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CALCULATIONS OF DYNAMIC OPERATING MODES OF ELECTRIC DRIVES OF SELF-PROPELLED MINING MACHINES

Evgenii K. ESHCHIN
Kuzbass State Technical University named after T.F.Gorbachev, Kemerovo, Russia

The task of improving the calculations of the dynamic modes of electric drives of self-propelled mining machines, particulary, tunneling machines, is considered. Attention is drawn to the possibility to opearte in dynamic modes of a spatial change in the an asynchronous electric motor stator housing position, included in the electric drive, around the axis of its rotor due to the ultimate rigidity of the supports of the mining machine. In connection to this, it is possible to change the absolute angular velocity of rotation of the electromagnetic field of the stator of this electric motor. The necessity of introducing into existing mathematical models that determine the state and behavior of asynchronous electric motors, additional differential and algebraic relations for calculating the absolute speed of the electromagnetic field of the stator and the nature of the motion of the stator housing of the electric motor as part of the mining machine is noted. The results of calculations of the idle start mode of the electric motor of the executive body of the mining combine are shown, showing the difference in the nature of its electromagnetic moment variation, rotor rotation speed, as well as efforts in individual reducer elements of the driving body driving the stator body from similar calculation results without taking into account the stator body movement. The conclusion is made about the possible discrepancy between the calculated and experimental results in the study of the dynamic modes of self-propelled mining machines.

***Key words*:** electric drive; motor stator; absolute speed of the electromagnetic field; dynamic modes of operation

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Introduction. Mining machines (MM) are usually divided into two groups: machines that do not change their position in space – stationary, and machines whose work is fundamentally related to changes in the position of their housings (GOST R 54976-2012. Mining equipment. Terms and definitions) – self-propelled, for example, tunneling machines. The self-propelled can also be attributed to shearers with integrated feed system. The actuators of these machines are integral with their enclosures and also change with every spatial change. First of all, this refers to the spatial change in the stators of induction motor (IM) relative to the longitudinal axes of their rotors. IM are the main electromechanical converting devices of electric drives self-propelled MM. These changes can be estimated by the angular velocity of the stator housing. (ω_{st} on Fig.1), which is algebraically summed with the moving synchronous speed of rotation of the stator field $\omega_п$ and forms the absolute speed of rotation of the electromagnetic field of the stator $\omega_{abs} = \omega_m \pm \omega_{st}$.

When working with varying load on the SGM actuator, the change in the angular velocity of the stator housing of the induction motor is equivalent to the implementation of a frequency converter into the stator power supply circuit. It is known that even small changes in the frequency of the supply voltage can lead to a significant change in the dynamic state of the MM electromechanical system [3].

An increase in the instantaneous value of the rotation speed of the stator field $\omega_{abs} = \omega_m \pm \omega_{st}$ under constant supply conditions will lead to a decrease in the instantaneous value of the electromagnetic moment developed by the IM. A decrease in the instantaneous value of the rotation speed of the stator field will ensure an increase in the overload capacity and an increase in the instantaneous value of the electromagnetic torque of the motor.

The arising electromagnetic moment of the induction motor at its start contributes to the occurrence of oscillatory rotational motions around the rotor axis of the rigidly non-fixed stator, which, in turn, provide a change in the absolute electric speed of rotation of the electromagnetic field of the stator and the electromagnetic moment that generated these processes. There is a qualitative and quantitative characteristic deformation of the change in the electromagnetic moment produced by the motor. The effect of the IM changes on the mechanical transfer device (MTD) – gearbox.

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In the study of the state of IM, the transients in electromechanical converters theory is basically used, which is focused on the stationary stator of an electric motor [2, 5, 6, 8, 11-16], for example [2, p.9; 8, p.52; 15, p. 81]), and does not take into account changes in possible changes in the electromagnetic moment of IM due to spatial movements of the stator.

Thus, the questions of the formation of electromagnetic moments of asynchronous electric motors with rigidly non-fixed stator have not been adequately studied. Clarifying the effect of possible changes in the stator field velocity due to its rigid non-attachment to the characteristics of the IM is relevant and significant for a number of MM electric drives [10].

