The determination of the characteristics of iron ore slurry under the conditions of ultrasonic control

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Received June 03.2013: accepted July 11.2013

Summary. The paper presents the results of theoretical investigations of the characteristics of the iron ore slurry necessary for controlling the processes of the iron ore beneficiation. It is shown that such physical characteristics as magnetic permeability can be calculated with the distribution of firm particles of suspension by size and density being taken into account. The calculation algorithm is given.

Key words: ore crushing, iron ore slurry, magnetic permeability.

INTRODUCTION

At the modern mining and processing factories the iron ore beneficiation is usually carried out in several stages. Herewith ore crushing-classification at the first stage is one of the primary operations defining the overall performance of the production line. This results from the fact that, on the one hand, this operation implies the maximum losses of iron in the waste. On the other hand, the process of ore crushing is the most power expensive, and its efficiency considerably defines the general economic effect of the beneficiation process. The necessary extent of the mineral disclosure, which defines the beneficiation results, is determined exactly by the crushing processes. Therefore the continuous control of the technological parameters, which characterize the quality of processed ore materials, is an essential condition for the effective use of automatic control systems in the technological processes of beneficiation.

ANALYSIS OF PUBLICATIONS, MATERIALS, METHODS

The ultrasonic control appeared to be the most applicable for the definition of the main characteristics of a slurry – the density and the granulometric structure [2, 7, 8, 11, 13, 15]. For these purposes the volume [3, 6] and the superficial [14, 19, 20, 24, 25] ultrasonic waves are used.

The research reported in the work [17] showed that the quality of a crushed product is characterized by the content W of a firm phase in a slurry and by the granulometric structure of a firm phase. Also the quality is defined by the quality indicators of initial raw materials (the content of useful components, the mineral structure etc.), which do not depend on a technological operating mode of a crushing cycle [27, 28]. Within the work [10] it was concluded that there exists an essential interrelation between the density and the granulometric structure of a firm phase in the qualifier discharge, i. e. in the final product of a crushing cycle. The higher the discharge density, the greater the size of a firm material particles in a product. Within the work [12] the analysis of the granulometric characteristics at the stages of crushing and at the first stage of magnetic beneficiation was conducted. There was made a conclusion that the full disclosure of a useful component for each type of ore during its crushing-classification is reached in the terms of a certain granulometric structure, which has to be supported constant at this technological stage.

Within the works [9, 10] it was also mentioned that one of the major technological indicators – the extent of a useful component disclosure – is defined by the density of fixed-size particles. Therefore, measuring the size and the density of the crushed material particles in a slurry allows to define the extent of useful component disclosure. Such measurements can be carried out on the basis of ultrasonic methods.

The fundamental analysis of control methods based on volume ultrasound was conducted within the work [10]. It was shown that most of the abovementioned methods have common disadvantages. For example, the methods basing on the work [7] are based on the following. The signal being defined by the intensity ratio of volume ultrasonic waves in the pure water I_0 and the slurry I_v depends on the concentration $\frac{N}{V}$ of solid particles $F(r)$ and on their size distribution r:

$$A = \frac{1}{Z}\ln(I_0/I_v) = \frac{N}{V}F(r)\sigma(\nu,r),$$

where: $\sigma(\nu,r)$ the section of the attenuation of ultrasound with frequency ν on a solid spherical particle of radius r [1].

The disadvantages of this method, as well as of many other methods considering the volume ultrasound only, are associated with the need of the slurry degasation, which is especially necessary when using the low frequencies [12]. Furthermore, it is necessary to use a large number of ultrasonic measuring channels to provide the sufficient frequency range.

Similar methods were proposed within the works [5, 8] with variations in the number of channels, in the frequency range of ultrasound and in certain design features. In the terms of analyzing the abovementioned methods, apart from the disadvantage associated with the need for degasation, the low accuracy of the controlled parameters measurement [7, 26] and the need to configure devices at the monitoring place [5, 8] can be mentioned.

The use of ultrasonic superficial waves, such as Lamb's waves [16, 18, 23], in the terms of the same tasks allowed to avoid many problems inherent in the methods based on the use of volume ultrasound. Figure 1 shows an example of the spread of the Lamb's wave.

