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THE SELECTION OF INFORMATION-MEASURING MEANS FOR THE ROBOTOTECHNICAL COMPLEX AND THE RESEARCH OF THEIR WORKER CHARACTERISTICS

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ABSTRACT

Context. The topic of the article is devoted to the issue selection of the means of the information-measurement system (IMS) for automation of robototechnical complexes (RTC) of flexible production systems applied in various fields of industry, and the research of their technological characteristics.

Objective. The goal is using the mathematical models to researching of the working characteristics of the new construction transmitters for information – measurement and automated control of robototechnical complex in flexible production areas.

Method. In the article, the following issues were set and solved: the analysis of the application object, the selection of the types of information-measurement and management elements of RTC creation and structure scheme; research of the characteristics of the information-measuring transmitter for managing the active elements of the RTC; determining the error of the analog output transmitter of the information-measurement system of RTC active elements.

Based on the analysis of the application object, it was determined that the structure scheme of the RTC at the flexible production system includes complex technological, functionally connected production areas, modules and robotic complexes, their automated control system IMS, regulation, execution, microprocessor control system and devices and devices of the industrial network. includes The functional block diagrams of the IMS of RTCi of the flexible production system are given. Based on research, it was found that it is convenient to use a magnetoelastic transducer with a ring sensitive element to measure the mechanical force acting on the working organs of an industrial robot (IR). For this, unlike existing transmitters, the core of this transmitter is made of whole structural steel. The inductive coil of the proposed transmitter is included in the LC circuit of the autogenerator. The magnetoelastic emitter semiconductor is assembled at the base of the transistor. The cross-section of its core is calculated for the mechanical stress that can be released for the steel. The block-scheme of the inductive transmitter is proposed. The proposed transmitters work on the principle of an autogenerator assembled on an operational amplifier. A mathematical expression is defined for determining the output frequency of the autogenerator. The model of the autogenerator consists of a dependent source, the transmission coefficient is determined.

Results. A new transmitter is proposed to measure the information of the manipulator to perform special technological operations synchronously.

Conclusions. A mathematical model was developed to determine the error of the analog output transmitter of the information-measurement system of RTC active elements. The expression ehq is used to determine the error of the transmitter whose output is analog during the measurement of the current technological operation. It was determined that in practice, the geometric dimensions of the transmitter and the number of windings remain unchanged during the work process, where it is changed due to the influence of the environment. Considering this variation, a mathematical model was developed to determine the transmitter error.

KEYWORDS: Robototechnical complex, information-measuring system, transmitter, inductive sensor, autogenerator, LC motor, semiconductor commutator, analog output transmitter, transmitter error.

ABBREVIATIONS

IMM is information-measurement and management;
RTC is robototechnical complex;
FMS is flexible manufacturing system;
IMS is information-measurement system;
MCS is microprocessor control system;
IND is industrial network devices;
IT is intelligent transmitter;
IR is industrial robot;
TEPM is technological equipment of production module; MT is machine tool;
F is furnaces;
PQCT is products quality control tool;
IT is intelligent transmitter.

NOMENCLATURE

δ is a proportion;
L_1 is an inductance of the oscillation circuit;
L_2 is an inductance of the oscillation circuit;

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r_e is an emitter switching resistance of the transistor;
r_b is a base switching resistance of the transistor;
r_k is a collector switching resistances of the transistor;
r_2 is an ohmic resistance of the oscillation circuit;
K_u is a load factor;
K is a transmission factor;
R is a resistance;
R_1 is an active resistance;
R_2 is an active resistance;
R_{out} is an output resistance;
ω is an angular frequency of the induced current;
L is an inductive;
α is a current amplification factor of the transistor;
ω_0 is a specific frequency of the oscillation contour of the autogenerator;
f_0 is an autogenerator frequency;
z is a k load resistance;
ΔU is a displacement of power;
X_m is a maximum displacement;
X is a current value of displacement;
k is a proportionality coefficient;
W_1 is a number of affected laps;
W_2 is a number of section laps;
h is a depth of the slot;
a is a width of the slot;
δ is a length of the air gap between the housing and the rotating cylinder;
μ is a corresponding to the equivalent extinction depth of the core;
μ_0 is corresponding to the equivalent extinction depth of the core;
$\dot{I}_T$ – is a complex value of induced current;
M is a mutual induction;
L_T is an induction of section windings;
r_T is an active resistance in section windings;
$\dot{E}$ is an induction ehq in section windings;
C_1 is a constant factor;
C_2 is a constant factor;
N is a speed of rotation;
S is an elative magnetic permeability of the core and absolute magnetic permeability of the cavity, respectively;
d is an equivalent depth of the magnetic flux in the core;
l is a length of the core.

INTRODUCTION

The many different types of mechanical quantity transmitters, transmitters based on magnetic systems are of great interest. However, numerous constructive options do not reflect their quality indicators, but reflect their technical and economic indicators. Structurally, the magnetic system of existing transmitters is rectangular, cylindrical, etc. is prepared in the form [1, 2]. Cylindrical magnetic systems are highly resistant to obstacles, have low scattered magnetic flux, high sensitivity, and simple manufacturing technology.

