The outer grooves of the spirally rolled pipes and the relative position of the tube stack relative to each other create ordered and organized vortex flows that serve as a source of additional turbulence and make a significant contribution to the intensification of the heat transfer process. This is especially important for tubular-lattice packing of column apparatus, in which chemical processes take place during phase contact and are accompanied by the release of a large amount of heat. In addition, pipes with spiral turbulators provide efficient mixing and an increase in the rate and removal of the heat of reaction , which is directly proportional to the quality and quantity of products obtained and increases the possibilities for control purposes .

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MATHEMATICAL MODELING OF A BALL MILL IN GMZ-2 NGMK BASED ON THE DIFFUSION MODEL

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Abstract: *In the mining and metallurgical industry, in addition to raw materials, the quantitative volume of technological operations has a significant impact on the cost of the extracted metal. As practice shows, the most energy-intensive process is crushing of rocks, which accounts for 30-50% of all production costs. In this connection, the management of this process is one of the main technical and economic factors in the chain of rock dressing. In this paper, the mathematical function of the ball mill MSHTs 75x55 is derived, on the basis of which a computer model is built in the*

SIMULINK subsystem of the Matlab software package. As a result, the transient and impulse characteristics of the mill were built, and the stability of the system was determined from the calculated transfer function.

Key words: *grinding, ball mill, control, mathematical model, diffusion model, computer model, material balance conditions, analysis, transfer function, step signal, pulse step signal, transient response, impulse transient response, stability.*

Introduction

Crushing of rocks is one of the main technological processes of concentration plants and mining and metallurgical plants. The processes of crushing and grinding in the technology of extracting precious metals from ores are the most energy-intensive processes, the costs of these processes amount to 30-50% of the cost of mining and processing. Grinding ores to a certain size determines the technological, technical and economic performance of mining and metallurgical plants. The results of all further processing of the enriched product depend on the quality indicators of grinding, primarily such as productivity, recovery of each valuable component, its content in concentrate and losses in tailings [1] .

In recent years, scientific research has been actively carried out in the field of increasing the efficiency of grinding processes for ore materials. Controlling the grinding process, along with technological, resource and energy indicators, is considered the main one. The most widespread in the practice of the mining and metallurgical industry are mills filled with metal balls. To control the process of grinding ore raw materials in a ball mill and select the optimal conditions for its operation, it is necessary to know how this process proceeds in time, i.e. know its kinetics [2].

Theory and methods

Effective control of the grinding process requires knowledge of the mathematical model of this process, and the presence of a large number of disturbing influences on it allows using only statistical modeling.

The experimental study of complex objects that do not allow for multiple impacts and require large material costs for conducting experiments in real conditions led to the development of methods that would allow not only to process experimental data, but also to organize the experiment in the best way. The mathematical apparatus used in such an organization of the experiment is based on the composition of methods of mathematical modeling, statistics and methods for solving extreme problems.

The construction of a mathematical model that combines the analysis of the crack initiation process in the particles of the crushed material and the description of the structure of feed flows in ball mills based on the diffusion model of the grinding process is very effective. The main advantages of using the diffusion model in the grinding process is the ability to describe most of the factors that affect the efficiency of the grinding process as accurately as possible; the possibility of a detailed, with the required degree of detail, description of systems with a complex structure and the possibility of using existing software packages for the implementation of mathematical models [3].

In order to obtain a mathematical model of the grinding process, we represent the mill in the form of a flow structure (Figure 1).

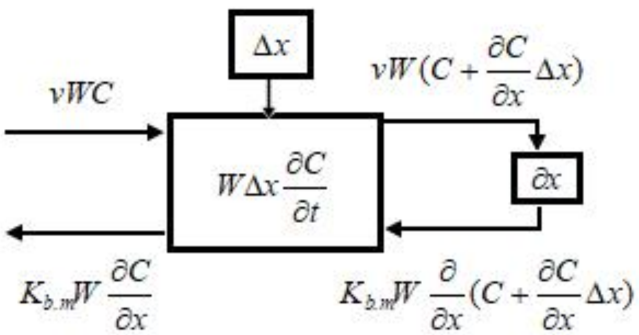

Figure 1. ***Model of the flow structure of a backmixed mill.***

In Figure 1: v - mass movement speed (*m/s*), W - mass feeding rate (*t/m*), C - concentration of a substance of a size class of -0.074 mm (*g/t*), $K_{b.m}$ – back mixing ratio (*m²/s*)

