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ALMATY UNIVERSITY OF POWER ENGINEERING AND TELECOMMUNICATIONS

Department of engineering cybernetics

METROLOGY, STANDARDIZATION, CERTIFICATION AND QUALITY MANAGEMENT

Methodical guidelines for laboratory works for specialty 5B070200 – Automation and control

Almaty 2017

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The present methodological guidelines contain descriptions for 9 laboratory works and suppose conducting virtual works based on computer by using the method of simulation modeling.

The methodological guidelines are used when carrying out laboratory works on the course "Metrology, standardization, certification and quality management".

Figures -32, tables -14, references - 6 items.

Reviewer: S. Bukhina, senior instructor of the department for language studies

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METROLOGY , STANDARTIZATION , CERTIFICATION AND QUALITY MANAGEMENT

Methodical guidelines for laboratory works
for specialty 5B070200 – Automation and Control

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Content

Introduction

The course "Metrology, standardization, certification and quality management" is studied by students majoring in specialty «Automation and control» at the second year of study as a basic discipline (elective component), three credits. The knowledge of discipline’s material, in our opinion, is compulsory for future specialists (bachelors) of technical profile whose work is associated with elaboration or maintenance of various equipment and measuring devices. The working program of the course "Metrology, standardization, certification and quality management" includes a large amount of theoretical and practical material.

The proposed methodological guidelines for laboratory works contain nine works. In accordance with the working program, the amount of laboratory works is 30 hours. Three works (№ 3, 4, 6) are performed within 2 hours per a work, six works (№1,2,5,7,8,9) –within 4 hours because of a large quantity of theoretical calculations in these works. Laboratory works themes are as follows: studying practical standard method of statistical processing results of multiple measurements in absence and presence of gross errors, processing results of direct and indirect single measurements, research ways to reduce errors of measurement channels, as well as verification and calibration of transducers.

Variant number for a student is given by the lecturer at the first lesson and remains unchanged during all subsequent works. The list of relevant literature is given at the end of the methodological guidelines.

The reports on laboratory works should be performed and documented in accordance with corporate standard of Almaty University of power engineering and telecommunications ST NC JSC 56023-1910-04-2014 "Methodological and educational works. General requirements for making out, presentation, design and maintenance of methodological and educational works".

1 Laboratory work №1. Standard processing results of direct measurements with multiple observations

Work Purpose: get skills on standard processing results of multiple measurements and on determination of laws of distribution of measuring errors, estimation of measuring errors and presentation of results.

1.1 Assignment for the laboratory work

Explore structural schemes and technical specifications of two different measuring instruments submitted on screen of virtual laboratory work.

Carry out a simulation experiment to measure a given input value by means of given measuring instruments.

Carry out a statistical analysis of results of the simulation experiment.

Estimate the laws of distribution of errors of these measuring instruments.

Test the hypothesis of belonging observations results to normal distribution using Pearson's criterion.

1.2 Laboratory work performance order

1.2.1 Get a variant from the instructor to carry out the laboratory work and register in the system:

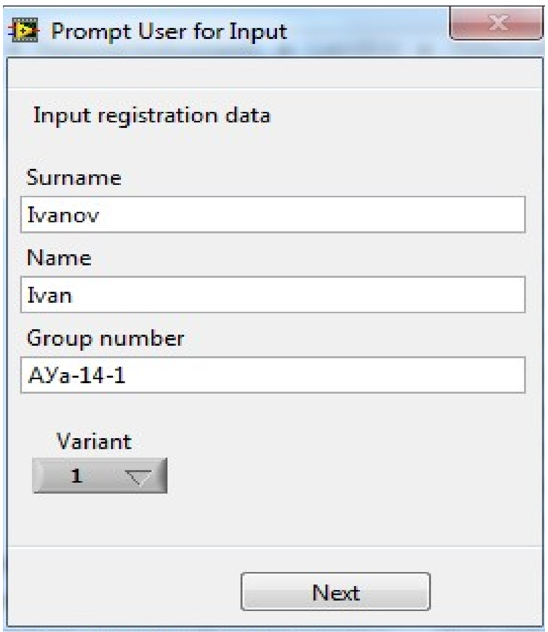


Figure 1.1 – Window of student registration

- download file "Metlab.exe", select your variant of laboratory work from the main menu then the window of student registration will appear (figure 1.1);
- enter your surname, name, group number;
- enter the given variant of the laboratory work;

- click "Next".

1.2.2 Explore the assignment given in appeared virtual laboratory work window (figure 1.2) and enter inlet temperature value (according to your variant) into the input window, located under switch of inlet temperature and press "Enter". Then you can proceed to instruments selection for carrying out the laboratory work.

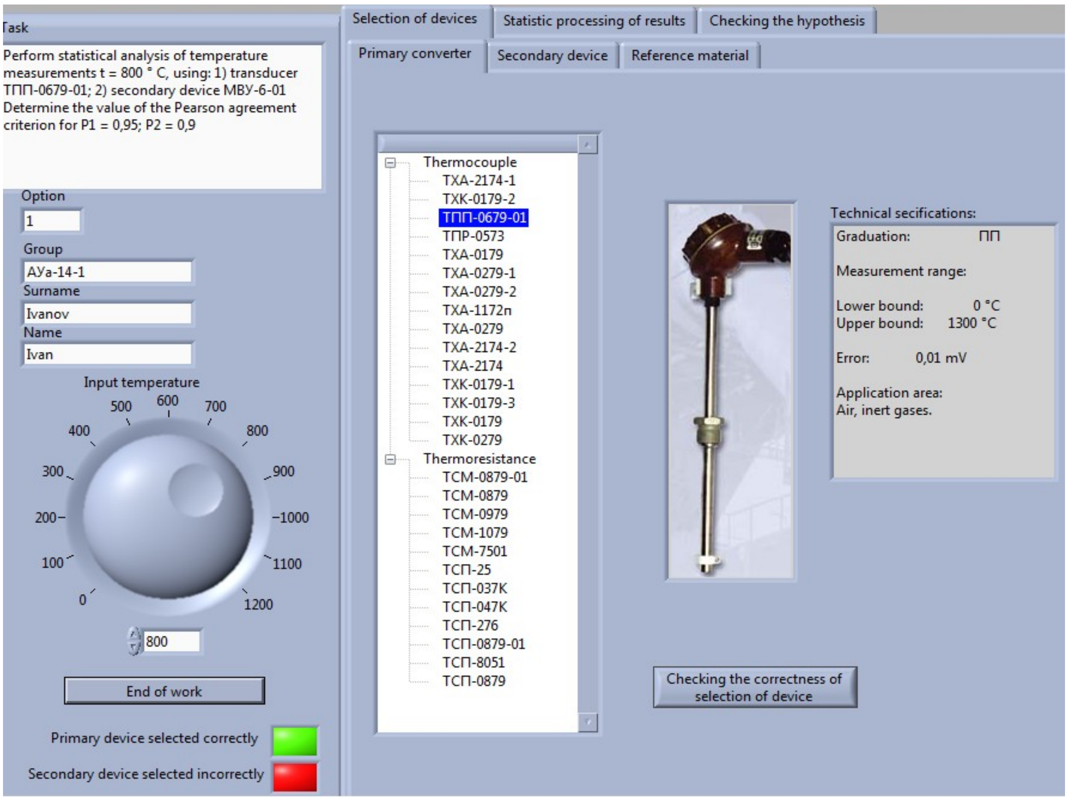


Figure 1.2 –Virtual laboratory work window

1.2.3 On "Primary transducers" tab select the type of primary converter from thermocouples and RTD list according to the laboratory work.

1.2.4 Click "Check suitability of device".

1.2.5 If the primary device is selected correctly, green LED "Primary device is selected correctly" will light on bottom left.

1.2.6 Go to epy next phase of work "Secondary device" selection (Figure 1.3).To do this, go to tab "Secondary device" tab.

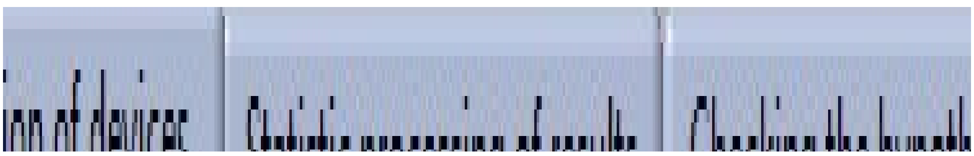


Figure 1.3 –Selection steps of works window

Similarly as in chapter 1.2.3 - 1.2.5 make selection of the secondary device with the type specified in the assignment.

1.2.7 Next stage of work is "Simulation experiment". To do this, go to tab "Statistical processing of results" (figure 1.3). In window "Imitation experiment and statistical processing of results" (figure 1.4) it is possible to carry out imitation experiments on inlet temperature measurement using two measuring instruments, on left - using the primary converter selected in chapter 1.2.3, on the right - with the secondary device selected in p.1.2.6.

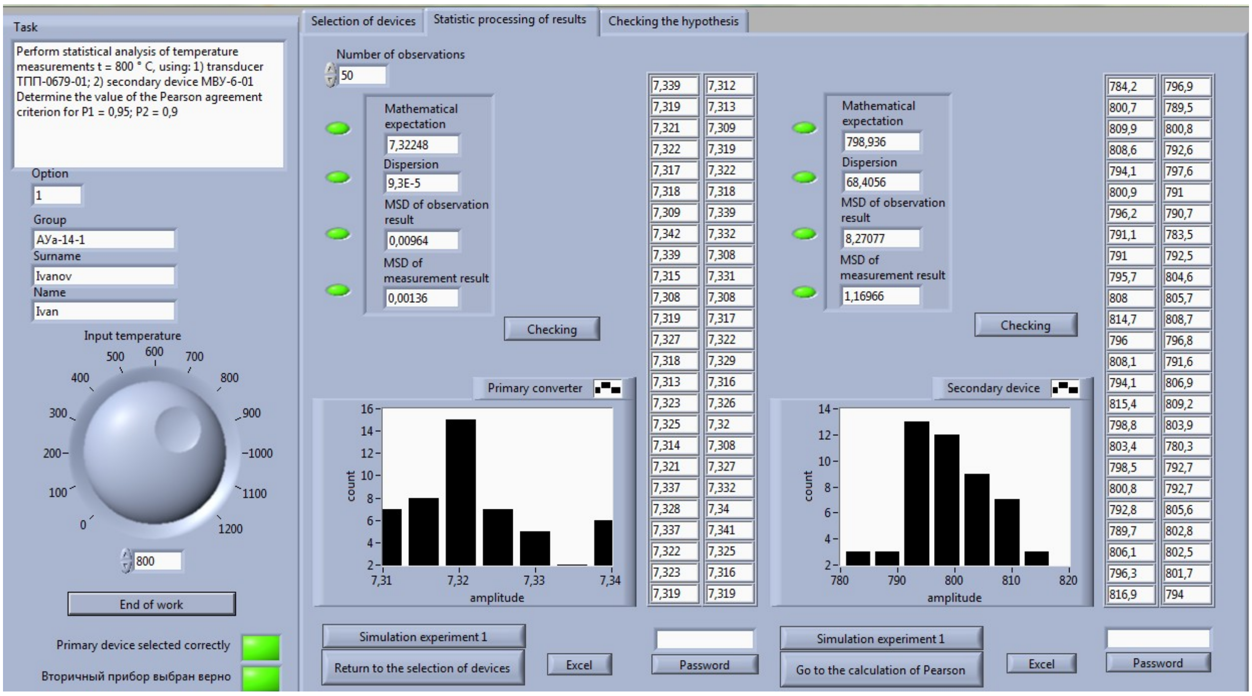


Figure 1.4 – Window of simulation experiment and statistical processing of results

Enter the number of observations equal to 50 and press two buttons "Simulation experiment" on left and bottom right of the window.

Two columns with 50 values of input magnitude, measured by the primary transducer and two columns with 50 values of input magnitude measured by the secondary device obtained as result of randomly measuring values specified in point 1.2.2 of input temperature will appear.

1.2.8 Next stage of work is "Statistical analysis of results".

Carry out the statistical analysis of results of simulation experiment conducted with the primary transducer. To do this, press button "Excel", after that obtained 50 values of measured magnitude are automatically transferred to a file with ".xls" extension. In the appeared window for writing down the file, it is necessary to specify file name with extension ".xls".

In a new window for writing down the file, you should specify file name with ".xls" extension. Open file "Excel" and calculate estimation of expectation value, dispersion and value of root mean square deviation of observations results and measurement result (point 1.4). Build a diagram of distribution for observations results of measured value, containing random errors.

1.2.9 Check obtained estimations of expectation value, dispersion and root-mean square deviation of measurement results and observations results with calculations, obtained by the computer. For this purpose, you should enter calculated values in appropriate windows and click "Check". In case of correct performed calculations, green LEDs will light up on left of appropriate windows (figure 1.4).

1.2.10 The constructed distribution diagram of measured value observations of results you should compare with a diagram, constructed by computer, which is shown on screen.

1.2.11 Repeat carrying out articles 1.2.8 – 1.2.10 for another measurement instrument– secondary device.

1.2.12 Next stage of work is "Test hypothesis of belonging observations of results to normal distribution using Pearson's criterion".

Go to tab "Check hypothesis" (figure 1.3).Open tab "Calculation of Pearson function" (figure 1.5).

Calculate Pearson function for the primary and secondary device in «Excel» according to point 1.3.5.

Enter in appropriate windows given values of confidence probability, level of significance and calculated value of Pearson function chi square and value of chi-square critical, found in table on tab "Check hypothesis": "Reference material".

1.2.13 Press "Calculate". The computer will calculate Pearson function. There will be a result of testing hypothesis by the computer in window "Confirmation of the law of distribution": either the hypothesis of normal distribution is confirmed, or not.

1.2.14 Click "Test". Calculated values of significance level, value of Pearson function chi square and value of chi-square critical are checked for compliance with calculations performed by the computer. In the case of correct calculations, green LEDs will light on left of appropriate windows. In the case of wrong calculations you should apply to your instructor, who, after entering password, will get the detailed picture of Pearson function calculations, performed by the computer.

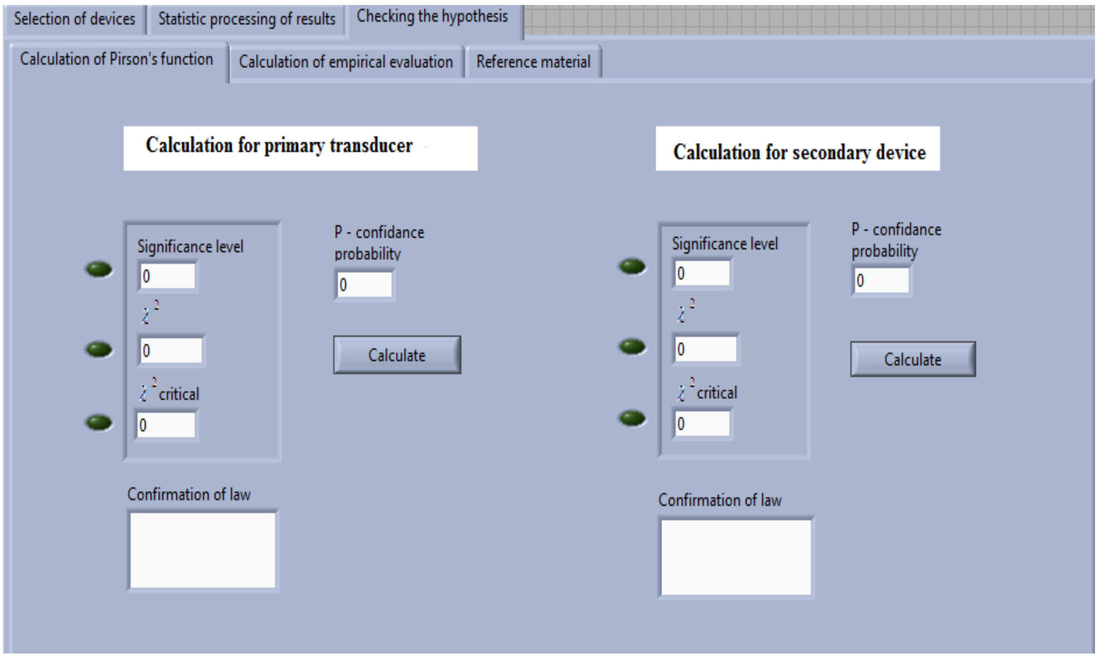


Figure 1.5 - Testing normal distribution hypothesis according to Pearson criterion

1.3 Standard methods of processing results of direct measurements with multiple independent observations

This method corresponds to the recommendations of current standard 8.207-76 "Direct measurements with multiple observations. Methods of processing results of observations".

In accordance with the method, processing a number of observations should be carried out in the following sequence [4]:

a) eliminate the known systematic errors of observation results;

b) calculate an arithmetic average of corrected results observation that is taken as a measurement result;

c) calculate standard deviation estimation of observation results;

d) calculate standard deviation estimation for measurement results;

e) avoid major errors and failures from observations results;

f) in the case of detection gross errors and blunders after their elimination, repeat from b) to d);

g) test hypothesis of belonging observations results to normal distribution;

h) calculate a random component of error's confidence limits for measurement result error;

i) calculate residual systematic error limits for measurement result;

j) calculate error's confidence limits for measurement result;

k) present the measurement result in accordance with the requirements.

1.4 Presentation of measurement result

The measurement result - is a value found by means of a measurement. When presenting the measurement result, it is always necessary to indicate the error (accuracy) with which it is carried out. High precision is corresponded to low values of errors. To quantify the accuracy a number of criteria is used. The most frequently evaluation of accuracy is the measurement accuracy, which is determined by an interval, in which with an established probability the total measurement error is located. Herewith the following presentation of measurement result is accepted:

$$X = X_{measured} \pm \Delta, \quad P, \tag{1.1}$$

where $X_{measured}$ – measurement result in terms of a measured value;

$\pm\Delta$ - confidence interval, expressed by limits of summary absolute error in measured value units;

P – confidence probability.

