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Impact voltage deviation on the technological characteristics of crushers

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Abstract. The results of research on the influence of voltage deviation on the technological characteristics and energy losses in electric drive of the crusher are presented. Dependence of the productivity, of specific consumption of energy and grinding module on the voltage are established.

Key words: crusher, electric drive, voltage deviation, productivity, specific consumption of energy, power loss, the grinding module.

INTRODUCTION

Voltage deviation from normalized values leads to inflicted losses from disruption of processes, reduced service life of electrical equipment, rising costs or loss of electricity supply, for example in emergency situations [1–7].

Economic losses, caused by the poor quality of electricity, have two components: the electromagnetic and technology. Electromagnetic component is determined mainly by the loss of active power and change in the life of electrical insulation. Technological component is caused by the influence of energy quality on productivity of technologic plants and the cost of products [8].

Allowable voltage deviation in Ukraine and Russia is ± 5%, and the maximum permissible deviation of ± 10 % [9]. In the European Community RMS deviation voltage should be within ± 10 % [10–12].

However, the actual voltage deflection in Ukraine and Russia is much higher than the permissible value. The range of voltage variation is 15–28 % of the nominal [13].

Voltage deviation causes a change in the angular speed of the electric motor, which causes a change of technological characteristics of working machines.

As a result of experimental studies prof. I. Revenko found that the speed of hammers is the most significant factor in a crusher [14]. Increasing the angular speed of the rotor increases the intensity of crushing grinding due to increased deformation and fracture of particles of the processed material, which with increasing strain behave like a brittle body. However, the practical application of increasing the intensity of grinding by increasing the speed of the rotor is limited by crushing capacity of installed sieve.

Therefore, the angular speed of the rotor at crushing shredding process can be divided into three characteristic periods [14]. In the initial period the growth of speed causes increase in grinding, resulting in reduced energy process, and productivity increases. In most profitable workflow period, which corresponds to a change in the speed range from minimum intensity until the maximum performance crusher, the crusher operates with high performance, ensuring a good quality of shredding. But bandwidth sieve begins to affect the speed of the surface layer of the processed material crushing chamber, which affects productivity and causes growth of energy consumption for grinding material. In the third, critical period energy expenditure for further increase in the speed does not lead to increased productivity or a sufficient degree of comminution, and excessive chafing of the product is caused.

The purpose of research was to establish the influence of voltage deviation on the technological characteristics and energy losses in the electric drive of crushers.

MATERIALS AND METHODS

The analysis of changes in angular speed of electric drives with voltage deflection was carried out using the theory of electric drives related to electromechanical properties of asynchronous motors, driving characteristics of working machinery, and the use of mathematical modelling.

Laboratory studies were conducted on the experimental setup, performed on the basis of universal crusher

KDU-2 [15]. Clover and lupine hay were used as the processed material.

In experimental studies the voltage on the motor was replaced by autotransformer, while measuring the rotational speed of the shaft by tachometer. The change of technological parameters of crusher from voltage deviation was defined, using the technological characteristics of crusher and the experimental dependence of angular speed on voltage.

The influence of voltage deviation on the energy loss in electric drives was determined using the theory of electric drives related to electromechanical properties of asynchronous motors, energetics of electric drives and application of mathematical modelling.

RESULTS AND DISCUSSION

In the steady state the asynchronous motor operates on the working area of mechanical properties that can be considered linear [16]:

$$M_{\partial} = \beta_{\partial}(\omega_0 - \omega), \tag{1}$$

where: M_{∂} – moment of the motor, N·m, β_{∂} – stiffness of the mechanical characteristics of the motor, N·m·s, ω_0 – synchronous angular speed, s^{-1}, ω – given angular speed, s^{-1}.

At voltage deviation the mechanical characteristics of the motor in the work area can be described by the equation:

$$M_{\partial} = \beta_{\partial} U_*^2(\omega_0 - \omega), \tag{2}$$

where: $U_* = U/U_н$ – voltage relative units.

Mechanical characteristics of crushers is described by the equation [17, 18]:

$$M_c = M_0 + (M_{сн} - M_0)\left(\frac{\omega}{\omega_н}\right)^2, \tag{3}$$

where: M_c – moment of static resistances of working machine, N·m, at a given angular speed; M_0 – initial moment, N·m; $M_{сн}$ –moment of static resistance, N·m, at nominal angular speed; ω i $\omega_н$ – given and the nominal value of angular speed, s^{-1}.

In the steady state:

$$\beta_{\partial} U_*^2(\omega_0 - \omega) = M_0 + (M_{сн} - M_0)\left(\frac{\omega}{\omega_н}\right)^2, \tag{4}$$

or

$$\beta_{\partial} U_*^2(\omega_0 - \omega_н\omega_*) = M_0 + (M_{сн} - M_0)\omega_*^2, \tag{5}$$

where: $\omega_* = \omega/\omega_н$ – angular speed in relative units.

