INCREASED PRODUCTIVITY WITH PERFORMANCE MONITORING OF THE KEY TECHNOLOGICAL INDICATORS FOR POWER SHOVELS AND DRAGLINE BY MEANS OF ELECTRIC DRIVE

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ABSTRACT

The report focuses on the process measurements of the mass of rock in the bucket power shovels and dragline excavators. The mathematical models are suggested of AC and DC electric drives of excavators. These models are a basis for calculation methods of the electric drive electromagnetic torque. The design schemes of mechanical equipment of excavators considered to account the situation of bucket in the plane of the boom. The methods of static moment allocation and identification of the excavator technological operations are developed. The results of the work are experimentally tested on power shovels with bucket capacity of 12 and 18 m^3.

KEYWORDS

Power shovels, Dragline, Electric drive, Productivity, Calculation of electromagnetic torque, Identification of technological operations, Measurement the mass of rock

INTRODUCTION

The problem of to develop methods for control of electromechanical systems shovels that lead to increased efficiencies excavators is important today. To achieve this goal have been solved the problem of develop a methods to measure the performance of excavators, including methods of recognition of technological modes of excavator and a method of measuring static electric current.

Also increased productivity shovels possible through feedback between the engineer and the process of excavation. For this purpose excavators are fitted with an information system, a key indicator of which is a mass of rock in the bucket. Mass measurement is possible by means of electric drive based on indirect methods of measurement [1]. Modern excavator electric drive operates on the basis of squirrel-cage induction motors (SCIM). In particular, such a scheme made electric drive main mechanisms mining excavator with a bucket capacity of 18 m^3 EKG-18 production "Uralmash" machine-building corporation. Excavator is equipped with an information system in this connection the problem arises of calculating the SCIM electromagnetic torque.

METHODS

Methods for measuring the electromagnetic torque

Electromagnetic torque DC motor with separate excitation is calculated using the well-known and not difficult. Therefore, a closer look at the calculation of electromagnetic torque of the induction motor with squirrel-cage rotor (SCIM).

In order to improve the accuracy of the electromagnetic torque in the dynamic modes of electric drive the mathematical description induction motor is performed in the space vectors in a coordinate system. The following types of coordinate systems: a fixed space coordinate system x-y; rotating with the rotor speed coordinate system d-q; rotating with the arbitrary angular velocity ω_k coordinate system α-β. Fixed in space x-y coordinate system does not allow a mathematical description of the equation with constant coefficients. Therefore, the mathematical description of SCIM made in d-q and the α-β coordinate system.

We make the following assumptions in the description of electromagnetic processes in SCIM: magnetic core and winding machines are symmetrical, the magnetomotive force and magnetic induction coils sinusoidally distributed around the circumference of the air gap, the phenomenon of displacement current is ignored.

We write the differential equation of the mathematical model SCIM taking into account magnetic conductor saturation in the coordinate system α-β [1]:

$$
\begin{aligned}
i_{m\alpha} &= \frac{\psi_{m\alpha}}{L_m(\psi_m)};\\
i_{m\beta} &= \frac{\psi_{m\beta}}{L_m(\psi_m)};\\
i_{r\alpha} &= i_{m\alpha} - i_{s\alpha};\\
i_{r\beta} &= i_{m\beta} - i_{s\beta};\\
\psi_{m\alpha} &= \psi_{r\alpha} - i_{r\alpha} L_{r\sigma};\\
\psi_{m\beta} &= \psi_{r\beta} - i_{r\beta} L_{r\sigma};\\
p\psi_{r\alpha} &= -i_{r\alpha} R_r + (\omega_k - \omega)\psi_{r\beta};\\
p\psi_{r\beta} &= -i_{r\beta} \cdot R_r - (\omega_k - \omega)\psi_{r\alpha};\\
m &= \frac{3}{2} Z_P \left(\psi_{m\alpha} i_{s\beta} - \psi_{m\beta} i_{s\alpha}\right),
\end{aligned}
\tag{1}
$$