The magnetic system of the transmitters in this form is made of a material called ferrite, which is fragile due to mechanical shocks and vibrations, so it quickly breaks down and loses its working capacity. Thus, on the basis of a long-term study, it was determined that when the core of the magnetic system of the existing inductive transmitters is made of ordinary structural steel, the above-mentioned shortcomings are reduced, that is, their sensitivity increases, they are resistant to mechanical shocks, reliable operation is ensured, and quality indicators increase. In this regard, many Azerbaijani and Russian scientists, including academician Aliyev R.A., Aliyev T.M., Mammadov F.I., Nabiyev M.A., Mostovoy B.H., Ahmadova T.A. in their research, they used structural steel in the preparation of transmitters [3, 4, 5].

The comparative analysis of magnetic circuits of different designs allows such transmitters to be used in the measurement of mechanical quantities. According to the setting conditions of the magnetic system, make it consist of a high-grade homogeneous magnetic field of the magnetic system and calculate the high-precision displacement, speed, oscillation, acceleration, force, pressure, torque, etc. at the base of this system. it is necessary to create transmitters that measure quantities. Thus, it is necessary to unify different types of magnetic systems. The mass, dimensions, energy demand, structural simplicity, and manufacturing technology of the transmitters are considered to be one of the main important issues [6, 7, 8, 9].

The object of study.

Nowadays, every RTC and FMS systems are widely used, and they contain numerous non-contact transmitters, and with their help, various physical quantities are converted into electrical quantities and provide information about the technological process [10–16]. Because, as an object os study, it was chosen the RTC in FMS, where for its effective control and automation, information-measuring, processing and executing elements characteristics must be researched.

The subject of study is based on the methods for researching energetically characteristics of the inductive transmitter for the converting manipulator and industrial robot served the active elements at RTC.

The analyze of the known methods [1–27] shown that have the non solved problems at complex design of information measure systems applied to robototechnical and manipulator of FMS, and at that needs to decision these tasks.

The purpose of the work – using the mathematical models to researching of the working characteristics of the new construction transmitters for information-measurement and automated control of robototechnical complex in flexible production areas. In order to achieve the set goal, the following issues should be solved:

– analysis of the application object, selection of types of information-measuring and control elements of the robotic complex and creation of a structural scheme;

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– study of the characteristics of the information-measuring transmitter for the management of the active elements of the robotic complex;

– determining the error of the transmitter with analog output of the information-measurement system of active elements of RTC.

1 PROBLEM STATEMENT

Let us consider the issue of developing an algorithm for improving static characteristics, which include correction of the initial offset, increase in the slope of the linear static characteristic, correction of the scale of the measuring path, linearization of the static characteristic and approximation using a polynomial. In this regard, in accordance with the above-presented static characteristics, we will present the input data as follows:

1. Bridge-type measuring transducers based on strain gauges have an initial offset of the output signal, which can reach 15 mV/V with a sensitivity of the primary transducer of 2 ... 4 mV/V.

2. The slope coefficient is the partial derivative of the power with respect to the corresponding parameters.

3. All errors of the measuring path can be legitimately considered as a single centered random variable and characterized by a single indicator – the second central moment (variance) – as the average value of the power of the error change curve.

4. The small deviation method is used to linearize the characteristics of the measuring path.

In Figure 1 the block diagram of the inductive transmitter is given.

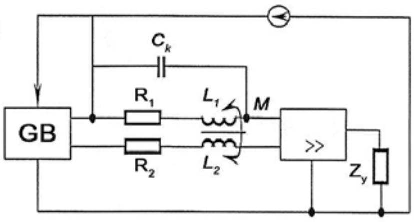

Figure 1 – Inductive substitution block-scheme

In the block-scheme, GB-voltage divider; z_y is the load resistance. By that, an operational amplifier is taken as an amplifier. Such an amplifier has strong feedback. In ideal operational amplifiers $R_g = \infty$, and accordingly, the voltage gain is also $K_u = \infty$ obtained. The output resistance of such amplifiers is close to zero.

For solution of the task of definition of output frequency of the autogenerator, let the given list of the following input variables:

1. ω_0 – the specific frequency of the oscillation contour of the autogenerator;

2. L_1, L_2 – the inductances of the oscillation circuit;

3. r_e – the emitter switching resistance of the transistor;

4. r_b – the base switching resistance of the transistor;

5. r_k – the collector switching resistances of the transistor;

6. r_2 –ohmic resistance of the oscillation circuit;

7. α – current amplification factor of the transistor.

Then the task consists of determination of output frequency of the autogenerator worked on the principle of an autogenerator assembled on an operational amplifier. Thus output frequency of the autogenerator is determined as follows:

$$\omega = \omega_0 \sqrt{\frac{L_1\left[r_e + (r_2 + r_b)(1-\alpha)\right]}{L_1\left[r_e + (r_e + r_b)(1-\alpha)\right] + L_2 r_k (1-\alpha)}}. \qquad (1)$$

2 REVIEW OF THE LITERATURE

Automation of various technological processes, effective management of aggregates, machines, and mechanisms require the measurement of many different physical quantities. All the requirements for the elements of automation to increase the reliability, quality and economic efficiency, the increase of all the requirements for the information-measurement and management (IMM) technique require new developments, extensive field research. In this field, great attention is paid to the development of electromagnetic elements, including their reliability, simplicity of technology and low cost.

