Section 6. Electrical engineering

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A RESEARCH MODEL FOR THE OPERATING MODES OF THE MECHANICAL PART OF THE ORE CRUSHER ELECTRICAL DRIVE SYSTEM

Abstract. A simulation model, allowing to study and evaluate the operating modes of mechanical transfer link of an induction electrical drive system that ensures the operation of ore crusher is developed. The model was implemented in the Simulink environment of the MatLab software package and can be successfully used to identify the defects in the mechanical part of the induction electrical drive systems operating with the percussive application of a load, and to make decisions aimed at improving the operating conditions.

Keywords: simulation model, percussive load, mechanical part, elastic link, operating mode, rigidity.

Introduction. The electrical drive system research model should reflect the peculiarity of the structural scheme of the given system, as well as the loading mode. Taking into account the structural diversity of electrical systems and the variety of technological load changing, it is of scientific and technical interest to develop a model for the study of the working modes of the mechanical part of the electrical drive system with percussive load.

There are numerous works which are devoted to the modeling and investigation of different links of the electrical drive system [1–4].

Ivanchenko's monographs devoted to the investigation of the dynamic phenomena occurring during the operation of metallurgical machines are of particular interest [1; 2]. In these works, the development of the mathematical models for investigation

the transient processes and the steady state of single-motor and multi-motor electrical drive systems has been considered.

Rational parameters providing transient attenuation and reduction of electric drive system dynamics are obtained. Mathematical models have been developed for technological mechanisms with a constant and variable load changing with certain regularity.

In the work devoted to the study of the mechanical subsystem of the electrical drive system with a reducer [3], transient functions for the main regulated coordinates were obtained.

The torque of resistance created by some technological mechanisms operating with the percussive load has a random character and a specific form whose impact on the mechanical part of the electrical drive system needs a comprehensive study. Such a special torque of resistance is created by the ore crushers widely used in mining and metallurgical industry. That is why, in the present paper, a model for research the mechanical part of the electrical drive system has been developed.

The **goal of the work** is to develop the research model of the mechanical part of the ore crusher electrical drive system which will give an opportunity to

estimate the change in the operation modes of the mechanical transfer links of the system and reveal the possible defects.

The obtained results. In practice, an asynchronous electrical drive is used for ore crushers. The mathematical description of the mechanical part of the asynchronous electrical drive system of the ore crusher can be represented in the form of a system of differential equations given below:

$$\begin{cases} J_1 \frac{d\omega_1}{dt} - M_{12} = -M_c \\ J_2 \frac{d\omega_2}{dt} + M_{12} = M_D - \beta\omega_2 \\ M_{12} = \frac{c_1}{p}(\omega_2 - \omega_1), \end{cases} \quad (1)$$

where J_1 and J_2 are the moments of inertia of the crusher and the induction motor rotor's respectively; c_1 is the rigidity of the drive link between the crusher and the electric motor; ω_1 and, ω_2 are the angular speeds rotation of the crusher and the motor respectively; M_c is the torque of resistance of the crusher load; M_D is the torque of the induction motor; M_{12} is the load torque of the elastic element; β is the rigidity of the motor characteristics.

Figure 1. The structural scheme of the crusher's electrical drive elastic subsystem

Using the system of differential equations (1), the structural scheme of the elastic subsystem has been obtained (Fig. 1). The scheme has been plotted in the Simulink environment of the MatLab software package [5; 6].

In the structural scheme given in Fig. 1, the form of change in load resistance torque M_c was chosen taking into account the operating mode of crushers used in the mining and metallurgical industry.

The torque of resistance created by the crusher over time undergoes a random change. The conical crushers which have found wide application operate in a continuous mode, while the jaw crushers – in a discontinuous mode. Taking into account the abovementioned, to develop a model for investigating the operation modes of the system's mechanical part, the form of the torque M_c change presented in (Fig. 2) has been used.

Figure 2. The form of the change of the crusher's M_c torque of resistance

Figure 3. The change of the elastic element load torque at $c_1 = 25500 \text{ kg.m/rad}$

It is known that the insufficient rigidity of the shaft causes bending in the gear transmission which

leads to a non-uniform distribution of the load on the gear teeth.

The insufficient rigidity of the parts increases friction and pressure in the movable conjugation.

Taking into account that the above phenomena can contribute to the emergence of emergency modes, in this work the characteristics of the me-

chanical part of the system have been considered for different rigidities of the transmission link.

By means of the model presented in (Fig. 2), the M_{12} torque changes in time at different values of the c_1 rigidity of the transmission link have been obtained (Fig. 3, 4).

Figure 4. The change of the elastic element load torque at $c_1 = 15000 \text{ kg.m/rad}$

From Figures 3 and 4, it can be seen that the decrease in the rigidity of the c_1 link brings about the intensity of the M_{12} torque change.

