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Power stabilization system for the regulated electric drive of transport vehicles

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Power stabilization system for the regulated electric drive of transport vehicles

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Abstract. One of the important parameters of using the hydraulic transport system in mining enterprises is considered. A method for regulating the ground pump drive and a computer model of the drive power stabilization system are proposed. The simulation was performed in the Scilab program. The performance of the proposed model was checked. The results of simulation with different values of the current and torque are shown. The efficiency of the proposed method for regulating the ground pump drive is evaluated.

1. Introduction

Many mining transport vehicles operate under sharply variable loads with limited power from a primary energy source such as a heavy-duty dump truck diesel generator, battery, or power grid for a mine electric locomotive [1, 2]. In such conditions, it is rational to implement a power stabilization mode in the electric drive, in which the speed of rotation of the drive motor shaft decreases with the increase of the load. In the authors ' opinion the same operating mode would be advisable to use in systems of controlled electric drive of slurry pumps used in hydraulic transport systems at mining and processing enterprises. When the concentration of the pumped pulp changes, the load on the drive increases in proportion to the increase in mass flow. It leads to increased wear of the electromechanical equipment of pumping stations and to a decrease in the efficiency of the hydraulic transport system.

It is important to increase the energy intensity of systems for reducing production costs. The equation of the energy intensity is [3]:

$$e = \frac{N}{q_{sol} L} = \frac{\rho_{mix} g I_{mix}}{3.6 \rho_{sol} c_{vol}}, \qquad (1)$$

where N - pump output, kW; q_{sol} - productivity of the system of solid material, tons per hour; L - pipeline length, km; ρ_{mix} - density of the slurry, kg/m^3; ρ_{sol} - density of solid material, kg/m^3; g - acceleration of gravity, meters per second; I_{mix} - specific pressure loss; c_{vol} - volume concentration of solid particles.

The formula shows the dependence. The pulp concentration increases above the nominal value, the energy consumption of hydraulic transport increases significantly. In this case, the mechanical power on the motor shaft exceeds the nominal value. This leads to increased heating of the engine and to a decrease in its resource. Since it is not always possible to ensure the stability of the pulp concentration, it is proposed to limit the power consumed by the engine by using a frequency-controlled electric drive. Its algorithm will generate an artificial mechanical characteristic close to the constant power curve. In this case, when the load increases, the speed setting will automatically decrease and the load on the drive motor is limited.

When the power is stabilized, this problem is partially solved, since when the pulp concentration changes, the drive load changes simultaneously, which leads to an automatic change in the drive speed and accordingly to a change in the mass flow rate.

2. Analytical studies of regulation

The power stabilization mode cannot be provided over the entire load range. At low loads, the speed of rotation of the engine shaft may exceed the permissible for the mechanical design of the engine and mechanism, in particular, for their bearing units [4]. The maximum torque of the electric drive must also be limited for reasons of limiting the permissible drive current and mechanical forces. The artificial mechanical characteristic must have the form shown in figure 1.

Usually, in electric drive systems, when it is necessary to obtain a curve close to the constant power curve, DC series-wound motors or universal collector machines were used. In such motors, the field winding is switched on in series with the armature winding, which automatically reduces the field flow when the load of the electric motor decreases and increases it when the load increases. The mechanical characteristic is obtained automatically like a constant power curve.

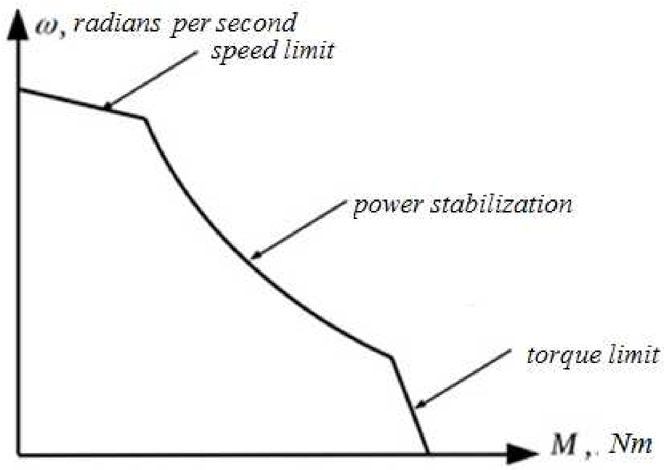

Figure 1. Artificial mechanical characteristics of an electric drive with power stabilization.

AC drives have significant advantages over DC drives. They have the best mass-dimensional characteristics, simple design, high reliability, lower maintenance costs [5]. Usually they have a rigid natural mechanical characteristic far from the constant power curve, so the development of control systems that provide the formation of artificial mechanical characteristics is an urgent task (figure 1). This paper considers the formation of such a characteristic in an adjustable electric drive based on an asynchronous electric motor with a vector control system.

