DEVELOPMENT OF THE AUTOMATED ELECTRIC DRIVE OF THE MINERAL FERTILIZER LOADER WITH DEVELOPMENT OF THE CONTROL SYSTEM

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Abstract. *At present, the automated electric drive is the basis of complex mechanization and automation of industrial processes. Automation frees a significant number of service personnel from constant shifts, during which in some cases there are only a few shifts per shift. The introduction of automatic control helps to improve the quality of service of the main technological process.*

At the enterprises the tendency of modernization of control systems of the old equipment has recently appeared. The control systems are outdated and the mechanical parts of the equipment remain at a sufficient level. New equipment is very expensive, and the modernization of the old is the only way out of this situation.

The purpose of this work is to replace the old control system of the electric drive of the reloader with a new one.

The peculiarities of the transmission conveyor operation are considered in the work, the electric drive capable of providing the necessary technological indicators of the installation is chosen. The calculation of the elements of the automatic control system, the calculation of the parameters of the electric drive. The MICROMASTER 420 frequency converter was chosen to control the induction motor. A mathematical model of the electric drive speed control system was developed.

Keywords: *power line, mathematical model of control system, reloader, agro-industrial complex, mineral fertilizers, automation of technological process.*

INTRODUCTION

At present, the automated electric drive is the basis of complex mechanization and automation of industrial processes. Automation frees up a significant number of service personnel from constant shifts, during which in some cases there are only a few shifts per shift. The introduction of automatic control helps to improve the quality of service of the main technological process.

At the enterprises the tendency of modernization of control systems of the old equipment has recently appeared. The control systems are outdated and the mechanical parts of the equipment remain at a sufficient level. New equipment is very expensive, and the modernization of the old is the only way out of this situation.

The paper considers the issue of replacing the old control system of the reloader with a new one. In this case, the mechanical parts of the conveyor remain and the electric drive control system is replaced with a more modern one. The modern electronics industry has great potential for new developments in the field of automated control systems for electric drives. With the unification of the creation of automated systems has recently gained the advantage of creating complete automated drives. This increases the performance of technological equipment. New possibilities of connection or control of the batcher by means of the computer appear.

1. ANALYSIS OF THE BASIC CONTROL SYSTEM OF THE ELECTRIC DRIVE OF THE LOADER OF MINERAL FERTILIZERS

When developing automation devices for rural installations, they must rely on the broad limits of changes in environmental parameters. This will provide highly reliable tools, as the most effective measures to combat the reliability of automation devices - the choice of elements with low risk of failure and various ways to increase reliability in the design. These specific features primarily affect the primary transducers (sensors) and executive bodies of automation, which are installed directly on the objects of automation and experience all adverse environmental conditions. Other automation units can be located in separate rooms or special cabinets that eliminate adverse environmental influences.

The sequence of nodes in the RSSC (Rheostat-contactor control system) depends on their electrical connections, reflected in the electrical circuits. The electric scheme of RSSC is a graphic form of the image of RSSC. Figure 1 shows the general functional diagram of the RSSC. It shows the functional composition of the RSSC in the form of nodes and noted their relationship. As the most complete information about the control system gives the so-called schematic diagram. It lists all the elements of the control system, displayed and marked in accordance with the standard, reflect all the electrical connections of the elements [5-7].

1.1. The choice of the electric motor for the drive of the loader of mineral fertilizers

To drive a mineral fertilizer reloader, choose the engine, power, kW, which is determined by the formula:

$$\mathrm{P} = \frac{k_3 Q}{1000\eta_{\text{м}}}(cL + H), \tag{1}$$

where k_3- he power reserve factor of the conveyor, equal 1,1 – 1,25; Q – conveyor productivity, H/c; L – distance between the axes of the end drums, m; H – lifting height, m; $\eta_{\text{м}}$ - efficiency of the reducer mechanism 0,7÷0,85; c = 1,5÷2 – for scraper conveyors; c = 0,14÷0,32 – for plate conveyors.

1.2. Development of a mathematical model of an automated electric drive

In the study of transients in three-phase asynchronous motors, it is advisable to accept the following assumptions that simplify the expression of the basic parameters and coordinates of the motor: the magnetizing forces of the motor windings are distributed sinusoidally along the circumference of the air gap; losses in the steel of the stator and rotor are absent; stator and rotor windings are strictly symmetrical with a shift of the axes of the windings by 120 °; there is no saturation of the magnetic field [13].

The equations of voltage equilibrium for the windings of the three phases of the stator have the form:

$$\left.\begin{aligned} u_{1a} &= i_{1a}R_1 + \frac{d\psi_{1a}}{dt} \\ u_{1b} &= i_{1b}R_1 + \frac{d\psi_{1b}}{dt} \\ u_{1c} &= i_{1c}R_1 + \frac{d\psi_{1c}}{dt} \end{aligned}\right\} \quad (2)$$

where $u_{1a}, u_{1b}, u_{1c}, u'_{2a}, u'_{2b}, u'_{2c}$ - instantaneous values of the phase voltages of the stator and rotor engine; $i_{1a}, i_{1b}, i_{1c}, i'_{2a}, i'_{2b}, i'_{2c}$ - instantaneous values of the stator and rotor phase currents; $\psi_{1a}, \psi_{1b}, \psi_{1c}, \psi_{2a}, \psi_{2b}, \psi_{2c}$ - complete flux couplings of phase windings; R_1, R_2 - active supports of stator and rotor windings.

In the mathematical description of three-phase asynchronous electric motors, it is convenient to operate not with instantaneous coordinate values, but with their resulting vectors. If, for example, the instantaneous current values are equal i_a, i_b, i_c then the resulting current vector is determined by the equation:

$$i = \frac{2}{3}(a^0 i_a + a i_b + a^2 i_c) = \frac{2}{3}(i_a + a i_b + a^2 i_c)\,, \quad (3)$$

where $a^0 = e^{j0} = 1$; $a = e^{j\frac{2\pi}{3}}$; $a^2 = e^{j\frac{4\pi}{3}}$.

The resulting voltage vectors are determined similarly

$$u = \frac{2}{3}\cdot(u_a + a u_b + a^2 u_c) \quad (4)$$

and flux coupling:

$$\psi = \frac{2}{3}(\varphi_a + a\varphi_b + a^2\varphi_c) \quad (5)$$

Using the expression of the resulting vectors, equation (1) can be written as a single differential equation in vector form. To do this, the first equation from (1) is increased by $\frac{2}{3}\ \alpha^0$, second on $\frac{2}{3}\ \alpha$, third on $\frac{2}{3}\ \alpha^2$. Summarizing the obtained products, we obtain:

$$\frac{2}{3}(u_{1a} + a u_{1b} + a^2 u_{1c}) = \frac{2}{3}(i_{1a} + a i_{1b} + a^2 i_{1c})R_1 + \frac{2}{3}\frac{d}{dt}(\psi_{1a} + a\psi_{1b} + a^2\psi_{1c}) \quad (6)$$

or in vector form:

$$u_1 = I_1 R_1 + \frac{d\psi_1}{dt} \quad (7)$$

The equation of an induction motor in a coordinate system rotating at an arbitrary speed ω_k, have the form:

$$\left.\begin{aligned} u_1 &= i_1 R_1 + \frac{d\psi_1}{dt} + j\omega_k\psi_1 \\ u'_2 &= i'_2\, R'_2 + \frac{d\psi_2}{dt} + j(\omega_k - p_{\ddot{I}}\,\psi_2) \end{aligned}\right\}, \quad (8)$$

where ω - angular speed of rotation of the rotor; $p_{\ddot{I}}$ - number of pole pairs.

