$\lambda = \lambda_0\left(\frac{1}{z-1}[2(\frac{r}{R})^{z+1} - (z+1)(\frac{r}{R})^2 + 1\right) \tag{18}$$

where $z = f(\lambda_0)/h$.

Based on experimental data, we can establish a change in membrane deflection due to its non-linearity, which is reduced to the output current signal, equal to $\pm$ 0.05mA.

So, substituting into formula 7, we get:

$$U_{nlin} = \frac{2 \cdot 0.25}{2\sqrt{3}} = \pm 0.15mA$$

For the developed sensor, the non-uniformity of stiffness is:

$$\Delta_f = \frac{0.1\% \cdot 20\text{mm}}{100\%} = 0.02\text{mm}$$

In the range of 0.1 mA, we get:

$$U_f = \frac{2 \cdot 0.1}{6} = 0.03mA$$

So, substituting the data, we get:

$$U_{\text{tem.ef.}} = \frac{2 \cdot 0.1}{2\sqrt{3}} = 0.06mA$$

In addition, the total uncertainty of the pressure measurement channel is affected by the uncertainty of the secondary BPVI-1, which, according to its passport data, is 0.25%.

The change in the sensor output signal in the interval will be $\pm$ 0.005mA.

We determine the uncertainty of the operation of the entire circuit of the device; we assume a normal law of distribution of this component.

Therefore, we get:

$$U_{\text{BPVI}} = \frac{2 \cdot 0.005}{6} = 0.0017mA$$

Since the pressure measurement channel is also connected to the computer through an interface converter and a MIDI port, its total uncertainty also includes the above-mentioned components: the uncertainty of the port and the uncertainty of the interface converter, which are respectively equal to for port:

$$U_{MIDI.} = \frac{2 \cdot 0.02}{2\sqrt{3}} = 0.012mA$$

for the interface converter

$$u_f = \frac{0.02 + 0.02}{6} = 0.0067mA$$

The total uncertainty of the pressure measurement result along the measurement channel is calculated according to formula 13 and is equal to:

$$u_{\text{aver}} = \sqrt{0.15^2 + 0.03^2 + 0.06^2 + 0.0017^2 + 0.012^2 + 0.0067^2} = 0.165mA$$

The expanded standard uncertainty for this case is determined similarly to the standard uncertainty for temperature.

With the value of the coefficient $k_1 = 1.1$ [11] and the confidence level P=0.95, we will get the value of the extended uncertainty:

$$U(P = 0.95) = 1.1 \cdot 0.165 = 0.1815\text{m}A,$$

this value at a pressure range of 0 to 4 kPa and a nominal current of 2 mA means an expanded uncertainty of the pressure measurement of 0.363 kPa.

The level measurement channel works on the principle of measuring the hydrostatic pressure of a liquid column and contains devices similar to those that make up the level measurement channel.

Therefore, the uncertainty of the level measurement channel is numerically equal to the uncertainty in pressure measurement:

$$u_{cl} = \sqrt{0.15^2 + 0.03^2 + 0.06^2 + 0.0017^2 + 0.012^2 + 0.0067^2} = 0.165mA$$

The expanded standard uncertainty for this case is determined similarly to the standard uncertainty for pressure. With the value of the coefficient $k_1 = 1.1$, and the confidence level P=0.95, we will get the value of the expanded uncertainty:

$$U(P = 0.95) = 1.1 \cdot 0.165 = 0.1815\text{m}A,$$

this value at a nominal current of 2 mA for a liquid level value of 0.1 m to 2 m gives an expanded level measurement uncertainty equal to 0.172 m.

Larger uncertainty values for pressure and level measurement channels are associated with the use of a low-precision primary transducer (difmanometer). Large numerical values of the uncertainty of DM diffmanometers, as can be seen from the calculations, are a consequence of the use of membranes in them, which are characterized by non-linearity of elasticity and hysteresis.