When vector control of the speed of an asynchronous electric motor in a coordinate system oriented by the vector of the flow coupling of the rotor, the electromagnetic moment is equal to [6]:

$$M = \frac{3}{2} p K_r \psi_r i_{sq}, \tag{2}$$

where p - number of pairs of poles; $K_r = \frac{L_m}{L_r}$ - a constant coefficient equal to the ratio of the magnetization inductance to the rotor scattering inductance; ψ_r - rotor flux linkage, Wb; i_{sq} - moment-forming component of the motor stator current, A.

For special projections on the d and q axes, the equations take the form (3-8). For an engine with a closed-loop rotor we used:

$$\overrightarrow{U_r} = 0.$$

$$\omega_k = \omega_r$$

As a result, we have the equations:

$$U_{sd} = R(1+T_s^{'}s)I_{sd} - \omega_k L_s^{'} i_{sq} - \frac{K_r}{T_r}\Psi_{rd}, \tag{3}$$

$$U_{sq} = R(1+T_s^{'}s)I_{sq} + \omega_k L_s^{'} i_{sd} + K_r p\omega\Psi_{rd}, \tag{4}$$

$$0 = -K_r R_r i_{sd} + \frac{1}{T_r}\Psi_{rd} + s\Psi_{rd}, \tag{5}$$

$$0 = -K_r R_r i_{sq} + (\omega_k + p\omega)\Psi_{rd}, \tag{6}$$

$$M = \frac{3}{2} pK_r \psi_r i_{sq}, \tag{7}$$

$$Js\omega = M - M_c. \tag{8}$$

Block diagrams (figures 2-5) answer the equation (3-8).

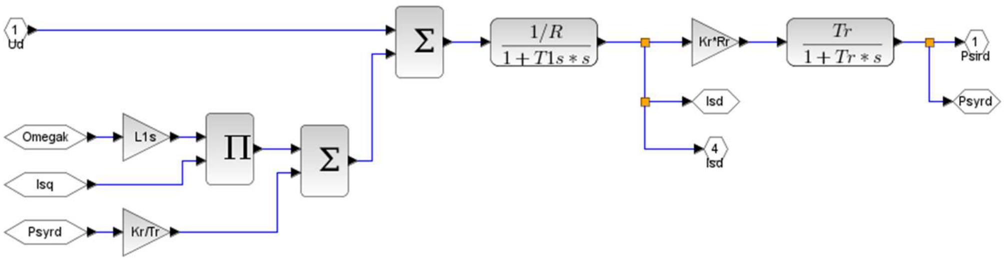

Figure 2. Computer model of current computations i_{sd}.

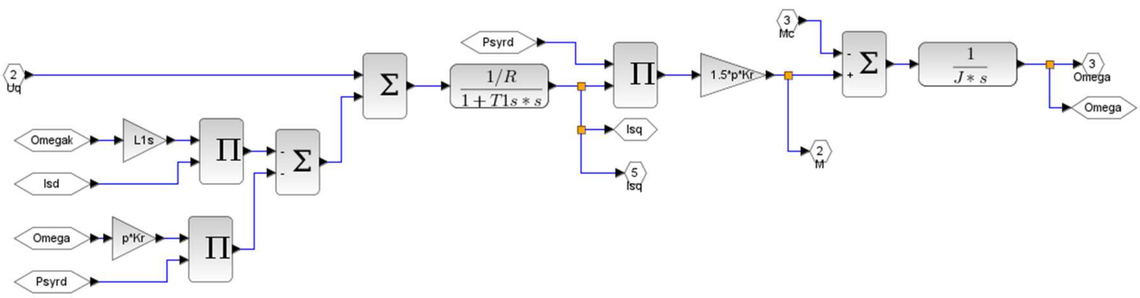

Figure 3. Computer model of current computations i_{sq}, rotation speed ω and torque M .

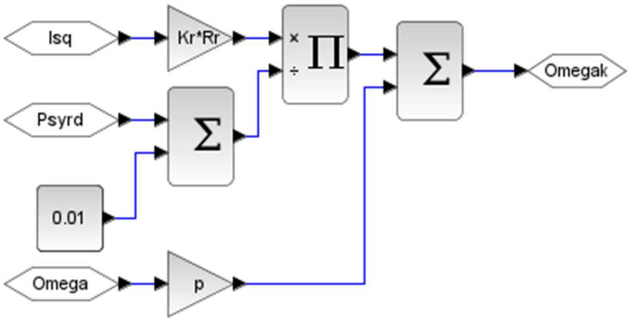

Figure 4. Computer model of rotation speed computations ω.