The mass conservation equation for the system will look like this:

$$W\Delta x\frac{\partial C}{\partial t}=vWC+K_{b.m}W\frac{\partial}{\partial x}(C+\frac{\partial C}{\partial x}\Delta x)+vW(C+\frac{\partial C}{\partial x}\Delta x)-K_{b.m}W\frac{\partial C}{\partial x} \quad (1)$$

After transformation and passing to the limit at $\Delta x \to 0$, we get the equation:

$$\frac{\partial C}{\partial t}=K_{b.m}\frac{\partial^2 C}{\partial x^2}-v\frac{\partial C}{\partial x} \quad (2)$$

Equation (2) is the basic equation of the developed mathematical model of the grinding process [4].

Obviously, for equation (2) one initial and two boundary conditions must be specified. As an initial condition, let us set the concentration profile over the apparatus at the initial moment of time:

$$C(0,x) = C_0(x) \text{ by } t=0.$$

We set the boundary conditions based on the material balance condition at the ends of the apparatus (Figure 2)

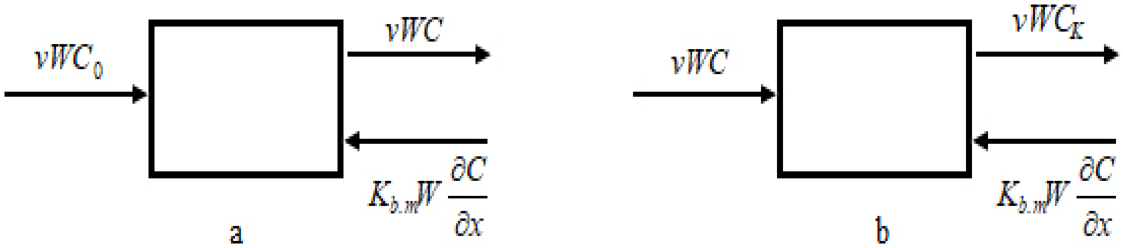

Figure 2. ***Material balance at the ends of the grinding unit:***
a - at the left edge of the unit, b - at the right edge of the unit.

Figure 2: C_0 - concentration of a substance with a size class of at least 0.074 mm, in the mill load, C_K - concentration of a substance with a size class of not more than 0.074 mm, at the exit from the apparatus.

Consider the left end of the apparatus, which receives ore at a certain average rate (Figure 2, a). The sum of the flows approaching the boundary must be equal to the flow of matter leaving the boundary. Thus, for the left border we get:

$$v(C_0-C)+K_{b.m}\frac{\partial C}{\partial x}=0 \quad (3)$$

Similarly, at the right edge of the device:

$$v(C_K-C)+K_{b.m}\frac{\partial C}{\partial x}=0 \quad (4)$$

Since from the point of view of the mathematical description a ball mill is an apparatus of finite length, we will assume that at the exit from the mill $C \approx C_K$, taking this into account, boundary condition (4) takes the form:

$$\frac{dC}{dx}=0 \quad (5)$$

To simplify the equations and find the transfer function of the process of crushing rocks, we introduce dimensionless variables:

$$z=\frac{x}{l} \quad (6)$$

$$\theta=\frac{t}{\bar{t}} \quad (7)$$

where l - mill length, t - the time during which the particle is viewed, x - the coordinate in which the considered particle is located, $\bar{t}$ - the average residence time of all particles in the mill.

We represent equation (2) in the form [5]

$$\frac{\bar{t}}{\bar{\bar{t}}}\frac{\partial C}{\partial t}+\frac{v}{l}l\frac{\partial C}{\partial x}=\frac{K_{b.m}}{l^2}l^2\frac{\partial^2 C}{\partial x^2} \quad (8)$$

In accordance with the introduced dimensionless coefficients, we obtain

$$\frac{1}{\bar{\bar{t}}}\frac{\partial C}{\partial \theta}+\frac{v}{l}\frac{\partial C}{\partial z}=\frac{K_{b.m}}{l^2}\frac{\partial^2 C}{\partial z^2} \quad (9)$$

or after grouping variables

$$\frac{vl}{K_{b.m}}\frac{\partial C}{\partial \theta}+\frac{vl}{K_{b.m}}\frac{\partial C}{\partial z}=\frac{\partial^2 C}{\partial z^2} \quad (10)$$

Multiplier *(vl)/* $K_{об.пер}$ is the dimensionless Peclet number (Pe), taking into account equation (10) it will look like this [6]

$$Pe\frac{\partial C}{\partial \theta}+Pe\frac{\partial C}{\partial z}=\frac{\partial^2 C}{\partial z^2} \quad (11)$$

