ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 1, January 2025

Statistical Analysis of Ball Mill Synchronous Electrical Drive Operation Modes Using Matlab Simulink Program

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ABSTRACT. This work considers methods and modes of saving electricity by starting synchronous motors of ore crushing mills using the Matlab software package. Ball mills are the most important processing equipment used in crushing mining ores. Ball mills consume a large amount of electricity from the network, and during their start-up, a high level of electricity is also consumed. This article presents priority areas for selecting energy-saving operating modes and mechanisms for the electric drive of ball mills. Starting large-power synchronous motors requires high electricity consumption. Preventing them, modernizing them and increasing their efficiency with local devices, and selecting optimal operating modes are one of the current problems.

KEY WORDS: Ball mill, matlab simulink, high-power synchronous motors, operating efficiency, starting, excitation current, torque, statistical analysis

I. INTRODUCTION

Given that synchronous motors typically operate in asynchronous mode for 10-13 seconds during start-up, some changes occur in their electrical parameters during the time required to establish synchronous mode. The balance between power and torque during load start-up is of great importance [1,2].
Synchronous motors have lower power losses compared to asynchronous frequency-controlled electric drives [3]. The developed method for calculating energy parameters (stator and rotor current, voltage, power, power dissipation, cos φ , load factor, etc.) of a frequency-controlled synchronous motor was carried out for a synchronous motor with a power of 900 kW at a voltage of 6 kV.
Mechanical characteristics of a synchronous motor

$$M = const \quad (1)$$

Angular characteristic of a synchronous motor

$$M = M_{\max} \cdot \sin\theta \quad (2)$$

Maximum torque of a synchronous motor

$$M_{\max} = \frac{3 \cdot U_1 \cdot E_0}{\omega \cdot X_1} \quad (3)$$

Here E 0 – Electromotive force in the stator V; X 1 – inductive resistance in the stator; θ – angular load of the synchronous motor.

$$M = \left(\frac{m_1}{\omega_1}\right) \cdot \left(\frac{U_1 \cdot E_0}{X_1}\right) \cdot \sin\theta \quad (4)$$

Here m1 is the number of stator phases, ω_1 is the angular velocity in the stator field, U1 is the voltage in the stator, E0 is the induction in the stator windings (EMF), X 1 is the inductive resistance in the stator windings.

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International Journal of AdvancedResearch in Science, Engineering and Technology
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Considering that the mechanical characteristics of synchronous motors consist only of straight lines, the concept of maximum torque M max is also introduced in their angular characteristics. If we relate the initial angular velocity ω0 to the torque, the angular velocity and rotational speed together with the rotational torque form the following descriptions[4]. This equation allows you to determine all the variable parameters of the transient process when starting synchronous motors.