After transformations we obtain:

$$U_* = \sqrt{\frac{M_0 + (M_{сн} - M_0)\omega_*^2}{\beta_{\partial}(\omega_0 - \omega_н\omega_*)}}. \tag{6}$$

As follows from (6), the angular speed of crusher by changing the voltage varies by a complicated algorithm.

If we neglect the initial moment $M_0=0$, we obtain:

$$U_* = \sqrt{\frac{M_{сн}\omega_*^2}{\beta_{\partial}(\omega_0 - \omega_н\omega_*)}}. \tag{7}$$

Because

$$M_{сн} = K_з M_{\partial н}, \tag{8}$$

where: $K_з$ – load factor of the motor,

$$\beta_{\partial} = \frac{M_{\partial н}}{\omega_0 - \omega_н} = \frac{M_{\partial н}}{\omega_0 s_н}, \tag{9}$$

where: $s_н$ – nominal motor slip,
the expression (7) can be written as:

$$U_* = \sqrt{\frac{K_з\omega_*^2 s_н}{s}} = \frac{1-s}{1-s_н}\sqrt{\frac{K_з s_н}{s}}. \tag{10}$$

Auditing changes of angular speed of crusher's motor with a nominal slip 0.02, 0.05 and 0.1 at the voltage deviation are shown in Fig. 1.

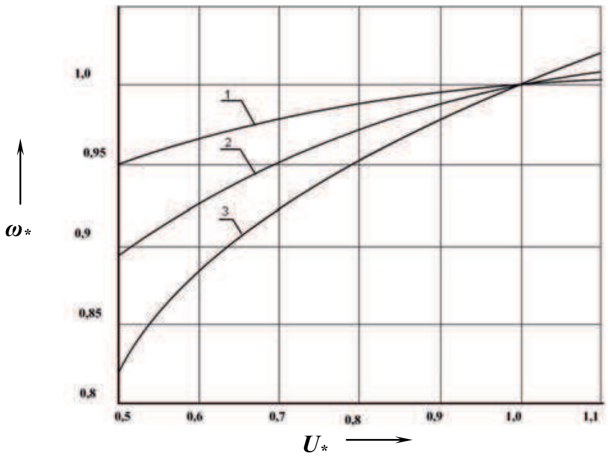

Fig. 1. Changing of the angular speed of the crusher's motor from voltage at nominal motor slip: 1 – 0.02, 2 – 0.05, 3 – 0.1

Since the voltage deviation causes a change in angular speed of crushers, their productivity, specific energy consumption and grinding module change as well.

The dependences of specific energy consumption and productivity of the crusher KDU-2 on voltage for clover hay are shown in Fig. 2, and lupine hay – in Fig. 3. Dependence of grinding module on the voltage is shown in Fig. 4.

The studies found that the productivity of crushers decreases with increasing and with decreasing voltage from the nominal value. The specific energy consumption at lower voltages decreases, but the grinding module increases nonlinearly. When the voltage increases, the unit cost of energy does not lead to increased productivity or degree of comminution, and causes only excessive chafing of the product.

The voltage deviation also causes a change in active power losses in electric drive of crusher.

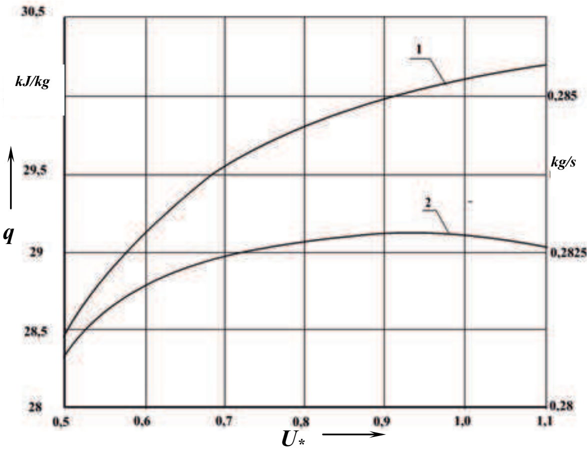

Fig. 2. Dependence of specific energy consumption (1) and productivity (2) of the crusher KDU-2 from voltage for clover hay

