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Two-propulsion travelling mechanisms of shearers for thin beds

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ABSTRACT: The paper deals with urgent for coal industry problem of designing of shearers for thin beds. The shearers should be equipped with travelling mechanisms with two frequency-controlled drives, one frequency converter, and rigid traction unit. The paper deduces from the experiments and theoretically explains a phenomenon of originating of out-of-phase load variations within drives of such a type. The paper gives recommendations on decrease in affect of load variations on shearer efficiency. The paper proposes a version of correcting a proportional control law in frequency-controlled drive, providing extension of a range of service speeds of the shearer as well as required moving forces.

1 INTRODUCTION

Experience of new shearers designing and applying assures that they should provide working travel of machines at a speed of up to 10-15 meters per minute; moving force should be up to 300-400 kN within faces which length is up to 300-400 meters.

Under the conditions of reduced clearances of machines, such high rates are possible only owing to application of electrical travelling mechanisms. Such integral electrically driven travelling mechanisms with frequency-controlled asynchronous drive and rigid traction unit as УКД300, УКД400, and КДК500 (Ukraine), SL300 and EL600 (Germany), 7LS1and 7LS3 (the USA) etc. are widely used in modern mine-building.

Together with other factors, applications of the above-mentioned electric drive of travelling mechanisms identify transformation of modern shearers to mechatronic machine (Stadnik, N.I., Sergeiev, A.V. & Kondrakhin, V.P. 2007). Advanced travelling mechanism of a shearer with frequency-controlled drive is a mechatronic assembly covering all components being typical for such devices. Components of different physical nature incorporated in one assembly originate a problem of their interacting which provides required traction-speed and resource characteristics. Availability of two interacting frequency-controlled electric drives is the travelling mechanisms feature.

Practice of such shearers designing and exploitation shows (Kosariev, A.V., Stadnik, N.I., Sergeiev, A.V., Kondrakhin, V.P., Lysenko, N.M. & Kosariev, V.V. 2007; Kondrakhin, V.P., Lysenko, N.M., Kosariev, A.V., Kosariev, V.V. & Stadnik, N.I. 2006) that in a number of cases uncoordinated performance of movers takes place. The fact prevents achievement of planned tractional factors as well as the machine life.

As it is seen hereafter, the incardination depends on out-of-phase load variations in drives.

Besides, relative to safety requirements, axial drive is dual-motor with a single frequency converter for downsizing. That is why it is practically impossible to apply closed-loop controls (both scalar and vector).

In this connection, applied open-loop control mode $U_1 / f_1 = const$ (proportional control) should be corrected.

Problems of interacting and coordinated operations of electric drives of shearers travelling mechanisms are considered to be the least studied, and their analysis determines the paper content notably.

Mechatronics-based approach to formation of a law of frequency-controlled drive of shearers providing required control range, traction and speed characteristics, and overload capability is introduced.

2 FORMULATING THE PROBLEM

Loads in frequency-controlled drive of two-propulsion travelling mechanisms of shearers with rigid tractional unit are of dynamic nature. Firstly, the nature depends on inequality of resistive forces of machine movement (forces on operative devices and friction in bearing parts). Secondly, it depends on sprocket-rod action character.

Accordingly, one may provisionally distinguish two components of loads in drives.

Oscillations matching first components take place within two sprocket drives in phase.

Availability of in-phase and out-of-phase oscillations is typical for second component. Their period is equal to one sprocket tooth overlapping.

The oscillations amplitudes depend on a phase shift value between start of engagement teeth of driving sprockets with pin rode, mean shifting speed, and rated slip of motor sets.

Low-frequency oscillations which period is equal to a period of a shearer move over a distance similar to a length of a rod section are also typical for second component (Kosariev, A.V., Stadnik, N.I., Sergeiev, A.V., Kondrakhin, V.P., Lysenko, N.M. & Kosariev, V.V. 2007; Kondrakhin, V.P., Lysenko, N.M., Kosariev, A.V., Kosariev, V.V. & Stadnik, N.I. 2006).

Sustained moment value plays important part for drives having dynamic loading condition while identifying their parameters, initial data for stress analysis, and function. The value is maximum value of average level of motor set torque when it can operate steadily, without stalling under static conditions.

Paper (Starikov, B.Ya., Azarkh, V.L. & Rabinovich, Z.M. 1981) proposes expressions to identify sustained moment of actuator of shearer taking into consideration randomness of acting loads.

Paper (Starikov, B.Ya., Azarkh, V.L. & Rabinovich, Z.M. 1981) gets similar expressions for dual-motor drive of operative devices of a shearer taking into account engine scatter, and its dynamic properties.

However, to assess sustained moment of dual-motor frequency-controlled drive of travelling mechanism, the results may be applied only after further research.