This form of result presentation is accepted as basic for evaluating measurement accuracy in power engineering automation systems.

When making out your measurement result, it is necessary to follow the rules for rounding off measurement result [3]:

a) rounding off measurement result starts by rounding error value Δ;

b) if *the first significant digit* in error value Δ is equal to 1 or 2, two digits remain: this *significant digit* and following digit; *if the first significant digit* is equal to 3 and more, this digit remain; the remaining digits are zero or fall off and the value of Δ is rounded according to arithmetic rules;

c) measurement result X $\square_{measured}$ is rounded up (according to arithmetic rules) up to the last digit, which is the last in rounded value of error;

d) rounding is done only in the final result and preliminary calculations can be done with one or two extra digits.

1.5 Content of report

The report shall include for each studied measuring device:

- block diagram of measuring instruments;
- technical characteristics of measuring instruments;
- obtained fetching of 50 measured values;
- calculations of expectation value, dispersion and root-mean-square deviation observations results and measurement result;
- graph of distribution diagram of measured value and conclusion on obtained form of distribution law of the random error;
-Pearson function calculations and results of testing normal distribution hypothesis ;
- calculation of confidence limits of random error in measurement result;
- measurement result according to (1.1), made out in accordance with rule of rounding, presented in point 1.4;
- conclusions about the work.

1.6 Control questions

1.6.1 Define "Metrological characteristics of measuring instruments".

1.6.2 List metrological characteristics of measuring instruments.

1.6.3 Define "Systematic errors of measurement tools" and "Random errors of measurement tools".

1.6.4 How is a standard procedure for processing results of measurements with multiple observations carried out?

1.6.5 How to construct a histogram?

1.6.6 What types of distribution laws of random value are random errors distributed by?

1.6.7 Estimations of main characteristics of random variable’s distribution laws.

1.6.8 Rules of rounding and presentation of measurement result.

2 Laboratory work №2. Processing results of direct measurements with multiple observations in case of gross errors presence

Work purpose: familiarization with method of performing direct measurements with multiple observations in case of gross errors presence (blunders, emissions). Obtaining skills of processing observation results and evaluation of measurement results errors.

2.1 Assignments for the laboratory work

Explore structural schemes and technical specifications of two different measuring instruments, shown on screen of the virtual laboratory work.

Conduct simulation experiment to measure given inlet value using given measurement instruments.

Conduct statistical processing results of the simulation experiment.

Estimate errors distribution laws of these measuring instruments.

Test hypothesis of belonging observations results to normal distribution by using coefficient of asymmetry and kurtosis coefficients.

Test hypothesis that observation's controversial result does not contain a gross error, using statistic, called surveillance function v and using "three-sigma" rule.

2.2 Laboratory work performance order

2.2.1 Get a variant from the instructor to carry out the laboratory work and register in the system:

- download file "Metlab.exe", select your variant of laboratory work from the main menu then the window of student registration will appear (figure 1.1);
- enter your surname, name, group number;
- enter the given variant of the laboratory work;
- click "Next".

2.2.2 Explore the assignment given in appeared virtual laboratory work window (figure 1.2) and enter inlet temperature value (according to your variant) into the input window, located under switch of inlet temperature and press "Enter". Then you can proceed to instruments selection for carrying out the laboratory work.

2.2.3 On tab "Primary transducers" select the type of primary transducer according to the task from thermocouples and RTD list.

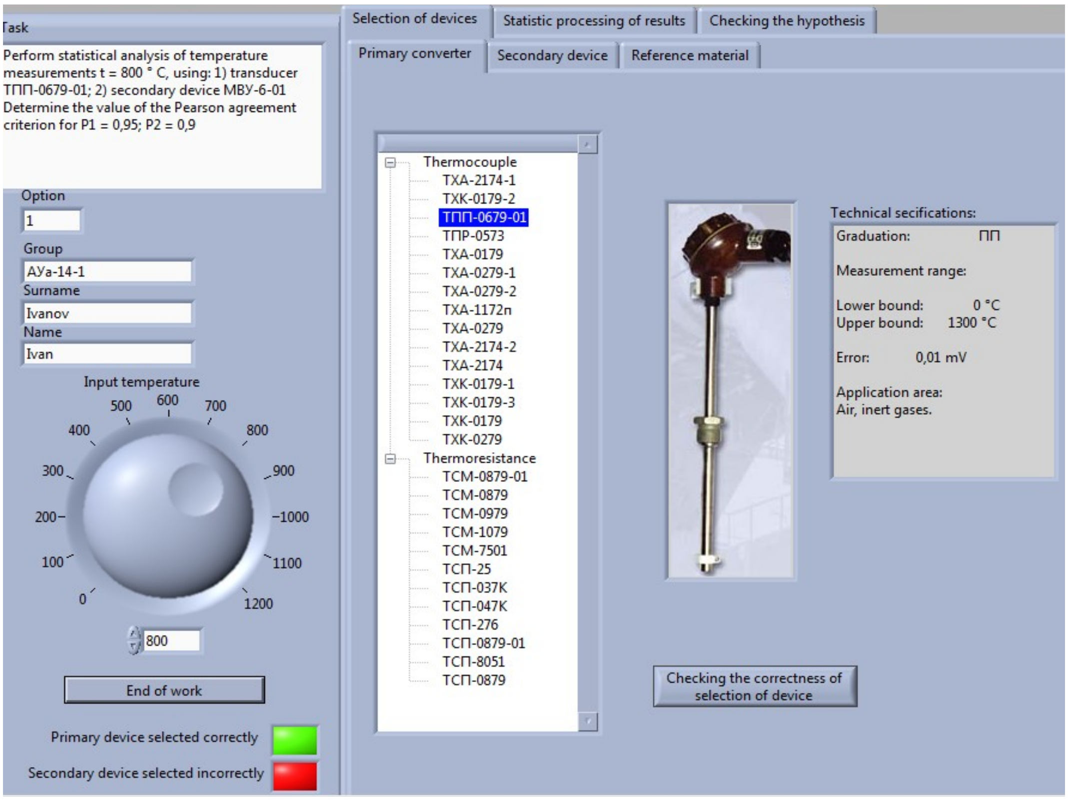


Figure 2.1 –Virtual laboratory work window

2.2.4 Click "Check correctness of instrument selection".

2.2.5 If the primary device is selected correctly, then green LED "Primary transducer is selected correctly" will light on bottom left.

2.2.6 Go to next phase of work "Selection of secondary instrument". To do this go to tab "Secondary devices".

Analogically 2.2.3 - 2.2.5 points, select the secondary device, the type of which is specified in the assignment.

2.2.7 Next stage of work- "Simulation experiment". To do this go to tab "Statistical processing of results". In "Simulation experiment and statistical processing of results" window (figure 2.2) it is possible to carry out simulation experiments for inlet temperature measurement using two measurement instruments: on left –with primary transducer, selected in 2.2.3, on right – with secondary instrument, selected in 2.2.6. Enter observation number equal to "25" and press two buttons "Simulation experiment" on left and right of the window bottom.

2 columns with 25 input quantity values, measured by the primary transducer and 2 columns with 25 input quantity values, measured by the secondary device, which were obtained in random way, as a result of measuring inlet temperature, will appear.

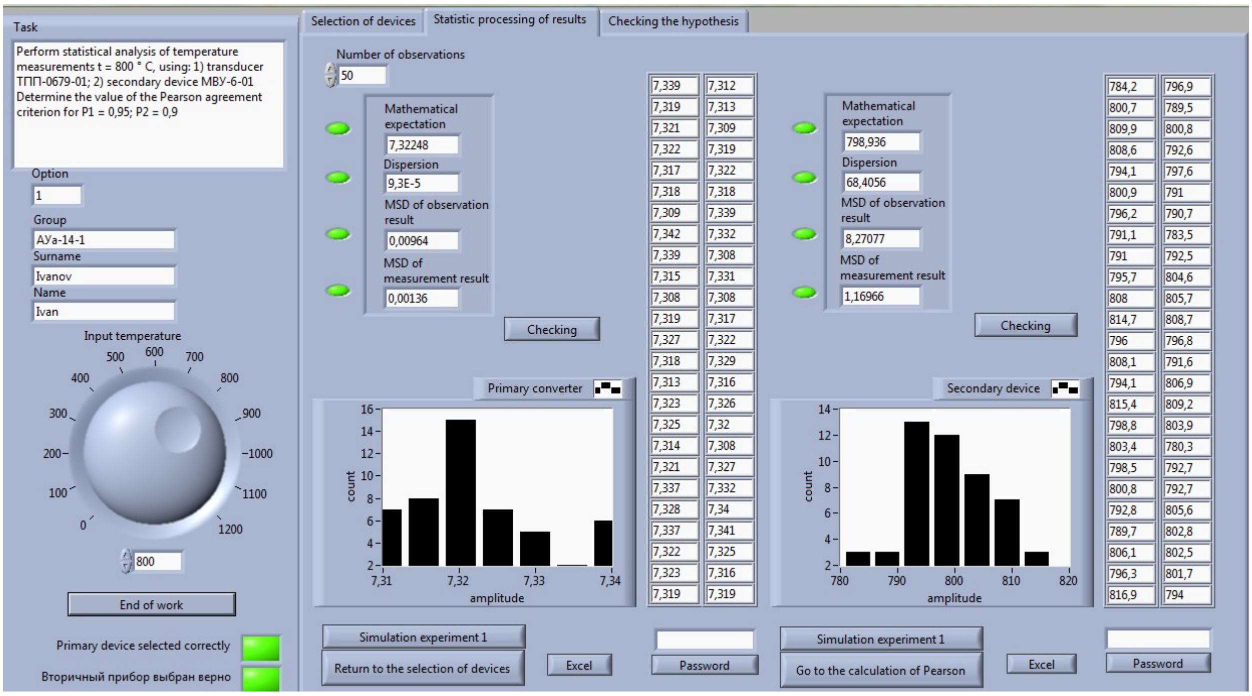


Figure 2.2 – Window of simulation experiment and statistical processing results

2.2.8 Next stage of work "Statistical processing of results".

Make statistical processing results of the simulation experiment, conducted with the primary transducer. To do this, press button "Excel", by pressing of which, the obtained 25 values are automatically transferred to the file with extension ".xls". In an appeared window it is necessary to specify file name with extension ".xls".

You should open file "Excel" and calculate the values of estimates of the expectation, variance and root-mean square deviation of observation results, as well as measurement results (point 1.4). Construct a diagram for distribution law of measured value’s observations results, containing random errors.

2.2.9 Check obtained values of the expectation value estimations, variance and root-mean square deviation of measurement results and observation results with calculations obtained by computer. For this purpose, you should enter calculated values into appropriate windows and click 'Check'. In case of correct performed calculations, green LEDs will light on left of appropriate windows with entered values of estimations.

2.2.10 Compare the constructed distribution diagram of observation results of a measured value with the diagram constructed by computer, shown on screen.

2.2.11 Repeat the implementation of points 2.2.8 – 2.2.10 for other measurement instrument– secondary device.

2.2.12 Next stage of work "Test the hypothesis of belonging of the results of observations to normal distribution according empirical estimates".

Go to tab "Test hypothesis". Open tab "Calculation of empirical evaluation" (figure 2.3).

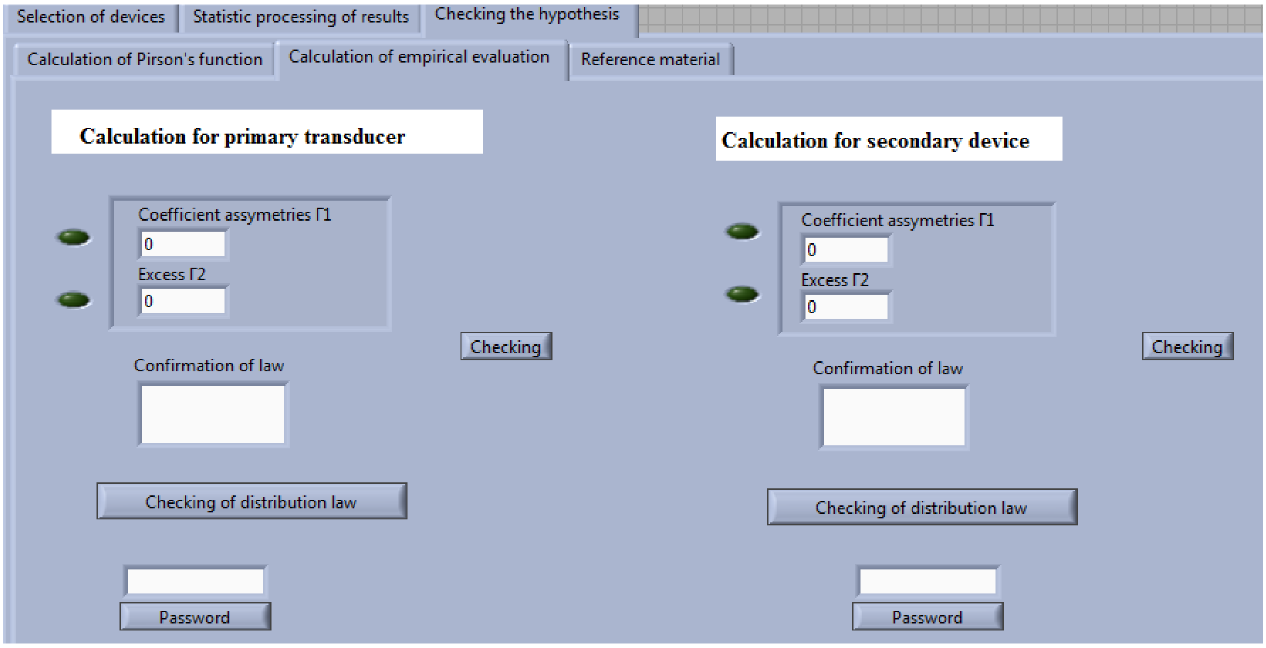


Figure 2.3 - Test hypothesis of belonging observations results to normal distribution according empirical estimates

Calculate asymmetry coefficient and that of kurtosis for the primary and secondary device in "Excel" according to point 2.3.3.

Enter obtained result of calculation values of asymmetry coefficient G1 and kurtosis coefficient G2 in appropriate windows.

2.2.13 Press button "Calculation". Computer will calculate asymmetry coefficient G1 and coefficient of kurtosis G2. In window "Confirmation law of distribution" will be a result of testing hypothesis by computer: hypothesis of normal distribution will be confirmed, or – will not be confirmed.

2.2.14 Press button "Checkup". Calculated values of asymmetry coefficient G_1 and kurtosis coefficient G_2 are checked for compliance with calculations made by computer. In case of correct calculations, green LEDs will light on left of appropriate windows. In case of wrong calculations you should apply to your teacher who, after entering a password, will get a detailed picture of asymmetry and kurtosis coefficients' calculations performed by computer.

2.2.15 Next stage of work "Elimination of gross errors and failures".

Go to tab "Estimation of gross errors". You have to make calculations of gross errors by rule of "three sigma" in "Excel" file (point 2.3.1) and with the help of statistics, called surveillance function (point 2.3.2).

Enter in appropriate windows obtained calculation of values:

- for "three sigma" rule: X_{max}, X_{min} and the number of obtained values, which goes beyond limits $\pm 3\sigma$;

- for statistics, called surveillance function v : v_{max}, v_{min} and result of checking statistics.

2.2.16 Click button "Checkup". The number of obtained values, which goes beyond limits $\pm 3\sigma$; calculated values v_{max}, v_{min} and results of checking statistics are checked for coincidence with calculations, performed by computer. In case of correct calculations on leftward of appropriate windows green LEDs will light. In case of wrong calculation, you should apply to your teacher. The teacher will get detailed picture given by computer after entering a password.

2.3 Methods of processing results of direct measurements with multiple observations in the case of gross errors (gross errors, crude errors)

To improve the quality of measurements, they are often performed with multiple observations, i.e., the same operator repeats single measurements several times in the same conditions, using the same means and methods of measurement.

Having been obtained observations results, received data is processed, and herewith various statistical processing procedures can be used, for example, a standard (point 1.3) or simplified method. Uniformity requirement, i.e., belonging of all elements in the sample to same general totality is one of conditions for appropriateness of multiple observation results of statistical processing. In other words, if there are observations in the sample, whose results clearly exceed the boundaries due to the course of the experiment as a whole, and then the results of these observations should be excluded from the sample. Value and sign of random error cannot be determined. To account a random error, repetitive (statistical) measurements are performed. Estimating a random error one can say about an *expected error*. *Gross error is a* random error significantly higher than expected error in given conditions. *Crude error* is an error clearly distorting measurement result. Experimenter's random subjective error is taken as crude error.

In experimental practice searching crude errors is based on procedure, which is called "censorship in sampling". The censorship in sampling involves usage of formal criteria. There is a number of criteria, the simplest of which is known as the rule of "three sigma".

2.3.1 Identification and elimination of gross errors and crude errors by "three-sigma" rule [2].

Exclude from given observations fetching the values that go beyond $\pm \bar{X} \pm 3\sigma$.

Confidence interval of $\pm 3\sigma$ corresponds to $P = 0{,}997$. This means that practically with probability very close to 1, none of possible error values for normal distribution law will not go beyond boundaries of the interval. Therefore, for normal distribution of errors, a random error with boundaries of $\pm 3\sigma$ is considered to be maximum possible error. Errors that go beyond these boundaries are classified as gross errors or crude errors. Gross errors and crude errors are usually excluded from experimental data before statistical analysis of observations.

This rule is easy and convenient, but it is too "hard", therefore, when you use it, there is an apprehension to remove legitimate result from the fetching.

