Simulation modeling of DC electric drive for mine hoist

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Abstract. The article describes the adjustable electric drive of skip hoisting installations of the mining enterprise. A simulation model of this object has been developed in the MatLab software package using the Simulink environment. The lift cycle was simulated using a five-period motion tachogram and graphs of dependencies of the following variables on time were obtained: the movement speed of the skip, the armature current and the motor torque. The simulation results showed that this simulation model corresponds to the actual technological process and allows further research on the operation of skip hoists.

1. Introduction
The development of the mining industry leads to construction large deep mines for the extraction of a coal and ore. Hoists are one of the most important and energy-intensive parts of the technological process for the extraction of minerals by the underground method [1, 2] - sometimes the payload reaches 50 tons with a lifting height of 1200–1600 m and drive power up to 5000 kW and more [3, 4]. Skip and cage hoists are used to movement loads along vertical and inclined mine shafts [5]. These hoists operate in the cyclic modes of lifting and lowering loads in accordance with the set movement tachogram.

The development of mine hoisting installations contributes to the solution of the common tasks of creating economic efficient productions of the mining industry [6]. However, the development of hoist equipment is accompanied by increased requirements for electric drives and automatic control systems [7, 8]. In recent years, with the development of computer technologies based on powerful application software packages, the focus of many researchers has been on simulation modeling methods that allow solving these problems with high speed and automation of research processes [9]. The purpose of this article is to develop model is to reliably predict the operation of hoist equipment of underground mines.

2. Description of electrical drive model
The scheme of electric drive for skip hoist of the mine enterprise depicted in Figure 1. This scheme design uses an electric drive built on the system, built according to the “Thyristor converter - separately excited DC machine” system [10]. The electric drive is powered by 6-kV distributor bus via matching transformers TSZP-4000. Two six-pulse thyristor converters UKTES-6300/825-211-500YHL4, connected in parallel, were used as controlled rectifiers. The transformers provide phase shift of the voltage to obtain a twelve-pulse scheme of rectifier [11]. The set speed of the motor P2Sh-800-256-7KUHL4 is achieved by changing the voltage at the output of the thyristor converters.
by adjusting the control angle. The reversible 6-pulse thyristor converter ECT 500/440-95 UHL4 is used to control the voltage of the field winding.

The mathematical model of the hoist electric drive with control system is the cascaded multiloop system [12, 13]. The system includes an external speed loop and two slave internal loops of the armature current and field current. Each loop has its own proportional-integral controller: the speed controller is tuned to a symmetrical optimum, and the armature current and field current regulators are tuned to modular optima. The following assumptions were made in the mathematical model: the mechanical part is one concentrated mass that is affected by the following forces: engine torque and load torque, and there is no saturation of the magnetic circuit of the engine. The scheme of the mathematical model depicted in Figure 2.

Where, $V_r$ – reference speed voltage, $V_f$ – feedback speed voltage, $V_{cct}$ – current controller voltage, $V_{ce}$ – speed controller voltage, $V_{cf}$ – current feedback voltage, $V_{cf}$ – field current controller voltage, $I_{cf}$ – nominal field current, $K_{sf}$ – speed feedback ratio, $K_{kcf}$ – field current feedback ratio, $K_{tf}$ – field thyristor converter ratio, $E_b$ – induced back emf voltage, $\omega$ – motor speed, $R_a$ – armature resistance, $T_e$ – engine torque, $T_L$ – load torque, and $T_a = L_a/R_a$ and $T_f = L_f/R_f$.

The MatLab software package with the built-in program Simulink and the internal library SimPowerSystem was used to create a simulation model of a skip hoist electric drive [6, 9, 10, and 14]. The use of this model will allow investigating the electrical and mechanical parameters of the electric skip hoist, such as currents, voltages, movement speed, torque and others [15].

**Figure 1.** The scheme of DC electric drive for mine skip hoist.

**Figure 2.** The scheme of the mathematical model electric drive skip hoist.
The simulation model is shown in the Figure 3. The model contains the following elements: three-phase source, three-phase power air and cable lines with lumped parameters, three-phase two-winding 110/6 kV power transformer (TRDN 25000 110/6 kV), current-limiting reactors, matching three-phase double-winding transformers with various connections of secondary windings (TSZP 4000), thyristor converters (subsystems “12 pulse TC” and “rev 6 pulse TC”), DC machine, unit for measuring parameters of DC machine (subsystem “Machine measurement”), control system (subsystem “Control System”), speed signal reference (Speed, m/s), torque signal reference (Torque, N*m), measurement modules.

The contents of the subsystem “12 pulse TC” are presented in Figure 4. The simulation model contains the following main elements: thyristor 12-pulse generator (Pulse Generator); two universal bridges (Y Thyristor converter and D Thyristor converter); smoothing filters (Lreactor1, Lreactor2), PLL unit, measurement modules.

The contents of the subsystem “rev 6pulse TV” are presented in Figure 5. The simulation model contains the following main elements: thyristor 6-pulse generator (Pulse Generator), two universal bridges (Thyristor converter1 and Thyristor converter2), breakers, switches, PLL unit, various measurement modules.

The contents of the subsystem “Control System” are presented in Figure 6. The simulation model contains the following main elements: regulator transfer functions, transfer function of feedbacks, saturation units and various mathematical units. The input values of the “Control system” subsystem are: speed reference signal (ZC), speed feedback signal (OC), armature current feedback signal (OT) and field current feedback signal (OTf). Output values are: the angle of control of the motor armature thyristor converter (alpha_TP), the angle of control of the thyristor converter of the field winding (alpha_TV), the signal of the required direction of the magnetic field (DIR).

Figure 3. The simulation model of skip hoist.

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Figure 4. The subsystem “12 pulse TC”.

Figure 5. The subsystem “rev 6 pulse TC”.

Figure 6. The subsystem “Control System”.
3. Simulation results

The lift cycle was simulated using a five-period motion tachogram: starting, boost, even movement, braking and reach. The oscillogram of hoist movement speed are given in Figure 7.

![Figure 7. The oscillogram of the hoist movement speed.](image1)

The oscillogram of the engine torque is presented in Figure 8. The engine torque decreases with increasing height due to the unbalance of the ropes. The engine brakes at a negative motor torque, which is achieved by changing the direction of the magnetic field.

![Figure 8. The oscillogram of the hoist torque alteration.](image2)

The oscillogram of the hoist armature current alteration is presented in Figure 9.
Figure 9. The oscillogram of the hoist armature current alteration.

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