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Mathematical Modeling of Processes in the System of Performance Automatic Control of the Small Feed-Processing Plant

Seitkazy Keshuov, Rashit Omarov, Gulmira Baisenova and Ainur Tananova
LLP "Kazakh Scientific Research Institute of Mechanization and Electrification of Agriculture",
312 Rayimbek Avenue, 050005 Almaty, Republic of Kazakhstan

Abstract: Mathematical model of the automatic control system for the performance of the small feed-processing plant has been developed. In the mathematical model, electromagnetic transients in the induction machine of the operating device, the mechanical characteristic of the operating device during the idle run, the dependence of the resistance moment of the operating device on the angle of rotating valve upon its opening and closing and the variable component of the resistance moment were taken into account. The formalization of the operation algorithm of the regulation system is carried out. The following processes in the control system are studied: engine-starting time, the process of loading the plant to steady state, working with a variable load. Recommendations for improving the algorithm and the control program were made.

Key words: Smallfeed-processing plant, system of performance automatic control, functional chart, mathematical model, transient processes, operating device

INTRODUCTION

Feed-processing plants, universal crushers and fodder crushers have been developed for small farms in the Republic of Kazakhstan. They are distinguished by their simplicity, cheapness and reliability. To improve the performance of these machines, we using the example of a small feed-processing plant DU-11, develop an automatic system for controlling the productivity of the plant.

At the same time, for carrying out numerical experiments, there is a need for mathematical modeling of processes in the control system. Numerical experiments allow us to explore the various modes of the system operation and choose the optimal parameters of its elements without conducting expensive field experiments they can also be used to train students.

One of the first work on modeling processes in the crusher was conducted by Gauldie (1953, 1954) who presented a model for predicting the output of jaw and gyratory crushers. Whiten presented one of the first studies on modeling processes in a gyratory crusher. This basic model connects the input flow, velocity and output flow of the material (Whiten, 1972). Subbotin studied the influence of disturbances at the input of the crusher on the possibility of maintaining the productivity and physico-mechanical properties of the ore. Based on the studies carried out, he proposed a system for controlling the loading of the crusher by the load of the drive motor (Subbotin, 1965). Lynch extended a simple whiten model to the dynamic model of the grinding process. Afanasiev (1975) investigated the control system of crusher load as an object of automatic control on the productivity channel, consumed for crushing power. He defined the transfer function of grain crusher in control action:

$$W(p) = \frac{K}{Tp+1} e^{pt} \quad (1)$$

Where:

K and TP+1 = Operational image of the input and output quantities
P = Operator (Afanasiev, 1975)

Herbst and Oblad (1985) presented a model in which the crusher was divided into three zones. A dynamic model was developed to describe the distribution of the material size in each zone. Energy consumption models were obtained. Tikhonov and Oleinikov (1986) carried out the similar studies as Afanasiev studies on the evaluation of the power consumed for crushing. Leite (1990) introduced the crusher model for continuous flow of material. The basic idea was to have two modes of grinding. Evertsson (1998, 1999, 2000) conducted a

Corresponding Author: Seitkazy Keshuov, LLP "Kazakh Scientific Research Institute of Mechanization and Electrification of Agriculture", 312 Rayimbek Avenue, 050005 Almaty, Republic of Kazakhstan

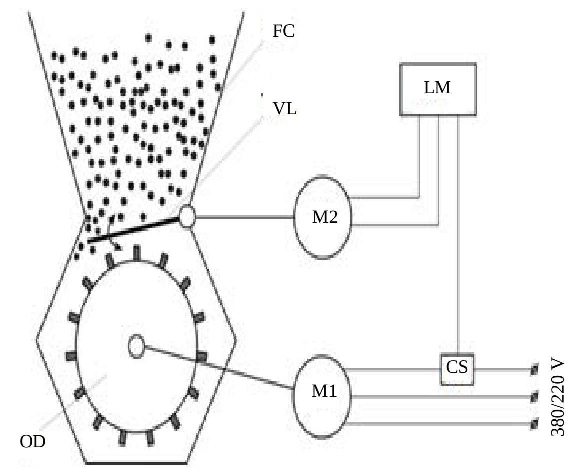

Fig. 1: Functional chart of automatic control system of the small feed-processing plant; FC: Feed Chamber of grain material; VL: Valve; OD: Operating Device; M1, Electric motor of operating device; CS: Current Sensor; LM: Logic Microcontroller; M2: Electric motor of valve

detailed study of gyratory crushers and developed a detailed model describing the movement of material within the crusher, taking into account the grindingand sorting process. Pankratov (2006) experimentally investigated and obtained the dependence of the crusher's performance on the size of the discharge gap for various materials:

$$Q = C\frac{d_{ave}+c_1}{d_{ave}+c_2} \quad (2)$$

Where:

- Q = Capacity int/h
- C, C_1, C_2 = Constant coefficients for various grain materials
- d_{ave} = Average size of gap

Johansson (2009) developed a model with a logarithmic distribution of the material size. The transport behavior of the crusher was taken into account. The process model in the crusher proposed by Itavuo (2009, 2011) and Itavuo *et al*. (2013) is based on the known static behavior of the crusher.

