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Influence of electricity quality on technological characteristics of agricultural machines

***Abstract**. In case of voltage deviation and asymmetry, the speed and productivity of agricultural machines changes according to a complex algorithm. The limits of change of these values are determined by mechanical characteristics of a machine and the stiffer modulus of electric motor's mechanical characteristics. They change most significantly in machines with a moment of static resistance, independent and hyperbolically dependent on the speed.*

Streszczenie. W przypadku odchylenia napięcia i asymetrii prędkość wydajność maszyn rolniczych zmienia się zgodnie ze złożonym algorytmem. Granice zmiany tych wartości wyznaczają właściwości mechaniczne maszyny oraz sztywniejszy moduł właściwości mechanicznych silnika elektrycznego. Najbardziej zmieniają się one w maszynach z momentem statycznego oporu, niezależnym i hiperbolicznie zależnym od prędkości.(***Wpływ jakości energii elektrycznej na charakterystyki technologiczne maszyn rolniczych***)

Keywords: voltage deviation, voltage asymmetry, productivity, technological characteristics of a working machine..
Słowa kluczowe: jakość napięcia, maszyny rolnicze.

Introduction

Deviation of electricity quality indicators from normalized values causes negative consequences, among which the most significant are violations of the normal course of technological processes, downtime and production of low-quality products, reducing the service life of electrical equipment, increasing electricity losses [1].

Low quality of electricity causes economic losses [2]. These losses have two components: electromagnetic and technological. The electromagnetic component is determined mainly by the loss of active power and changes in the service life of electrical equipment. Technological component of losses is due to influence of electricity quality on the productivity of technological installations and cost of production [3, 4].

According to EN50160, standard voltage deviation must be within ± 10 %. In reality, these indicators can be both significantly lower (in some settlements of Ukraine 170-190 V) and much higher than normal (up to 300 V) [5].

Voltage deviations and asymmetry have the greatest impact on the electric drives of agricultural machines. In the course of data processing of more than 170 experiments it was found out that electricity quality indicators, which most often go beyond the established limits, are voltage deviation (68 %) and the coefficient of asymmetry in zero sequence (38 %) [6].

When the voltage at the terminals of electric motors changes, torque [7], power consumption and service life of the winding insulation change [8, 9]. A significant voltage drop can lead to a stop of the electric motor or impossibility of starting it [10]. It is established that both a decrease and an increase in voltage from the nominal value cause a decrease in the power factor, which leads to energy losses in the network.

Due to voltage asymmetry, the torque of the induction motor decreases and energy losses increase [11]. The reverse sequence current causes additional heating of the rotor and stator, which leads to rapid aging of the insulation and a decrease in motor power [12, 13].

Research Methods.

Due to deviation and asymmetry of voltage the angular speed of the motor changes, which, in turn, causes a change in the technological characteristics of the working machines.

In experimental studies of the effect of voltage deviation on the technological characteristics of working machines, the voltage on the motor was changed using autotransformers, while measuring the motor speed with a tachometer. Using technological characteristics of working machines, dependence of working machine productivity on the voltage on the motor stator was determined.

In experimental studies of the effect of voltage asymmetry on the stiffness of mechanical characteristic and angular speed of the asynchronous motor a rheostat was switched on in one of the stator phases. The researched motor loading was a DC machine with independent excitation, angular speed of which was regulated by the system "generator - motor". The speed of the electric motor was measured by a tachometer, and the current of the loading machine was measured by an ammeter, which was used to determine the torque of the motor.

Voltage was measured with voltmeters in each phase of the motor and voltage asymmetry coefficient was determined in reverse order.

Influence of voltage deviation on technological characteristics of agricultural machines

When the voltage deviates, the mechanical characteristics of the asynchronous motor on the working area has the form [14]:

$$M_m = \beta_m U_*^2 (\omega_0 - \omega), \quad (1)$$

where: M_m – motor torgue, N· m; β_m – stiffer of mechanical characteristics of the electric motor, N· m· c; $U_*=U/U_n$ – voltage in relative units; ω_0 – synchronous angular speed, c^{-1}; ω – set angular speed, c^{-1}.