where $i_{s\alpha}$, $i_{s\beta}$, $i_{r\alpha}$, $i_{r\beta}$, $i_{m\alpha}$, $i_{m\beta}$ - projection of the stator, rotor and magnetizing current vector on coordinate axis α, β; $\psi_{r\alpha}$, $\psi_{r\beta}$, $\psi_{m\alpha}$, $\psi_{m\beta}$ - projection of the rotor and magnetizing linkage vector on coordinate axis α, β; ω_k, ω_r - angular frequency of the stator field rotation and rotor rotation; m – electromagnetic torque; R_r , $L_{r\sigma}$, L_r , L_m - rotor resistance, rotor leakage inductance, inductance of the rotor, magnetizing inductance; T_r – rotor electromagnetic time constant; k_r – rotor electromagnetic coupling coefficient; Z_p – number of pole pairs.

When the orientation of the rotating coordinate system α-β for the rotor flux vector the mathematical description (2) can be represented as:

$$
\begin{aligned}
p\psi_r &= \frac{1}{T_r}(L_m i_{s\alpha} + \psi_r);\\
m &= \frac{3}{2} Z_P k_r \psi_r i_{s\beta}.
\end{aligned}
\tag{2}
$$

Methods for calculating the electromagnetic torque SCIM with an arbitrary orientation of the coordinate system α-β and the orientation of the rotor flux vector based on the equations of the mathematical description (1) and (2). Numerical solution of equations by using the Tustin's method.

Recognition technological operations of excavator

The problem of recognition is to mathematically classify multivariate observation $x = (x_1, x_2, ..., x_n)^T$ to one of several clasters (classes). As applied to control dynamic object classes can match the state s_m, m = 1, ..., M. It is assumed that the number of classes is fixed and finite.

In this formulation of the components of the vector x is the measured output coordinates electromechanical systems excavator. Recognition can be performed as one multivariate observation x, and in their totality xn, consisting of n observations. Classes s_1, s_2, ..., s_m correspond working operations excavator and the same set of attributes p_1, p_2, ..., p_l, which allow to calculate, according to certain rules, a measure of the difference between classes and use of reliable D, solve the problem of the recognition .

The main difficulties that arise when using classical methods of discriminant analysis, is the failure of the hypothesis of normal distribution of the populations $f_1(x)$, ..., $f_m(x)$. Therefore, we propose a method for recognition based on the analysis of information characteristics of the object's vector surveillance management.

In general, each component of surveillance is a continuous function of time, and therefore can be interpreted as a continuous source of information. But this model requires knowledge of the source of information of statistical characteristics of the source, given by a probability density function. Statistical analysis of the observation vector x shows that usually the components can not be reliably measured are the known laws of distribution of random variables. Therefore, the transition is made to a binary vector x, receiving one of a finite set of possible, the value of the discrete times t_k.

For definiteness, we choose the scale of measuring the components of the vector x with the range from -1,20 to 1,20. The scale is divided into k intervals. Thus, each component of x is characterized by discrete values (states) z_1, z_2, ..., z_k, the totality of which is the source alphabet posts. We can estimate a priori probabilities p_1, p_2, ..., p_k occurrence values for each component of the vector x for a certain period of time, and the sum of the probabilities for each component equal to one. Considering that the state of the source of information are implemented independently, the a priori uncertainty private message element appears

$$H_{(pi)} = -\log p(z_i) \tag{3}$$

After measurement of x and obtain the discrete element u_i message becomes known the value of the a posteriori probability $p(z_i/u_i)$ implementing message element z_i. Then the posterior partial uncertainty

$$H_{(zi/ui)} = -\log p(z_i/u_i) \tag{4}$$

Particular amount of information obtained when receiving a message u_i relative to the message z_i

$$I_{(zi)} = H_{(pi)} - H_{(zi/ui)} = \log\,(p(z_i/u_i)/p(z_i)) \tag{5}$$

may be a sign of discrimination multivariate observation x into one of several classes (states of a control object).

Selecting Private Information in the reception message element u_i as a sign of discrimination determines that the most important for discrimination are components whose contribution to the total variance is the smallest.

For the components of the measurement, making a great contribution to the total variance, the probability of occurrence of each of the elements of posts about the same, and therefore the amount of private information is close to zero. Thus, the method of data assumes that you recognize conditions obtaining prior probability P matrix elements of the alphabet source of information for the whole period of time and matrices P_1, P_2, ..., P_M probabilities for recognized states.

