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UDK 543.3

# Device for Measuring Total Dissolved Solids in Water

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**Key words and phrases:** control and measuring device; solution; simulation; content of substances.

**Abstract.** The development of a device for measuring the total content of dissolved substances in water was completed. A functional diagram of the device under development has been developed and described on the basis of a block diagram. A description of a machine experiment on simulating the operation of an operational amplifier in Micro-Cap, its results and their analysis is given.

The quality of drinking water is largely affected by impurities of various origins [1]. Such impurities include: salts, metals, soluble organic substances [2]. The odor [3] and taste of water [4] depend on the presence and amount of these substances in water. In addition, many of them can harm human health [5; 6] or animals [7], and lead to malfunctions in household appliances [8–10]. To determine how dangerous the water is to use, specialized TDS meters are used.

TDS meters are electronic water quality meters. The abbreviation “TDS” in their name means “Total Dissolved Solids”, i.e. “the total number of dissolved impurities”. In Russian, this is usually called “general mineralization”.

Such devices are used in cases where it is necessary to quickly determine the quality of waste, tap or natural water [9]. The devices are often used when starting up and testing wastewater treatment plants. They accurately measure the concentration of impurities in a liquid in seconds.

In everyday life, small filter systems are usually responsible for the purity of drinking water. However, they cannot guarantee high water quality. After all, cheap filters are quickly filled with suspension, after which they cease to cope with the load.

The water may suddenly smell like sewage, become greenish in color, or taste like rotten eggs. Such a decrease in the quality of the liquid is a consequence of the dissolution of foreign substances, natural or artificial, in the water. A water quality control device will help you quickly determine the cause of the problem.

In addition, tap water can adversely affect a person's health, even if it looks clean. For example, in the food industry, hard water degrades the quality of food by causing salt precipitation during storage, stains on surfaces, etc. To avoid such an effect, the quality of the liquid must be checked regularly.

Ordinary drinking water is a good conductor of electricity. This is the basis for the operation of the water quality assessment device. The device creates an electric field inside the liquid, measures the current value, and uses it to determine the presence and concentration of

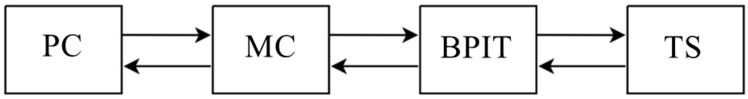


**Fig. 1.** Block diagram of a device for measuring the total content of dissolved substances in water

impurities [10].

The received data is displayed on the device display. The number displayed on it indicates the number of impurity molecules per million water molecules (abbreviated as ppm). In the usual system of measurement, this is the weight of impurities in milligrams per liter of liquid.

The operation of the measuring device is based on the ability of water to conduct electric current. The device produces electrons that create an electric field in the liquid. Then he fixes the number of ions of salts and other substances, since it is they who affect the strength of the current in the liquid.

Electrical conductivity is one way of assessing water quality, since an increase in the presence of total dissolved solids as expressed by electrical conductivity can be an indicator of contaminants. Electrical conductivity can be affected by carbonates from limestone, artificial point source pollutants such as sewage treatment plants, or artificial non-point sources such as septic systems or agricultural runoff. The electrical conductivity indicates the total amount of dissolved solids, of which the total dissolved salts are components. If the salt level in the TDS is high, this can also contribute to the acidity of the water. However, if the carbonate level in the TDS is high, this can increase the alkalinity. Acceptable levels of electrical conductivity in rivers and streams vary depending on the type of solids dissolved in them, and this determines the use of the reservoir, for example, for fishing, swimming or as a source of drinking water. The best way to measure conductivity is with a TDS meter.

In industry, TDS meters may also be used. They are needed for water purification in industrial conditions, in various food industries, where hard water can greatly change the taste of the finished product. In swimming pools, very hard water can cause pipes to rust. Therefore, it is also important here to control the concentration of salts, which cannot be done without a salt meter.

The block diagram of the developed device for measuring the total content of dissolved substances in water is shown in Fig. 1.

The structural diagram shows:

– PC is a personal computer;
– MC is a microcomputer;
– BPIT is a block of precision impedance transducer;
– TS is a testing solution.

The device works as follows. Using a PC, the user interacts with the device. MC provides interaction between the PC and the BPIT. The BPIT measures the complex impedance by applying a test signal of known frequency and amplitude. The response signal received from the TS is digitized and processed by the BPIT.

The development of the functional diagram was carried out on the basis of the block diagram shown in Fig. 1. The functional diagram is shown in Fig. 2.

The functional diagram shows: PC is a personal computer; A is an adapter; MC is a microcomputer; BPIT is a block of precision impedance transducer; G is a generator; I is an interface; FFTB is fast Fourier transform block; DCS is a digital computational synthesizer; DAC

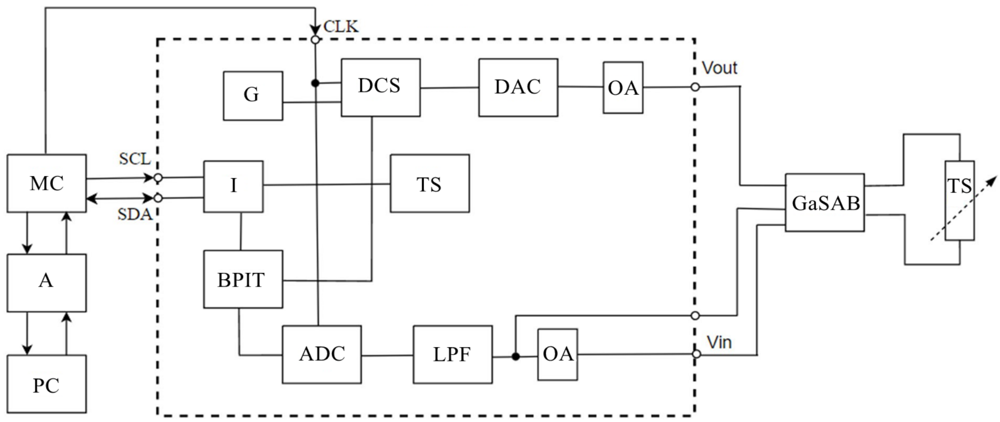


**Fig. 2.** Functional diagram of the developed device

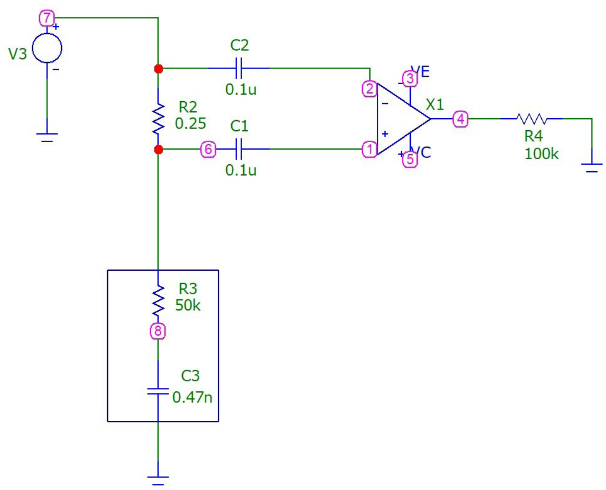


**Fig. 3.** Diagram of the gain block

is a digital-to-analog converter; OA is an operational amplifier; TS is a temperature sensor; LPF is a low pass filter; ADC is an analog-to-digital converter; GaSAB is a gain and sensitivity adjustment block; TS is a testing solution.

The device works as follows. The contacts of the device are placed in a container with an aqueous solution. From the PC, the person gives the command to start the measurement. This command is processed by the MC and sent to the BPIT. The BPIT is a high-frequency impedance converter that combines a built-in frequency generator and a 12-bit ADC. The frequency generator allows you to excite external complex impedance with a known frequency. The response signal from the impedance is digitized by the built-in ADC. Based on the response signal received during the measurement, the content of dissolved substances in the water is calculated.

We will assemble the amplification block circuit and check its performance using the "transient analysis" tool. The assembled circuit is shown in Fig. 3.

Elements R3 and C3 create active-reactive readings of water resistance. The V3 signal generator supplies the signal to be applied by the AD5933 impedance converter to the test solution. Subsequently, the signal obtained from the test solution, in our case, water, is fed to

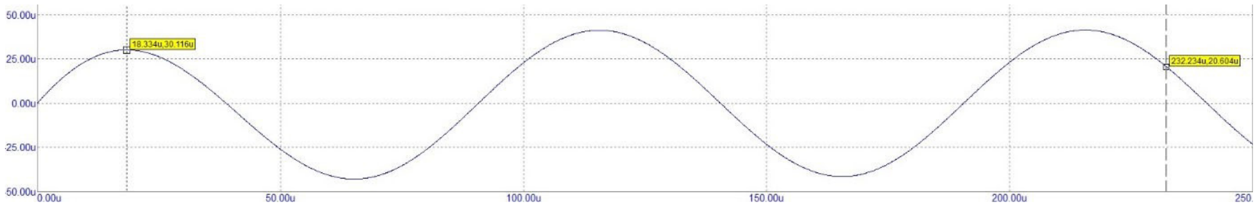


**Fig. 4.** Node 2 voltage waveform

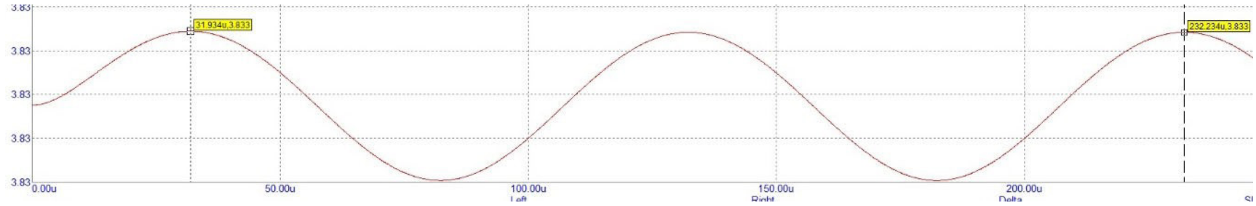


**Fig. 5.** Node 4 voltage waveform

the OS for amplification and subsequent processing.

Consider the signal readings at circuit nodes 2 and 4.

Fig. 4 shows the oscillogram of the original signal at node 2.

In node 2, the maximum voltage is $U_2$ = 30,116 μV.

Fig. 5 shows an oscillogram with an amplified signal at node 4.

In node 4, the maximum voltage is $U_4$ = 3,833 V.

Based on the data obtained, we can conclude that the OS amplified the incoming signal by $127 \cdot 10^3$ times. What gives us the opportunity for further processing of this signal.

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## Устройство для измерения общего содержания растворенных веществ в воде

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**Ключевые слова и фразы:** контрольно-измерительное устройство; моделирование; раствор; содержание веществ.

**Аннотация.** выполнена разработка устройства для измерения общего содержания растворенных веществ в воде. Разработана и описана функциональная схема разрабатываемого устройства на основе структурной схемы. Приведено описание машинного эксперимента по моделированию работы операционного усилителя в Micro-Cap, его результаты и их анализ.

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UDK 621.317.785

# Development and Research of an Intelligent Single-Phase Electric Energy Meter

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**Key words and phrases:** energy meter; electric; intelligent control; single-phase.

**Abstract.** The purpose of this work is to develop an intelligent single-phase electric energy meter that provides remote control of electric energy consumption, online measurement of network parameters and restricts consumer access to electricity. Specifications: Input voltage is 220 V ±10 %; Input current is 0–40 A; Voltage measurement error is 0.5 %; Current measurement error is 0.5 %; Measurement error of active power and energy is 1.0 %.

A microprocessor-based electric energy meter is a device for metering active and reactive energy in alternating current circuits (in single-tariff or multi-tariff modes). Their work is based on the analog-to-digital conversion of voltage and current, followed by the calculation of powers and energies [1]. The measurement results are obtained by processing and calculating the input current and voltage signals by the microprocessor circuit of the meter board [2; 3]. In addition to measuring electrical energy, such devices provide control of its quality, registration of emergency situations [4, 5] and overvoltages in electrical networks, control and regulation of power consumption [6–10], etc.

Functional diagram of an intelligent single-phase energy meter is shown in Fig. 1.

The device works as follows: The current in the phase ($L$) wire is supplied to the shunt ($R_{sh}$), then the voltage drop from the shunt is increased using an operational amplifier (the gain is set by a digital potentiometer) to the value necessary for the normal operation of the analog-to-digital converter (**ADC**). The mains voltage is reduced using a resistive divider ($R_1$, $R_2$). Value conversion is performed by ADCs, which convert the instantaneous values of the input signals into a digital code. Communication of a digital potentiometer, ADC with a microcontroller is carried out by means of an SPI interface isolated through an optocoupler galvanic isolation. A load control relay is installed in the open circuit of the phase wire, which is necessary to disconnect the consumer from the load. The microcontroller controls all nodes of the counter. A GSM module is installed to exchange data with remote devices. The photo fixation camera is turned on when you try to open the meter, the picture is saved to the FIFO buffer and then sent to the remote server of the governing bodies. To display information about the consumed values, a liquid crystal display is installed. To match the microcontroller and the liquid crystal display, a logic level converter is required. The power supply unit of the module converts the AC voltage of the network into a DC voltage required to power all the nodes of the meter board. Non-volatile memory consists of a FRAM chip, which is used to store relatively frequently changing data,

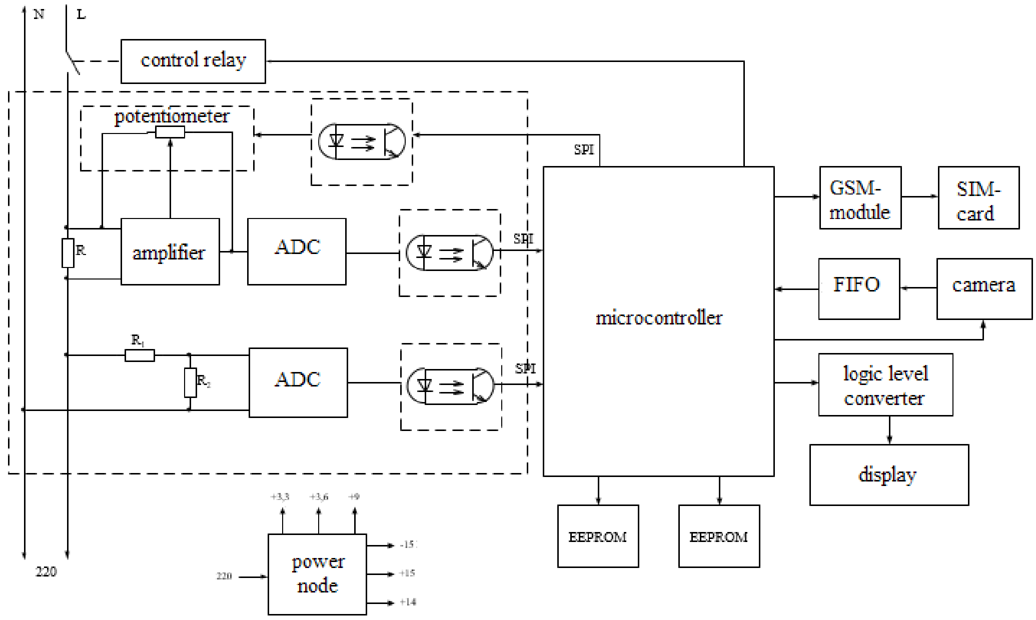


**Fig. 1.** Functional diagram of an intelligent single-phase energy meter

**Table 1.** Matrix of the experiment

| № | № of exper. | $X_1$ | $t$, $^0C$ | | | | $X_2$ | $I_I$, A | $U_U$, B | $U_I$, мВ | $P$calc, kW | Δ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $t$, °C | $R_{1\text{-}6}$, kOhm | $R_7$, kOhm | $R_{sh}$, μOhm | | | | | | |
| 1 | 1 | – | –40 | 324.06 | 30.624 | 1871.625 | – | 1 | 3.411 | 1.872 | 0.208 | 0.055 |
| 2 | 2 | – | –40 | 324.06 | 30.624 | 1871.625 | – | 1 | 3.411 | 1.872 | 0.208 | 0.054 |
| 3 | 3 | – | –40 | 324.06 | 30.624 | 1871.625 | – | 1 | 3.411 | 1.872 | 0.208 | 0.056 |
| 4 | 4 | + | 50 | 330.99 | 33.693 | 1876.688 | – | 1 | 3.670 | 1.877 | 0.224 | 0.018 |
| 5 | 5 | + | 50 | 330.99 | 33.693 | 1876.688 | – | 1 | 3.670 | 1.877 | 0.224 | 0.017 |
| 6 | 6 | + | 50 | 330.99 | 33.693 | 1876.688 | – | 1 | 3.670 | 1.877 | 0.224 | 0.019 |
| 7 | 7 | – | –40 | 324.06 | 30.624 | 1871.625 | + | 40 | 3.411 | 74.865 | 8.308 | 0.056 |
| 8 | 8 | – | –40 | 324.06 | 30.624 | 1871.625 | + | 40 | 3.411 | 74.865 | 8.308 | 0.055 |
| 9 | 9 | – | –40 | 324.06 | 30.624 | 1871.625 | + | 40 | 3.411 | 74.865 | 8.308 | 0.057 |
| 10 | 10 | + | 50 | 330.99 | 33.693 | 1876.688 | + | 40 | 3.670 | 75.068 | 8.962 | 0.018 |
| 11 | 11 | + | 50 | 330.99 | 33.693 | 1876.688 | + | 40 | 3.670 | 75.068 | 8.962 | 0.017 |
| 12 | 12 | + | 50 | 330.99 | 33.693 | 1876.688 | + | 40 | 3.670 | 75.068 | 8.962 | 0.019 |

and an EEPROM chip, which stores relatively infrequently changing data. A regression model of the ADC of the electric energy meter is built.

It is necessary to build a mathematical model of the change in the relative error of power measurement depending on temperature at different current consumption. As influencing factors, we take the ambient temperature $t$ and load current Il, and as a response, the relative error of power measurement.

To conduct the experiment, it is necessary to calculate the theoretical power $P$:

| | 1<br>t | 2<br>Iн | 3<br>Дельта |
|---|---|---|---|
| 1 | -40 | 1 | 0,055 |
| 2 | -40 | 1 | 0,054 |
| 3 | -40 | 1 | 0,056 |
| 4 | 50 | 1 | 0,018 |
| 5 | 50 | 1 | 0,017 |
| 6 | 50 | 1 | 0,019 |
| 7 | -40 | 40 | 0,056 |
| 8 | -40 | 40 | 0,055 |
| 9 | -40 | 40 | 0,057 |
| 10 | 50 | 40 | 0,018 |
| 11 | 50 | 40 | 0,017 |
| 12 | 50 | 40 | 0,019 |

**Fig. 2.** Experiment planning matrix in the Statistica

Effect Estimates; Var.:Дельта; R-sqr=,99811; Adj:,9974 (Kursovoy new1)
2**(2-0) design; MS Pure Error=,000001
DV: Дельта

| Factor | Effect | Std.Err. Pure Err | t(8) | p | -95,% Cnf.Limt | +95,% Cnf.Limt | Coeff. | Std.Err. Coeff. | -95,% Cnf.Limt | +95,% Cnf.Limt |
|---|---|---|---|---|---|---|---|---|---|---|
| **Mean/Interc.** | 0,036750 | 0,000289 | 127,3057 | 0,000000 | 0,036084 | 0,037416 | 0,036750 | 0,000289 | 0,036084 | 0,037416 |
| (1)t | -0,037500 | 0,000577 | -64,9519 | 0,000000 | -0,038831 | -0,036169 | -0,018750 | 0,000289 | -0,019416 | -0,018084 |
| (2)Iн | 0,000500 | 0,000577 | 0,8660 | 0,411694 | -0,000831 | 0,001831 | 0,000250 | 0,000289 | -0,000416 | 0,000916 |
| 1 by 2 | -0,000500 | 0,000577 | -0,8660 | 0,411694 | -0,001831 | 0,000831 | -0,000250 | 0,000289 | -0,000916 | 0,000416 |

**Fig. 3.** Table of the resulting model in coded values

Regr. Coefficients; Var.:Дельта; R-sqr=,99811; Adj:,9974 (Kursovoy new1)
2**(2-0) design; MS Pure Error=,000001
DV: Дельта

| Factor | Regressn Coeff. | Std.Err. Pure Err | t(8) | p | -95,% Cnf.Limt | +95,% Cnf.Limt |
|---|---|---|---|---|---|---|
| **Mean/Interc.** | 0,038541 | 0,000421 | 91,4548 | 0,000000 | 0,037570 | 0,039513 |
| (1)t | -0,000411 | 0,000009 | -44,1383 | 0,000000 | -0,000432 | -0,000389 |
| (2)Iн | 0,000014 | 0,000015 | 0,9564 | 0,366891 | -0,000020 | 0,000049 |
| 1 by 2 | -0,000000 | 0,000000 | -0,8660 | 0,411694 | -0,000001 | 0,000000 |

**Fig. 4.** Table of the resulting model in physical terms

$$P = U_U \cdot K_U \cdot U_I \cdot K_I,$$

where $U_U$ is an output voltage of the voltage divider; $K_U$ is is the voltage conversion factor equal to 60,993; $U_I$ is a voltage drop across the shunt; $K_I$ is a voltage conversion factor equal to 533,333.

The matrix of the experiment $N = 4$ is presented in Table 1. The data will be analyzed using the Statistica program. Let us set the number of repeated experiments $m = 3$. This is necessary to check the model for adequacy.

We create a second-order experiment planning matrix (Fig. 2).

Next, we calculate the estimates of the regression coefficients based on the coded initial values of the factors (column “Coeff” in the table in Fig. 3).

We calculate the estimates of the regression coefficients based on the uncoded (physical) initial values of the factors (column “Regressn Coeff” in the table in Fig. 4).

To test the hypothesis about the adequacy of the obtained model $F$ – Fisher's criterion is used and is determined by the following formula:

| Factor | ANOVA; Var.:Дельта; R-sqr=,99793; Adj:,99747 (Kursov 2**(2-0) design; MS Pure Error=,000001 DV: Дельта | | | | |
|---|---|---|---|---|---|
| | SS | df | MS | F | p |
| **(1)t** | 0,004219 | 1 | 0,004219 | 4218,750 | 0,000000 |
| (2)Iн | 0,000001 | 1 | 0,000001 | 0,750 | 0,411694 |
| Lack of Fit | 0,000001 | 1 | 0,000001 | 0,750 | 0,411694 |
| Pure Error | 0,000008 | 8 | 0,000001 | | |
| Total SS | 0,004228 | 11 | | | |

**Fig. 5.** Table for assessing the adequacy of the model

$$F_{calc} = \frac{S_{av}^2}{S_{rv}^2},$$

where $S_{av}$ is an adequacy variance, showing the error in the response obtained from the regression equation; $S_{rv}$ is a reproducibility variance, indicating the error in a response obtained experimentally.