When studying transients in an induction motor, which is controlled by the frequency and voltage of the stator, it is convenient to use the system coordinates that rotate at a speed ω_k, and is equal to the angular velocity of the magnetic field $\omega_0^{'}$, which is reduced to the number of pairs of poles and is equal to 1 (reduction to a two-pole motor).

$$\omega_0^{'} = \omega_1 = 2\pi f_1, \tag{9}$$

where f_1 - stator voltage frequency, Hz;

Therefore, based on equations (7) we can write:

$$\left.\begin{array}{l} u_1 = i_1 R_1 + \dfrac{d\psi_1}{dt} + j\omega_1\psi_1 \\ u'_2 = i'_2\, R'_2 + \dfrac{d\psi_2}{dt} + js\omega_1\psi_2 \end{array}\right\}, \tag{10}$$

where s – electric motor slip:

$$s = \frac{\omega_0 - \omega}{\omega_0} = \frac{\omega_1 - p_i\omega}{\omega_1} \tag{11}$$

Current couplings are related to currents due to inductors:

$$\left.\begin{array}{l} \psi_1 = i_1 L_1 + i_2^{'} L_m \\ \psi_2 = i_1 L_1 + i_2^{'} L_2^{'} \end{array}\right\} \tag{12}$$

To determine the electromagnetic moment of an induction motor, we use a vector product ψ_1 and i_1, then:

$$M = \frac{3}{2} p_n (\psi_1 \times i_1) \tag{13}$$

or vector product ψ_2 and $i_2^{'}$, then:

$$M = -\frac{3}{2} p_n (\psi_2 \times i_2^{'}) \tag{14}$$

Given equation (11), we can write (15) and (16):

$$M = \frac{3}{2} p_{\Pi} (i_1 L_1 + i_2^{'} L_m) \times i_1 = \frac{3}{2} p_{\Pi} L_m (i_2^{'} \times i_1) \tag{15}$$

$$M = -\frac{3}{2} p_{\Pi} (i_1 L_m + i_2^{'} L_2^{'}) \times i_2^{'} = -\frac{3}{2} p_{\Pi} L_m (i_1 \times i_2^{'}) \tag{16}$$

These equations are correct because the vector product of two equally directed vectors is zero.

To fully describe the transients in an induction motor by comparing voltages and moments, you need to add the equation:

$$M - M_o = J\frac{d\omega}{dt} \tag{17}$$

For further researches of dynamic properties of asynchronous electric motors it is expedient to present the resulting vectors in the form of projections on the complex plane and to write down them through material and imaginary parts in the following kind:

$$\left.\begin{array}{ll} u_1 = u_{1a} + ju_{1\beta}; & u_2^{'} = u^{'}_{2a} + ju^{'}_{2\beta}; \\ i_1 = i_{1a} + ji_{1\beta}; & i_2^{'} = i^{'}_{2a} + ji^{'}_{2\beta}; \\ \psi_1 = \psi_{1a} + j\psi_{1\beta}; & \psi_2 = \psi_{2a} + j\psi_{2\beta}; \end{array}\right\} \tag{18}$$

Combining the stator voltage vector with the real axis of the coordinate system $u_{1\beta} = 0$ ie putting we get:

$$u_{1a} = \frac{d\psi_{1a}}{dt} - \omega_1\psi_{1\beta} \tag{19}$$

$$0 = \frac{d\psi_{1\beta}}{dt} + \omega_1\psi_{1a} \tag{20}$$

$$u'_{2a} = i'_{2a}R'_2 + \frac{d\psi_{2a}}{dt} - s\omega_1\psi_{2\beta} \tag{21}$$

$$u'_{2\beta} = i'_{2\beta}R'_2 + \frac{d\psi_{2\beta}}{dt} + s\omega_1\psi_{2a} \tag{22}$$

Expressing also the electromagnetic moment on the equation (11) through components of vectors of currents and flux coupling:

$$M = \frac{3}{2}p_П(\psi_{1a} + j\psi_{1\beta}) \times (i_{1a} + ji_{1\beta}) \tag{23}$$

and applying the rule of vector product of vectors, we obtain the absolute value of the moment: $M = \frac{3}{2}p_П(\psi_{1a}i_{1\beta} - \psi_{1\beta}i_{1a})$, (24)

where

$$\psi_{1a} = i_{1a}L_1 + i'_{2a}L_m;\ \psi_{1\beta} = i_{1\beta}L_1 + i'_{2\beta}L_m \tag{25}$$

Using expression (2.15), we can similarly obtain:

$$M = -\frac{3}{2}p_П(\psi_{2a}i'_{2\beta} - \psi_{2\beta}i'_{2a}) \tag{26}$$

The component currents of the rotor can be expressed through the components of the flux coupling in the following form:

$$\left.\begin{aligned} i'_{2a} &= \frac{1}{L'_2}(\psi_{2a} - k_1\psi_{1a}) \\ i'_{2\beta} &= \frac{1}{L'_2}(\psi_{2\beta} - k_1\psi_{1\beta}) \end{aligned}\right\}, \tag{27}$$

where k_1 - stator electromagnetic coupling coefficient.

$$k_1 = \frac{L_m}{L_1} \tag{28}$$

$$L''_2 = L'_2 - \frac{L_m^2}{L_1} \approx L_{1\sigma} + L'_{2\sigma} \tag{29}$$

Taking into account (10) and (25), the moment expressions can be written in a form convenient for outputting the transfer functions of the engine:

$$M = -\frac{3}{2}p_П k_1\psi_1 \times i'_2 \tag{30}$$

or

$$M = -\frac{3}{2}p_П k_1(\psi_{1a}i'_{1\beta} - \psi_{1\beta}i'_{2a}) \tag{31}$$

For a motor with a short-circuited rotor in equations (19), (20) $u'_{2a} = u'_{2\beta} = 0$.

Expressed from the equations (26) ψ_{2a} and $\psi_{2\beta}$ substituting them in equations (22), (23) we obtain:

$$0 = i'_{2a} R'_2 + L'_2 \frac{di'_{2a}}{dt} - s\omega_1 L''_2 i'_{2\beta} - k_1 s\omega_1 \psi_{1\beta} \qquad (32)$$

$$0 = i'_{2\beta} R'_2 + L''_2 \frac{di'_{2\beta}}{dt} + s\omega_1 L''_2 i'_{2a} \qquad (33)$$

$$M = \frac{3}{2} p_П k_1 \psi_{1\beta} i'_{2a} \qquad (34)$$

Considering the variables in increments relative to the initial values $i'_{2a} = I'_{2a} + \Delta i'_{2a}$, $i'_{2\beta} = I'_{2\beta} + \Delta i'_{2\beta}$, $\omega_1 = \Omega_1 + \Delta\omega_1$, $s = S + \Delta s$, $M = M_{поч} + \Delta M$, we obtain equations for static mode that relate the initial values of the coordinates:

$$\frac{U_{1a}}{\Omega_1} = -\psi_{1\beta} = const \qquad (35)$$

$$0 = I'_{2a} R'_2 - S\Omega_1 L''_2 I'_{2\beta} - k_1 S\Omega_1 \psi_{1\beta} \qquad (36)$$

$$0 = I'_{2\beta} R'_2 + S\Omega_2 L''_2 I'_{2a} \qquad (37)$$

$$M_{поч} = \frac{3}{2} p_n k_1 \psi_{1\beta} I'_{2a} \qquad (38)$$

and equations for dynamic mode, which connect the increment of coordinates:

$$\Delta i'_{2a}(T_e p + 1) = \frac{s}{S_{kp}} \Delta i'_{2\beta} + \left(\frac{i'_{2\beta}}{S_{kp}} + \frac{k_1 \psi_{1\beta} \Omega_1}{R'_2}\right)\Delta s \qquad (39)$$

$$\Delta i'_{2\beta}(T_e p + 1) = \frac{s}{S_{kp}} \Delta i_{2a} - \frac{i'_{2a}}{S_{kp}} \Delta s \qquad (40)$$