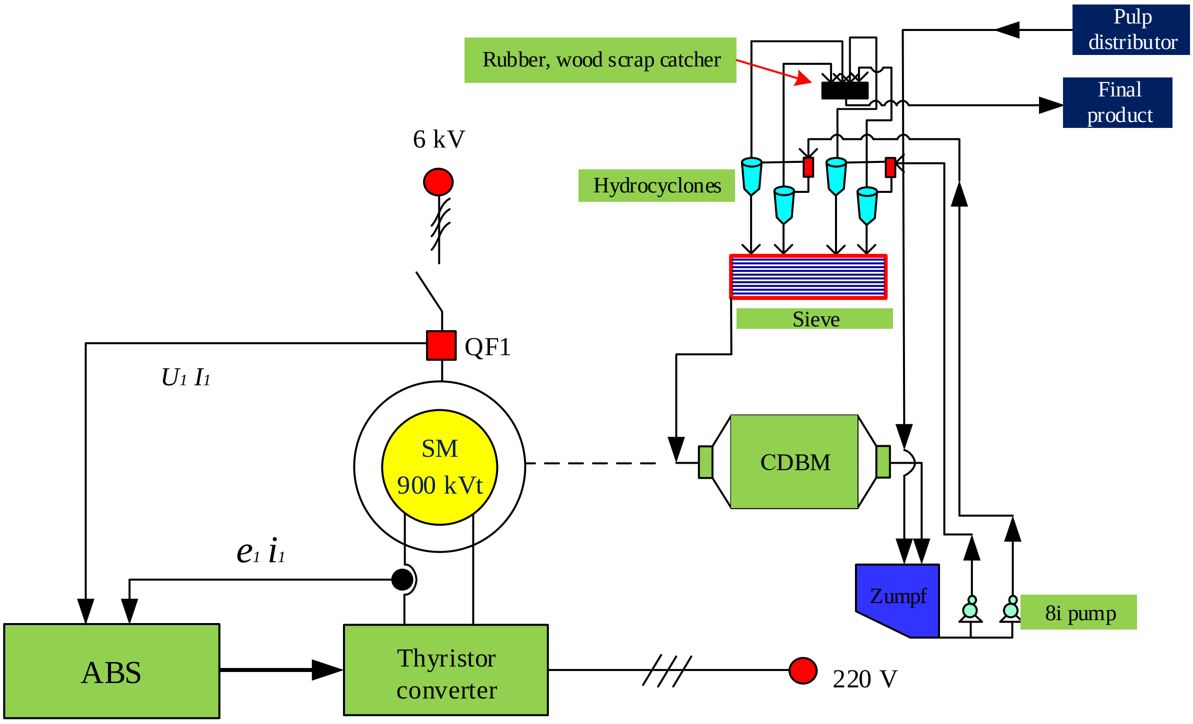

Figure 1. Schematic diagram of thyristor start-up of a CDBM (central discharge ball mill) mill
ABS – automatic backup switch

Figure 1 shows the kinematic diagrams of the devices operating in the crushing section of the processing plant, where the 2nd stage of crushing is carried out. In this case, the product from the pulp distributor falls into the sump. From there, 8 pumps send it to the hydrocyclone. Then, the product, divided into two, passes through a device that traps rubber and wood residues and is transferred to the thickener. The second, as a heavy fraction in the hydrocyclone, falls back into the mill. A thyristor converter connected to the rotor of the synchronous motor that rotates the mill, creates synchronous rotation by evenly supplying the current supplied to the rotor.
The above equations relate the instantaneous values of currents, magnetic fluxes, and voltages on the coordinate axes (d, q) associated with the rotor.

$$l = -w\frac{d\Phi}{dt} = \frac{d\psi}{dt} \qquad l = U + ir - \frac{d\psi}{dt} = U + ir \qquad (5)$$

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1) $$\begin{cases} U_a = -\frac{d\psi_a}{dt} - r_a i_a \\ U_b = -\frac{d\psi_b}{dt} - r_b i_b \\ U_c = -\frac{d\psi_c}{dt} - r_c i_c \\ U_f = -\frac{d\psi_f}{dt} - r_f i_f \end{cases}$$ 2) $$\begin{cases} \psi_a = L_a i_a + M_{ab} i_b + M_{ac} i_c + M_{af} i_f \\ \psi_b = M_{ba} i_a + L_b i_b + M_{bc} i_c + M_{bf} i_f \\ \psi_c = M_{ca} i_a + M_{cb} i_b + L_c i_c + M_{cf} i_f \\ \psi_f = M_{fa} i_a + M_{fb} i_b + M_{fc} i_c + L_f i_f \end{cases}$$ (6)

The instantaneous values of the mode parameters are defined as the projections of the phases a, b, c of the current vector (voltage, EMF, current) rotating with angular velocity on the time axis. This current vector is called generalized [5].
One of the advantages of synchronous motors is that they are self-compensating. The change in torque and speed during starting is analyzed by the vector diagram of currents and voltages and the change in the load angle between them.
Considering the rotor of a synchronous motor in ball mills, we can write the electric field equations as follows.

$$\frac{di_d}{dt} = \frac{1}{L_d}(v_d + L_q \omega_e i_q - R_s i_d) \quad (15)$$

Here ω e - singular speed of rotation of the synchronous motor; R s – active resistance of the cross-sectional area of the synchronous motor winding;

$$\frac{di_d}{dt} = \frac{1}{L_d}(v_d - R_s i_d - L_q \omega_e i_q - \Phi_m \omega_e) \quad (16)$$

The electromagnetic torque equations for a synchronous motor in ball mills are as follows.

$$M = \frac{P}{2}(\frac{3}{3})(\Phi_d i_q - \Phi_q i_d) \quad (17)$$

Here P is the power of the synchronous motor; Φ d i q and Φ q i q are the magnetic fluxes in the d,q system;

$$\Phi_d = L_d i_d + \Phi_m \quad (18)$$

Here L d i d is the inductive resistance and current;

$$\Phi_q = L_q i_q \quad (19)$$

$$M = \frac{P}{2}(\frac{3}{2})((L_d i_d - \Phi_m) i_q - L_q i_q i_d) \quad (20)$$

$$M = \frac{P}{2}(\frac{3}{2})(L_d i_d i_q - \Phi_m i_q - L_q i_q i_d) \quad (21)$$

$$M = \frac{P}{2}(\frac{3}{2})((L_d - L_q) i_q i_d + \Phi_m i_q)) \quad (22)$$

The mechanical torque equations for a synchronous motor in ball mills are as follows.