According to the calculation results $S_{av}$ = 0,000001, $S_{rv}$ = 0.000001 (the MS column is used, where the MS, where the $S_{av}$ value corresponds to the number in the “Lack of Fit” row, and the $S_{rv}$ value corresponds to the number in the “Pure Error”, Fig. 5).

$F_{cr} > F_{calc}$ (4.46 >1). Therefore, the resulting model is adequate.

The regression equation for the coded factor values is:

$$Y = 0.03675 - 0,01875 \times X_1.$$

The regression equation for uncoded (physical) factor values is:

$$\Delta = 0.038541 - 0.000411 \times t.$$

A mathematical model was built for changing the relative error in measuring the power of an electric energy meter depending on the influence of the ambient temperature and load current. With the help of a full factorial experiment, a first-order empirical model was built and the influence of factors on the scheme was estimated. The regression equation for the coded values consists of two terms: the free term and the product of the coefficient and the temperature.

As a result of the experimental data obtained, it can be concluded that the relative error in power measurement is most affected by changes in ambient temperature.

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## Разработка и исследование интеллектуального однофазного счетчика электрической энергии

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**Ключевые слова и фразы:** интеллектуальное управление; одна фаза; счетчик энергии; электричество.

**Аннотация.** Целью данной статьи является описание разработки интеллектуального однофазного счетчика электрической энергии, обеспечивающего удаленное управление потреблением электрической энергии и измерение параметров сети в режиме online, а также ограничивающего доступ потребителя к электроэнергии. Технические характеристики: входное напряжение – 220 В ±10 %; входной ток – 0–40 А; погрешность измерения напряжения – 0,5 %; погрешность измерения тока – 0,5 %; погрешность измерения активной мощности и энергии – 1,0 %.

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UDK 620.178.3

# Helicopter Rotor Bearing Fatigue Test Bench

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**Key words and phrases:** helicopter rotor; test bench; methods; modeling.

**Abstract.** The article considers the development of a device for fatigue testing of a helicopter rotor bearing. In the course of designing a device for fatigue testing of a helicopter rotor bearing, the types and design of rolling bearings were analyzed, a review of existing methods for testing rolling bearings was made, and a block diagram of a device for fatigue testing of a helicopter rotor bearing was developed. A functional electrical circuit has been developed and a power amplifier has been modeled.

In rolling bearings, rolling friction plays a dominant role, because sliding friction between the cage and the rolling elements, as a rule, is small [1; 2]. Therefore, in rolling bearings, in comparison with plain bearings [3–5], there are significantly lower energy losses, as well as less mechanical wear. The main problem of bearing assemblies is strength [6]. Most often it is associated with the initial load, which is very difficult to establish. During the running-in period, the moment of resistance of preloaded bearings decreases rapidly [7]. Therefore, the initial load can only be controlled in new bearings. Nevertheless, damage can also occur at low loads [8; 9].

The block diagram of the device is shown in Fig. 1.

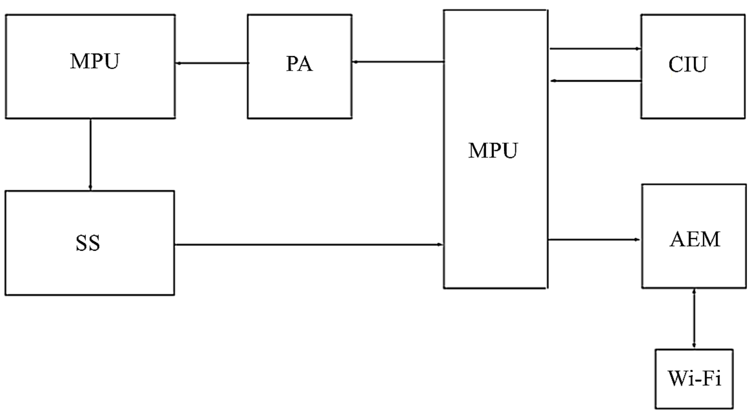


**Fig. 1.** Structural diagram of the developed device

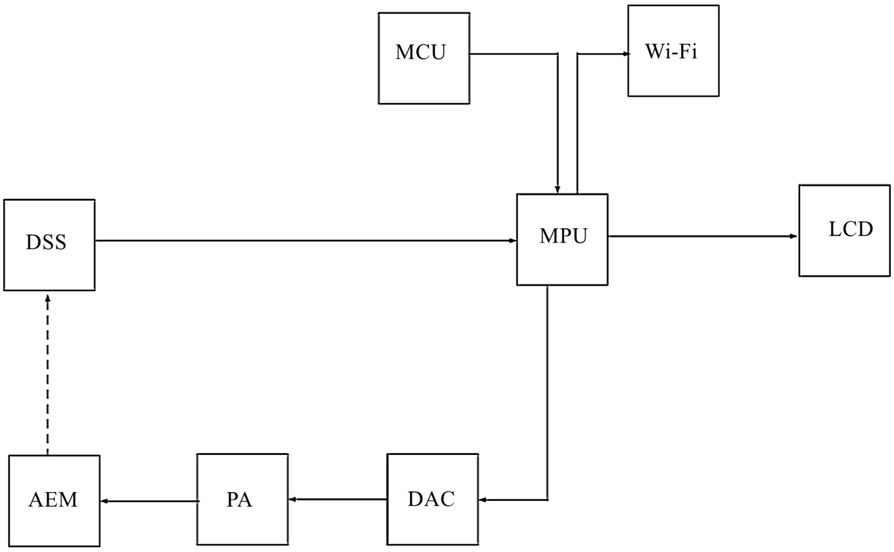


**Fig. 2.** Functional diagram of the developed device

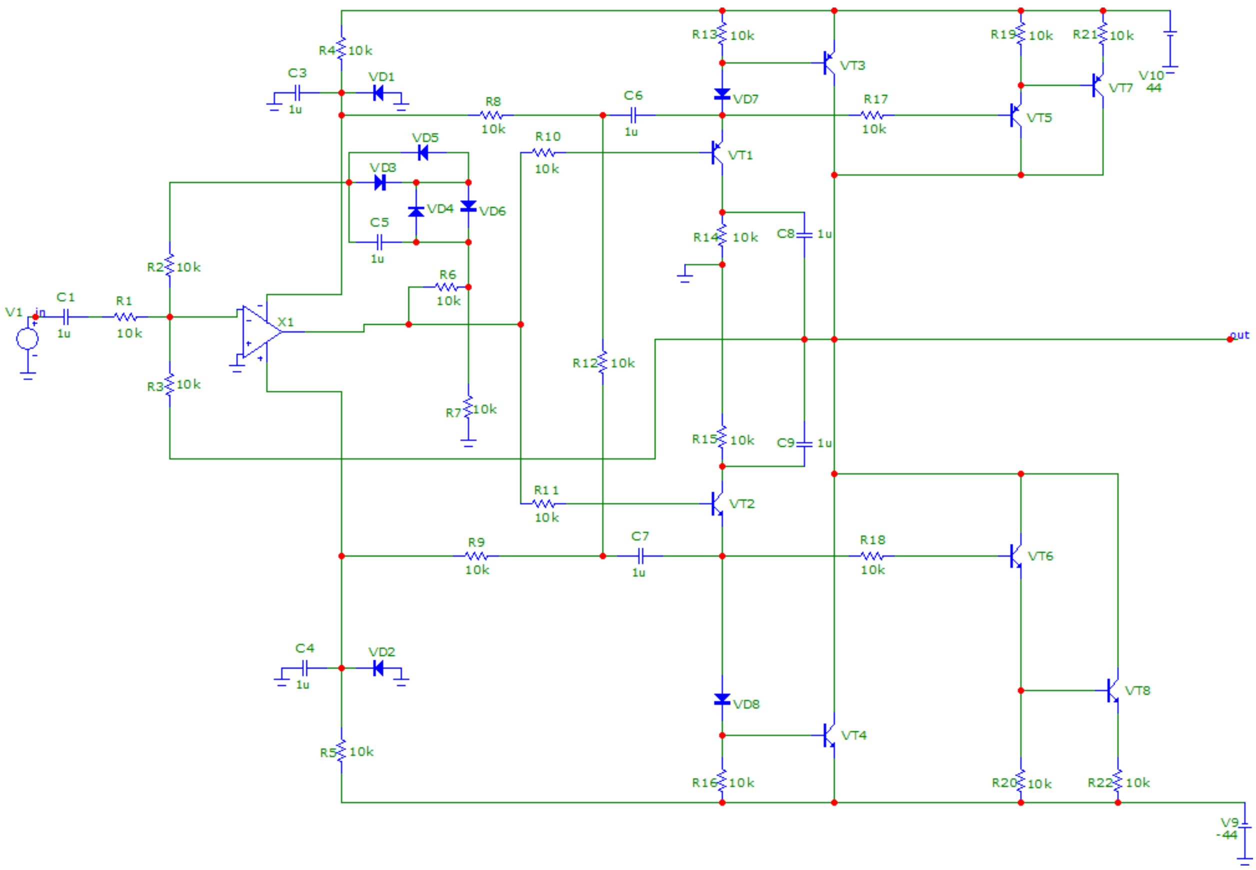


**Fig. 3.** Power amplifier circuit

PA is a power amplifier, MPU is a microprocessor unit, CIU is a control and indication unit, IN – interface unit of the wireless network, SS is a speed sensor. AEM is an asynchronous electric motor, Wi-Fi is a wireless local area network technology with devices based on IEEE

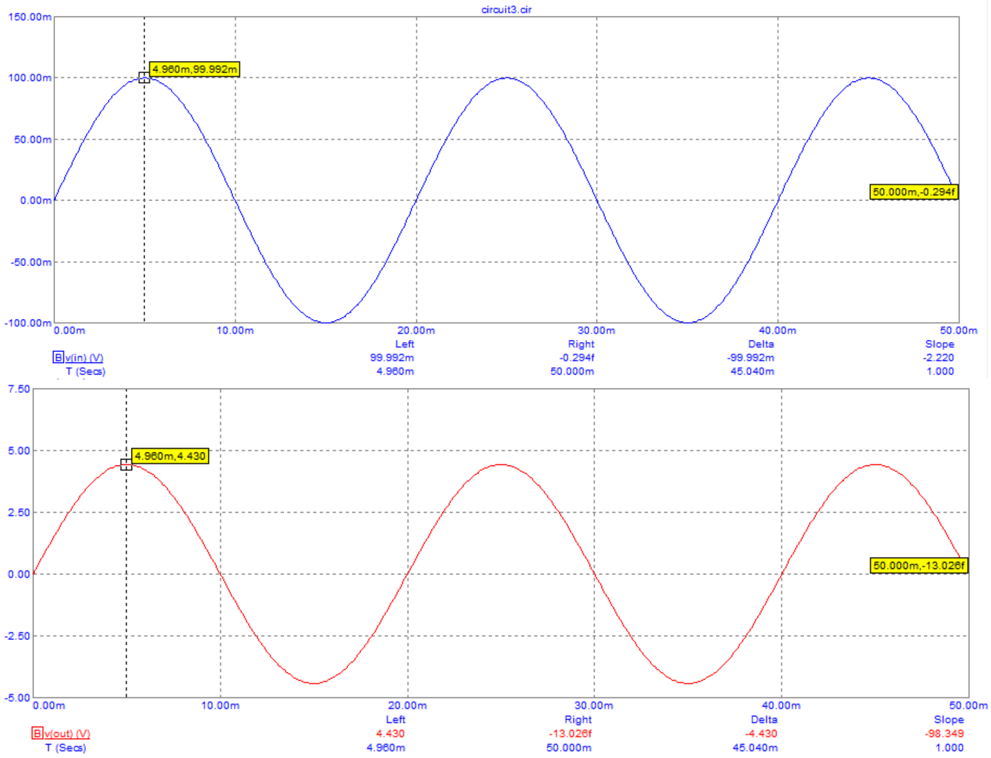


**Fig. 4.** Simulation results of the operation of the power amplifier when applying a sinusoid with a frequency of 50 Hz

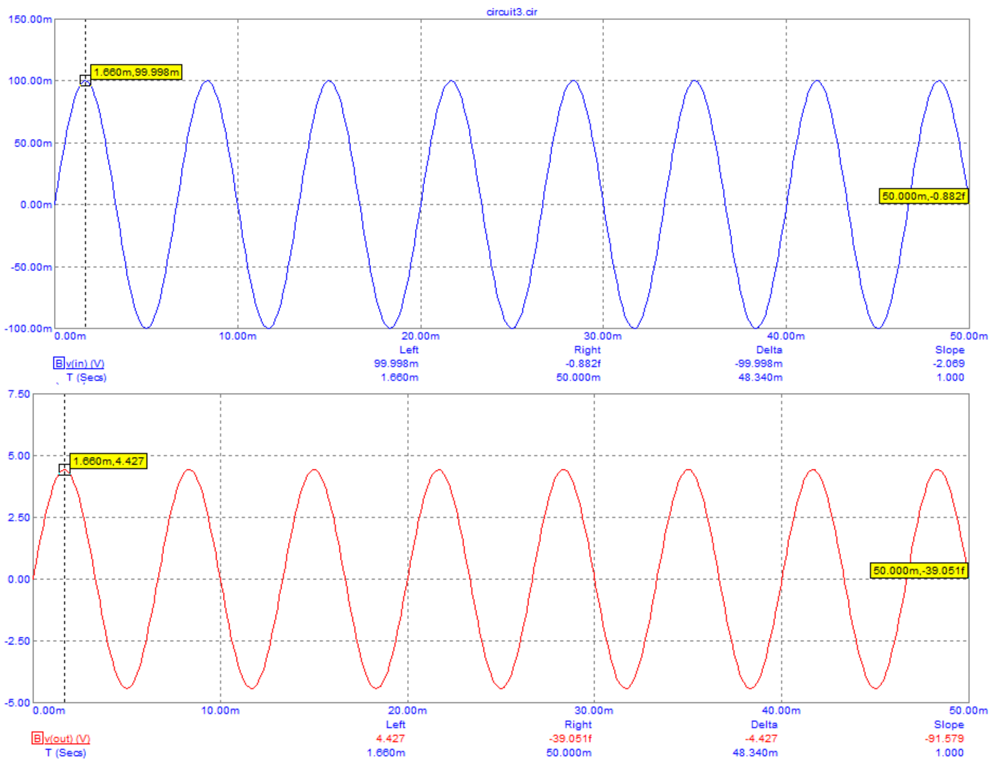


**Fig. 5.** Simulation results of the operation of the power amplifier when applying a sinusoid with a frequency of 150 Hz

802.11 standards.

The functional diagram of the device is shown in Fig. 2.

MPU is a microcontroller, a microcircuit designed to control electronic devices. The microcontroller combines the functions of a processor and peripheral devices on a single chip, contains RAM and ROM. In fact, it is a single-chip computer capable of performing simple tasks.

MCU is a manual control unit, designed to enter information into the MPC using buttons.

DAC is a digital-to-analog converter, a device for converting a digital code into an analog signal (current, voltage).

PA is a 150 W power amplifier designed to amplify the signal when applied to a low power asynchronous electric motor.

LCD is a liquid crystal display, digital information display device.

Wi-Fi is a wireless data exchange interface module, which is a microcircuit.

AEM is a low-power asynchronous electric motor controlled by a frequency change using a microprocessor controller.

DSS is a digital engine speed sensor, connected directly to the microcontroller.

The MPC microcontroller generates signals of a given shape to control a low-power asynchronous motor ED, which are fed to the digital-to-analog converter DAC, and then to the PA power amplifier and amplified to the required current and voltage level according to the maximum power. A DODC speed sensor is connected to the pulley of an asynchronous motor of low power ED, from which a signal is taken in digital form and fed to the MPC microcontroller. The parameters of the control signal are displayed on the LCD, and the control is performed using the BRU manual control unit. Externally, through the Wi-Fi unit, the module of the wireless data exchange interface, the results of the control are uploaded to the Internet.

The simulation results are shown in Fig. 3–5. The power amplifier circuit was analyzed using the integrated software system Micro-CAP 12.

The simulation results confirm the correctness of the calculation of the electronic components of the functional block of the amplifier.

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## Стенд для усталостных испытаний подшипника винта вертолета

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**Ключевые слова и фразы:** винт вертолета; методы; моделирование; стенд.

**Аннотация.** Разработано устройство для усталостных испытаний подшипника винта вертолета. В ходе проектирования устройства для усталостных испытаний подшипника винта вертолета были проанализированы виды и конструктив подшипников качения, проведен обзор существующих методов испытаний подшипников качения, разработана структурная схема устройства для усталостных испытаний подшипника винта вертолета. Разработана функциональная электрическая схема и смоделирован усилитель мощности.

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UDK 629.3.038

# Application of Neuro-Fuzzy Algorithms to Control a Power Plant of a Hybrid Car

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**Key words and phrases:** adaptive control; neuro-fuzzy logic; hybrid engine control systems.

**Abstract.** The purpose of this article was the neuro-fuzzy control system of the hybrid power plant of the car. The article uses methods of mathematical analysis, adaptive control and fuzzy logic. The main objective of the study was to obtain a neural network model to refine forecasts of system state parameters at each control step. The paper presents a formal formulation of the problem, considers its solution by the method of neuro-fuzzy control based on adaptive criticism with the construction of a fuzzy neural network Wang–Mendel.

## Introduction

An increase in the performance indicators of internal combustion engines of cars is associated with the use of hybrid power plants (**HPP**). Such a power plant includes, in addition to the main internal combustion engine (**ICE**), an auxiliary traction electric motor and an energy recovery circuit using a traction battery (**TB**) as an energy storage device. Charging of the TB can be carried out in the presence of excess power of the main engine or by recuperating the braking energy of the vehicle. The key element of the HPP is a power distributor that provides the redistribution of power flows between the chassis of the car, the main engine, the auxiliary engine and the energy recovery circuit [1; 2].

## Problem statement

The main task of the HPP control is to maintain a given vehicle speed $V_{zd}(k) = V_{zd}(t_s + k \times \Delta T)$, $k = \overline{0, N}$ with a minimum error, in the presence of disturbances $\boldsymbol{\xi}(k)$ and restrictions on possible system states $\mathbf{x} \in \mathbf{X}$ and permissible controls $\mathbf{u} \in \mathbf{U}$. In addition, the control process must meet a number of additional conditions: minimizing fuel consumption, the level of toxicity of exhaust gases, deviation of the degree of charge of the TB from the optimal one. At the same time, it is convenient to consider the control of the HPP as a multi-step discrete process with a time sampling step $\Delta T$:

$$\begin{cases} \mathbf{x}(k+1) = \mathbf{x}(k) + \Delta T \times f\left(\mathbf{x}(k), \mathbf{u}(k), \xi(k)\right), \\ \mathbf{y}(k) = h\left(\mathbf{x}(k), \mathbf{u}(k)\right); \end{cases}$$
$$k = \overline{0, N}; \quad N = \left(t_f - t_s\right) \times \Delta T^{-1},$$

where $\mathbf{x} = [\omega, \theta_{TAB}]^T$ is the state vector, the components of which are the current angular velocity of rotation of the driving wheels (ω) and the degree of charge of the TB ($\theta_{TAB}$); $\mathbf{u} = [\beta_D, \beta_M, \beta_T. \gamma]^T$ is the control vector, including control signals for the power of the internal combustion engine ($\beta_D$), the electromagnetic torque of the traction motor ($\beta_M$), the hydraulic braking system ($\beta_T$) and the transmission ratio (γ) of the transmission from the internal combustion engine to the driving wheels; $\boldsymbol{\xi} = [\alpha, \vartheta_0]^T$ is the vector of disturbing influences, which are the slope of the road (α) and the speed of the headwind ($\vartheta_0$); $\mathbf{y} = [V, G_T, E_T]^T$ is the output vector, including the vehicle speed ($V$), hourly fuel consumption ($G_T$) and the degree of toxicity of the exhaust gases of the internal combustion engine ($E_T = f_T(C_{NO}, C_{CO}, C_{HC})$), which is a function of the hourly emission of nitrogen oxides, carbon monoxide and hydrocarbons, respectively; $t_s$, $t_f$ are the time points of the beginning and end of the driving cycle, respectively; $f(\bullet)$ and $h(\bullet)$ are known continuous or piecewise continuous vector functions of vector arguments defined on the corresponding sets [3; 4]. The functional of the quality of HPP management, when using linear convolution of optimality criteria to isolate the only solution of the optimization problem from the field of Pareto-optimal controls, can be represented as:

$$\mathbf{J}_{SV\mu}(k) = \sum_{j=0}^{\infty} \mu^j \times \sum_{i=1}^{4} \mathbf{K}_{P.i} \times \Im_i(k+j),$$

where μ is a discount factor that takes into account the degree of reliability of the assessment of future values of quality criteria $0 < \mu < 1$; $\mathbf{K}_P$ is a priority vector that determines the degree of importance of individual criteria in different sections of the driving cycle: $\sum_i \mathbf{K}_{P.i} = 1$, $\mathbf{K}_{P.i} > 0$, $i = \overline{1, 4}$.

### Adaptive control of the hybrid power plant

Studies show that the errors in the implementation of the speed controller $M_{GSU.zd} = f_{V.rg}(V, V_{zd})$ does not significantly affect the efficiency and environmental safety of the HPP. Acceptable control quality can be achieved by using a PI-controller with fairly roughly selected coefficients. To describe the load redistribution between the HPP units, we introduce the electric drive utilization factor:

$$\varepsilon = \gamma_M \times M_{VD} \times M_{GSU}^{-1}, \quad M_{GSU} \neq 0.$$

In the process of braking the car, when $M_{GSU} < 0$, the coefficient $\varepsilon \in [0, 1]$ characterizes the level of recovery of braking energy. At $\varepsilon = 0$ braking is carried out exclusively by means of a hydraulic braking system. At $\varepsilon = 1$ the entire required braking torque is created by the traction electric drive-in generator mode: $M_{GSU} = \gamma_M \times M_{VD}$, $M_{VD.min} \le M_{VD} < 0$, where $M_{VD.min}$ is the maximum braking torque of the valve electric motor in generator mode. At $0 < \varepsilon < 1$ the braking force is created using both braking systems.

