



The study of volume ultrasonic waves propagation in the gas-containing iron ore pulp



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ABSTRACT

The results of research of the volume ultrasonic waves propagation in the gas-containing iron ore slurry using ultrasonic phased array technology is presented.

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1. Introduction

Ore crushing department is an intermediate link in the process line of mineral processing, however, despite this, it has a decisive influence on the course of subsequent operations, and the final performance of the whole beneficiating plant.

Process optimization of mineral processing requires a rigorous mathematical and economic-mathematical methods for calculating the optimal separation limits ρ_{sopt} of physical properties variation range of the feedstock particles [1].

The solution of this task allows to define both the best beneficiation technological line structure, and the technological units parameters providing its maximum productivity at set quality of the final product and the minimum costs for process.

Various methods and devices of ultrasonic testing, which found application in process automation in [2–14] are discussed. It is noted the advantages of these methods, such as high accuracy and reliability in aggressive media parameters measuring. Thus, the use of these methods is one of the most promising approaches in the development of measurement systems for process automation.

The ultrasonic measurement methods in the practice of minerals beneficiation have been used primarily for determining the parameters of the pulp, as well as for liquid and lumpy materials level monitoring in process vessels.

The known ultrasonic testing methods of the pulp parameters allow to identify two of its main characteristics – density and par-

ticle size distribution [15]. The volume ultrasonic vibrations are generally used for the parameters measurement.

The purpose is to investigate the features of volume ultrasonic vibrations propagation in a randomly heterogeneous medium (gas containing iron ore pulp) in the process of natural and specially organized movement.

2. Materials and methods

The theoretical analysis results of the volume ultrasonic vibrations propagation in the gas containing suspensions is presented in [3,4].

The main characteristic of the ultrasonic radiation field $I_i(\vec{r}, \vec{\Omega})$ is determined from the kinetic equation. Here $I_i(\vec{r}, \vec{\Omega})$ is the intensity of the ultrasonic wave (with wavelength λ), which is defined as the radiation power passing through a unit area perpendicular to the direction $\vec{\Omega}$ of the point \vec{r} per solid angle unit. $\vec{\Omega}$ – is the unit vector defining the direction in space, \vec{r} is the radius vector defining the position of a given point in space.

Kinetic equation which is solved by function $I_i(\vec{r}, \vec{\Omega})$ obtained from the energy balance in the elementary volume of the phase space

$$\vec{\Omega} \nabla I_i(\vec{r}, \vec{\Omega}) = - \sum (\lambda) I_i(\vec{r}, \vec{\Omega}) + \int d\vec{\Omega}' \sum_s (\vec{\Omega}' \rightarrow \vec{\Omega}) I_i(\vec{r}, \vec{\Omega}') + S_i(\vec{r}, \vec{\Omega}), \quad (1)$$

where $\sigma_c(\lambda)$ and $\sigma_s(\lambda)$ are the total cross sections of the ultrasonic wave absorption and scattering on the particle;

$$\sum (\lambda) = \sum_c (\lambda) + \sum_s (\lambda)$$

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$$\sum_s (\vec{\Omega} \rightarrow \vec{\Omega}') = n \sigma_s (\vec{\Omega} \rightarrow \vec{\Omega}')$$

n – particle concentration (number of particles per volume unit), $\sigma_s (\vec{\Omega} \rightarrow \vec{\Omega}')$ is the corners differential energy scattering cross section on the solid phase particle, $S_s(\vec{r}, \vec{\Omega})$ – the density function of the ultrasound radiation source, which determines the average amount of energy emitted from the phase volume unit per unit of time.

Under the phase coordinates means a series of variables \vec{r} , and $\vec{\Omega}$ and the elementary phase volume is determined by the product $d\vec{r} \cdot d\vec{\Omega}$.

The meaning of this equation is as follows: change in the intensity of the ultrasonic beam, which has a direction $\vec{\Omega}$ at a point \vec{r} is occurs, firstly, due to its absorption and scattering (the first term of the right side), secondly, due to scattering of energy flow, which previously had the direction $\vec{\Omega}'$ in the direction $\vec{\Omega}$ (the second term of the right side), and, finally, due to the energy coming to this beam from the sources (the last term of the right). Eq. (1) can be reduced to an integral equation

$$I_\lambda(\vec{r}, \vec{\Omega}) = \int d\vec{r}' \int d\vec{\Omega}' \sum_s (\vec{\Omega}' \rightarrow \vec{\Omega}) \frac{e^{-\tau(\vec{r}, \vec{r}', \lambda)}}{|\vec{r} - \vec{r}'|^2} \times \delta \left[\vec{\Omega} - \frac{(\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|} \right] I_\lambda(\vec{r}', \vec{\Omega}') + I_\lambda^0(\vec{r}, \vec{\Omega}), \quad (2)$$

where $\tau(\vec{r}, \vec{r}', \lambda) = \sum(\lambda) |\vec{r} - \vec{r}'|$; $\delta(\cdot)$ is the Dirac delta function; $I_\lambda^0(\vec{r}, \vec{\Omega}) = \int_0^\infty S_s(\vec{r} - \xi \vec{\Omega}, \vec{\Omega}) e^{-\tau(\xi, \lambda)} d\xi$ – free term of the integral Eq. (2), which determines the intensity of the unscattered ultrasonic wave $\xi = |\vec{r} - \vec{r}'|$.

As the frequency increases sharply the ultrasonic waves scattering cross section on the solid particles increases. In this case, the radiation field is formed both with unscattered and scattered waves.

