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REGRESSION MODEL OF THE CLASSIFICATION PROCESS AT JET GRINDING

Annatation. The aim of the work is creating a regression model of the material classifying process in a jet grinding plant based on the experimental results. The data of various bulk material grinding in a laboratory mill and in industrial conditions were used. The main technological parameters affecting the performance of the classifier are determined. On gas-jet installations a number of dependences of changes in the volumetric flow rate of the material at the outlet of the classifier from the volumetric flow rate of the material at the inlet of the classifier and from the speed of the classifier rotor were experimentally got. The magnitude of the influence of each adopted factor and their mutual influence on the performance of the classifier with the determination coefficient R = 0.88 – 0.95 are obtained. The regression dependences make it possible to improve the control system for the classification process of jet grinding in a closed cycle.
Keywords: classifier, regression model, factor, jet grinding.

Introduction. Nowadays grinding of solid materials is one of the urgent problems of modern industry. In most cases, the use of solid materials in heterogeneous and solid-phase reactions without their preliminary grinding is generally impossible. And if you take into account that many materials used by industry are in a solid state, then grinding is the main operation for their processing.

Gas-jet grinding is one of the most promising methods for fine material production. However, the high energy intensity of the technological process inhibits its widespread adoption in industry. With the selected technological parameters, the optimal grinding mode is determined by the filling of the jets with material. For an excess (overload of the mill) and a shortage (unloading of the mill) of the material, productivity decreases, the grinding process can stop [1].

Analysis of publications. Open cycle grinding plants provide for a single loading of the material, i.e. all material from the grinding zone passes through a classifier, in which the entire material stream is divided into the ready product, i.e. the required size class and larger than it, and exit from the grinding cycle. From the beginning of grinding, small particles are formed, their further stay in streams leads to overgrinding and waste of energy [2]. When grinding operates in a closed cycle, the mill works with a classifier, where the product larger than the required size is continuously returned for repeated grinding into the mill. This scheme is widely used in fine grinding, when size uniformity of the ready product is required. Closed-loop operation allows reducing energy consumption for grinding and increasing mill productivity [3].

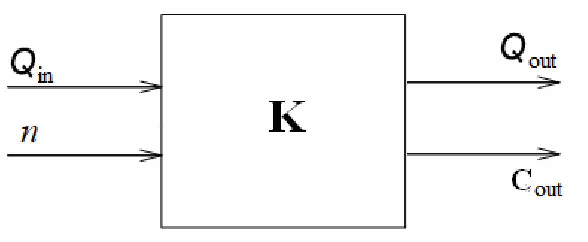
Improving the classification efficiency and optimizing the circulating load, with causes an increase in the passage speed of the material through the mill, can also reduce the amount of overground material.

The aim of the work is to design a regression model of the material classifying process in a jet grinding plant based on the experimental results.

To construct a regression model of the material classification process in the mill, we used the experimental results of slag grinding in the USI-20 experimental unit [4] and zircon grinding in the industrial jet mill of the Volnogorsk Mining and Metallurgical Factory [5]. These plants used dry separators.

During the research, the technological parameters were determined, on which the performance of the classifier (separator) depended. The classification process is considered from the position of changing the volume of material passing through the classifier. Therefore, for the regression model the response function is the volume flow of the material at the outlet of the classifier Qout. At gas jet units experimentally there were obtained a number of dependencies of the volumetric flow rate of material leaving the classifier from values of the following parameters: the volumetric flow rate of material in a classifier inlet Qin; classifier rotor speed n. These are the main factors of influence on the volumetric material flow rate at the outlet of the classifier on the studied device.

Figure 1 shows a classifier model of a jet grinding plant as a control object.



Q_{out} – volumetric consumption of material at the outlet of the classifier, kg / h;
Q_{in} – volumetric consumption of material at the entrance to the classifier, kg / h;
n – classifier rotor speed, s^{-1};
C_{out} –material feeding the circulating load at the output of the classifier, kg / h
Figure 1 – Classifier model of a jet grinding plant

At the experimental studies, one of the parameters is varied at fixed values of the others, and then the experiments are repeated at other values of the fixed variables. This approach made it possible to conduct both paired regression analysis and multiple analyses that took into account the mutual influence of the considered factors.

Before conducting a regression analysis, it is necessary to code factors. Coding of factors allows transferring the natural values of factors into dimensionless quantities, which provides the possibility of a comparative impact assessment of various parameters on the process regardless of their dimension, and also allows you to construct a standard orthogonal plan matrix of the experiment.

The relationship between the encoded and natural expression of the factor is given by the formula 1:

$$x_i = \frac{X_i - X_{i0}}{\Delta X_i}, \tag{1}$$

where x_i – coded expression of the *i*-th factor; X_i – natural value of the factor; X_{i0} – the value of the *i*-th factor at zero level; ΔX_i – interval of variation of the *i*-th factor.