That depends on peculiarities of load oscillation formation in travelling mechanisms, and their low-frequency nature.

Besides, a problem of speed frequency regulation range plays important part for travelling mechanism drive. The problem is directly connected with a value of sustained moment of a drive.

The paper formulates and solves the problem of assessment of sustained moment, and a range of frequency control of dual-motor drives of shearer travelling mechanism to make grounded choice of their parameters.

3 RESULTS OF INVESTIGATION

Frequency-controlled drive of shearers move (Stadnik, N.I., Sergeiev, A.V. & Kondrakhin, V.P. 2007) covers two identical axial drive units $УПП_i$ (Figure 1), supplied by electric energy transducer (EET). They consist of electromechanical transducer $ПЭВ_i$ (asynchronous motor), mechanical transducer $ПВВ_i$ (speed reducer), and mechanical transducer $ПВП_i$ (three-element mover "sprocket – pin sprocket – pin rod").

Input control function $\varepsilon_{вх}(V_п)$ which value identifies set speed $V_п$ of shearer supply is transformed by EET electronic component into electric signal ε_1 with running voltage U_1 and frequency f_1 values.

Output function $\mu_{вых}$ quantitatively determined by means of travelling force $Y_п$ characterizes mechanical step of a shearer.

Modules $ПЭВ_i$ represent electromechanical components. Electrical energy ε_I with U_1 and f_1 converts into rotational movement – interface ω_{i1} characterized by moment $M_{Дi}$ and rotating speed $n_{Дi}$.

Modules $ПВВ_i$ and $ПВП_i$ represent mechanical component. Modules $ПВВ_i$ convert interface ω_{i1} into interface ω_{i2} - rotational movement into rotational movement with other parameters. Modules $ПВП_i$ convert mechanical rotational movement into mechanical step – function μ_i. Tractive force is realized while adding forces developed by $УПП_i$.

Speed-control range, required tractive efforts, and overload capability to be important owing to dramatic load dynamics are basic parameters of axial drive.

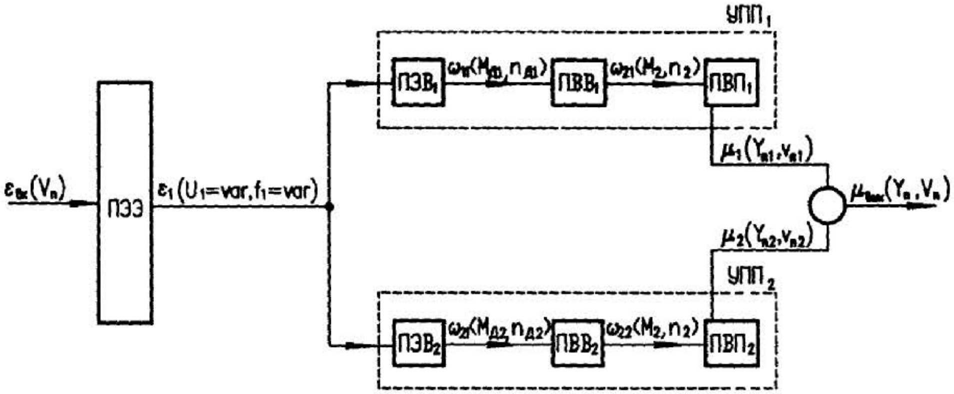

Figure 1. Structural circuit of frequency-controlled axial drive

Travelling mechanisms of such shearers for thin beds as УКД300 and УКД400 are considered as test objects.

Due to serious space limitations, problems of choosing rational parameters of a drive are of great importance for such machines.

Basic parameters of travelling mechanisms of УКД300 and УКД400 shearers are in Table 1.

Studies of results of load measurement in dual-motor axial drives of УКД300 and УКД400 shearers show that such loads as motor currents and moments have random oscillating components.

Highest possible oscillating frequency increases proportionally to mean travel speed not exceeding 1.6 Hz.

Table 1. Parameters of travelling mechanisms

Parameter	УКД300	УКД400
Mover	Three-element	Two-element
Rack arrangement	From a goaf side of conveyer	From a face side of conveyer
Distance between sprocket axes, mm	2160	882
“Sprocket-rack” gear pitch, mm	100	126
Axial drive power, kW	2x30	2x30
Maximum operating speed, meters per minute	8,5	8
Maximum creep speed, meters per minute	12	12
Maximum tractive force, kN	300	300

Figure 2 shows oscillograph of torques of left and right electric motors of УКД300 shearer axial drive as a result of rig tests.

It should be noted that under rig conditions, forces of cutting and feeding on operating devices were simulated by approximately constant, static resistance.

