

MICROPROCESSOR CONTROL OF THE HIGH-POWER AND HIGH-VOLTAGE SYNCHRONOUS ELECTRIC DRIVE OF A BALL MILL

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Abstract: Direct starting of synchronous motors by the high-voltage high-power asynchronous method leads to serious problems, in which a starting current of $5\div 8$ times greater than the nominal current appears in the stator winding of the synchronous motors and short-term engine failure is observed. Analysis of the starting modes of high-voltage high-power synchronous motors used in various devices showed that the starting methods have a number of drawbacks and require further improvement. This article presents technical solutions for smooth starting of high-power and high-voltage synchronous motors, increasing energy and resource efficiency, and extending the service life of electric drives..

Keywords: ball mill, synchronous motor, starting current, high power, high voltage, coil, thyristors, voltage converter, service life, pulse, electric drive, energy consumption, mill pump.

Introduction

The practice of direct asynchronous starting of high-voltage and high-power synchronous motors causes serious technical problems. In this case, a starting current 5-8 times higher than the nominal value passes through the

motor stator winding, which increases the probability of short-term device failure. By analyzing the starting modes of high-voltage synchronous motors used in various equipment, it was established that the existing methods have a number of shortcomings and require further improvement. This article proposes technical solutions aimed at smooth starting of high-power and high-voltage synchronous motors, increasing energy and resource savings, and extending the service life of electric drives.

Materials and methods

High-voltage and high-power synchronous motors with uncontrolled speed and direct connection to the network are widely used in processing plants in the mining industry, cement production enterprises, the metallurgical industry, as well as in compressor units at thermal power plants and other areas. Synchronous electric drives with a voltage of 6 kV and a power from 3200 kW to 8000 kW, activated by the asynchronous method, are used in the operation of ball mills for rock crushing at processing plants, in high-performance centrifugal pumping units, and in compressor units for compressed gas supply to boiler rooms of thermal power plants. These indicators show that these electric drives are major consumers of electricity.

The most energy-intensive technological processes include crushing, grinding, filtration, gas compression, pumping, and ventilation equip.

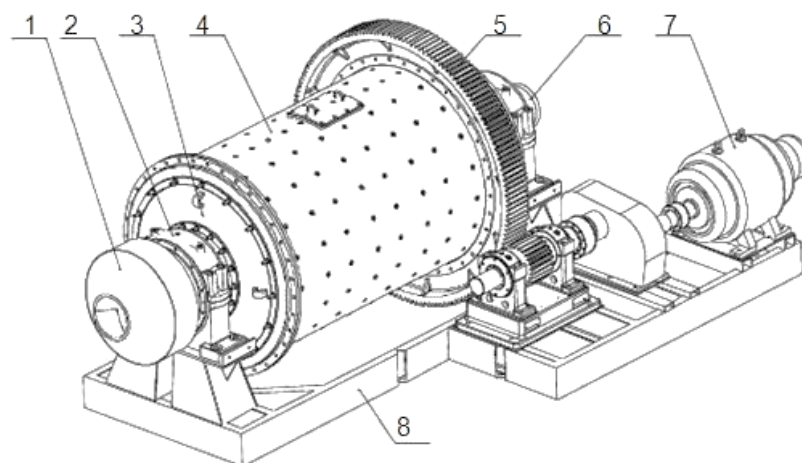


Figure 1. High-power synchronous electric drive of a ball mill.

By reducing the starting current, the following efficiency is achieved: increasing the service life of electrical solutions without repair; ensuring the continuity of the grinding process; increasing production efficiency; increasing the service life of grinding balls and internal coatings installed in the housing. Increasing the service life of electric mortars without repair consists of selecting and implementing the optimal option for smooth starting methods [4,6].

The results of the analysis of many scientific and practical works in world practice show that in general, to improve the starting mode of electric drives, smooth speed control can be used using the thyristor converter-DC motor (TC-DCM) system, directly connected frequency converter-asynchronous motor (FCM-ASM) or/or frequency converter-asynchronous motor (FCM-ASM) with a DC link. The TO-OTM system is not widely used due to the difficult climatic conditions of the electric drive, as well as high maintenance requirements. Taking these works into account, a smooth-starting "thyristor voltage converter-synchronous motor" system was developed for synchronous motors started by the asynchronous method [1,3,4].