Table 1

Experimental Factors for a Laboratory Mill

Factor	Factor levels				
	-1,42	-1	0	+1	+1,42
Q_{in}, kg/h	5	10	12	14	19
n, s^{-1}	500	850	1000	1150	1500

Table 2

Experimental Factor Values for an Industrial Mill

Factor	Factor levels				
	-1,42	-1	0	+1	+1,42
Q_{in}, kg/h	630	665	680	695	730
n, s^{-1}	170	173,5	175	176,5	180

Generalized regression dependences of the change in the volumetric material flow at the exit from the classifier Q_{out} from two variable factors for calculation are set in the form of a second degree polynomial taking into account the mutual influence of variables:

$$Y = a_0 + \sum_{i}^{n} a_i \cdot x_i + \sum_{i}^{n} a_{ii} \cdot x_i^2 + \sum_{i<j}^{n} a_{ij} \cdot x_i \cdot x_j \quad , \tag{2}$$

where Y – response function (Q_{out}); a_0 – free term of the equation; $a_i \cdot x_i$, $a_{ii} \cdot x_i^2$ – linear and quadratic terms; $\pm a_{ij} \cdot x_i \cdot x_j$ – terms of paired products of factors; n = 2 – number of variable factors.

The coefficients of the given dependence are determined by the least squares method by means of the application package for processing statistical data Statgraphics Plus. After each cycle, the adequacy F (Fisher statistics) of the obtained model is evaluated by the experimental data. The determination coefficient R is calculated, which shows how much percent the variability of the function is explained by the influence of the factors taken into account in the model. By the sign of the regression coefficient a_i the influence of the corresponding factor can be determined x_i on function: a positive sign indicates an increase in function with increasing factor x_i, negative - about the decline. The absolute value of the coefficient a_i shows how much the effective attribute will change when the corresponding factor changes on the unit. Interaction ratios ($\pm a_{ij} \cdot x_i \cdot x_j$) evaluate the influence of each factor depending on the level at which another factor is located. Sign plus coefficient a_{ij} indicates that a simultaneous increase or decrease in factors x_i and x_j leads to increased response. If the interaction coefficient has a minus sign, then the increase in the response value (of the studied function) is ensured if one of the factors decreases and the other increases.

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Thus, as a result of the calculation, a generalized regression dependence of the change in the volumetric material flow rate at the outlet of the classifier with the variation of two type parameters is established:

$$Q_{\text{out}} = c + a_1 \cdot Q_{\text{in}} + b_1 \cdot n + a_2 \cdot Q_{\text{in}}^2 + b_2 \cdot n^2. \qquad (3)$$

It should be noted that in the equations there are no products of the first degrees of parameters. For example, for slag of the initial size less than 2.5 mm ground in a laboratory unit, the regression dependence has the form:

$$Q_{\text{out}} = 10 + 3{,}47 \cdot Q_{\text{in}} + 2{,}25 \cdot n + 0{,}22 \cdot Q_{\text{in}}^2 - 1{,}16 \cdot n^2 \qquad (4)$$

For ground zircon in an industrial mill, the equation is as follows:

$$Q_{\text{out}} = 577{,}5 + 25{,}17 \cdot Q_{\text{in}} + 21{,}64 \cdot n + 1{,}25 \cdot Q_{\text{in}}^2 + 1{,}25 \cdot n^2 \qquad (5)$$

This regression dependence within the studied parameters has a determination coefficient of R=0,88 – 0,95, which shows that the variability of the function Q_{out} is explained same value by the influence of factors taken into account in the model.

Figures 2 and 3 present a three-dimensional graph of the dependence of Q_{out} on the considered factors for classifiers of a laboratory and industrial mill, respectively.

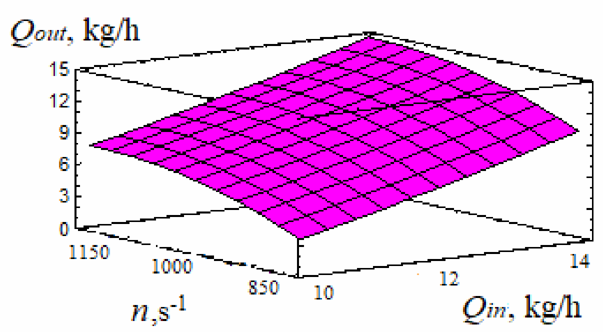

Figure 2 – Q_{out} response surface for the USI-20 classifier

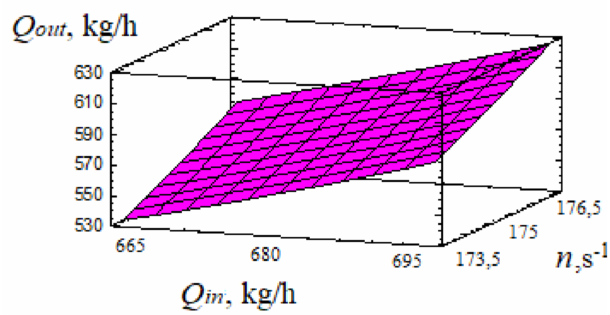

Figure 3 – Q_{out} response surface for industrial plant classifier

Figure 4 shows the influence of each factor and group of factors on the response function Q_{out} (in percent) for a laboratory mill. The graph shows that the factor A exerts the greatest influence on the Q_{out} value, i.e., the volumetric material consumption at the inlet to the classifier. Thus, the volumetric flow rate of the material at the inlet more significantly affects the volumetric material flow rate at the output of the classifier, than the rotation speed of the classifier rotor (41 % and 26 %, respectively).