As Figure 2 shows, important out-of-phase load variations are formed in drives of travelling mechanism of УКД300 shearer.

Period of high-frequency components is equal to a period of sprocket tooth-rack gearing. As for low-frequency, it is equal to a period of a shearer move over a distance similar to length of one spout (1.5 m).

Papers (Kosariev, A.V., Stadnik, N.I., Sergeiev, A.V., Kondrakhin, V.P., Lysenko, N.M. & Kosariev, V.V. 2007; Kondrakhin, V.P., Lysenko, N.M., Kosariev, A.V., Kosariev, V.V. & Stadnik, N.I. 2006) interpret the oscillations nature.

As distance between sprocket axes of УКД300 shearer is reasonably large (2.160 m), and there are gaps between rack sections, sprocket teeth gears rack out of synchronization. That can explain availability of out-of-synchronization load variations with a period equal to a period of tooth gear (about 1.5 s) (in Figure 2).

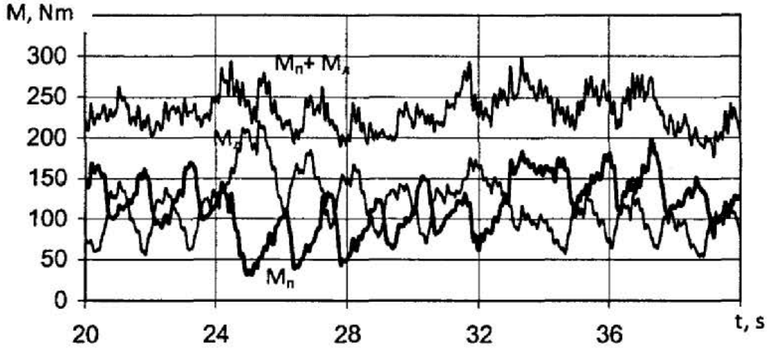

Figure 2. Oscillogram of torques of left Mл and right $M_п$ of electric motors, and total moment of УКД300 shearer axial drive, when its speed is 4.2 meters per minute

Figure 3 demonstrates oscillogram of current of left and right electric motors of УКД400 shearer axial drive obtained in the process of measurement in a mine.

The oscillogram is recorded while coal mining at a speed of 5 meters per minute if amount of inclination is 0°.

A curve of both motors total current is also shown here.

The singularity of formation of a drive of УКД400 shearer travelling mechanism is that during some period (more specifically, 5/12 of total operating time conforming to sprocket gear with five teeth of twelve placed on one section of rack) both sprockets are geared with one rack teeth.

During other periods, sprockets are geared with neighbouring racks teeth.

If sprockets contact with different racks teeth, starting points of teeth gearings are mistimed due to gaps between racks. Phase displacement between start of teeth gearing originates resulting in out-of-phase load variations in drives with considerable amplitude.

Above-mentioned modes of loads forming correspond to 0-12-s section in Figure 4.

As distance between sprockets axes is taken as that multiple as a rack teeth distance (ratio 7), under similar wear degree, both sprockets teeth gear with one rack teeth is synchronous.

In this case, load variations in both drives are in-phase having comparatively small amplitude (section 12-20 s in Figure 2).

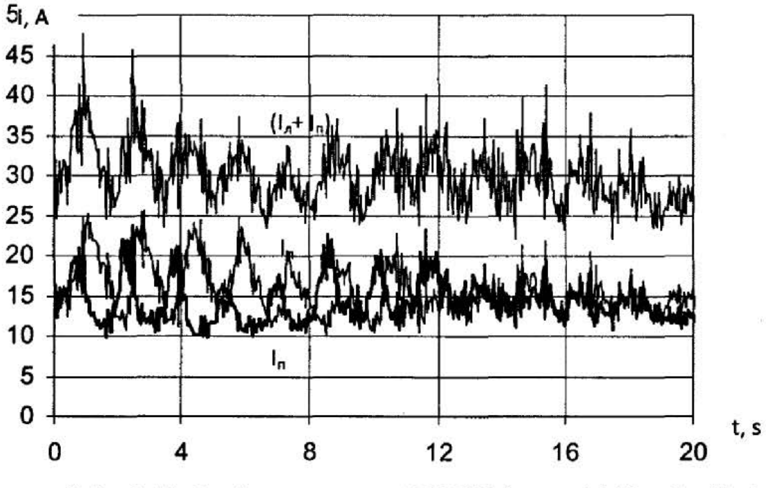

Figure 3. Oscillogram of left and right electric motors current of УКД400 shearer axial drive when $V_П$=5meters per minute

As both drives of travelling mechanism work in common tractional unit, then electric motors stalling (on-load stop) will take place simultaneously despite difference in momentary values of both engines in steady-state.