2.3.2 Identification and elimination of gross errors and crude errors by surveillance function v.

There is a more qualified criterion, according to which the hypothesis is tested that a dubious result X_i of the observation does not contain a gross error. The largest and smallest results of the observations are dubious. Therefore, to test the hypothesis, statistics called surveillance function, $v_{\max}=\frac{X_{\max}-\bar{X}}{\sigma}$ or $v_{\min}=\frac{\bar{X}-X_{\min}}{\sigma}$, is used. The corresponding distribution functions coincide and are tabulated for the normal distribution of the results of observations (table 2.1).

Given a confidence $P=\alpha$ or a significance level $q=1-\alpha$, one can find those largest values v_q that a random variable v can in principle accept for random reasons.

Thus, if value v, calculated by empirical data, will be less than v_q, the hypothesis of observations homogeneity is accepted, otherwise the hypothesis is rejected as contrary to experimental data. If observations series is not uniform, then result $X_{\max}$ or $X_{\min}$ is regarded as containing a gross error and can be eliminated from further consideration. In $q=1-\alpha$ proportion of cases out of a hundred we can make an error of the first kind, i.e, that is, take it for heterogeneity of fetching, which is homogeneous. After removing crude errors, the processing of observations is carried out in a usual way.

Table 2.1 – v_q values at different numbers of observations n and significance level q

n	***q***=1- P			
	0,10	0,05	0,025	0,01
3	1,406	1,412	1,414	1,414
4	1,645	1,680	1,710	1,723
5	1,731	1,869	1,917	1,955
6	1,894	1,996	2,067	2,130
7	1,974	2,093	2,182	2,265
8	2,041	2,172	2,273	2,374
9	2,097	2,237	2,349	2,464
10	2,146	2,294	2,414	2,540
11	2,190	2,383	2,470	2,606
12	2,229	2,387	2,519	2,663
13	2,264	2,426	2,562	2,714
14	2,297	2,461	2,602	2,759
15	2,326	2,493	2,638	2,808
16	2,354	2,523	2,670	2,837
17	2,380	2,551	2,701	2,871
18	2,404	2,557	2,728	2,903
19	2,426	2,600	2,754	2,932
20	2,447	2,623	2,778	2,959

End of table 2.1

21	2,467	2,644	2,801	2,984
22	2,486	2,664	2,823	3,008
23	2,504	2,683	2,843	3,030
24	2,520	2,701	2,862	3,051
25	2,537	2,717	2,880	3,071

2.3.3 It should be specially noted, that the above-mentioned criteria of gross errors work only if the distribution of observations results belongs to the normal law. If the number of observations is small $(15 < n < 50)$, Pearson criterion does not work. To test hypothesis of belonging observations results to normal distribution, one can use the fact that coefficients of asymmetry and kurtosis for normal distribution are equal to zero. Empirical evaluation G_1 of asymmetry coefficient can be found by formula:

$$G_1 = \sum_{j=1}^{n} (X_j - \bar{X})^3 \quad . \qquad (2.1)$$

Empirical evaluation G_2 of kurtosis coefficient can be found by formula:

$$G_2 = \sum_{j=1}^{n} (X_j - \bar{X})^4 \quad . \qquad (2.2)$$

The degree of scattering for values G_1 and G_2 can be approximately estimated by comparing them with estimation of root-mean deviation for coefficients of asymmetry σ_{G1} and kurtosis σ_{G2} .

$$\sigma_{G1} = \sqrt{\frac{6(n-1)}{(n+1)(n+3)}} \; ; \qquad (2.3)$$

$$\sigma_{G2} = \sqrt{\frac{24n(n-2)(n-3)}{(n-1)^2(n+3)(n+5)}} \quad . \qquad (2.4)$$

The distribution is considered to be normal, if relations $G_1 < 3\sigma_{G1}$ and $G_2 < 3\sigma_{G2}$ are true at same time.

If number of observations $n \le 15$, belonging to normal distribution with the help of fitting criteria should not be checked.

2.4 Contents of report

The report shall include for each studied means of measurement:

- structural scheme of measurement instruments;
- technical specification of measurement instruments;
- obtained fetching of 25 measured values;

- calculations of expectation value, dispersion and root-mean-square deviation of measurement results;

- graph of measured value distribution diagram and conclusion on obtained form of random error distribution law;

- calculations to test hypothesis of belonging observations results to normal distribution by using coefficient of asymmetry and kurtosis;

- calculations to test hypothesis that controversial observation result X_i does not contain a gross error, using statistics, called surveillance function v and by "three-sigma" rule;

- presentation of measurement result according to (1.1), formalized by the rule of rounding, presented in article 1.4;

- conclusions about the work.

2.5 Control questions

2.5.1 When do we perform measurements with multiple independent observations? What is taken as the result of these measurements?

2.5.2 What is a confidence interval?

2.5.3 How to calculate a confidence interval?

2.5.4 What is a gross error? How to eliminate their influence on measurement result?

2.5.5 What fitting criteria are used in processing the results of multiple observations, if you expect the presence of gross errors?

2.5.5 What are the advantages and disadvantages of "three-sigma" rule?

2.5.6 How to process the results of observations after gross errors elimination?

3 Laboratory work №3. Simulation modeling of the total error of temperature measuring channel

Work Purpose: gain skills in constructing various circuits of the temperature measurement channel and estimating the total error of the measuring channel (MC).

3.1 Assignment for the laboratory work

Assemble the scheme of temperature measurement channel according to the given assignment on the screen of virtual laboratory work.

Conduct an imitation experiment to measure a given input value using this measuring channel.

Carry out statistical processing of the results of the simulation experiment.

Estimate the total error of temperature-measuring channel.

3.2 Laboratory work performance order

3.2.1 Get a variant from the instructor to carry out the laboratory work and register in the system:

- download file "Metlab.exe", select your variant of the laboratory work from the main menu then the window of student registration will appear (figure 3.1);

- enter your surname, name, group number;
- enter the given variant of the laboratory work;
- click "Next".

3.2.2 Explore attentively the task in appeared virtual laboratory work window (figure 3.1).

Assemble measuring channel scheme to measure the given temperature:

- to select the primary converter you should open tab "Primary transducer";
- select from the list of devices the type of primary transducer - thermocouple or thermistor, using recommendations of point 3.3;

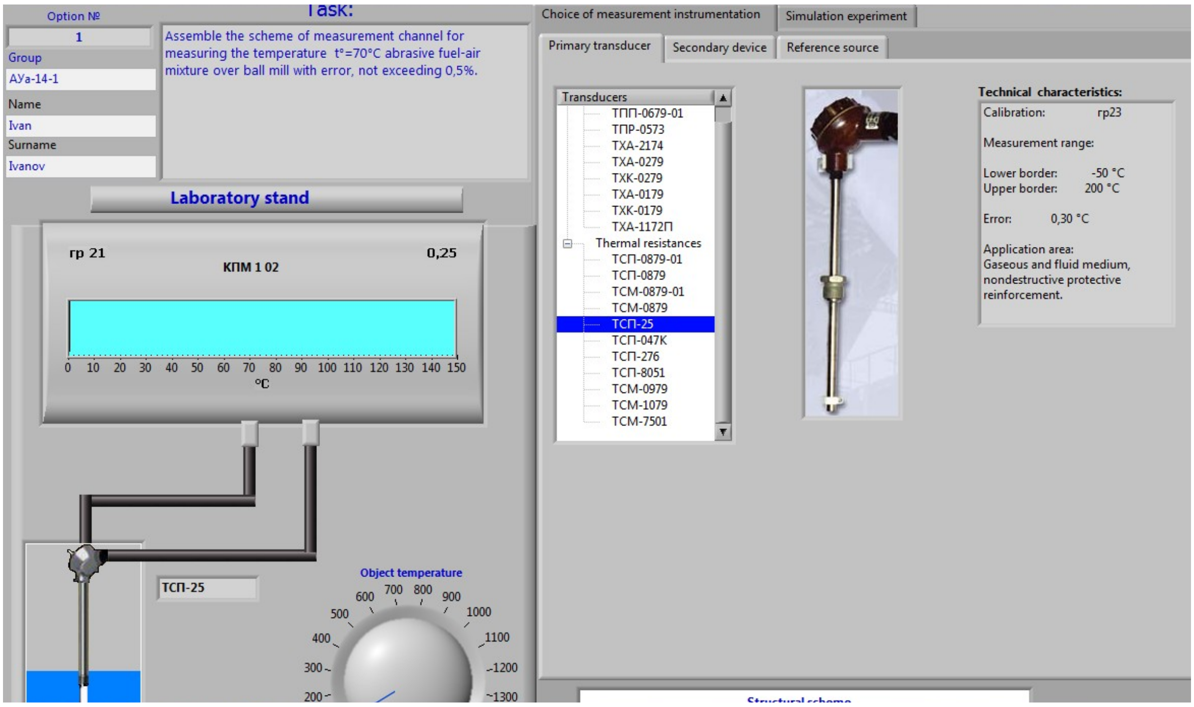


Figure 3.1 - Primary device selection window

- select a particular model of primary transducer; to do this "click" on "+" near the selected type of primary device. While selecting a sensor model you must use technical characteristics of this device, which will appear automatically on this tab "Primary transducer";
- the selected sensor model is set automatically on laboratory stand scheme (on left);
- to select the secondary instrument open tab «Secondary instrument» (figure 3.2);
- from the given list of devices (millivoltmeters, potentiometers, bridge circuits and logometers) select a type of the secondary device, using recommendations of point 3.3;
- select the given secondary instrument model, to do this "click" on "+" near the selected type of the secondary device. While selecting device model you must use technical characteristics of this device (range, accuracy class, calibration), which are indicated on the front panel.

- Having selected secondary device model, press button "Set secondary device" to install the device into measuring channel scheme on the laboratory stand;

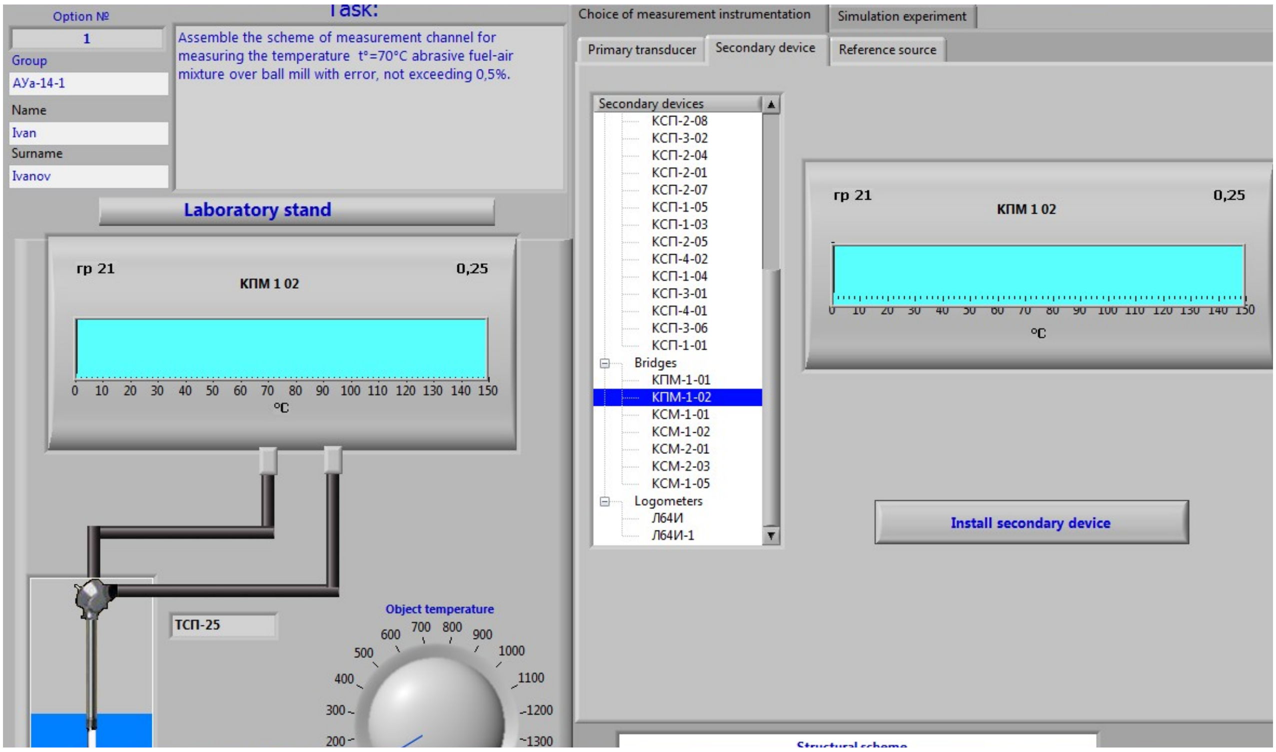


Figure 3.2 –Secondary device selection window

- Assembling measuring channel scheme is over. If the scheme is assembled correctly, then near message "Scheme is assembled correctly" the green LED will light; otherwise – near message "Scheme is assembled incorrectly" the red LED will light; in this case it is necessary to repeat point 3.2.2 until the scheme will correctly assembled.

3.2.3 Having assembled the correct scheme one may proceed to carry out simulation experiments, for this you need to open tab "Simulation experiment" (figure 3.3).

3.2.4 Set a number of simulations equal to 50.

3.2.5 Set the given temperature using "Object temperature" handle on virtual laboratory installation (see the assignment).

3.2.6 Press button "Start simulation experiment".

Simulation experiment results will appear on tab "Simulation experiment" (50 values of measured quantity, obtained randomly as the result of measuring the given measurement value) and distribution diagram will appear too (figure 3.3).

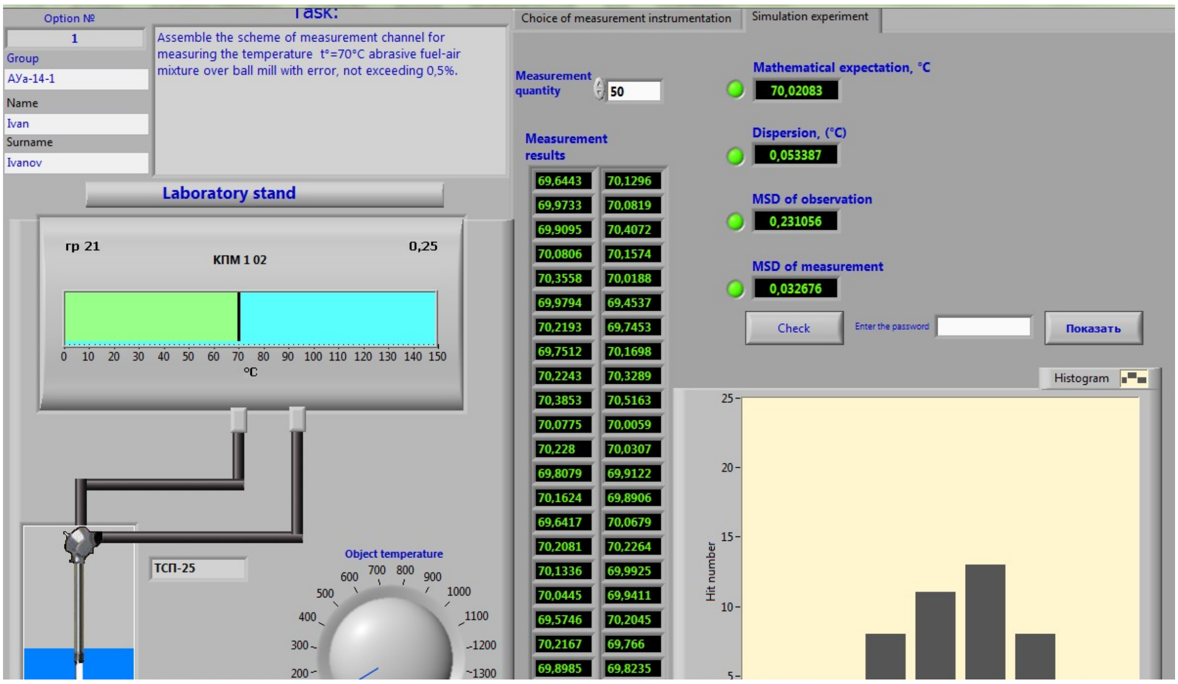


Figure 3.3 – Simulation experiment window

3.2.7 Perform statistical processing results of the simulation experiment:

For this purpose you should refer to point 1.4;

- calculate from the sample obtained using EXCEL, mathematical expectation, dispersion, standard deviation of the observation result and standard deviation of the measurement result.

- build a distribution diagram of observations results.

3.2.8 Enter calculated values in appropriate windows on tab "Simulation experiment". Check obtained values of mathematical expectation, dispersion and standard deviation with calculations obtained by computer; for this, you should address to your instructor.

3.2.9 Compare the distribution diagram of observations results with the diagram obtained on screen.

3.2.10 Finish the laboratory work by clicking "Finish work".

3.3 Selection and justification of the structure of temperature measurement channel

In this subsection, the rationale for choosing measuring instruments is considered taking into account the environmental parameters: temperature, pressure, humidity, composition, dustiness, electrical properties.

When choosing measuring instruments, it is necessary to take into consideration their accuracy, measurement range and operating conditions.

When choosing a primary transducer, it is necessary to take into account that when measuring temperatures up to 200 - 240 □° C from the point of view of greater accuracy of measurement, it is preferable to use resistance thermometers, whereas when measuring temperatures above 200 □° C - thermoelectric converters.

Normalizing transducers, millivoltmeters and automatic potentiometers work as secondary devices and secondary transducers in complete with thermoelectric transducers.Normalizing transducers, bridge circuits and logometers work as secondary devices and secondary transducers in complete with resistive thermometer.

Measuring range of primary and normalizing transducers, as well as the scale of secondary instrument are selected by a given nominal value of measured temperature, taking into account, that for the most accurate measurements, it is desirable to select a secondary device with suppressed-zero scale and a normalizing converter - with suppressed-zero conversion range. In addition, measured temperature should be in the second half of range (scale) of measurement, closer to the upper limit of measuring range or the range of conversion.