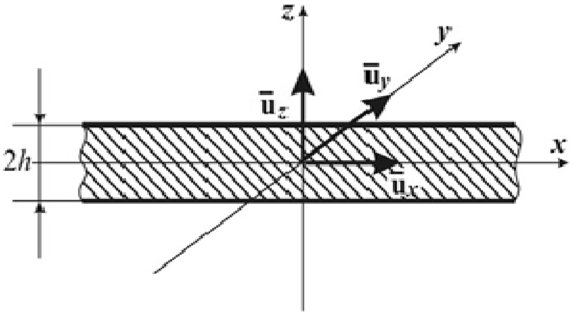

Fig. 1. Displacements caused by the spread of an ultrasonic Lamb's wave in a slab

The energy of the superficial wave is mainly concentrated in a narrow layer of material near its surface. In the terms of a contact of such a surface with various environments, the emission of the wave in the environment takes place; such emission causes a decrease of the energy and the intensity of the wave. The intensity change is dependent on the properties of the environment the wave is emitted in. These dependencies are the fundamental basis for the methods of controlling the technological environment properties using superficial ultrasound.

In the terms of using various methods to determine the characteristics of the slurry there arises a need for experimental determination of the constants inherent for each method. For example, within the work [21, 22] the controlled values were determined on the basis solving the system of equations:

$$\begin{cases} (1-\eta)\left(\dfrac{\sigma_s}{\sigma_{nm}}\right)^{1/3} = \dfrac{\sigma_m - \sigma_s}{\sigma_m - \sigma_{nm}}, \\ \mu(W,\eta) = W\eta \cdot \mu_m + 1, \\ \rho_{hp}(W,\eta) = (1-W)\rho_w + W\left[(1-\eta)\cdot\rho_{nm} + \eta\cdot\rho_m\right] \\ S(W,\eta) = \dfrac{\sigma(W,\eta)\cdot\mu^2(W,\eta)H^2\beta^2(W,\eta)}{2\cdot\rho_{hp}(W,\eta)\cdot c_o c^2\left(1+\beta^2(W,\eta)\right)}l, \end{cases}$$

where: ρ,μ,σ — the density, the magnetic permeability and the electrical conductivity of various system components respectively. Thus there arises a need to determine the physical characteristics (ρ,μ,σ) of the slurry as of the complex heterophase system.

Within the work [20], the following expression for finding the magnetic component fraction in the slurry was obtained as a result of the analysis of ultrasound and magnetic influences on the slurry:

$$\eta = A\frac{(\mu-1)H}{\ln(\frac{I_{ov}}{I_v})} = A_1\frac{(qC_1-1)}{\ln(\frac{I_{ov}}{I_v})},$$

where: H — the magnetic field strength; q — the charge. Thus it is proposed to determine the value of C_1 experimentally.

In order to improve the accuracy and efficiency of ultrasonic methods of controlling the characteristics of the slurry, there should be the possibility to operatively determine the auxiliary values used in the control algorithm.

OBJECT AND TASKS OF RESEARCH

The purpose of the research presented in this paper is to determine the average physical characteristics of the iron ore slurry, which are required for the effective application of ultrasonic control methods.

The studied environment is considered as a two-component heterophase system: the heterogeneous solid phase particles are placed in a homogeneous liquid. The size and the composition of the solid particles may vary within certain limits. It is considered that the solid particles have a two-component structure. They include: a ferromagnetic component with density ρ_m and magnetic permeability μ_m, a nonmagnetic component with density ρ_n, and μ_n magnetic permeability (e. g., magnetite and quartz).

The magnetic permeability of the considered environment is calculated as follows. At first the simple case is considered: all the solid particles are similar in size and composition. The task is solved in two steps: 1) the magnetic permeability of the two-component solid particle is determined; 2) the magnetic permeability of the "liquid — solid particles" system is determined. Herewith is is possible to use the approach proposed by A. K.Weinberg [4] at the first step.