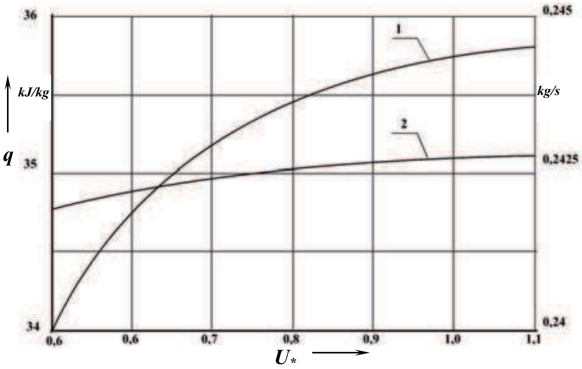

Fig. 3. Dependence of specific energy consumption (1) and productivity (2) of the crusher KDU-2 from voltage for lupine hay

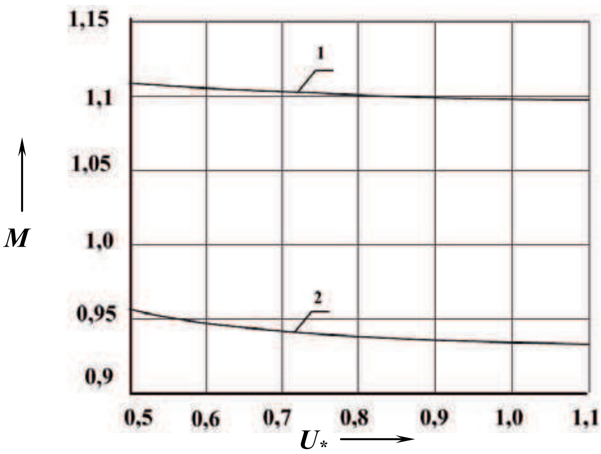

Fig. 4. Dependence of grinding module from the voltage: 1 – lupine hay, 2 – clover hay

Mechanical losses are determined by the approximate formula:

$$\Delta P_{м} = \Delta P_{м.н}\left(\frac{\omega}{\omega_{н}}\right)^2, \tag{12}$$

where: $\Delta P_{м.н}$ – mechanical losses at nominal speed.

The steel losses from eddy currents and hysteresis are determined by the formula:

$$\Delta P_{cm} = \Delta P_{cm1} + \Delta P_{cm2} \approx \Delta P_{cm1н}\left(\frac{U}{U_{н}}\right)^2\left(\frac{f_1}{f_{1н}}\right)^{1,3}\left(1+s^{1,3}\right), \tag{13}$$

where: – steel losses of the stator at nominal values of frequency and voltage.

At the voltage deviation $f_1 = f_{1н}$ and the expression (13) has the form:

$$\Delta P_{cm} \approx \Delta P_{cm1н} U_*^2\left(1+s^{1,3}\right). \tag{14}$$

To drive of crushers used motors with stiff mechanical characteristics, so the first factor in the expression (10) is close to unity. Then the voltage deviation:

$$U_* \approx \sqrt{\frac{K_з s_н}{s}}, \tag{15}$$

and steel losses:

$$\Delta P_{cm} \approx \Delta P_{cm1н}\left(U_*^2 + \frac{K_з^{1,3} s_н^{1,3}}{U_*^{0,6}}\right). \tag{16}$$

As follows from (12), the voltage deviation is not significantly affected by steel losses of asynchronous motor.

Variable power losses in asynchronous motor are determined by the expression [20]:

$$\Delta P_v = \Delta P_{v2} + \Delta P_{v1} = \left(1+\frac{R_1}{R_2^{/}}\right) M_{д}\omega_0 s, \tag{17}$$

where: ΔP_{v2}, ΔP_{v1} – variable power losses in the circles of the rotor and stator, W; R_1 – rotor winding resistance, Ohm; R'_2 – rotor winding resistance, reduced to the stator windings, Ohm; $M_{д}$ – moment of the motor, N · m; ω_0 – synchronous angular speed, s^{-1}; s – motor slip.

Expression (17) with (2) and (15) can be written as:

$$\Delta P_v = \left(1+\frac{R_1}{R_2^{/}}\right)\beta_{д} U_*^2 \omega_0^2 s^2 = \left(1+\frac{R_1}{R_2^{/}}\right)\frac{\beta_{д}\omega_0^2 s_н^2}{K_з^2 U_*^2}, \tag{18}$$

or

$$\Delta P = \Delta P_{н} / U_*^2, \tag{19}$$

where: $\Delta P_{н}$ – variable loss at rated voltage.

Thus, variable power losses in electric drive of crusher are inversely proportional to the square of the voltage. At higher voltages the losses are reduced compared with the nominal, but at the growing variable loss. At lower voltage power losses increase.

CONCLUSIONS

At voltage deviation the angular speed of crushers varies by a complex algorithm, which causes the change of productivity, specific energy consumption and grinding module. Based on the studies found, if the voltage drop to 20 % , productivity of crushers is reduced by 2 % and the grinding module increases. This reduces specific energy consumption by 5 % and energy losses increase in electric drive by 1.5 times.

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