Distinctive features of the considered plant are small size, hammer operating device and the use of a rotating valve for regulating the flow of grain, when the power of the flow depends not only on the size of the gap but also on the angle of the valve.

Main part: The functional chart of the investigated control system of the crusher is shown in Fig. 1. It adopts the principle of controlling the productivity of a grain crusher by the magnitude of drive motor current, the device controlling the flow of material is a valve with a reversible electric drive. The control circuit includes a regulator (valve), a grain flow an operating device, a motor of the operating device, a controller, a valve drive, a valve. The controller monitors the output of the current sensor. If the current does not match the set value, the microprocessor commands the opening or closing of the valve. In this case, the valve will move until the current reaches the required value.

MATERIALS AND METHODS

Mathematical model of induction motor: When choosing a mathematical model of an induction motor, it is necessary to take into account the following factors: the load diagram of the feed-processing plant during the crushing of feeds is sharply variable with a high frequency of change in the resistance moment; starting characteristics of an engine under various operating conditions; the logic microcontroller of the control system reads the amplitude of the instantaneous current value for each period of its change.

Therefore, it is advisable to use the system of induction machine differential equations recorded for a two-phase machine equivalent to the magnetizing forces produced by the stator and rotor currents to a real three phase machine.

During the formulation of equations, depending on the problem, different coordinate systems are used. In our case, it is advisable to use the system of axes x, y, 0 rotating with respect to the stator with synchronous speed (Keshuov, 1993). Then, the transformed differential equations of the induction motor will have the following form:

$$\left.\begin{aligned}
\frac{d\psi_{x1}}{dt} &= u_{x1}-\omega_0\alpha_s^1\psi_{x1}+\omega_0\alpha_s^1k_r\psi_{x2}+\omega_0\psi_{y1}\\
\frac{d\psi_{y1}}{dt} &= u_{y1}-\omega_0\alpha_s^1\psi_{y1}+\omega_0\alpha_s^1k_r\psi_{y2}+\omega_0\psi_{x1}\\
\frac{d\psi_{x2}}{dt} &= -\omega_0\alpha_r^1\psi_{x2}+\omega_0\alpha_r^1k_s\psi_{x1}+(\omega_0-\omega)\psi_{y2}\\
\frac{d\psi_{y1}}{dt} &= -\omega_0\alpha_r^1\psi_{y2}+\omega_0\alpha_r^1k_s\psi_{y1}-(\omega_0-\omega)\psi_{x2}\\
M &= \frac{3}{2}p\omega_0\frac{k_r}{x_s\sigma}(\psi_{x2}\psi_{y1}-\psi_{x1}\psi_{y2})\\
\frac{d\omega}{dt} &= \frac{p}{J}(M-M_r)
\end{aligned}\right\} \quad (3)$$

Where:

- Ψ_{x1} and Ψ_{y1} = Stator flux-linkage along the x and y axes
- Ψ_{x2} and Ψ_{y2} = Rotor flux-linkage along the x and y axes

ω	= Angular synchronous speed and rotor speed of the motor
M and M_r	= Motor torque and resistance moment of the machine
$u_{x1} = U_{m1}\cos\gamma_0$ и $u_{y1} = U_{m1}\sin\gamma_0$	= Circuit voltage along the x and y axes
$U_{m1} = \sqrt{2}U_1$	= The maximum value of the network phase voltage
γ_0	= Initial phase of voltage
U_1	= Effective value of the network phase voltage
$x_s = x_\mu + x_1$ and $x_r = x_\mu + x_2^1$	= Synchronous reactance for rotor and stator coils
x_μ	= Inductive resistance of the magnetizing circuit, equal to the resistance of the stator and the rotor mutual inductance
r_1 and x_1	= Active and inductive resistance of the stator coil
r_2^1 and x_2^1	= Active and inductive resistance of the rotor coil, reduced to the stator winding
p	= Number of pole pairs of the motor
J	= Total moment of inertia of the rotating parts
t	= Time

$\alpha_s^1 = \frac{\alpha_s}{\sigma}$, $\alpha_r^1 = \frac{\alpha_r}{\sigma}$, $k_s = \frac{x_\mu}{x_s}$, $k_r = \frac{x_\mu}{x_r}$, $\sigma = 1 - k_r k_s$, $\alpha_r = \frac{r_2^1}{x_r}$, $\alpha_s = \frac{r_1}{x_s}$ are coefficients. Current values i_{x1}, i_{y1}, i_{x2} and i_{y2} along the x and y will be found as:

$$\left.\begin{aligned} i_{x1} &= \frac{\omega_0\alpha_s^1}{r_1}\psi_{x1} - \frac{\omega_0\alpha_s^1 k_r}{r_1}\psi_{x2} \\ i_{y1} &= \frac{\omega_0\alpha_s^1}{r_1}\psi_{y1} - \frac{\omega_0\alpha_s^1 k_r}{r_1}\psi_{y2} \\ i_{x2} &= \frac{\omega_0\alpha_r^1}{r_2^1}\psi_{x2} - \frac{\omega_0\alpha_r^1 k_s}{r_2^1}\psi_{x1} \\ i_{y2} &= \frac{\omega_0\alpha_r^1}{r_2^1}\psi_{y2} - \frac{\omega_0\alpha_r^1 k_s}{r_2^1}\psi_{y1} \end{aligned}\right\} \quad (4)$$

Resistance moment of the machine: Resistance moment of the machine will depend on time. In normal mode, the start is carried out at idle of the machine during the time t_1. If $t>t_1$ as the valve is opened, the flow of the grain to the feed chamber increases and with the resistance moment.