Moment $M_{поч}$ in the second term of the numerator (41) can be written taking into account the accepted assumptions in the form:

$$M_{поч} = \frac{2M_{kp}}{\dfrac{S}{S_{kp}} + \dfrac{S_{kp}}{S}} \qquad (41)$$

Expression (40) will take the following for

$$\frac{\Delta M(p)}{\Delta s(p)} = \frac{M_{П.Ф.} \left[(T_e p + 1) - \dfrac{\left(\dfrac{S}{S_{kp}}\right)^2}{1 + \left(\dfrac{S}{S_{kp}}\right)^2} (T_e p + 2) \right]}{(T_e p + 1)^2 + \left(\dfrac{S}{S_{kp}}\right)^2} \qquad (42)$$

For the working part of the mechanical characteristics of the engine can be taken:

$$\left(\frac{S}{S_{кр}}\right)^2 << 1 \qquad (43)$$

Representing the dependence of the slip of the motor on the angular frequency of the stator voltage in increments and performing linearization, provided that in the working area, $S << 1$, we obtain:

$$\Delta s = \frac{\Delta\omega_1 - p_П \Delta\omega}{\Omega_1} \qquad (44)$$

The equilibrium equation of moments (18) can be written in increments as:

$$\Delta M - \Delta M_o = Jp\Delta\omega \tag{45}$$

block diagram of an induction motor when controlling the angular frequency of the stator voltage and provided that the stator flux is constant: $M_{П.Ф.Н.}$, $\Omega_{1Í}$, U_{1aH}, $\Omega_{0H} = \frac{\Omega_{1H}}{p_{Ï}}$, де Ω_{0H} - synchronous angular velocity of the motor.

Then $(\frac{\Delta\omega}{\Omega_{0H}}) = \Delta\overline{\omega}$, $(\frac{\Delta\omega_1}{\Omega_{1H}}) = \Delta\overline{\omega_1}$, $(\frac{\Delta M}{M_{П.Ф.Н}}) = \Delta\overline{M}$, $\left[\frac{\Delta M_o}{M_{П.Ф.Н}}\right] = \Delta\overline{M_o}$, $(\frac{\Delta u_{1a}}{U_{1aH}}) = \Delta u_{1a}$

Taking into account (44) will be written as:

$$\frac{\Delta\overline{M}(p)}{\Delta\overline{\omega_1}(p) - \Delta\overline{\omega}(p)} = \left(\frac{\gamma}{\nu}\right)^2 \frac{(T_e p + 1) - \dfrac{(\frac{S}{S_{kp}})^2}{1 + (\frac{S}{S_{kp}})^2}(T_e p + 2)}{(T_e p + 1)^2 + (\frac{S}{S_{kp}})^2} \tag{46}$$

where $\gamma = \frac{U_{1a}}{U_{1aH}}$ - relative stator voltage; $\nu = \frac{\Omega_1}{\Omega_{1H}}$ - the relative frequency of the stator voltage.

Or in a simplified form:

$$\frac{\Delta\overline{M}(p)}{\Delta\overline{\omega_1}(p) - \Delta\overline{\omega}(p)} = \left(\frac{\gamma}{\nu}\right)^2 \frac{1}{T_e p + 1} \tag{47}$$

Accordingly, based on equation (41) we have:

$$\frac{\Delta\overline{M}(p)}{\Delta\overline{\omega_1}(p) - \Delta\overline{\omega}(p)} = (\frac{\gamma}{\nu})^2 \frac{1}{T_M p} \tag{48}$$

where $T_M = \frac{J\Omega_{0H}}{M_{П.Ф.Н}}$ - mechanical time constant of the engine.

A simplified block diagram of an induction motor when controlling the angular frequency of the stator voltage, built on the basis of expressions (45), (46), is shown in Fig. 2.

1.3. Development of the structural scheme of the electric drive control system

Formation of necessary static and dynamic properties of the asynchronous frequency-regulated electric drive is possible only in the closed system of regulation of its coordinates. The generalized functional scheme of such a system (Fig. 2) in addition to AM and controlled frequency converter (FC) contains regulators P and sensors D of variable electric drive.

A variant of the functional diagram of the frequency control system of the AM with feedback on the stator current is presented in Fig. 3. Here are the signals i_{sa} and i_{sc}, proportional to the instantaneous value of the currents of phases A and C of the stator windings, from the output of the current sensors $ДТ_a$ and $ДТ_c$ enter the functional current converter FT, where the output signals are formed I_1, i I_{1a}, proportional to the current value of the stator current and the active component of this current. In the nodes

Σ_1, i Σ_2 summarizes control and feedback signals from functional devices A1, A2 i A3. The A4 device provides signal transmission I_1, to the input A3 only when it is exceeded on the adder Σ_3 signal I_{1max}, proportional to the value of the maximum allowable current of the stator AM. To protect the frequency converter and the motor from current overloads, the current cut-off mode with the help of an adder is used. Σ_3 and device A4.

As the load on the shaft of the AM (from the moment M1 to the moment M_2 in fig. 5 by reducing the speed of the AM and, consequently, the signal $u_{зз}$ the mismatch signal increases $\delta_s = u_к - u_{зз.} \equiv \omega_{00} - \omega \equiv s_a$, proportional to the absolute slip of the engine. Here ω_{00} — the set speed of ideal idling BP corresponding to the initial control signal $u_к$; ω — the actual speed of the BP at a given load on its shaft. At $\delta_s \neq 0$ signal $u_{РШ}$ at the output of the slider, summing with the signal $u_{к1} = u_к$ (при $I_1 < I_{1max}$), due to the integrated component of the transfer function of the controller A5 provides such an increase in the control signal u_f a frequency converter at which the frequency of the output voltage of the inverter becomes equal $f_{10}(1 + s_a)$. Simultaneously with the change of frequency due to the functional converter FP changes in comparison with the initial voltage U10 and the output voltage of the converter U1 (see Fig. 6, b). At the same time the engine speed is restored to the set value ω_{00}, that is, the absolute rigidity of the mechanical characteristics of the BP is provided (line 1 in Fig. 6, a).

When the maximum allowable stator current is exceeded AM ($I_1 \geq I_{1max}$ i, in accordance, $M \geq M_{max}$), the slider must be switched off, for example by limiting its output signal $u_{РШ}$ on level $u_{Ршmax}$ (fig. 6, C). At the same time negative feedback on the stator current with the regulator A3 come into operation, providing at the expense of simultaneous reduction of frequency and voltage of the stator of AM to their minimum values. f_{1min} i U_{1min} limiting the moment of BP at $\omega = 0$ on level Mmax (line 2 in Fig. 6, a). Minimum synchronous motor speed ω_{0min} will match the values f_{1min} i U_{1min}, and mechanical characteristics - line 3 (Fig. 6, a).

In fig. 7 presents a block diagram of a linearized system, the functional diagram of which is shown in Fig. 4, when operating the AM in the area of mechanical characteristics within the values of absolute slip $s_a < s_к$. The following notations are accepted in the scheme: β — the modulus of rigidity of the linearized mechanical characteristic AM ($\beta=2M_к/(\omega_{0ном}s_к)$).

T_e — equivalent electromagnetic time constant of the stator and rotor circuits of the BP, determined by the formula $T_e= 1/(\omega_{0эл.ном}s_к)$, where $\omega_{0ел.ном}$ — the angular velocity of the electromagnetic field of the AM at its nominal supply frequency $f_{1ном}$ = 50 Гц ($\omega_{0ел.ном} = 2\pi f_{1ном} = 314$ $с^{-1}$). Дfor BP of general industrial execution $s_к$ = 0,05…0,5 (smaller values are typical for more powerful engines), T_e = (0,006…0,06) c;

$k_{ПЧ}$ – inverter transfer factor ($k_{ПЧ} = \Delta\omega_0/\Delta u_{РШ} = 2\pi\Delta f_1/(p_п\ \Delta u_{РШ})$. When operating BP in the frequency band $f_1 \leq f_{1ном}$ = 50 Hz and the nominal control signal of the converter $u_{к.Пчном}$ correlation $\Delta f_1/\Delta u_{РШ} = f_1/u_{у.Пчном}$.