Figure 4 shows a fragment of oscillogram of current while stalling of electric motors of travelling mechanism of УКД400 shearer.

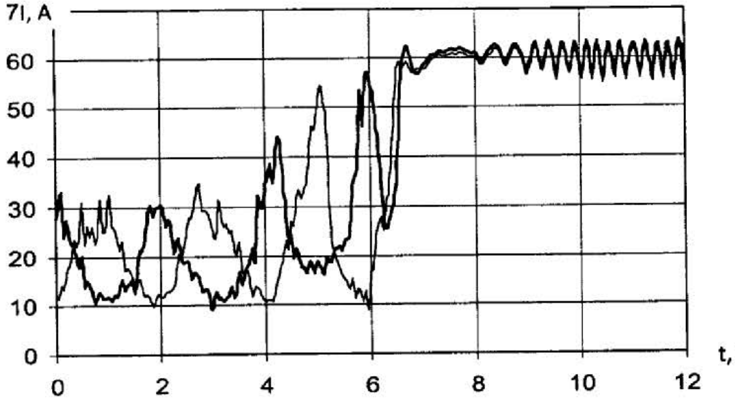

Figure 4. Oscillogram of current while stalling of electric motors of travelling mechanism of УКД400 shearer

As Figure 4 demonstrates, current oscillations of electric motors take place in opposition around average level close to rated current 24.5 A until their values approach critical value.

After that, increase in both motors current occurs more or less synchronously.

It follows that to assess sustained moment of dual-motor drive of travelling mechanism one should take into consideration irregularity of total load moment.

Figures 2 and 3 mean that evolution of total load of axial drive of shearer should be considered as random.

To assess sustained moment as a parameter characterizing spread of values of random process as for average one, paper (Starikov, B.Ya., Azarkh, V.L. & Rabinovich, Z.M. 1981) proposes to take into account load variation factor.

Oscillogram sections with roughly constant level of mean load and constant travelling speed were taken for statistical analysis.

Minimum realization length was taken as such to make a distance by a shearer close to length of one conveyer spout (1.5 m).

Chosen realization length of random process helps to take into account peculiarities of loads forming from the viewpoint of their amplitudes and variation factor.

Results of the statistical analysis show that on a first approximation, within 0.6 to 1.6 current range of rated value, current and a moment in operative current range have direct proportion, and proportion factor is about 12 Nm/A.

Variation factor (VF) of every motor of УКД300 shearer travelling mechanism increases with speed increase varying within 0.200 (1.7 meters per minute (10 Hz) to 0.365 (4.2 meters per minute (25Hz).

With it, VF of total moment stays more or less constant being 0.1; this points to the fact that on the whole load on a drive is constant.

Statistical analysis shows that VF of loads of every motor of УКД300 shearer travelling mechanism is 1.08 to 2.07 times greater to compare with УКД400 shearer.

The greatest VF drop of УКД400 shearer load is within the most typical rate of mining being 4 to 5 meters per minute (1.7 to 2.07 times).

It should be noted that real effect of VF drop of УКД400 shearer is higher to compare with specified as when loads of УКД300 shearer were measured, dynamic components of cutting and loading forces were not available.

That confirms effective strength of engineering decisions made to drop out-of-phase load variations of УКД400 shearer travelling mechanism (centers between sprockets are taken as multiple of gear pitch and as low as practicable, traction unit is located from a face, etc.).

At that very time variation factors of total loads of УКД400 shearer travelling mechanism are 1.1 to 1.3 times greater. It depends on load difference resulting from feeding forces on operating devices while coal cutting and loading.

As it is above-mentioned, jig tests of УКД300 shearer showed zero difference.

Available experimental data can not make it possible to determine a dependence of variation factor of total load of shearer travelling mechanism ν_c on average displacement speed (on feeding frequency).

Hence, to assess sustained moment with stability margin, one may take maximum VF value being ν_c=0.13 for УКД400 shearer.

The value corresponds to meaningful operational conditions of a shearer. For this reason, it may be assumed as basic one while calculating sustained moment of travelling mechanism drive.

To determine sustained moment, the following assumptions are taken:

- Due to low-frequency (up to 1.6 Hz) character of oscillations, dynamic properties of electric motor may be neglected as natural frequency of asynchronous electric motor is about 11 Hz slightly depending on power frequency.
- Possible scatter of nominal parameters of engines decreasing in the process of heat is ignored.
- With rather high probability, random values of total load of a drive are not greater than M_c $(1+3\nu_c)$, where M_c is estimation of expectation (average level).