Some of the converters used in FMS and RTC[s] work mainly in relay mode. In such systems, in addition to transmitters working in relay mode, measuring transmitters that can measure technological parameters with high accuracy or various vision devices are also used [17, 18]. In the technological lines of FMS and RTC systems, the product is moved along the line and is subjected to certain technological operations in different parts of this line. In this regard, in order to ensure continuity and consistency in the technological line, it is necessary to use devices that indicate the presence of products in one or more places of the line. For this purpose, electromagnetic inductive transmitters are used in the IMM systems.

Research of information and measuring systems applied to robotic systems of mechanical engineering flexible production have shown that the used sensors belong to the areas measuring mechanical states of the industrial robot in the environment. At the same time, the main elements of the information and measuring systems of robotic complexes – sensors, receive a wide range of data about the environment, such as position, size, orientation, speed, distance, temperature, weight, force, etc. [19, 20, 21]. This information allows industrial robots and mechatronic means to function effectively, interacting with the environment, while performing complex manipulation, operational and planned production tasks.

The used sensors of industrial robots and mechatronic means of the robotic complex are based on the principle of energy conversion, also known as transduction [22]. Given the complexity and presence of a large number of standard industrial robots, process equipment, logistics and transport technologies, different sensors are required to improve efficiency, measurement accuracy, control

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reliability, monitoring and flexible response in the working environment of the robotic complex. Complex in structure industrial robotic sections, manipulation of hands, gripping devices and transportation industrial robots require contact sensors [23], which function when changing the speed, position, acceleration, torque or force in the links of the manipulator and the working body of industrial robots. Insufficient research in this direction requires careful consideration of the issue of determining the parameters that arise during physical contact in order to effectively direct the industrial robot to appropriate actions in the robotic complex. In this case, the sensors used to measure contact are performed using various switches, such as a limit switch, a push-button switch and a tactile bumper switch. In the works [24, 25], the contact sensors under consideration are used to avoid obstacles encountered in the robotic complex. When any obstacle is detected, it transmits a signal to the robot so that it can perform various actions, such as reversing, turning or simply stopping. Special research requires the issue of measuring sensors for detecting objects, which are considered in the work [26, 27]. In this paper, using the capabilities of a magnetic field to detect the objects in question, the required energy characteristics of ultrasonic sensors are determined, which measure distances to a certain object by emitting ultrasonic sound waves and converting the reflected sound into an electrical signal. However, obtaining large errors when using such technology requires the use of a new approach to accurately determine the distance from one object to another object without the need for physical contact [28]. On the review of the literature can do conclusion that the primary elements of the existing information-measurement and management systems – transmitters have low reliability. They fail quickly due to the corresponding mechanical vibration and shocks under heavy duty conditions. Measuring transmitters, technical vision systems and other control and regulatory devices working in such harsh conditions work unsteadily [29]. Thus, it is necessary to increase the stability of the transmitters and the IPC. This remains a problem in production.

3 MATERIALS AND METHODS

The autogenerator model consists of a dependent source $K_u^0 u_{y.i} = u_0$, where the transmission factor is written as follows [30]:

$$K = \frac{R}{(1+j\omega CR)\left[\dfrac{R}{1+j\omega CR} + R_2 + j(\omega L - \dfrac{1}{\omega C})\right]}, \quad (2)$$

Fig. 2 shows the replacement scheme of the autogenerator built on the basis of the EP scheme. When creating an autogenerator, it is convenient to choose its active resistance, i.e $R_1 = R_2 = R_{or}$

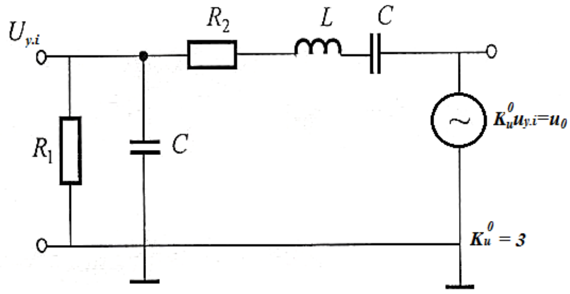

Figure 2 – Autogenerator replacement scheme

(1) for the resonant condition of the autogenerator by slightly changing the expression

$$\omega_0^2 C^2 R^2 + \omega_0^2 C L - 1 = 0. \quad (3)$$

From the solution of this equation

$$\omega_0 = \pm\sqrt{\frac{1}{C(R^2 C + L)}}. \quad (4)$$

For the real circuit, the following equation is satisfied in the autogenerator

$$L = R^2 C. \quad (5)$$

Real operational amplifiers are designed to have an infinitely large input resistance and a minimum output resistance. It happens because it is accepted $\omega = \omega_0 = 2\pi f_0$ where $d \approx 1$. That is

$$f_0 = \frac{1}{2\pi\sqrt{LC}}. \quad (6)$$

From the last statement, it can be seen that when the frequency of the autogenerator is high, it is more sensitive to the change of inductance and to the change of capacitance at low frequency.