$$M_c = M_d + b\omega_m + J\frac{d\omega_m}{dt} \quad (23)$$

Here M c and M d are the static and dynamic torques of the synchronous motor rotation:

$$J\frac{d\omega_m}{dt} = M_c - M_d - b\omega_m \quad (24)$$

Here J is the moment of inertia of the synchronous motor; ω m is the maximum angular speed of rotation of the synchronous motor

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$$\frac{d\omega_m}{dt} = \frac{1}{J}(M_c - M_d - b\omega_m) \tag{25}$$

Park-Clorke equation

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \frac{2}{3} \cdot \begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ -\sin\theta & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \cdot \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{26}$$

The calculation of the rotating torque of the ball mill drum is carried out precisely according to the maximum bending moment.

$$M_{\max eg} = \sqrt{M^2_{y\max eg} + M^2_{z\max eg}} \tag{27}$$

Where: M 2 ymax eg – maximum bending moment in the Y axis; M 2 zmax eg – maximum bending moment in the Z axis.

The formula for the torque at the distance from the coupling to the bearings that rotate the mill drum is as follows.

$$M = \frac{1000 \cdot P}{\omega} \tag{28}$$

Where: P – motor power kW; ω – angular velocity rad/s ;

Let's define the formula for the driving torque.

$$M_{yur} = \sqrt{M^2_{\max eg} + J^2} \tag{29}$$

Where: M 2 maxeg – maximum bending moment kNm ;

II. RESULTS AND DISCUSSIONS.

We will create a simulation model of all these equations in Matlab Simulink and insert them into it. The model assembled from these equations will look like the following. This model was assembled based on the operating parameters of a ball mill powered by a 900 kW synchronous motor. This allows us to adjust the values of the load angle between the electromotive force, voltage and current, taking into account the transient processes that occur during the start-up of the mill [6,7,8,9].

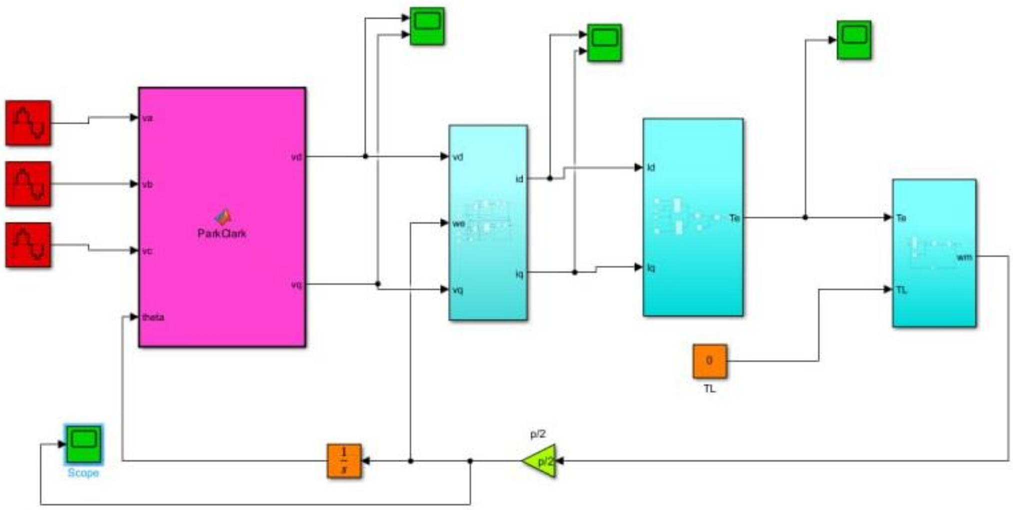

Figure 2. Modeling of a ball mill permanent magnet synchronous motor in Matlab simulink.

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Figure 2 shows a model of a ball mill and a synchronous motor with a permanent magnet system rotating it, made in Matlab Simulink. As a result of running this model, sinusoidal voltage and current signals were obtained, and several oscilloscopes were used to visualize various parameters. Under each subsystem, elements that depend on voltage, current, and torque are placed. Scopes are placed at the input and output to obtain signals of these indicators.