Flow coupling is related to the engine parameters by an equation in operator form:

$$\Psi_{rd} = \frac{T_r}{1+T_r s} K_r R_r i_{sd}, \tag{9}$$

where $T_r = \frac{L_r}{R_r}$ - the constant time of the rotor circuit; R_r - reduced resistance of the rotor winding, Ω; i_{sd} - flow-forming component of the stator current, A; s - Laplace operator.

There are two control channels in the vector control system. One channel stabilizes the flow coupling of the rotor by stabilizing the flow forming component of the stator current i_{sd} in accordance with the expression (9). The second channel provides speed control by affecting the moment forming component of the stator current i_{sq}.

Such control systems and their modeling in the program Scilab are considered by the authors in the [7, 8].

To obtain an artificial mechanical characteristic close to the constant power curve, it is proposed to adjust the setting of the control loop of the flow-forming component of the stator current in proportion to the moment-forming component of the stator current. The flow coupling will change in proportion to the drive load similar to what happens in a DC electric drive based on a series-wound motor.

In addition to changing the setting of the flow control loop, it is necessary to provide non-linear delayed feedback on the speed of rotation and on the moment-forming component of the stator current. These feedbacks will correct the speed controller setting to limit the speed and load, respectively. The operation of these feedbacks can be described:

if $x \le x_c$, that

$$y = 0, \tag{10}$$

if $x > x_c$, that

$$y = k_{oc} x, \tag{11}$$

where x - the input signal from the sensor with limited value; x_c - the value of x at which delayed feedback is enabled; y - the output feedback signal; k_{oc} - customizable feedback coefficient.

3. Computer model and result of simulation

A computer model of a controlled vector asynchronous electric drive system was developed, which provides the formation of a curve that is close to the constant power curve (figure 5). The model is similar to the one given in [7-11], but it has a block for forming the flow coupling task in the function of the moment-forming component of the stator current and blocks for limiting the speed and torque.

The adjustment coefficients of these blocks were determined by selection during experiments with a computer model.

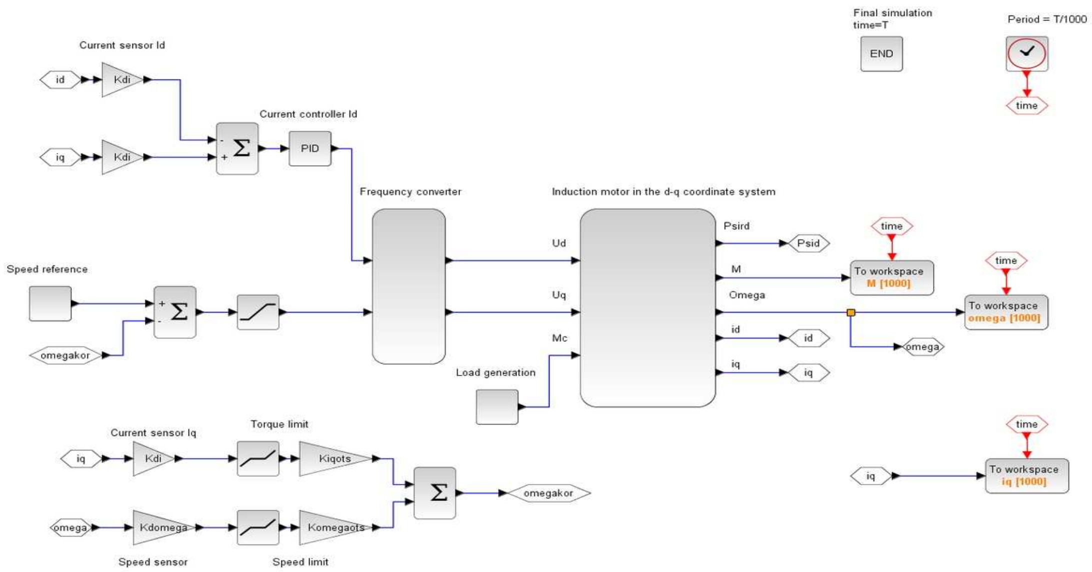

Figure 5. Computer model of electric drive power stabilization system.

A simulation was performed for starting the drive at a drag moment equal to a quarter of the rated motor torque $M_c = 0.25 M_H$ and for a sudden change in the drag moment to a value of $M_c = 4 M_H$. Graphs of transition processes are shown in figure 6 and figure 7. Straight lines show the nominal values of the current and torque of the electric drive.