Proper recognition procedure is based on expression (5) the value of the private information (feature recognition) for each component of the vector x, under the assumption that there is a state s_m of M possible, summing the values obtained for each prospective state and selecting the possibility of such a state, for whose total number of private information as possible.

Table 1 provides an example of an ordered in ascending values of the expectation of the results of statistical processing of values measures the differences between the classes, which is the equivalent of the amount of private information for each prospective state for single-bucket excavator

Table 1 – Statistical characteristics of the measures the difference between the classes

Statistical characteristics amount of private information	**State of the object (technological operations of excavator)**			
	1	2	3	4
Mean	-5,101	4,390	-2,411	1,716
Standard deviation	1,104	1,063	0,624	0,703

Analysis of the results suggests a high degree of difference between the classes characterized by the amount of private information. Indeed, if we calculate the 95% limits for the best followed by a measure value differences between the classes, the values obtained indicate that the value ranges do not overlap. Of reliable recognition should be taken as the lower limit of the 95% confidence interval for the largest amount of information.

Another advantage of this method is the possibility of a direct quantitative assessment of the reliability of the recognition, expressed in terms of private information.

Method of measuring the static current of power drive

We propose a new method for measuring the static current motor (patent RU 2097495 C1), which allows you to exclude the operation of differentiation to determine the dynamic power and formulate a rule according to which the dynamic current of the motor is defined as an amount proportional to the difference between the supply voltage of the motor and a value proportional to the integral of the dynamic DC electric motor. The static electric current found by determining the difference between the total and dynamic shock.

The proposed measurement method allows an order to improve the performance measure static electric current in transient operating conditions, compared with the known method (relative error of 1.99% and 12% respectively).

Table 2 shows the histograms of the sample processing of the measured values of static current, obtained respectively known and the proposed methods.

Table 2 –The results of processing the histograms

Method of measurement	Minimum	Maximum	Mean	The standard deviation	The systematic error	relative error, %
Well-known	0,272	0,456	0,348	0,042	0,052	12,01
The proposed	0,383	0,430	0,401	0,008	0,001	1,99