It should be noted that the voltage change obtained at the final resistance

$$\Delta U = \frac{k}{X_m} X. \quad (7)$$

The proportionality factor k is obtained from the interaction of the influence loop located in the transmitter housing and the section loops [31]. Let's assume that the transmitter is fed from an alternating current source with a frequency of 400 Hz, and in this case the magnetic field around the slot 5 is extinguished at a depth of about 1 mm. In this regard, the magnetic field at that depth of the core is considered homogeneous. According to the same

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rule, the extinction depth of the magnetic flux in each section is assumed to be close to 1mm. If we consider all the above for the magnetic field generated around the induced loop, the mutual magnetic induction

$$M = \frac{W_1 W_2 \mu \mu_0 S}{2\left[h + a + \mu\delta\right]} \quad (8)$$

happens. Where W_1, W_2 –, the number of affected and section laps, respectively, h, a – the depth and width of the slot; δ – the length of the air gap between the housing and the rotating cylinder; S – cross-sectional area μ, μ_0 – corresponding to the equivalent extinction depth of the core; $S = dl$ relative magnetic permeability of the core and absolute magnetic permeability of the cavity, respectively; d – the equivalent depth of the magnetic flux in the core; l – is the length of the core. Induction ehq in section windings is defined by the expression

$$\dot{E} = -j\omega M \dot{I}_T , \quad (9)$$

where, ω – the angular frequency of the induced current; $\dot{I}_T$ – complex value of induced current; M – is mutual induction.

The complex value of the current flowing through the excitation loop

$$\dot{I}_T = \frac{\dot{U}}{r_T + j\omega L_T} \quad (10)$$

is defined by the expression If we consider expression (4) in (3) and make some transformation:

$$\dot{E} = \frac{\omega M \dot{U}}{\sqrt{r_T^2 + (\omega L_T)^2}} e^{j\varphi} . \quad (11)$$

Inductance obtained from the study of the magnetic system of the inverter

$$L_T = \frac{W_2^2 \mu\mu_0 S}{2(h + a + \mu\delta)} \quad (12)$$

is defined as If we substitute expressions (8) and (12) in (10) and carry out a transformation, we get for the modulus or k coefficient of ehq:

$$E_m = k = \frac{\omega W_1 W_2 \mu\mu_0 S}{2(K + a + \mu\delta)} \cdot \frac{U}{\sqrt{r_1^2 + \left(\omega \dfrac{W_2^2 \mu\mu_0 S}{2(h + a + \mu\delta)}\right)^2}} . \quad (13)$$

If we write the last expression in formula (7):

$$\Delta U = \frac{\omega W_1 W_2 \mu\mu_0 S U}{\sqrt{4(h + a + \mu\delta)^2 r_T^2 + (\omega W_2^2 \mu\mu_0 S)^2}} \cdot \frac{X}{X_m} . \quad (14)$$

The obtained expression (14) allows to find the operating characteristic of the transmitter. Where, a motor is used as an actuator for the manipulator to perform angular rotation. The scheme of connecting such an execution engine to the circuit is shown in Figure 3. Where, the normally open and normally closed contacts K_3, K_4 used in the system K_1, K_2 are used. Contacts electric motor is influenced by a permanent magnet and consists of an angle transmitter indicating the position of the rotor and a semiconductor commutator [32].

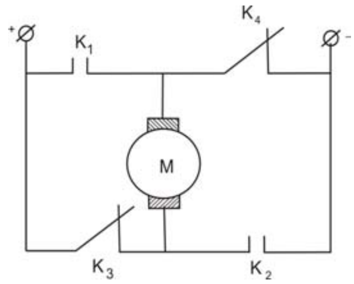

Figure 3 – Scheme of connecting the motor to the circuit through contacts

In a contactless motor, the motor and the commutator are placed in one housing or they are installed in separate housings, connected to each other by a cable. The principle of operation of this motor is as follows: the interaction between the armature current and the magnetic flux in the poles creates a torque, which rotates the armature and the poles in different directions (Fig. 9). Due to this, the torque maintains its direction, and the motor continues the direction of rotation.

Due to the effect of the torque, the rotor rotation speed n increases. In this regard, the ehq generated in the anchor

$$E = C_1 n \Phi \quad (15)$$

happens.

In the active resistance l of the armature and the corresponding armature rotation speed

$$n = \frac{(u - lr)}{C_m \Phi} \quad (16)$$

happens.

In the model shown in Fig. 4, the brush acts as a commutator and synphase works with the rotation of the rotor. Where, the sections of the windings of the rotor are connected in such a way that the current in the windings is always in the same direction [33].

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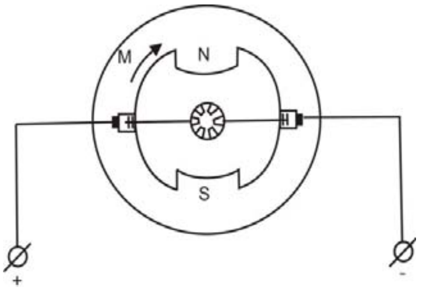

Figure 4 – DC motor connection diagram

4 EXPERIMENTS

A contactless of the motor consists of three main parts: 1) in the stator m – phase winding and affected rotor; 2) rotor status transmitter; 3) contactless switch. Here, the currents flowing through the stator windings are switched from the status transmitter signals. An angle transmitter is used as a transmitter to indicate the position of the rotor. Through this, the control signal is processed, and the windings of the motor determine the sequence of switching.

