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Modeling the Moment of Resistance Generated by an Ore-Grinding Mill

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Abstract**—**The pertinence of modeling the moment of resistance generated by the ore-grinding mill is substantiated. Based on the ranking of technological indices obtained in the result of the survey among the specialists of several beneficiating plants, the factors determining the level of the moment of resistance generated by the mill are revealed. A priori diagram of the ranks is obtained in which the factors are arranged in the descending order of the impact degree on the level of the moment. The obtained model of the moment of resistance shows the technological character of the operation modes of the ore-grinding mill and can be used for improving the operation modes of the system motor-mill and preventing the abnormal mode of the drive synchronous motor.

Keywords**—**Model, abnormal mode, mill, correlation, moment of resistance, rotational speed.

I. Introduction

THE ore-grinding technological process is characterized by difficulties, mainly depending on different interrelations of technological and power indices. Sometimes, even a negligible change in one of the technological indices can lead to a break of the whole technological process [1]-[4]. Investigations have shown that the increase in the moment of resistance, exceeding its maximally permissible value leads to the disruption of the normal operation of the synchronous motor drive of the ore-grinding mill within the electromechanical system mill – motor. In particular, when the moment of resistance generated by the ore-grinding mill is bigger than the maximum torque of the motor, the synchronous drive motor falls out of synchronism.

The moment of resistance generated by the ore-grinding mill has a random character. This can be accounted for by the fact that the value of the moment is largely produced from technological indices such as the bulk weight of the raw material, the fill factor of the mill drum, which can change in the period of grinding N tons of ore.

It is obvious that in the period of grinding a given amount of ore, the magnitude of the moment may change, resulting in abnormal operation of the drive motor. To prevent the possible emergency events, arising as a consequence of variation of the moment of resistance within the electromechanical system mill – motor, it is necessary to develop the mathematical model of the moment of resistance, taking into account its random nature which is the goal of the present work.

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II. Problem Statement and Justification of the Method

The well-known models [5], [6] of the mill's moment of resistance determine only its average values, and therefore, they are not suitable to be used for the analysis of the random nature of the mill drive motor operation modes.

In [7], [8], models of the moment of resistance, varying randomly in time are developed. The constructed model for determining the changes in the resistance moment of the ore-grinding mill is implemented by:

- developing an algorithm, determining the amount of material on each step of grinding;
- developing a random time function of the mill's moment of resistance M(t).

To develop the algorithm, determining the amount of material on each step, the grinding process is represented by the action of elementary processes, proceeding on certain sections of the material passage (circular, parabolic, inactive). On the whole, the grinding process is considered as a sequence of the grinding steps (one step corresponds to a period of one cycle). Although the developed model allows to theoretically investigate the change in the moment of resistance and to assess its impact on the operation conditions of the mill drive motor, the application of its results is inefficient, as the given model:

- requires the usage of numerous transducers to control the necessary information;
- requires the usage of computational tools for handling the flow of information;
- does not allow to detect the impermissible jumps of the moment in time and thus prevent the abnormal mode of the synchronous drive motor.

The moment of resistance generated by the mill depends on numerous technological factors. Given the lack of control of many technological parameters important from the standpoint of the change in the resistance moment, priori information on the impact degree of the factors on the level of the moment has been obtained and processed by us. For that purpose, the specialists of a number of beneficiating plants have been surveyed to reveal the factors, determining the level of the moment of resistance generated by the mill. A priori chart of ranks (Fig. 1) is obtained, in which the factors are arranged in the order of decreasing degree of the impact on the moment level. The technological factors are arranged in the following order: intramill loading G; the mill productivity by the initial ore Q; the size of the initial d_p and the d_u ore to be ground; the specific weight of the ore -δ; the wear degree of the mill lining -Φ. The results of estimating the factors are shown in

Fig. 2, in which these factors are arranged according to the degree of the magnitude of the calculated inputs.