In order to solve the problems of smooth starting of a synchronous motor using microprocessor control, to increase the voltage and power of the "thyristor voltage converter (VTC)," ways to solve the problems were considered by introducing thyristor groups (TGs) connected in series-parallel connection instead of each thyristor in the VTC. The reliable operation of such a TKO is ensured by the simultaneous opening of all thyristors in the TG. The results of the study of dynamic processes of thyristor opening are presented, the requirements for the thyristor control signal and the degree of influence of SM parameters on the dynamic process of thyristor switching are considered, and the need for microprocessor control is substantiated (Fig. 2).

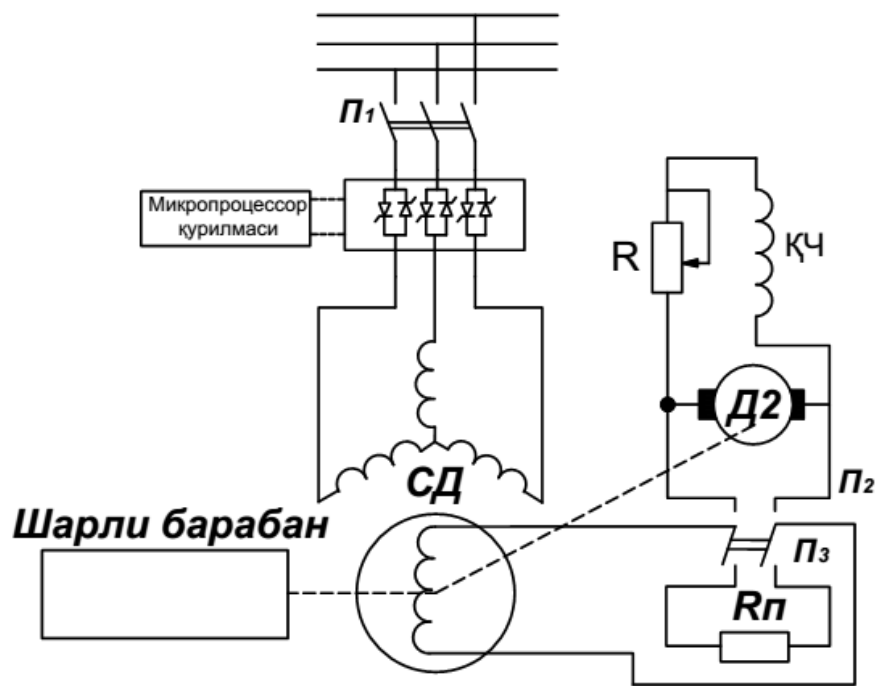


Figure 2. Functional diagram of smooth start-up of the synchronous electric drive of a ball mill with microprocessor control.

Deviations in the volt-ampere characteristics of thyristors during their manufacture from the technology lead to a difficult operation process with their serial and/or parallel connection. This leads to overloading of some parallel and series-connected thyristors in terms of current and voltage, resulting in their premature failure [3,4].

To eliminate these shortcomings, a critical analysis of the dynamic modes of opening of parallel and series-connected thyristors was carried out in the dissertation work, at the same time, from the point of view of using this motor in the TKO'-SM system, the influence of the dynamic modes of starting the SM on the dynamic indicators of thyristor opening was also taken into account.

Two methods can be used to ensure smooth distribution of forward current between thyristors in static and dynamic valve modes: selection of thyristors of the same type with identical characteristics; forced current distribution using additional electrical devices. The first method has been studied in detail

in technical literature. Therefore, we will consider the second method in more detail [2,4].

If the values of the reverse current and eddy current, the value of the forward voltage in the conductive state of the thyristor, the capacitances of the p-n junction, and the opening and closing times of individual thyristors do not coincide, the conditions for effective operation of the thyristors are not met - the conditions for instantaneous opening of TG thyristors are not met. If there is only one thyristor in the circuit, a control pulse is applied to it, and after the thyristor opens, the control current I_u (Fig. 3.4) no longer affects the thyristor's operation. Therefore, to control a single thyristor, a control pulse with a duration of not more than $1 \div 3 \mu\text{s}$ is used in practice