Boundary conditions (3) and (5) are also reduced to the dimensionless form

$$(C_0-C)+\frac{1}{Pe}\frac{dC}{dz}=0 \text{ at } z=0 \quad (12)$$

$$\frac{dC}{dz}=0 \quad \text{at } z=1 \quad (13)$$

We obtain the transfer function of the diffusion model of the grinding process, for this we apply the Laplace transform to equation (11), as a result we obtain a linear homogeneous second-order differential equation

$$Pep\tilde{C}+Pe\frac{d\tilde{C}}{dz}=\frac{d^2\tilde{C}}{dz^2} \quad (14)$$

$$\frac{d^2\tilde{C}}{dz^2}-Pe\frac{d\tilde{C}}{dz}-Pep\tilde{C}=0 \quad (15)$$

Applying the Laplace transform to the boundary conditions (12) and (13), we obtain the following:

$$1-\tilde{C}+\frac{1}{Pe}\frac{d\tilde{C}}{dz}=0 \text{ by } z=0 \quad (16)$$

$$\frac{d\tilde{C}}{dz}=0 \text{ by } z=1 \quad (17)$$

Let us find the solution of Eq. (15) with respect to the sought-for, Laplace-transformed concentration $\tilde{C}$(p), for this, we compose the characteristic equation:

$$k^2+Pek-Pep=0 \quad (18)$$

Roots of the characteristic equation (18):

$$k_{1,2}=\frac{Pe}{2}\pm\sqrt{\frac{Pe^2}{4}+Pep} \quad (19)$$

Let's introduce a substitution:

$$\beta=\frac{Pe}{2} \quad (20)$$

$$\alpha = \sqrt{\frac{Pe^2}{4} + Pep} \tag{21}$$

and we will substitute into equation (19), thus, the roots of the characteristic equation will have the form:

$$k_1 = \beta + \alpha \tag{22}$$

$$k_2 = \beta - \alpha \tag{23}$$

An arbitrary linear combination of all particular solutions is a general solution to the homogeneous equation (15), then

$$\tilde{C} = A_1 e^{k_1 z} + A_2 e^{k_2 z} = A_1 e^{(\beta+\alpha)z} + A_2 e^{(\beta-\alpha)z} \tag{24}$$

Find the value of the derivative d$\tilde{C}$/dz:

$$\frac{d\tilde{C}}{dz} = A_1(\beta+\alpha)e^{(\beta+\alpha)z} + A_2(\beta-\alpha)e^{(\beta-\alpha)z} \tag{25}$$

Using the boundary conditions, we define the constants A_1 и A_2. From condition (16) at z=0 we get:

$$1 - A_1 - A_2 + \frac{1}{Pe}(A_1(\beta+\alpha) + A_2(\beta-\alpha)) = 0 \tag{26}$$

Let's introduce the replacement $\gamma = \alpha / \beta$, then equation (26) can be represented as:

$$1 - A_1 - A_2 + A_1 \frac{1}{2}(1+\gamma) + A_2 \frac{1}{2}(1-\gamma) = 0 \tag{27}$$

From the second boundary condition (17), taking into account the introduced replacement, we obtain:

$$A_1(\beta+\alpha)e^{(\beta+\alpha)z} + A_2(\beta-\alpha)e^{(\beta-\alpha)z} \tag{28}$$

From equation (28) we express the constant A_1:

$$A_1 = A_2 \frac{(\gamma-1)e^{-\alpha}}{(\gamma+1)e^{\alpha}} \tag{29}$$

Substituting expression (29) into equation (27), after certain calculations, we get:

$$1 + \frac{1}{2}\frac{(\gamma-1)^2 e^{-2\alpha}}{(\gamma+1)} A_2 - A_2 \frac{1}{2}(\gamma+1) = 0 \tag{30}$$

Let us express from equation (30) the constant A_2:

$$A_2 = \frac{2(\gamma+1)e^{\alpha}}{(\gamma+1)^2 e^{\alpha} - (\gamma-1)^2 e^{-\alpha}} \tag{31}$$

Now we write the equation for the definition of the constant A_1, for this we substitute (31) into equation (29):

$$A_1 = \frac{2(\gamma-1)e^{-\alpha}}{(\gamma+1)^2 e^{\alpha} - (\gamma-1)^2 e^{-\alpha}} \tag{32}$$