$T_{пч}$ — the time constant of the inverter control circuit, which at high frequencies modulation of the output voltage of industrial inverters (2 (50 kHz) does not exceed 0.001 s.

Transfer function PI speed controller:

$$W_{РШ}(p) = \frac{\Delta u_{РШ}}{\Delta u_{к}} = k_{РШ} + \frac{1}{T_{РШ}p} \tag{49}$$

Motor speed feedback transmission function

$$W_{зз}(p) = \frac{\Delta u_{зз}}{\Delta\omega} = k_{зз} \tag{50}$$

When the nominal control signal of the electric drive is equal $u_{зсном}$ and the corresponding nominal speed of the AM:

$$k_{зз} = u_{зсном}/\omega_{ном} \tag{51}$$

According to the structural scheme of AM, its resulting transfer function in relation to the deviation $\Delta\omega_0$:

$$W_{Д}(p) = \frac{\Delta\omega}{\Delta\omega_0} = \frac{1}{T_{е}T_{м}p^2 + T_{м}p + 1} \tag{52}$$

With $T_{м} > 4T_{е}$:

$$W_{Д}(p) = \frac{1}{(T_{01}p + 1)(T_{02}p + 1)} \tag{53}$$

where

$$\frac{1}{T_{01}} = \frac{1}{2T_e}\left(1 + \sqrt{1 - \frac{4T_{е}}{T_{м}}}\right); \quad \frac{1}{T_{02}} = \frac{1}{2T_{е}}\left(1 - \sqrt{1 - \frac{4T_{е}}{T_{м}}}\right) \tag{54}$$

If we include constants T_{02} and $T_{пч}$ to small uncompensable constants and as an assessment of their impact to take $T_{\mu} = T_{02} + T_{пч}$, then when adjusting the electric drive to the modular optimum, the integral constant and the transmission ratio of the proportional part of the RC controller will be determined as follows:

$$T_{РШ} = k_{ос}k_{пч}a_{\mu}T_{\mu}; \tag{55}$$

$$k_{РШ} = T_{01}/T_{РШ}$$

2. DESCRIPTION OF THE AUTOMATED ELECTRIC DRIVE FOR THE MINERAL FERTILIZER LOADER

Taking into account the shortcomings of the basic control system of the asynchronous electric drive of the ventilation system of the distribution station listed in the first section, it was decided to replace it with a modern one based on a frequency converter.

Frequency converter-based control systems can have any technologically necessary functions, the implementation of which is possible both due to the programmable controllers built into the converter, and additional controllers that operate in conjunction with the converters.

When operating a standard induction motor, the inverter must be selected with the appropriate power. If a large starting torque or a short acceleration time (deceleration) is required, select a converter one degree higher than the standard one.

When choosing a converter to work with special motors (motors with brakes, powerful motors, with a retraction rotor, synchronous motors, high-speed, etc.) should be guided primarily by the rated current of the converter, which should be greater than the rated motor current and features settings of converter parameters.

For the control system of the asynchronous electric drive of the loader of mineral fertilizers we will apply the frequency converter MICROMASTER 420 which general view is presented in fig. 8 [23].

The main characteristics of the MICROMASTER 420 frequency converter shown in fig. 1 [23].

The MICROMASTER 420 converter can be used to solve many tasks that require the use of drives with variable speeds. Above all, it is suitable for use in pumps, fans and conveyors. The main characteristics of the frequency converter MICROMASTER 420 are listed in table 1.

The converter differs in high productivity and comfortable use. The wide range of mains voltage allows you to use it in any part of the world.

MICROMASTER 420 has a modular design. The control panel and communication modules can be replaced without the use of any tool [23].

The connection diagram of the MICROMASTER 420 frequency converter is shown in fig. 9 [23].

Class B filter with low leakage current, it is EMC - filter for converters 1 AC 200 .. 240 V, size A and B without built-in EMC - class A filter. 1 Technical characteristics of the MICROMASTER 420 frequency converter.

Thanks to this filter, the converter meets the radiation standards EN 55011, class C.

3. CALCULATION OF ELEMENTS OF THE CONTROL SYSTEM OF THE ELECTRIC DRIVE OF THE FORKLIFT TRUCK

For the analysis of dynamics we will use the linearized block diagram received in section 1. The engine is chosen as the electric motor of a drive of system of ventilation of distributive station serial 4A90L4У3.

According to the relevant characteristics of the selected engine, calculate the values of the coefficients of the block diagram. Rated idle speed of the engine:

$$\omega_{0\text{ном}} = n \cdot \frac{2\pi}{60} = 1500 \cdot \frac{2\pi}{60} = 157 \text{ с}^{-1}$$

Rated engine speed:

$$\omega_{\text{ном}} = \omega_{0\text{ном}} \cdot (1 - s_{\text{ном}}) = 157 \cdot (1 - 0{,}067) = 146{,}6 \text{ с}^{-1}$$

Rated torque on the motor shaft:

$$M_{\text{ном}} = 9{,}57 \cdot \frac{P_{\text{ном}}}{n \cdot (1 - s_{\text{ном}})} = 9{,}57 \cdot \frac{3000}{1500 \cdot (1 - 0{,}067)} = 20{,}6 \text{ Н·м}$$

Critical moment on the motor shaft:

$$M_{\text{к}} = m_{\text{к}} M_{\text{ном}} = 2{,}2 \cdot 20{,}6 = 45{,}3 \text{ Н·м}$$

The modulus of rigidity of the linearized mechanical characteristics of AM:

$$\beta = \frac{2 \cdot M_{\text{к}}}{\omega_{0\text{ном}} \cdot s_{\text{к}}} = \frac{2 \cdot 45{,}3}{157 \cdot 0{,}279} = 1{,}03 \text{ (кг·м}^2\text{)/с}$$

Equivalent electromagnetic time constant of the stator and rotor circuits of the motor:

$$T_e = \frac{1}{\omega_{0ном} \cdot s_к} = \frac{1}{157 \cdot 0{,}279} = 0{,}023 \text{ с}$$

The parameters of the frequency converter are calculated according to the method described in [8]:

$$k_{пч} = 7; \; T_{пч} = 0{,}001 \text{ с.}$$

Speed feedback ratio:

$$k_{зз} = u_{з.с.ном}/\omega_{ном} = 1/157 = 0{,}0068 \text{ В·с}$$

Mechanical engine time constant:

$$T_м = (J_{дв} + J_{мех})/\beta = (0{,}023 + 0{,}388) / 1{,}3 = 0{,}399 \text{ с}$$

Additional time constants:

$$T_{01} = \frac{1}{\frac{1}{2 \cdot T_e} \cdot \left(1 + \sqrt{1 - \frac{4 \cdot T_e}{T_м}}\right)} = 0{,}024 \text{ с}$$

$$T_{02} = \frac{1}{\frac{1}{2 \cdot T_e} \cdot \left(1 - \sqrt{1 - \frac{4 \cdot T_e}{T_м}}\right)} = 0{,}375 \text{ с}$$

$$T_\mu = T_{02} + T_{пч} = 0{,}376 \text{ с}$$

Integral constant and transmission ratio of the proportional part of the speed controller when adjusting the electric drive to the modular optimum:

$$T_{РШ} = 4 \cdot k_{зз} \cdot k_{пч} \cdot T_\mu = 0{,}072 \text{ с}$$

$$k_{РШ} = \frac{T_{01}}{T_{РШ}} = 0{,}338 \text{ с}^{-1}$$

The schematic diagram of the PI speed controller is shown in Fig. 10.