Hence, sustained moment of dual-motor drive can be determined by

$$M_y(\alpha)=\frac{M_\kappa(\alpha)}{1+3\nu_c} \qquad (1)$$

where $M_\kappa(\alpha) = 2\cdot M_{\kappa\partial}(\alpha)$ is critical moment of dual-motor drive; $M_{\kappa\partial}(\alpha)$ is critical moment of single electric motor; $\alpha = f_1 / f_{1\text{ном}}$ is current proportional frequency of stator; f_1 – voltage frequency of stator; and $f_{1\text{ном}}$ = 50 Hz.

Paper (Chilikin, M.G. & Sandler, A.S., 1981) proposes a formula to determine values of critical moment of asynchronous electric motor at any artificial characteristic:

$$M_{\kappa\partial}(\alpha)=\frac{m_1\cdot U_{1\text{нф}}^2\cdot\gamma^2}{2\cdot\omega_{1\text{ном}}}\cdot\frac{1}{r_1\alpha+\sqrt{\left(b^2+c^2\alpha^2\right)\left(d^2+e^2\alpha^2\right)}} \qquad (2)$$

where $U_{1\text{нф}}$ is actual value of coil voltage of engine if $f_{1\text{ном}}$ = 50 Hz; m_1=3 is number of stator phases; $\omega_{1\text{ном}}$ is a normal angular of frequency of revolution; $\gamma = U_1/U_{1\text{нф}}$ is a stator relative voltage; U_1 is a stator voltage; $\tau_1 = x_1/x_0$ is dissipation coefficient of a stator; $\tau_2 = x'_2/x_0$ is dissipation coefficient of a rotor; $\tau = \tau_1 + \tau_2 + \tau_1\,\tau_2$ is gross dissipation coefficient; b=r_1 $(1 + \tau_2)$; $c = x_0\tau$; $d = r_1/x_0$; $e = (1 + \tau_1)$ are coefficients depending on equivalent circuit parameters; r_1, x_1 are coil resistance and inductive resistance of a stator; x'_2 is reduced inductive resistance of a rotor; and x_0 is reactive impedance of magnification circuit.

For ЭКВ4-30-6-02 electric motor parameters are: $U_{1\text{нф}}$ = 548 V, $\omega_{1\text{ном}}$= 103 c^{-1}, r_1= 1,09 Ohm, x_1= 2,35 Ohm, r_2= 0,724 Ohm, x_2= 2,50 Ohm, and x_0= 53 Ohm.

As a rule, open-loop control system by law of frequency regulation U_1/f_1=const (or $\gamma = \alpha$) is taken up in travelling mechanisms of shearers while controlling down of nominal frequency ($\alpha < 1$).

If $\alpha > 1$, then control law U_1 = const is taken up. Efficient use of more complex feedback-control systems (both scalar, and vector) is made much difficult by the fact that travelling mechanism drive is dual-motor. With it, one frequency rectifier powers both engines. Such a design of drive depends on stringent requirement for its overall dimensions (especially height).

At the voluntary moment, both motor load and rotational frequency may differ greatly (Figure 2 and 3); that makes inefficient closed-loop control on current or on rotational frequency of either motor. If two frequency converters are applied in a roadway, then individual cable for each motor is required. It can hardly be carried out in practice. Due to severe space limitations, mounting of two on-board changers is possible only for high-coal shearers. Hence, in the majority of cases, it is expedient to apply open-circuit systems of variable-frequency control for travelling mechanisms of shearers operating in thin beds.

To plot $M_{\kappa\partial}(\alpha)$ characteristic for two-region control in expression (2), one should assume $\gamma = \alpha$ if $\alpha < 1$, and $\gamma = 1$ if $\alpha > 1$. Figure 5 shows $M_\kappa(\alpha)$ и $M_y(\alpha)$ dependence diagrams for parameters of a drive with two ЭКВ4-30-6-02 motors if ν_c=0,13.

Marks "□" in Figure 5 mean the points obtained as a result of experimental research of travelling mechanism of УКД300 shearer on a loading jig under steady loading. The points correspond closely to a $M_\kappa(\alpha)$ curve. That confirms ability to apply expression (2) for assessment of critical moment of electric motors of travelling mechanisms of shearers.

Figure 5 also demonstrates torque rating $M_н$ of dual-motor drive (dot line) which is identified with the help of warming-up allowance of engine under continuous service if supply frequency is nominal (that is $\alpha = 1$). In this context, it is assumed on a first approximation that a value of allowed warming-up moment within considered range does not depend on supply frequency (or on α). For motors with independent cooling (water cooling in this instance) when control is performed down of nominal frequency, the assumption is also practically assured. While controlling up of nominal frequency, extra research is expedient to check the assumption.

Intersections of curve $M_y(\alpha)$ and line $M_н$ determine edges of control range α_1 and α_2 in which sustained moment of a drive is greater than rated one.