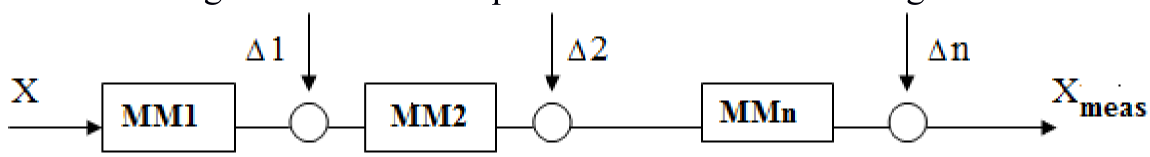
If possible, you should use the same type of equipment, which greatly facilitates the maintenance, operation and arrangement of them on shields.

3.4 Method of calculating total error of measuring channel

Typically, information-measuring systems contain several measurement channels, which in their turn consist of a number of series-connected measuring instruments such as sensors, normalizing converters, secondary devices, computers, etc.

Determination of measuring channel errors is treated as a calculation of summary action of all included in measurement channel measuring instruments errors.

Each measuring channel can be represented as a structural diagram



MM 1, MM 2, and others are means of measurement, included in a measurement channel;

Δ 1, Δ 2, ..., Δ n and others are errors of measurement means.

To summarize errors, they need to be represented by their root-mean square deviations, rather than by limit values, because it opens a possibility for summation of any number of error components.To solve these tasks, it is necessary to establish dependencies between root-mean square deviation and the error of single observation, which is determined by an accuracy class.

3.4.1 Errors of means of measurement and their normalization.

Errors of measuring instruments are classified according to same criteria as measurement errors.[3].

In technological measurements the most widespread form of accuracy class presentation is the form of presentation with usage of reduced errors:

$$\gamma = \frac{\Delta}{X_N} \times 100 \quad , \qquad (3.1)$$

where γ - reduced error expressed in %;

Δ - absolute error, expressed in units of measured values;
X_N - normalized value of a measurable value.

In this case, the accuracy class in normative and technical documentation for measurement means is a number equal to the reduced error, expressed in %.

It is well known that mathematical apparatus of probability theory is used to estimate measurements results of multiple observations and their measurement error.

Since errors of single measuring instruments are random variables, the calculation of total uncertainty of measurement channel can not be performed by a simple arithmetic addition of components because it gives an extremely high value of total error. In addition, summarizing errors you should take into account the existence of correlations between individual errors. Taking into account these circumstances for purpose of summing, error of measuring means,included in the measurement channel, should be represented by its root-mean square deviation. So $\sigma[\Delta_i]$ – root-mean square deviation of absolute error i-th measuring instrument is equal to:

$$\sigma[\Delta_i]=\frac{\Delta_i}{k} \quad , \tag{3.2}$$

where k - quantile factor determined by the distribution of measurement instrument's accepted basic error and the value of fiducial probability.

In addition, for convenience of the summation of additive and multiplicative components of errors, the root- mean square deviation should be submitted in a relative form. So, the root mean square deviation of a relative error of i-th measuring instrument is equal to:

$$\sigma[\delta_i]=\frac{\sigma[\Delta_i]}{X}100 \quad , \tag{3.3}$$

where X - measurable value.

According to probability theory, the standard deviation of errors sum is determined by the following expression:

$$\sigma[\delta_\Sigma]=\sqrt{\sigma^2[\delta_1]+2\rho\sigma[\delta_1]\sigma[\delta_2]+\sigma^2[\delta_2]} \quad , \tag{3.4}$$

where ρ - correlation coefficient.

If errors of measuring devices included in measurement channel are uncorrelated, then $\rho = 0$ and formula (3.4) takes the form:

$$\sigma[\delta_\Sigma]=\sqrt{\sigma^2[\delta_1]+\sigma^2[\delta_2]} \quad . \tag{3.5}$$

If measuring instruments errors are strongly correlated, for example, equally depend on some influencing parameter, then $\rho = 1$, and formula (3.4) takes form:

$$\sigma[\delta_\Sigma]=\sqrt{\sigma^2[\delta_1]+2\sigma[\delta_1]\sigma[\delta_2]+\sigma^2[\delta_2]}=\sigma[\delta_1]+\sigma[\delta_2] \quad . \tag{3.6}$$

Thus, strictly correlated errors are added algebraically. If correlation coefficient is negative, the errors will be deducted.

3.4.2 Practical rules for calculating total error of measuring channel.

3.4.2.1 Initial data for calculation should be characteristics of measurement devices' errors- absolute error of each measuring device included in measurement channel Δ_i .

3.4.2.2 Standard deviation of measurement errors of measurement instruments should be presented, at first, in absolute (3.2), and then in relative terms by formula (3-3).

3.4.2.3 Errors should be divided into two types by degree of correlation:

- strongly correlated ρ = 0,7 - 1,0;
- weakly correlated ρ ¿¿¿ 0,7.

3.4.2.4 Strongly correlated errors are summarized under formula (3.6), others by formula (3.5).

3.4.2.5 Group of strongly correlated errors is added with others by formula (3.6).

3.4.2.6 Confidence interval, in which with probability P total relative error of the measurement channel is located, is assumed to be equal to:

$$\delta_{\text{mc}}=k\times\sigma[\delta_\Sigma] \quad , \tag{3.7}$$

where k - quantile factor ;

$\sigma[\delta_\Sigma]$ - root-mean square deviation of measuring channel's relative total error according (3.4).

3.4.2.7 Confidence interval, in which with probability P total absolute error of measurement channel is located , is equal to:

$$\Delta_{\text{mc}}=k\times\sigma[\delta_\Sigma]\times\frac{X}{100} \quad . \tag{3.8}$$

3.4.2.8 Measurement result is represented as (1.1).

3.5 Contents of report

The report should include:

- assignment;
- structural scheme of temperature measurement channel;
- technical specifications of selected measurement instruments;
- 50 measured values fetching;
- calculation of mathematical expectation, dispersion and root-mean square deviation of measurement result;
- evaluation of systematic and random error of measuring means;

- graph of distribution diagram of measured value and conclusion on the obtained form of random error distribution law ;

- calculations of theoretical value of the total error of temperature measurement channel, according to point 3.4;

- measurement result presentation (of simulation experiment and theoretical calculation) by formula (1.1);

- conclusions about the work.

3.6 Control questions

3.6.1 What are the secondary devices, working with thermocouple?

3.6.2 What are the secondary devices, working with thermal resistance?

3.6.3 Give the definition and formula of "Absolute error" and "Reduced error".

3.6.4 Give definition and formula of "Random error" and "Systematic error".

3.6.5 What is a quantile factor for normal and uniform laws of distribution of random error equal to?

3.6.6 How to calculate total error of measurement channel?

4 Laboratory work №4. Studying ways to reduce errors in temperature measurement channel

Work purpose: gain skills on assembling measurement channel schemes with different types of lengthening wires of thermoelectric converters and compensation temperature device; as well as to study their impact on temperature measurement result in the structure of measurement channel.

4.1 Assignment for the laboratory work

Assemble the scheme of temperature measurement channel according to the given assignment on virtual lab screen.

Conduct six simulation experiments on measurement of given input value using this measuring channel, by introducing in its structure lengthening wires of different types and temperature compensation device.

Conduct statistical analysis of simulation experiment results.

Estimate the channel error of temperature measurement in each experiment.

4.2 Laboratory work performance order

4.2.1 Get a variant from the instructor to carry out the laboratory work and register in the system:

- download file "Metlab.exe",

- enter surname, first name, group number;

- enter laboratory work variant;

4.2.2 Explore the assignment in appeared window of the virtual laboratory work (figure 4.1).

Assemble the scheme of measuring channel to measure given temperature:

- to select a primary transducer open tab "Primary transducer";

- choose from the list of devices the type of primary transducer - thermocouple or thermal resistance, guided by the initial task;

-when selecting a sensor model, it is automatically set onto laboratory stand scheme (on the left);

- to select a secondary instrument open tab "Secondary device"; from the proposed list of devices (millivoltmeters, potentiometers, bridge circuits and logometers) select the type of secondary device, guided by the initial task;

- having selected secondary instrument model press button "Set" to install the device onto the scheme of measuring channel on the laboratory stand;

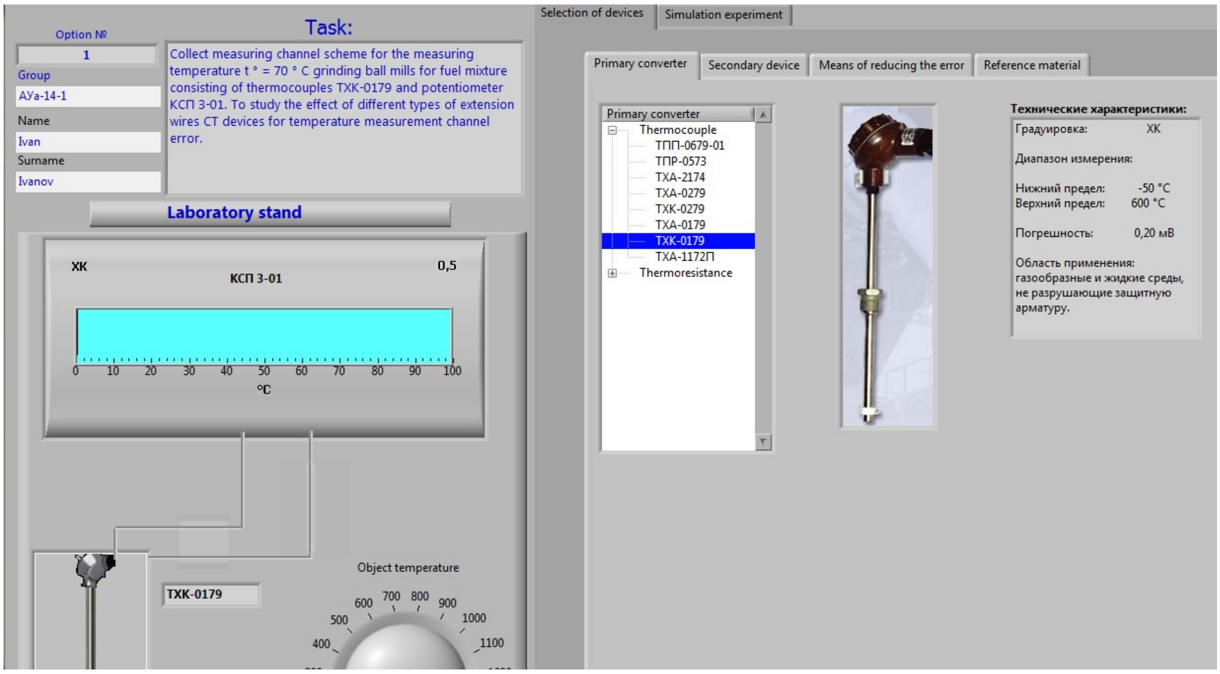


Figure 4.1 – Window of virtual laboratory work

- assembly of measuring channel scheme is over (figure 4.1).

If the scheme is assembled correctly, then near message "Scheme is assembled correctly" green LED will light; otherwise – near message "Scheme is assembled incorrectly" red LED will light; in this case it is necessary to repeat 4.2.2 until scheme will correctly assembled.

4.2.3 Having assembled the correct scheme one may proceed to carry out simulation experiments, for this you need to open tab "Simulation experiment".

4.2.4 Set a number of simulations equal to 50.

4.2.5 Set the given temperature using "Object temperature" handle on virtual laboratory installation (see the assignment).

4.2.6 Press button "Start simulation experiment".

Simulation experiment results will appear on tab "Simulation experiment" (50 values of measured quantity, obtained randomly as the result of measuring the given measurement value) and distribution diagram will appear either (figure 4.2).

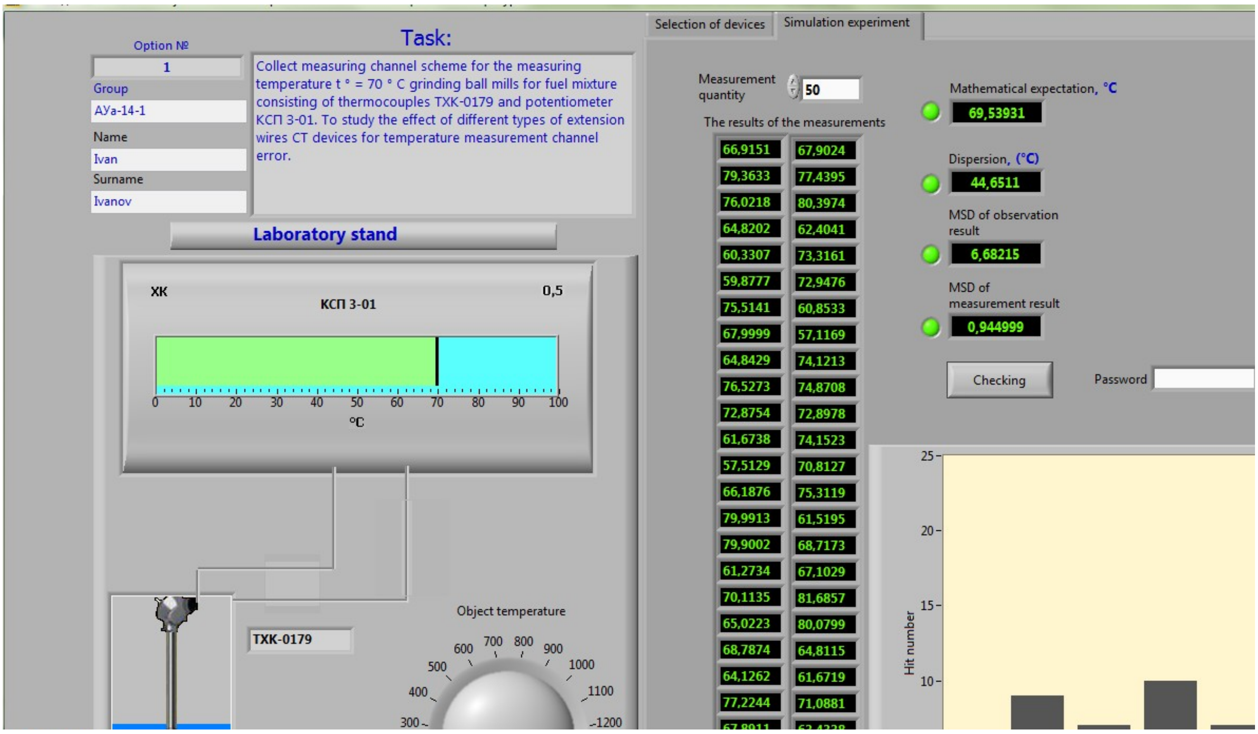


Figure 4.2 – Window of simulation experiment

4.2.7 To automatically record the results of the simulation experiment in EXCEL file (.xls extension), click "Save Selection" button. Perform statistical processing of the results of the simulation experiment:

- calculate by obtained fetching, using EXCEL, the expectation value, dispersion, standard deviation of observations result and measurement result,
- build a distribution diagram of observations results.

4.2.8 Enter calculated values in appropriate windows on tab «Simulation experiment». Check obtained values of mathematical expectation, dispersion and standard deviation with calculations obtained by computer; for this, you should address to your instructor.

4.2.9 Compare the distribution diagram of observations results with the diagram obtained on screen.

4.2.10 The next three simulation experiments will be conducted to study the effect of lengthening wires on the measurement result of the given temperature. The assembled scheme of the measuring channel will change.

Now we will complicate the scheme, by adding lengthening wires running in complete with a selected type of primary converter - with thermocouple; to do this, open tab "Means of reducing errors" (figure 4.3). The means of reducing errors: three types of lengthening wires: HK type, M type, PP type and a device of temperature compensation will appear.

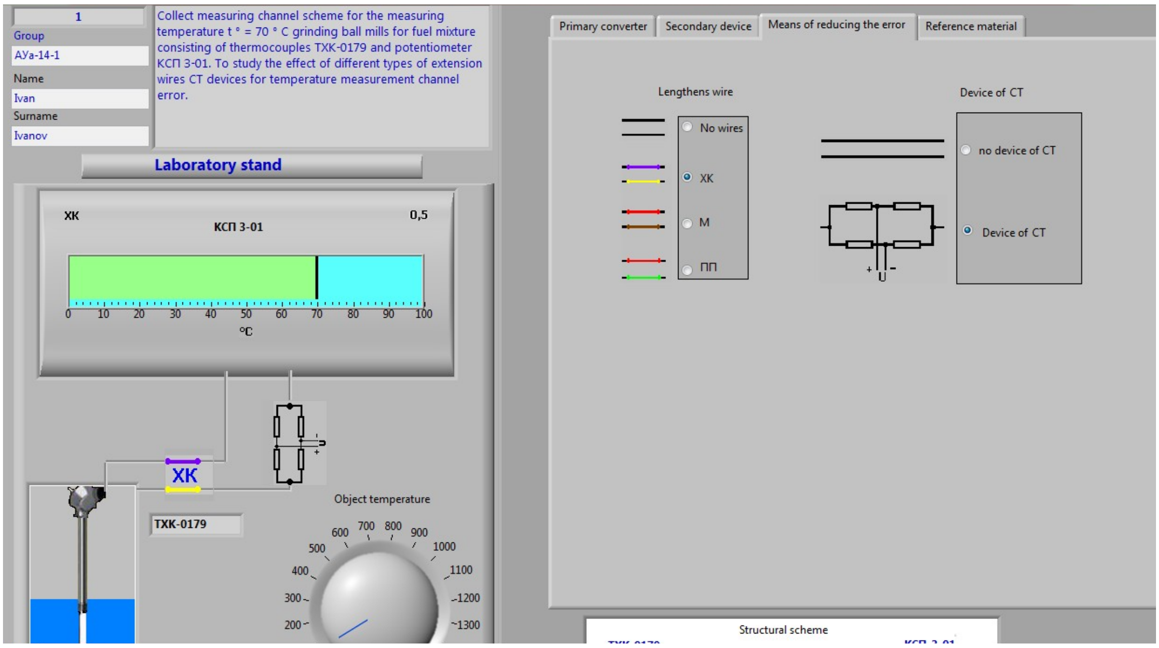


Figure 4.3 – Tab "Means of reducing error"

Lengthening wires of only certain type will work with the selected type of thermocouple [2, §4-9] - one of three offered ones on the tab; in this case measurement error will be the least one. It is necessary to define this type of lengthening wires, by the way of studying measurement channel error, alternately connecting different types of lengthening wires. For this purpose, you should:

1) Select wires of HK type by clicking the circle near their names. The wires of HK type will appear on the scheme of measuring channel on laboratory stand. Repeat points 4.2.3 -4.2.9 to obtain the scheme of measuring channel.