After the constants have been found A_1 and A_2 it is possible to write down the solution of equation (15), which will be the desired transfer function of the ball mill:

$$W(p) = \frac{4\gamma e^{\beta}}{(\gamma+1)^2 e^{\alpha} - (\gamma-1)^2 e^{-\alpha}} \qquad (33)$$

After substitution of values for γ, α and β, taking into account the mechanical strength and moisture content of the ore, we get:

$$W(p) = \frac{4 \cdot R \cdot (1-\varphi)\sqrt{\frac{Pe+4p}{Pe}}\, e^{Pe/2}}{\left(\sqrt{\frac{Pe+4p}{Pe}}+1\right)^2 e^{\sqrt{\frac{Pe^2}{4}+Pep}} - \left(\sqrt{\frac{Pe+4p}{Pe}}-1\right)^2 e^{-\sqrt{\frac{Pe^2}{4}+Pep}}} \qquad (34)$$

Practical application of the diffusion model in mills MShTs 75x55

As can be seen from equation (34), the main parameter of the model is the Peclet number, which is defined as $(vl)/K_{b.m}$. Supply mill parameters MShTs 75x55, mill height l=7,5 м, ore flow rate v=0,04 t / s and back mixing ratio $K_{b.m} = 0{,}118$ find the Peclet number $Pe = 2{,}542$. According to the found values, the transfer function of the mill MShTs 75x55 has the following form.

$$W(p) = \frac{12{,}25\sqrt{1+1{,}57p}}{(\sqrt{1+1{,}57p}+1)^2 \cdot e^{\sqrt{1{,}6+2{,}542p}} - (\sqrt{1+1{,}57p}-1)^2 \cdot e^{-\sqrt{1{,}6+2{,}542p}}}$$

By the transfer function, we define the transient and impulse transient characteristics on the Matlab software package [7], which are shown in Fig.4 and Fig. 6. To determine the transient response, we construct a transfer function model in the SIMULINK subsystem (Fig. 3). The impulse transient response is different from transient introduction of the block derivative. To determine the behavior of the system per unit deviation, we construct a model in the SIMULINK program shown in Fig. 5.

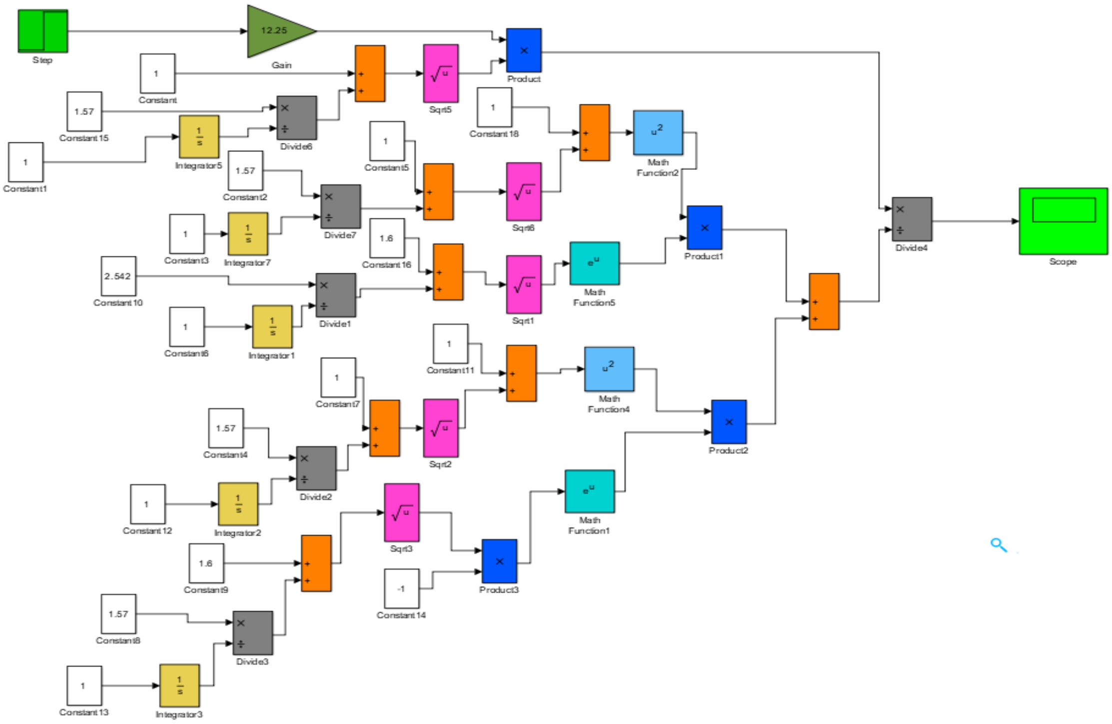

*Figure 3. **Mathematical model of ball mill ball mills with central discharge. 75x55 built in the SIMULINK subsystem.***