To calculate the start of the crusher at idle, the corresponding mechanical characteristic of the crusher operating device was used. The variable component of the resistance moment was taken into account in the form of sinusoidal harmonics of a given amplitude and frequency. Based on the results of experimental studies, we obtained the dependence of the resistance moment M_r of the operating device on the angle of valve rotation $\varphi_3 = \omega_3 t$ at a constant angular speed ω_3. If valve is opening:

$$M_r = a_{10} + k_1\alpha_{11}\omega_3(t-t_1) + k_1\alpha_{12}\omega_3^2(t-t_1)^2 \quad (5)$$

If valve is closing:

$$M_r = a_{20} + k_2\alpha_{21}\omega_3(t-t_2) + k_2\alpha_{22}\omega_3^2(t-t_2)^2 \quad (6)$$

Where:

a_{10} and a_{20}	= Initial values of the resistance moment
k_1 and k_2	= Coefficients determining the intensity of growth or decrease of the resistance moment in time

$a_{10} = 3.5$, $a_{11} = 2.8$, $a_{12} = 160$, $a_{20} = 68.9$, $a_{21} = -190$ $a_{22} = -139$ constant coefficients. Taking into account Eq. 6 of the resistance moment, we get:

$$\left.\begin{aligned} M_r &= M_{ir} + (M_{XH} - M_{ir})\left(\frac{\omega}{\omega_H}\right)^X \text{ as } t \le t_1 \\ M_r &= M_C(t_1) + M_{C\Pi} + M_{CM} \text{ as } t>t_1 \\ M_{C\Pi} &= \sum_{i=1}^{N} M_{cmi}\sin[\omega_{Mi}(t-t_1) + \varphi_{Mi}] \\ M_{CM} &= k_1[\alpha_{11}\omega_3(t-t_1) + \alpha_{12}\omega_3^2(t-t_1)^2] \text{ or} \\ M_{CM} &= k_2[\alpha_{21}\omega_3(t-t_2) + \alpha_{22}\omega_3^2(t-t_2)^2] \end{aligned}\right\} \quad (7)$$

Where:

M_{io}	= Initial resistance moment of idle run
M_{ir}	= The resistance moment of idle run at rated speed of the motor
ω_r	= Rated speed of the motor
x	= Constant coefficient characterizing the law of the resistance moment change
$M_r(t_1)$	= The value of the resistance moment of idle run at time t_1
M_{rv}	= Variable component of the resistance moment
M_{rm}	= The resistance moment of the machine in operating mode
M_{rmi}	= The maximum value
ω_{mi}	= The angular frequency
φ_{mi}	= The harmonic initial phase of the variable component of the resistance moment
i and n	= Number and quantity of harmonics
t_1, t_2	= The moments of valve opening and closing, determined in accordance with the conditions of the problem

First equation for M_{rm} is used during the valve opening, the second during closing. Equation 7 in accordance with the algorithm of the control system, the speed of the valve will be:

$$\left.\begin{aligned} \omega_v &= b \text{ if value is opening} \\ \omega_v &= b \text{ if value is closing} \end{aligned}\right\} \quad (8)$$

where, b angular speed value of the valve. In the case of modeling, for example, four consecutive perturbations of theresistance moment in the system of Eq. 7, the resistance moment of the machine M_{rm} will be written in the following form:

$$\left.\begin{aligned} &\text{if } t_2 \le t < t_3 \text{ then } M_{rm} = k_{12}[\alpha_{11}\omega_3(t-t_2)+\alpha_{12}\omega_3^2(t-t_2)^2] \\ &\varphi_v = \omega_v(t-t_2) \\ &\text{if } t_3 \le t < t_4 \text{ then } M_{rm} = k_{23}[\alpha_{21}\omega_v(t-t_3)+\alpha_{22}\omega_3^2(t-t_v)^2] \\ &\varphi_v = \omega_v(t-t_3) \\ &\text{if } t_4 \le t < t_5 \text{ then } M_{rm} = k_{14}[\alpha_{11}\omega_v(t-t_4)+\alpha_{12}\omega_3^2(t-t_4)^2] \\ &\varphi_v = \omega_v(t-t_4) \\ &\text{if } t \ge t_5 \text{ then } M_{rm} = k_{25}[\alpha_{21}\omega_3(t-t_5)+\alpha_{22}\omega_3^2(t-t_5)^2] \\ &\varphi_v = \omega_v(t-t_5) \end{aligned}\right\} \quad (9)$$

Here, an increase in the value of k leads to a proportional increase in the resistance moment of the machine, a decrease, to a decrease of the resistance moment. The value and sign of ω_3 is determined by the conditions of the experiment, the angle of the valve opening or closing starts from the moment of time $t_2, \ldots, t_5$ of the load variation.