When the car is accelerating or moving uniformly, when $M_{GSU} > 0$, the coefficient $\varepsilon \in (-\infty; 1]$ characterizes the distribution of power produced by the HPP between the internal combustion engine and the traction electric drive. At $\varepsilon < 0$, when the traction electric drive operates in generator mode and recharges the traction battery using the energy. At $0 < \varepsilon < 1$, when the traction force is created due to the joint use of the traction electric drive and the internal combustion engine. At $\varepsilon = 1$, then using only a traction electric drive. If the value of the required torque $M_{GSU.zd}$ and the speed of the car $V = \omega \times r_{col}$ are known, then with a given scheme for constructing the HPP, the coefficient completely determines the control vector $\mathbf{u} = f_{GSU.rg}(\varepsilon, M_{GSU.zd}, V)$.

**The structure of the Wang–Mendel fuzzy neural network**

In this structure, the first layer performs fuzzification of input variables. It is assumed that the term set of a linguistic variable $\omega^L$ contains three terms, the variables $\theta^L_{TAB}$ and $M^L_{GSU.zd}$ are five terms each. The second layer provides aggregation of prerequisites for fuzzy production rules. The third layer is the aggregation of the conditions of the rule base and the generation of a normalizing signal. Consisting of a single neuron, the output layer normalizes the output signal, forming the value of the electric drive utilization factor ε.

Calculation of the electric drive utilization factor at the k-st control step based on the Wang–Mendel fuzzy inference algorithm is described by the expression:

$$\varepsilon(k) = \frac{1}{\sum_m \left( \prod_i \mu_{\mathbf{T}_{jmi}} \left( \mathbf{x}_{FC.i}(k) \right) \right)} \times \sum_m d_m \times \left( \prod_i \mu_{\mathbf{T}_{jmi}} \left( \mathbf{x}_{FC.i}(k) \right) \right).$$

The HPP controller determines the control vector $\mathbf{u} = f_{GSU.rg}(\varepsilon, M_{GSU.zd}, \mathbf{x})$ according to the expressions given earlier. Control actions are applied to the input of the control object. At the same time, the neural network model $\left[\hat{M}_{DVS}, \hat{\theta}_{TAB}\right]^T = \mathbf{F}_{GSU.MD}(\varepsilon, \mathbf{x}, M_{GSU.zd})$, based on the current state of the HPP and the applied control, evaluates the parameters of the system state, which are critical from the point of view of functional $\mathbf{J}_{SV\mu}$ evaluation, for the next control step. The neural network model is implemented in the form of a two-layer direct propagation INS containing 24 neurons in a hidden layer with activation functions in the form of a hyperbolic tangent and two linear neurons of the output layer:

$$\begin{bmatrix} \bar{\varepsilon}(k) \\ \bar{\mathbf{x}}(k) \\ \bar{M}_{GSU.zd}(k) \end{bmatrix} = \left( \begin{bmatrix} \varepsilon(k) \\ \mathbf{x}(k) \\ M_{GSU.zd}(k) \end{bmatrix} - \underset{k=0,N}{\underline{\mathbf{M}}} \left\{ \begin{bmatrix} \varepsilon(k) \\ \mathbf{x}(k) \\ M_{GSU.zd}(k) \end{bmatrix} \right\} \right) : \underset{k=0,N}{\underline{\text{std}}} \left\{ \begin{bmatrix} \varepsilon(k) \\ \mathbf{x}(k) \\ M_{GSU.zd}(k) \end{bmatrix} \right\};$$

$$\mathbf{N_{11}} = 2 : \left( 1 + \exp\left( -2 \left( \mathbf{W_{11}} \left[ \bar{\varepsilon}(k) \;\; \bar{\mathbf{x}}(k) \;\; \bar{M}_{GSU.zd}(k) \right]^T + \mathbf{B_{11}} \right) \right) \right) - 1;$$

$$\left[ \bar{\hat{M}}_{DVS}(k), \bar{\hat{\theta}}_{TAB}(k+1) \right]^T = \mathbf{W_{12}} \mathbf{N_{11}} + \mathbf{B_{12}};$$

$$\begin{bmatrix} \hat{M}_{DVS}(k) \\ \hat{\theta}_{TAB}(k+1) \end{bmatrix} = \begin{bmatrix} \bar{\hat{M}}_{DVS}(k) \\ \bar{\hat{\theta}}_{TAB}(k+1) \end{bmatrix} * \underset{k=0,N}{\underline{\text{std}}} \left\{ \begin{bmatrix} \hat{M}_{DVS}(k) \\ \hat{\theta}_{TAB}(k) \end{bmatrix} \right\} + \underset{k=0,N}{\underline{\mathbf{M}}} \left\{ \begin{bmatrix} \hat{M}_{DVS}(k) \\ \hat{\theta}_{TAB}(k) \end{bmatrix} \right\},$$

where $\mathbf{W}_{11}$, $\mathbf{W}_{12}$ are the matrices of the weighting coefficients of the neurons of the first and second layers of the INS neural network model, respectively; $\mathbf{B}_{11}$, $\mathbf{B}_{12}$ are the displacement vectors of the neurons of the corresponding layers. When denormalizing the output signal of the INS, the symbol "*" indicates the element-wise multiplication of vectors. The purpose of training a neuro-fuzzy controller is the formation of such control actions of the HPP that would contribute to reducing the quadratic value of the evaluation of the control quality functional:

$$E_{FC} = \frac{1}{2} \times \hat{\mathbf{J}}_{SV\mu}^{2} \to \min.$$

In the learning process, the correction of the Wang–Mendel network parameters is carried out according to the expressions:

$$d_m(k+1) = d_m(k) - \lambda_{FC.d} \times \frac{\partial E_{FC}}{\partial \varepsilon} \cdot \left.\frac{\partial \varepsilon}{\partial d_m}\right|_{\substack{d_m = d_m(k) \\ \varepsilon=\varepsilon(k)}};$$

$$c_{\mathbf{T}_{ji}}(k+1) = c_{\mathbf{T}_{ji}}(k) - \lambda_{FC.c} \times \frac{\partial E_{FC}}{\partial \varepsilon} \times \left.\frac{\partial \varepsilon}{\partial c_{\mathbf{T}_{ji}}}\right|_{\substack{c_{\mathbf{T}_{ji}} = c_{\mathbf{T}_{ji}}(k) \\ \varepsilon=\varepsilon(k)}};$$

$$\sigma_{\mathbf{T}_{ji}}(k+1) = \sigma_{\mathbf{T}_{ji}}(k) - \lambda_{FC.\sigma} \times \frac{\partial E_{FC}}{\partial \varepsilon} \times \left.\frac{\partial \varepsilon}{\partial \sigma_{\mathbf{T}_{ji}}}\right|_{\substack{\sigma_{\mathbf{T}_{ji}} = \sigma_{\mathbf{T}_{ji}}(k) \\ \varepsilon=\varepsilon(k)}}.$$

To ensure the linear ordering of the elements of the term sets of the fuzzy inference system, appropriate restrictions must be imposed on the parameters $c_{\mathbf{T}_{ji}}$ and $d_m$, which do not allow the adaptation algorithm to make, for example, the fuzzy set "Low" greater than the fuzzy set "High".

## Conclusion

The use of HPP control using a neuro-fuzzy controller and neural network models of the control object and adaptive critic allows overcoming the lack of a priori information about the parameters of the driving cycle and the relief of the underlying surface, as well as the low accuracy of mathematical models of a hybrid car. This approach assumes the adaptation of the HPP management strategy to the traction-speed mode of the car movement based on the concept of training neural networks with reinforcement. The use of a fuzzy inference system for the formation of control actions of the HPP allows the use of poorly formalized expert knowledge about the optimal management strategy.

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## Применение нейро-нечетких алгоритмов для управления силовой установкой гибридного автомобиля

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**Ключевые слова и фразы:** адаптивное управление; нейро-нечеткая логика; системы управления гибридными двигателями.

**Аннотация.** Целью данной статьи являлась разработка нейро-нечеткой системы управления гибридной силовой установкой автомобиля. В статье использованы методы математического анализа, адаптивного управления и нечеткой логики. Основной задачей исследования являлось получение нейросетевой модели для уточнения прогнозов параметров состояния системы на каждом шаге управления. В работе представлена формальная постановка задачи, рассмотрено ее решение методом нейро-нечеткого управления на основе адаптивной критики с построением нечеткой нейронной сети Ванга–Менделя.

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UDK 53.083

# Construction of a Regression Model of the Electrode Belt of an Electrical Impedance Tomograph

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**Key words and phrases:** electrical impedance tomography; experiment planning; lung examination; disease diagnostics; modeling.

**Abstract.** The article describes the construction of a regression model of the error in the approximation of the voltage at the output of the bend sensors from the factors that affect this error. The following factors were chosen as influencing factors: the length of the sensors and the radius of their bending. Experimental data were obtained as a result of simulation of electrical processes occurring in the system of pulsed magnetization reversal. Statistical processing was carried out in the Statistica software environment. Based on the data obtained, it was concluded that the amplitude of the measuring circuit is most affected by the value of the radius, and least of all by the value of the length. This result will optimize the design of the electrode belt and improve the quality of visualization of the electrical impedance tomography method.

Currently, there are imaging diagnostic methods associated with the construction of an image of the internal environment of a biological object [1–3]. These include methods of X-ray, magnetic resonance, proton, positron emission, optical tomography, ultrasound and radioisotope diagnostics, and many others [4–6]. Their implementation has made it possible to significantly improve the quality of diagnostics [7–9]. One of the most effective, but still not very well-known methods of tomographic studies is the method of electrical impedance tomography (**EIT**) [10], in which electric current is used as a probing agent. The purpose of this method is to build the distribution of electrical impedance inside a biological object. This method is non-invasive, portable and easy to technically implement, and also allows you to get a dynamic image of a biological object. In well-known implementations of EIT for visualization of measurement results, most often they are given by a round or ellipsoidal shape of the model (Fig. 1–2). The selected shapes of the model may differ from the actual shape of the biological object, which leads to a distortion of the image of the results of the electrical impedance distribution. To select the shape of the model, it is necessary to accurately determine the type of the patient's chest, which increases the requirement for the qualification of the medical worker conducting the procedure. In addition, any person is prone to make mistakes, and the wrong choice of the

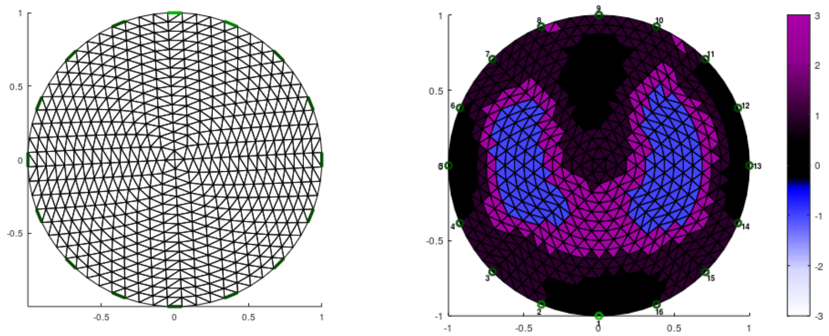

**Fig. 1.** The shape of the model "circle" and the result of the reconstruction impedance distribution

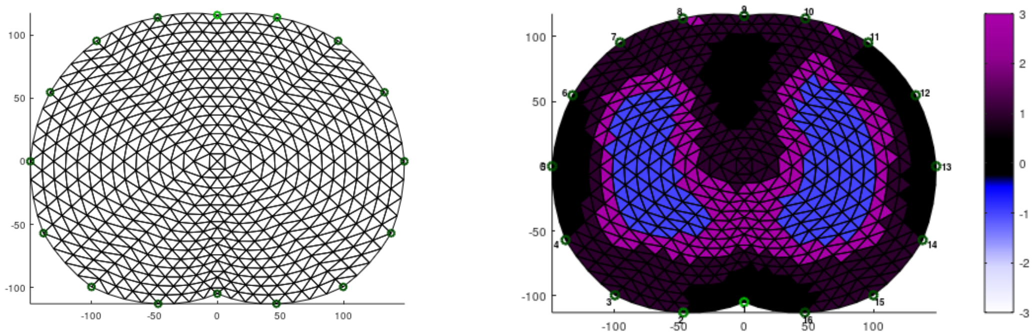

**Fig. 2.** The shape of the "ellipsoidal" model and the result of the reconstruction impedance distribution

**Table 1.** Results of testing sensors of various lengths

| L, mm | R, mm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 60.00 | 80.00 | 100.00 | 120.00 | 140.00 | 160.00 | 180.00 | 200.00 | 220.00 |
| 90.00 | 1.00 | 0.77 | 0.61 | 0.56 | 0.52 | 0.49 | 0.44 | 0.39 | 0.35 |
| | 1.01 | 0.75 | 0.60 | 0.56 | 0.52 | 0.48 | 0.45 | 0.39 | 0.38 |
| | 0.98 | 0.75 | 0.61 | 0.56 | 0.54 | 0.49 | 0.46 | 0.41 | 0.40 |
| 140.00 | 0.99 | 0.81 | 0.67 | 0.58 | 0.55 | 0.40 | 0.38 | 0.32 | 0.35 |
| | 1.01 | 0.83 | 0.71 | 0.60 | 0.57 | 0.42 | 0.38 | 0.34 | 0.34 |
| | 1.00 | 0.82 | 0.71 | 0.60 | 0.53 | 0.44 | 0.39 | 0.35 | 0.37 |
| 190.00 | 1.02 | 0.86 | 0.67 | 0.58 | 0.51 | 0.41 | 0.40 | 0.34 | 0.32 |
| | 0.97 | 0.93 | 0.71 | 0.63 | 0.54 | 0.43 | 0.40 | 0.36 | 0.32 |
| | 1.01 | 0.89 | 0.69 | 0.62 | 0.55 | 0.44 | 0.41 | 0.34 | 0.33 |

form of the model will lead to distorted results.

In this connection, the task of recognizing the shape of a biological object for a more accurate reconstruction of the impedance distribution for the method of electrical impedance tomography is relevant.

Data: Spreadsheet2* (3v by 27c)

| | 1 L | 2 R | 3 U |
|---|---|---|---|
| 1 | 190 | 220 | 0,32 |
| 2 | 190 | 220 | 0,32 |
| 3 | 190 | 220 | 0,33 |
| 4 | 90 | 220 | 0,35 |
| 5 | 90 | 220 | 0,38 |
| 6 | 90 | 220 | 0,40 |
| 7 | 190 | 60 | 1,02 |
| 8 | 190 | 60 | 0,97 |
| 9 | 190 | 60 | 1,01 |
| 10 | 90 | 60 | 1,00 |
| 11 | 90 | 60 | 1,01 |
| 12 | 90 | 60 | 0,98 |
| 13 | 190 | 140 | 0,51 |
| 14 | 190 | 140 | 0,54 |
| 15 | 190 | 140 | 0,55 |
| 16 | 90 | 140 | 0,52 |
| 17 | 90 | 140 | 0,52 |
| 18 | 90 | 140 | 0,54 |
| 19 | 140 | 220 | 0,35 |
| 20 | 140 | 220 | 0,34 |
| 21 | 140 | 220 | 0,37 |
| 22 | 140 | 60 | 0,99 |
| 23 | 140 | 60 | 1,01 |
| 24 | 140 | 60 | 1,00 |
| 25 | 140 | 140 | 0,55 |
| 26 | 140 | 140 | 0,57 |
| 27 | 140 | 140 | 0,53 |

**Fig. 3.** Experiment planning matrix in the Statistica program

s; Var.:U; R-sqr=,99665; Adj:,99586 (Spreadsheet2)

Effect Estimates; Var.:U; R-sqr=,99665; Adj:,99586 (Spreadsheet2)
2 factors, 1 Blocks, 27 Runs; MS Pure Error=,0003091
DV: U

| Factor | Effect | Std.Err. Pure Err | t(18) | p | -95,% Cnf.Limt | +95,% Cnf.Limt | Coeff. | Std.Err. Coeff. | -95,% Cnf.Limt | +95,% Cnf.Limt |
|---|---|---|---|---|---|---|---|---|---|---|
| **Mean/Interc.** | 0,544284 | 0,007566 | 71,9352 | 0,000000 | 0,528388 | 0,560181 | 0,544284 | 0,007566 | 0,528388 | 0,560181 |
| (1)L(L) | -0,014323 | 0,008288 | -1,7280 | 0,101096 | -0,031736 | 0,003091 | -0,007161 | 0,004144 | -0,015868 | 0,001545 |
| L(Q) | -0,017967 | 0,014356 | -1,2515 | 0,226774 | -0,048128 | 0,012194 | -0,008983 | 0,007178 | -0,024064 | 0,006097 |
| (2)R(L) | -0,648437 | 0,008288 | -78,2335 | 0,000000 | -0,665851 | -0,631024 | -0,324219 | 0,004144 | -0,332925 | -0,315512 |
| R(Q) | 0,273150 | 0,014356 | 19,0268 | 0,000000 | 0,242989 | 0,303311 | 0,136575 | 0,007178 | 0,121494 | 0,151655 |
| 1L by 2L | -0,026725 | 0,010151 | -2,6327 | 0,016895 | -0,048052 | -0,005398 | -0,013363 | 0,005076 | -0,024026 | -0,002699 |

**Fig. 4.** Table of the resulting model in coded values

Strain gauges, bending resistors or capacitive bending sensors can be used as bend sensors. To recognize the shape of a biological object, a measuring belt is developed, consisting of a number of sensors for measuring bending.

To solve this problem, you need to find the dependence of the output voltage across the resistor on the bending radius of the tube. For this, sensors of various lengths (90 mm, 140 mm, 190 mm) were tested on a stand consisting of a number of half-cylinders of various radii. To minimize the error, each experiment was carried out 3 times. To unify the characteristics of sensors with different lengths, the signal was normalized. The test results are shown in Table 1.

To build a regression model, the experiment planning method will be used, the length of the sensors L and the bending radius R are taken as factors, and the output voltage of the sensor will be the response.

We use the orthogonal central compositional plan of the second order. Zero levels of factors and intervals of their variation:

$$L = 140 \text{ mm}, h_1 = 50 \text{ mm};$$

| Factor | Regressn Coeff. | Std.Err. Pure Err | t(18) | p | -95,% Cnf.Limt | +95,% Cnf.Limt |
|---|---|---|---|---|---|---|
| | Regr. Coefficients; Var.:U; R-sqr=,99665; Adj:,99586 (Spreadsheet2) 2 factors, 1 Blocks, 27 Runs; MS Pure Error=,0003091 DV: U | | | | | |
| Mean/Interc. | 1,414074 | 0,061354 | 23,0479 | 0,000000 | 1,285175 | 1,542973 |
| (1)L(L) | 0,001331 | 0,000827 | 1,6080 | 0,125239 | -0,000408 | 0,003069 |
| L(Q) | -0,000004 | 0,000003 | -1,2515 | 0,226774 | -0,000010 | 0,000002 |
| (2)R(L) | -0,009560 | 0,000365 | -26,2280 | 0,000000 | -0,010326 | -0,008794 |
| R(Q) | 0,000021 | 0,000001 | 19,0268 | 0,000000 | 0,000019 | 0,000024 |
| 1L by 2L | -0,000003 | 0,000001 | -2,6327 | 0,016895 | -0,000006 | -0,000001 |

**Fig. 5.** Table of the resulting model in physical terms

| Factor | SS | df | MS | F | p |
|---|---|---|---|---|---|
| | ANOVA; Var.:U; R-sqr=,99665; Adj:,99586 (Spreadsheet2) 2 factors, 1 Blocks, 27 Runs; MS Pure Error=,0003091 DV: U | | | | |
| (1)L(L) | 0,000923 | 1 | 0,000923 | 2,986 | 0,101096 |
| L(Q) | 0,000484 | 1 | 0,000484 | 1,566 | 0,226774 |
| (2)R(L) | 1,892120 | 1 | 1,892120 | 6120,485 | 0,000000 |
| R(Q) | 0,111916 | 1 | 0,111916 | 362,018 | 0,000000 |
| 1L by 2L | 0,002143 | 1 | 0,002143 | 6,931 | 0,016895 |
| Lack of Fit | 0,001174 | 3 | 0,000391 | 1,266 | 0,316011 |
| Pure Error | 0,005565 | 18 | 0,000309 | | |
| Total SS | 2,014325 | 26 | | | |

**Fig. 6.** Table for assessing the adequacy of the model

$$R = 140 \text{ mm};\ h_2 = 80 \text{ mm}.$$

We create an experiment planning matrix for an empirical second-order model (Fig. 3). Next, we calculate the estimates of the regression coefficients based on the coded initial values of the factors (column "Coeff" in Fig. 4).

Regression Equation in Coded Values:

$$U = 0.544284 - 0.007161L - 0{,}324219R - 0.008983L^2 + 0{,}136575R^2 - 0.013363LR.$$

Then we calculate the estimates of the regression coefficients based on the uncoded (physical) initial values of the factors (column "Regressn Coeff").

Equation in physical values of factors:

$$U = 1.414074 + 0.001331L - 0.00956R - 0.000004L^2 + 0.000021R^2 - 0.000003LR.$$

The adequacy of the obtained model was checked using the Fisher criterion (Fig. 6).

It can be seen from the table that the resulting model is adequate.

As a result, we can conclude that the amplitude of the measuring circuit is most affected by the value of the radius, and least of all by the value of the length. This result will optimize the design of the electrode belt and improve the quality of visualization of the electrical impedance tomography method.

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## Построение регрессионной модели электродного пояса электроимпедансного томографа

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**Ключевые слова и фразы:** диагностика заболеваний; исследование легких; моделирование; планирование эксперимента; электроимпедансная томография.

**Аннотация.** В статье описывается построение регрессионной модели погрешностей аппроксимации напряжения на выходе датчиков изгиба от факторов, влияющих на эту погрешность. В качестве влияющих факторов выбраны длина датчиков и радиус их изгиба. Экспериментальные данные получены в результате моделирования электрических про-

цессов, протекающих в системе импульсного перемагничивания. Статистическая обработка проводилась в программной среде Statistica. Исходя из полученных данных, сделан вывод, что сильнее всего на амплитуду измерительной схемы влияют значение радиуса, а меньше всего – значение длины. Данный результат позволит оптимизировать конструкцию пояса электродов и повысить качество визуализации метода электроимпедансной томографии.

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UDK 621.311.6

# Development and Research of a Control and Measuring Stand for Checking a Backup Secondary Power Supply Source

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**Key words and phrases:** secondary power; measuring; measuring stand; model.

**Abstract.** The purpose of this work is to develop and study a system for monitoring and diagnosing uninterruptible power supply (**UPS**) boards. This system will have to measure the voltage and current of the device under test, check the correct operation of the control board, namely: mains operation mode; battery operation mode; battery charge, in the presence of mains power; operation of the indicator LEDs. Digital measuring devices, in particular, a microcontroller with a built-in ADC, will be used as information collection systems. The use of microprocessors that allow for such functions as automatic correction of systematic errors, fault diagnosis, processing of received data, control of individual nodes, etc., makes it possible to organize an effective and flexible monitoring and diagnostic system.