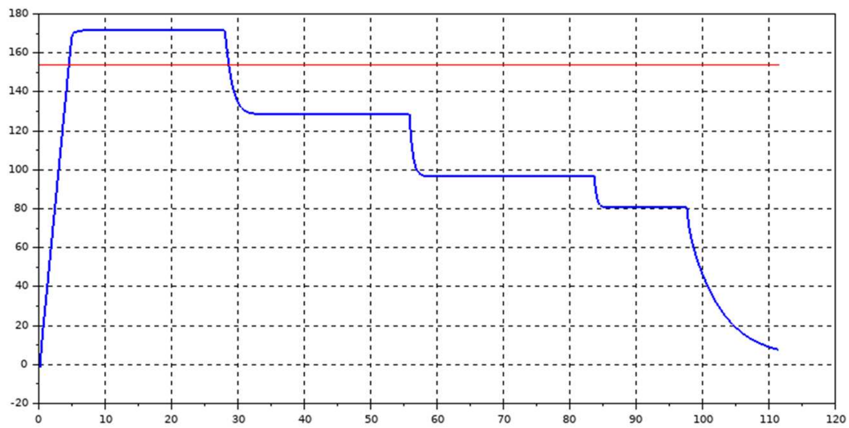

Figure 6. The dependence of speed with increasing load.

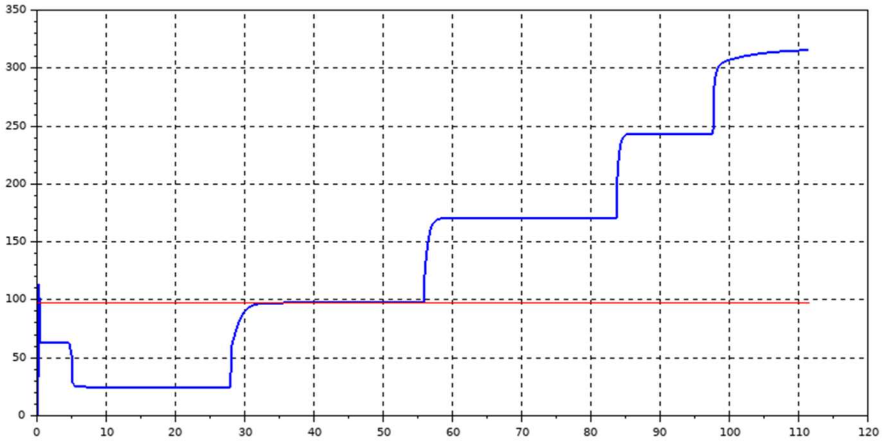

Figure 7. The dependence of torque with increasing load.

Based on the results of experiments, an artificial mechanical characteristic of the drive was constructed (figure 8). The characteristic is similar to the one shown in figure 1. This confirms the efficiency of the proposed structure of the control system.

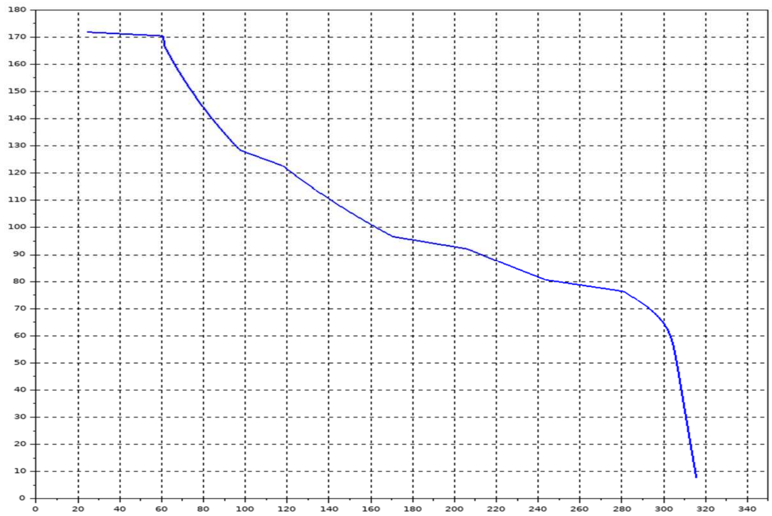

Figure 8. Artificial mechanical characteristics of the electric drive.

4. Conclusion

As a result of simulation, it is shown that it is possible to form an artificial mechanical characteristic of an AC regulated electric drive, which is close to the constant power curve by changing the setting value for the control loop of the flow-forming component of the stator current in the function of its moment-forming component. The required speed and torque limits of the drive are achieved by introducing additional nonlinear delayed feedbacks on the moment-forming component of the stator current and rotor speed, which correct the drive speed setting. The computer model shows the efficiency of the control system.

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