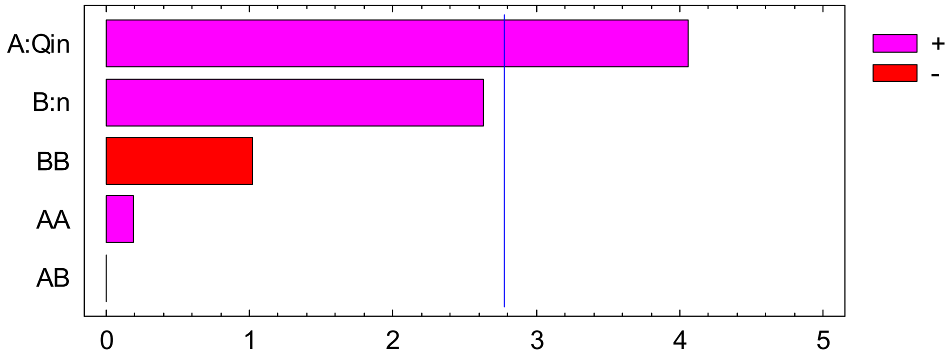

Figure 4 – Pareto graph for response function Q_{out}

Conclusions. The constructed regression model of the material classification process in jet grinding plant showed the predominant influence of the loading degree of the grinding chamber on the performance of the classifier. The obtained regression dependences of the influence of each adopted factor on the classifier productivity adequately describe the classification process and can be used to increase the efficiency of jet grinding.

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Регресійна модель процесу класифікації при струминному подрібненні

Підвищення ефективності класифікації та оптимізація циркулюючої навантаження, що викликає збільшення швидкості проходження матеріалу через млин, дозволяють поліпшити якість готового продукту і знизити кількість перездрібненого матеріалу. Актуальність роботи визначена необхідністю визначення впливу основних технологічних параметрів на ефективність роботи класифікатора в замкнутому циклі струминного подрібнення. Мета роботи - побудова регресійної моделі процесу класифікації матеріалу в струминній подрібнювальній установці на підставі отриманих експериментальних результатів.

Процес класифікації розглядається з позиції проходження масопотоків через сепаратор і поділу на виході на готовий продукт і циркуляційне навантаження, яке поповнює млин.

Використовувалися дані подрібнення різних сипучих матеріалів на лабораторному млині і в промислових умовах. Визначено основні технологічні параметри, що впливають на продуктивність класифікатора. На газоструминних установках експериментально отримано ряд залежностей зміни об'ємної витрати матеріалу на виході з класифікатора від величини об'ємної витрати матеріалу на вході в класифікатор і числа оборотів ротора класифікатора. Отримано величина впливу кожного прийнятого фактора і їх взаємний вплив на продуктивність класифікатора з коефіцієнтом детермінації R = 0,88 - 0,95. Залежність являє собою квадратичну функцію від об'ємної витрати матеріалу на вході в класифікатор і швидкості обертання ротора класифікатора. Побудована регресійна модель процесу класифікації матеріалу в струминній подрібнювальній установці показала переважний вплив ступеня завантаження помольної камери на продуктивність класифікатора. Отримані регресійні залежності дозволяють удосконалити систему управління процесом класифікації струминного подрібнення в замкнутому циклі, що є частиною системи управління всім млином.

Regression model of the classification process at jet grinding

Grinding of solid materials is one of the urgent problems of modern industry. Improving the classification efficiency and optimizing the circulating load, which causes an increase in the passage speed of material through the mill, can raise the quality of ready product and also reduce the amount of over ground material. The relevance of the work is determined by the need to determine the influence of the main technological parameters on the efficiency of the classifier in a closed cycle of jet grinding. The aim of the work is constructing a regression model of the material classifying process in a jet grinding plant based on the experimental results.

The classification process is considered from the point of view of the mass flows passage through the separator and separation at the outlet at the ready product and the circulation load, which feeds the mill. The data of grinding various bulk materials in a laboratory mill and in industrial conditions are used. The main technological parameters affecting the classifier productivity are determined. On gas-jet installations, a number of dependences of changes in the volumetric flow rate of the material at the outlet of the classifier from the volumetric flow rate of the material at the inlet of the classifier and the speed of the classifier rotor are experimentally obtained. The magnitude of the influence of each adopted factor and their *mutual influence on the performance of the classifier with the determination coefficient R = 0.88 - 0.95 are obtained. The dependence is a quadratic function of the volumetric flow rate of the material at the entrance of the classifier and the rotor speed of the classifier. The simulated regression model of the material classification process in the jet grinding plant showed the predominant influence of the loading degree of the grinding chamber on the classifier productivity. The regression model allows us to improve the control system for the classification process of jet grinding in a closed cycle, which is a part of control system of whole jet mill.*

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