The mechanical characteristics of agricultural machinery are described by the equation [15]:

$$M_s = M_0 + (M_{sn} - M_0) \left(\frac{\omega}{\omega_n}\right)^x, \quad (2)$$

where: M_s is the moment of static resistance of the working machine at a given angular speed, N· m; M_0 – initial moment, N· m; M_{sn} – moment of static resistance at nominal angular speed, N· m; ω and ω_n – set and nominal value of angular speed, c^{-1}; x – exponent.

In steady mode

(3) $$\beta_m U_*^2(\omega_0 - \omega_n\omega_*) = M_0 + (M_{sn} - M_0)\omega_*^x,$$

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

After the transformations we get:

(4) $$U_* = \sqrt{\frac{M_0 + (M_{sn} - M_0)\omega_*^x}{\beta_m(\omega_0 - \omega_n\omega_*)}}.$$

In feeder and scraper conveyors, the moment of static resistance does not depend on the angular speed. Then from equation (3) we obtain:

(5) $$Q_* = \omega_* = \frac{\omega_0}{\omega_n} - \frac{M_{sn}}{\beta_m\omega_n U_*^2},$$

where: Q – productivity of machine.

Thus, for machines in which the moment of static resistance does not depend on the angular speed [16], the productivity changes inversely proportional to the square of the voltage and stiffness of the mechanical characteristics of the motor (Fig. 1).

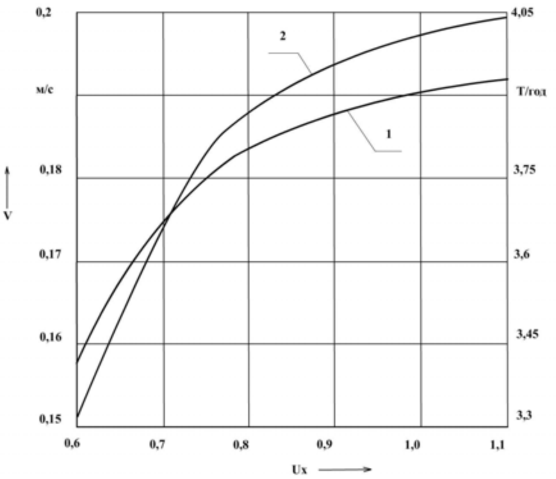

Fig.1. Dependences of speed (1) and productivity (2) of the manure conveyor TSN-2,0B on voltage in relative units

For working machines, in which the moment of static resistance depends linearly on the angular speed (x = 1), equation (4) will look like that:

(6) $$U_* = \sqrt{\frac{M_0 + (M_{sn} - M_0)\omega_*}{\beta_m(\omega_0 - \omega_n\omega_*)}}.$$

For centrifugal pumps and fans (x = 2), so equation (4) is written as:

(7) $$U_* = \sqrt{\frac{M_0 + (M_{sn} - M_0)\omega_*^2}{\beta_m(\omega_0 - \omega_n\omega_*)}}.$$

Since for these machines the productivity is directly proportional to the change in angular speed, then

(8) $$U_* = \sqrt{\frac{M_0 + (M_{sn} - M_0)Q_*^2}{\beta_m(\omega_0 - \omega_n Q_*)}}.$$

In pumps and fans, the initial torque is small ($M_0 \approx 0$), so the algorithm for changing the productivity is quite accurately described by the equation (Fig. 2):

(9) $$U_* == Q_*\sqrt{\frac{Ks_n}{1 - Q_*(1 - s_n)}},$$

where: K – load ratio; s_n – motor rated slip.

