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Noncontact NDT method of crushed ore particle size and density distribution in the pulp flow

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Abstract
The method for determining of pulp solid phase particle size distribution and density is proposed. The measurement of pulp solid phase particles concentration (low-frequency ultrasound waves) and their density (gamma radiation) during controlled action of high-energy ultrasound radiation pressure on the trajectory of their movement in pulp flow is carried out.
Keywords: PULP, SOLID PHASE, PARTICLE SIZE DISTRIBUTION, ULTRASOUND

In [1, 5-7] several methods of ultrasonic testing of mineral disclosure degree (useful component) during ore grinding are proposed and investigated. It is noted that the mineral disclosure degree control with the known fineness of analyzed particle may be reduced to measuring of this particle density.

One of the proposed methods is based on the action of powerful (high-energy) ultrasound on the particle during its motion. The strength of the radiation pressure on a particle in plane wave is determined by the formula, which was obtained by Westervelt [2-4]

$$F_r = \overline{E}(\sigma_s + \sigma_p) - \overline{E}\oint I_v \cos v dS \, , \quad (1)$$

where E - is the time average energy density in the incident wave; σ_s and σ_p – are the effective cross sections of scattering and absorption; *v* – is the angle between the incident and scattered waves; I_v – is the value of the scattered wave intensity at an angle *v*.

For estimation of particles displacement under the influence of high-intensity ultrasound the change in the value of ultrasonic probe signal with frequency *v* in a direction perpendicular to the motion of pulp is determined. In [1] the ratio of two probe signal values was studied, one of which S_0 is determined without the influence of a powerful ultrasonic field, the other S_1 – with the presence. It is concluded that the density of the pulp solid phase particles can be determined by value of S_1/S_0.

However, this determination method has its disadvantages. First of all, it should be noted that the ultrasonic attenuation coefficient of the probe signal *a* depends on the volume fraction of solids in the pulp, therefore change of this value can have a greater effect than the change in particle density. Furthermore, the expression, defining the value of S_1/S_0, is strong enough approximation, since it does not considers a number of factors, such as changes in particle size distribution law by coefficient *a* etc. It should be noted that the use of high-intensity ultrasound of gi-ven intensity is a promising direction for a preliminary purposeful redistribution of crushed material particles in a controlled pulp flow at development of its parameters control systems [1].

In [1, 7-9] a method for pulp solid phase density measuring, based on the use of two measurement channels is considered. One of channels is performed using gamma radiation, and the second - using Lamb surface waves. Coefficient of gamma radiation attenuation by pulp can be represented as follows

$$\mu = (1-W)\rho_w\mu_w + W\rho_s\mu_s \, , \quad (2)$$

where μ_w and μ_s – are mass attenuation coefficients of water and solid component of pulp; p_w and p_s – are density of water and pulp solid particles; *W* – is the volume fraction of solids in pulp.

If the radiation source is collimated, the detector will register generally non-scattered radiation, the intensity of which can be represented by

$$I = I_\circ \exp\left\{-\left[(1-W)\rho_w\mu_w + W\rho_s\mu_s\right]l\right\}, \quad (3)$$

where I_o - the intensity of gamma radiation in the absence of pulp (liquid) in the measuring module (pulp line).

If there is a pure water in a measuring module, then the intensity of gamma radiation will be determined by the formula

$$I^* = I_\circ \exp\left(-\rho_w\mu_w l\right). \quad (4)$$

As seen from (3) and (4), the radiation intensity can be represented by

$$I = I^* \exp\{-W[\rho_s\mu_s - \rho_w\mu_w]l\}. \quad (5)$$

The amount of gamma-ray detector current is proportional to the radiation intensity, so the value of the signal S at the output of the logarithmic amplifier is proportional to *ln I*. From (5) it is clear that the difference between the signals S and *S*(S** - signal for clean water) will be determined by the formula

$$S_\gamma = S^* - S = \ln\frac{I^*}{I} = AW[(\rho_s\mu_s - \rho_w\mu_w)l], \quad (6)$$

where K – is the coefficient of proportionality.

Such signals difference over the Lamb surface waves channel gives a value, which is also proportional to the volume fraction *W*, i.e.

$$S_L = BW[\rho_s - \rho_w]Z \cdot \quad (7)$$

The ratio of signals S_L and S_γ is given by

$$S=\frac{S_L}{S_\gamma}=\frac{BZ(\rho_s-\rho_w)}{Al(\rho_s\mu_s-\rho_w\mu_w)}. \quad (8)$$

As can be seen from (8), the signal, which obtained in this manner will depend on the average density of the solid p_s.

This measurement method does not require pre-degassing of pulp, but is not convenient due to the need to have a large measuring base (the distance between the Lamb surface waves source and receiver) to achieve sufficient sensitivity.

In proposed method for determining of pulp solid phase particle size distribution and density the measurement of pulp solid phase particles concentration (low-frequency ultrasound waves) and their density (gamma radiation) during controlled action of high-energy ultrasound radiation pressure on the trajectory of their movement in pulp flow is carried out.