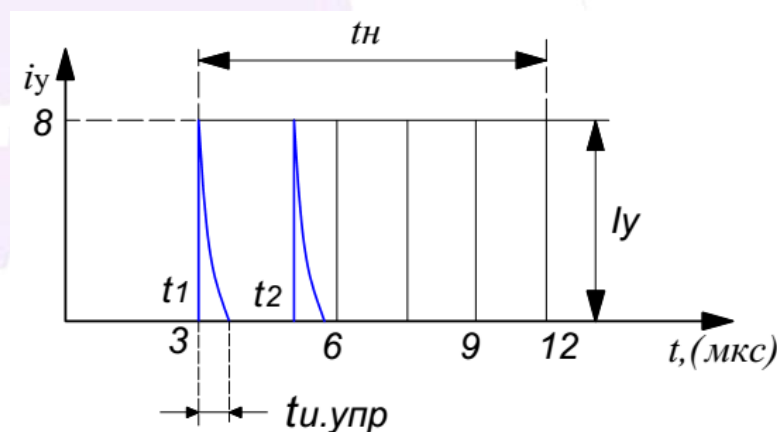


Figure 3. Time diagram of the electromagnetic process

When the thyristors are connected in series, if the control pulse arrives at one of the thyristors with some delay, for example, $t_2 - t_1 \neq t_{i.upr}$ (Fig. 3.4), then the circuit is in a closed state, since the current I_{pr} does not flow through the thyristors in the right direction (due to the non-fulfillment of the law of constant current), and the process of injecting electrons from the emitter region of the thyristors does not begin as in the initial state. Thus, unlike the operation of a single thyristor, one of the main requirements for the reliable

operation of a series-connected TG arises, which is formulated as follows [2,6,7].

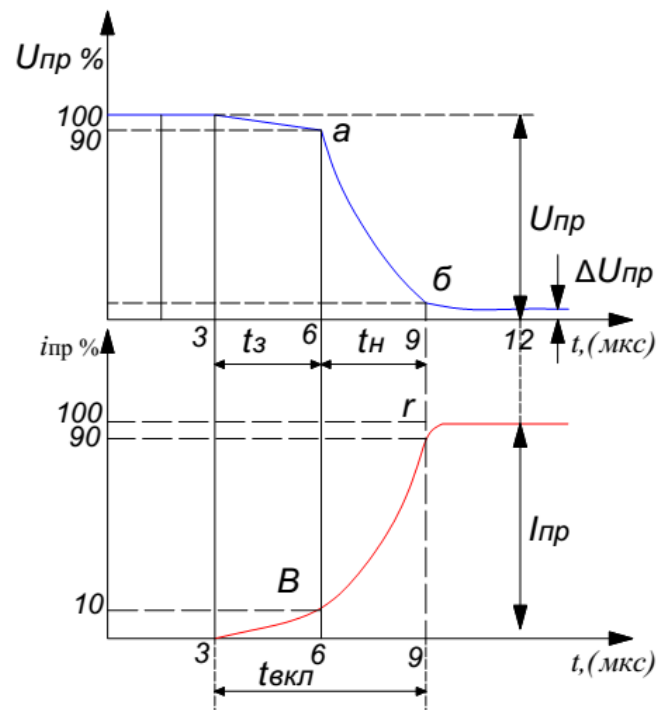


Figure 4. Time diagram of current and voltage across thyristors

The control signal must arrive instantaneously (without delay) to all thyristors in a group of series-connected thyristors. If we use two or more parallel-connected (N) thyristors (Figure 5) for starting high-power short-circuited SMs, then the large starting current of the SM is evenly distributed among all thyristors $I_{work} = (5 \div 8) \cdot I_n$.

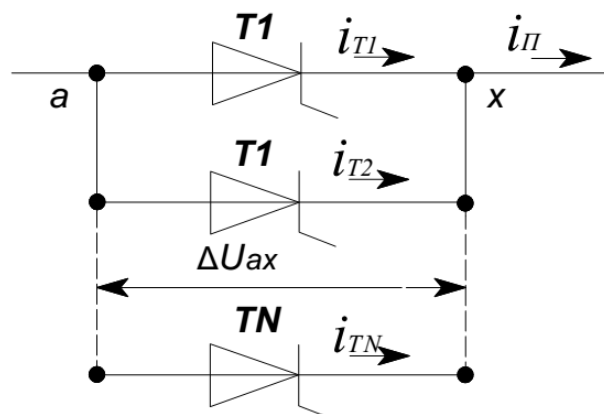


Figure 5. Parallel-connected thyristors in the thyristor group

In this case, each thyristor is loaded with a part of the motor's starting current, and the current is less than the permissible value for this type of thyristor: $I = I_{\text{work}}/N$.

The dynamics of the opening of TKO TGs with parallel-connected thyristors during the direct startup of high-power SM is as follows. If a control signal is transmitted to the control electrode of the first thyristor T1 at time t_1 , then in the time interval $t_1 + t_{\text{vkl}}$ (Figure 3.4), it opens and the process of flowing the full starting current of the SM through thyristor T1 begins (Figure 3). In such a situation, the second thyristor T2, which receives a delayed signal to the control electrode (i.e., in the time interval $t_1 + t_{\text{vkl}}$), will not open, because at this moment the current flowing through T1 will have time to increase, and the potential difference Δu_{ax} between the input "a" and output "x" points (Figure 3) will be very small (Figure 3.4). To determine the permissible signal delay of the control electrode of thyristor T2, let us assume that the signal arrives at the moment of time $t_1 + \Delta t$.