The SKAT-1200D version 1 is designed to provide uninterrupted power supply to fire and security alarm systems, video surveillance and other consumers with a rated supply voltage of 12 V DC.

The source is intended for installation inside a guarded facility in enclosed spaces and is designed for round-the-clock operation under the following conditions: power is supplied from a 220 V network with a frequency of 50 ± 1 Hz with a voltage variation range of 170–242 V and from a built-in battery; ambient temperature from –10 to +40 °C; relative air humidity not more than 90% at +25 °C; the absence of vapors of aggressive media (acids, alkalis, etc.)

The functional diagram of the device is shown in Fig. 1. In the diagram, FS1-3 are photosensors; battery input is a terminal for connecting the equivalent of the storage battery; X8 is a jumper, the closure of which prohibits the disconnection of the battery; EN is an electronic load for checking the battery charge; CMVS is controlled main voltage source; CCVS is a controlled source of constant voltage; SW is a switch.

Figure 1 shows a functional diagram of the test stand SKAT 1200D version 1, where VD1-3 are voltage dividers; CS1-3 are current sensors; HL1 is OUT LED; HL2 is battery LED; HL3 is power LED; MC is microcontroller ARDUINO MEGA 2560; POWER is a power input.

The principle of operation is as follows. A controlled source of mains voltage, controlled by pulse-width modulation (**PWM**), is connected to the device under test through a switch block; it

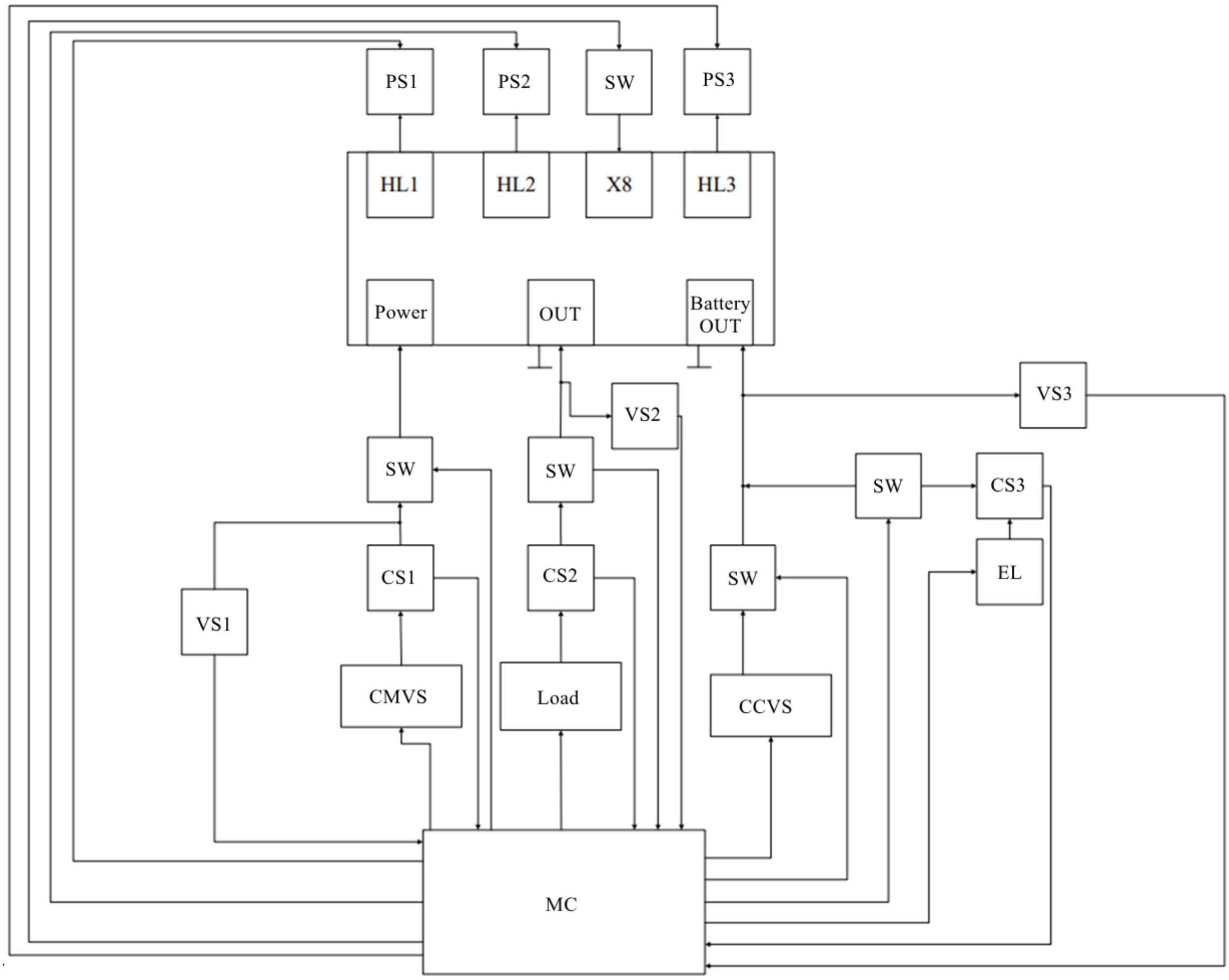


**Fig. 1.** Functional diagram of the test stand SKAT 1200D version 1

supplies mains voltage with the required parameters (voltage 170–242 V and frequency 50 Hz). The load controlled by PWM signal at the output of the device under test is intended for testing the output parameters. A controlled source of constant voltage, designed to simulate both a charged and a discharged battery. The second electronic load, controlled by a PWM signal, is designed to check the battery charge current supplied by the device from the battery output. It has less power than the load installed at the output of the device under test. To measure voltages and currents in different parts of the circuit, current sensors and voltage dividers are designed to reduce the voltage to a measurable value. The relay on jumper X8 is provided according to the device check algorithm. Photo sensors are needed to check the performance of the board indicators. The microcontroller ensures the collection of information, as well as the management of all elements of the stand for testing the product SKAT-1200D version 1.

The following parameters will need to be monitored during operation: Output voltage in the range from 9.5 to 14 V; rated load current from 2.5 to 3 A; battery charge current 0.45 A; the magnitude of the ripple voltage is not more than 30 mV.

Information about the operating modes of the UPS gives an understanding of how to check the correct operation of the control board of the device under test.

We will develop a load circuit to check the battery charge in the Micro-Cap 9 circuit simulation

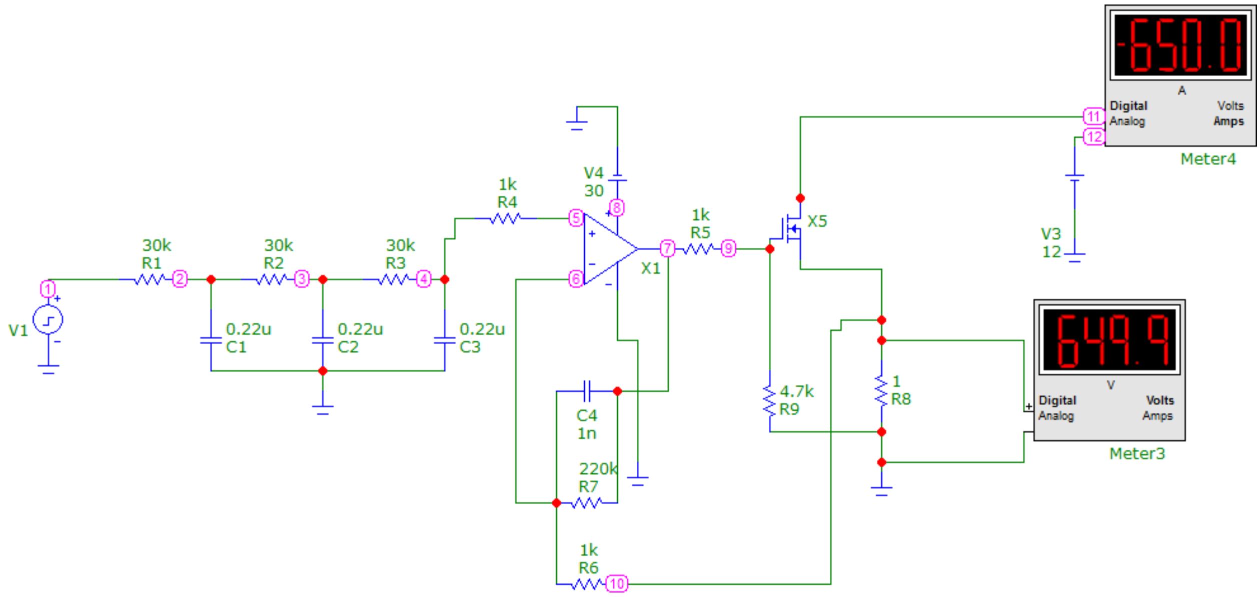


**Fig. 2.** Load model for checking battery charge in Micro-Cap

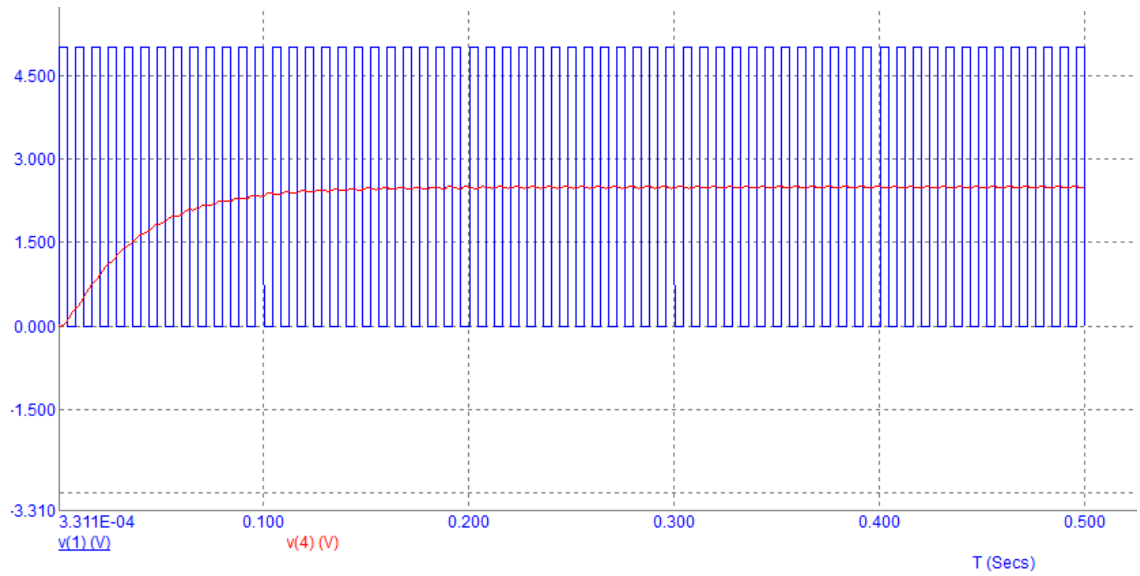


**Fig. 3.** Graph of PWM pulse and smoothed signal at half (50 %) duty cycle

environment, to check the possibility of controlling the load using a PWM signal rectified using a converter. The model is shown in Fig. 2.

In the diagram, the constant current source ($V_3$) simulates the power consumption of the devices connected to the UPS under test. $V_1$ is a PWM signal source.

As a result of the simulation, the graphs of the output signal were obtained after the PWM converters. Figure 3 shows the graph for a 50 % duty cycle.

Figure 4 shows a graph with a maximum fill factor.

Figure 5 shows a graph of the dependence of the current through the resistor R8 and the smoothed PWM signal. It follows from the graph that by changing the duty cycle of the PWM signal, we can make the transistor open as much as necessary. Thus, smoothly change the

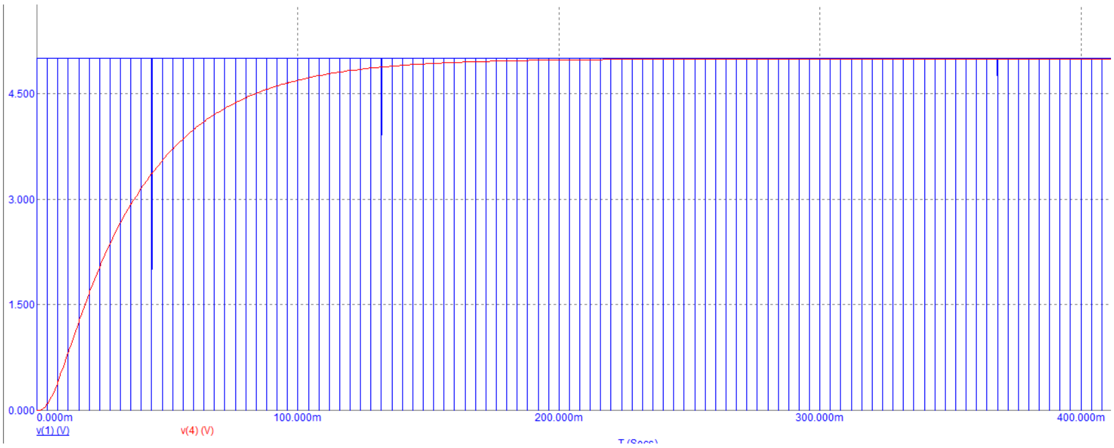


**Fig. 4.** Graph of PWM pulse and smoothed signal at maximum duty cycle

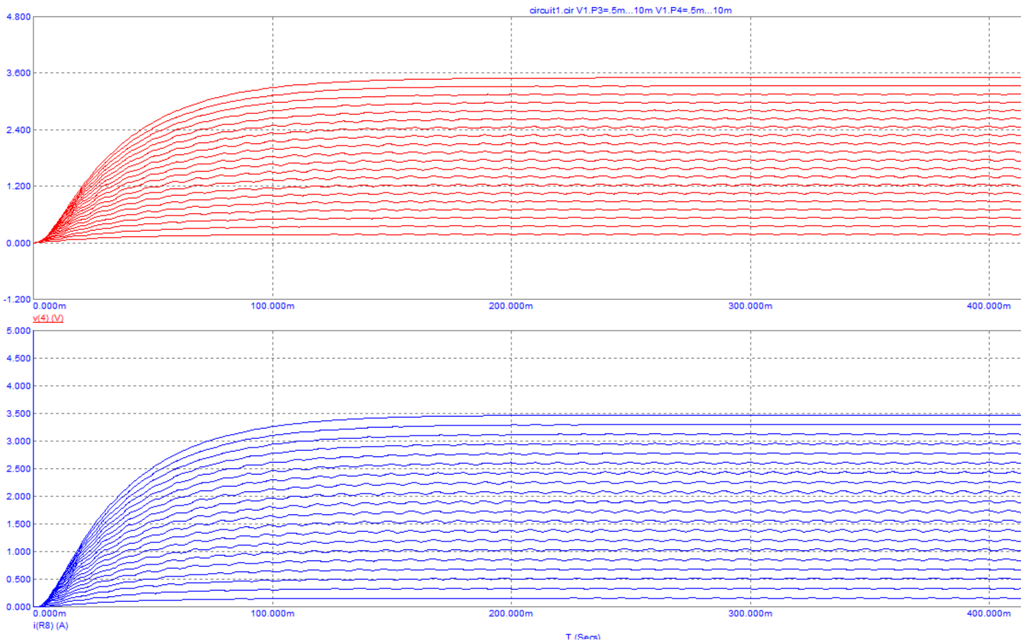


**Fig. 5.** Graph of the dependence of the current through the resistor R8 and the smoothed PWM signal

resistance of its channel, which allows you to control the level of current passing through the load starting from 1 mA.

Thus, at a given value of the PWM duty cycle, it is possible to achieve the current that is required according to the specification.

Let us analyze the results obtained by modeling based on the results:

$$\delta_I = \left| \frac{I_{\text{norm}} - I_{\text{mod}}}{I_{\text{norm}}} \right| \times 100\%,$$

where $\delta_I$, % is the relative error of the output current; $I_{\text{mod}}$, mA is a current obtained as a result of simulation; $I_{\text{norm}}$, mA is a current specified by the technical data of the device.

Output voltage error $\delta_l$,%:

$$\delta_l = \left|\frac{0.65 - 0.6499}{0.65}\right| \times 100\% = 0.02\%.$$

The calculated modeling errors do not exceed 5 %, which satisfies the requirements specification. Therefore, the calculation of the electronic load to check the battery charge is correct.

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# Разработка и исследование контрольно-измерительного стенда проверки источника вторичного электропитания резервированного

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**Ключевые слова и фразы:** вторичное питание; измерительный стенд; измерения; модель.

**Аннотация.** Целью данной работы является разработка и исследование системы контроля и диагностики плат источников бесперебойного питания (**ИБП**). Данная система должна будет измерять напряжение и ток испытуемого устройства, производить проверку правильности работы платы управления, а именно: режим работы от сети; режим работы от АКБ; заряд АКБ при наличии сетевого питания; срабатывание индикационных светодиодов. В качестве систем сбора информации будут задействованы цифровые измерительные устройства, в частности микроконтроллер со встроенным аналого-цифровым преобразователем. Использование микропроцессоров, которые позволяют осуществлять такие функции, как автоматическая коррекция систематических погрешностей, диагностика неисправностей, обработка полученных данных, управление отдельными узлами и т.д., дает возможность организовать эффективную и гибкую систему контроля и диагностики. Также в данной работе произведено моделирование блока электронной нагрузки и построение его регрессионной модели при помощи теории планирования эксперимента.

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UDK 520.8

# Development and Research of a Device for Calibration and Verification of Electrical Measuring Instruments

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**Key words and phrases:** calibration device r; verification; electrical measuring instruments; measurements.

**Abstract.** At present, to control the quality of manufacturing products, much attention is paid to the accuracy of measuring instruments. To verify digital and analog devices of direct and alternating current, introduced into the practice of measurements, it was necessary to create multi-valued measures, called calibrators in the domestic literature. The calibrator is a high-precision instrument designed for checking (determining the error) and calibrating a wide range of instruments and devices of measuring and generator type [1]. The value of the standard and the measured value are compared with each other, the operation of this instrument is based on this. For the need to ensure the unity and the required accuracy of measurements, such a group of control and measuring equipment is used.

## Introduction

In order to ensure unity and the required accuracy, in accordance with the federal law of the Russian Federation No. 102-FZ "On ensuring the uniformity of measurements", mandatory requirements are established for measurements performed in the following areas: production, safety and labor protection, state and production control, healthcare, execution of settlement and state accounting operations, trade and banking, tax and customs, judicial and sports. With the help of accurate reproduction, storage of established units of physical quantities and transfer of their sizes to working measuring instruments using standards and exemplary measuring instruments, one can achieve the unity of measurements [1; 2]. Standards are considered the highest link in the metrological chain of transferring the sizes of units of measurement. There are the following requirements for the standard: high accuracy, versatility, ease of transfer of the unit of magnitude, and stability. There are various calibrators and installations, which are sources of calibrated currents, voltages and resistances, designed for verification of analog and digital devices [3; 4]. Each of them has certain advantages and disadvantages. Some are designed to reproduce the power and voltage of direct current, others – to reproduce the power and voltage of alternating current, etc. The use of high-speed calibrators in measuring systems also makes it possible to automate the verification of the output characteristics of many semiconductor devices, microcircuits and other electrical radio elements [5; 6]. The use of such a group of control and measuring equipment is due to the need to ensure the unity and required accuracy of measurements.

## Method and materials

Currently, the market of metrological equipment, and in particular reference equipment, presents various models of installations and calibrators designed to reproduce electrical quantities in order to carry out verification and calibration, as well as repair measuring instruments [7, 8]. Multifunctional portable verification devices are popular because of their mobility and versatility.

The functional diagram of the developed device for verification and calibration of electrical measuring instruments is shown in Fig. 1.

The device for checking and calibrating electrical measuring instruments contains an input divider 1, an input amplifier 2, an ADC 3, a DC voltage DAC 4, a DC reference voltage source 5, a device scale amplifier 6, a device amplifier 7, a switch that closes the device output voltmeter input 8, device output terminal 9, voltmeter input terminal 10, common bus input/output 11, AC/DC converter 12, AC voltage DAC 13, AC voltage reference 14, operation mode switches (DC or AC voltage) 15.16, voltage-to-current converter 17.

The operation of the developed device is as follows. When using the input voltage measurement mode, the input voltage ($U_{in}$) is supplied (from the input terminal 10) to the input of the ADC 3. This happens through the input device (divider 1 and input amplifier 2). For an input device, the gain is the gain *R/nR*, where *n* >1. In case of resetting DAC 4 ($U_{DAC}$ = 0) and the minimum sensitivity of the ADC, the input voltage is "roughly" measured last. According to his testimony, a DAC is installed (the digital code of the ADC is "written" into the DAC control circuit). Then the ADC is affected by the voltage difference $U_{in}$ – $U_{DAC}$. This difference is measured by the ADC already at the highest sensitivity. The voltmeter reading is indicated based on the ADC reading and the DAC position.