Figs. 1 and 2 show that on the whole, the degree of the moment of resistance is conditioned by the technological parameters whose change leads to the necessity of regulating the rotational velocity of the mill drum. The rotational velocity of the mill drum is formed, depending on the angular velocity of the motor rotor, the angle of the drive shaft twisting, and the angle of crushing environment rotation. Based on the fact mentioned above, to develop the moment of resistance generated by the ore-grinding mill, the dependence of the moment of resistance on the mill drum rotational speed has been studied.

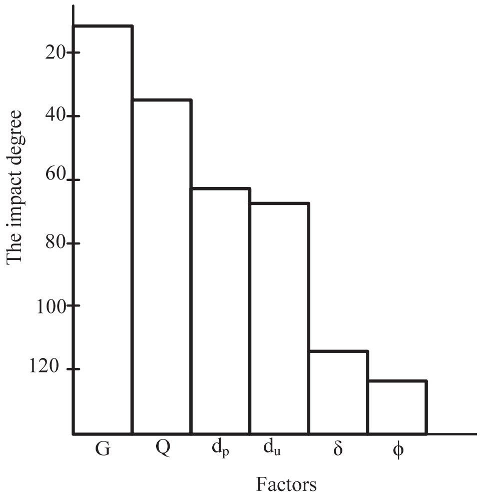

Fig. 1 The priori diagram of the grinding parameter ranks

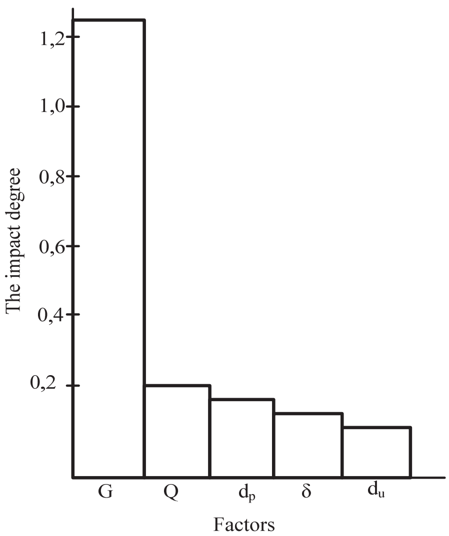

Fig. 2 The diagram of the impact degree of the technological factors on the moment of resistance generated by the mill

III. The Investigation Results

The initial basis for modeling were the experimental data obtained in the result of the conducted experimental investigations of the moment of resistance (M_{ST}), generated by the ore-grinding mill at the change in the drum rotational velocity (n). To develop a generalized model of the moment of resistance of the mills having different capacities of structural performance, a system in relative units has been applied. In particular, the experimental values of the drum rotation velocity (n) and the moment of resistance (M_{ST}) of the mill are respectively introduced in parts of the critical frequency (n_{kp}) and the nominal moment of the drive motor (M_{ND}):

$$\psi = \frac{n}{n_{kp}}, \quad M = \frac{M_{ST}}{M_{ND}}$$

Investigations have shown that not only the values of the mill drum rotational velocity but also a number of uncontrollable factors like the measurement error, the uncontrollable changes in the environment, etc affect the M_{ST}. That is why, even at the fixed values of the drum rotation velocity, the function $M = F(\psi_1, \psi_2, ..., \psi_m)$ behaves randomly. In connection with this, before passing on to the investigation of the change in the moment of resistance, the close relationship between the values of M and Ψ, called the ρ_{XY} coefficient has been determined [9], [10]. In Table I, the experimental and calculation data for determining the correlation coefficient are introduced.

The correlation coefficient is in the interval -1 and +1. The obtained negative correlation shows that at the increase of one random value, the other decreases on the average. In Fig. 3, the scattering diagram of observation between the random values M and Ψ is introduced which confirms the accuracy of the correlation coefficient.