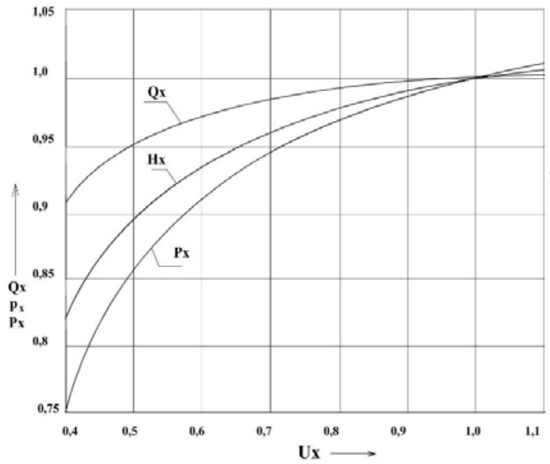

Fig. 2. Dependences of productivity (Q), pressure (H) and power (P) of the centrifugal pump KM8/18 on voltage in relative units

Studies have shown that the productivity of a shredder decreases when increasing and decreasing the voltage from the nominal value (Fig. 3). Specific energy consumption decreases with decreasing voltage, but fineness modulus increases. As the voltage increases, the specific energy consumption increases, which does not increase the productivity of the shredder, but only to excessive grinding of the product.

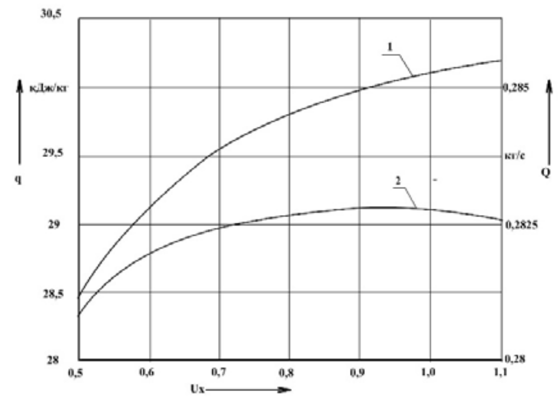

Fig.3. Dependences of specific energy consumption (1) and productivity (2) of KDU-2 shredder on voltage for clover hay

Experimental studies of the change in the angular speed of the feed mixer stirrer when the voltage changes have shown that these dependences are nonlinear. When the voltage decreases from the nominal the angle, speed of the stirrer decreases nonlinearly, and when the voltage increases, it increases slightly. The unevenness of mixing increases both with decreasing and increasing voltage (Fig. 4).

Productivity of milk separators

(10) $$Q_* = \omega_*^2.$$

Then the variation of milk separator productivity by changing the voltage can be written as:

(11) $$U_* = \sqrt{\frac{M_0 + b\omega_н^2 Q_*}{\beta_д(\omega_0 - \omega_н\sqrt{Q_*})}}.$$

As the voltage increases, the angular speed and productivity of the milk separator increase nonlinearly. Since the process of cream separating requires a constant angular speed of the drum, the voltage deviation will reduce the quality of the product.

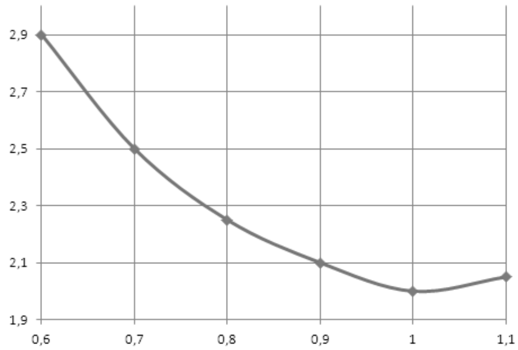

Fig.4. Dependence of mixing irregularity of C-12 feed mixer on voltage

Voltage deviation affects the transients in the electric drive of the milk separator. As follows from the experimental curves of the transient process start *n* = f (*t*) of the milk separator COM-3-1000M (Fig. 5), reducing the voltage increases the start time, which can lead to overheating of the motor.