If $t_z \leq \Delta t \leq t_{\text{vkl}}$ (Figure 3.4), then the potential difference between points "a" and "x" will be equal to $\Delta u_{\text{ax}} \approx (10 \div 90) \% \cdot U_{\text{pr}}$, and the current passing through T1 will rapidly increase from 10% to 90% of the full starting current I_{sh} (Figure 3) and the probability of thyristor T2 opening will be very small. If $0 \leq \Delta t \leq t_z$, the potential difference between points "a" and "x" is $\Delta u_{\text{ax}} \approx (100 \div 90) \% \cdot U_{\text{pr}}$, and the value of the total starting current I_{work} passing through T1 increases slowly from 0% to 10%, and the probability of opening the second thyristor T2 is high (Figure 3). However, this does not exclude the possibility of disruption of the switching ability of thyristor T2. Therefore, the first and necessary condition for the operation of parallel-connected thyristors in the TG, as in series-connected thyristors, without switching failure, is the simultaneous transmission of control signals to all thyristors in the TG [1,2,3].

Failure to comply with these conditions leads to the following consequences.

After opening the thyristor with a control pulse of a sufficiently short duration, a gradual increase in current should occur, including a change in current - a "delay" time interval t_Z (Fig. 3) and a "growth" time interval t_H . In this case, the main condition for ensuring the necessary thyristor switching is ensuring the continuity of the current passing through each series-connected thyristor. Delay or failure to open one of the thyristors leads to a violation of the principle of continuity of current. Consequently, all series-connected thyristors are closed, and the electrical circuit does not open. To ensure the simultaneous opening of the thyristors in the TG, it is necessary that the duration of the thyristor control signals u_I be the same and greater than the opening time duration (t_{VKL}), which is the sum of the "delay" time interval t_3 and the "increase" time interval t_H of the current.

Thus, contrary to the generally accepted recommendations for the use of thyristors, where it is stated that the minimum duration of the control pulse is sufficient, the duration of the control pulse for the TG of the "TCU-SM" system must be greater than the "delay" time interval established for these thyristors.

If the "delay" time interval t_3 depends only on the type of thyristor, then the duration of the thyristor's opening time also depends on the "growth" time interval t_H of the current included in the PVL load (see below).

If, at time t_1 , a control signal is transmitted to the control electrode of thyristor T1, then at time $t_1 + t_{VKL}$, thyristor T1 opens, and a full starting current of current SM flows through it. The thyristor T2, which receives a delayed signal opening the thyristor to the control electrode (at time $t_1 + t_{VKL}$), does not open, because at this moment, due to the current flowing through the thyristor T1, the potential difference Δu_{ax} between the input "a" and output "x" points (Figure 5) becomes zero. The load corresponding to the

CCD with a capacitor compensator (CC) has an active character, i.e., at $\cos\varphi = 1.0$, the shape of the current when the thyristor opens is similar to the shape of the voltage [3,4].

In this case, the duration of the thyristor opening time t_{VKL} is minimal - the thyristor switching is close to the failure mode. If the load is active-inductive, the current in the thyristor will have a delay character depending on $\cos\varphi$.

With an increase in the inductive component of the load, the rate of current increase at the time of thyristor opening decreases, and the probability of thyristor switching failure increases.

The microprocessor control system, in addition to forming the desired shape of the thyristor control pulses, also controls the rate of change of the average voltage of the ASM using feedback in the rotor speed and stator current, thereby removing the rotor from the braking mode when starting the electric drive [2,4,7].

Conclusion

Conditions for the smooth operation of the thyristor group switching within the thyristor voltage converter have been developed. As a result, it was clarified that the duration of the control pulses of the thyristors should not be less than the duration of activation of each individual thyristor. A microprocessor control method for a high-power high-voltage asynchronous motor with a short-circuited rotor using a thyristor voltage converter, consisting of a group of thyristors with a combination of connections, is proposed. As a result, it allows smooth starting of high-voltage asynchronous motors with high power. When starting the "Thyristor Voltage Converter - Asynchronous Motor" system, a refined mathematical model of the transient process of microprocessor control, a simulation model, and a program that ensures simultaneous opening of the thyristors were created. As a result, various tests and calculations were carried out using the developed

mathematical model, software, and simulation models, and a relatively optimal option was selected.

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