Its transfer function:

$$W_{Ш}(p) = \frac{1 + C_1 R_2 p}{C_1 R_1 p} = \frac{1 + k_{РШ} T_{РШ} p}{T_{РШ} p} \quad (65)$$

Calculate the parameters of the regulator. We set the value of the capacity C_1=1 uF. Then:

$$R_1 = \frac{T_{РШ}}{C_1} = \frac{0{,}072}{10^{-6}} = 72 \text{ кОм}$$

$$R_2 = \frac{k_{РШ} T_{РШ}}{C_1} = \frac{0{,}024}{10^{-6}} = 24 \text{ кОм}$$

3.1. Evaluation of quality management indicators of the modernized SAC

The simulation model of the electric drive for the analysis of dynamics in the MatLab environment is given in fig. 11.

From fig. 12 shows that with increasing the transmission ratio of the proportional part of the speed controller krsh the transition time decreases from 1.55 s to 1.25 s. With a decrease in krsh, the transition time increases from 1.55 s to 1.75 s.

Transitional characteristics in Fig. 13 show that with increasing the integral constant of the speed controller TRS time of the transition process increases from 1.55 s to 2.25 s When the TRS decreases, the transient time decreases from 1.55 s to 1.25 s, but the ascetic acidity increases from 0% to 10%.

From the characteristics in Fig. 14 - 15 it is seen that the designed system is able to work out any changes in the load during operation of the electric drive and provide a constant speed for the entire period of operation of the mechanism.

CONCLUSIONS

The task of scientific work was to develop an automated electric drive of a mineral fertilizer reloader with the development of a control system. In accordance with this task performed: justification of the need to automate the technological process of the agro-industrial complex; analysis of the basic control system of the electric drive of the mineral fertilizer reloader, on the basis of which the basic control system of the electric drive of the transmitting conveyor on the basis of RKSK on the asynchronous electric drive with control from the frequency converter which allows to increase reliability of the electric drive and its service life is executed.

The MICROMASTER 420 frequency converter was chosen to control the induction motor. A mathematical model of the electric speed control system and a block diagram of the electric control system were developed.

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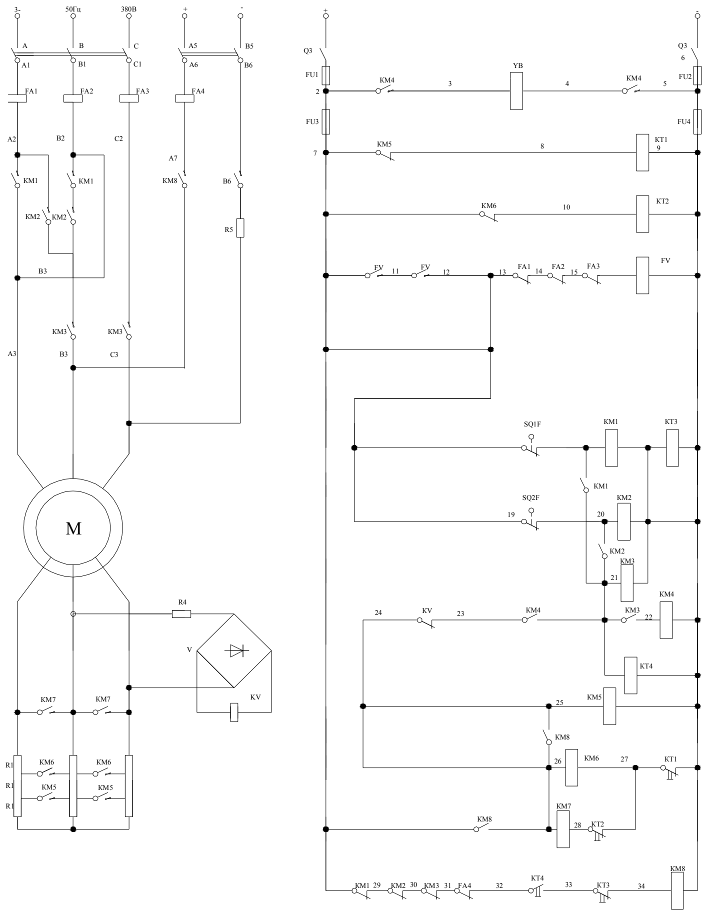

Fig.1. Schematic diagram of RCCS asynchronous motor with phase rotor

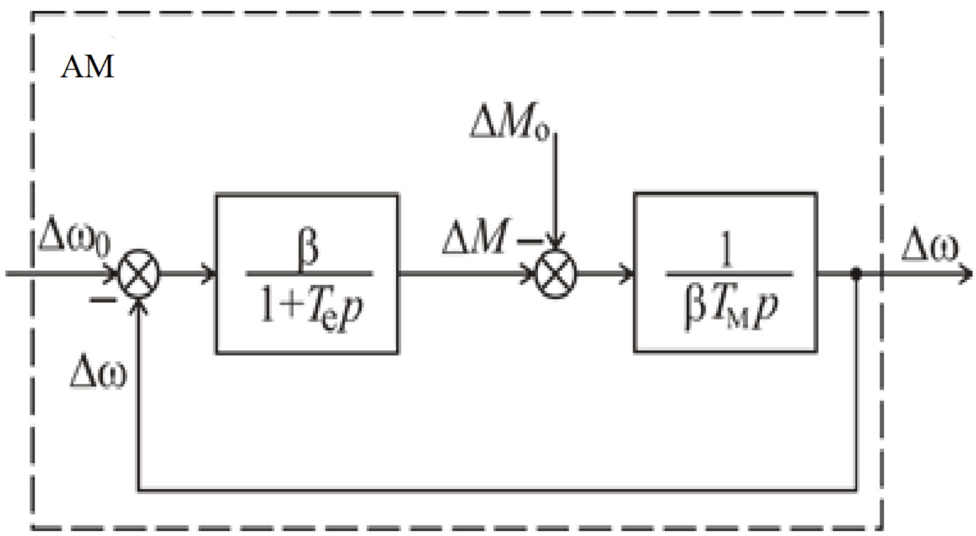

Fig. 2 Simplified block diagram of an induction motor when controlling the angular frequency of the stator voltage