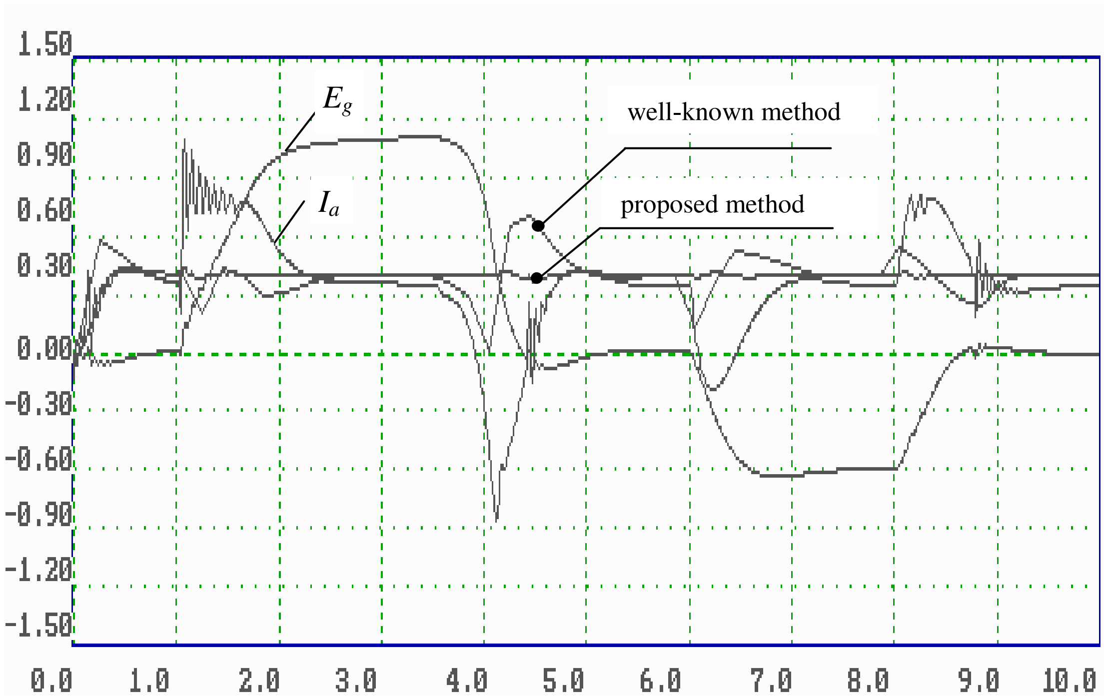

Figure 2 – Simulation results cycle mining shovels with bucket capacity of 5,0 m^3 (PU)

RESULTS

Error estimation methods for measuring the electromagnetic torque

As input values for the calculation of electromagnetic torque of electric drive of hoist bucket mechanism using the experimental data of the projections of the stator current vector, the rotor angular speed and slip of electric drive excavator EKG-18. Sampling interval of values of 20 ms. The data were obtained for two cycles of simulation a machinist excavator working cycle with empty bucket: digging, turn to unload, unloading and turning to the face. Lowering the bucket is carried out at high speed, which reduces the value of the projection is $i_{s\alpha}$ and increase the frequency of the stator field. This mode is entered in the calculation of the magnetizing inductance value of the other circuit.

Figure 3 shows plots of the electromagnetic torque for the methods without orientation (1) and orientation (2) coordinate system. From the graphs (Fig. 3) that the average value of electromagnetic torque in the process of holding the bucket at zero speed different from the average value of the electromagnetic torque at steady speed of 36% for the method with an arbitrary orientation of the coordinate system and 55% for the method to the orientation of flux vector of the rotor.

We calculate a torque of electric drive of hoist bucket mechanism in engine and braking modes of operation:

$$T_{mech.}^{motor} = T \cdot \eta_{el.motor} \cdot \eta_{gear};$$
$$T_{mech.}^{brake} = \frac{T \cdot \eta_{el.motor}}{\eta_{gear}}, \qquad (6)$$

where $\eta_{el.motor}$ – the efficiency of the motor mechanism for lifting the bucket; η_{gear} – the efficiency of the hoist bucket mechanism reducer.

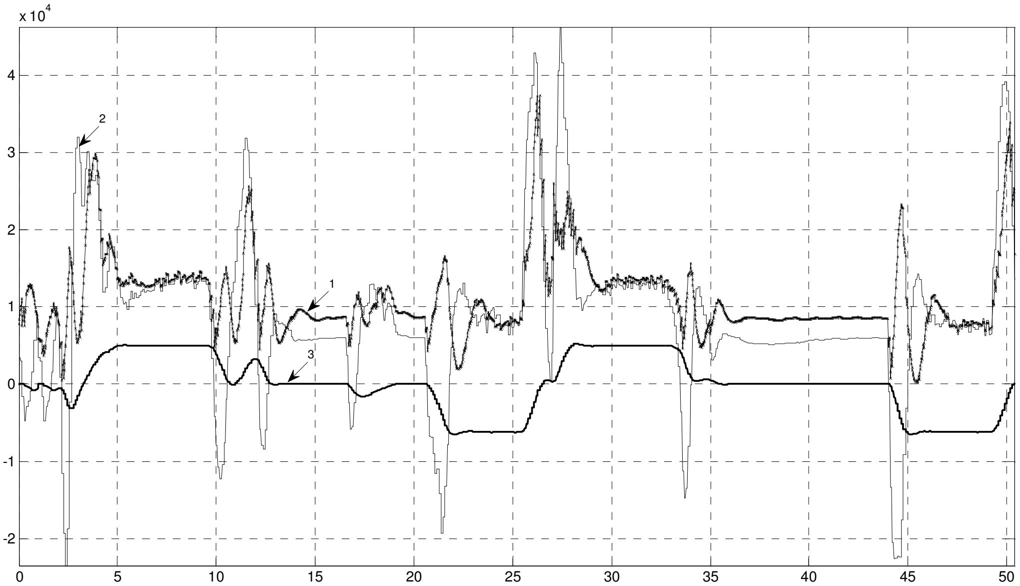

Figure 3 – Electromagnetic torque electric drive of hoist bucket mechanism
1 - for an arbitrary orientation of the coordinate system α-β, N·m; 2 - for the orientation of the coordinate system α-β of the rotor flux vector, N·m; 3 – w_r (angular frequency of the rotor rotation), RPM×10