Switch 8 closes when using the voltage reproduction mode (of the device. The input of the amplifier of device 7 with a transfer coefficient *nr/r* (ratio of divider resistors 6) is supplied

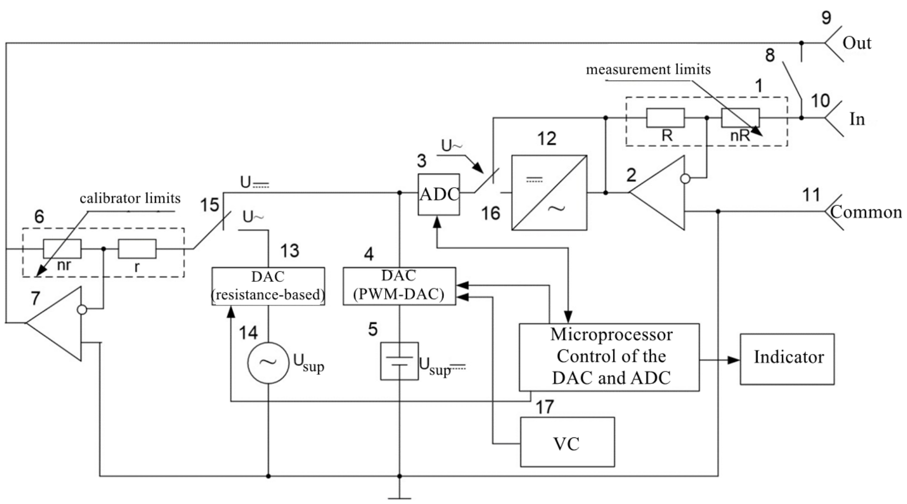


**Fig. 1.** Functional diagram of a device for verification and calibration

**Table 1.** Matrix of the experiment

| № | № of exp. | $X_1$ | T, °C | $X_2$ | $U_{sup}$, B | $X_3$ | I, A | $U_{out}$, B | $U_{out}/I$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1 | – | 5 | – | 10 | + | 50 | 2.47295 | 0.049459 |
| 2 | 2 | – | 5 | – | 10 | + | 50 | 2.522 | 0.05044 |
| 3 | 3 | – | 5 | – | 10 | + | 50 | 2.423 | 0.04846 |
| 4 | 4 | – | 5 | + | 14 | + | 50 | 2.47295 | 0.049459 |
| 5 | 5 | – | 5 | + | 14 | + | 50 | 2.522 | 0.05044 |
| 6 | 6 | – | 5 | + | 14 | + | 50 | 2.423 | 0.04846 |
| 7 | 7 | + | 40 | – | 10 | + | 50 | 2.48887 | 0.049777 |
| 8 | 8 | + | 40 | – | 10 | + | 50 | 2.539 | 0.05078 |
| 9 | 9 | + | 40 | – | 10 | + | 50 | 2.439 | 0.04878 |
| 10 | 10 | + | 40 | + | 14 | + | 50 | 2.48887 | 0.049777 |
| 11 | 11 | + | 40 | + | 14 | + | 50 | 2.539 | 0.05078 |
| 12 | 12 | + | 40 | + | 14 | + | 50 | 2.439 | 0.04878 |
| 13 | 13 | – | 5 | – | 10 | – | 5 | 0.23074345 | 0.046149 |
| 14 | 14 | – | 5 | – | 10 | – | 5 | 0.235 | 0.047 |
| 15 | 15 | – | 5 | – | 10 | – | 5 | 0.226 | 0.0452 |
| 16 | 16 | – | 5 | + | 14 | – | 5 | 0.23074345 | 0.046149 |
| 17 | 17 | – | 5 | + | 14 | – | 5 | 0.235 | 0.047 |
| 18 | 18 | – | 5 | + | 14 | – | 5 | 0.226 | 0.0452 |
| 19 | 19 | + | 40 | – | 10 | – | 5 | 0.23233404 | 0.046467 |
| 20 | 20 | + | 40 | – | 10 | – | 5 | 0.237 | 0.0474 |
| 21 | 21 | + | 40 | – | 10 | – | 5 | 0.228 | 0.0456 |
| 22 | 22 | + | 40 | + | 14 | – | 5 | 0.23233404 | 0.046467 |
| 23 | 23 | + | 40 | + | 14 | – | 5 | 0.237 | 0.0474 |
| 24 | 24 | + | 40 | + | 14 | – | 5 | 0.228 | 0.0456 |

with voltage $U_{DAC}$. Thus, the voltage $U_K = U_{DAC} \times n$ is formed (where $n$ is usually 1, 10 or 100) at the amplifier output of the device. Voltage can be monitored with a voltmeter. The limit of its measurement is set according to the set limit of the device (10 V, 100 V or 1000 V). It is possible to adjust the limit if necessary. Significantly reduce the performance requirements The latter can be achieved by including a voltmeter in the control circuit of the output value of the device. The requirements of high temperature and long-term stability are transferred to the voltmeter. Because of the possibility of carrying out auto-calibration of the voltmeter every time before the next "intervention" of it in the output correction system of the device being developed, the implementation of these requirements is simplified. In contrast from of the developed device, the discrete nature of the voltmeter operation is in good agreement with the principles of autocalibration [9].

With them, you can turn on auto-calibration cycles in the pauses between measurements. It is not necessary to create voltmeter units from components with high long-term and temperature

Effect Estimates; Var.:Uвых; R-sqr=,99934; Adj:,99911 (таб.sta)
2**(3-0) design; MS Pure Error=,0012123
DV: Uвых

| Factor | Effect | Std.Err. Pure Err | t(16) | p | -95,% Cnf.Limt | +95,% Cnf.Limt | Coeff. | Std.Err. Coeff. | -95,% Cnf.Limt | +95,% Cnf.Limt |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean/Interc. | 1,346167 | 0,007107 | 189,4059 | 0,000000 | 1,331100 | 1,361233 | 1,346167 | 0,007107 | 1,331100 | 1,361233 |
| (1)T | 0,048667 | 0,014215 | 3,4237 | 0,003482 | 0,018533 | 0,078800 | 0,024333 | 0,007107 | 0,009267 | 0,039400 |
| (2)Uпит | 0,000000 | 0,014215 | 0,0000 | 1,000000 | -0,030134 | 0,030134 | 0,000000 | 0,007107 | -0,015067 | 0,015067 |
| (3)I | 2,219667 | 0,014215 | 156,1537 | 0,000000 | 2,189533 | 2,249800 | 1,109833 | 0,007107 | 1,094767 | 1,124900 |
| 1 by 2 | 0,000000 | 0,014215 | 0,0000 | 1,000000 | -0,030134 | 0,030134 | 0,000000 | 0,007107 | -0,015067 | 0,015067 |
| 1 by 3 | 0,037333 | 0,014215 | 2,6264 | 0,018330 | 0,007200 | 0,067467 | 0,018667 | 0,007107 | 0,003600 | 0,033733 |
| 2 by 3 | 0,000000 | 0,014215 | 0,0000 | 1,000000 | -0,030134 | 0,030134 | 0,000000 | 0,007107 | -0,015067 | 0,015067 |

**Fig. 2.** Estimates of regression coefficients based on coded input factor values

ANOVA; Var.:Uвых; R-sqr=,99934; Adj:,99911 (таб.sta)
2**(3-0) design; MS Pure Error=,0012123
DV: Uвых

| Factor | SS | df | MS | F | p |
|---|---|---|---|---|---|
| (1)T | 0,01421 | 1 | 0,01421 | 11,72 | 0,003482 |
| (2)Uпит | 0,00000 | 1 | 0,00000 | 0,00 | 1,000000 |
| (3)I | 29,56152 | 1 | 29,56152 | 24383,99 | 0,000000 |
| 1 by 2 | 0,00000 | 1 | 0,00000 | 0,00 | 1,000000 |
| 1 by 3 | 0,00836 | 1 | 0,00836 | 6,90 | 0,018330 |
| 2 by 3 | 0,00000 | 1 | 0,00000 | 0,00 | 1,000000 |
| Lack of Fit | 0,00000 | 1 | 0,00001 | 0,00 | 0,999998 |
| Pure Error | 0,01940 | 16 | 0,00121 | | |
| Total SS | 29,60349 | 23 | | | |

**Fig. 3.** Checking the adequacy of the model

stability (these should be only internal standards, according to which auto-calibration is implemented), since immediately after auto-calibration, the voltmeter has a very high accuracy. All adjustment effects are realized virtually (in the form of a corrected digital readout) in the voltmeter. In the form of a corresponding change in the output signal, such effects can manifest themselves in the device being developed [10]. Inside the device there is a voltmeter and a programmable source with a large voltage range. This allows you to perform auto-calibration and diagnostics of the device, not forgetting about metrological failures. The structure allows the implementation of all the main operations of the measuring process. These are reproduction, comparison, measurement, static information processing (embedded microcomputer) and scaling. It is possible to implement deep diagnostics of the DAC and ADC by supplying each bit sequentially from the DAC. This is controlled by the ADC. Based on the high linearity of the DAC (with PWM), auto-calibration of the ADC, is carries out with resistive dividers. When a constant voltage is reproduced, the switches 15 and 16 remain in their original state.

## Results

It is necessary to build a mathematical model of the change in the output voltage depending on the source current, supply voltage and temperature. As influencing factors, we take the source current $I$, supply voltage $U_{sup}$ and the ambient temperature $t$, and as a response, the output voltage from the operational amplifier (op-amp) $Uout$.

Matrix of the experiment with $N$ = 8 is filled in Table 1. Data analysis will be carried out using the Statistica.

Fig. 2 shows the result of calculating the estimates of the regression coefficients based on the coded initial values of the factors.

The regression equation for the coded values of factor levels has the form:

$$\delta = 1,346167 + 0,024333 \times X_1 + 1,109833 \times X_3 + 0,018667 \times X_1 X_3.$$

Fig. 3 shows a table that was obtained to test the adequacy of the resulting model.

$F_{cr} > F_{calc}$ (3.01 > 0.008). Therefore, the resulting model is adequate.

## Conclusion

A mathematical model was built of the dependence of the output voltage of the instrumental amplifier on the influence of the source current, supply voltage and ambient temperature. As a result of the data obtained, it can be concluded that the operation of the instrumental amplifier is strongly influenced by the source current and ambient temperature, and the supply voltage does not significantly affect the operation of the instrumental amplifier.

Thus, it can be concluded that the instrumentation amplifier will operate stably in a given temperature range.

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## Разработка и исследование устройства для калибровки и поверки электроизмерительных приборов

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**Ключевые слова и фразы:** измерения; поверка; прибор для калибровки; электроизмерительные приборы.

**Аннотация.** В настоящее время для контроля качества изготовления продукции много внимания уделяют точности средств измерений. Для поверки цифровых и аналоговых устройств постоянного и переменного тока, внедренных в практику измерений, потребовалось создать многозначные меры, называемые в отечественной литературе калибраторами. Калибратор представляет собой высокоточный прибор, предназначенный для поверки (определения погрешности) и калибровки широкой номенклатурной группы приборов и устройств измерительного и генераторного типа [1]. Величина эталона и измеряемая величина сравниваются друг с другом, на этом основано действие данного прибора. Применение такой группы контрольно-измерительной техники обусловлено необходимостью обеспечения единства и требуемой точности измерений.

UDK 537.8

# Device for Measuring the Average Plasma Velocity with Control of the Differential Signal of the Position Sensors

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**Key words and phrases:** control and measuring device; induction; plasma; gaussmeter.

**Abstract.** The article considers the development of a device for measuring the average plasma velocity with the control of the differential signal of position sensors. A block diagram of the designed device has been developed. On the basis of the block diagram, a functional diagram of the device was developed and its description was made. Multiplexer simulation completed in NI Multisim 14.0.

In various fields of science and technology, the problem arises of accelerating bodies to high (on the order of several kilometers per second) linear velocities [1]. At the end of the last – the beginning of this century, the range of problems requiring high-speed acceleration of bodies, and successfully solved with the help of electrodynamic accelerators (**EDA**) [2], has significantly expanded [3; 4]. For example, in experimental physics, using the technique of high-speed impact, phase transformations of matter under strong collisions are studied [5], the possibility of using high-speed acceleration techniques for solving problems of controlled thermonuclear fusion [6] is analyzed, high-speed collisions of meteorite particles [7] and space debris are simulated on test benches. with the skin of spacecraft in the study of the strength properties of materials. Another application of EDA in the field of space research is associated with the launch of microspacecraft (microspacecraft) [8]. Recently, electrodynamic installations for processing various parts with high-speed low-temperature plasma flows have been used to harden parts [9]. Another modern application of EDA is associated with the physical modeling of the processes of destruction of parts of the designed ITER fusion reactor [10] to solve the problems of durability and environmental safety of the reactor.

One of the most important problems is to provide a controlled acceleration of the plasma and the bodies pushed by it, which implies the possibility of correcting the acceleration process directly during the experiment in order to achieve a given acceleration rate at the end of the internal ballistics section (at the output of the EDA channel). The solution to this problem requires, in turn, the development of appropriate algorithms and technical means for controlling acceleration and monitoring the parameters of plasma and body motion in the EDA channel.

The block diagram of the device for measuring the average plasma velocity with the control of the differential signal of the position sensors is shown in Fig. 1. On the block diagram, the following are indicated: SB – sensor block, IB – integrator block, SwB – switch block, AB – analyzer block, CU – computing unit, ADC – analog-to-digital converter, MC – microcontroller,

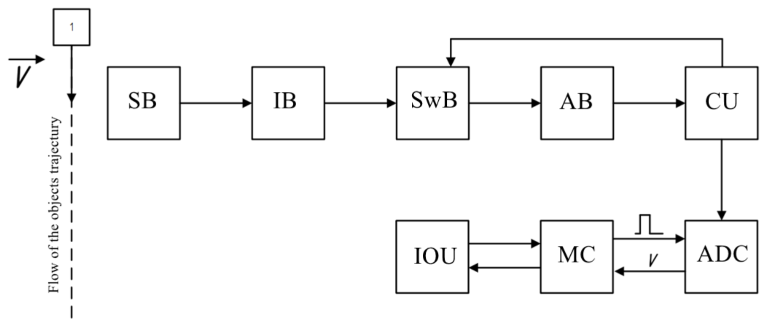


**Fig. 1.** Structural diagram of the device for measuring the average plasma velocity with the control of the differential signal of the position sensors

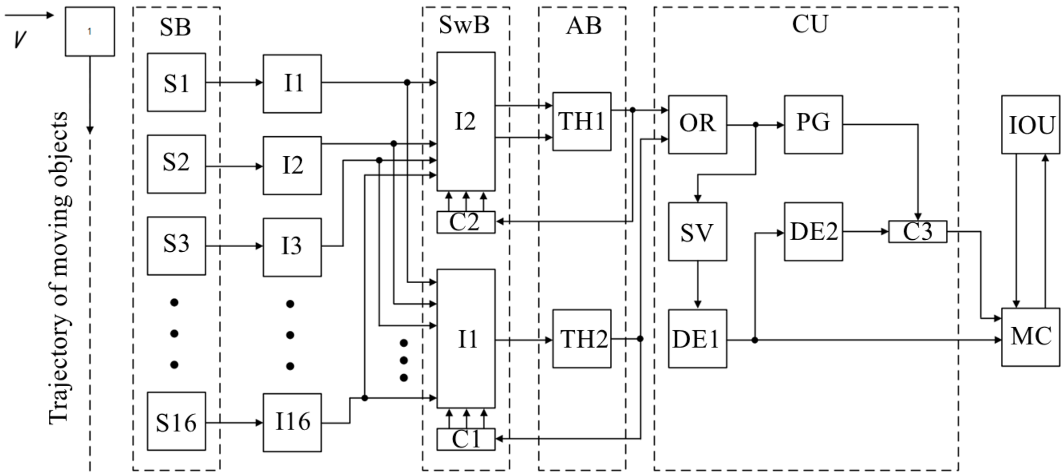


**Fig. 2.** Functional diagram of the device for measuring the average plasma velocity with the control of the differential signal of the position sensors

IOU – input/output unit. The device works as follows: a plasma clot, moving along a trajectory directed along the sensor block of the railgun SB, acts on them and an EMF occurs on the windings.

A bell-shaped signal is formed on the IB integrator block, which is transmitted through the SwB switch block and the AB analyzer block to the CU computing unit. The operation of the SwB switch block is carried out according to a given program, in accordance with the movement of the body along the trajectory of movement. The ADC converts the signal into a digital code, which is then transmitted to the MC microcontroller for further processing. Communication with external devices is carried out through the IOU block. The development of the functional diagram of the device was carried out on the basis of the block diagram. The functional diagram of the device is shown in Fig. 2.

The scheme works according to the following algorithm: when flying over the railgun object 1, inductive sensors S1–S32 record the change in the magnetic field. During the initialization of the device, the first sensor S1 is connected to the analyzers AB and TH2 through the M1 multiplexer and the M2 multiplexer. When the body passes the first sensor S1, the analyzer TH2 registers the peak point of the signal and generates an impulse, which, through the OR element with a trailing edge, gives a command to start the pulse generator PG. Counter C3 starts timing. The leading edge of this pulse translates the second counter C1 and the multiplexer M1 to

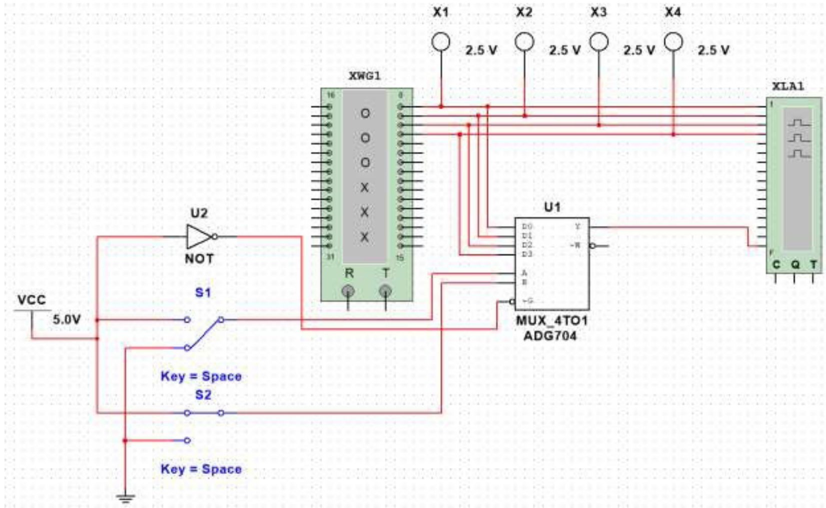


**Fig. 3.** Model for studying the multiplexer in the NI Multisim 14.0 environment

the next position. A pair of inductive sensors S1 and S2 through the second multiplexer M2 is connected to the AB analyzer, which performs the operation of comparing two signals from sensors S1 and S2. When the signals are compared, a pulse is formed that, through the OR element with a leading edge, stops the PG pulse generator and, through the single vibrator SV and delay element DE1, strobes the input port of the MC microcontroller to rewrite information from the C3 counter to the MC microcontroller. Further, through the delay element DE2, the information of the counter C3 is reset. The pulse at the output of the MC moves the counter C2 and the multiplexer M2 to the next position. The induction sensor D2 is connected to the analyzer input TH2. The trailing edge of the pulse again starts the pulse generator GI and the counter C3 starts timing again. In the calculator, which performs the functions of dividing two numbers and storing the data array, the average speed is calculated on the first ($V_{mid\ j1}$) and second ($V_{mid\ j2}$) halves of the distance between adjacent sensors:

$$V_{mid\ j1} = \frac{\Delta x_j}{2\Delta t_1}, \quad V_{mid\ j2} = \frac{\Delta x_j}{2\Delta t_2},$$

where $\Delta x_j$ is the base distance between two adjacent sensors; $\Delta t_1$, $\Delta t_2$ are the time intervals between the moments of body fixation on the section of the motion trajectory; $j = 1, 2, \ldots, N$ is the number of the interval between two adjacent sensors; $N = m - 1$; $m$ is the number of sensors.

As an object of modeling, we choose a switch based on a multiplexer. To simulate the multiplexer, we will use the NI Multisim 14.0 circuit simulation program. Since the simulation package does not have a 16-channel multiplexer in its library, we will use a 4-channel one. The operation of a multiplexer with 16 channels is similar. The developed multiplexer model is shown in Fig. 5. The diagram shows: VCC is a voltage source 5V; U1 is a 4-channel multiplexer chip model; U2 is a virtual inverter; XWG1 is a serial binary word generator; X1–X4 are level indicators; XLA1 is a logic analyzer.

To start the operation of the multiplexer, a low-level control signal is required, which is applied to its input G. To switch the inputs D0–D3, it is necessary to apply signals in the form of binary numbers using the switches S1, S2 to the address inputs A and B of the U1 microcircuit.

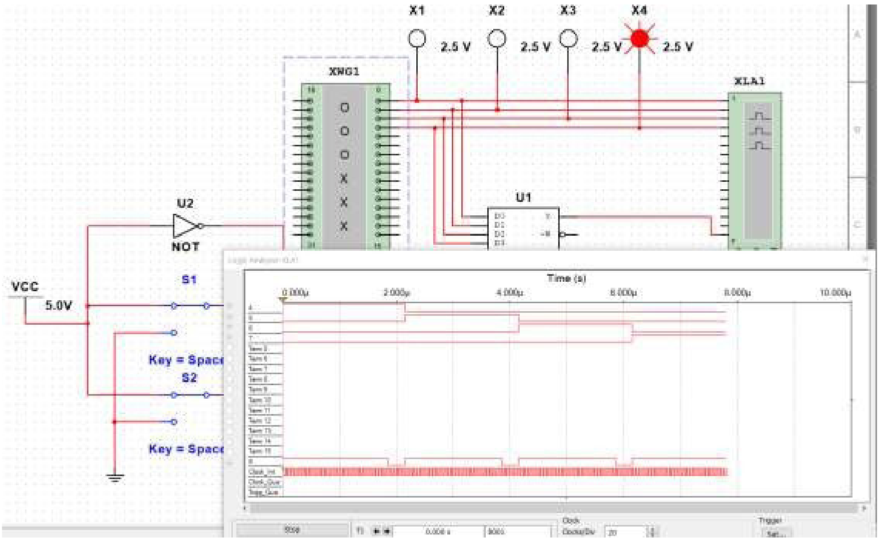


**Fig. 4.** Simulation results

For the generator to work, it is necessary to set the frequency to 500 kHz in its settings panel, select the step-by-step mode "Step" and enter the derived number of binary numbers in the input field. The simulation results are shown in Fig. 4.

As a result of circuit simulation, a circuit was developed to demonstrate the operation of a multiplexer-based switch in the NI Multisim package. Since the standard library does not include a device with 16 channels, a 4-channel multiplexer was used.

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## Устройство измерения средней скорости плазмы с контролем дифференциального сигнала датчиков положения

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**Ключевые слова и фразы:** гауссметр; индукция; контрольно-измерительное устройство; плазма.

**Аннотация.** Выполнена разработка устройства измерения средней скорости плазмы с контролем дифференциального сигнала датчиков положения. Разработана структурная схема проектируемого устройства. На базе структурной схемы разработана функциональная схема устройства и выполнено ее описание. Выполнено моделирование мультиплексора в среде NI Multisim 14.0.

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UDK 621.311.6

# Development and Research of the Control and Measuring Stand for Checking the SKAT-2400I7 Product

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**Key words and phrases:** measuring stand; controlling parameters; SKAT-2400I7; power supply.

**Abstract.** The goal of modern enterprises is to increase productivity, efficiency, speed and quality, which will lead to greater competitiveness of companies on the way to the future. This raises the need for fast and accurate verification of the characteristics of manufactured devices. To achieve these goals, stands for measuring and controlling parameters are used. At the heart of these devices, as a rule, is a microcontroller, which acts as the main element. Using an analog-to-digital converter (**ADC**), it measures the controlled value and compares it with a predetermined one. Based on these data, he concludes about the error of this parameter. The purpose of this work is to develop and study the control and measuring stand for checking the SKAT-2400I7 product. This device is a source of secondary power supply for fire alarm systems, video surveillance systems, and other consumers with a supply voltage of 24 V DC and current consumption of 4.5 A, as well as a backup power supply for devices with a current consumption of up to 5 A.