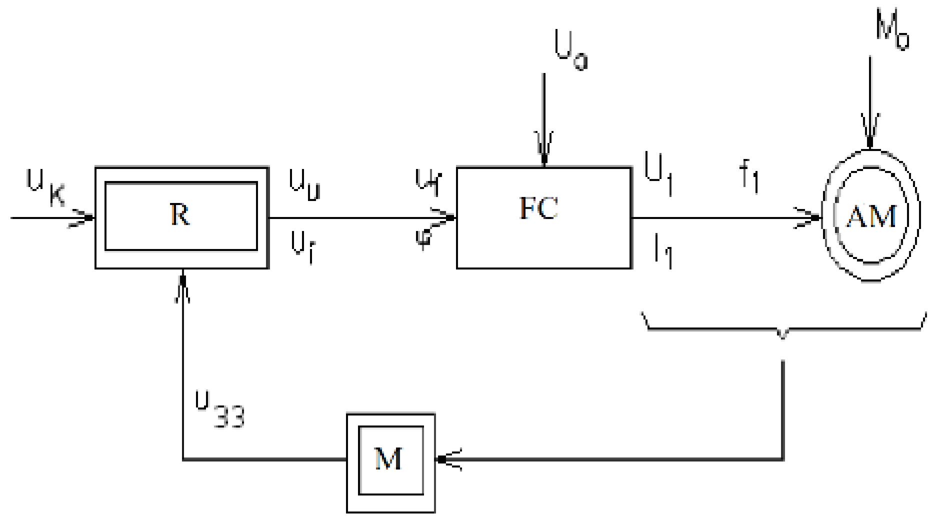

Fig. 3 Functional diagram of a closed FC-AM system
with scalar control

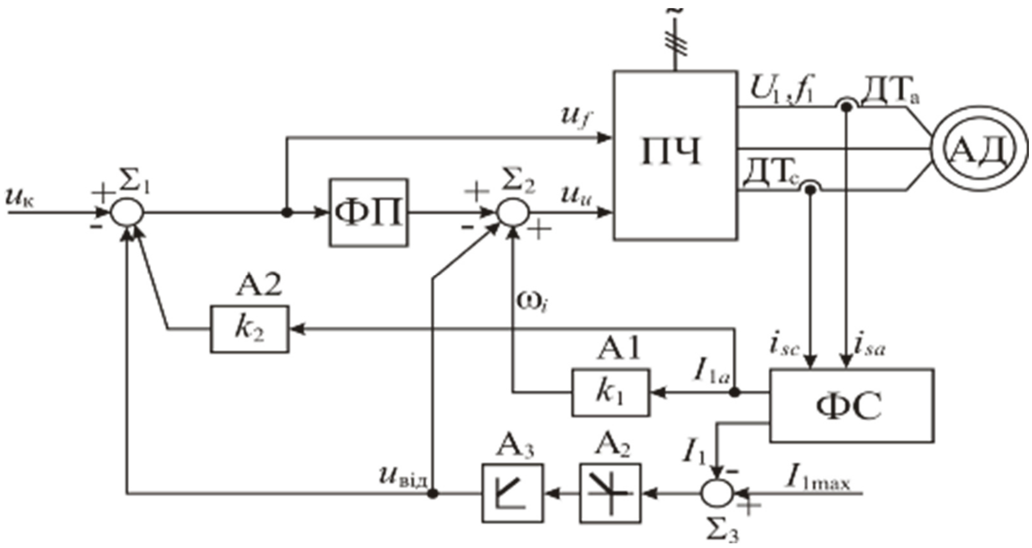

Fig. 4 Functional diagram of the FC-AM system with feedback
on the stator current

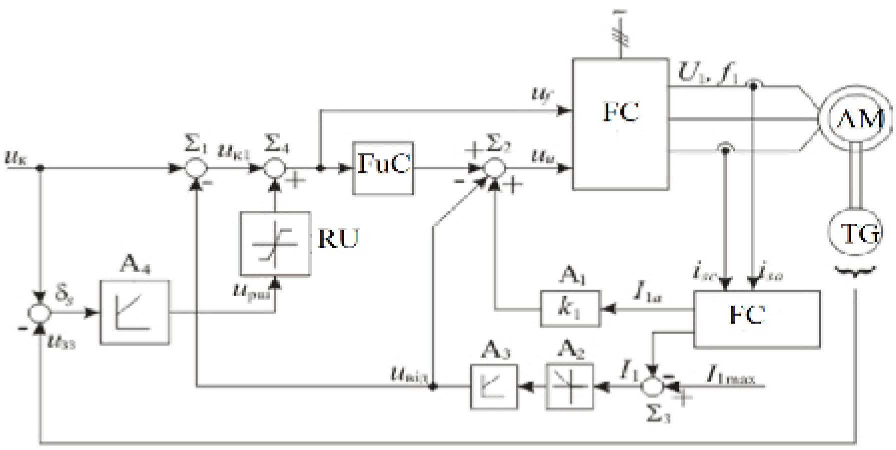

Fig.5 Functional diagram of the inverter system FC-AM
with speed feedback

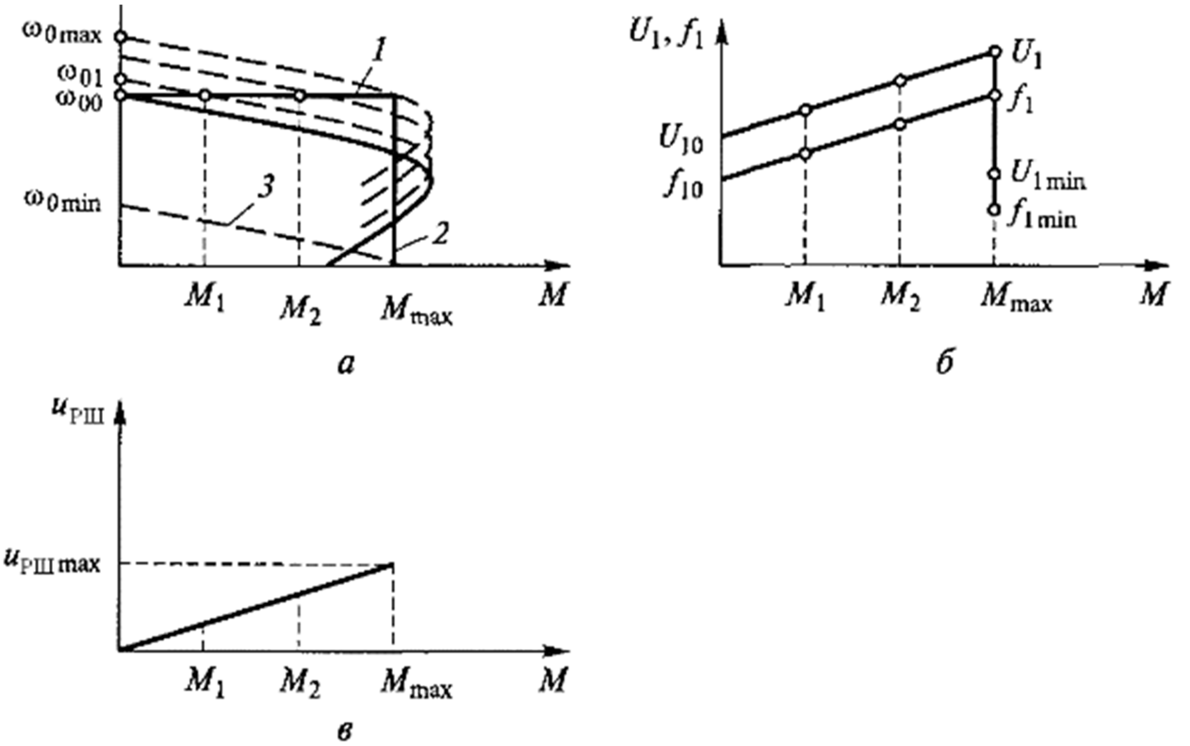

Fig.6 Mechanical characteristics (a), the dependence of the output voltage and frequency of the inverter FC (b), as well as the voltage of the speed regulator (c) from the moment in the FC-AM system with speed feedback