You can significantly increase the accuracy of pressure and level measurement by replacing the primary transducer with a transducer with better characteristics.

4. Calculation of the total error of the measuring channels using the entropy coefficient

The temperature measurement channel contains a primary transducer is a resistance thermometer of the TCM type.

The error of this sensor according to its passport data is normalized by the maximum value γ_t=0.5%.

This error is multiplicative and normally distributed. Having set the probability value equal to 0.98 according to the table of quantiles of the normal distribution [12], we find that the probability P=0.98 corresponds to the limit of ±2.3σ.

Hence, the desired σt = 0.5/2.3 = 0.218%, and the parameters of the distribution law (Table 1.).

The BPO-32 resistance conversion unit is used to convert the output signal of the resistance change of the thermoresistive converter into a unified current signal.

Table 1
Distribution parameters

#	Distribution class	$\Delta m/\sigma$	ε	χ	k
1	Normal	–	3	0.577	2.066
2	Even	$\sqrt{3} \approx 1.73$	1.8	0.745	1.73
3	Trapezoidal	$\sqrt{4{,}15} \approx 2.04$	1.9	0.745	1.83
4		$\sqrt{4{,}8} \approx 2.19$	2.016	0.745	1.94
5		$\sqrt{5{,}2} \approx 2.32$	2.184	0.745	2.00
6	Triangular	$\sqrt{6} \approx 2.44$	2.4	0.645	2.02

The error of the block is normally distributed additive and is normalized according to the passport data by the maximum value of her $\gamma P = 0.25\%$. The probability of P=0.98 corresponds to the limit of $\pm 2.3\sigma$. Hence, the required $\sigma P=0.25/2.3=0.109\%$. The parameters of the distribution law correspond to the above. The error of the ADC of the sound card $\gamma K = 0.3\%$ can be considered as half the width of this uniform distribution, and the SWR can be determined as $\sigma K = \gamma K/\sqrt{3} = 0.3/\sqrt{3} = 0.173\%$, k = 1.73 ε=1.8 i $\chi = 0.745$.

The error of mathematical calculations on a computer is additive, with a uniform distribution, its value is of the order of 10-6% and is small enough compared to other components of the total error, so this error can be neglected.

The error summation rules are based on the assumption that the absolute value of the error is always much smaller than the value of the measured value itself.

In this case, there is no connection between the components of the total error, that is, these components are uncorrelated. Accordingly, the total error of the channel is defined as the geometric sum of all component errors. The component with the second, then the obtained result with the third, etc. In this way, the estimated values of $\sigma\Sigma$ and $\varepsilon\Sigma$ can be determined when summing any number of components. Calculation of the variance weight of one of the summed components in the total variance:

$$p = \sigma_1^2 / (\sigma_1^2 + \sigma_2^2)$$

The excess of this distribution will be defined as:

$$\varepsilon_c = \varepsilon_1 \cdot p^2 + 6 \cdot p\,(1 - p) + \varepsilon_2\,(1 - p^2)$$

and counterexcess

$$\chi_c = 1/\sqrt{\varepsilon_c}$$

The entropy coefficient of the composition of two distributions is determined using curves on the Figure 1 [13].

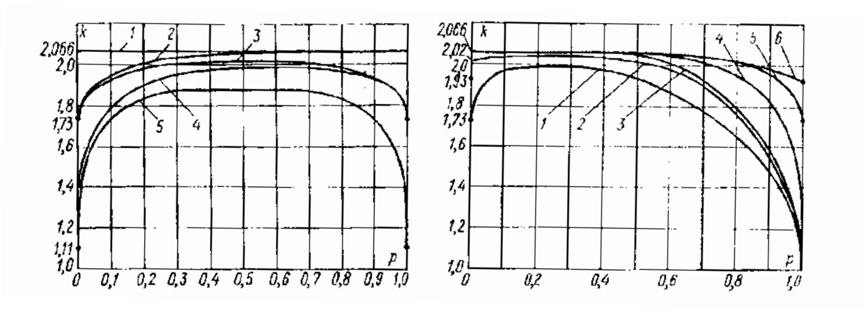


Figure 1: Dependencies of the entropy coefficient k and their entropy coefficients