The technical parameters of the contactless direct current motor are shown in Table 1.

Table 1 – technical parameters of the contactless direct current motor

№	The name of the indicators	Unit of measure	The value
1	Nutritional stress	V	27
2	Useful power	Vt	14
3	Rotational frequency	Cycle/min	4500
4	Ambient temperature	^{0}C	–10 ÷+40
5	The relative humidity of the air at a temperature of 25^0 C	%	98
6	Required current	A	1.1
7	Useful work factor	%	60
8	Mass Engine Switch	kg	0.58 0.4
9	Overall dimensions of the switch	mm.mm.mm	0 x 64 x 81

For accurate and reliable management of complex technological operations in RTC, precise analog signals of the measured parameters must be received and processed from the information-measuring transmitters used at the 1st level of the automated control system to the input of the microprocessor control system and the programmable logic controller [34]. When measuring the current technological operation, it is necessary to use the expression ehq to determine the error of the transmitter whose output is analog. The modulus of this expression is written as follows:

$$E = \frac{\omega W_1 W_2 \mu\mu_0 S u}{2\left(h+a+\mu\delta\right)\sqrt{r_1^2+\left(\frac{\omega W_2^2 \mu\mu_0 S}{2(h+a+\mu\delta)}\right)^2}}. \quad (17)$$

In practice, it appears that the geometric dimensions of the transmitter and the number of windings remain unchanged during the work process. Where, ω, μ, u, δ, r it is changed due to the influence of the environment. Given this change,

$$E_{ao}\left(1\pm\frac{\Delta E}{E_{ao}}\right)=\frac{W_1W_2\mu_0 S\omega_{ao}\left(1\pm\frac{\Delta\omega}{\omega_{ao}}\right)\left(1\pm\frac{\Delta\mu}{\mu_{ao}}\right)}{2\left[\left(h+a+\mu_{ao}\left(1\pm\frac{\Delta\mu}{\mu_{ao}}\right)\delta_{ao}\left(1\pm\frac{\Delta\delta}{\delta_{ao}}\right)\right)\right]}\times$$

$$\times\frac{1}{\sqrt{r_{1ao}^2\left(1\pm\frac{\Delta r}{r_{1ao}}\right)^2+\left(\frac{\omega_{ao}\left(1\pm\frac{\Delta\omega}{\omega_{ao}}\right)W_2^2\mu_0 S\mu_{ao}\left(1+\frac{\Delta\mu}{\mu_{ao}}\right)}{2\left(h+a+\mu_{ao}\left(1\pm\frac{\Delta\mu}{\mu_{ao}}\right)\delta_{ao}\left(1\pm\frac{\Delta\delta}{\delta_{ao}}\right)\right)}\right)^2}}. \quad (18)$$

If we raise the numerator and denominator of the obtained fraction to a power and consider the quantities whose degree is greater than unity, the expression (18) is written as follows:

$$E_{ao}\left(1\pm\frac{\Delta E}{E_{ao}}\right)=\frac{W_1W_2\mu_0 S\omega_{ao}U_{ao}\left(1\pm\frac{\Delta\omega}{\omega_{ao}}\pm\frac{\Delta U}{U_{ao}}\pm\frac{\Delta\mu}{\mu_{ao}}\right)\mu_{ao}}{2\left[\left(h+a+\mu_{ao}\delta_{ao}\left(1\pm\frac{\Delta\delta}{\delta_{ao}}\pm\frac{\Delta\mu}{\mu_{ao}}\right)\right)\right]}\times$$

$$\times\frac{1}{\sqrt{r_{ao}^2\left(1\pm2\frac{\Delta r}{r_{1ao}}\right)+\left(\frac{\omega_{ao}W_2^2\mu_0 S\mu_{ao}\left(1\pm\frac{\Delta\omega}{\omega_{ao}}\pm\frac{\Delta\mu}{\mu_{ao}}\right)}{2\left(h+a+\mu_{ao}\delta_{ao}\left(1\pm\frac{\Delta\mu}{\mu_{ao}}\pm\frac{\Delta\delta}{\delta_{ao}}\right)\right)}\right)^2}}. \quad (19)$$