In the case under consideration, α_1=0.28 and α_2=1.28; that is torque rating of a motor may be implemented under 14 to 64 Hz supply frequency. Obtained limit values α should correspond to minimum and maximum working speed of travelling mechanism.

Obtained curves show that under control mode $\gamma = \alpha$ critical moment value decreases when frequency drops. To keep it constant within control range, less voltage is required at small frequencies to compare with frequency drop.

Consider ability of lower frequency drop (14 Hz), and at the expense of that to extend range of speed control. To analyze abilities of a drive, and to adopt dependencies of transformer voltage on frequency, apply equivalent circuit shown in Figure 6. Method (Chilikin, M.G. & Sandler, A.S. 1981) is used for motor moment estimation.

Following symbols are applied while calculating.

Absolute slip parameter β, or relative frequency of a rotor – absolute slip $\Delta\omega$ ratio to synchronous angular rate $\omega_{1н}$ at nominal frequency

$$\beta = \Delta\omega / \omega_{1н} = f_2 / f_{1н}, \tag{3}$$

where f_2 is current frequency of a rotor.

Parameter β is used instead of s slip and correlates with it in such a way

$$s = \Delta\omega / \omega_1 = \beta / \alpha . \tag{4}$$

Dissipation coefficient for stator and rotor is respectively

$$\tau_1 = x_1 / x_m \text{ and } \tau_2 = x_2' / x_m . \tag{5}$$

Total dissipation coefficient is

$$\tau_1 = \tau_1 + \tau_2 + \tau_1\tau_2 . \tag{6}$$

Set of equations (7) identifying performance of frequency-regulated drive of supply is:

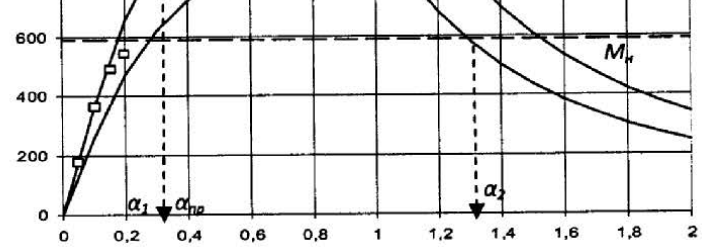

Figure 5. Critical moment and sustained moment of a drive of travelling mechanism with two electric motors ЭКВ4-30-6-02

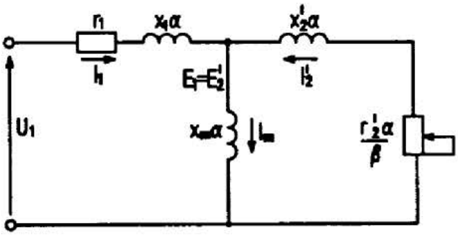

Figure 6. Equivalent circuit of asynchronous motor under variable-frequency control

$$\left.\begin{cases} M_{Дi} = \dfrac{m_1 U_1^2}{\omega_{1н}} \cdot \dfrac{r_2' \beta}{(b^2 + c^2\alpha^2)\beta^2 + 2r_1 r_2' \alpha\beta + (d^2 + e^2\alpha^2) r_2'^2} \\ M_{Д.кi} = \dfrac{m_1 U_1^2}{2\omega_{1н}} \cdot \dfrac{1}{r_1\alpha + \sqrt{(b^2 + c^2\alpha^2)(d^2 + e^2\alpha^2)}} \\ n_{Д_i} \equiv \omega_{Дi} \equiv f_1 \\ Y_{ni} = \dfrac{M_{Дi}}{r_{ci}} u \eta_n \\ n_{Дi} = \dfrac{V_n}{r_{кi}} u \\ Y_n = \sum Y_{ni} \end{cases}\right\} i = 1,2 \qquad (7)$$

where m_1 is the number of stator phases; $M_{Дкi}$ is maximum torque of a motor; $b = r_1(1+\tau_2)$; $c = x_m\tau$; $d = r_1 / x_m$ are coefficients depending on equivalent circuit parameters; x_m is reactive impedance of magnification circuit; $\omega_{Д_i}$, $n_{Д_i}$ are angular rate and motor speed; u is reduction ratio; r_{ci}, $r_{кi}$ are reduced power gearing radius and kinematic gearing radius (Sandler, A.S. & Sarbatov, R.S., 1974); Y_{ni} is moving force of each $УПП_i$; and Y_n is total moving force.