You can also use analytical calculations based on formulas approximating the curves shown in Figure 1. Thus, for curves 1, 3, 5, Figure 1 a) the dependence has the form:

$$k_\Sigma = k + 1.15(k_H - k)^{0.75}\left[p(1-p)\right]^{0.21k^{1.15}},$$

where *k* is the entropy coefficient of the summed components,

p and (*p*-1) are the weights of the components,

k_H is the entropy coefficient of the normal distribution (k_H = 2.066).

Asymmetric curves of the type of curve 4 in Figure 1, and with the beginning at $k=k1$ and the end at $k=k2$, where $k1<k2$ can be described by the expression

$$k_\Sigma = k_1 + (k_2 - k_1)\left[p + a_0 p^{a_1}(1-p)^{a_2}\right],$$

where p is the weight of the component with $k= k_1$,

(1-p) is the weight of the component with $k= k_2$,

$$a_0=0.817(1+ k_1/ k_2);\ a_1=0.75(1+ k_1/ k_2)^{4,5};\ a_2=1.23(k_1/ k_2)^2$$

Asymmetric curves of curve 2 in Figure 1,a and curves 4-6 in Figure 1,b for the summation of normally distributed errors with errors with entropy coefficient k are described by the expression:

$$k_\Sigma = k_H - p^{1,4(5,7 - k)}[0.14 + 0.4(k_H - k)^2],$$

where p is the weight of the component with the entropy coefficient k,

k_H is the entropy coefficient of the normal distribution (k_H = 2.066).

To simplify the calculations of the total error of the channel, we will use the "Error Calculator 1.0" program described in [14], which allows you to find the total error of the channel based on the known characteristics of the components. The result of the program for the errors of the channel elements calculated above.

The total error of the temperature measurement channel is 1.423 °C.

The previously calculated uncertainty value for this channel was 1.406 °C, that is, the difference between these characteristics is quite small. Such a difference is a consequence of differences in calculation algorithms and calculation inaccuracy [15].

The error value for the temperature measurement channel is small enough and at an average measured temperature of 45 °C, the relative error will be δ = (1.423 °C / 45 °C) • 100% = 3.16%.

As can be seen from the earlier calculations of extended uncertainty for the pressure measurement channel, this channel contains a primary transducer with significant components of uncertainty.

The analysis of the sources of errors of the pressure measurement channel shows that the main part of the errors is caused by the dependence of the characteristics of the membrane on external influences, as well as the imperfect design of the membrane itself (hysteresis phenomena and uneven stiffness of the membrane).

In order to improve the characteristics of the pressure measuring channel, it is proposed to replace the primary transducer (difmanometer) with a device with higher accuracy indicators, possibly made on the basis of a tensor-resistive transducer [16].

At present, primary pressure transducers with a standard current output signal of 4-20 mA and sufficiently high conversion accuracy are manufactured industrially. The use of such a device will improve the overall accuracy of the pressure and level measurement channels due to the use of a primary converter with better characteristics, but also due to the absence of a secondary BPVI device, which will be unnecessary due to the fact that the signal from the primary device will be sent directly to the interface transformer.

5. Static studies and obtaining experimental results

The purpose of statistical research is to create prerequisites for spreading the obtained experimental results from testing a specific process to a whole class of phenomena of this type. When conducting experimental measurements, the question arises:

- which result of multiple measurements of the same quantity can be considered true. Due to both objective (e.g. change in external conditions) and subjective (e.g. deviation in the operator's actions) circumstances, these results may differ slightly;
- is it possible to combine the results of experimental measurements carried out according to the same technique, but in different circumstances;
- how to estimate the level of random errors that always accompany a measurement experimen.