MAIN PART WITH RESULTS AND ANALYSIS

Let the magnetic permeability of the non-magnetic solid phase component be μ_n, of the magnetic component – be μ_m, and of the entire particle – be μ_p. The volume fraction of the magnetic component — ν — is interrelated with the mass fraction $x = {}^{m_m}\!/_{m_p}$ as follows:

$$v = \frac{x\rho_n}{x\rho_n + \rho_m(1-x)}. \qquad (1)$$

For the systems with a small fraction of magnetic of spherical inclusions, the Maxwell's expression can be used:

$$\mu_p = \mu_n \frac{\mu_m + 2\mu_n + 2(\mu_m - \mu_n)v}{\mu_m + 2\mu_n - (\mu_m - \mu_n)v} \qquad (2)$$

If it is expanded into a power series with respect to v, then one will get the following expression with the accuracy up to the first two terms of the expansion:

$$\mu_p = \mu_n + \frac{3\mu_n(\mu_m - \mu_n)}{\mu_m + 2\mu_n}v \qquad (3)$$

Let's consider the expression (3) as a basis for further transformations. Since it is applicable only for small values of v, let's determine μ for particles in the terms of incremental filling a non-magnetic environment with small portions of the magnetic component. Having determined the magnetic permeability μ at some stage, let's determine the increment $d\mu$ of the magnetic component at the next step, taking into account the expression (3):

$$d\mu = \frac{3\mu(\mu_m - \mu)}{\mu_m + 2\mu}dn \qquad (4)$$

where: dn is a small amount of the contributed magnetic component. Since in the terms of such contribution the correspondent part of the non-magnetic component is being replaced, the increment of the volume fraction dv will be equal to:

$$dv = (1-v)dn \qquad (5)$$

After integrating (4) with respect to (5) one will get the following expression:

$$(1-v)\left(\frac{\mu_p}{\mu_n}\right)^{1/3} = \frac{\mu_m - \mu_p}{\mu_m - \mu_n} \qquad (6)$$

or, after applying certain transformations:

$$\mu_p^3 + \mu_p^2(-3\mu_m) + \mu_p(A + 3\mu_m^2) - \mu_m^3 = 0 \quad (7)$$

where: $$A = \frac{(\mu_m - \mu_n)^3(1-v)^3}{\mu_n}. \qquad (8)$$

Considering the abovementioned, on gets the following expression for the magnetic permeability of the solid particles:

$$\mu_p = \mu_m + \left(\sqrt{\left(\frac{A}{3}\right)^3 + \left(\frac{A\cdot\mu_m}{2}\right)^2} - \frac{A\mu_m}{2} \right)^{1/3} + \left(-\sqrt{\left(\frac{A}{3}\right)^3 + \left(\frac{A\cdot\mu_m}{2}\right)^2} - \frac{A\mu_m}{2} \right)^{1/3} \qquad (9)$$

After that, a similar procedure needs to be done to determine the magnetic permeability of the "liquid — solid particles" system (second stage). The liquid is now considered as the nonmagnetic component, and the solid phase particles – as the contributed magnetic inclusions. Analogously to the expression for the particle, a formula for the magnetic permeability of the system is obtained:

$$\mu_s = \mu_p + \left(\sqrt{\left(\frac{B}{3}\right)^3 + \left(\frac{B\mu_p}{2}\right)^2} - \frac{B\mu_p}{2} \right)^{1/3} + \left(-\sqrt{\left(\frac{B}{3}\right)^3 + \left(\frac{B\cdot\mu_p}{2}\right)^2} - \frac{B\mu_p}{2} \right)^{1/3}, \qquad (10)$$

where: $B = \dfrac{(\mu_p - \mu_l)^3 (1 - v_s)^3}{\mu_l}$.