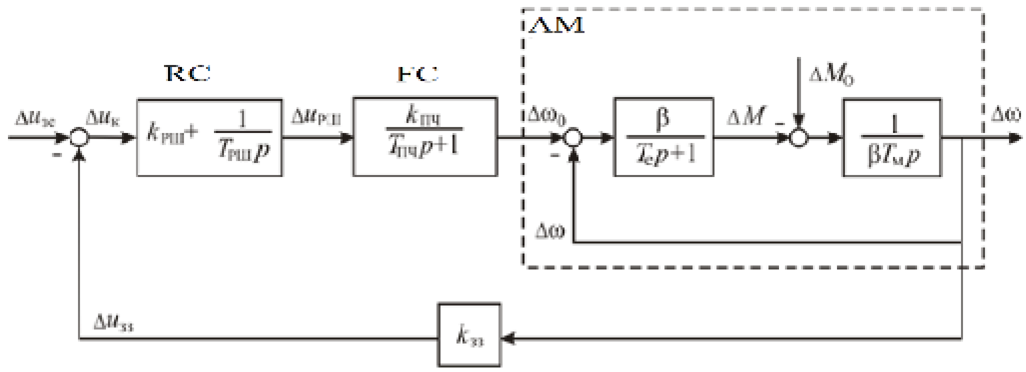

Fig.7 Block diagram of the inverter system FC-AM with speed feedback

Fig. 8. Frequency converter MICROMASTER 420

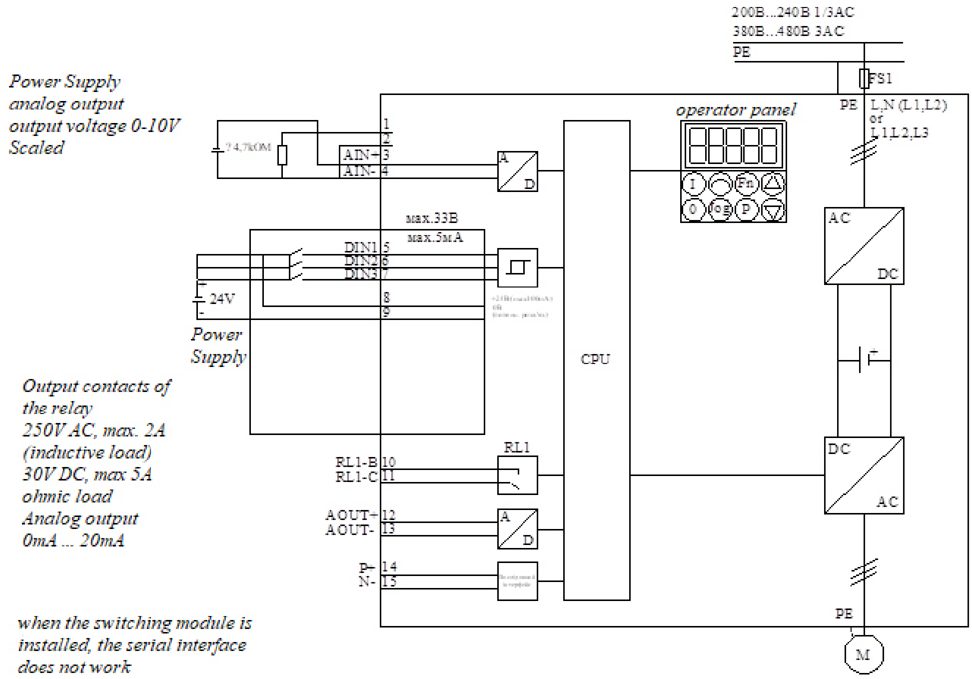

Fig. 9 Wiring diagram of the MICROMASTER 420 frequency converter

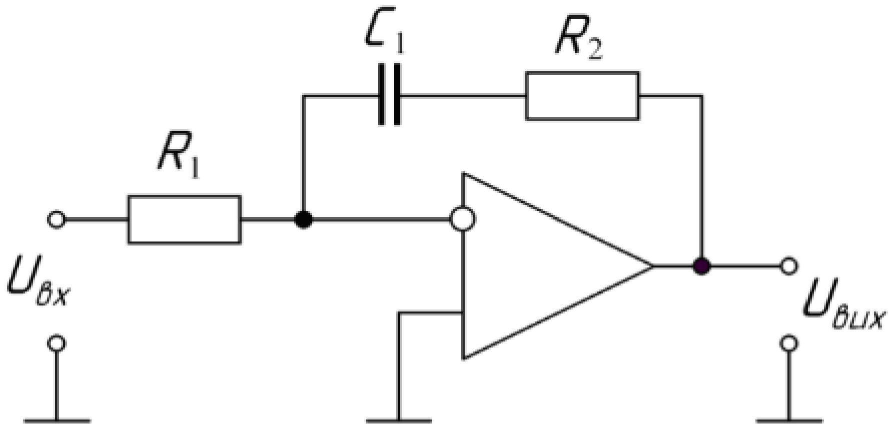

Fig. 10 Schematic diagram of the PI speed controller

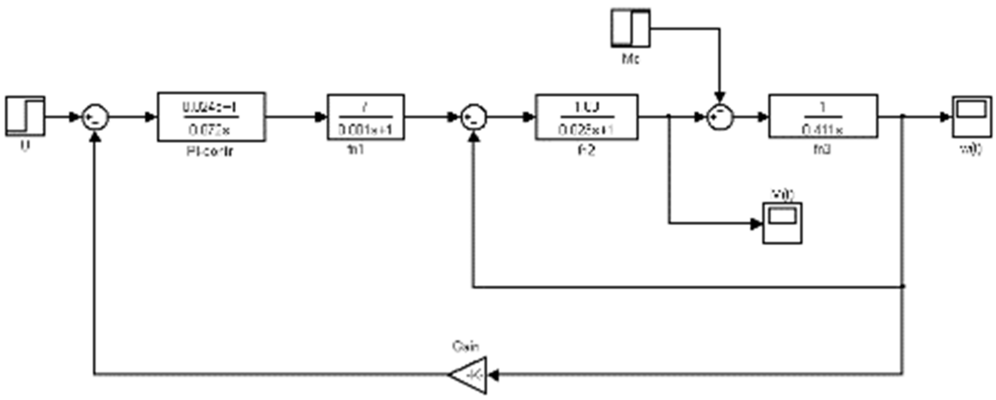

Fig.11 Simulation scheme of the modernized SAC

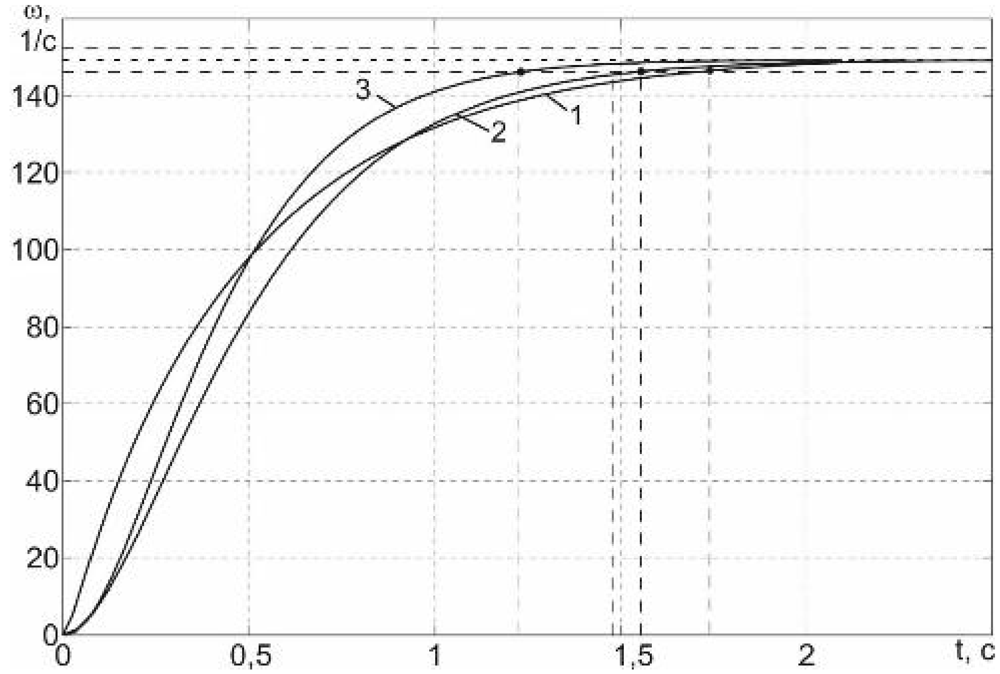

Fig.12 Transients of the system at angular velocity at $T_{РШ}$=0,072 c:
1 – $k_{рш}$=0,1; 2 – $k_{рш}$=0,338; 3 – $k_{рш}$=0,7