2) Select wires of M type by clicking the circle near their names. The wires of M type will appear on the scheme of measuring channel on the laboratory stand. Repeat points 4.2.3 -4.2.9 to obtain the scheme of measuring channel.

3) Select wires of PP type, by clicking the circle near their names. The wires of PP type will appear on the scheme of measuring channel on the laboratory stand. Repeat points 4.2.3 -4.2.9 to obtain the scheme of measuring channel.

4.2.11 Evaluate obtained in point 4.2.10 values of root-mean square deviation for three schemes of the measuring channel with different types of lengthening wires. Select the scheme with the least value of standard deviation.

4.2.12 The next simulation experiment (the fifth one) will be conducted to study effects of temperature compensation device on temperature measurement error. To do this, go back to tab "Means to reduce errors." The initial scheme of measuring channel will change.

There are no lengthening wires: "Click" to the circle near "No wire". We add a device of temperature compensation into the scheme, for this purpose, "click" to the circle near "Temperature compensation device". The laboratory stand in the initial scheme of measuring channel of the device of temperature compensation appears (bridge circuit). Repeat points 4.2.3 -4.2.9 to obtain the measuring channel scheme.

4.2.13 The sixth simulation experiment is conducted on the virtual laboratory stand to study the joint impact of lengthening wires and temperature compensation device onto temperature measurement errors. A real situation is simulated if suitable lengthening wires are used when measuring the temperature of an object with the help of thermocouple. Also a real situation is simulated if temperature correction of free ends of the thermocouple is automatically introduced with the help of temperature compensation device .For this, we will add to the scheme of laboratory stand lengthening wires, selected while analyzing point 4.2.11. Repeat points 4.2.3 -4.2.9 to obtain the measuring channel scheme.

4.2.14 Finish the laboratory work by pressing button "Completion of work".

4.3 Contents of report

The report should include:

-assignment;

- structural scheme of temperature measurement channel;
- technical specifications of selected measurement instruments;
- for each simulation experiment with a measurement channel scheme it is necessary to make:

a) 50 measured values fetching;

b) calculations of mathematical expectation, dispersion and root-mean square deviation of measurement results;

c) graph of distribution diagram of measured value and conclusion on the obtained form of random error distribution law ;

d) measurement result presentation (of simulation experiment and theoretical calculation) by formula (1.1);

- conclusions about the work.

4.4 Control questions

4.4.1 Standard calibrations of thermoelectric converters.

4.4.2 Lengthening thermocouple wires, their purpose.

4.4.3 Main characteristics of standard lengthening thermocouple wires.

4.4.4 Scheme and operation principle of temperature compensation device.

4.4.5 What is the purpose of temperature correction of thermocouple free ends?

5 Laboratory work №5. Studying basic and additional errors of measuring means

Work purpose: gain skills to calculate basic and additional errors of measuring instruments taking into account the influence of environmental parameters such as temperature, external electromagnetic field and power supply voltage on the measurement result.

5.1 Assignment for the laboratory work

Assemble the scheme of temperature measurement channel according to the given assignment on the screen of virtual laboratory work.

Conduct an imitation experiment to measure a given input value using the measuring channel in normal and operational conditions of the experiment.

Carry out statistical processing of the results of the simulation experiment.

5.2 Laboratory work performance order

5.2.1 Get a variant from the instructor to carry out the laboratory work and register in the system:

- download file "Metlab.exe", select your variant of the laboratory work from the main menu then the window of student registration will appear (figure 1.1);
- enter your surname, name, group number;
- enter the given variant of the laboratory work;
- click "Next".

5.2.2 Explore the assignment in appeared window of the virtual laboratory work (figure 5.1). Specific types of measuring instruments and conditions to carry out the experiment are given in the assignment: influence quantities (ambient temperature, power supply voltage, electromagnetic field strength) in dilated value domain, in normal conditions and operating conditions.

Assemble the scheme of measuring channel to measure the given temperature:

- to select a primary transducer open tab "Primary transducer";
- choose from the list of devices the type of primary transducer - thermocouple or thermal resistance, guided by the initial task;
- while selecting a sensor model it will be automatically set on the scheme on laboratory stand (on the left);

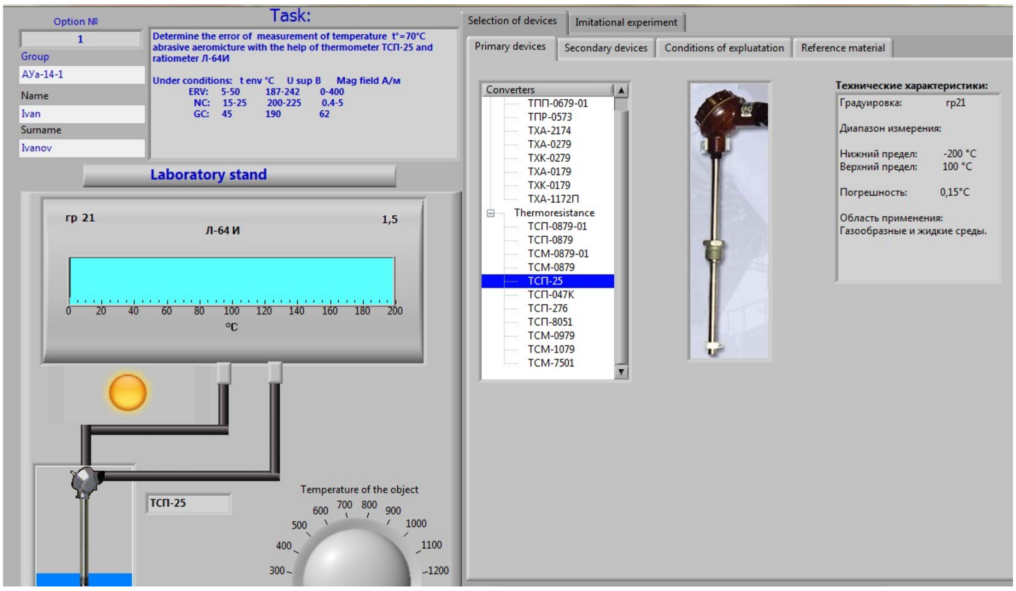


Figure 5.1 - Window of virtual laboratory work №5

- to select a secondary device, you should open tab «Secondary device»; from the list of devices (millivoltmeters, potentiometers, bridge circuits and logometers) select the type of secondary device, guided by the initial task ;
- having selected a secondary device model, press button "Set" to install the device in measuring channel scheme on the laboratory stand;

- assembly of measuring channel scheme is over (figure 5.1).

If the scheme is assembled correctly, the green light near message "The scheme is assembled correctly" will light; otherwise –the red light message "The scheme is assembled incorrectly" will light; in this case it is necessary to repeat 5.2.2 until the scheme will be correctly assembled.

5.2.3 The means of measurements work under normal operating conditions. The operating conditions are set on tab "Operating conditions" (figure 5.2): click tick "without the influence of external factors".

5.2.4 Having assembled the correct scheme of measuring channel and set the operating conditions one may proceed to carry out the simulation experiment, for this, you need to open tab "Simulation experiment".

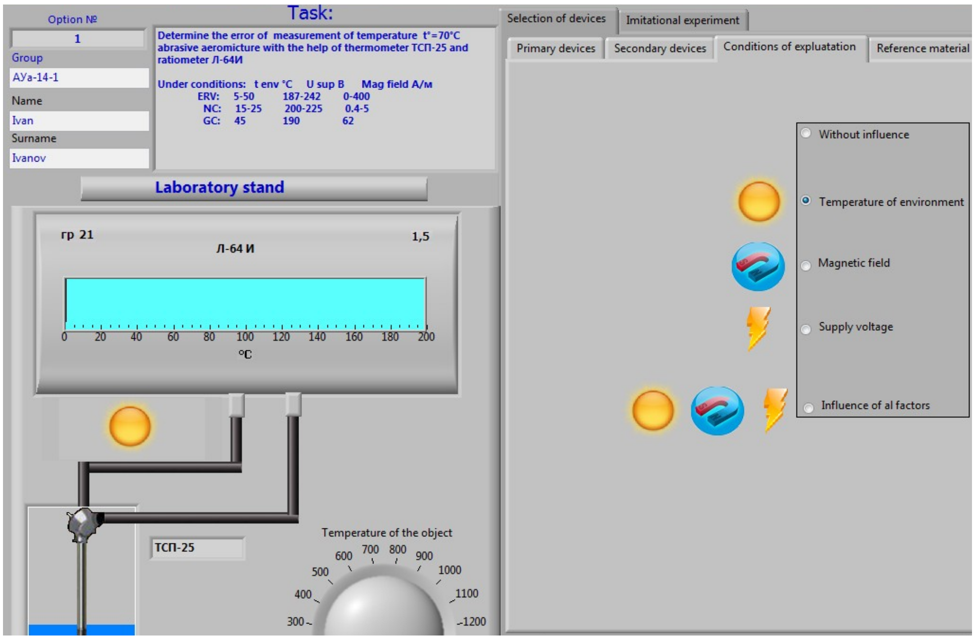


Figure 5.2 –Setting operating conditions window

5.2.5 Set the number of simulations equal to 50.

5.2.6 Set the given temperature using "Object temperature" handle on virtual laboratory installation (see the assignment).

5.2.7 Press button "Start simulation experiment". Simulation experiment results will appear on tab "Simulation experiment" (50 values of measured quantity, obtained randomly as the result of measuring the given measurement value) and distribution diagram will appear either (figure 5.3).

5.2.8 Press button «Save fetching» to record automatically the simulation experiment results in EXCEL file (extension .xls). Conduct statistical processing simulation experiment results:

- calculate the expectation value, dispersion, standard deviation of observations result and measurement result by the obtained fetching, using EXCEL;

- build a distribution diagram of observations results.

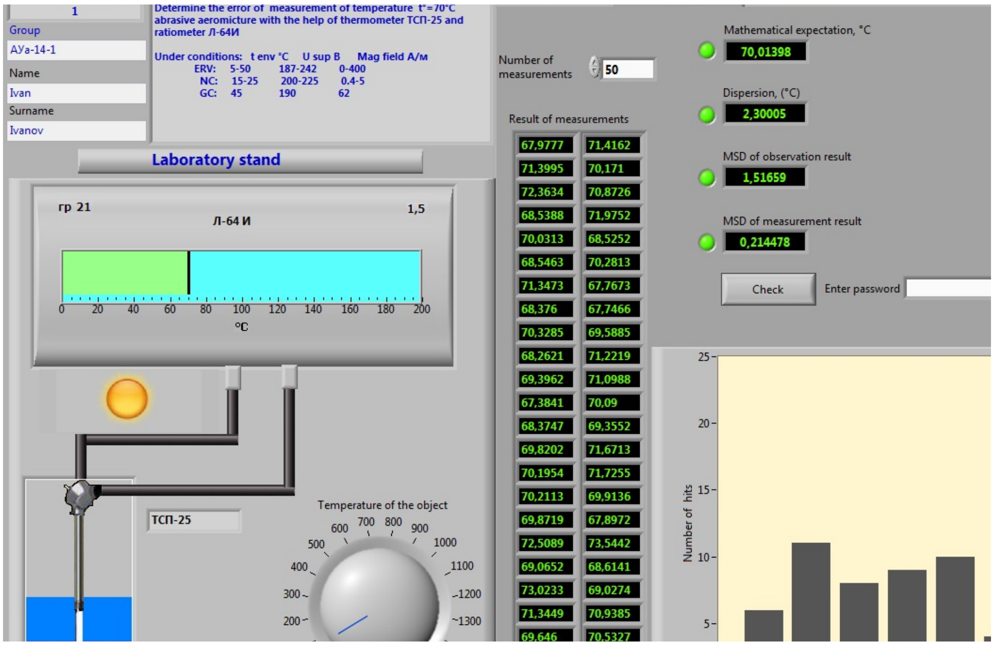


Figure 5.3 – Simulation experiment window

5.2.8 Enter calculated values in appropriate windows on tab "Simulation experiment". Check obtained values of mathematical expectation, dispersion and standard deviation with calculations obtained by computer; for this, you should address to your instructor.

5.2.9 Compare the distribution diagram of observations results with the diagram obtained on screen.

5.2.10 The specified normal conditions for the use of measuring instruments are usually not the operating (operational) conditions for their use. Therefore, for each type of measuring instrument in the standards or technical conditions, a dilated value domain of influencing values is established, within which the value of an additional error should not exceed the established limits.

The assembled circuit of the measuring channel remains unchanged. Let us change the experimental conditions.

The following four simulation experiments are conducted to study the effect of external influences on the error of measuring means of a given temperature:

- add in laboratory stand scheme the effect of external influence

- ambient temperature, for this purpose we open tab "Operating conditions" (figure 5.2): click mark "Environmental temperature", thus, the impact of external influence on the work of measuring instruments is introduced. Repeat points 5.2.3 –5.2.9 for the obtained scheme of measurement channel;

- add in laboratory stand scheme the effect of external influence:

- electromagnetic field, for this purpose we open tab "Terms of Use" (figure 5.2): click mark "Electromagnetic field", thus, the impact of external influences on the work of measuring instruments is introduced. Repeat points 5.2.3 –5.2.9 for the obtained scheme of measurement channel;

- add in laboratory stand scheme the effect of external influence:

- voltage supply, for this purpose we open tab "Terms of Use" (figure 5.2): click mark "Power supply", thus, impact of external influences on the work of measuring instruments is introduced. Repeat points 5.2.3 –5.2.9 for the obtained scheme of measurement channel;

- add in laboratory stand scheme the simultaneous effect of three external factors – ambient temperature, electromagnetic field and voltage supply, for this purpose we should open tab "Terms of Use" (figure 5.2): click mark "All influence quantities". Repeat points 5.2.3 –5.2.9 for the obtained scheme of measurement channel.

5.2.11 Finish the laboratory work by pressing button "Close".

5.3 Calculation of basic and additional errors of measuring instruments

5.3.1 Calculation of errors of measuring instruments under normal operating conditions.

Permissible variation (error) of primary device calibration according to [2] depends on the type and technical characteristics of its type, and are set in technical characteristics of the primary device (figure 5.1).

The limit of permissible basic absolute error of the readings of the secondary device is determined by the formula:

$$\Delta_2=\frac{k(X_u-X_l)}{100}\quad, \tag{5.1}$$

where k - secondary device accuracy class;

X_u, X_l - upper and lower boundaries of the secondary device range of variation, mV (for millivoltmeter or potentiometer) or Ohm (for a bridge or logo meter).

The limiting absolute basic indications error of measurement channel in normal conditions are determined by formula:

$$\Delta_{\text{nc}}=\pm\sqrt{\Delta_1^2+\Delta_2^2}\quad. \tag{5.2}$$

To get the error value in Celsius degrees (ΔT_{nc}), you should use a standard reference table (conversion function) of corresponding primary transducer [2, tables P4-7-1, 2, 3, 4, 5, 6] , or tables on tab "The choice of measuring instruments": "Reference material".

5.3.2 Calculation of measuring channel error in working (operational) conditions.

According to secondary instruments specifications, the variation of instrument indications, used with primary converter, can occur:

a) due to the changes in ambient temperature from normal conditions. If this change does not come out of limits of the dilated value domain, so, the variation in indications for each $10^0 C$ does not exceed:

$$\Delta \text{add}_1=\pm\frac{0.2\times(X_u-X_n)}{100}\quad; \tag{5.3}$$

b) due to the changes in voltage supply of the electrical circuit of the device. If this variation is within 10% and 15% of nominal value, the variation of instrument indications does not exceed:

$$\Delta \mathrm{add}_2 = \pm \frac{0.25 \times (X_u - X_l)}{100} \quad ; \tag{5.4}$$

c) due to the influence of external electromagnetic field. If the external electromagnetic field strength formed by alternating current with frequency of 50 Hz, is not more than 400 A / m, the variation in device indications will not exceed:

$$\Delta \mathrm{add}_3 = \pm \frac{0.5 \times (X_u - X_n)}{100} \quad . \tag{5.5}$$

To obtain the values of these errors in Celsius degrees ($\Delta t_1, \Delta t_2, \Delta t_3$) you must use the calibration table corresponding to the primary converter [2, tables P4-7-1, 2, 3, 4, 5, 6].

One can estimate approximately the limit of the variation of secondary device total indications by formula:

$$\delta_{\mathrm{additional}} = \pm \sqrt{\sum \delta_{i^2}} \quad , \quad \% \quad , \tag{5.6}$$

where δ_i - maximal relative error of impact of i - th influence quantity is calculated by formula:

$$\delta_i = \pm \frac{\Delta t_i}{t_{\mathrm{meas}}} 100 \quad , \quad \% \quad , \tag{5.7}$$

where Δt_i - additional error due to influence of i-th influencing value in Celsius degrees;

t_{meas} - measured temperature value.