The volume fraction of the solid component ν_s is interrelated with the mass fraction of fluid in the system $y = m_l / m_s$ (m_l — the mass of the liquid, m_s — the mass of the system) as follows:

$$v_s = \frac{\rho_l (1 - y)}{\rho_l (1 - y) + \rho_p y} \qquad (11)$$

or, with respect to the expression for the particle density:

$$\rho_p = \frac{\rho_n \cdot \rho_m}{\rho_m + x(\rho_n - \rho_m)},$$

the expression (11) takes the following form:

$$v_s = \frac{\rho_l (1 - y)}{\rho_l (1 - y) + \dfrac{\rho_n \cdot \rho_m \cdot y}{\rho_m + x(\rho_n - \rho_m)}}. \qquad (12)$$

As follows from the expressions (10)-(12), the magnetic permeability of the environment depends on the magnetic component fraction in solid particles, x, which may vary within the range $0 \le x \le 1$, as was mentioned at the first step. In order to consider the classification of the particles according to composition, the following method for determining the magnetic permeability is proposed. Firstly, the respect is paid to the fact that the expression (9) allows to calculate the magnetic permeability μ_{pj} for each j-th class of particles:

$$\mu_{pj} = \mu_m + \left(\sqrt{\left(\frac{A_j}{3}\right)^3 + \left(\frac{A_j\cdot\mu_m}{2}\right)^2} - \frac{A_j\mu_m}{2} \right)^{1/3} + \left(-\sqrt{\left(\frac{A_j}{3}\right)^3 + \left(\frac{A_j\cdot\mu_m}{2}\right)^2} - \frac{A_j\mu_m}{2} \right)^{1/3}, \qquad (13)$$

where: $A_j = \dfrac{(\mu_m - \mu_n)^3 \left(1 - \dfrac{\rho_n \cdot x_j}{\rho_n \cdot x_j + \rho_m (1 - x_j)} \right)}{\mu_n}$.

Secondly, it is considered that the solid particles have different composition. Let the fraction of particles with a certain composition x_j be v_j. Thirdly, the "filling" of the liquid phase with solid particles is produced not only step by step, but also considering the composition of the particles. That is, the solid particles with a minimum of magnetic component are "contributed" first, and then the particles with greater values of x_j are "contributed". If necessary, each class is fractioned to the desired number of portions for the reasons of small increments. After "contributing" the particles of the j-th class, the magnetic permeability of the system is assumed to be equal to μ_j, and in the terms of integrating the expression (4) the limits of integration will have corresponding indices:

$$\int_{\mu_{j-1}}^{\mu_j} \left(\frac{1}{3\mu} + \frac{1}{\mu_{pj} - \mu}\right) d\mu = \int_0^{v_j} \frac{dv}{1 - v}. \qquad (14)$$

Here the respect is paid to the fact that before "contributing" the particles of the j-th class the magnetic permeability is equal to μ_{j-1}; in the terms of filling the environment with particles of the j-th class, their volume fraction in the system will increase from 0 to v_j; μ_{pj} is determined from the expression (13). The integration of the expression (14) allows to get a formula, which relates the magnetic permeabilities of the two sequential iterations:

$$(1 - v_j)\left(\frac{\mu_j}{\mu_{j-1}}\right)^{\frac{1}{3}} = \frac{\mu_{pj} - \mu_j}{\mu_{pj} - \mu_{j-1}}, \quad j = \overline{1, N_B}, \quad \mu_0 = \mu_l.$$

It can be represented as the cubic equation and solved analogously to the equation (6). The number of iterations is determined by the number of classes N_B.

CONCLUSIONS

Thus, the expressions allowing to theoretically calculate the required physical properties of the slurry without conducting experimental electromagnetic research were obtained. The algorithm for the calculation of the magnetic permeability is presented within the paper. The proposed technique can also be used to determine the electrical conductivity and other characteristics of the system.

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ОПРЕДЕЛЕНИЕ ХАРАКТЕРИСТИК ЖЕЛЕЗОРУДНОЙ ПУЛЬПЫ В УСЛОВИЯХ УЛЬТРАЗВУКОВОГО КОНТРОЛЯ

Ольга Поркуян, Татьяна Сотникова

Аннотация. В статье представлены результаты теоретических исследований характеристик железорудной пульпы, необходимых для контроля технологических процессов обогащения железной руды. Показано, что физические характеристики, такие как магнитная проницаемость, могут быть рассчитаны с учетом распределения твердых частиц суспензии по размерам и плотности. Приведена методика расчета.

Ключевые слова: измельчение, железорудная пульпа, магнитная проницаемость.