According to (Kondrakhin, V.P., Lysenko, N.M., Kosariev, A.V., Kosariev, V.V. & Stadnik, N.I. 2006), static moving force $Y_{n.c}$ of axial drive is determined in such a way:

$$Y_{n.c} = k_f(G(\sin\alpha \pm f''\cos\alpha) + \sum_{i=1}^{N_u} Y_{u.i}), \qquad (8)$$

where k_f is a coefficient taking into account added resistance of a shearer move (is assumed as equal to 1.4); α is a pitch angle of a face line; f'' is a shearer friction coefficient (on a sill – 0.35; on transfer tracks – 0.21); G is a shearer mass; $\sum_{i=1}^{N_u} Y_{u.i}$ is total feed force on operating device; and N_u is the number of operating devices.

In this context, as it is shown hereinafter, control mode is formulated on the basis of practicable traction performance of a drive allowing decrease in a motor overload capability being less than rated one, nevertheless providing sustained performance of a drive.

In terms of idealized traction and speed characteristic of a drive, supply drive power P_n (S1 mode) is identified by:

$$P_n = \frac{Y_{n.c.\max} V_{n.\max}}{\eta_n}, \qquad (9)$$

where $V_{n.\max}$ maximum axis velocity; $Y_{n.c.\max}$ is static moving force adequate to $V_{n.\max}$; the coefficient is calculated on (1); and η_n is a drive transmission efficiency (assumed as 0.75 in calculations).

According to (9), P_n=57.5 kW in terms of $Y_{n.c.\max}$=22 t and $V_{n.\max}$=12 meters per minute (-α =10° for meaningful operation conditions, and cuttability is 240 N/mm); hence, power of singular machine axis drive motor is assumed as equal to 30 kW (57.5/2). With it, specified motor should have adequate overload capability (2.5-2.7). On the basis of the requirements, ЭКВ4-30-6-02 motor has been designed.

Now it is required to make a choice of a drive ration depending on a number of inter-related issues (which concern the design including parameters of sprocket, rake etc.) which the paper does not consider. Ultimately, noted ratio identifies axis velocity $V_{\text{п.н}}$ being adequate to nominal frequency of converter $f_{1н}$. This paper assumes it as $V_{\text{п.н}}$=8 meters per minute. It should be noted that designing must determine the parameter with the help of iteration method each time forming adequate law of statutory variable-frequency control to provide required overload capacity of a drive over a range of speed regulation.

Noted law is determined analytically by means of a motor torque moment $M_{\text{Д.к}i}$ values calculation, adequate values of moving force $Y_{\text{п.к}i}$, implemented overload capacity λ_p (in relation to static moving force $Y_{\text{п.с}}$ for the axis velocity):

$$\lambda_p = \frac{Y_{\text{п.к}i}}{Y_{\text{п.с}}}. \qquad (10)$$

In this case, required moving forces should not be greater than rated values of a motor warming-up calculated on approach (Chilikin, M.G. & Sandler, A.S. 1981). Necessary overload capacity can't be under 1.5. That is identified including a value of sustained moment $M_{\text{п.уст}}$ (1) of machine axis drive motor (maximum possible mean value of drive torque by the motor specified at established loading dynamism), and adequate moving force $Y_{\text{п.уст}}$ calculated on the assumption of meaningful value a motor coefficient of variation $\nu_{\text{дв}}$.

Formation of variable-frequency control law is performed by means of iteration method through assigning a number of values of frequency and voltage (in increment equal to 0.1 of value $U_{1н} / f_{1н}$, obtained experimentally). The law for sharer УКД400 axial drive is in Figure 3; voltage values are greater than those for proportional control law ($U_1 / f_1 = const$) for 2.5 to 50 Hz variations of stator frequency if rated current is kept. Dependences diagram $\gamma = f(\alpha)$ for considered control laws are in Figure 7.

Mechanical characteristics of axial drive developed for two above-mentioned voltage control laws of frequency are shown in Figure 8.

Values λ (loading capacity relative to torque rating) indicate the efficiency of proportional control law "correction" for natural and simulated characteristics equal to 2.1; 1.5; 0.911 and 2.6; 2.4; and 1.7 for such frequency values as 30, 15 and 7.5 Hz; in this regard value of the index is 2.6 according to the motor specifications.