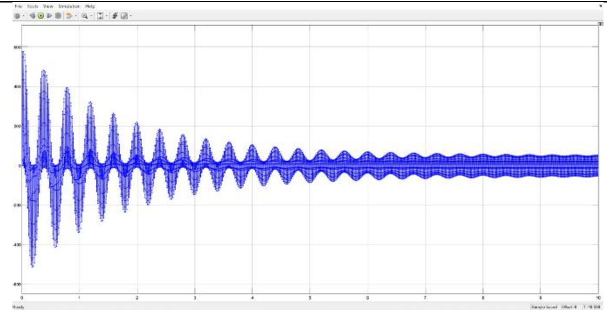

Figure 3. Time variation of electromagnetic torque during starting of a ball mill synchronous motor

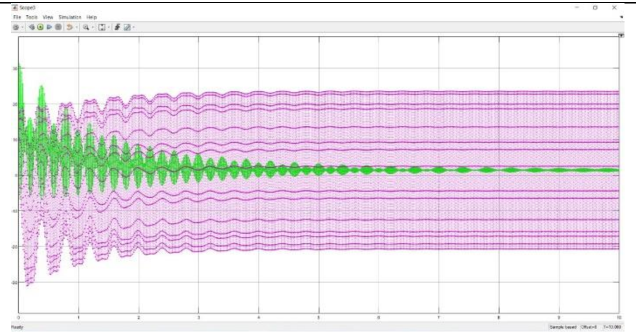

Figure 4. Time variation of currents i q and i d during starting of a ball mill synchronous motor

Figure 3 shows the time-dependent variation of the electromagnetic torque during the start-up of a ball mill synchronous motor. As can be seen, the torque increases for 9 seconds during the start-up of a synchronous motor and then continues at a constant rate.

Figure 4 shows the time-dependent variation of the currents i q , i d during the start-up of a ball mill synchronous motor. As can be seen, the current increases for 20 seconds during the start-up of the synchronous motor and then continues at a constant rate.

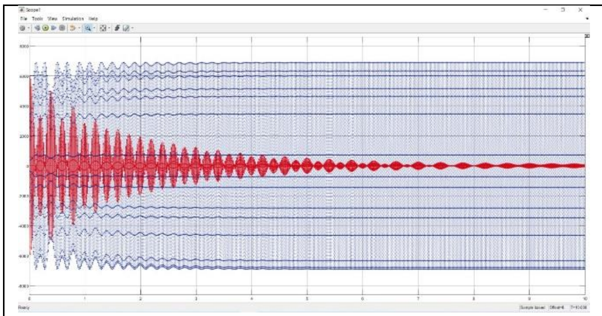

Figure 5. Time variation of voltages u q and u d during starting of a ball mill synchronous motor

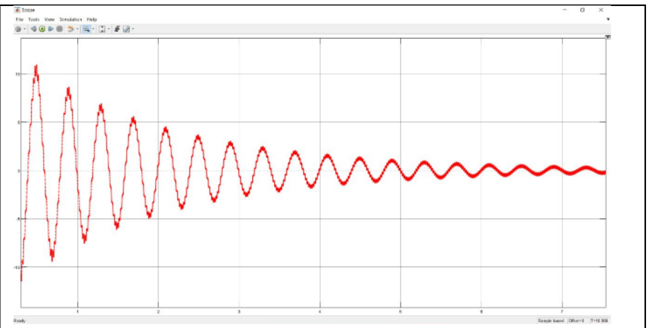

Figure 6. Time variation of rotation speed during starting of a ball mill synchronous motor

Figure 5 shows the time-dependent variation of the voltage u q , u d during the start-up of a ball mill synchronous motor . As can be seen, when starting a synchronous motor, the value of the voltage coming from the network decreases significantly and then continues to increase.

Figure 6 shows the time-dependent variation of the motor speed during the start-up of a ball mill synchronous motor. As can be seen, the synchronous motor rotates at a lower speed for a while to reach the operating speed, and then continues at a constant speed. Since the start-up requires a large torque value, the speed requires a small value at first.

III. CONCLUSION

Due to the continuous and different hardness of the ores in ball mills, the magnetic field generated in the stator and rotor of the synchronous motor weakens. This also happens during the start-up of the synchronous motor. The level of ball loading in the mill also significantly affects the consumption of electricity. It is advisable to determine the optimal level of ball loading, taking into account the quality indicators of the ore. By controlling the level of ball loading, it is possible to increase the efficiency of the electric energy consumed by the mill. The results obtained according to the model

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implemented in this work showed that during the start-up and operation of synchronous motors, we were able to control their electrical parameters and electrical characteristics (stator and rotor current, grid voltage, EMF, mill and synchronous motor rotation speeds, load angle between current and voltage, active, reactive powers, power dissipation, etc.).

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