These questions can be answered based on the basic principles of mathematical statistics - this is a branch of applied mathematics, the subject of which is the development of rational techniques and methods of obtaining, describing and processing experimental data in order to study the regularities of mass random phenomena. The main tasks of mathematical statistics are [17]:

- definition of random distribution laws based on statistical data values;
- determination of the parameters of the distribution of random variables based on statistical data;
- determination of the type of connection between different according to statistical data phenomena (objects) or properties of the same phenomenon (object);
- determination of the strength (closeness of connection) between various phenomena (objects) or properties of the same phenomenon (object);
- verification of the probability of statistical hypotheses;
- development of recommendations for the conduct of the experiment and its processing results.

A set of objects or observations, all elements of which are subject to statistical analysis, is called a general set. It can be finite or infinite. Thus, when studying the impact of the brightness of workplace lighting on employee productivity, the general set of observations is theoretically infinite, since the brightness of lighting can change continuously within a certain interval. The number N of objects (observations) of the general population is called the volume of the general population. Since in practice it is not often possible to study every element of the general population during statistical analysis, as a rule, not the entire general population is studied, but some part of it [18].

Part of the objects of the general population studied in the course of the study is called a sample, and the number n of objects (observations) of the sample is called its volume. A sample that adequately characterizes the general population is called a representative sample. For representativeness, it is necessary that each value X_i was obtained under the same conditions, and that the random variables X_i were pairwise independent.

Ordered sample values $x_1 \le x_2 \le ... \le x_n$ make up the variation series: $x_1 = \min\{x_i\}$, $x_n = \max\{x_i\}$. If the segment $[x_1, x_n]$ is divided into k equal segments and i the members of the variational $[x_i, x_{i+1}]$ series fall into the n_i-th segment, then the graph of the function represents $f(x) = \frac{n_i}{n}$, $x \in [x_i; x_{i+1}]$ a histogram (Figure 2) [19], [20] .

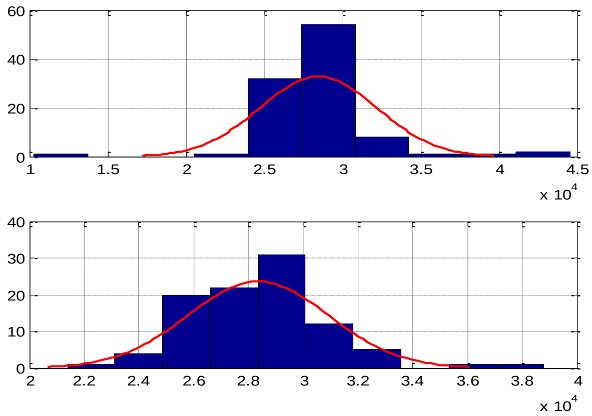


Figure 2: Histogram of arrays of measured data

Accompanying software allows you to get a graphical interpretation of data that can be processed statistically. Thus, a series of values of the measured value (in this case, the array x) can be represented by generalized characteristics, the content of which is shown in Figure 3 [21], [22]:

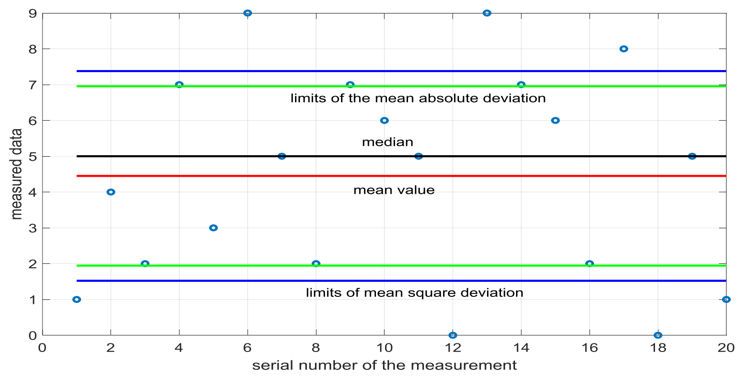
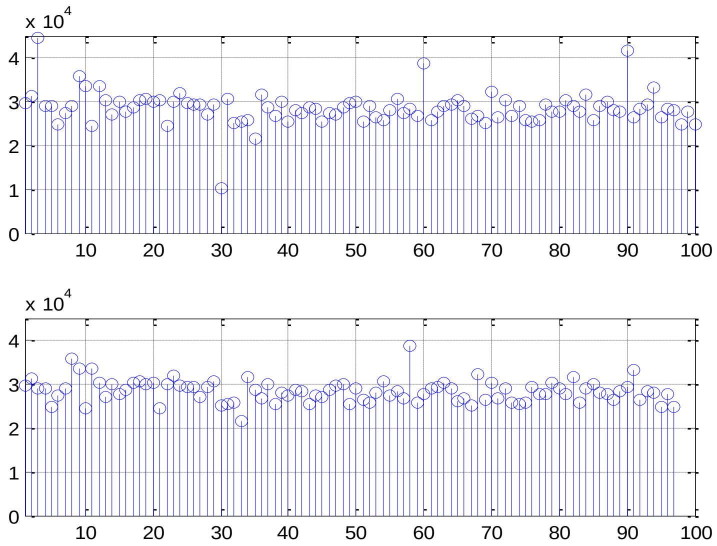
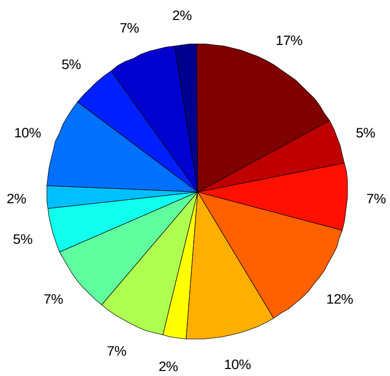


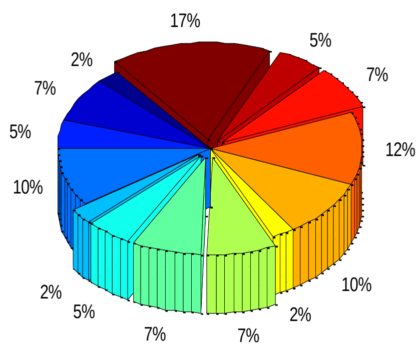
Figure 3: Estimates of the above statistical characteristics for the data set x=[1 4 2 7 3 9 5 2 7 6 5 0 9 7 6 2 8 0 5 1]

Figure 4 a) shows a graphical representation of the array S as a whole and S1 - limited by the values mean(S)-3*std(S) from below and mean(S)+3*std(S) from above:



a)





b) c)

Figure 4: Graphical interpretation of arrays of measured values S and S1 or pie charts b), c).

The use of the developed software significantly facilitates work and increases the productivity of service personnel.

6. Conclusion

The material presented in this work is related to the development of channels for measuring processes of temperature, pressure, and level and is focused on a practical solution for optimizing the operation of reversible information and measurement systems on the example of the oil economy of industrial enterprises.

For the quantitative assessment of the parameters of oil formation in circulating systems, the modeling method is the most effective from the point of view of learning the mechanism of this process, the possibility of forecasting and management in the desired direction.

The developed models and the methodological approach to their construction can be used for any branch of the economy. In particular, the obtained qualitative characteristics of the parameters on the example of oil production will be compared with experimental studies of the operating systems of industrial enterprises in further work. This makes it possible to significantly increase the metrological reliability and service life of information and measurement systems.

In the following studies, based on the proposed method, it is planned to evaluate the accuracy of information and measurement systems in medicine [23, 24], biosensor systems [25], electronic communication systems and networks [26, 27]. This approach will allow expanding the concept of uncertainty presented in the work and conduct a metrological analysis of information and measurement systems with the possibility of their extension to cyber-physical systems.

7. References

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