If we have considered the second, third and fourth order variables in the expression (19), we can write the changed form of the expression (19) as follows:

$$E_{ao}\left(1\pm\frac{\Delta E}{E_{ao}}\right)=\frac{W_1W_2'\mu_0 S\omega_{ao}'U_{ao}\mu_{ao}\left(1\pm\frac{\Delta\omega}{\omega_{ao}}\pm\frac{\Delta U}{U_{ao}}\pm\frac{\Delta\mu}{\mu_{ao}}\right)}{2\left[\left(h+a+\mu_{ao}\delta_{ao}\left(1\pm\frac{\Delta\delta}{\delta_{ao}}\pm\frac{\Delta\mu}{\mu_{ao}}\right)\right)\right]}\times$$

$$\times\frac{1}{\sqrt{r_{ao}^2\left(1\pm2\frac{\Delta r}{r_{ao}}\right)+\frac{\omega^2_{ao}W_2^4\mu^2_0 S^2\mu^2_{ao}\left(1\pm\frac{\Delta\omega}{\omega_{ao}}\pm\frac{\Delta\mu}{\mu_{ao}}\right)^2}{\left[4(h+a+\mu_{ao}\delta^2_{ao})^2\left(1\pm\frac{\Delta\mu}{\mu_{ao}}\pm\frac{\Delta\delta}{\delta_{ao}}\right)\right]^2}}}. \quad (20)$$

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$K_1=\dfrac{\mu_0\mu_{ao}}{(h+a+\delta+\mu_{ao})}$ if we consider that we have divided the first part of the received fraction into its first-order variables

$$E_{ao}\left(1\pm\frac{\Delta E}{E_{ao}}\right)=\frac{W_1W_2\mu_o SU_a\omega_{ao}\mu_{ao}\left(1\pm\frac{\Delta\omega}{\omega_{ao}}\pm\frac{\Delta U}{U_{ao}}\pm\frac{\Delta\mu}{\mu_{ao}}\right)}{2(h+a+\mu_{ao}\delta_o)}\times$$
$$\times\left(1\pm\frac{\Delta\omega}{\omega_{ao}}\pm\frac{\Delta U}{U_{ao}}\pm I\pm K_1\Delta\mu\mu\omega_0\mp\frac{\Delta\delta}{\delta_{ao}}\right)\times$$
$$\times\frac{1}{\sqrt{r_{ao}^2\left(1\pm 2\frac{\Delta r}{r_{ao}}\right)+\frac{\omega^2{}_{ao}W_2^4\mu^2{}_0S^2\mu^2{}_{ao}\left(1\pm\frac{\Delta\omega}{\omega_{ao}}\pm\frac{\Delta\mu}{\mu_{ao}}\right)^2}{4(h+a+\mu_{ao})^2\left(1\pm\frac{\Delta\mu}{\mu_{ao}}\pm\frac{\Delta\delta}{\delta_{ao}}\right)}}}.\qquad(21)$$

(21) to the power, and consider the second and third and higher-order expressions,

$$\left(1\pm K_1\frac{\Delta\mu}{\mu_{ao}}\pm K_1\frac{\Delta\delta}{\delta_{ao}}\right)\text{ and }\left(1\pm\frac{\Delta\omega}{\omega_{ao}}\pm\frac{\Delta\mu}{\mu_{ao}}\right)\qquad(22)$$

we will get that. Where, if we multiply $\left(1\pm K_1\dfrac{\Delta\mu}{\mu_{ao}}+K_1\dfrac{\Delta\delta}{\delta_{ao}}\right)$ the inverse of the expression $\left(1\pm\dfrac{\Delta\omega}{\omega_{ao}}\pm\dfrac{\Delta\mu}{\mu_{ao}}\right)$ by the expression and keep the first-order quantities, then their product is in the following form

$$\left(1\pm\frac{\Delta\omega}{\omega_{a0}}\pm\frac{\Delta\mu}{\mu_{a0}}\right)\left(1\mp K_1\frac{\Delta\mu}{\mu_{a0}}\mp K_1\frac{\Delta\delta}{\delta_{a0}}\right)=1\mp K_1\frac{\Delta\mu}{\mu_{a0}}\mp K_1\frac{\Delta\delta}{\delta_{a0}}+1\pm\frac{\Delta\omega}{\omega_{a0}}\pm\frac{\Delta\mu}{\mu_{a0}}=$$
$$=2\pm(1-K_1)\frac{\Delta\mu}{\mu_{a0}}\pm\frac{\Delta\omega}{\omega_{a0}}\pm\frac{\Delta\delta}{\delta_{a0}}(1-K_1)=2\pm(1-K_1)\left(\frac{\Delta\mu}{\mu_{a0}}+\frac{\Delta\delta}{\delta_{a0}}\right)\pm\frac{\Delta\omega}{\omega_{a0}}.\qquad(23)$$

Thus,

$$\frac{1}{\sqrt{r_{a0}^2\pm 2\frac{\Delta r}{r_{a0}}+K_2^2\left[2\pm(1-K_1)\left(\frac{\Delta\mu}{\mu_{a0}}+\frac{\Delta\delta}{\delta_{a0}}\right)\pm\frac{\Delta\omega}{\omega_{a0}}\right]}}=$$
$$=\frac{1}{\sqrt{r_{a0}^2+K_2^2}\sqrt{3\pm 2\frac{\Delta r}{r_{a0}}\pm(1-K_1)\left(\frac{\Delta\mu}{\mu_{a0}}+\frac{\Delta\delta}{\delta_{a0}}\right)\pm\frac{\Delta\omega}{\omega_{a0}}}},\qquad(24)$$

where

$$K_2^2=\frac{\omega_{ao}^2W_2^4\mu_0^2S^2\mu_{ao}^2}{4(h+a+\mu_{ao}\delta_{ao})},$$
$$K_3=\sqrt{r_{ao}^2+K_2^2},$$
$$K_4=\frac{W_1W_3\mu_0SU_{ao}\omega_{ao}\mu_{ao}}{2(h+a+\mu_{ao}\delta_{ao})}.$$