RESULTS AND DISCUSSION

Formalization of the control system operation algorithm: The algorithm of the automatic valve position control system, developed earlier is shows in Fig. 2. As can be seen from the algorithm, the control system, depending on the value of the motor current can be in one of three possible states: ±Δ<>

$$\left.\begin{aligned} &\text{State 0:} \\ &\omega_v = 0 \text{ if } I_{m_{max}} \ge I_{m1} \ge I_{m_{min}} \\ &\text{State 1:} \\ &\text{if } I_{m1} < I_{m_{min}} \text{ then } \omega_v = b \\ &\text{if } I_{m1} = I_{m_{op}} \pm \Delta I_{m_{op}} \text{ then } \omega_v = 0 (\text{State } 0) \\ &\text{State 2:} \\ &\text{if } I_{m1} < I_{m_{max}} \text{ then } \omega_v = -b \\ &\text{if } I_{m1} = I_{m_{op}} \pm \Delta I_{m_{op}} \text{ then } \omega_v = 0 (\text{State } 0) \end{aligned}\right\} \quad (10)$$

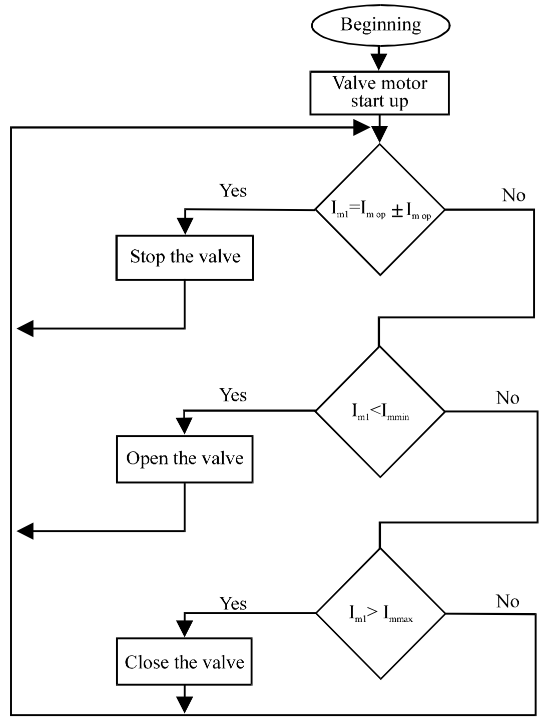

Fig. 2: Algorithm of automatic valve position control system

Where:

$I_{m_{min}}, I_{m_{max}}$ and $I_{m_{op}}$ = The maximum instantaneous value for the period of the smallest permissible, the maximum permissible and operating current

$\Delta I_{m_{op}}$ = Permissible operating current deviation

Mathematical model of the control system. For specific calculations, the obtained equations are reduced to the standard form:

$$\left.\begin{aligned} \frac{d\psi_{x1}}{dt} &= c_{11}\psi_{x1}+c_{12}\psi_{y1}+c_{13}\psi_{x2}+c_{14}\psi_{y2}+c_{15} \\ \frac{d\psi_{y1}}{dt} &= c_{21}\psi_{x1}+c_{22}\psi_{y1}+c_{23}\psi_{x2}+c_{24}\psi_{y2}+c_{25} \\ \frac{d\psi_{x2}}{dt} &= c_{31}\psi_{x1}+c_{32}\psi_{y1}+c_{33}\psi_{x2}+(c_{34}-\omega)\psi_{y2}+c_{35} \\ \frac{d\psi_{y2}}{dt} &= c_{41}\psi_{x1}+c_{42}\psi_{y1}+(c_{43}-\omega)\psi_{x2}+c_{44}\psi_{y2}+c_{45} \\ M &= c_{51}\psi_{x2}\psi_{y1}+c_{52}\psi_{x1}\psi_{y2} \\ \frac{d\omega_g}{dt} &= c_{61}M+c_{62}M_C \end{aligned}\right\} \quad (11)$$

Here, M_r calculated according to Eq. 7. Operation of control system rest on conditions Eq. 10. Current along the x and y axes will be as follows:

$$\left.\begin{aligned} i_{x1} &= c_{71}\psi_{x1}+c_{72}\psi_{y1}+c_{73}\psi_{x2}+c_{74}\psi_{y2} \\ i_{y1} &= c_{81}\psi_{x1}+c_{82}\psi_{y1}+c_{83}\psi_{x2}+c_{84}\psi_{y2} \\ i_{x2} &= c_{91}\psi_{x1}+c_{92}\psi_{y1}+c_{93}\psi_{x2}+c_{94}\psi_{y2} \\ i_{y2} &= c_{101}\psi_{x1}+c_{102}\psi_{y1}+c_{103}\psi_{x2}+c_{104}\psi_{y2} \end{aligned}\right\} \quad (12)$$