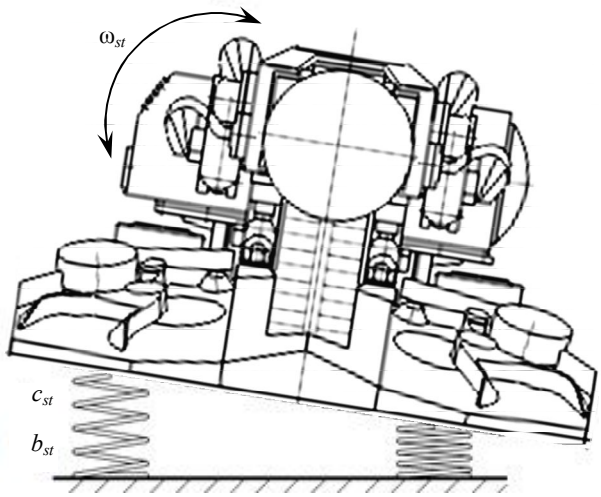


Fig.1. Possible spatial change of the KSP-32 tunneling machine frame due to the reaction of the supports under varying load

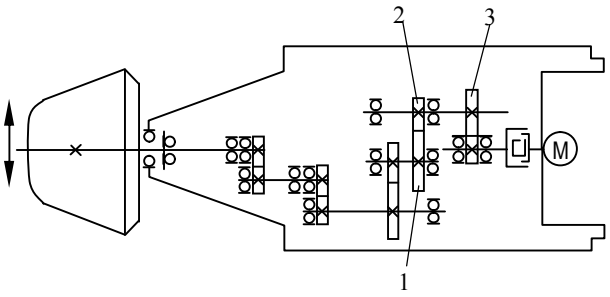


Fig.2. Kinematic diagram of the reducer of the actuator of the KSP-32 tunneling machine [7]
1 – gear wheel; 2 – gear; 3 – shaft (gear shaft)

Formulation of the problem. It is clear that a natural way to clarify the effect of possible changes in the absolute IM stator velocity of the electromagnetic field of in dynamic modes of operation is to determine the formation rules of ω_{abs} parameter in IM's mathematical models. This parameter must be clearly presented in the model of IM. This raises the problem of supplementing the mathematical and computer models of IM with equations and blocks realizing them, determining possible movements of the IM stator housing and the values of the absolute speed of rotation of the electromagnetic field of the stator – the parameter ω_{abs}. As a result, it becomes possible to specify the calculations of the electromagnetic states of the IM and the mechanical components of the MM electric drive in dynamic operating modes.

Methodology. Let us consider the solution of the problem on a specific example KSP-32 tunneling machine electric drive actuator [7]. The kinematic scheme is shown in Fig.2. The original mathematical model of IM will take with the designations [6, p.493]:

$$\begin{cases} \boldsymbol{U}_s = R_s \boldsymbol{I}_s + \dfrac{d\boldsymbol{\Psi}_s}{dt} + j\omega_k \boldsymbol{\Psi}_s, \\ \boldsymbol{U}_r = R_r \boldsymbol{I}_r + \dfrac{d\boldsymbol{\Psi}_r}{dt} + j(\omega_k - p\omega)\boldsymbol{\Psi}_r, \end{cases} \quad (1)$$

where $\boldsymbol{U}_s$, $\boldsymbol{U}_r$ – stator and rotor winding voltage vectors; $\boldsymbol{I}_s$, $\boldsymbol{I}_r$ – stator and rotor current vectors; $\boldsymbol{\Psi}_s$, $\boldsymbol{\Psi}_r$ – stator and rotor flux linkage vectors; ω_k – coordinate system rotation speed; ω – rotational speed of rotor; p – number of pole pairs; R_s, R_r – active resistances of stator and rotor windings.