(24) and multiply it by the $\sqrt{3\pm 2\dfrac{\Delta r}{r_{a0}}\pm(1-K_1)\left(\dfrac{\Delta\mu}{\mu_{a0}}+\dfrac{\Delta\delta}{\delta_{a0}}\right)\pm\dfrac{\Delta\omega}{\omega_{a0}}}$ inverse of the expression (23).

$$\left[1\pm\frac{\Delta\omega}{\omega_{ao}}\pm\frac{\Delta U}{U_{ao}}\pm(1-K_1)\left(\frac{\Delta\mu}{\mu_{ao}}+\frac{\Delta\delta}{\delta_{ao}}\right)\right]\left[3\mp 2\frac{\Delta r}{r_{ao}}\mp(1-K_1)\left(\frac{\Delta\mu}{\mu_{ao}}+\frac{\Delta\delta}{\delta_{ao}}\right)\pm\frac{\Delta\omega}{\omega_{ao}}\right]\qquad(25)$$

is taken.

At the opening of the last statement

$$3\pm 3\frac{\Delta\omega}{\omega_{a0}}\pm 3\frac{\Delta U}{U_{ao}}\pm 3(1-K_1)\left(\frac{\Delta\mu}{\mu_{ao}}+\frac{\Delta\delta}{\delta_{ao}}\right)\mp 3\mp 2\frac{\Delta r}{r_{ao}}\mp(1-K_1)\left(\frac{\Delta\mu}{\mu_{ao}}+\frac{\Delta\delta}{\delta_{ao}}\right)\pm\frac{\Delta\omega}{\omega_{ao}}\qquad(26)$$

we will get that. If we consider the high rates of growth where,

$$E_{ao}\left(1\pm\frac{\Delta E}{E_{ao}}\right)=K_4\left[2\pm 2\frac{\Delta\omega}{\omega_{ao}}\pm 3\frac{\Delta U}{U_{ao}}\pm 2(1-K_1)\left(\frac{\Delta\mu}{\mu_{ao}}+\frac{\Delta\delta}{\delta_{ao}}\right)\mp 2\frac{\Delta r}{r_{ao}}\right]\qquad(27)$$

is taken.
Where

$$\pm\frac{\Delta E}{E_{ao}}=1\pm 2\frac{\Delta\omega}{\omega_{ao}}\pm 3\frac{\Delta U}{U_{ao}}\pm(1-K_1)\left(\frac{\Delta\mu}{\mu_{ao}}+\frac{\Delta\delta}{\delta_{ao}}\right)\pm 2\frac{\Delta r}{r_{ao}}.\qquad(28)$$

Let us denote the right side of the obtained equation by β_0

$$\beta_0=1\pm 2\frac{\Delta\omega}{\omega_{a0}}\pm 3\frac{\Delta U}{U_{a0}}\pm(1-K_1)\left(\frac{\Delta\mu}{\mu_{a0}}+\frac{\Delta\delta}{\delta_{a0}}\right)\mp 2\frac{\Delta r}{r_{a0}}.\qquad(29)$$

5 RESULTS

From the last expression it is clear that the largest error is obtained from the change in voltage, the second error is obtained from the change in network frequency, and the third error is obtained due to the change in the active resistance in the opposite direction. The smallest error is obtained by multiplying $(1-K_1)$ the expression by the expression $\dfrac{\Delta\mu}{\mu_{ao}}+\dfrac{\Delta\delta}{\delta_{ao}}$.

Computer experiments were conducted to construct the asymptotic diagram (Figure 5).

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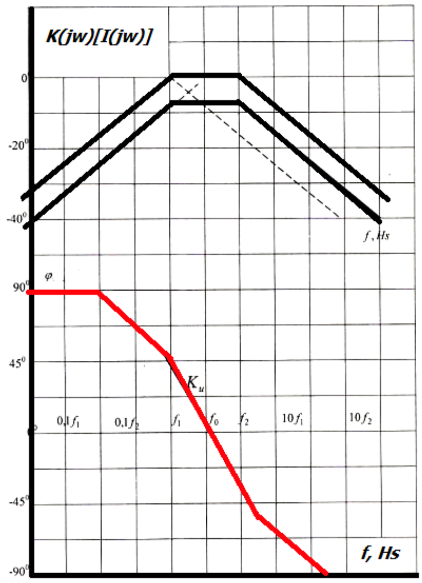

Figure 5 – The asymptotic diagram got by means of computer experiment

The feedback loop assumed in the asymptotic diagram is determined as a function of the RC resistance of the filter.