Coefficients of Eq. 11 and 12 are equal to:

$$c_{11} = c_{22} = -\omega_0\alpha_s^1;\ c_{12} = \omega_0; c_{13} = c_{24} = \omega_0\alpha_s^1 k_r$$

$$c_{14} = c_{23} = c_{32} = c_{35} = c_{41} = c_{45} = 0;\ c_{15} = U_{x1}$$

$$c_{21} = -c_{12};\ c_{25} = U_{y1};\ c_{31} = c_{42} = \omega_0\alpha_r^1 k_s$$

$$c_{33} = c_{44} = -\omega_0\alpha_r^1;\ c_{34} = \omega_0;\ c_{43} = -c_{34}$$

$$c_{51} = \frac{3}{2}p\omega_0\frac{k_r}{x_s r};\ c_{52} = -c_{51};\ c_{61} = \frac{p}{I};\ c_{62} = -c_{61}$$

$$c_{71} = c_{82} = \frac{\omega_0\alpha_s^1}{r_1};\ c_{72} = c_{74} = c_{81} = c_{83} =$$

$$c_{92} = c_{94} = c_{101} = c_{103} = 0$$

$$c_{73} = c_{84} = \frac{\omega_0\alpha_s^1 k_r}{r_1}; c_{91} = c_{102} = -\frac{\omega_0\alpha_s^1 k_s}{r_2^1}$$

$$c_{93} = c_{104} = \frac{\omega_0\alpha_r^1}{r_2^1}$$

Instantaneous real voltage values u_A and current i_A of the motor phase is found as:

$$u_A = u_{x1}\cos\gamma + U_{y1}\sin\gamma \quad (13)$$

$$i_A = i_{x1}\cos\gamma + i_{y1}\sin\gamma \quad (14)$$

where, $\gamma = \int_0^t \omega_0\,dt + \gamma_o$ rotation angle of the stator magnetic field. The maximum and effective values of voltages and currents can be found as:

$$U_{m1} = \sqrt{U_{x1}^2 + U_{y1}^2} \quad (15)$$

$$U_1 = \frac{1}{\sqrt{2}}\sqrt{U_{x1}^2 + U_{y1}^2} \quad (16)$$

$$I_{m1} = \sqrt{i_{x1}^2 + i_{y1}^2} \quad (17)$$

$$I_1 = \frac{1}{\sqrt{2}}\sqrt{i_{x1}^2 + i_{y1}^2} \quad (18)$$

$$I_{m2} = \sqrt{i_{x2}^2 + i_{y2}^2} \quad (19)$$

$$I_2 = \frac{1}{\sqrt{2}}\sqrt{i_{x2}^2 + i_{y2}^2} \quad (20)$$

Equations 11-20 allow simulating the basic operating modes of the feed-processing plant and the system for controlling its productivity. When developing a control system, it is important to select the currents magnitude $I_{m_{min}}$ and $I_{m_{max}}$. The choice is carried out by criterion of motor power efficiency and productivity of the plant. The energy efficiency of the motor is mainly determined by the efficiency factor η. The magnitude of current $I_{m_{min}}$ is assumed to be $\kappa_3 = 0.875$, at which the efficiency reaches the largest value equal to $\eta = 0.88$. The current $I_{m_{max}}$ is limited by the heating conditions and cannot be greater than the nominal value I_{mn}, therefore, $I_{m_{max}} = I_{mn}$ and corresponds to $\kappa_3 = 1$.

The value of the operational current $I_{m_{op}}$ is taken equal to the arithmetic mean value of the detected currents. Numerical solutions of the obtained ordinary differential equations with initial conditions were carried out based on MathCad Software package by Runge-Kutta method of the fourth order. The integration step taken by the condition $|f(x_0)-f(x_1)|<10^{-3}$ was 10^{-6}sec.

To find the solution of nonlinear differential equations, the program code RK (y, x1, xn, n, R, C) for this method was written by means of MathCad. Processes study in the control system. Starting time of the motor. The start-up time is necessary to determine the time setting t_1 of the control system, from which the opening of the valve starts.

Simulation of the start-up was carried out in the idle mode of the machine, the presence of grain in the feed chamber of the machine and the presence of grain in the feed chamber with reduced network voltage. Hereinafter, the load diagrams of the motor are given in the form of the dependence $I_{m1} = f(t)$, since, the control is performed on the maximum value of the instantaneous current.

An example of calculation of the dynamic mechanical characteristicand the load diagram during the motor start-up under the worst conditions is shown in Fig. 3. The following initial data for calculations were given:

$$U_1 = 203.5\ V;\ \omega_0 = 314\ \frac{rad}{sec};\ \gamma_o = 0;\ I_{xx} = 8{,}59A;\ r_1 = 0.42\Omega;\ x_1 = 0.64\ \Omega;\ r\frac{1}{2} = 0.26\ \Omega;\ x\frac{1}{2} = 0.12\ \Omega;\ x\mu = 4.2\,\Omega\ p = 1;\ M_{io} = 25\ N\cdot m;\ M_{ir} = 25\ N\cdot m;\ \omega_{gH} = 303.53\ \frac{rad}{sec};\ x = 1;\ M_{rm} = 0;\ \omega_m = 5\ \frac{rad}{sec};\ \varphi_m = 0;\ J = 0.02\ kg\cdot m^2;\ k = 1;\ \alpha_1 = 2.8;\ \alpha_2 = 160;\ \omega_v = 0.01\ \frac{rad}{sec};\ I_{m_{min}} = 26.9A;\ I_{m_{max}}\ 30.7\,A;\ I_{m_{op}} = 28.8A;\ \Delta I_{m_{op}} = 0.1A;\ t_1 = 1\ sec;\ t = 1.25\ sec$$