The reduced set of differential correlations must be supplemented by equations of motion that determine the rotor motion and possible movements of the stator housing

$$\begin{cases} \dfrac{d\omega}{dt} = \dfrac{1}{J_{ad}}(M - M_{cad}), \\ \dfrac{d\omega_{st}}{dt} = \dfrac{1}{J_{st}}(M - M_{yst}), \\ \dfrac{dM_{yst}}{dt} = c_{st}\omega_{st} + b_{st}\dfrac{d\omega_{st}}{dt}, \end{cases} \quad (2)$$

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where ω, ω_{st} – angular velocity of stator and rotor of IM; M – electromagnetic torque of IM; M_{cad} – IM shaft modulus of resistance; J_{ad} – moment of inertia of IM; J_{st} –moment of inertia MM parts adjusted to IM frame; M_{yst} – elastic moment arising in the supports of MM when it moves; c_{st} – stiffness (elasticity) of MM supports; b_{st} – vibration damping coefficient (viscosity) in supports.

Note that the movement of the housing of the stator IM is determined by the mode of its work «on the support».

In the synchronous coordinate system (u, v), the absolute angular velocity of stator electromagnetic field rotation of the electromagnetic field determined by the algebraic sum of the angular moving (ω_n – nominal field rotation speed) and relative (ω_{st}) velocities – $\omega_{abs} = \omega_n \pm \omega_{st}$.

In stationary coordinate system (α, β) $\omega_{abs} = \pm \omega_{st}$. Sign in front of ω_{st} *is* determined by the mode of acceleration or deceleration of the rotor IM and is determined by the rule $-sign(d\omega/dt)$, those in practical calculations, the absolute speed of the electromagnetic field of the stator is determined as:

$$\begin{cases} \omega_{abs} = \omega_n - \omega_{st} sign(d\omega/dt) \ (u,v), \\ \omega_{abs} = -\omega_{st} sign(d\omega/dt) \ (\alpha,\beta). \end{cases} \quad (3)$$

Implementing correlations (1)-(3) in the Matlab tool environment taking into account the formation of the load on the shaft of IM according to [4] for the mode of starting the IM by direct connection to the mains without load, it was possible to obtain the results shown in Figure 3-6. Note that in this mode, the moment of resistance on the IM shaft is determined by the series connection of the inertial mass of gears and gear wheels of the gearbox (see Fig.2).

It is seen (Fig.3) that taking into account possible movements of the stator housing in the start mode leads to a significant change in the shape of the dependence of the electromagnetic moment M in time (1 in Fig.3). There is a significant shift «to the left» relative to the calculated form of the change in M without taking into account the effect of the movement of the stator housing of the IM. The latter is understandable. When starting the IM there is a movement of its body, estimated by the angular velocity of the stator ω_{st} (5 in Fig.4). It can almost always be recorded as a small «push», which is felt even without the use of special recording equipment.

Maximum value (in the given example) ω_{st} equal to 0.09 p.u. (with $t \approx 0.1$ c) or 14.13 c^{-1}. These are relatively small changes. ω_{st} will entail a decrease in the absolute value of the speed of rotation of the electromagnetic field of the stator ω_{abs} (at maximum ω_{st} to 143 c^{-1} or the frequency of the supply voltage from 50 to 45.5 Hz). In turn, this decrease ω_{abs} while maintaining the amplitude of the supply voltage unchanged causes an increase in the magnitude of the electromagnetic moment, which leads to significant deformations of the variables of the IM state(2 in 1, 4 in 3 in Fig.3; 2 in 1, 4 in 3 in Fig.4).

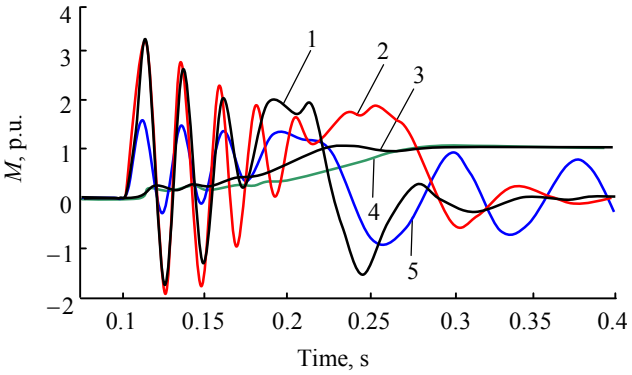


Fig.3. Electromagnetic moment of the IM behavior (1, 2, 5) and its speed (3, 4), taking into account (1, 3) and without (2, 4) movements of the stator housing in the start mode, 5 – when powered via a cable