6 DICUSSION

Based on the analysis of the application object, it was determined that the structure scheme of the RTC at the flexible production system includes complex technological, functionally connected production areas, modules and robotic complexes, their automated control system IMS, regulation, execution, microprocessor control system and devices and devices of the industrial network. includes The functional block diagrams of the IMS of RTCi of the flexible production system are given. Based on research, it was found that it is convenient to use a magnetoelastic transducer with a ring sensitive element to measure the mechanical force acting on the working organs of an industrial robot (IR). For this, unlike existing transmitters, the core of this transmitter is made of whole structural steel. The inductive coil of the proposed transmitter is included in the LC circuit of the autogenerator. The magnetoelastic emitter semiconductor is assembled at the base of the transistor. The cross-section of its core is calculated for the mechanical stress that can be released for the steel. The block-scheme of the inductive transmitter is proposed. The proposed transmitters work on the principle of an autogenerator assembled on an operational amplifier. A mathematical expression is defined for determining the output frequency of the autogenerator. The model of the autogenerator consists of a dependent source, the transmission coefficient is determined.

It is clear from the last expression that the largest error is obtained from the change in voltage, the second error is obtained from the change in the frequency of the network, the 3rd error is obtained due to the change in the active resistance in the opposite direction, and the smallest error $(1-K_1)$ is obtained from the product of the expression of $\frac{\Delta\mu}{\mu_{ao}}+\frac{\Delta\delta}{\delta_{ao}}$.

CONCLUSION

Based on the conducted research, the following results were **the scientific novelty** obtained:

1. The issues of constructor design of transmitters of new construction for the active elements of the robotic complex have been resolved, and the increase in their technical characteristics has been justified.

2. Mathematical models were built for determining the functional parameters of electromagnetic type transmitters with a core made of structural steel, and the advantages of these transmitters were justified.

The practical significance of obtained result is that a replacement circuit that keeps the output frequency of transmitters stable at the information-measurement level of the automated control system in robotics complexes has been established and a research model.

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ВИБІР ІНФОРМАЦІЙНО-ВИМІРЮВАЛЬНИХ ЗАСОБІВ ДЛЯ РОБОТОТЕХНІЧНОГО КОМПЛЕКСУ ТА ДОСЛІДЖЕННЯ ЇХНІХ РОБОЧИХ ХАРАКТЕРИСТИК

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АНОТАЦІЯ

Актуальність. Стаття присвячена питанням вибору засобів інформаційно-вимірювальної системи (ІВС) для автоматизації робототехнічних комплексів (РТК) гнучких виробничих систем, що застосовуються в різних галузях промисловості, та дослідженню їхніх технологічних характеристик.

Мета. Мета – використання математичних моделей для дослідження робочих характеристик передавачів нової конструкції для інформаційно-вимірювального та автоматизованого керування робототехнічним комплексом у гнучких виробничих зонах.

Метод. У статті були поставлені та вирішені наступні питання: аналіз прикладного об’єкта, вибір типів інформаційно – вимірювальних та керуючих елементів створення та структури РТК; дослідження характеристик інформаційно-вимірювального передавача для керування активними елементами РТК; визначення похибки аналогового виходу передавача інформаційно-вимірювальної системи активних елементів РТК.

На основі аналізу об’єкта застосування встановлено, що структурна схема РТК на гнучкій виробничій системі включає складні технологічні, функціонально пов’язані виробничі ділянки, модулі та робототехнічні комплекси, автоматизовану систему керування ними ІСУ, регулювання, виконання, мікропроцесорну систему керування та пристрої та пристрої промислової мережі. включає в себе Наведено функціональні блок-схеми ІВС РТК і гнучкої виробничої системи. На основі досліджень встановлено, що для вимірювання механічної сили, яка діє на робочі органи промислового робота, зручно використовувати магнітопружний перетворювач з кільцевим чутливим елементом. Для цього, на відміну від існуючих передавачів, серцевина цього передавача виготовлена з цільної конструкційної сталі. Індуктивна котушка запропонованого передавача включена в LC-ланцюг автогенератора. На базі транзистора зібраний магнітопружний емітерний напівпровідник. Поперечний переріз його серцевини розрахований на механічне навантаження, яке може вивільнити сталь. Запропоновано блок-схему індукційного передавача. Пропоновані передавачі працюють за принципом автогенератора, зібраного на операційному підсилювачі. Визначено математичний вираз для визначення вихідної частоти автогенератора. Модель автогенератора складається із залежного джерела, визначений коефіцієнт передачі.

Результати. Пропонується новий передавач для вимірювання інформації маніпулятора для синхронного виконання спеціальних технологічних операцій.

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Висновки. Розроблено математичну модель визначення похибки аналогового вихідного передавача інформаційно-вимірювальної системи активних елементів РТК. Вираз ehq використовується для визначення похибки передавача, вихід якого є аналоговим, під час вимірювання поточної технологічної операції. Встановлено, що на практиці геометричні розміри передавача та кількість обмоток залишаються незмінними в процесі роботи, де вона змінюється через вплив зовнішнього середовища. Враховуючи цей варіант, була розроблена математична модель для визначення помилки передавача.

КЛЮЧОВІ СЛОВА: робототехнічний комплекс, інформаційно-вимірювальна система, передавач, індуктивний датчик, автогенератор, LC двигун, напівпровідниковий комутатор, аналоговий вихідний передавач, помилка передавача.

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