The transfer function $W(s) = M_{12}(s)/M_D(s)$ of the electrical drive elastic subsystem has been derived for different values of c_1 rigidity of the transmission link.

$$W(s) = \frac{68s}{s^3 + 24,4s^2 + 159,1s + 2222},$$

when

$$c_1 = 25500 \text{ kg.m/rad}, \quad (2)$$

The characteristic equation has the following form:

$$s^3 + 24,4s^2 + 159,1s + 2222 = 0$$

whose solutions are:

$$s_1 = -21,7808; \quad s_2 = -1,3096 + j10,0154;$$

$$s_3 = -1,3096 - j10,0154$$

For the characteristic equation, the obtained roots are left to the false axis, which shows that the system is stable:

$$W(s) = \frac{40s}{s^3 + 24,4s^2 + 93,57s + 1307}, \text{ when } c_1 = 15000 \text{ kg.m/rad}, \quad (3)$$

The characteristic equation of the transfer function (3) has the following form:

$$s^3 + 24,4s^2 + 93,57s + 1307 = 0,$$

whose solutions are:

$$s_1 = -22,8101; \quad s_2 = -0,7950 + j7,5282;$$

$$s_3 = -0,7950 - j7,5282.$$

The obtained results show that the system is stable.

To investigate the system, the amplitude-frequency and phase-frequency characteristics of the function are obtained (Fig. 5). For that, $s = j\omega$ is placed in the $W(s)$ transfer function. The obtained function $W(j\omega)$ consists of real and false components. The $W(j\omega)$ frequency transfer function can be presented in the following form:

$$W(j\omega) = A(\omega)e^{j\phi(\omega)},$$

where $A(\omega)$ is the amplitude-frequency characteristic of the system which shows how much the output signal amplitude is higher than the input signal

amplitude; $\phi(\omega)$ is the phase-frequency characteristic which shows the magnitude of the phase shift of the output and input signals for a fixed frequency.

a)

b)

Figure 5. The logarithmic form of the amplitude-frequency and phase-frequency characteristics of the transfer function: a) $c_1 = 25500 \text{ kg.m/rad}$; b) $c_1 = 1500 \text{ kg.m/rad}$

Taking into account the fact that the Nyquist criterion gives an opportunity to follow the impact of the

change in the transfer function parameters on the system stability, the Nyquist curves of the W transfer func-

tion for different values of the link rigidity have been obtained (Fig. 6). From the curves, one can see that in case of the frequency change in the range from 0 to $+\infty$

, the phase-amplitude characteristics of the open-loop system do not include the $(-1, j0)$ coordinate (Fig. 6), from what it follows that the given system is stable.

Figure 6. The Nyquist curves of the W transfer function for different values of the link rigidity:

a) $c_1 = 25500 \text{ kg.m/rad}$; b) $c_1 = 15000 \text{ kg.m/rad}$

From (Fig. 7), it can be seen that in case of the c_1 decrease, the period of stabilization increases.

The transfer function $G(s) = M_{12}(s)/M_c(s)$ of the electrical drive's elastic subsystem for different

values of the c_1 rigidity of the transmission link have been derived:

$$G_1(s) = \frac{91,07s + 2222}{s^3 + 24,4s^2 + 159,1s + 2222}, \quad (4)$$

when $c_1 = 25500 \text{ kg.m/rad}$,

a)

b)

Figure 7. The curves of the transient process of the F transfer function: a) $c_1 = 25500 \text{ kg.m/rad}$;
b) $c_1 = 15000 \text{ kg.m/rad}$

The roots of the characteristic equation
 $s^3 + 24,4s^2 + 159,1s + 2222 = 0,$

are $s_1 = -21,7808$; $s_2 = -1,3096 + j10,0154$;
 $s_2 = -1,3096 - j10,0154$.

$$G_1(s) = \frac{53,57s + 1307}{s^3 + 24,4s^2 + 93,57s + 1307},$$

$$c_1 = 15000 \text{ kg.m/rad},$$

The roots of the characteristic equation

$$s^3 + 24,4s^2 + 93,57s + 1307 = 0$$

$$\text{are } s_1 = -22,8101; \quad s_2 = -0,7950 + j7,5282;$$

$$s_2 = -0,7950 - j7,5282.$$

(5)

From the roots obtained for the characteristic equations it follows that for both values of the link rigidity c_1 the system is stable.

For studying the system the amplitude-frequency and phase-frequency characteristics of the function $G_1(s)$ have been obtained (Fig. 8). For that, $s = j\omega$ is placed in the $G_1(s)$ transfer function.

a)

b)

Figure 8. The logarithmic form of the amplitude-frequency and phase-frequency characteristics of the G transfer function: a) $c_1 = 25500 \text{ kg.m/rad}$; b) $c_1 = 15000 \text{ kg.m/rad}$

In (Fig. 9), the form of the G transfer function transient process for different values of the c_1 link rigidity is represented, from what it follows that

along with the c_1 decrease, the time of the system stabilization increases.

a)

b)

Figure 9. The form of the G transfer function transient process: a) $c_1 = 25500 \text{ kg.m/rad}$;

b) $c_1 = 15000 \text{ kg.m/rad}$

Conclusion

The developed simulation model allows to carry out a comprehensive study and evaluation of the working condition of the mechanical part of the

asynchronous electric drive system, and make decisions that will prevent the system from appearing in irregular operating modes.

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