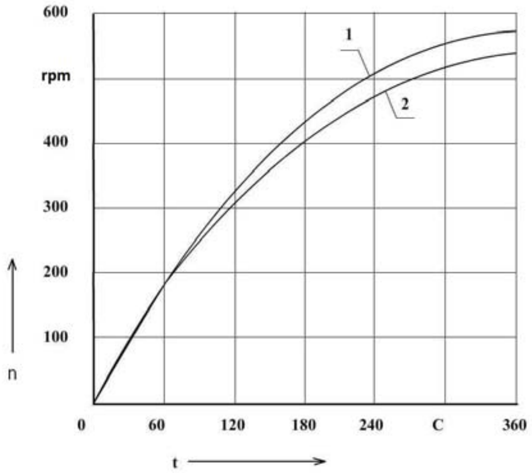

Fig. 5. Acceleration curves of the milk separator COM-3-1000M at nominal (1) and reduced in √3 times voltage (2)

In noria and screw conveyors the moment of static resistance decreases with increasing angular speed (*x*=-1). Then equation (4) looks like this:

(12) $$U_* = \sqrt{\frac{M_0 + (M_{sn} - M_0)/\omega_*}{\beta_m(\omega_0 - \omega_n\omega_*)}} = \sqrt{\frac{M_{sn} - M_0(1-\omega_*)}{\beta_m(\omega_0\omega_* - \omega_n\omega_*^2)}}.$$

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

(13) $$U_* = \sqrt{\frac{M_{sn}}{\beta_m(\omega_0 - \omega_n\omega_*^2)}}.$$

hence

(14) $$U_* = \sqrt{\frac{Ks_n}{s\omega_*}} = \sqrt{\frac{Ks_n(1-s_n)}{s(1-s)}}.$$

As follows from the expression (12) when voltage decreases the productivity of the bucket elevators decreases due to the increase in the filling coefficient of the buckets (Fig. 6), and the moment of static resistance increases.

The magnitude of the change in angular speed is also affected by the stiffness of the mechanical characteristics of the drive motor. Motors with a rigid mechanical characteristic have a smaller change in the angular speed and productivity of the working machine than engines with a softer mechanical characteristic (Fig. 7).

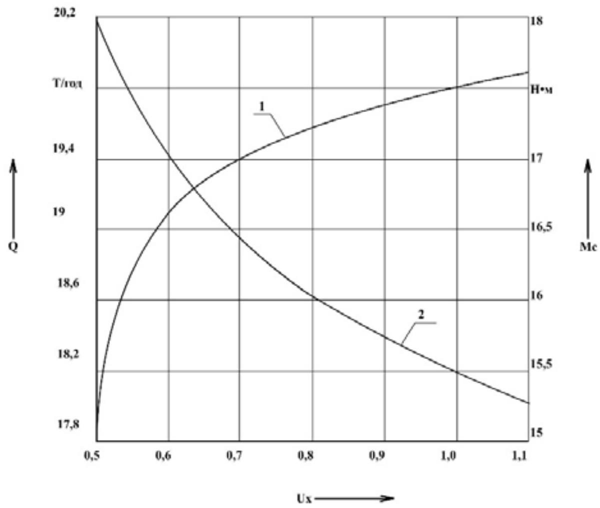

Fig .6. Dependences of productivity (1) and moment of static resistances (2) of noria NZ-20 on voltage.

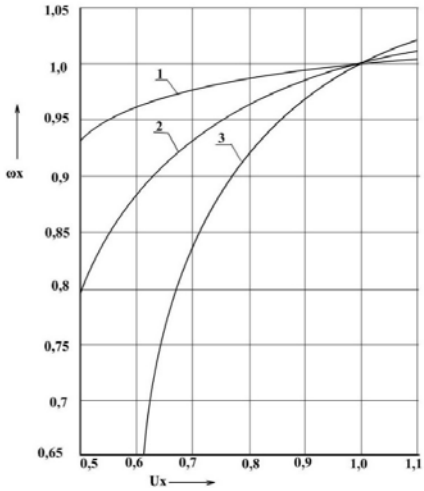

Fig. 7. Change of angular speed from voltage in electric drives of bucket elevator at nominal sliding of the motor: 1– 0,02; 2 - 0.05; 3 - 0.1

Influence of voltage asymmetry on technological characteristics of working machines

When the voltage asymmetry due to the action of the negative phase sequence voltage stiffness of mechanical characteristics changes.