The SKAT-2400I7 product is designed to provide power to devices with a rated supply voltage of 24 V and a consumption current of up to 5 A. An uninterruptible power supply (**UPS**) is used to power the load from the mains, if available, and from a battery (hereinafter referred to as the battery) in the absence of a mains. It is difficult to implement and control parameters, since each parameter must be measured and controlled manually, for this it is necessary to connect measuring devices, close contacts and check the operation of the product under various operating modes, such as checking the operation of the product with a supply voltage in the range from 175 V to 245 V. All these operations take quite a long time and require personnel with certain qualifications. And also when measuring and controlling parameters, a person is involved in the assessment of the error, therefore, he can make a mistake either when measuring a parameter, or when calculating the error due to inattention or being distracted from the measurement and control process. From this it follows that in order to simplify the measurement and control of the parameters of the SKAT-2400I7 product, it is necessary to develop an automated stand that would perform all measurements itself and display the results

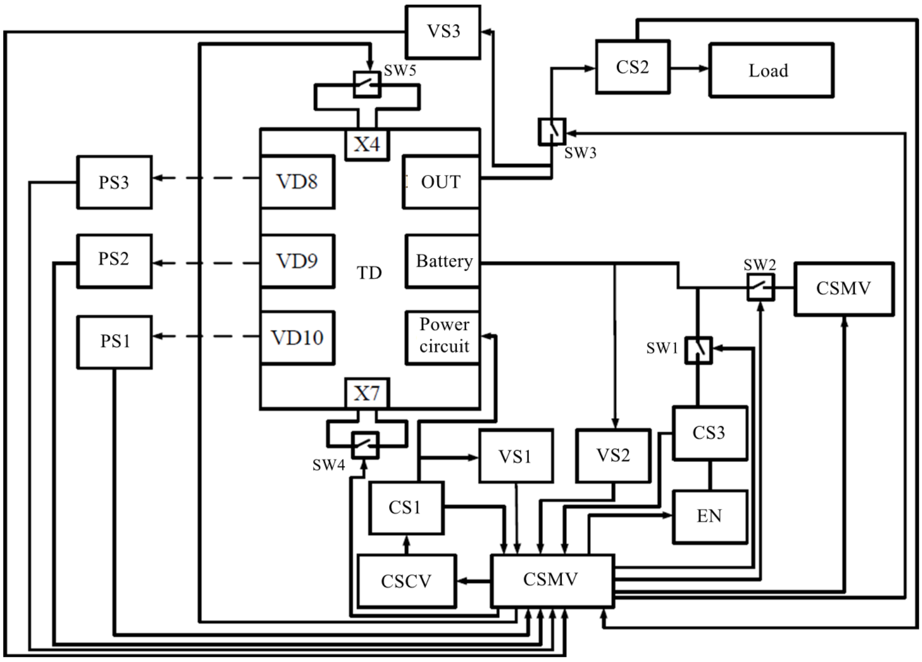


**Fig. 1.** Functional scheme of the stand

to the operator.

Functional diagram of the designed stand was drawn up. It is shown in Fig. 1.

On the diagram, CD is a control device that includes an ADC, an input switch for switching connected measuring parts, and a DAC. CSMV is a controlled source of mains voltage. CS 1÷3 are current sensors (CS1 is used to measure the current consumed from the network; CS2 is used to measure the current at the output of the device; CS3 – to measure and control the battery charge current). VS 1÷3 are voltage sensors (VS1 is designed to measure the mains voltage; VS2 is used to measure the voltage at the battery terminals; VS3 - to measure the voltage at the output of the product). Load is the load on the output of the EH device, the electronic load. PS 1÷3 are photo sensors (for control of light indication of product operation modes). TD is a device under test. CSCV is a controlled source of constant voltage K1÷K5 – relay. VD8÷VD10 are LEDs. The principle of operation is as follows. CSMV supplies with the help of a PWM signal, through the relay block, the mains voltage with the required parameters. The load controlled by a PWM signal at the output of the device is designed to test the output parameters of the product. CSCV is designed to simulate a 24 V battery. The electronic load is designed to check the battery charge current supplied by the device from the battery output. It is controlled by a PWM signal. To measure voltages and currents in different parts of the circuit, current sensors and voltage sensors are designed. Relays on jumpers X4, X7 are provided according to the device test algorithm. Photo sensors are needed to check the performance of the indicators.

It is necessary to build a mathematical model of the change in the output voltage. We take the ambient temperature t, the input voltage and the control voltage as the influencing factors, and the output voltage as the response.

Zero levels of factors and intervals of their variation:

$t$ = 20 °C, $h_1$ = 30 °C,

$U_{in}$ = 23.406 V, $h_2$ = 1 V,

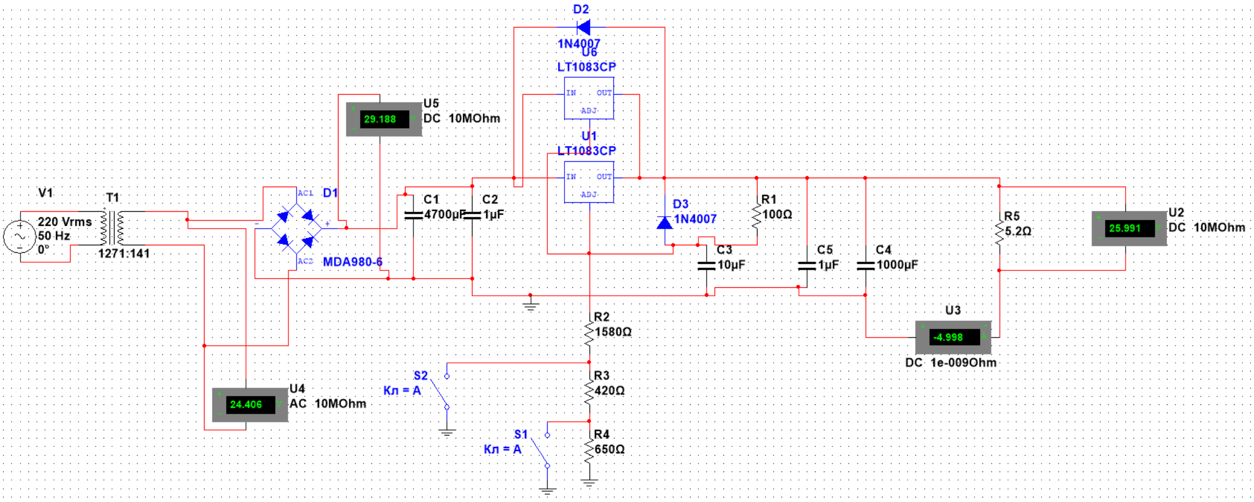


**Fig. 2.** Diagram of the battery emulator in NI Multisim

Effect Estimates; Var.:Uвых; R-sqr=,95986; Adj:,94569 (Spreadsheet5)
2**(3-0) design; MS Pure Error=,2148147
DV: Uвых

| Factor | Effect | Std.Err. Pure Err | t(16) | p | -95,% Cnf.Limt | +95,% Cnf.Limt | Coeff. | Std.Err. Coeff. | -95,% Cnf.Limt | +95,% Cnf.Limt |
|---|---|---|---|---|---|---|---|---|---|---|
| **Mean/Interc.** | 23,09192 | 0,094608 | 244,0808 | 0,000000 | 22,89136 | 23,29248 | 23,09192 | 0,094608 | 22,89136 | 23,29248 |
| (1)t | 0,11133 | 0,189215 | 0,5884 | 0,564482 | -0,28979 | 0,51245 | 0,05567 | 0,094608 | -0,14489 | 0,25623 |
| (2)Uвх | 1,05133 | 0,189215 | 5,5563 | 0,000043 | 0,65021 | 1,45245 | 0,52567 | 0,094608 | 0,32511 | 0,72623 |
| (3)Uy | 3,68517 | 0,189215 | 19,4760 | 0,000000 | 3,28405 | 4,08629 | 1,84258 | 0,094608 | 1,64202 | 2,04314 |
| 1 by 2 | 0,08383 | 0,189215 | 0,4431 | 0,663656 | -0,31729 | 0,48495 | 0,04192 | 0,094608 | -0,15864 | 0,24248 |
| 1 by 3 | -0,26333 | 0,189215 | -1,3917 | 0,183056 | -0,66445 | 0,13779 | -0,13167 | 0,094608 | -0,33223 | 0,06889 |
| 2 by 3 | 0,71567 | 0,189215 | 3,7823 | 0,001633 | 0,31455 | 1,11679 | 0,35783 | 0,094608 | 0,15727 | 0,55839 |

**Fig. 3.** Estimates of regression coefficients based on coded raw factor values

Regr. Coefficients; Var.:Uвых; R-sqr=,95986; Adj:,94569 (Spreadsheet5)
2**(3-0) design; MS Pure Error=,2148147
DV: Uвых

| Factor | Regressn Coeff. | Std.Err. Pure Err | t(16) | p | -95,% Cnf.Limt | +95,% Cnf.Limt |
|---|---|---|---|---|---|---|
| **Mean/Interc.** | 69,50628 | 20,16527 | 3,44683 | 0,003316 | 26,75782 | 112,2547 |
| (1)t | 0,00872 | 0,07916 | 0,11012 | 0,913685 | -0,15910 | 0,1765 |
| (2)Uвх | -2,72807 | 0,86042 | -3,17065 | 0,005932 | -4,55207 | -0,9041 |
| (3)Uy | -2,57803 | 0,88692 | -2,90672 | 0,010296 | -4,45822 | -0,6978 |
| 1 by 2 | 0,00140 | 0,00315 | 0,44306 | 0,663656 | -0,00529 | 0,0081 |
| 1 by 3 | -0,00176 | 0,00126 | -1,39171 | 0,183056 | -0,00443 | 0,0009 |
| 2 by 3 | 0,14313 | 0,03784 | 3,78229 | 0,001633 | 0,06291 | 0,2234 |

**Fig. 4.** Estimates of regression coefficients based on uncoded raw factor values

$U_y$ = 23.537 V, $h_3$ = 2,5 V.

Zero resistance values used in the voltage divider circuit (at normal temperature):

$R_1$ = 100 Ohm; $R_2$ = 1.58 kOhm; $R_3$ = 420 Ohm; $R_4$ = 650 Ohm; $R_5$ = 5.2 Ohm.

Once you have these values, you can start modeling in NI Multisim.

Let us simulate the battery emulator circuit shown in Fig. 2.

Let us set the number of repeated experiments $m$ = 3. This is necessary to check the model for adequacy.

Then, we fill in the matrix of the experiment $N$ = 8, presented in Table 1. Data analysis will

**Table 1.** Matrix of the experiment

| № | № of exper. | $X_1$ | t, °C | | | | | | $X_2$ | $U_{in}$, V | $X_3$ | $U_y$, V | $U_{out}$, V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | t, °C | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_5$ | | | | | |
| 1 | 1 | – | –10 | 98.95 | 1563 | 415.59 | 647.725 | 5.182 | – | 22.406 | + | 25.037 | 24.04 |
| 2 | 2 | – | –10 | 98.95 | 1563 | 415.59 | 647.725 | 5.182 | – | 22.406 | + | 25.037 | 24.521 |
| 3 | 3 | – | –10 | 98.95 | 1563 | 415.59 | 647.725 | 5.182 | – | 22.406 | + | 25.037 | 23.559 |
| 4 | 4 | – | –10 | 98.95 | 1563 | 415.59 | 647.725 | 5.182 | + | 24.406 | + | 25.037 | 25.981 |
| 5 | 5 | – | –10 | 98.95 | 1563 | 415.59 | 647.725 | 5.182 | + | 24.406 | + | 25.037 | 26.501 |
| 6 | 6 | – | –10 | 98.95 | 1563 | 415.59 | 647.725 | 5.182 | + | 24.406 | + | 25.037 | 25.461 |
| 7 | 7 | + | 50 | 99.65 | 1574 | 418.53 | 651.625 | 5.213 | – | 22.406 | + | 25.037 | 24.062 |
| 8 | 8 | + | 50 | 99.65 | 1574 | 418.53 | 651.625 | 5.213 | – | 22.406 | + | 25.037 | 24.543 |
| 9 | 9 | + | 50 | 99.65 | 1574 | 418.53 | 651.625 | 5.213 | – | 22.406 | + | 25.037 | 23.581 |
| 10 | 10 | + | 50 | 99.65 | 1574 | 418.53 | 651.625 | 5.213 | + | 24.406 | + | 25.037 | 25.655 |
| 11 | 11 | + | 50 | 99.65 | 1574 | 418.53 | 651.625 | 5.213 | + | 24.406 | + | 25.037 | 26.168 |
| 12 | 12 | + | 50 | 99.65 | 1574 | 418.53 | 651.625 | 5.213 | + | 24.406 | + | 25.037 | 25.142 |
| 13 | 13 | – | –10 | 98.95 | 1563 | 415.59 | 647.725 | 5.182 | – | 22.406 | – | 20.037 | 21.065 |
| 14 | 14 | – | –10 | 98.95 | 1563 | 415.59 | 647.725 | 5.182 | – | 22.406 | – | 20.037 | 21.486 |
| 15 | 15 | – | –10 | 98.95 | 1563 | 415.59 | 647.725 | 5.182 | – | 22.406 | – | 20.037 | 20.644 |
| 16 | 16 | – | –10 | 98.95 | 1563 | 415.59 | 647.725 | 5.182 | + | 24.406 | – | 20.037 | 21.059 |
| 17 | 17 | – | –10 | 98.95 | 1563 | 415.59 | 647.725 | 5.182 | + | 24.406 | – | 20.037 | 21.48 |
| 18 | 18 | – | –10 | 98.95 | 1563 | 415.59 | 647.725 | 5.182 | + | 24.406 | – | 20.037 | 20.638 |
| 19 | 19 | + | 50 | 99.65 | 1574 | 418.53 | 651.625 | 5.213 | – | 22.406 | – | 20.037 | 21.098 |
| 20 | 20 | + | 50 | 99.65 | 1574 | 418.53 | 651.625 | 5.213 | – | 22.406 | – | 20.037 | 21.52 |
| 21 | 21 | + | 50 | 99.65 | 1574 | 418.53 | 651.625 | 5.213 | – | 22.406 | – | 20.037 | 20.676 |
| 22 | 22 | + | 50 | 99.65 | 1574 | 418.53 | 651.625 | 5.213 | + | 24.406 | – | 20.037 | 21.775 |
| 23 | 23 | + | 50 | 99.65 | 1574 | 418.53 | 651.625 | 5.213 | + | 24.406 | – | 20.037 | 22.211 |
| 24 | 24 | + | 50 | 99.65 | 1574 | 418.53 | 651.625 | 5.213 | + | 24.406 | – | 20.037 | 21.34 |

be performed using the Statistica program.

Next, we calculate the estimates of the regression coefficients based on the coded initial values of the factors; the result is shown in Fig. 3.

The regression equation for the coded values of factor levels has the form:

$$\delta = 23.09192 + 0.52567 \times X_2 + 1.84258 \times X_3 + 0.35783 \times X_2 X_3 .$$

Below are estimates of the regression coefficients that are on non-coded primary factor values (Fig. 4).

In the column, Regressn Coeff. (Fig. 4) estimates of regression coefficients are found based on uncoded original factor values. The regression equation for uncoded values of factor levels has the form:

ANOVA; Var.:Uвых; R-sqr=,95986; Adj:,94569 (Spreadsheet5)
2**(3-0) design; MS Pure Error=,2148147
DV: Uвых

| Factor | SS | df | MS | F | p |
|---|---|---|---|---|---|
| (1)t | 0,07437 | 1 | 0,07437 | 0,3462 | 0,564482 |
| (2)Uвх | 6,63181 | 1 | 6,63181 | 30,8722 | 0,000043 |
| (3)Uy | 81,48272 | 1 | 81,48272 | 379,3164 | 0,000000 |
| 1 by 2 | 0,04217 | 1 | 0,04217 | 0,1963 | 0,663656 |
| 1 by 3 | 0,41607 | 1 | 0,41607 | 1,9369 | 0,183056 |
| 2 by 3 | 3,07307 | 1 | 3,07307 | 14,3057 | 0,001633 |
| Lack of Fit | 0,39887 | 1 | 0,39887 | 1,8568 | 0,191868 |
| Pure Error | 3,43703 | 16 | 0,21481 | | |
| Total SS | 95,55611 | 23 | | | |

**Fig. 5.** Checking the adequacy of the model

$$K = 69.50628 - 2.72807 \times U_{in} - 2.57803 \times U_{y} + 0.14313 \times U_{in}U_{y}.$$

To check the adequacy of the resulting model, a table was obtained, shown in Fig. 5.

$F_{cr} > F_{culc}$ (2.74 > 1.8568). Therefore, the resulting model is adequate.

The NI Multisim circuit simulation program was chosen, the battery emulator block was modeled. An experiment was carried out on the model, the result of which was a mathematical regression model of the battery emulator.

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## Разработка и исследование контрольно-измерительного стенда проверки изделия СКАТ-2400И7

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**Ключевые слова и фразы:** блок питания; измерительный стенд; контроль параметров; СКАТ-2400И7.

**Аннотация.** Целью современных предприятий является повышение производительности, эффективности, скорости и качества, что приведет к большей конкурентоспособности компаний. При этом возникает необходимость в быстрой и точной проверке характеристик производимых устройств. Для достижения этих целей применяются стенды измерения и контроля параметров. В основе этих устройств, как правило, лежит микроконтроллер, который выполняет роль главного элемента. Он с помощью аналого-цифрового преобразователя осуществляет измерение контролируемой величины и сравнивает с заранее заданной. На основе этих данных он делает вывод о погрешности этого параметра. Целью данной работы является разработка и исследование контрольно-измерительного стенда проверки изделия СКАТ-2400И7. Это устройство является источником вторичного электропитания систем охранно-пожарной сигнализации, систем видеонаблюдения и других потребителей с напряжением питания 24 В постоянного тока и токами потребления 4,5 А, а также резервного питания устройств с током потребления до 5 А.

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UDK 658.56

# Management of University Educational Activities in the Quality Management System

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**Key words and phrases:** quality; TQM; quality of education; quality management system; university; quality management.

**Abstract.** Currently, the competitiveness of the university is determined by the quality of its services and the economic efficiency of its activities. The purpose of the article is to substantiate a possible system of forming the competitiveness of the university through an assessment of the quality of the educational process in it. The hypothesis of the study is based on the assumption that the required competencies of university graduates as future world-class specialists can be achieved only with close interrelation and interaction of all levels of the QMS. The methods used are system analysis, synthesis, analogy, generalization, classification. The importance of the university's education quality management system is shown, its main characteristics and functions are considered, internal and external “consumers” of university services are highlighted, namely students, enterprises of the real sector of the economy and the state (as the main customer).

## Introduction

The role of higher education in general, and universities in particular, is one of the fundamental ones in the development of society, opening up new horizons of knowledge for students, the opportunity to express themselves, make new discoveries, broadcasting them to the world scientific community. The key feature of the modern stage of society's development is that fundamental science and education dictate to entrepreneurs the directions of production development [1]. A student who receives a high-quality higher education is able to become a high-level specialist in his chosen field, and the success of enterprises and, consequently, the country's economy will depend on this. It is obvious that highly qualified personnel will be in demand as specialists at the enterprises of future employers.

For effective management of education, it is necessary to follow modern world trends and modernize it in a modern way. The reform of the education system can be based on the application of the principles of Total Quality Management (**TQM**) in the educational activity management system. TQM is the basis of the idea of producing high-quality products and services, thanks to which the quality of products (services rendered) increases, and the costs of its creation decrease, since everything happens in balance and costs are minimized as much as possible.

Product quality management and production processes, and the process of educational activity, including, is carried out cyclically and contains certain stages, the totality of which makes up the Deming cycle [2]. These stages of process improvement include the following stages such as planning, action, verification, adjustment. At the last stage, a decision is made to use, for example, the chosen educational methodology in the educational process, or to refine it. With a positive result, the methodology is accepted and planned to be used in the process of teaching students, with a negative result, it requires working out all the points first, taking into account the comments and clarifications put forward in the previous paragraphs.

## University QMS

The quality management system (**QMS**) at the university is designed to solve problems to increase its competitiveness and consists of a complex of various processes. The main directions for development are the main components of the competitiveness of the university, such as the level of technology used in the university, the number of employed graduates in the specialty, etc.

The QMS of the university must constantly and continuously support the effective flow of the educational process. An effective process can be called one in which the quantity and quality of the results obtained justifies the resources spent on it. At the university, this implies a full payback of the costs allocated for the creation of a quality management system.

The quality of higher education is a multidimensional concept that differs from the definition of “quality” in the production process. This concept covers all aspects of the university's activities, such as educational and academic programs, research activities, teaching staff, material and technical base, etc. The "consumers" of higher education services are students receiving education, enterprises of the real sector of the economy, for which highly qualified personnel are trained, and the state as the main customer of the results of the educational process.

Then the quality of education is a set of properties and characteristics of educational services that meet the needs for knowledge and professional skills, and quality management of education is a process, as a result of which the needs of all “consumers”, i.e. students, enterprises and the state will be satisfied.

The following provisions form the basis of the quality system concept at the university [3].

1. One should not be responsible and take on tasks that the system cannot perform in any way. The quality system should ensure only the fulfillment of those tasks that the management system is able to solve.

2. It is impossible to achieve success with the efforts of only one participant in the process. As quality improvement takes place in the form of a complex structured system, so the interested participants in the process constitute a system that has one goal and a joint path to achieve it.

The development of the QMS is based on the following principles.

## Customer orientation

To maintain its position in the market of services, each educational institution must take into account the demand of its “consumers”, take into account even small wishes and serious requirements. Organizations that fully satisfy the consumer receive great benefits, as they become interesting for a larger circle of those who want to gain knowledge. In the education model, it is necessary to understand that the “consumers” of this sphere are divided into two types: internal and external. External consumers are various organizations that students enter to continue their studies and improve their qualifications, or companies that a person comes to work directly after studying at the university. Internal consumers are the students themselves who study at the university, gaining new knowledge and professional skills.

### Leadership

The person holding the position of manager must provide a number of actions to ensure the workflow. A number of such tasks include:

- ensuring the unity of the direction of the organization's work, setting a single goal (will create an environment that engages in the process, which will definitely lead to the achievement of the company's goals);
- formation of a friendly and positive atmosphere around the workflow (will create a favorable environment, raising the overall spirit of the team);
- fair encouragement of employees for their actions, as well as timely training and professional development of employees.