From the graphs of the mechanical torque (Fig. 3) that the average value of the mechanical momentum in the process of holding the bucket at zero speed different from the average value of the mechanical torque at the steady speed of 5% for the method with an arbitrary orientation of the coordinate system and 33% for method orientation of the rotor flux vector.

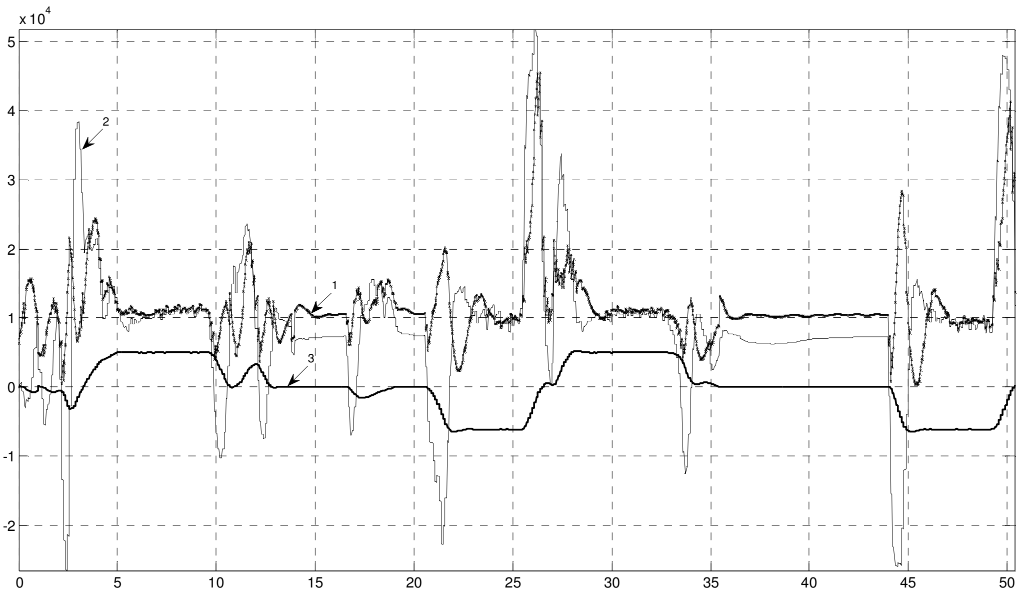

Figure 4 - Mechanical torque electric drive of hoist bucket mechanism

1 - for an arbitrary orientation of the coordinate system α-β, N·m; 2 - for the orientation of the coordinate system α-β of the rotor flux vector, N·m ; 3 – w_r (angular frequency of the rotor rotation), RPM×10

DISCUSSION

Developed a method for the recognition of technological modes of electromechanical systems main drives and excavator as mining machines, based on information theory. The advantage of the method is the invariance of the statistical characteristics of the multidimensional vector measurement output coordinates of electromechanical systems and related problems of intermittent and statistical components of the relationship. The above invariance due to the transition from continuous to discrete vector, which can be considered as a discrete message with subsequent evaluation of information properties of a message, in particular, the amount of information. The decision rule is to select a message that has the maximum amount of information on the assumption that the vector belongs to a given class. Because the amount of information for a valid message is positive, the proposed method sets a limit at which the message can be regarded as significant.

Showed a new method for measuring the static current, which eliminates the operation of differentiation to determine the dynamic current. The proposed measurement method allows an order to improve the performance measure static electric current in transient operating conditions.

CONCLUSIONS

Thus, establishing the basic theoretical principles for creating algorithms and software for information-measuring systems performance indicators of mining shovels and draglines.The effectiveness of the algorithms and software of information measuring systems performance shovels excavators confirmation of operating experience in the mining plants in Russia.

REFERENCES

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