Mechanical characteristics of the motor with voltage asymmetry in the working area can be described by the equation:

(15) $$M_m = \beta_{mas}(\omega_0 - \omega),$$

where: β_{mas} is stiffness of the mechanical characteristics of the motor at voltage asymmetry, N·m·s.

In steady mode

(16) $$\beta_{mas}(\omega_0 - \omega) = M_0 + (M_{sn} - M_0)\left(\frac{\omega}{\omega_n}\right)^x.$$

For working machines in which the moment of static resistance does not depend on the angular speed (*x* = 0), from equation (16) we obtain:

(17) $$\omega_* = \frac{\omega_0}{\omega_n} - \frac{M_{sn}}{\beta_{mas}\omega_n}.$$

For working machines in which the moment of static resistance depends linearly on the angular speed (*x* = 1)

(18) $$\omega_* = \frac{\beta_{mas}\omega_0 - M_0}{(\beta_c + \beta_{mas})\omega_n}.$$

For working machines with a fan (x = 2) and a hyperbolic (x = -1) mechanical characteristic, equation (16) has no analytical solution. However, for these working machines, it is possible to linearize the mechanical characteristics, because the range of changes in angular speed with voltage asymmetry is not large. Then the law of angular speed change is described by equation (18).

The dependences of the change in the angular speed of the motor on the coefficient of voltage asymmetry in the reverse sequence when used to drive working machines with different types of mechanical characteristics are shown in Fig.8.

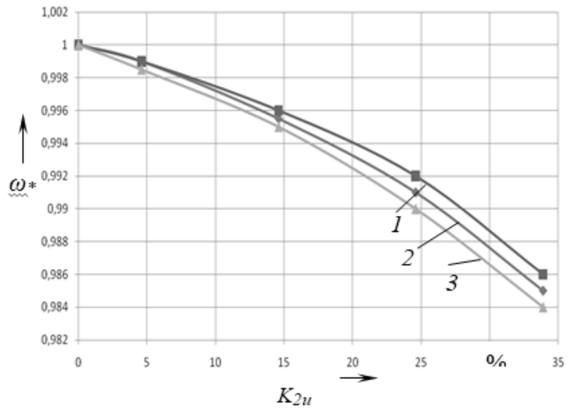

Fig. 8. Dependences of change of angular speed of the electric motor on coefficient of voltage asymmetry on reverse sequence for a drive of working machines with an indicator of mechanical characteristic degree 1 – x = 1, x = 2; 2 – x = 0; 3 – x = -1

If machine productivity is directly proportional to the angular speed $Q_* = \omega_*$, then the dependence of the productivity of the working machine with voltage asymmetry with a constant moment of static resistance:

(19) $$Q_* = \frac{\omega_0}{\omega_n} - \frac{M_{sn}}{\beta_{mas}\omega_n},$$

and for machines in which the moment linearly depends on the angular speed:

(20) $$Q_* = \frac{\beta_{mas}\omega_0 - M_0}{(\beta_c + \beta_{mas})\omega_n}.$$

Conclusions

The change in angular speed and productivity of agricultural machines with voltage deviation occurs according to a complex algorithm. The change in productivity of working machines with asynchronous electric drive is inversely related to the square of the voltage.

The limits of change in the productivity of working machines when the voltage deviates from the nominal value and voltage asymmetry are determined by the mechanical characteristics of the working machine and the stiffness coefficient of the mechanical characteristics of the motor. They change most significantly in working machines with a moment of static resistance, independent and hyperbolically dependent on the angular velocity.

The productivity of working machines which are driven by electric motors with soft mechanical characteristic, at deviation and voltage asymmetry changes more, than at application of electric motors with rigid mechanical characteristic.

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