Initial conditions:

$$\psi_{x1}(0) = 0;\ \psi_{y1}(0) = 0;\ \psi_{x2}(0) = \psi_{y2}(0) = \omega_g = 0$$

As can be seen from Fig. 3, the maximum start-up time is about 1 sec, therefore in the control system operation algorithm, the time t_1 must be at least 1 sec. The process of loading the machine to a steady state. Modeling is carried out with the same initial data and initial conditions, except for the voltage value of the network U_1 = 220 V. In addition for this and subsequent modes, we introduce the following conditions: the maximum instantaneous value for the period of the permissible operating current $I_{m_{max}} = 30.7$ A. We shall carry out experiments for different intensities of load increase k = 0.5, 1 and 1.5 and different angular speed of the valve ω_3 = 0.005, 0.01 and 0.02 rad/sec.

The results of calculations without indication of the start-up process are shows in Fig. 4. As we can see in all cases the steadystate mode sets in at $I_{m_{op}} = 20.5\,A$ which corresponds to the given control algorithm.

Variable load mode: This mode should be modeled to study the operation of the control system according to conditions (Eq. 10).

During the experiments, the resistance moment increased and decreased within the limits corresponding to the currents $I_{m_{min}}$ and $I_{m_{max}}$, then decreased below the value $I_{m_{min}}$ and increased up to the value $I_{m_{max}}$.

The calculation results of the load diagram of the machine M_{rm} = f (t), the motor I_{m1} = f (t) and the change in the opening angle of the valve φ_v = f (t) for the case of a single decrease in the resistance moment within the currents $I_{m_{min}}$ and $I_{m_{max}}$ and changes in the resistance moment below the value $I_{m_{min}}$ are shown in Fig. 5.

The results of the experiments showed that the mathematical model provides a simulation of the control system operation in accordance with the specified algorithm. Mode with sharply variable load of different amplitude and frequency. In the feed-processing plant, the frequency of the fundamental harmonic of the variable component of the resistance moment, can vary in the range 0-4 Hz depending on the type of the processed crop. In certain modes of operation, the frequency can reach more than 190 Hz by the number of strokes of four hammers of the rotor with a speed of 29001/min. The variable component of the load moment in the mathematical model of the control system is taken into account by the moment M_{rv} in the system of Eq. 7. By changing the amplitude M_{rmi} and the angular frequency ω_{mi} of th harmonic, the required law of variation M_{cn} can be established. If necessary, it is also possible to set the initial phase φ_{mi}.

During the simulation, the amplitude and angular frequency of the moment M_{cn} were equal to M_{rm} = 10 N·m, ω_m = 24 and 1193 rad/day (4 and 200 Hz). The calculations were made for the limits of the change in the instantaneous value of the variable component of the resistance moment corresponding to the values of the current I_{m1}between $I_{m_{min}}$ and $I_{m_{max}}$ beyond.

Results of calculating the load diagram of the motor I_{m1} = f (t) and changes of the valve opening angle φ_v = f (t) for M_{rm} = 10 N·m, ω_{m1} = 24 rad/sec (4 Hz), n = 1 as the appearance of the variable component after full opening and during the opening of the valve are shows in Fig. 6.

It can be seen from the figures that at an angular frequency of 24 rad/sec, the amplitude of the variable current component, relative to the corresponding amplitude of theresistance moment decreases by 7.4 times due to mechanical and electromagnetic inertia. In accordance with the motor load control algorithm, if the variable component appears after the valve is fully opened if the amplitude of the current I_{m1} is within $I_{m_{min}}$ and $I_{m_{min}}$ the position of the valve does not change.

In the case of theresistance moment variable component appearance during the opening of the valve, the valve stops when the amplitude of the variable component reaches $I_{m_{op}}$. This leads to the stabilization of