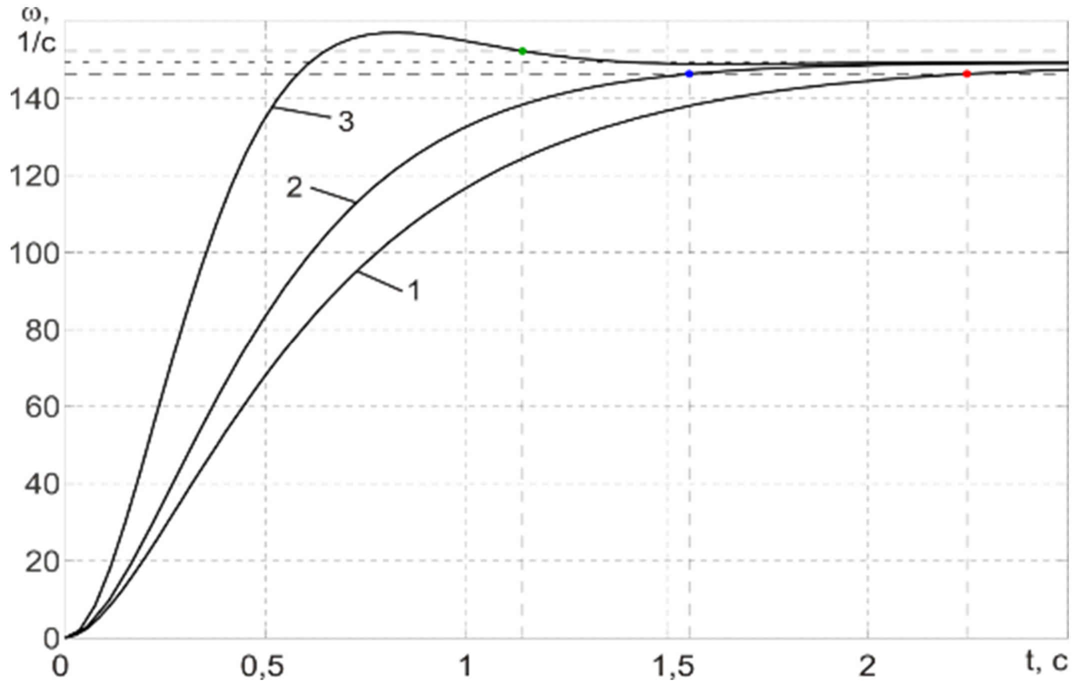

Fig. 13 Transients of the system by angular velocity при $k_{рш}$=0,338:
1 – $T_{РШ}$=0,036 c; 2 – $T_{РШ}$=0,072 c; 3 – $T_{РШ}$=0,144 c

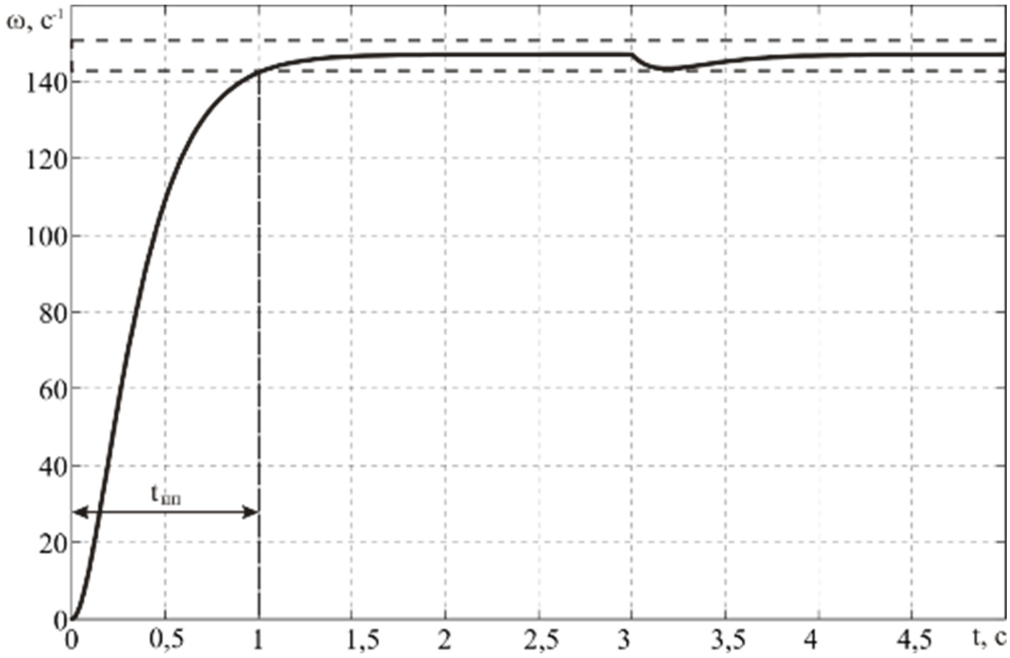

Fig. 14 Motor shaft speed transient at abrupt change of loading 100% $M_{\text{ном}}$

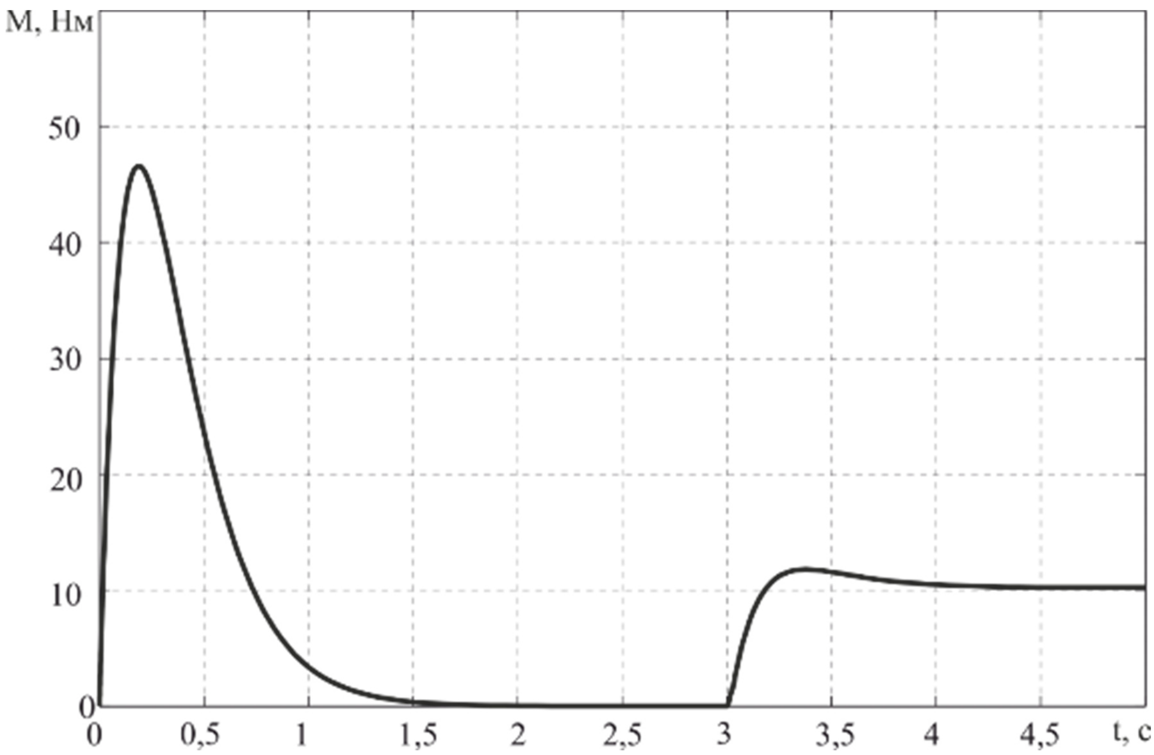

Fig. 15 Transient torque on the motor shaft
at abrupt change load 100% $M_{\text{ном}}$

Table 1

The main characteristics of the MICROMASTER 420 frequency converter

Power range	0,12 kW … 11 kW
Mains voltage	1 AC 200 V … 240 V 3 AC 200 V … 240 V 3 AC 380 V … 480 V
Laws of management	• linear dependence U/f; • programmable dependence of U/f; • direct flow control (FCC)
Technological regulator	Built-in PI controller
Digital and analog inputs	3 digital, 1 analog
Entrance	1 relay, 1 analog
Interface	Best suited for automation tasks with controllers SIMATIC S7 - 200, SIMATIC S7 - 300/400 (TIA) or SIMOTION
Additional features	BICO technology