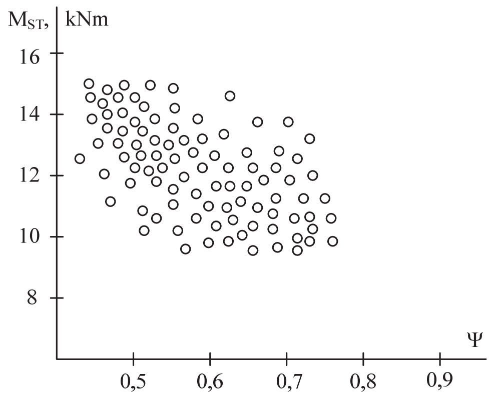

Fig. 3 The scattering diagram of observation between the random values M and Ψ

To determine the dependencies of the moment of resistance, the method of regression analysis is used according to which, variables M and ψ are connected by the dependency [11].

$$M(\psi) = F(\psi) + \varepsilon, \tag{1}$$

where ε is a random variable, depending on the measurement error, uncontrollable changes of the environment, etc.

TABLE I
DATA FOR CALCULATING THE CORRELATION

n	$X=\psi$	$Y=M$	$(X_i-\overline{X})$	$(Y_i-\overline{Y})$	$(x_i-\overline{x})^2$	$(Y_i-\overline{Y})^2$	$(X_i-\overline{X})(Y_i-\overline{Y})$
1	0,3	0,53	0,53	-0,375	-0,13375	0,140625	0,05015625
2	0,35	0,59	0,59	-0,325	-0,07375	0,105625	0,02396875
3	0,40	0,65	0,65	-0,275	-0,01375	0,075625	0,00378125
4	0,45	0,7	0,7	-0,225	0,03625	0,050625	-0,00815625
5	0,5	0,745	0,745	-0,175	0,08125	0,030625	-0,01421875
6	0,55	0,765	0,765	-0,125	0,10125	0,015625	-0,01265625
7	0,6	0,77	0,77	-0,075	0,10625	0,005625	-0,00796875
8	0,65	0,78	0,78	-0,025	0,11625	0,000625	-0,00290625
9	0,7	0,79	0,79	0,025	0,12625	0,000625	0,00315625
10	0,75	0,8	0,8	0,075	0,13625	0,005625	0,01021875
11	0,8	0,77	0,77	0,125	0,10625	0,015625	0,01328125
12	0,85	0,69	0,69	0,175	0,02625	0,030625	0,00459375
13	0,9	0,64	0,64	0,225	-0,02375	0,050625	-0,00534375
14	0,95	0,5	0,5	0,275	-0,16375	0,075625	-0,04503125
15	1,0	0,46	0,46	0,325	-0,20375	0,105625	-0,06621875
16	1,05	0,44	0,44	0,375	-0,22375	0,140625	-0,08390625

$$\rho_{XY}=\frac{\sum(X_i-\overline{X})(Y_i-\overline{Y})}{\sqrt{\sum(X_i-\overline{X})^2\sum(Y_i-\overline{Y})^2}}=-0{,}13195$$

Based on the experimental data introduced in Table I, we will search for function $M(\psi)$ in the form:

$$M(\psi)=b_o+b_1\psi+b_2\psi^2+b_3\psi^3 \quad (2)$$

The best coefficients b_o,b_1,b_2,b_3 are regarded those for which the sum of the square deviation will be minimal:

$$S(b_o,b_1,b_2,b_3)=\sum_{i=1}^{n}\left[\left(b_o+b_1\psi_i+b_2\psi_i^2+b_3\psi_i^3\right)-M_i\right]^2\to\min. \quad (3)$$