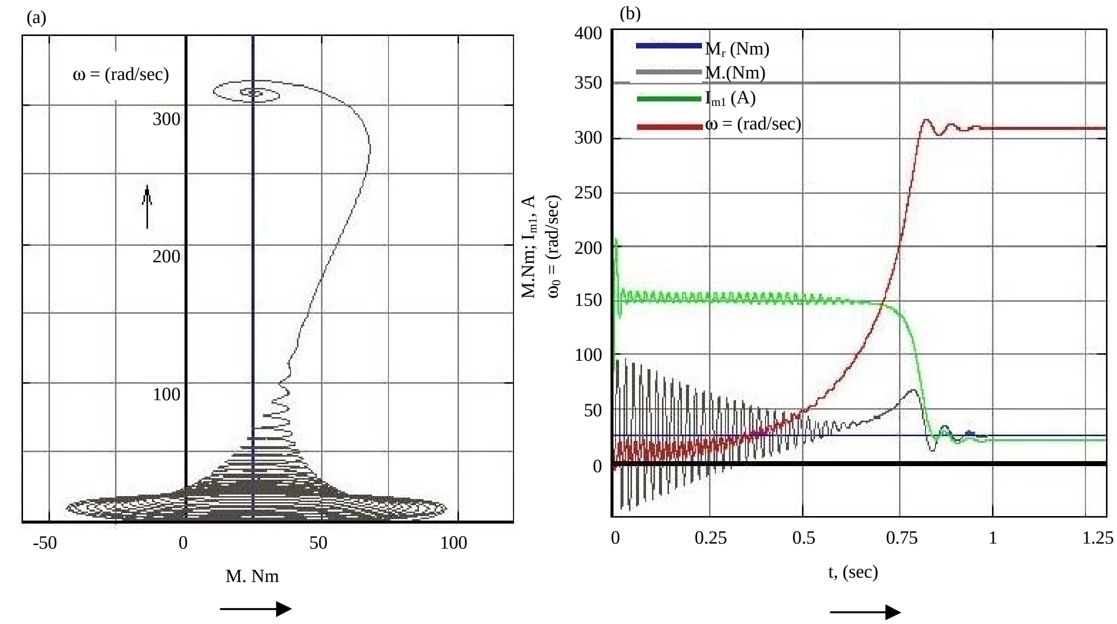

Fig. 3: The dynamic mechanical characteristi $\omega = f(M, M_r)$: a) Load diagram; M, M_r I_{m1}, $\omega = f(t)$ b) The motor and machine at start-up in case of grain presence in the feed chamber and reduce network voltage

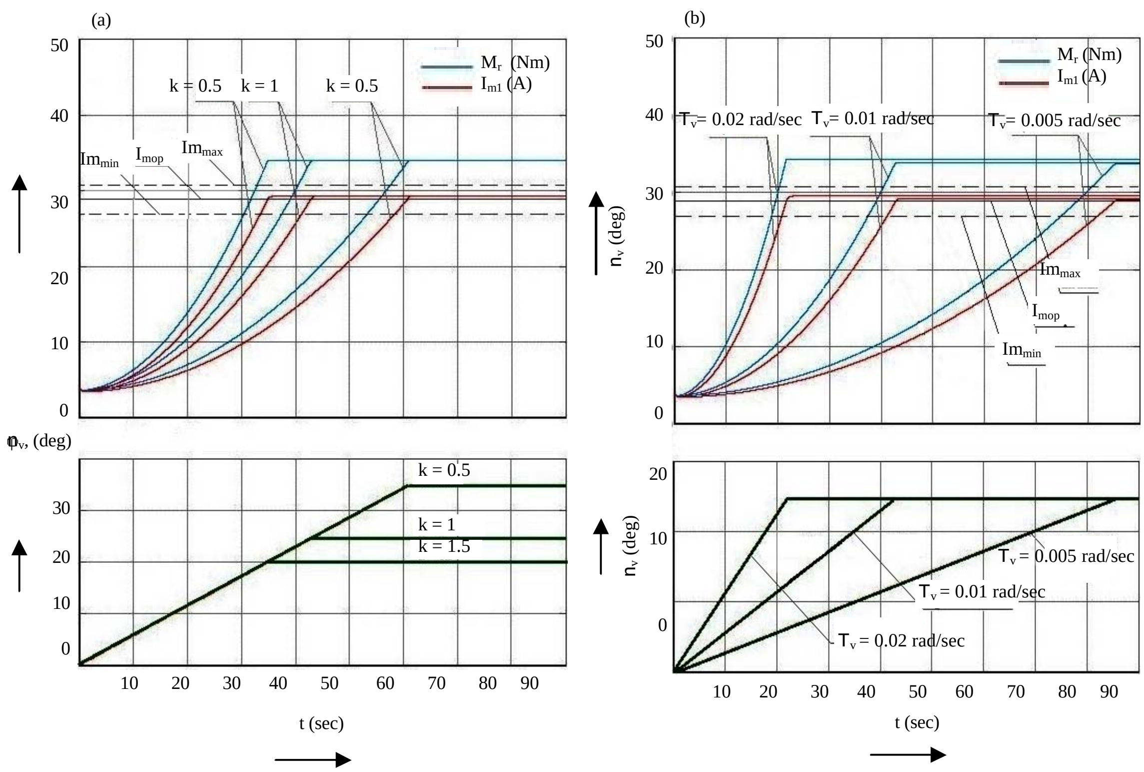

Fig. 4: Load diagrams M_r Im_1, $\omega = f(t)$ and opening angle of the valve $\varphi_v = f(t)$ in the loading of the machine to a steady value: a) k = var, v = const and b) k = const, ω = var

the average value of the current at a level below $I_{m_{op}}$ by the magnitude of the current variable component amplitude which in turn leads to an underload of the motor. This should be taken into account when developing and improving the algorithm and motor load control program.