All crushed material fineness classes or only of interest classes can be displaced to the measurement zone by increasing the high-intensity ultrasound from zero to a certain value and with constant pulp flow rate [8-10].

$$F(r)=(\int_0^{r_1} f(r)r^3dr+\int_{r_1}^{r_2} f(r)r^3dr+...+\int_{r_{m-1}}^{r_m} f(r)r^3dr)\Big/\int_0^{r_m} f(r)r^3dr. \quad (9)$$

For the measurement of pulp solid phase concentration the low-frequency ultrasonic waves is used. As shown in [1, 8, 9], the amplitude of the ultrasonic wave with frequency ν , which passed the distance z in pulp, can be described by the expression

$$A_\nu(z)=A_B\exp\left\{-\frac{zn}{V}\int_0^{r_m}\sigma(\nu,r)f(r)d\right\}, \quad (10)$$

where N – is the number of particles in the effective controlled amount of pulp V; A_W – is the amplitude of the wave, which passed the same distance through the clean water; r_m –is maximum solids size; $\sigma(\nu,r)$ – is the ultrasound attenuation cross-section with frequency ν on a solid spherical particle of radius r.

The value $\sigma(\nu,r)$ is determined by the sum of the absorption and scattering coefficients of ultrasound

$$\sigma(\nu,r)=\sigma_c(\nu,r)+\delta_s(\nu,r) \quad (11)$$

In the low-frequency region ($\nu\le10^5$Hz)) Ultrasonic attenuation caused mainly by viscous inertial losses, so $\sigma\approx\sigma_v$.

Then, the signal generated at the frequency ($\nu_1\le10^5$Hz))

$$S_1=\ln(A_{0_1}/A_{\nu_1})=Z_1N\int_o^{r_m}F(r)\sigma_\nu(\nu_1,r)=\frac{Z_1W}{\aleph}\int_o^{r_m}F(r)\sigma_\nu(\nu_1,r)dr \quad (12)$$

will be proportional to pulp solid phase concentration, as it depends on the volume fraction of solids W [9]. In this expression,

$$\aleph=\int_o^{r_m}F(r)4/3\pi r^3(dr). \quad (13)$$

Consequently, by the value of the signal S_1 it is possible to define pulp density or content of solids therein.

In the proposed control method the formed signal S, which proportional to the density of the pulp solid phase particles is determined by the mass attenuation coefficient of gamma radiation μ_T.

$$S=A\frac{(\rho_T\mu_T-\rho_T\mu_B)}{(\rho_T-\rho_B)}, \quad (14)$$

where A – is the proportionality coefficient; p_w and μ_w – are the density and mass attenuation coefficient of water.

In the case of two-component composition of the pulp solid phase, which consists, e.g., of η-th proportion of magnetite (Fe_3O_4) and (1-η)-th proportion of silica (SiO_2) pulp solid phase density is given by

$$\rho_T=\rho_1\eta+\rho_2(1-\eta), \quad (15)$$

and the generated signal S is given by

$$S=A\frac{[\rho_1\eta+\rho_2(1-\eta)][\eta\mu_1+(1-\eta)\mu_2]-\rho_{‰}\mu_{‰}}{\rho_1\eta+\rho_2(1-\eta)-\rho_{‰}}, \quad (16)$$

where μ_1 and μ_2 - mass attenuation coefficients Fe_3O_4 and SiO_2 respectively.

In [11] function was studied

$$N=f(k,\rho,q), \quad (17)$$

where N – is the intensity of the integrated flux of transmitted gamma radiation, k- is an amount of so- lid, ρ - is the pulp density, q – is the mass fraction of the useful component. The study results are presented on Fig. 1.

For the practical realization of this control method in [1, 8, 9] a number of issues are solved, which are associated with determination of radiation source energy, dimensions of the source and detector collimators, assessment of the scattered background radiation impact, detector operating mode selection, etc. Radiation source energy selection was based on quantitative criteria, related to the definition of signal change range, which is caused by possible variations in density and composition of pulp solid phase, as well as the method sensitivity to such changes.

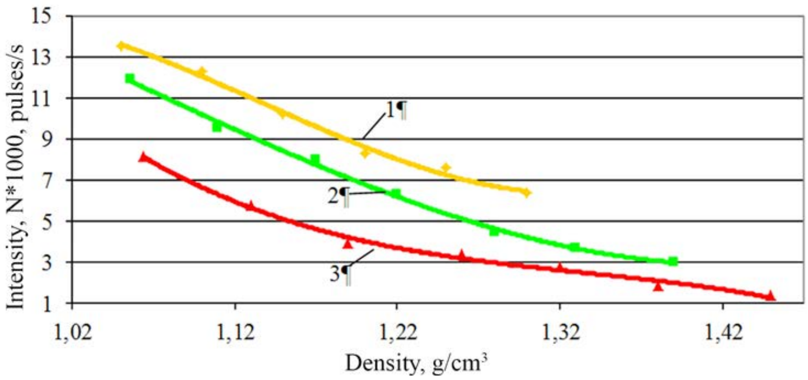

Figure 1. The dependence of gamma radiation intensity from a pulp density at different iron contents: 1 – Fe = 14,25%; 2 –Fe = 34,72%; 3 – Fe = 65,13%

Thus, the radiation pressure of high-energy ultrasound allows to change the trajectory of pulp solid phase particles and thus to perform their spatial separation by size and density. To determine the parameters of distribution function of crushed ore particles by size and density in pulp flow the measurements of low-frequency volume ultrasonic waves attenuation, and gamma radiation, passed a fixed distance in a controlled environment can be used.

Conclusions

The proposed method doesn't require pulp pre-degassing; because the gas bubbles under the influence of high-energy ultrasound radiation pressure is removed from the measurement zone.

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