The additional absolute error of summarized indications change of secondary device is determined by formula:

$$\Delta T_{\mathrm{additional}} = \pm \frac{\delta_{\mathrm{additional}}}{100} t_{\mathrm{meas}} \quad , \quad {}^0C \quad . \tag{5.8}$$

The limiting error of measuring channel in operating conditions will not exceed:

$$\Delta T_{\mathrm{EC}} = \pm (\Delta T_{\mathrm{nc}} + \Delta T) \quad , \quad {}^0C \quad . \tag{5.9}$$

5.4 Contents of report

The report should include:

-assignment;

-structural scheme of temperature measurement channel;

-technical specifications of selected measurement instruments;

-obtained fetching of 50 measured values; calculations of mathematical expectation, dispersion and root-mean square deviation of measurement results; estimation of the confidence interval; histogram graph of distribution diagram of measured value under normal conditions, under working (operational) conditions, under influence of three influence quantities separately and under their combined effect;

- calculations of theoretical value of the error of measuring channel under normal operation and working (operational) conditions on summary effect of influence quantities, according point 5.3;
- measurement result presentation (of simulation experiment and theoretical calculation) by formula (1.1);
- conclusions about the work.

5.5 Control questions

5.5.1 Give the definition of "Basic error" and "General error of measuring”.
5.5.2 What conditions are called normal operating and working?
5.5.3 Give examples of external influences.
5.5.4 Ways of numerical expression for measurement errors.
5.5.5 What is "Dilated value domain" ?
5.5.6 Classification of errors of measurement instruments.

6 Laboratory work №6. Testing and calibration of technical thermometers

Work purpose: to explore the method of technical thermometer calibration-and conduct its calibration.

6.1 Assignment for the laboratory work

Assemble the scheme of the laboratory stand to conduct the test of technical thermometer according to the given assignment on the screen of virtual laboratory work.

Conduct an imitation experiment to test and calibrate a technical thermometer.

Carry out statistical processing of the results of the simulation experiment.

6.2 Laboratory work performance order

6.2.1 Get a variant from the instructor to carry out the laboratory work and register in the system:

- download file "Metlab.exe", select your variant of the laboratory work from the main menu then the window of student registration will appear (figure 1.1);
- enter your surname, name, group number;
- enter the given variant of the laboratory work;
- click "Next".

6.2.2 Explore the assignment in appeared window of the virtual laboratory work (figure 6.1).

Assemble the scheme of the laboratory stand to test a specified technical thermometer; for this go on tab "Select mean of measurement":

- open tab "Exemplary thermocouple" to select exemplary technical thermocouple;

- select the particular brand of a given technical thermometer, for this purpose, "click" on "+" near selected type of a primary transducer. After that, it appears automatically in the laboratory stand diagram;

- open tab "Tested thermocouple" to select a tested technical thermocouple;

- select the specific brand of a given verified technical thermometer, for this purpose "click" "+" near selected type of a primary transducer. After that, it will appear automatically in the scheme of the laboratory stand;

- assembly of the measuring channel scheme is over. If the scheme is assembled correctly, then near message "Scheme is assembled correctly" green light will light; otherwise –near message "Scheme is assembled incorrectly" red light will light; in this case, it is necessary to repeat 6.1.2 until scheme will correctly assembled.

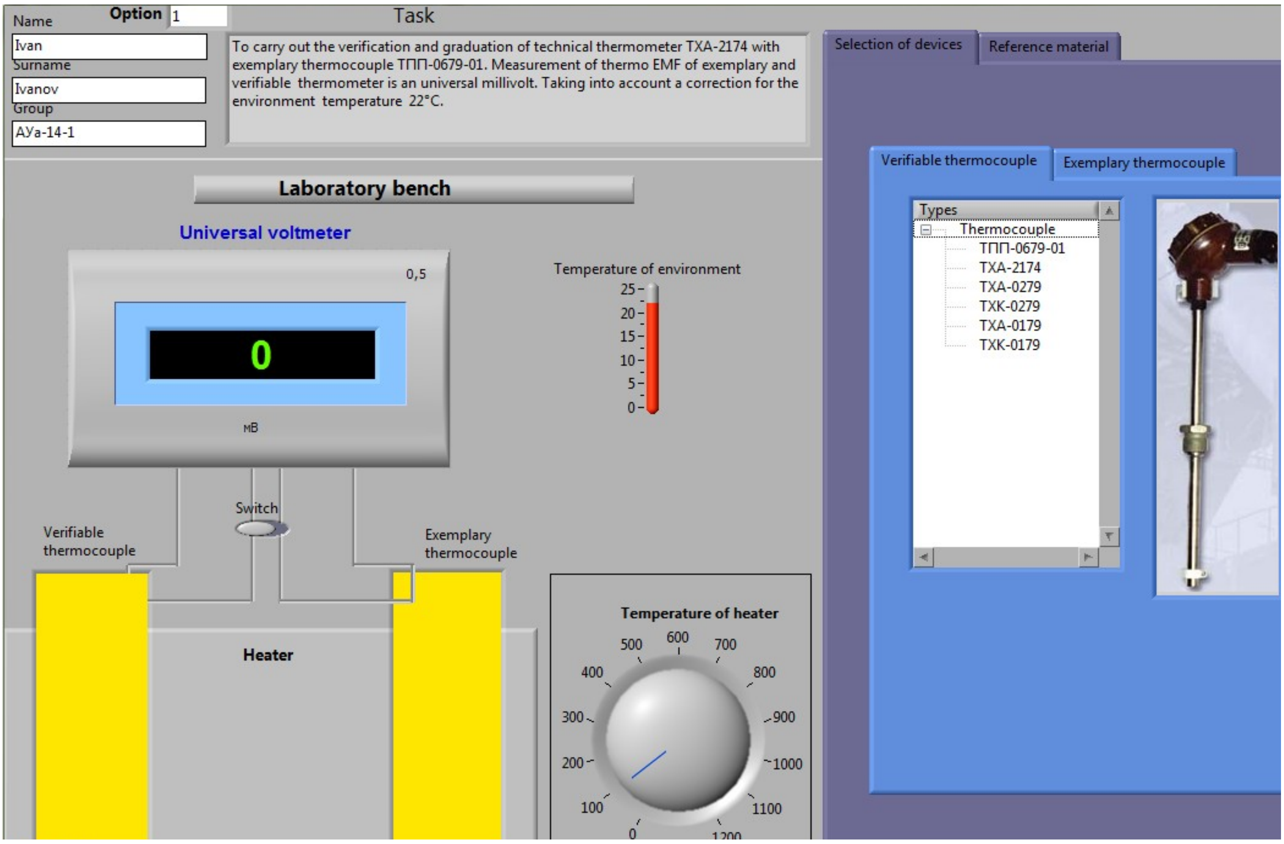


Figure 6.1 – Scheme of virtual laboratory stand to test technical thermometers

6.2.3 Start to take readings of a sample thermocouple, after that of a tested thermocouple alternately. The method of technical thermometer calibration testing is as follows:

a) according to verified thermocouple specifications (figure 6.1) you should divide its measuring range into five intervals (five verified points), write down the values of verified points t_{verified} in table 6.1, on the line "Temperature points" for sample and tested thermocouples;

b) set the first test point using toggle "Temperature of furnace";

c) turn the switch "Toggle" onto the right position "Reference thermocouple" on the laboratory stand;

d) make the first measurement of thermo EMF of the thermocouple by pushing button "Measure", and note down universal millivoltmeter readings in table 6.1, in column "Thermo EMF values" of the reference thermocouple;

e) turn the switch "Toggle" onto the left position "Tested thermocouple";

f) make the first measurement of thermo EMF of the tested thermocouple by pushing button "Measure", and note down universal millivoltmeter readings in table 6.1, in column "Thermo EMF values" of the tested thermocouple;

g) repeat from c) to-f) four times, by measuring temperature of the first verified point alternately with the help of sample and tested thermocouples, and you should write down the values of thermo EMF into the calibration report;

h) repeat from b) to g) for five calibrated temperature points.

6.2.4 To fill the calibration report and obtain the calibration conclusion, it is necessary to take into consideration the correction for temperature of thermocouple free ends, different from the calibration temperature equal to 0 ° C, formula (6.4) (point 6.3).

Since the laboratory stand operates at ambient temperature $t_0^{\square}$, and, respectively, free ends of the technical thermometer work at this temperature, so, it is necessary to take into account the above correction in the process of performing calculations in table 6.1. In order to determine the value of thermo EMF the correction by ambient temperature value, and to determine temperature t by the value of thermo EMF at free ends temperature $t_{\text{freeends.}}=t_0=0\,°C$, it is necessary to use the calibration table of corresponding primary device [2, tables P4-7-1,2,3,4,5,6], or tables on tab "Choice of measuring instruments": "Reference material".

6.2.5 You should construct a real calibration characteristic of the technical thermometer obtained by measuring results of thermo EMF of the tested thermocouple (table 6.1).

You should construct a nominal calibration characteristic of the tested thermocouple $E_{\text{AB}}(t_{\text{verified}}, t_0)=F(t_{\text{verified}})$ according to the calibration table of the tested thermocouple in the same coordinate system.

Table 6.1 –Calibration report of the technic thermocouple

Variant____

Date________________

REPORT

of calibration of the technical thermometer___________________________ of grading _______,
presented at virtual laboratory stand in room____________at AUPET.

The calibration was done with the help of reference instruments

reference thermometer__________________________ of grading______ and reference digital millivoltmeter.
Notes on visual inspection: _______________________________

Calibration conditions: free ends temperature- _______ºC.

Thermometers indications , mV

Thermometer	Reference					Tested				
Temperature (test) points t_{verified} °C										

End of table 6.1

Value of thermo EMF, mV 1										
2										
3										
4										
5										
Arithmetic mean value of thermo EMF, mV										
Thermo EMF correction of free ends, mV										
Thermo EMF at temperature of free ends t_0 = 0°C										
Temperature, t °C										
Tested thermometer error, °C										

Conclusion about calibration	

6.3 Temperature correction of thermocouple free ends

The temperature measurement by technical thermometers, thermoelectric converters, is based on the usage of *thermoelectric effect* discovered by T. Seebeck in 1821.

Thermoelectric converter is a circuit composed of two or more interconnected dissimilar conductors (figure 6.2).

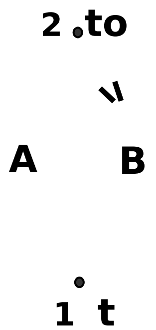


Figure 6.2- Thermoelectric converter

A, B – thermo electrodes; 1, 2 – junctions.

Seebeck effect: If we take two dissimilar wire, joined together, and heat up junctions so that t $\neq$ t_o, the electric current will flow in the closed circuit.

If t > t_o, current direction as shown in figure 6.2 (in junction 1 from B to A).

If we break the circuit, thermo-EMF will appear at its ends

The junction, immersed into temperature measurement object, is called a hot junction (junction 1), and junction outside the object is called a cold junction (junction 2).

Let us introduce notations: $e_{AB}(t)$ – thermo EMF in junction 1 between thermal electrodes A and B at t = t; $e_{AB}(t_o)$ – thermo EMF in junction 2 between thermal electrodes A and B at $t=t_0$; $E_{AB}(t,\ t_o)$ –thermo EMF of circuit, consisting of thermo electrodes A and B under hot junction temperature t and cold junction temperature $t_{o.}$

Let us assume that $e_{AB}(t) = - e_{BA}(t);$ $e_{AB}(t_o) = - e_{BA}(t_o)$. Then, for the claused circuit:

$$E_{AB}(t,\ t_o) = e_{AB}(t) - e_{AB}(t_o)\ . \tag{6.1}$$

Equation (6.1) is called a *basic equation of thermoelectric converter.* During the process of calibration of the thermoelectric converter, free ends temperature $t_o = const$, usually $t_o = 0\ ^oC$.

The temperature correction of cold-junction of thermoelectric converter is introduced when $t_o \neq 0$, in order to use the calibration table of corresponding thermocouple while determining desired temperature t. If free ends temperature is different from zero and is equal to t'_0 , the readings of instrument at temperature of working ends equal to t, will correspond to the generated EMF in this case, according to the basic equation of thermoelectric converter.

$$E_{AB}\ (t, t_0^{\square}) = e_{AB}(t) - e_{AB}(t\ \square_0^{\square}\ )\ . \quad (6.2)$$

The calibration table corresponds to condition $t_o = 0$:

$$E_{AB}(t, t_o) = e_{AB}(t) - e_{AB}(t_o)\ . \quad (6.3)$$

Let us subtract equation (6.2) from equation (6.3), then:

$$E_{\mathrm{AB}}(t, t_0) = E_{\mathrm{AB}}(t, t_0^{\square}) + E_{\mathrm{AB}}(t_0^{\square}, t_0)\ , \quad (6.4)$$

where $E_{\mathrm{AB}}(t, t_0)$ - thermo EMF of thermocouple AB при $t_{\mathrm{freeends}} = t_0 = 0\,°C$ and measured temperature t ;

$E_{\mathrm{AB}}(t, t_0^{\square})$ - thermo EMF of thermocouple AB at $t_{\mathrm{freeends}} = t_0^{\square} \neq 0\,°C$ and measured temperature t ;

$E_{\mathrm{AB}}(t_0^{\square}, t_0)$ - correction on $t_{\mathrm{freeends}} = t_0^{\square}$, different from $0\,°C$.

6.3 Contents of report

Report should contain:

-purpose of the work;

-assignment;

-scheme of the laboratory stand to test a technical thermometer;

-technical specifications of chosen measuring instruments;

-calibration report of the technical thermometer;

-graphs of nominal and real calibration characteristics of the tested thermocouples;

-conclusions about the work.

6.4 Control questions

-State metrological control and supervision [4];

-definition of "measurement calibration";

-definition of "calibration interval";

-methods of measurement instruments calibration;

-types of standards, definitions;

-thermoelectric effect, definition;

-basic equation of thermoelectric converter;

-what is the purpose of temperature correction of free ends, different from calibration temperature? ;

-formula for calculating temperature correction of free ends temperature different from calibration temperature.

7 Laboratory work №7. Processing results of single direct and indirect measurements

Work purpose: to gain skills on planning and performing single direct and indirect measurements. Get experience on measuring instruments choice, providing the solution of measurement problems. Studying ways of processing and correct representing results of single direct and indirect measurements.

7.1 Assignment for the laboratory work

Explore virtual models of measurement instruments and their technical specifications.

Conduct the simulation experiment on measurement of given input value using given measurement instruments.

Calculate errors of direct measurements results performed on virtual laboratory stand using three measurement instruments (optional).

Calculate the error of the result of indirect measurement of dividing coefficient of divider.

7.2 Description of virtual models of measurement instruments

The virtual laboratory stand is a LabVIEW computer model, located on PC desktop. There are the following measuring instruments models at the stand: magnetoelectric voltampermeter model; electronic analogue millivoltmeter model; digital multimeter model; universal power supply model; AC power supply model; galvanic cell model; voltage divider model; switching device model.

7.2.1 Magnetoelectric voltampermeter front panel

The model of magnetoelectric volt-ammeter is used for modeling the process of direct measurements of constant voltage and strength of DC by direct estimation method.

Technical specifications, reproduced with the help of magnetoelectric voltampermeter model:

- in DC measurement mode, measurement range can be selected within the range from 0.075 V to 600 V;
- in DC measurement mode, measurement range can be selected within the range from 0,075 mA to 3 A;
- accuracy class is normalized for reduced error and is equal to 0,5.

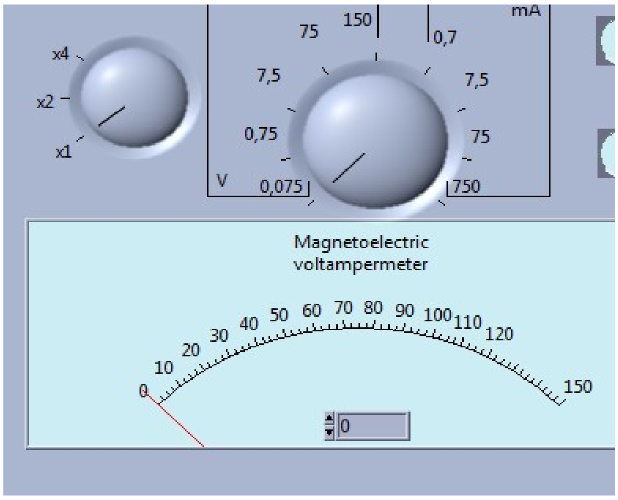


Figure 7.1 –Magnetoelectric voltampermeter front panel

7.2.2 Electronic analogue millivoltmeter model.

The electronic analogue millivoltmeter model is used in simulating the process of voltage root-mean square value of direct measurements in AC circuits of sinusoidal and of distorted form with the help of direct evaluation method.

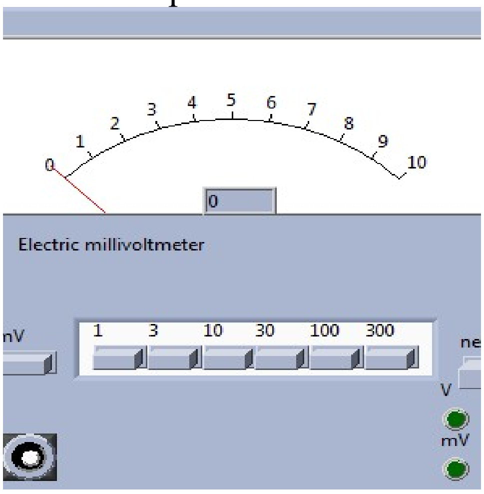


Figure 7.2 – Front panel of electronic analog millivoltmeter

Technical specifications, reproduced with the help of electronic analog millivoltmeter model:

- in alternating voltage measurement mode, measurement range can be selected from 0,1 mV to 300 V;
- operating frequency range from 10 Hz to 10 MHz;
- limits of permissible reduced basic error in frequency range from 50 Hz to 100 kHz should not exceed:

1. h<=1 % in range 1-3 mV;
2. h<=0,5 % in range 10 mV-300 V.

7.2.3 Digital multimeter model.

The digital multimeter model during the operation is used as a digital voltmeter for simulation process of constant voltage direct measurements and for simulation process of alternating voltage with sinusoidal form root-mean square value measurement with help of direct evaluation method.