### Employee engagement

Despite any profit, for a product of any quality, the company's employees are a huge value for the organization, so it is necessary, as mentioned in the previous paragraph, to fairly encourage and stimulate the development of their further professional growth. A conscious understanding by employees of the possibilities of meeting their needs, the adoption of a common system of values and participation in the decision-making process for the implementation of the common goals of the university increases the responsibility of staff for ensuring high quality work.

### Process approach

Almost always, in order to execute one process and get the output data, we first need to execute another process, the output of which will be the input for another process, larger and more important. Based on this, organizations should find such related processes and manage them efficiently. In this case, the organization's activity can be considered as a process, and based on the document MS ISO 9000:2008, where such separation and linking of processes is called a process-oriented approach, we can consider each process as a system.

The sequence of processes, as well as their number, is calculated based on the organizational structure, with the participation of logical analysis, the identification of a group of functions that are part of other, more significant functions is performed. This identification is carried out by the executor of these functions, and then documented with the appointment of an executor who has a high reputation among employees and has the necessary qualifications.

### A systematic approach to management

The identified interrelated processes optimize the workflow, achieving the fulfillment of the task, improves the efficiency of everyday work goals. Also, the system approach brings continuous progress in terms of system modernization with such tools as assessment and measurement.

### Continuous improvement

The process of improving the quality of products (services provided) and optimizing the QMS should be systematic and constant, as new technologies appear over time that improve optimization at the enterprise, as stated in the ISO 9000:2008 standard.

### Conclusion

Thus, the description of the principle of creation, development and implementation of QMS in universities allows you to determine the scope of work on their practical implementation. The reason for the need to implement the principles of TQM lies in the main task of modern training systems: improving curricula, improving the quality of educational services to meet the needs of society and training highly qualified specialists capable of being competitive in the market and meeting the needs of enterprises in the real sector of the economy.

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## Управление образовательной деятельностью университета в системе менеджмента качества

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**Ключевые слова и фразы:** TQM; качество; качество образования; система менеджмента качества; университет; управление качеством.

**Аннотация.** В настоящее время конкурентоспособность университета определяется качеством предоставляемых им услуг и экономической эффективностью деятельности. Целью статьи является обоснование возможной системы формирования конкурентоспособности университета через оценку качества образовательного процесса в нем. Гипотеза исследования строится на предположении о том, что высокий уровень требуемых компетенций выпускников университетов как будущих специалистов мирового уровня может быть достигнут лишь при тесной взаимосвязи и взаимодействии всех уровней системы менеджмента качества. Применяемые методы: системный анализ, синтез, аналогия, обобщение, классификация. Показана важность системы менеджмента качества образования университета, рассмотрены ее основные характеристики и функции, выделены внутренние и внешние потребители услуг университета, а именно студенты, предприятия реального сектора экономики и государство (как основной заказчик).

UDK 658.56

# Quality Management of Life Cycle Processes of Scientific Products and Services at University

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**Key words and phrases:** quality; quality management system; university; quality management; scientific activity; product life cycle.

**Abstract.** The purpose of the article is to study the planning and management of scientific activities of the university at the stages of the life cycle of products and services. The hypothesis of the study is based on the fact that the assessment of the quality of the service provided is a long-lasting process and covers all stages of the life cycle. For an adequate description of this process and its management, the question of the stages of the service life cycle in the quality management system becomes relevant. The methods used are system analysis, synthesis, analogy, generalization, classification. The sequence of stages of the life cycle of services resulting from scientific activities (scientific and technical products, research services, etc.) is considered., the requirements for products and services are analyzed.

When forming a quality management system for the scientific activity of the university, as for any other service, it is necessary to take into account the fact that the description of the service as a static model is incorrect. Any service, including research, should be properly considered in the dynamics of its creation, that is, in the process of its provision. In this regard, the assessment of the quality of the service provided is a time-consuming process that covers all stages of the life cycle. For an adequate description of this process and its management, the question of the stages of the service life cycle in the quality management system (**QMS**) of the university becomes relevant.

For the effective management of the scientific activity of the university, the issue of the introduction of QMS processes in accordance with the requirements of GOST R ISO 9001 [1] and additional requirements of GOST RV 0015-002 [2], their sequence and interrelation, risks and resources necessary for the production of scientific and technical products and services in accordance with the requirements of regulatory documents, the university's own requirements, issued in the form of local regulations, and external suppliers.

The product lifecycle is a set of the following stages: defining requirements for products and services; designing and developing products and services; managing processes, products and services supplied by external suppliers; manufacturing products and providing services; verifying the output of products and services; managing inappropriate process results.

The description of the activity for each process in accordance with the QMS is a process map and contains:

– the name and code of the process according to the functional scheme of the QMS approved by the university;
– position of the process activity manager (process owner);
– the purpose of the process aimed at fulfilling the obligations under the contract;
– names of input and output data (material and information flows);
– process participants (suppliers and consumers);
– the name of the control actions on the process in the form of references to the internal documents of the university used (procedures, standards, regulations, instructions, methods, etc.);
– list of resources required to support the activities of the process (organizational/personnel, information, financial and technical support);
– process performance indicators for monitoring processes, methods of their measurement and analysis.

Each process is aimed at achieving the set goals and is associated with the final indicators, which are used to verify the results of the university's activities as a whole. To assess the compliance of the QMS with the established requirements, methods of monitoring and evaluating the activities of processes are used, which are designed to demonstrate the ability of processes to achieve planned results, that is, determine the actual results in comparison with the planned ones.

When assessing the effectiveness of the QMS, activities aimed at achieving quality results/goals, identifying processes and resources to achieve them, taking into account risks and opportunities, are considered. These assessments make it possible to trace the dynamics of development and improvement of activities by processes over time.

Consider the requirements in products and services provided by the university in the framework of its scientific activities. The interaction of the university with consumers of the results of scientific activity (scientific and technical products, research services, etc.) is carried out on the basis of the current contract on the performance of scientific research.

The opportunities and risks of the work can be carried out at the pre-contractual stage at the request of the customer on the basis of the terms of reference or the draft contract, including by holding meetings with representatives of the customer. The data necessary for the contractor to carry out the activity is transmitted by the customer independently or upon request and checked by the contractor's specialists performing the relevant work.

In order to study the requirements and satisfaction with products and services, the work manager determines the necessary measures to maintain communication with the customer.

The main requirements for the development of a project document are determined by:

– compliance of the document being checked with the source data and the task for its implementation;
– the presence (and compliance) of requirements for the control of technological processes in working drawings and other documents;
– the correctness of the implementation of specifications related to the project document under review;
– the correctness of specifying dimensions, parameters, projections, sections, sections, types, materials;

– compliance of the manufactured prototype with the requirements of state standards, technical specifications, technical documentation and terms of the contract;

– sufficiency of theoretical and experimental study of design solutions;

– the correctness of the technical decisions taken when making changes;

– study of the customer's requirements for delivery and post-delivery activities;

– studying the competitive environment;

– study of legislative and other mandatory requirements applicable to services and products.

The working group performing work under the contract performs input control of the source data/documents of the organizations participating in the work under the contract; control of project documents during the design process, including self-verification performed by the developer of the project document, before technical control. The control of the development of project documents is carried out using a differentiated approach in the development and implementation of quality assurance methods.

In order to ensure the confidence of the university management in the successful and correct activities of employees and the satisfaction of interested parties, to demonstrate the compliance of project documents /services provided by the university with the established requirements, monitoring (observations), collection and analysis of data on the compliance of activities under the contract with the established requirements is carried out.

For this purpose, the work manager carries out activity planning; identification of information collection points; analysis of the data received; determination of resources for work; registration of analysis results; use of analysis results for the development of improvement measures.

When the requirements for products and services change, the work manager ensures that changes are made to the relevant documented information and notifies the employees involved in the project.

Amendments to the project documentation are carried out in accordance with the regulatory document established in the contract:

– in a planned manner – according to the results of standard control, technical control, self-verification and audit;

– in an unplanned manner (at the request of the customer);

– when making changes to contractual obligations;

– when changing the applicable rules and regulations in the field of quality;

– when making significant changes to the organizational structure of the university;

– when significant discrepancies are identified during internal or external audits (audits);

– when identifying inconsistencies related to the quality of project documents;

– for other reasons that require an unscheduled review.

Changes to documents developed at the university are carried out by the same working group that developed the original documents. The modified documents undergo the same procedure of approval, approval and distribution as the original documents. The same control methods are applied to the project documents that have been amended as to the original project documents. The distribution of the modified documents is carried out in the same quantity, to the same organizations and departments as for the original documents. If a change in one document affects other documents, then these documents should be adjusted accordingly. Changes are registered in the change registration sheet and agreed with the customer.

Thus, on the example of a university, the sequence of stages of the life cycle of services that are the result of scientific activity (scientific and technical products, research services, etc.) is considered. Special attention is paid to the planning and management of scientific activities and the analysis of requirements for products and services.

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## Управление качеством процессов жизненного цикла научной продукции и услуг в вузе


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**Ключевые слова и фразы:** качество; система менеджмента качества; университет; управление качеством; научная деятельность; жизненный цикл.



**Аннотация.** Целью статьи является исследование планирования и управления научной деятельностью вуза на стадиях жизненного цикла продукции и услуг. Гипотеза исследования строится на том, что оценка качества оказываемой услуги представляет собой процесс, продолжительный во времени и охватывающий все этапы жизненного цикла. Для адекватного описания данного процесса и управления им актуальным становится вопрос об этапах жизненного цикла услуги в системе менеджмента качества. Применяемые методы: системный анализ, синтез, аналогия, обобщение, классификация. Рассмотрена последовательность этапов жизненного цикла услуг, являющихся результатом научной деятельности (научно-технической продукции, научно-исследовательских услуг и др.), проанализированы требования к продукции и услугам.


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UDK 004

# Problems of Automatic Recognition of Human Characteristics for Management and Security Purposes

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**Key words and phrases:** face image; analysis; emotion recognition; automatic program; algorithm; emotions; phase portrait; facial asymmetry; video-computer psychodiagnostics; management.

**Abstract.** The article compares the photo recognition programs "PORTRAIT Super" and "Emotion-API" from Microsoft. Errors in the evaluation of emotions by automatic programs are considered. The principle of recognition of human qualities is shown by determining relative values – determining the phase portrait of a face, using difference algorithms and their derivatives. Evidence is given that emotion is a qualitative sign that cannot be recognized through physiognomy, since the shapes and sizes of facial features contain only quantitative information, from which it is impossible to determine the quality. Examples are given that confirm the advantages of the method of video-computer psychodiagnostics in recognizing emotions from a face image.

In recent years, much attention has been paid to the automation of human face image recognition in order to identify a person or recognize emotions on a face in order to determine the psychological state of a person. The relevance of this issue is related to the solution of problems of anti-terrorism, security, personnel management, as well as in medicine and psychology.

The most effective tool for recognizing emotions in a human face image is a Microsoft development called the "Emotion API" [6]. With the help of this software, the following emotions are recognized in a few seconds: Anger, Contempt, Disgust, Fear, Happiness (joy), Neutrality (calmness), Longing, and Surprise.

In this article, the method of recognizing emotions from Microsoft is compared with the method of video-computer psychodiagnostics (**VCP**) [1–5]. The difference between these methods is that the Emotion-API program (Microsoft) is based on physiognomy – the shapes and sizes of facial features and reacts to grimaces, and not to the psychological state of a person.

The method of video-computer psychodiagnostics is based on the asymmetry of the cerebral hemispheres, which is reflected as asymmetry of the face. It has been established that the psychological state of a person depends on two parameters: the dominance of one of

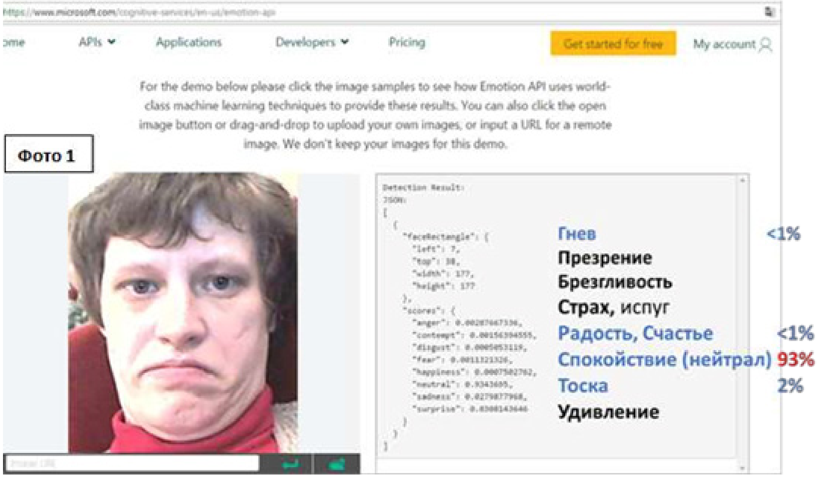


**Fig. 1.** The result of the diagnosis of the psychological state according to photo 1

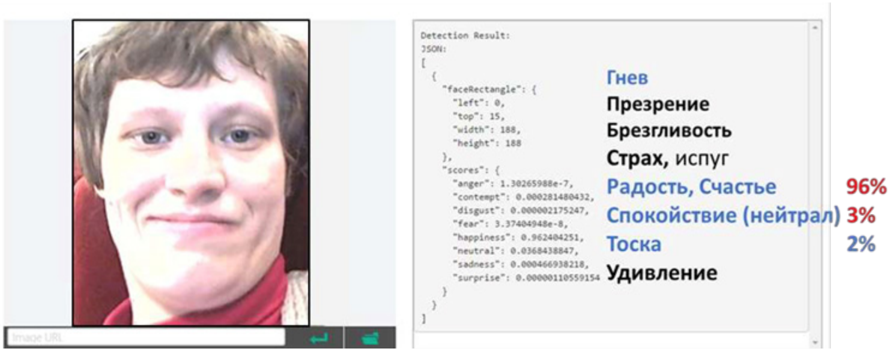


**Fig. 2.** The result of the condition diagnostics according to photo 2

the hemispheres of the brain and the consistency of oscillatory processes between them. [1] These parameters can be determined in the optical range by the computer program "PORTRAIT Super" by calculating the difference in angles between the features of the right and left halves of the person's face. By analyzing two synthesized portraits, composed of two right and two left halves of the image of his face and screen, the computer determines the psychological state of the person at the current moment. The degree of asymmetry of the face and emotions is preserved when facial expressions change, so this method is more resistant to interference.

To compare the effectiveness of the programs "Emotion-API" (Microsoft) and "PORTRAIT Super" (implemented on the basis of the VKP method), the following 4 emotions were chosen: Longing, Joy (happiness), Anger, and Calmness.

Below is a comparison of the results of recognizing the properties of a person from the image of his face. For the experiment, 2 photographs of a woman were selected. It is known in advance that her psychological type is "Choleric" and she has the ability to get angry periodically. In photo 1, she is in her usual state, i.e. she does not represent anything in particular. In photo 2, she makes a grimace – she smiled at our request.

The Microsoft program (Emotion-API) determines her state in photo 1 as follows: Calm (Neutral) 93 % – the maximum value, Happiness < 1 % (less than one percent) – the minimum value. These results are presented in Fig. 1.

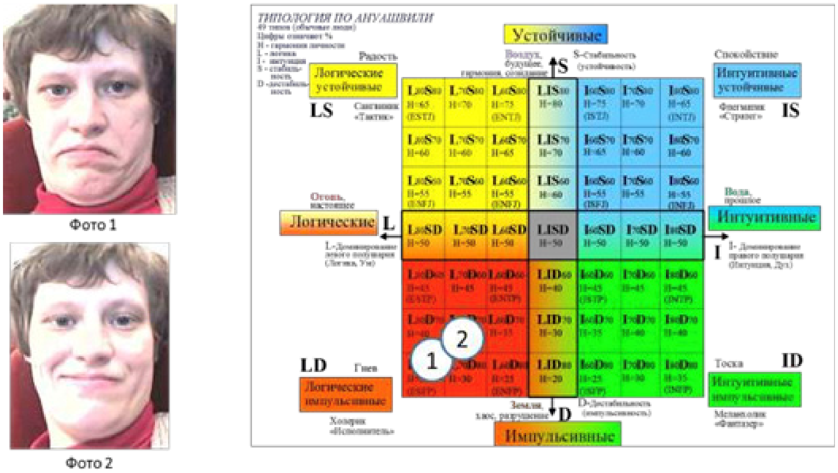


**Fig. 3.** The result of the diagnosis of Photo 1 and Photo 2

In photo 2, the woman changed her facial expressions – she smiled deliberately.

This time, the Emotion-API program determines its state as follows: Calmness (Neutral) = 3 % is the minimum value, Happiness = 96 % is the maximum value.

Thus, the Microsoft program reacts to changes in facial expressions and cannot determine the qualitative state of a person: a person cannot become 96 % happy in one minute, while before that happiness was less than 1 %. At the same time, peace of mind is lost from 93 % to 3 %. Happiness is an inner state of quiet joy (harmony). Therefore, happiness can be combined with calmness.

The same photographs were examined using the VCP method based on the brain wave model. The "PORTRAIT Super" program in both photographs defines the state of this person in the same way, as a "Logical impulsive" psychological type, which corresponds to "Choleric" (Fig. 3).

The VCP method does not take into account the shape and size of facial features and, therefore, does not respond to grimaces and facial expressions. The method is based on the asymmetry of the face – on the calculation of the difference in the angles of inclination of the eyes, nasolabial folds and lips on the left and right sides of the face, as well as the average angles between them [3].

Below is the result of the analysis of the above photographs. The following notation is adopted here:

- $a_{r1}$ is the angle of inclination of the right eye in the 1st photo from the horizontal;
- $a_{l1}$ is the angle of the left eye in the 1st photo;
- $\Delta a_{l1} = a_{r1} - a_{l1}$ is the difference in inclination angle between the right and left eye.

Similar designations apply for lips (β) and for the nasolabial fold (γ). Similarly ones apply for photo 2. These designations are shown in Fig. 4.

It is easy to see that the left side of the face is tilted more in both the 1st and the second photo. The change in facial expressions did not affect the asymmetry of the face. Facial asymmetry is stable and practically does not depend on facial expressions.

Thus, the Microsoft Emotion-API program, which is considered the best in the world, is easily fooled. This program cannot recognize emotions (for example, happiness), because emotion is a qualitative sign and cannot be recognized by analyzing the shapes and sizes of facial features. The shapes and sizes of facial features contain only quantitative information,

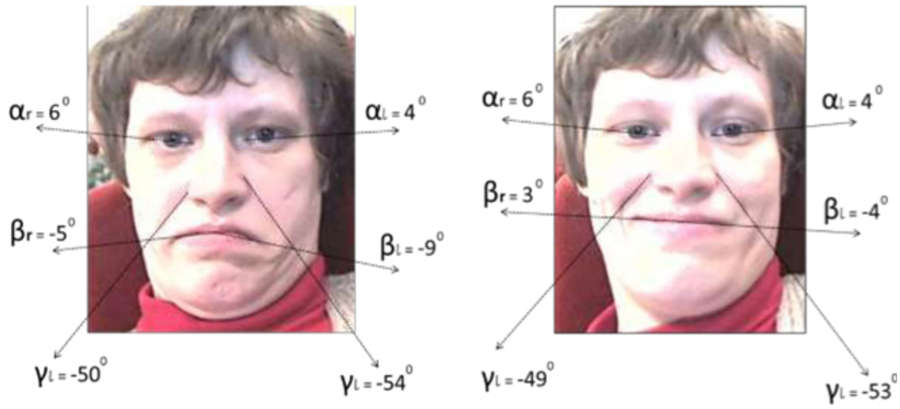


**Fig. 4.** The result of the diagnosis of Photo 1 and Photo 2 using the VCP method

from which it is impossible to infer quality. The quality of a person can only be recognized by determining relative values, for example, by determining the phase portrait of a face, using difference algorithms and their derivatives.

The scientific problem is to create a tool for remote automatic recognition of a person by the image of his face. It is necessary to distinguish between two tasks: identifying a person and recognizing the qualities of a person.

When identifying, there is a database that contains photographs of persons with a known biography. The received image is compared with the base and the similarity is determined. In this way, the person can be identified. The task of automatic identification has been successfully solved and is used in security systems.

When solving the problem of recognizing the psychological state of a person, there is no database of photographs, so identification does not occur. It is necessary to recognize the quality of a person. In this case, there are also standards, but they are theoretically (mathematically) compiled and classes are formed. According to the signs on the face, this person must be attributed to one of the classes. For this, physiognomy is usually used – an analysis of the size and shape of facial features. But this is a dead end: in the sizes and shapes of facial features there is no information about the quality of a person. Moreover, there is no such information in direct physical measurements. It exists in relative terms, in higher derivatives – the phase portrait of the face and brain. But even in this case, a fully automatic system does not work reliably. Therefore, in practice, semi-automatic systems based on the method of video-computer psychodiagnostics are currently used.

In general, it must be said that the problem of automatic recognition has not yet been solved. It is needed to solve anti-terrorist tasks: it is advisable to install such systems in public places, in the subway, airports in order to single out socially dangerous people from the crowd. The most intensive work on this problem is being carried out in the United States and Israel: certain systems have been installed at airports, but the task of automatically recognizing dangerous faces has not yet been solved.

Using the VCP method, you can solve the problems of personnel management, predicting human behavior in extreme conditions, checking personnel, determining professional suitability, team building, health improvement, psychocorrection, etc. The VKP method allows you to determine the main properties of the person under study, including his professional inclinations and reliability. Professional reliability refers to the psychological comfort of a person in the performance of their work. It does not refer to human ability. It is assumed that this person has the ability and therefore works in this profession. However, having the ability does not mean comfortable. If the work is comfortable, then the person does not get tired. If a person experiences psychological discomfort in the performance of his professional duties, then he will get tired. The lower the comfort is, the greater the fatigue is. If a person gets tired all the time at his job, then his professional reliability falls. Professional reliability is determined by the probability of psychological comfort when performing various kinds of work.

All these tasks do not require a fully automatic system for recognizing the quality of a person from the crowd; however, such a task has yet to be solved by the world scientific community.

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## Проблемы автоматического распознавания эмоций в целях управления: сравнение программ PORTRAIT-Super и Emotion-API

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**Ключевые слова и фразы:** автоматическая программа; алгоритм; анализ; асимметрия лица; видео-компьютерная психодиагностика; изображение лица; распознавание эмоций; управление; фазовый портрет; эмоции.