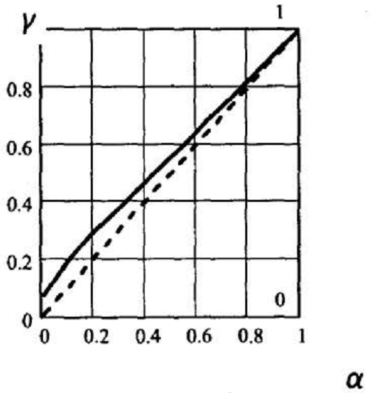

Figure 7. – Voltage dependences on frequency at the output of converter (dash line is for proportional control law $U_1 / f_1 = const$, and "corrected" is for control mode providing increase in overload capability)

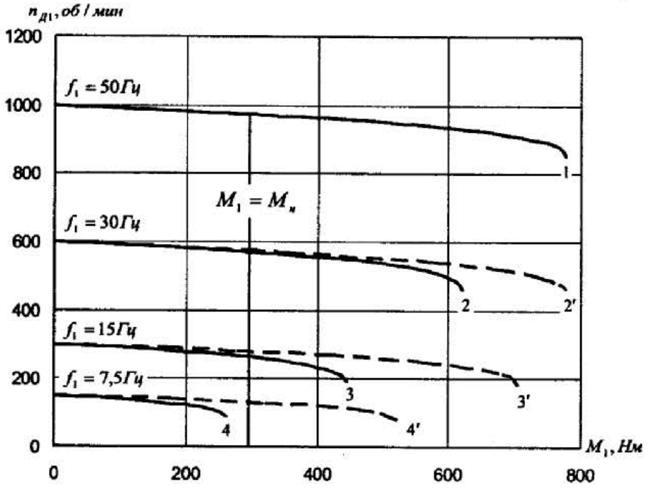

Figure 8. Mechanical characteristics of ЭКВ4-30-6-02 motor at frequency regulation: 1, 2, 3, and 4 are for control mode $U_1 / f_1 = const$; and 2', 3', and 4' are for control mode providing increase in the motor loading capacity

Figure 9 showing traction and speed characteristics of УКД400 shearer (α =10° for average operating conditions) demonstrates that maximum feeding speed is: 10 to 14.5 meters per minute in recovery mode depending on cuttability, and no less than 15 meters per minute in haulage mode if moving force is within the essential reserves. In this context, implemented loading capability λ_p is more than 1.5 per unit when cuttability is 360 N/m. The data belong to a drive ratio when velocity is 8 meters per minute at 50 Hz.

In this context, torque moment of the motor may be implemented within 7.5 to 64 Hz with corresponding change of shearer displacement speed within the regulation range.

Hence, the proposed law voltage control depending upon frequency provides required moving forces, axis velocity changes, and loading capability.

4 CONCLUSIONS

To assess sustained moment of dual-motor frequency-controlled drive of a shearer travelling mechanism, one should use values of variation coefficient of two drives total load. Variation coefficient of total load during recovery may be assumed as equal to 0.116…0.130 resulting from a mine measurement. The value of sustained moment of a drive travelling mechanism depends on supply frequency and control law type. While applying U_1/f_1 = const law, boundary values of per-unit frequency at which sustained drive moment with two ЭКВ4-30-6-02 motors is greater than its torque rating are equal to α_1=0,28 and α_2=1,28; that is torque rating of a motor may be implemented at 14 to 64 Hz. While applying "corrected" control mode, stability of a sustained drive moment is provided if control is performed down of nominal frequency to 7.5 Hz.

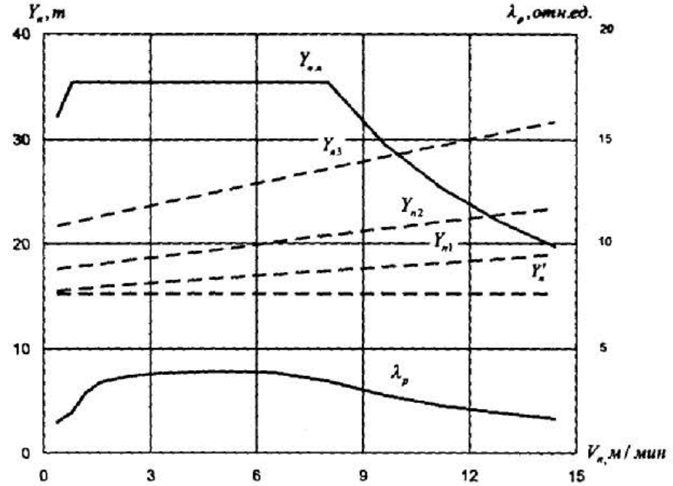

Figure 9. Dependences of moving forces on axis velocity in haulage mode Y_n', in recovery mode Y_{n1}, Y_{n2}, Y_{n3} (when cuttability is 120, 240 and 360 N/mm), allowable power on a motor warming-up $Y_{n.н}$, and implemented loading capability λ_p (if cuttability is 360 N/mm).

The paper approach to correction a law of voltage proportional control from frequency for a shearer axial drive based on mechatronics ideas makes it possible to formulate iteratively voltage dependence at the output of converter on frequency on the assumption of required control range and moving forces. The results of static mechanical characteristics calculation and implemented loading capability of electric drive are taken into consideration.

In future it is required to continue research into dynamic and thermal conditions of axial drive.

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