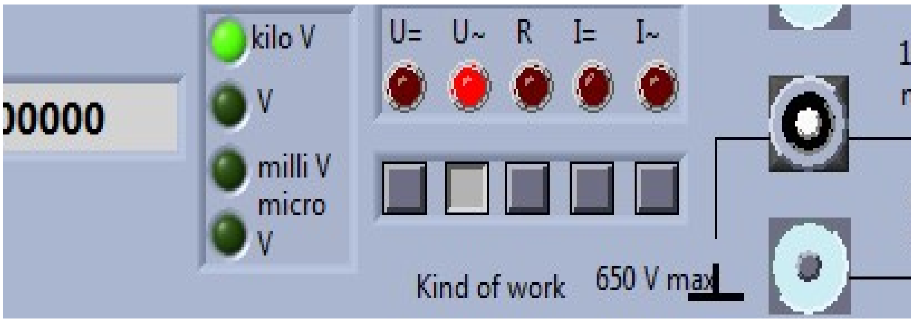


Figure 7.3 –Digital multimeter front panel

Technical specifications, reproduced with the help of the digital multimeter model:

1) The measurement limits can be selected from 1,0 mV to 300 V in constant voltage measurement mode.

2) The following subranges from 0,0 mV to 199,9 mV; from 0,000 V to 1,999 V; from 0,00 V to 19,99 V; from 0,0 V to 199,9 V; from 0 V to 1999 V can be set while measuring the voltage.

3) Basic relative error limits in voltage measurement are equal to:

- while measuring constant voltage:

$$\delta=\pm[0{,}1+0{,}02\times(\frac{U_k}{U}-1)] \quad ;$$

- while measuring alternating voltage in all frequency range:

$$\delta=\pm\left[0{,}6+0{,}1\times\left(\frac{U_k}{U}-1\right)\right] \quad ,$$

where U_k - final value of a set limit of measurement;
U - measured voltage at multimeter input.

4) Maximum permissible values of multimeter basic error while measuring an active electrical resistance are equal to:

$$\delta R=\pm[0{,}6+0{,}1\times(\frac{R_k}{R}-1)] \quad ,$$

where R_k – final value of a set limit of measurement;
R –measured resistance value.

7.2.4 Universal power supply model.

The universal power supply model is used for modeling the work of a regulated source of stabilized constant voltage.

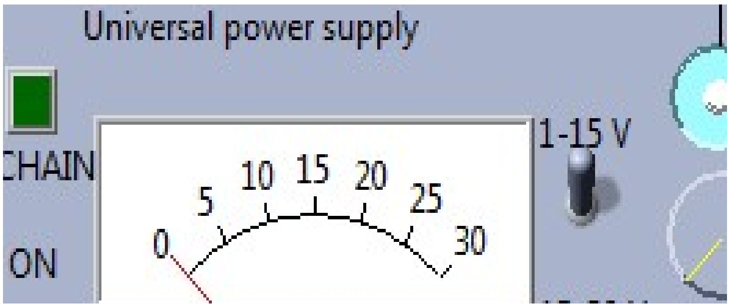


Figure 7.4 – Universal power supply front model

The technical specifications, reproduced with the help of a given universal power supply model.

Output voltage adjustment range is from 0 V to 30 V with two subranges, the one first - from 0 V to 15 V and second one- from 15 V to 30 V.

7.2.5 AC power source model.

AC power source model simulates harmonic AC voltage frequency of 50 Hz, current value is about 220 V, and internal resistance is negligibly little.

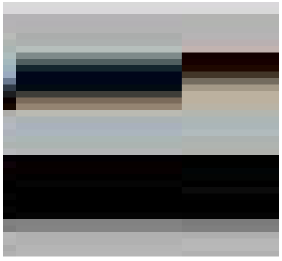


Figure 7.5 – Front panel of AC power source model

7.2.6 Galvanic cell model.

The cell model simulates the constant source of electromotive force with EMF of about 1.5 volts, and with negligible internal resistance.

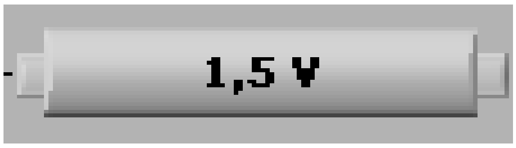


Figure 7.6 - Galvanic cell front panel

7.2.7 Voltage divider model.

The voltage divider model is used for modeling the work of a divider with division factor K equal to 1: 10 000, with accuracy class equal to 0.05, input resistance of at least 1 MW, output - less than 1 kohm. The divider can be used at AC and DC voltage up to 500 V and frequency of 20 kHz.

Figure 7.7 –Voltage divider model front panel

7.2.8 Switching device model.

The switching device model is used for modeling the connection inputs of voltmeter to measured voltage source output. Connecting voltmeters models to models of measured voltage sources is performed by installing upper switch at the number of input, to which a measured parameter source is connected, and lower switch - at the number of output, to which a measuring device is connected. The established connection is displayed on the front panel by yellow color.

The toggle switch "ON" for turning on the switching device, toggles to select the technique of commutation inputs and outputs of switching devices between themselves are located on front panel.

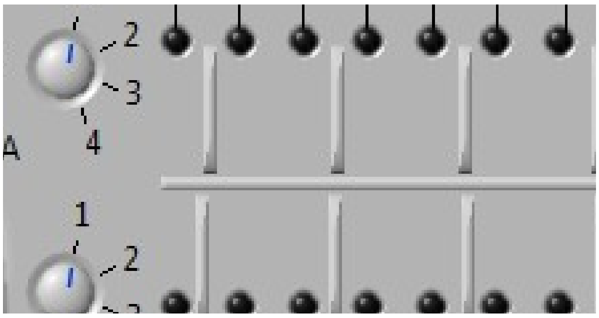


Figure 7.8 - Front panel of switching device model

7.3 Laboratory work performance order

7.3.1 Get a variant from the instructor to carry out the laboratory work and register in the system:

- download file "Metlab.exe", select your variant of the laboratory work from the main menu then the window of student registration will appear (figure 1.1);
- enter your surname, name, group number;
- enter the given variant of the laboratory work;
- click "Next".

7.3.2 Assignment.

7.3.2.1 You should acquaint with the location of individual measurement instruments models and other devices on the laboratory stand (figure 7.9).

7.3.2.2 Switch on the models of measuring instruments and auxiliary devices and try out their controls.

7.3.3 Implementation of direct single measurements.

7.3.3.1 Select a voltmeter on the laboratory stand to measure constant voltage at the output of a universal power supply with a relative error not exceeding 1%. The output voltage of the universal power supply may be set arbitrarily from 0 V to 30 V.

After choosing a voltmeter, set a suitable measuring range, and with the help of a switching device connect the voltmeter to the output of universal power supply.

Turn on the universal power supply, and set the voltage on its output within the specified range.

Take voltmeter indications by pressing button "Conduct measurement".

Write voltmeter indications in table 7.1 as well as the type and precision class of the voltmeter, selected measuring range and input signal value.

Repeat twice article 7.3.3.1 with other values of input voltage on the selected voltmeter.

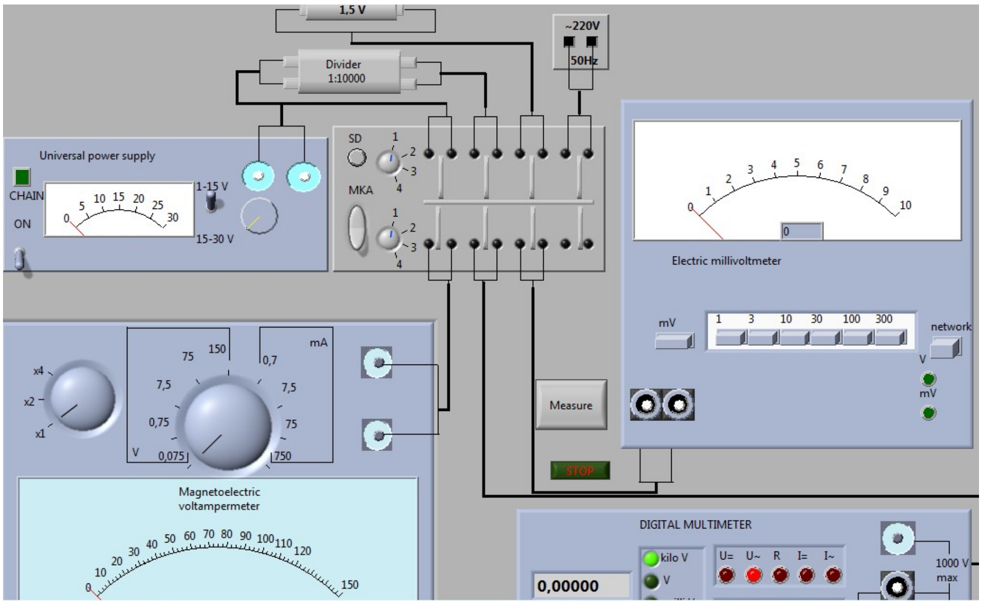


Figure 7.9 – Virtual laboratory stand

7.3.3.2 Select a voltmeter on the laboratory stand to measure electromotive force of the galvanic element with absolute error not exceeding 2 mV (EMF value is constant and is from 1.3 to 1.7 V).

After choosing the voltmeter, set a suitable measuring range, and with the help of the switching device connect the voltmeter to EMF output source. Take indications of the voltmeter by clicking button "Conduct measurement".

Write down voltmeter indications into table 7.2 as well as the type and precision class of the voltmeter, selected measuring range and input signal value. Repeat twice p.7.3.3.2 with other values of the input voltage on the selected voltmeter.

7.3.3.3 Select a voltmeter on the laboratory stand to measure voltage at the output of the source of alternating voltage with relative error not exceeding 0,5%.

After selecting a voltmeter, set a suitable measuring range and with the help of switching device, connect the voltmeter to the output of alternating voltage source. Take voltmeter indications by clicking button "Conduct measurement".

Write down voltmeter indications into table 7.3, as well as the type and precision class of the voltmeter, selected measuring range and the value of the input signal. Repeat twice p.7.3.3.3 with other values of input voltage on the selected voltmeter.

Table 7.1 - Direct measurements of voltage at the output of a universal power supply

Voltmeter: type ___________________ precision class ____________________						
№	Input voltage, V	Voltmeter indications, V	Range, V	Absolute error, V	Relative error, %	Measurement result, V
1						

2						

Table 7.2 - Direct measurement of galvanic element EMF.

Voltmeter: type ___________________ precision class ________________						
№	Input voltage, V	Voltmeter indications, V	Range, V	Absolute error, V	Relative error, %	Measurement result, V
1						
2						
3						

Table 7.3 - Direct measurements of alternating voltage

Voltmeter: type ___________________ precision class ________________						
№	Input voltage, V	Voltmeter indications, V	Range, V	Absolute error, V	Relative error, %	Measurement result, V
1						
2						
3						

7.3.4 Implementation of indirect measurements

7.3.4.1 Select a voltmeter on the laboratory stand for indirect measurement of a division factor of the voltage divisor.

After selecting a voltmeter, set a suitable measuring range.

Connect the divider to the output of the voltage source using a switching device.

With the help of the switching device you should alternately connect the voltmeter to the divider input and output, and take voltmeter readings in both cases, by clicking button "Carry out measurement".

Write down voltmeter readings into table 7.4, as well as the type and precision class of the voltmeter, selected measuring range and the information about the voltage divisor.

Repeat twice point 7.3.4.1 with other values of input voltage on the selected voltmeter.

Table 7.4 – Indirect measurements of dividing ratio of the voltage divisor

Voltmeter: type ___________________ precision class _____________ Voltage divisor type __________ precision class ____________				
№	Voltmeter indications at the divider *input*, V	Voltmeter indications at the divider *output*, V	Measuring range at the divider *input*, V	Measuring range at the divider *output*, V
1				

End of table 7.4

2				
3				
№	Relative error of voltage measurement at the divider *input*, %	Relative error of voltage measurement at divider *output*, %	Relative measuring error of division ratio, %	Measurement result of division ratio
1				
2				
3				

7.4 Contents of report

The report should contain:

- purpose and objectives of the laboratory work;
- virtual laboratory stand scheme, models and technical specifications of the used means of measurement;
- filled tables with the results of measurement errors of calculations;
- presentation of the measurement result according to formula (1.8) [8], formalized by rounding rule presented in item 1.5 [8];
- conclusions about the work.

7.5 Control questions

7.5.1 Define the following concepts: measurement, measurement result, absolute measurement error, relative error of measurement, physical quantity, true and actual value of physical quantity.

7.5.2 Basic equation of measurement.

7.5.3 Classification of measurements.

7.5.4 What is a direct measurement?

7.5.5 Evaluation of errors of single direct measurements.

7.5.6 What is an indirect measurement?

7.5.7 Evaluation of errors of single indirect measurements.

7.5.8 What is a measuring device?

7.5.9 Metrological characteristics of measuring instruments.

8 Laboratory work №8. Calibration and testing of analog transducer of thermo EMF by a single measurement method

Work purpose: studying methods of calibration and grading a normalizing transducer NP-TL1-M, which works with thermoelectric converters (thermocouples), and determination of total error of temperature measurement channel by the method of single measurements.

8.1 Assignment for the laboratory work

You should acquaint with virtual laboratory stand intended for studying normalizing converter NP-TL1-M.

Explore the calibration procedure of normalizing converter NP-TL1-M.

Conduct the calibration of normalizing converter NP-TL1-M.

Conduct the experiment to determine the total error of temperature measurement channel according to the indications of NP-TL1-M.

Perform processing experimental results.

Make the conclusion about calibration.

8.2 Virtual laboratory stand description

The virtual laboratory stand includes models of the following measurement instruments: adjustable voltage source, thermoelectric converters (thermocouples), normalizing converters and milliammeter, and it works in two modes: mode "Calibration and grading of thermocouple normalizing transducer" (figure 8.1) and "Determination of the total error of temperature measurement channel" (figure 8.2).

While calibrating the normalizing converter, it is necessary to set up the value of a measured parameter within the operating range of the converter at the input, and compare the output current signal with estimated value of current corresponding to ideal static characteristic of the converter. The calibration of converter consists in obtaining static dependence of output current signal of the transducer on the value of the measured parameter.

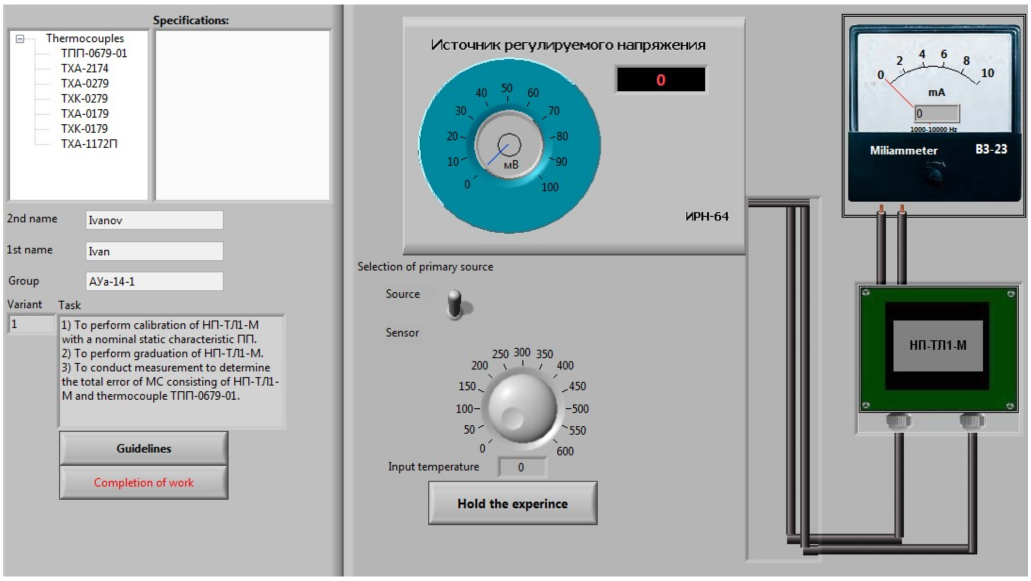


Figure 8.1 –Virtual laboratory work in mode "Calibration and grading of a normalization transducer of thermo EMF"

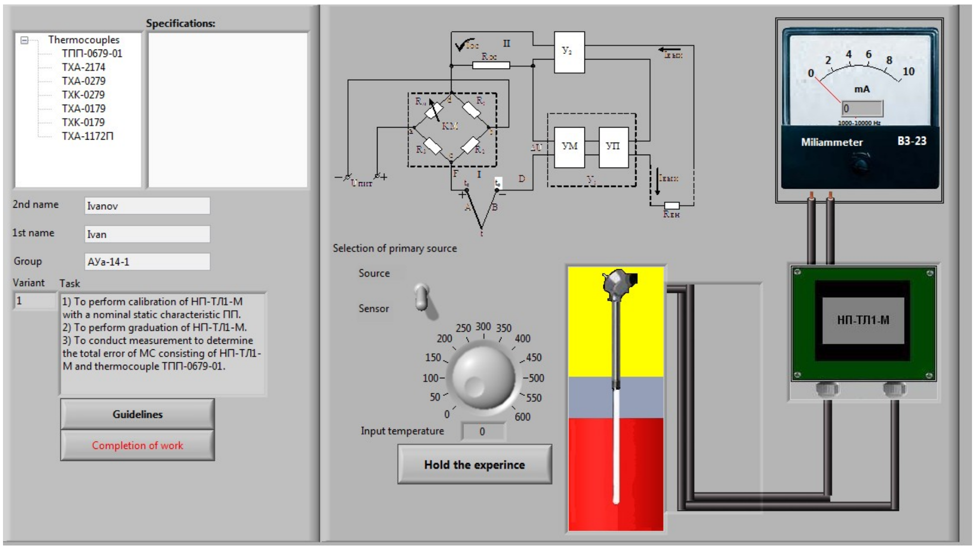


Figure 8.2 – Virtual laboratory work in mode "Determination of the total error of temperature measurement channel"

8.3 Laboratory work performance order

8.3.1 Get a variant from the instructor to carry out the laboratory work and register in the system:

- download file "Metlab.exe", select your variant of the laboratory work from the main menu then the window of student registration will appear (figure 1.1);
- enter your surname, name, group number;
- enter the given variant of the laboratory work;
- click "Next".