Figure 4. ***Transient response of the constructed model.***

From the transient characteristic it can be seen that this model is stable and has the following quality of assessment: the time to reach the set value is 46 min, the achieved output intensity 209. This transient response is monotonic - there is no overshoot to steady state. Due to the absence of overshoot in the unit, there is resource saving.

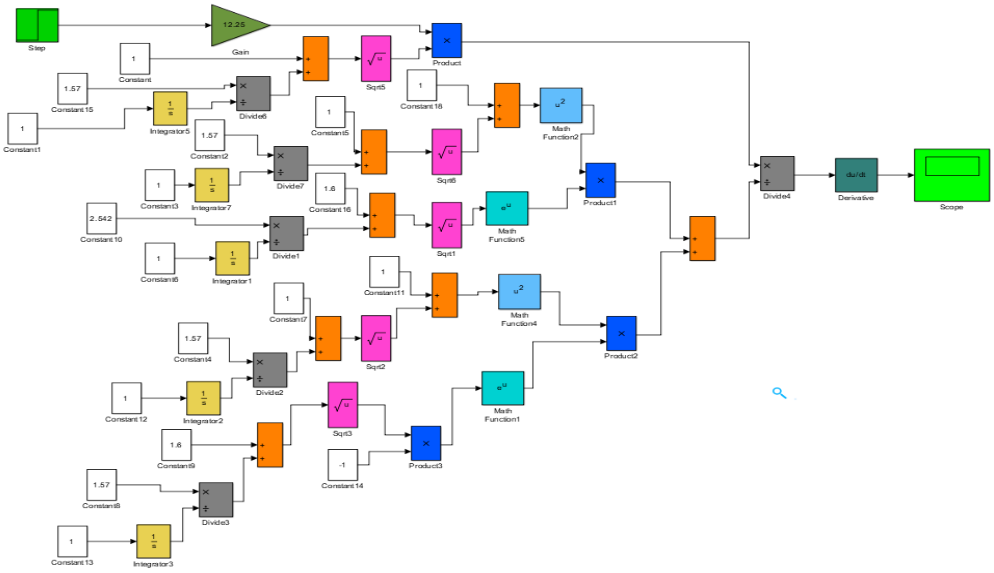

Figure 5. ***Mathematical model of ball mill ball mills with central discharge. 75x55 with differentiating blocks.***

Figure 6. ***Impulse transient response.***

The resulting impulse transient response is the derivative of the transient response. A single impulse action is abrupt, and therefore rather heavy for any system, in this case for a ball mill. Therefore, it is important to know the reaction of the system precisely under such an impact, i.e. impulse response. The resulting impulse transient response is stable under conditions of abrupt changes in the grinding process [8].

Conclusion

Thus, the work carried out mathematical modeling of a ball mill on the basis of diffusion modeling, according to which the transfer function of the grinding apparatus was obtained. Using the MATLAB application package and the SIMULINK subsystem of this program, a model of the mathematical apparatus of the mill was modeled [9]. Transient and impulse characteristics of the mill were constructed using a computer model.

The simulation results confirmed the correctness of the found function and its adequacy to the described grinding process in the ball mill MShTs 75 * 55 in the GMZ 2. The developed mathematical model is used in the study of the grinding process and the improvement of grinding technology, as well as in the educational process at the department when studying the discipline "Identification and modeling technological processes" [10].

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DISCRETE CURRENT MEASURING TRANSFORMERS

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***Annotation**: Article studies control and measuring systems in which high-voltage current measuring transformers are used, which are analogue measuring converters with a number of drawbacks. In this regard, it is proposed to use discrete current transformers, the use of which leads to simplification and cheapening of structures, are reliable carriers of measuring information, as well as discrete signals from discrete current transformers can be transmitted through connecting wires of smaller cross-section.*

***Keywords**: magnetic current transformer, analog signal, discrete signal, discrete current transformer, analog-discrete converter.*

Currently, high-voltage measuring transformers are used in control and measuring systems, as well as in relay protection and automation systems, which are analog measuring current transformers.