**Аннотация.** В статье приведено сравнение программ распознавания фотографий PORTRAIT Super и Emotion-API от Microsoft. Рассмотрены ошибки в оценке эмоций автоматическими программами. Показан принцип распознавания качеств человека путем определения относительных величин – определения фазового портрета лица, применения разностных алгоритмов и их производных. Приведены подтверждения, что эмоция – это качественный признак, который невозможно распознать через физиогномику, поскольку

формы и размеры черт лица содержат лишь количественную информацию, из чего невозможно определить качество. Приведены примеры, подтверждающие преимущества метода видео-компьютерной психодиагностики при распознавании эмоций по изображению лица.

UDK 005.94

# Social Networks as a Tool for Business Development in Russia

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**Key words and phrases:** social networks; e-commerce; online communications.

**Abstract.** Information technologies and new means of communication, such as electronic networks, have made a decisive contribution to the formation of a virtual environment for business development. New forms of relationships between organizations and the external environment through Internet technologies are today the subject of study by economists. Interest in business social networks has increased significantly in recent decades due to the greater effectiveness of brand promotion and profit generation. The article discusses the features of social networks as a tool for business development in Russia.

The implementation of technologies for interacting with customers in the Internet space is becoming more accessible, allowing you to extract significant profits from the use of new business models. E-commerce and online shopping generate profits and reduce costs. Many companies are creating new channels using digital network technologies.

Statistics in the field of application of information and communication technologies show the dynamics of the digitalization process in the Russian Federation, so the share of organizations that have broadband access to the Internet increased from 31.0 % to 86.6 % over the period from 2007 to 2019, the daily Internet use by 20 % [1].

The volume of the e-commerce market in Russia shows significant growth, so in 2021 it amounted to 4.0 trillion rubles, which is 29.0 % more than in the previous year. Also, online sales in retail turnover in Russia as a whole in 2021 increased by 2.5 p.p. and amounted to 8.3 % [2]. Business accounts have become a powerful marketing tool over the past decade.

Online shopping portals provide numerous benefits to traditional retailers in terms of marketing collaboration, website traffic generation, website management, order fulfillment services, and the ability to offer customers omnichannel retail.

For companies, new online tools that influence consumer buying behavior are becoming more competitive and sophisticated. The reason for the increased interest of business in social networks is a large number of users, low costs for demonstrating goods, and the possibility of individualizing appeals to various groups of buyers.

The business community is increasingly looking into social media as an effective and versatile marketing tool that brings significant benefits. Most often, social networks are used as advertising platforms, because. the possibility of access to targeted advertising tools is much higher here. Social networks also play a big role in brand promotion. A social network can act as a platform for communication with the target audience to form public opinion, as well as an Internet space for selling goods and services.

Castells [3] defines networks as open structures that can expand indefinitely by integrating new parts as long as they can communicate on the network using the same communication codes. Connections linking networks are instruments of power, i.e. connectors control the rules of the network.

Virtual networks are based on the union and connection of individuals, supported by mediated and directed norms, values and protocols. Virtual communities allow the exchange of information such as opinions, knowledge and experience. This exchange generates a network of interactions between people, and, despite its informal nature, the consequences of these interactions can be felt in other areas, such as the relationship of individuals with the state, with other institutions and society.

These communities are formed in so-called social networks, which are online communication platforms that provide greater reach as a marketing tool. This happens mainly due to reposts made by users [4]. Social networks are formed by groups of applications hosted on the Internet using compatible technologies that allow users to share information of interest to them, being a powerful source of information, communication and online distribution, thus causing interactivity [5].

The structure of social networks is decentralized, dynamic and flexible, established through collaboration and horizontal relationships. Its main features are: participation, as it encourages contributions and feedback from any user; the interest and openness of networks is achieved by encouraging user interaction through opinions, comments and information exchange. While traditional media works by distributing content, social media is about feedback as community allows people with common interests to quickly communicate on a topic; connectedness, as most social networks collect various types of media and information in one place.

Two classic models of brand promotion are SMM and SMO [6]. SMM (Social Media Marketing) is the promotion of a company's services or brand using social media marketing, communication with the target audience through social resources. With the help of SMM, it is possible to attract user traffic without search engines immediately, directly. Social Media Marketing has a wide scope: social networks, blogs, forums, media resources, online communities.

The SMO (Social Media Optimization) model represents actions to perform certain technical work that increase the effectiveness of site communications with social systems. Website optimization allows the integration of content with social platforms.

Information about consumer behavior is extremely important for the functioning of Internet commerce, as it allows those who offer a product or service to better understand the tastes of their buyer. This helps in identifying the various marketing activities of these companies that can use information from their customer history [7].

Classically, the value attached to the consumer was related to the expected profit that he could represent. However, this view overlooks the fact that the consumer, in addition to buying, can be a distributor, influencing other consumers to buy or not buy a product [8]. This new vision of the consumer as a critical success factor has revolutionized marketing, especially with the advent of the Internet, which has greatly facilitated the exchange of experiences and opinions between people. These changes in marketing, driven by the digital context, enable companies to more effectively recognize and reach target markets faster, more accurately, and more efficiently, while also driving customer development and retention.

Social media campaigns can generate content that builds brand loyalty and commitment, increasing the likelihood that your consumers will support the company in the future. This is due to the fact that consumers are made to feel part of the process that the organization develops.

Empirical studies on the effectiveness of media advertising show that they are mostly aimed at studying the influence of advertising characteristics on its clickability [9].

Based on a review of the literature, it is clear that social media is a great channel for a company to get closer to its customers and strengthen the brand. The length of time a user stays connected, as well as how they feel about a brand, can affect their buying behavior [10].

Content related to products and services is also present on social networks, this medium allows users to leave reviews that can influence the opinions of other participants [11] this impact on users' purchasing behavior is due to the fact that the more time people spend in communication, the lower their restrictions on online purchases.

As a result, it can be concluded that the degree of social media interactivity between a brand and consumers can be an important differentiator for a company, even helping to reduce writers' distrust and risk perception, which improves brand positioning and reduces the likelihood of negative consequences that could damage the brand, be it slogans or misguided campaigns.

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## Социальные сети как инструмент развития бизнеса в России

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**Ключевые слова и фразы:** онлайн-коммуникации; социальные сети; электронная коммерция.

**Аннотация.** Информационные технологии и новые средства коммуникации, такие как электронные сети, внесли решающий вклад в формирование виртуальной среды для развития бизнеса. Новые формы взаимоотношений организаций с внешней средой посредством интернет-технологий сегодня являются предметом изучения экономистов. Интерес к социальным сетям бизнеса в последние десятилетия значительно увеличился в связи с большой эффективностью продвижения бренда и извлечением прибыли. В статье рассмотрены особенности социальных сетей как инструмента для развития бизнеса в России.

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# Experience of State Regulation of International Labor Migration in Mexico

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**Key words and phrases:** emigration; immigration; geographical concentration coefficient; migration movement; regulation of labor migration.

**Abstract.** The purpose of the research is to identify the main trends and directions of Mexico's state policy to regulate the flows of emigration and immigration of labor in general and individual states of the country. In accordance with this purpose, the tasks were set: to analyze the statistics of international labor migration across the states of Mexico; to identify regions with high and low levels of distribution of migrant workers; to consider migration policy and state regulation of international labor migration; to identify the main projects and programs with the participation of labor migrants and ways to solve the main problems of the government of the country. The hypothesis of the research is that Mexico has enough strong government and tools, which determines the successful regulation and control of labor immigration. Methods of statistical, comparative, analytical, mathematical and cartographic analysis, calculation of coefficients of geographical concentration of migrants in Mexico were used in the study. The information base of the research was statistical data and reports containing information about the population of Mexico and its structure, published by the Government and the Institute of Statistics of Mexico, also various scientific publications on the subject under study, official websites of Mexican institutions and other materials.

Modern Mexico is a global migration hub. Due to its proximity to its northern neighbor and entry into NAFTA, the country is characterized by record emigration to the United States. At the moment, the number of Americans living in Mexico is growing and is already 1 million people, which makes it the largest expatriate community of United States. On the other hand, there is a growing flow of illegal immigration into the country, which seeks to use the US-Mexico border as a point of entry. This stream consists of residents of the countries of the Northern Triangle of Central America: El Salvador, Guatemala, and Honduras. In addition to Central Americans seeking to enter the United States through Mexico, flows from Haiti and Cuba are sent there. In these difficult conditions, the Government of Mexico faces a complicated task of state regulation of migration flows, which can be solved only in cooperation with the migration services of the United States and Central American countries.

Since the mid-19th century, legal systems and institutional foundations in most countries have tended to support immigration, while in Mexico the first immigration law was adopted only in 1908. At that time, the country's authorities expected the arrival of a large number of immigrants, but this did not happen, since Mexico could not compete with the attractiveness of the United States in migration flows. At the beginning of the 20th century, “privileged immigration” was popular: migrants who know English, French and German preferred to choose more developed countries and countries speaking these languages for immigration. The first migration legislation in Mexico was not only introduced late, but also did not match to the scientific foundations of that time [5].

Then the Constitution was adopted, which contained a large number of guarantees in favor of Mexicans and strict restrictions for those who are not. After that, problems arose related to the ethnic structure of the population and the demands of those segments of society who said that they were hindered by the presence of immigrants. The Migration Act of 1926 prevented the dangers of social, cultural and political stratification, as well as racial degeneration of the Mexican population. This legislation established the mandatory nature of registration and documentary control of immigrants, along with various sanctions to which they will be subjected in case of violation of the current legislation [5].

In 1936 and 1947, Laws on Population were issued, which covered only partially the migration situation in the country. The main task of these laws was to regulate the demographic situation about the natural movement of the population. But thanks to these laws, racial and ethnic discrimination was eliminated in Mexico, and marriages between people of different origins were also allowed [1].

The 1960 Law assumed prior permission from the Ministry of the Interior for all foreigners to buy or acquire real property rights in order to avoid economic speculation with real property. Considering that in the 1960s the demographic explosion in Mexico was already an obvious fact, the policy of attracting workers as a means of population growth has definitely lost all meaning. The new law proposed that immigration should no longer be understood as a mechanism for increasing the population, and from now on preference was given to foreigners who could contribute to the economic and social development of the country [3].

In 1974, a new Law on Population was adopted, which is still in force with some modifications. In this law, “immigration” definitely lost its significance as a demographic variable because in the end the so-called “collective immigration”, which was traditionally encouraged, was suppressed [3].

In 2020, the number of immigrants was about 1.2 million people (of which: men – about 610 thousand people, women – about 550 thousand people), which is less than 1 % of the total population of Mexico. The feature of the immigration flow of the country is that it is dominated by Americans (72.72 %), followed by Spaniards (7.59 %), Guatemalans (3.48 %), Argentines (1.35 %) and many others (Fig. 1). The high number of Americans can be explained by the growing integration of both countries under NAFTA, as well as the fact that Mexico has become a popular place for retirement. According to the Association of American Citizens Abroad, less than 1 million US citizens live in Mexico, which is 2 % of the total population of Mexico and 25 % of all US citizens living abroad [2].

The study conducted a comparative analysis of labor migration processes in the context of the states of Mexico. The work was carried out on the basis of calculating the coefficient of geographical concentration of migrant workers in the states of Mexico and on the basis of

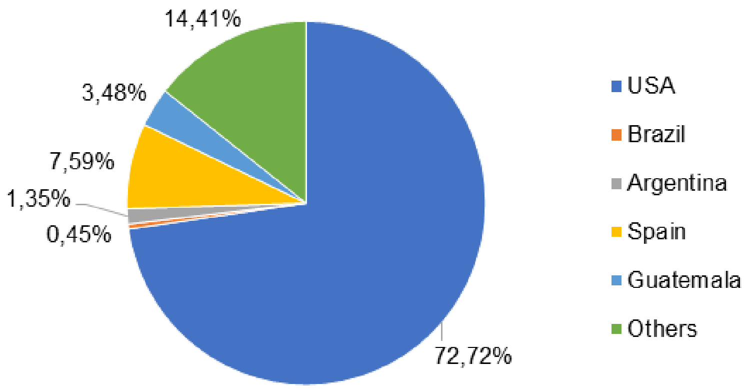


**Fig. 1.** Distribution of Mexican immigrants by country of origin, 2020. Based on data [9]

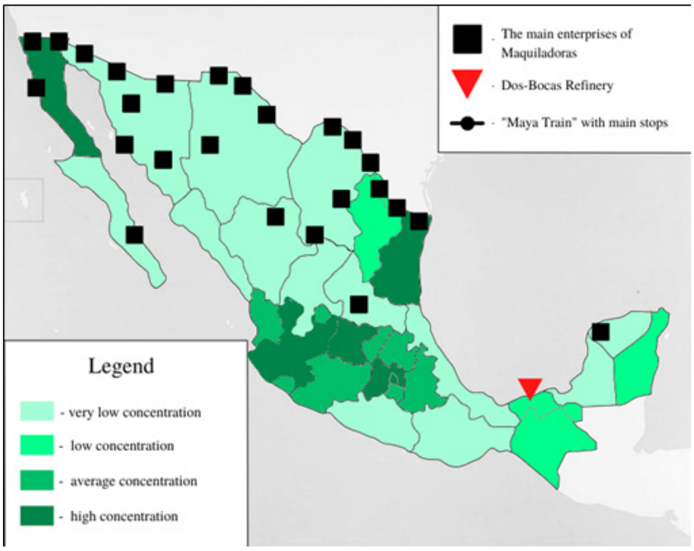


**Fig. 2.** Geographical concentration of migrant workers in the states of Mexico, the main projects and programs with their participation, 2020. Compiled on the basis of the calculations made

considering the processes of state regulation of migration movement in the states with the lowest concentration of migrant workers. The level of geographical concentration of migration is determined by the structure of the migration movement, grouped by operational territorial units. The more evenly labor migrants are dispersed throughout the territory, the lower the level of geographical concentration in the country. On average, there are 9 migrant workers per 1,000 people in Mexico [9].

According to the calculations made (Fig. 2), a very low and low concentration is observed in the north and south of the country, which indicates the uniformity of the dispersion of labor migrants across the states. The average and high concentration is characteristic of the central states and indicates, on the contrary, a low level of distribution of labor immigrants across the territory of the states. This trend is due to the fact that in the states bordering the United States, the government has created free economic zones – maquiladores. These zones are attractive not only for local residents, but also for ordinary workers and highly qualified specialists from the USA. Using a “ready-made” specialist, the country saves on education costs. Often such migrants are called “front-line workers”, as they travel to work in another country on a daily or weekly basis. In the south of the country, namely on the border with Guatemala and Belize, migrant workers are in great demand during seasonal work (agriculture, fishing, services – tourism). In the central part of the country, the uneven distribution of labor immigrants is associated with the arrival of highly qualified specialists in a small number of fields of activity such as IT technology, intellectual production, teaching and educational activities, as well as with the next "brain drain" due to lack of prospects.

To determine the preferences of migrant workers in choosing the states of Mexico for migration, a rating of the attractiveness of regions for labor migration was compiled. The study looked at such socio-economic indicators as the level of income of the labor force per capita, the level of employment of the able-bodied population, the dynamics of GRP, the amount of payment for housing conditions and the availability of medical care.

The dependence of the number of labor arrivals and the attractiveness of the states in question can be tracked using the ranking method. This method of economic analysis is an ordering of indicators relative to their positive or negative properties, which helps to evaluate them among themselves regardless of their nature. Based on the calculations made and the available statistical data, a rating of the competitiveness of the states of Mexico was compiled singly for the socio-economic indicators under consideration, as well as in common, as reflected in Table 1.

Based on the results obtained, it is worth noting that the most competitive states in attracting labor migration are the metropolitan Federal District-Mexico City and the northern states bordering the United States (Sonora, Chihuahua, Southern Baja California), followed by the states of the Pacific coast (Colima, Jalisco) and the states located in the central part of the country (Guanajuato, Aguascalientes). These states are very attractive for labor migration, because they have a developed labor market, high income indicators, and good access to medical care. The southern and southeastern states, where most of the labor force is geographically concentrated, are not the most attractive regions for immigrants to live and work. These southern states (Guerrero, Oaxaca, Morelos, Chiapas) are characterized by low economic development: high unemployment, low dynamics of the region's GDP, an undeveloped labor market.

State regulation of migration flows of labor consists in the fact that at the stage of arrival in the country, migrants are checked by the authorities. Citizens of Belize and Guatemala can get a visa for a year only to certain states of the country: Campeche, Chiapas, Quintana Roo and Tabasco (have a very low and low concentration), if there is a demand for work in these states [8].

According to the provisions of the Migration Law, foreign citizens who have already arrived in Mexico can engage in productive activities. The Government provides employment opportunities through major projects and investment programs: Sembrando Vida (extended to 20 states) – a program to eliminate rural poverty and decline in rural development. The most important projects also include the creation of free economic zones along the borders with the United States, the construction and maintenance of the further development of the tourist facility "Maya Trains" or the construction of the Dos Bocas oil refinery in Tabasco State. On the northern border of the country, the Ministry of Labor and Social Security (**STPS**) has opened an employment exchange that offers up to 50,000 jobs in the Maquiladora (export-manufacturing) and manufacturing industries (Fig. 1).

After obtaining a permit to enter the territory of Mexico, the laws of migration policy oblige migrants to be checked by the immigration authorities for the existence of various types of

**Table 1.** Ranks of Mexican states by socio-economic indicators, 2020

| States of Mexico | Rank by employment level | Rank by GRP dynamics | Rank by per capita income | Rank by average house price | Rank by access to qualified medical care | The region's place in the rating |
|---|---|---|---|---|---|---|
| Aguascalientes | 17 | 2 | 12 | 10 | 12 | 7 |
| Baja California | 8 | 22 | 4 | 19 | 7 | 10 |
| Southern Baja California | 2 | 1 | 2 | 26 | 4 | 2 |
| Campeche | 18 | 32 | 21 | 15 | 18 | 23 |
| Coahuila | 12 | 9 | 11 | 4 | 9 | 29 |
| Colima | 1 | 7 | 8 | 6 | 5 | 5 |
| Chiapas | 32 | 29 | 32 | 14 | 24 | 12 |
| Chihuahua | 9 | 13 | 10 | 11 | 3 | 4 |
| Federal District | 4 | 27 | 1 | 32 | 2 | 1 |
| Durango | 16 | 19 | 20 | 2 | 20 | 16 |
| Guanajuato | 11 | 3 | 19 | 12 | 13 | 8 |
| Guerrero | 26 | 25 | 31 | 24 | 19 | 28 |
| Hidalgo | 22 | 6 | 24 | 7 | 20 | 17 |
| Jalisco | 10 | 8 | 9 | 28 | 4 | 9 |
| Mexico | 17 | 15 | 17 | 29 | 21 | 22 |
| Michoacan | 19 | 11 | 22 | 13 | 17 | 19 |
| Morelos | 23 | 26 | 23 | 30 | 14 | 26 |
| Nayarit | 5 | 20 | 15 | 27 | 23 | 21 |
| Nuevo Leon | 6 | 18 | 3 | 20 | 1 | 6 |
| Oaxaca | 21 | 24 | 30 | 23 | 22 | 27 |
| Puebla | 16 | 16 | 28 | 17 | 27 | 23 |
| Queretaro | 25 | 4 | 7 | 31 | 10 | 16 |
| Quintana Roo | 4 | 14 | 6 | 21 | 20 | 11 |
| San Luis Potosi | 20 | 5 | 18 | 25 | 8 | 15 |
| Sinaloa | 14 | 21 | 13 | 16 | 7 | 14 |
| Sonora | 7 | 10 | 5 | 9 | 6 | 3 |
| Tabasco | 24 | 31 | 26 | 18 | 16 | 25 |
| Tamaulipas | 13 | 30 | 14 | 1 | 9 | 13 |
| Tlaxcala | 15 | 23 | 25 | 3 | 15 | 18 |
| Veracruz | 27 | 28 | 29 | 8 | 22 | 24 |
| Yucatan | 3 | 12 | 16 | 22 | 12 | 11 |
| Zacatecas | 24 | 17 | 27 | 5 | 11 | 20 |

offenses. In cases of any violations, the state will be forced to restrict or completely prohibit stay in the country [4]. Migrants who have been found dealing with narcotic substances or have previously been prosecuted for their sale or distribution are strictly limited in the possibility of obtaining a visa and arriving in Mexico.

When entering the country, migrant workers and their families face the problem of basic education and additional training. Thanks to the cooperation of the US and Mexican authorities, special schools for immigrants under the PROBEM program were organized, where immigrants from nearby countries can also be employed [10].

The study shows that the Mexican government controls the movement of legal migrant workers, limiting the territory of their possible settlement.

This is evidenced not only by the legislative acts of migration policy and the conditions for obtaining a visa, but also by the situation with the geographical concentration of migrants. The uniform settlement of labor immigrants in states with very low and low concentrations is a consequence of the state regulation of their movement by the visa regime, which determines these possible territories. However, these regions of the country are not the most attractive for labor migration, in particular for citizens of southern border countries, as evidenced by the corresponding attractiveness rating of the states. Highly qualified specialists prevail in competitive states, where the economic standard of living is quite high. This ensures the employment of jobs in the country that are associated with low-prestige or hard work, have a longer working week and lower wages (agriculture, extractive industries). The Government of Mexico protects the national labor market from the spontaneous flow of migrants and ensures the rational use of foreign workers in those industries that are not provided at the expense of domestic labor resources and does not extend restrictions to specialists in priority areas of activity (IT technology).

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## Опыт государственного регулирования международной миграции рабочей силы Мексики

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**Ключевые слова и фразы:** иммиграция; коэффициент географической концентрации; миграционное движение; регулирование рабочей миграции; эмиграция.

**Аннотация.** Цель исследования – выявление основных тенденций и направлений государственной политики Мексики по регулированию потоков эмиграции и иммиграции рабочей силы как в целом, так и в отдельных штатах страны. В соответствии с поставленной целью решались задачи: проанализировать статистику международной миграции рабочей силы по штатам Мексики; выявить регионы с высоким и низким уровнем распределения рабочих-мигрантов; рассмотреть миграционную политику и государственное регулирование международной миграции рабочей силы; определить основные проекты и программы с участием трудовых мигрантов и пути решения основных проблем правительством страны. Гипотеза исследования: Мексика обладает достаточно сильным государственным аппаратом и сопутствующими инструментами, что обуславливает успешное регулирование и контроль иммиграции рабочей силы. В работе использованы методы статистического, сравнительного, аналитического, математического и картографического анализов, а также метод расчета коэффициента географической концентрации рабочих-мигрантов по штатам Мексики для рассмотрения методов регулирования их движения правительством. Информационной базой исследования послужили статистические данные и отчеты, содержащие информацию об объемах иммиграционных потоков и уровне экономического развития штатов Мексики и страны в целом, опубликованные Правительством и Институтом статистики, географии и информатики Мексики, а также различные научные публикации по исследуемой тематике, официальные интернет-сайты мексиканских учреждений и другие материалы.

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