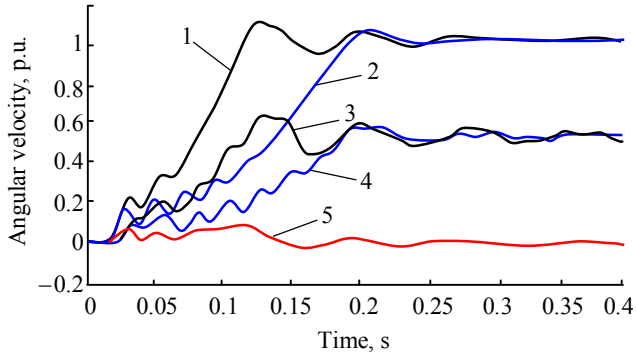


Fig.4. The change in the angular velocity of the IM rotor (1, 2), gearwheel 4 (2, 3 in Fig.2) and the angular velocity of the stator ω_{st} (5) when taking into account (1, 3) and without (2, 4) movements stator housing in start mode

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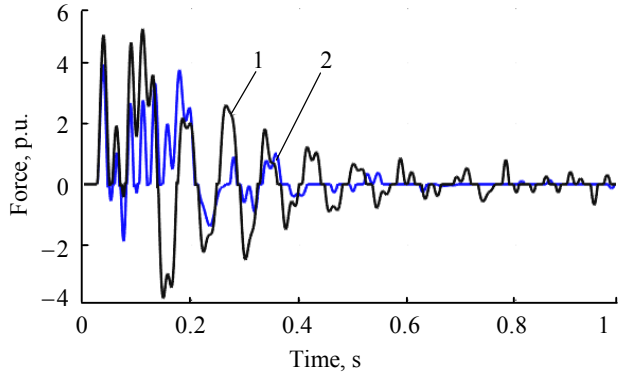


Fig.5. The change in the force in the gear connection and gearwheel (1, 2 in Fig.2), taking into account (1) and without (2) movements of the stator housing in the launch mode

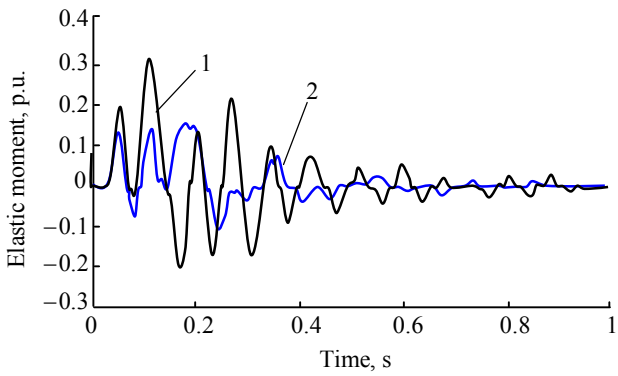


Fig.6. Change of the elastic moment of the shaft (3 in Fig. 2), taking into account (1) and without (2) movements of the stator housing in the start mode

Note that the change (decrease) in the amplitude of the supply IM voltage in the start-up mode when powered from the transformer substation through the cable network naturally reduces the amplitude values of the moment *M*, but almost retains its qualitative form (curve 5 in Fig.3).

The change in the engagement of the gear and gearwheel (1, 2 in Fig.2), as well as the change in the elastic moment of the shaft (3 in Fig.2) illustrate the change in the state of individual elements of the MTD (gearbox) when the body mobility is taken into account IM stator. It can be noted that there is an increase in the peak values of the efforts and the elastic moment, which is a consequence of an increase in the values of the electromagnetic moment of the IM.