The intensity of singly scattered waves can be found from the Eq. (3)

$$I_\lambda^s(\vec{r}, \vec{\Omega}) = \int d\vec{r}' \int d\vec{\Omega}' \sum_s (\vec{\Omega}' \rightarrow \vec{\Omega}) \frac{e^{-\tau(\vec{r}, \vec{r}', \lambda)}}{|\vec{r} - \vec{r}'|^2} \times \delta \left[\vec{\Omega} - \frac{(\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|} \right] I_\lambda^0(\vec{r}', \vec{\Omega}'), \quad (3)$$

We are interested in the integrated intensity of singly scattered waves, ie value

$$I_\lambda^s(\vec{r}) = \int_{4\pi} d\vec{\Omega} I_\lambda^s(\vec{r}, \vec{\Omega}), \quad (4)$$

The expression for determining of this value at the point on the ultrasonic beam axis in a cylindrical coordinate system is given by

$$I_\lambda^s(Z) = 2\pi \int_0^Z dZ' \int_0^a d\rho' \cdot \rho' \cdot I_{0,\lambda} e^{-\sum \sum (\mu)} \frac{e^{-\sum \xi}}{\xi^2}, \quad (5)$$

where $\xi = |\vec{r} - \vec{r}'| = \sqrt{(Z - Z')^2 + \rho'^2}$; $\mu = \vec{k} \cdot \frac{(\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|}$; \vec{k} – the unit vector directed along the axis Z ; $\rho = \sqrt{x^2 + y^2}$.

Taking into account the approximations and conducting the integration in (5), we obtain

$$I_\lambda^s(Z) = \frac{n\sigma_s}{4} e^{-\sum (\lambda) Z} I_{0,\lambda} \left\{ Z \ln \left(1 + \frac{a^2}{Z^2} \right) + 2a \cdot \arctg \frac{Z}{a} \right\}, \quad (6)$$

where a – is the radius of the disk ultrasound source.

Let's determine the value β_v ,

$$\beta_v = \frac{I_\lambda^0(Z) + I_\lambda^s(Z)}{I_\lambda^0 Z} + 1 + \frac{I_\lambda^s(Z)}{I_\lambda^0 Z}, \quad (7)$$

and find its asymptotic expression, under the condition that $Z \gg a$

$$\beta_v = 1 + \frac{n\sigma_s}{4} \left\{ Z \ln \left(1 + \frac{a^2}{Z^2} \right) + 2a \cdot \arctg \frac{Z}{a} \right\} \approx 1 + \frac{n\sigma_s \pi a}{4}. \quad (8)$$

The value $\beta_v - 1$ shows the commensurability of scattered and unscattered radiation contributions. Let's call it the accumulation factor. It is clear that the β_v more different from one, the larger the contribution of the scattered radiation.

Fig. 1 shows the dependence of the accumulation factor asymptotic values from the ultrasonic waves frequency for the particle sizes of: (1) 50 μm , (2) 74 μm , (3) 100 μm , (4) 140 μm . As can be seen from this figure, not only singly scattered, but multiple scattered radiation of ultrasonic waves can not be neglected at high frequencies.

Let the number of N_1 gas bubbles and N solid phase particles are located in suspension effective controlled volume. The solid phase particles size distribution function is denoted by $F(r)$, and the gas bubbles by $f(R)$.

In this case, the attenuation of the ultrasonic wave passing the distance in the medium will be described by the expression

$$I_v(Z) = I_0 \exp \left\{ -\frac{Z}{V} \left[\sum_{i=1}^{N_1} \sigma_p(v, R_i) + \sum_{j=1}^N \sigma(v, r_j) \right] \right\}, \quad (9)$$

where $\sigma_p(v, R) = \frac{4\pi R^2}{\left(\frac{v^2}{v_0^2} - 1\right)^2 + \delta^2}$ – is the attenuation coefficient of ultrasonic wave with frequency v on the bubble with radius R , δ – attenuation constant ($\delta \in 0,08 - 0,13$), v_0 – is the resonance frequency

of bubbles with radius R , which can be defined by the formula

$$v_0 R = 0,328 \cdot 10^3 \text{ Hz cm}$$

The cross section of the ultrasound attenuation on solid phase particles defined above.

The intensity of the wave $I_v(Z)$ is a random value since the number of solid and gas phases particles fluctuates in the volume V .

In order to eliminate the effect of these fluctuations, it is necessary to measure the average value of $I_v(Z)$.

If in the volume of V the average number of particles equal to $\langle N \rangle$, than the probability of detection k -particles in this volume is given by a Poisson distribution

$$P_N(k) = \frac{\langle N \rangle^k \exp(-\langle N \rangle)}{k!}, \quad (10)$$

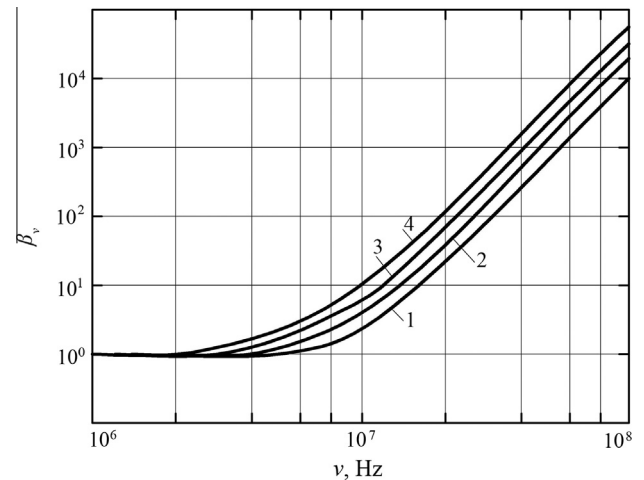


Fig. 1. The dependence of the accumulation factor asymptotic values from the ultrasound frequency for the particle sizes: 1–50 μm , 2–74 μm , 3–100 μm , 4–140 μm .

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