8.3.2 You should get acquainted with the location of individual measurement instruments models and other devices on the laboratory stand (figures 8.1, 8.2).

8.3.3 Verification converter NP-TL1-M of various grading.

8.3.3.1 Set switch "Selecting a primary instrument" in the position "Source".

8.3.3.2 The input voltage corresponding to six tested points is set alternately at the output of adjustable voltage source. Initial voltage values are set in accordance with table 8.1. The type of nominal static characteristic (NSC) is given in assignment for the virtual laboratory work; you should write down appropriate values of initial signal from table 8.1 into table 8.2.

Table 8.1 –NP-TL1-M conversion function

Type of NSC	Calibration points	1	2	3	4	5	6
	Output signal (mA)	0,0	1.0	2,0	3,0	4,0	5,0
PP	Input signal (mV)	0,00	3,34	6,69	10,01	13,36	16,71
HA	Input signal (mV)	0,00	10,48	21,01	31,46	41,95	52,43

End of table 8.1

HK	Input signal (mV)	0,00	13,30	26,59	40,01	53,18	66,47

8.3.3.3 The value of experimental current at NP-TL1-M output is measured by milliammeter when pushing button "Conduct experiment". The value of experimental current is measured while increasing (forward run) and decreasing (reverse run) voltage in output of adjustable voltage source. Experiment results are written down into table 8.2 – calibration report table.

8.3.4.3 To obtain the conclusion of verification converter NP-TL-M 1 it is necessary to determine errors of the converter in each verified point.

Converter error at any point within measurement range is determined by formulas:

$$\Delta 1 = I1 - \mathrm{Ip} \quad , \qquad \Delta 2 = I2 - \mathrm{Ip} \quad ; \tag{8.1}$$

$$\gamma 1 = \frac{I1 - \mathrm{Ip}}{\Delta I} 100 \quad , \qquad \gamma 2 = \frac{I2 - \mathrm{Ip}}{\Delta I} 100 \quad , \tag{8.2}$$

where I1, I2 - current value at convertor output on forward and reverse movement;

ΔI - range of variation of current at converter output;

I_p - calculated value of current at convertor output, corresponding to table value in verified point.

Reduced error value in these points shall not exceed limits of main permissible error is defined by device accuracy class, and equal to 1%.

8.3.4 Calibration of converter NP-TL1-M.

8.3.4.1 Set switch "Selecting a primary device" in mode "Source".

Table 8.2 - Report of NP-TL1-M convertor calibration

№ of verified point	Thermo-EMF according to	Experimental current value	Values of experimental current		Error			
			Forward run	Reverse run	Forward run	Reverse run	Forward run	Reverse run
	E	Ip	I_1	I_2	Δ 1	Δ 2	γ_1	γ_2
	mV	mA	mA	mA	mA	mA	%	%
1		0						
2		1						
3		2						
4		3						
5		4						
6		5						

8.3.4.2 Calibration of the convertor is performed at 8 points within measuring range of thermocouple, including boundary points. Measurements of output current were performed according to the scheme at figure 8.1 for selected in p.8.3.3.3 8 points and are written to table 8.3.

Table 8.3 – Report of NP-TL1-M convertor calibration

№ of point	Temperature	Thermo-EMF according to calibration table	Experimental values of current		
			Forward run	Reverse run	average value
	t	E	I1	I2	I_{av}
	°C	mV	mA	mA	mA
1					
…					
8					

8.3.4.3 On basis of results of convertor calibration, static characteristic $I_{cp}=f\,(T)$ will be built and its linearity will be analyzed.

8.3.5 Determination of the total error of temperature measurement channel, consisting of thermocouple and NP-TL1-M.

8.3.5.1 Set "Selecting a primary device" switch in mode "Sensor".

8.3.5.2 Select thermoelectric converter type according to the assignment from the list of thermocouples, located on the left at panel of the virtual laboratory work.

8.3.5.3 Rotating handle «Inlet temperature» change the measured temperature of the furnace, in which the sensor – thermocouple was placed, at any eight points of thermocouple measurement range.

8.3.5.4 Take readings of the milliammeter, connected to the output of NP-TL1-M, at each temperature point. Indications of experimental current you should write into table 8.4.

8.3.5.5 The current experimental values you should transfer by the calibration table in p.8.3.4.3 into the calculated values of input temperature and write them into table 8.4.

8.3.5.5 Calculate the absolute and reduced error of measuring channel at each checked point.

Table 8.4 – Determination of total error of temperature measurement channel

Number	atuInlet he	alues of	stimated alues of input	Errors	
				Absolute	Fiducial
	Tin	I_1	T_1	Δ	γ
	°C	mA	°C	°C	%
1					
…					
8					

8.3.5.6 Conduct theoretical calculation of total error of measuring channel, consisting of a thermocouple and analog transmitter NP-TL1-M, according to the calculation method mentioned in laboratory work number 3.

8.3.5.7 Compare experimental and theoretical values of total error in the temperature measurement channel.

8.4 Contents of report

The report should contain:

- purpose of the laboratory work;
- assignment of the individual variant;
- brief description of the work, structural scheme of the laboratory stand and circuit diagram of NP-TL1M normalizing convertor;
- calibration and grading reports of the normalizing converter;
-graph of static characteristic of the normalizing converter (calibration graph) according to table 8.3;
- table of determining total error of a temperature measurement channel;
- calculation of errors of current experimental values;
- theoretical calculation of total error of the measuring channel;
-conclusion about results of converter calibration and grading by calculation of total error;
- conclusions about the work.

8.5 Control questions

8.5.1 Determine measuring converters (transducers).

8.5.2 Measuring means working in complete with thermoelectric converters.

8.5.3 Purpose of normalizing transducers.

8.5.4 Method of calibration of thermo EMF normalizing transducer.

8.5.5 Method of constructing calibration characteristics of thermo EMF normalizing transducer.

9 Laboratory work №9. Calibration and testing RTD analog transmitters by repeated measurement method

Work purpose: studying the method of grading and calibration of NP-SL1-M normalizing transducer, which works with thermal resistance, and determination of total error of temperature measurement channel with the help of multiple measurements method.

9.1 Assignment for the laboratory work

You should acquaint with the virtual laboratory stand on studying NP-SL1-M normalizing converter.

To explore the method of NP-SL1-M transducer calibration.

To perform grading of NP-1 SL-M normalizing transducer.

Conduct the experiment to determine the total error of temperature measurement channel by indications of NP-SL1-M.

Make a conclusion about calibration.

9.2 Virtual laboratory stand description

The virtual laboratory stand includes the models of following means of measurement: resistance box, RTD of a normalizing transducer and milliammeter, and operates in two modes: mode "Testing and calibration of RTD of normalizing transducers" (figure 9.1) and mode "Determination of total error of temperature measurement channel" (figure 9.2).

9.3 Laboratory work performance order

9.3.1 Get a variant from the instructor to carry out the laboratory work and register in the system:

- download file "Metlab.exe", select your variant of the laboratory work from the main menu then the window of student registration will appear (figure 1.1);
- enter your surname, name, group number;
- enter the given variant of the laboratory work;
- click "Next".

9.3.2 You should get acquainted with locations of individual measurement instruments models and other devices on the laboratory stand (figures 9.1, 9.2).

9.3.3 Calibration of NP-1 SL-M converter of various gradings.

The calibration of the converter is carried out in same sequence as NP-TL1-M transducer (p. 9.3.3). The difference is that for NP-SL-1-M calibration, resistor bank MCR-60M is used as an equivalent of resistance thermometer.

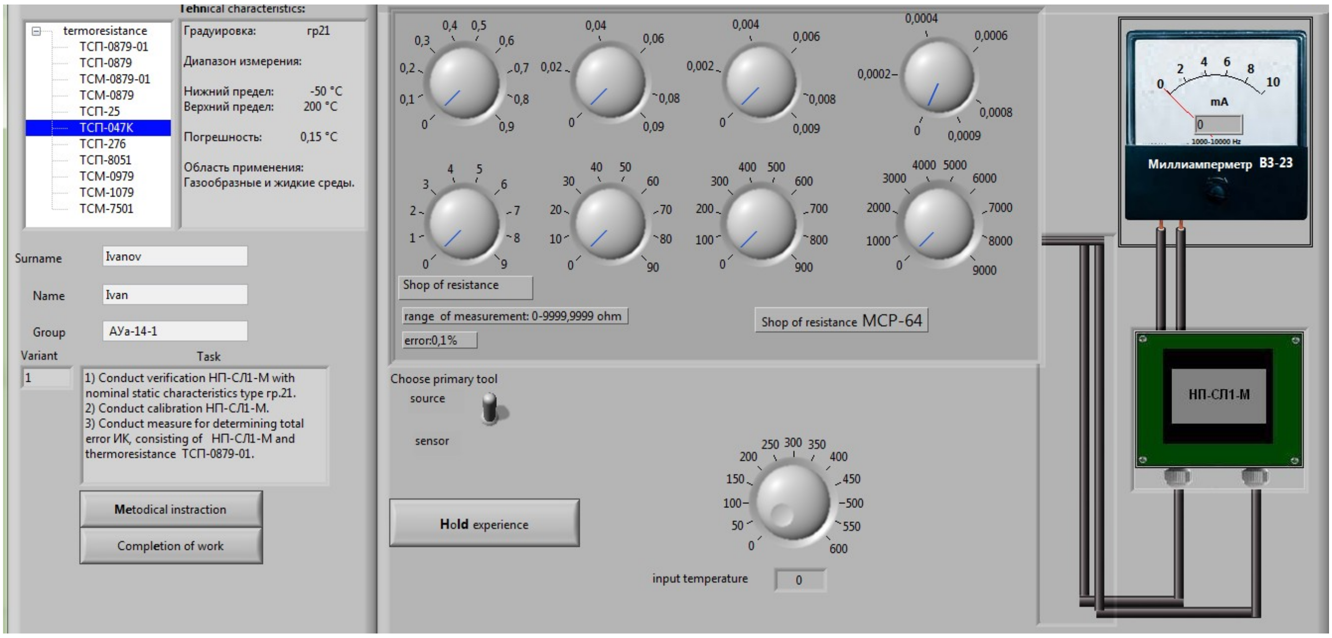


Figure 9.1 – Virtual laboratory work in mode "Grading and calibration of RTD of normalizing transducer"

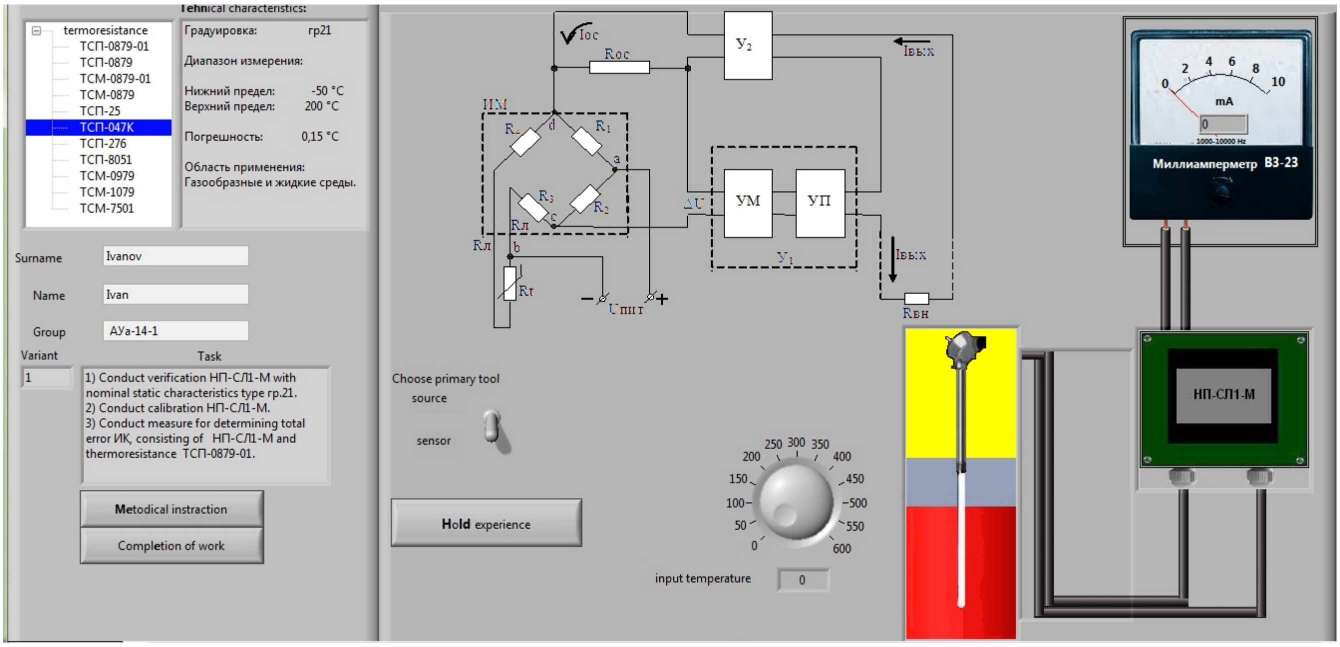


Figure 9.2 – Virtual lab in "Determination of total error of temperature measurement channel" mode

Table 9.1 – NP-SL-1-M conversion function

Type of NSC	Calibration points	1	2	3	4	5	6
	Output signal (mA)	0,0	1,0	2,0	3,0	4,0	5,0
Gr 23	Input signal(Om)	53, 00	61,12	69,26	77,38	77,4	93,64

End of table 9.1

Gr 21	Input signal(Om)	46,00	72,15	98,31	124,46	150,62	176,77

9.3.3.1 Set "Selection of primary device" switch to "Source" mode.

9.3.3.2 The type of nominal static characteristic (NSC) is given in the assignment to the virtual laboratory work; write into table 9.2 the appropriate initial signal values from table 9.1. By setting input resistance values at MSR-60 M resistor, you should take the experimental current readings.

The experimental current values are taken according to milliammeter readings and are written into table 9.2.

9.3.3.3 The transducer error at any point within the range is determined by formula:

$$\gamma 1 = \frac{I1 - \text{Ip}}{\Delta I} 100 \quad ; \qquad (9.1)$$

$$\gamma 2 = \frac{I2 - \text{Ip}}{\Delta I} 100 \quad , \qquad (9.2)$$

where $I1$, $I2$ - current values at converter output in forward and reverse run;

ΔI - range of current variation at transducer output ;

I_p - calculated value of current at transducer output, corresponding to the table value at a calibrated point.

The value of error in these points shall not exceed the limits of the main permissible error defined by device accuracy class, and is equal to ± 1%.

Table 9.2 – Report of NP-1 SL-M converter calibration

№ of point	Input signal value	Rated current value	Experimental value of current		Error	
			Forward run	Reverse run	Forward way	Reverse run
	R	Ip	i_1	i_2	γ_1	γ_2
	Om	mA	mA	mA	%	%
1		0				
2		1				
3		2				
4		3				
5		4				
6		5				

9.3.4 NP-1 SL-M converter calibration.

To get converter static characteristic at its input you should set resistance values (8 points). The control of experimental current of the normalizing transducer is performed by milliammeter indications. The transducer indications are taken at increasing and decreasing input resistance. The measurement of experimental current values is performed similarly to p. 9.3.3 for selected eight points and should be written into table 9.3.

According to the calibration results $I_{av}=f(T)$ characteristic will be built and its linearity will be analyzed.

9.3.5 Determination of RTD and NP-SL1-M measurement channel's total error .

9.3.5.1 Switch "Selecting a primary instrument" set in mode "Sensor".

9.3.5.2 Select the type of RTD according to the task from the list of RTD located on the left at panel of virtual laboratory work.

Table 9.3 - Protocol of graduation of NP-1-SL-M converter

№ of point	Temperature	Resistance in accordance with calibration table	Experimental value of current		
			Forward run	Reverse run	Average value
	T	$R_{calibration}$	I_1	I_2	I_{av}
	°C	Om	mA	mA	mA
1					
…					
8					

9.3.5.3 Switching handle "Inlet temperature" change the furnace temperature, in which the sensor - thermal resistance is placed, at any six points of thermal resistance measuring range.

9.3.5.4 Take readings of the milliammeter, connected to NP-SL1-M output, at one temperature point (from table 9.3) 30 times. You should write these readings of experimental current into table 9.4.

9.3.5.5 You should convert the indications of experimental current into input temperature values with the help of calibration curve $I_{av} = f(T)$, which is constructed by values of table 9.3 (p.9.3.4).

9.3.5.6 Conduct the theoretical calculation of total error of measurement channel consisting of RTD and NP-TL-1-M normalizing transmitters, according to the calculation method, given in laboratory work number 1.

The number of measurements is equal to 30. Confidence probability P is equal to 0.95.

9.3.5.7 Compare the experimental and theoretical values of total error of the temperature measurement channel.

Table 9.4 – Determination of temperature measurement channel's total error

№ of verified point from table 9.3	Inlet temperature of furnace	Experimental current value at direct run	Inlet temperature value according to calibration curve	Results of statistical processing of repeated temperature measurements	
	T_{in}	I_1	T_1		
	°C	mA	°C	Parameter	°C
		1		Mean	
		2			
		3		Root-mean-square deviation of observations results	
		4			
		…		Root-mean-square deviation of measurement results	
		…			
		…		Results of observations	
		…			
		…		Measurement result	
		…			
		30			

9.5 Control questions

9.5.1 Standardized measuring instruments.
9.5.2 Purpose of RTD normalizing converters.
9.5.3 Static characteristics of measuring devices.
9.5.4 Method of calculating total error of a measuring channel.

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