The calculated comparative practice, taking into account possible movements of the stator housing of the IM (Fig.3-6), shows their significant effect on the dynamic state of the IM and further on the processes in the MTD (gearbox). The movement of the stator housing IM confirms the extreme sensitivity of the characteristics of IM to changes in the supply voltage frequency [1, 9].

Thus, the practical significance of the work lies in the possibility of increasing the reliability of the calculation of the state of the electric drive of self-propelled mining machines in dynamic operating modes.

Conclusion. In the study of the dynamic modes of operation of self-propelled MM electric drives, it is problematic to use the classical theory of describing the state of an asynchronous electric motor due to the assumption of the stator immobility of an electric machine in it. The mobility of the stator housing of the IM, arising from the technological features of SGM, leads to a change in the absolute angular velocity of rotation of the electromagnetic field of the stator of the IM, which is known to be equivalent to changing the characteristics of the IM by changing the frequency of the supply voltage. The latter entails an arising uncontrollable error in the calculations and a possible inexplicable discrepancy between the results of experiments and theoretical calculations when performing research work with real electric drives of self-propelled mining machines.

REFERENCES

1. Bulgakov A.A. Frequency control of asynchronous motors. Moscow: Energoizdat, 1982, p. 216 (in Russian).
2. Gorev A.A. Transient of synchronous machine. Moscow-Leningrad: Gosenergoizdat, 1950, p. 551 (in Russian).
3. Eshchin E.K. Variant of frequency control of asynchronous electric drive of mining machines. *Elektrotekhnika*. 1996. N 1, p. 28-30 (in Russian).
4. Eshchin E.K. Detailed calculation of the dynamic modes of operation of mining machines. *Gornoe oborudovanie i elektromekhanika*. 2017. N 5, p. 35-39 (in Russian).
5. Klyuchev V.I. Electric drive theory. Moscow: Energoatomizdat, 2001, p. 704 (in Russian).
6. Kovach K.P., Rats I. Transients in ac machines. Moscow-Leningrad: Gosenergoizdat, 1963, p. 744 (in Russian).
7. Antipov V.T., Tapekhin N.S., Serov E.S., Gafanovich V.A. Tunneling machine KSP-32. Manual. AO «Yasinovatskii mashinostroitel'nyi zavod». 1999. B. 1, p. 119. // https://www.twipx.com/file/22907/ (in Russian)
8. Kopylov I.P. Electromechanical converters. Moscow: Energiya, 1973, p. 400 (in Russian).

9. Kostenko M.P. The work of a multi-phase asynchronous motor with a variable number of periods. *Elektrichestvo*. 1925. N 2, p. 85-95 (in Russian).

10. Khoreshok A.A., Mamet'ev L.E., Tsekhin A.M., Borisov A.Yu. Ensuring the stability of the tunneling machine with two crown-shaped reversible working body. *Gornoe oborudovanie i elektromekhanika*. 2016. N 6, p. 3-7 (in Russian).

11. Dieter Gerling. Electrical Machines. Mathematical Fundamentals of Machine Topologies. New York: Springer, 2015, p. 472.

12. Jan A. Melkebeek. Electrical Machines and Drives. Fundamentals and Advanced Modelling. Cham (Switzerland): Springer International Publishing AG, 2018, p. 442.

13. Juha Pyrhőnen, Tapani Jokinen, Valéria Hrabovcová. Design of rotating electrical machines. Chichester (United Kingdom), John Wiley & Sons, Ltd., 2008, p. 512.

14. Lyshevski S.E. Electromechanical systems and devices. New York: Taylor & Francis Group, 2008, p. 565.

15. Park R.H. Two-Reaction Theory of Synchronous Machines. Generalized Method of Analysis – Part I. Transactions of the American Institute of Electrical Engineers. 1929. Vol. 48. Iss. 3, p. 716-727.

16. Sen P.C. Principles of electric machines and power electronics. Chennai (India): John Wiley & Sons, Inc., 2014, p.618.

Author **Evgenii K. Eshchin,** *Doctor of Engineering Sciences*, *Professor*, *eke_kuzstu@mail.ru* (*Kuzbass State Technical University named after T.F.Gorbachev*, *Kemerovo*, *Russia*).

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