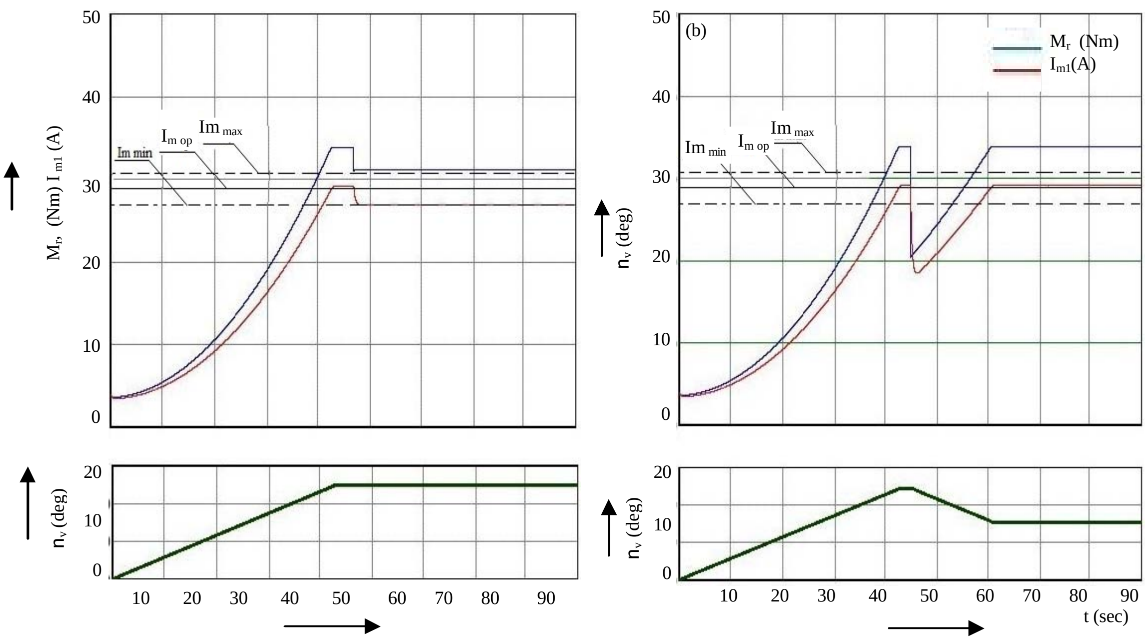

Fig. 5: Load diagrams M_r Im_1, = f (t) and changes of the valve opening angle φ_v = f (t) as the load decreases within the limits Im_{min} and b) below the value; a) below the value Im_{min}

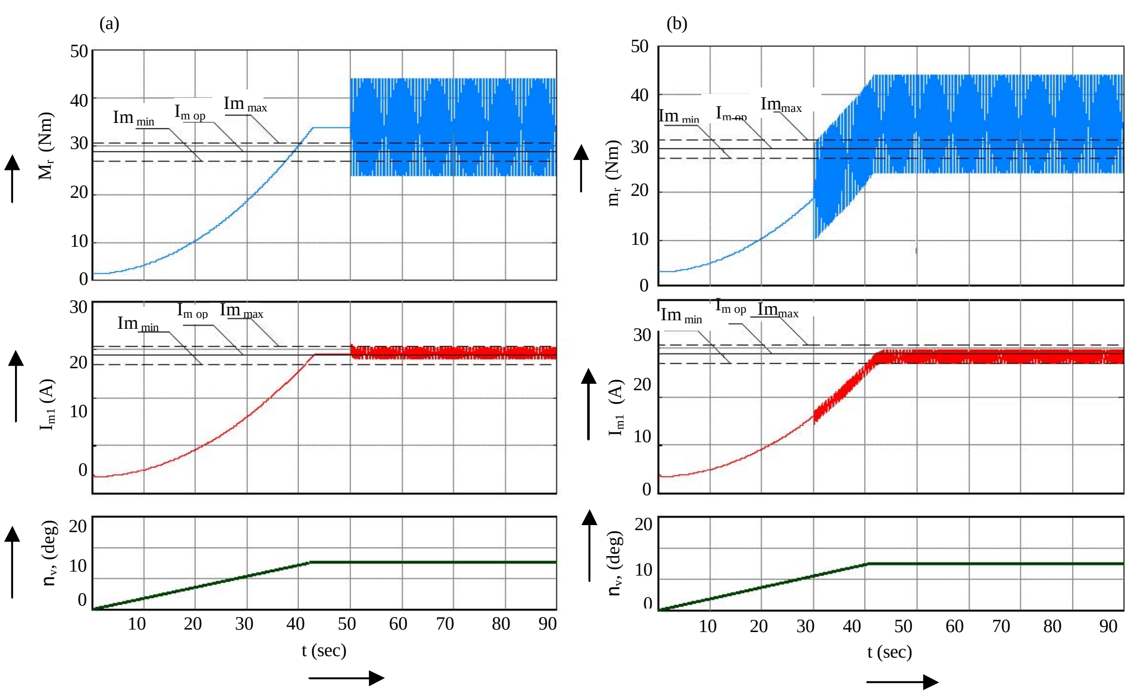

Fig. 6: Load diagrams M_r, Im_1 = f (t) and changes of the valve opening angle φ = f (t): a) The appearance of the variable component after full opening and b) during the opening of the valve

CONCLUSION

The developed mathematical model of the system for performance automatic control of the small feed-processing plant makesit possible by conducting numerical experiments to investigate various modes of the system operation to improve the algorithm and control program without carrying out expensive full-scale experiments. The results of the experiments showed that the delay in the opening of the valve at the start-up of the plant should be at least 1 sec. When developing a program for controlling the capacity of the plant, it is necessary to take into account the presence of the resistance moment variable component which leads to the stabilization of the current average value below the specified value. Numerical experiments allow us to verify the correctness of the control algorithm.

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