To determine b_o,b_1,b_2,b_3, let us differentiate (3) according to those coefficients. By equaling the obtained derivatives to zero, we will obtain the following system of equations:

$$\begin{cases} nb_o+b_1\sum\limits_{i=1}^{n}\psi_i+b_2\sum\limits_{i-1}^{n}\psi_i^2+b_3\sum\limits_{i-1}^{n}\psi_i^3=\sum\limits_{i=1}^{n}M_i \\ b_o\sum\limits_{i=1}^{n}\psi_i+b_1\sum\limits_{i-1}^{n}\psi_i^2+b_2\sum\limits_{i-1}^{n}\psi_i^3+b_3\sum\limits_{i-1}^{n}\psi_i^4=\sum\limits_{i=1}^{n}M_i\psi_i \\ b_o\sum\limits_{i-1}^{n}\psi_i^2+b_1\sum\limits_{i-1}^{n}\psi_i^3+b_2\sum\limits_{i-1}^{n}\psi_i^4+b_3\sum\limits_{i-1}^{n}\psi_i^5=\sum\limits_{i=1}^{n}M_i\psi_i^2 \\ b_o\sum\limits_{i-1}^{n}\psi_i^3+b_1\sum\limits_{i-1}^{n}\psi_i^4+b_2\sum\limits_{i-1}^{n}\psi_i^5+b_3\sum\limits_{i-1}^{n}\psi_i^6=\sum\limits_{i=1}^{n}M_i\psi_i^3 \end{cases} \quad (4)$$

To calculate the coefficients b_o,b_1,b_2,b_3, let us construct Table II.

Solving (4), we will obtain b_o,b_1,b_2,b_3.

In accordance with the method introduced above, the regression function will have the form:

$$M=-0.04698+2.35327\psi-1.30407\psi^2-0.51616\psi^3 \quad (5)$$

The adequacy of the obtained equation is checked according to the Fisher criterion for which the experiment and calculation dispersions S_1 and S_2 are found:

$$S_1^2[M]=\frac{1}{n-1}\sum_{i=1}^{n}\left(M_i-\overline{M}\right),\ \overline{M}=\frac{1}{n}\sum_{i=1}^{n}M_i, \quad (6)$$

$$S_2^2[M]=\frac{1}{n-k}\sum_{i=1}^{n}\left(M_i-M_C\right), \quad (7)$$

where, n is the number of experiments; k – the number of coefficients in the regression equation; M_i – the current value of M; M_C - the calculated value of M. Then, to estimate the difference between $S_1^2[M]$ and $S_2^2[M]$, the Fisher criterion is calculated:

$$F_C=\frac{S_1^2[M]}{S_2^2[M]}=5{,}32 \quad (8)$$

The comparison of the calculation F_C and the standard F values of the Fisher criterion shows the adequacy of the obtained equation, characterizing the dependence of the moment of resistance of the ore-grinding mill on its rotational speed, which is also confirmed by comparing the experimental and calculation data (Fig. 4).

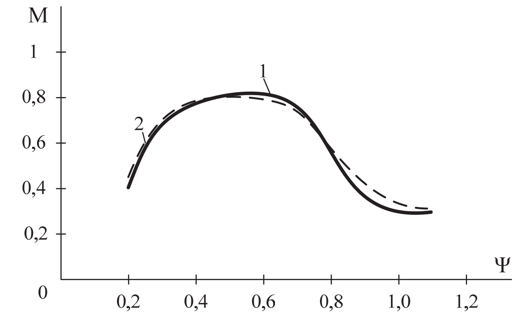

Fig. 4 Experiment (1) and calculation (2) curves of dependence of the moment of resistance on the mill drum rotation speed

TABLE II
DETERMINING THE PARAMETERS FROM (2)

n	16
$\sum\psi$	10,8
$\sum\psi^2$	8,1401
$\sum\psi^3$	6,642
$\sum\psi^4$	5,72605
$\sum\psi^5$	5,129055
$\sum\psi^6$	4,721897
$\sum Y$	10,62
$\sum\psi Y$	7,03125
$\sum\psi^2 Y$	5,133393
$\sum\psi^3 Y$	4,036982

IV. CONCLUSIONS

The obtained model shows the technological character of operation modes of ore-grinding mill taking into account its random nature. The proposed model of the moment of resistance can be used to improve the operation modes of the system motor – mill and prevent the abnormal mode of the drive synchronous motor.

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