Ultrasonic phased array parameters determination for the gas bubble size distribution control formation in the iron ore flotation

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Abstract
A method for the effective control of the pulp gas phase composition in the flotation process using dynamic effects of high energy ultrasound on the base of phased array technology and determination of its parameters are described.
Key words: PHASED ARRAY, ULTRASOUND, PULP, CONTROL, FLOTATIO

Introduction

Flotation is the most widely used separation process in the processing industries and is the most complete and versatile mineral processing operation.

The existing methods and automatic systems of flotation process control does not allow to efficiently control the gas phase parameters in terms of changing characteristics, medium parameters and equipment state.

For an understanding of the physical processes that determine flotation the accurate information about the gas phase parameters, the most important of which are the size and bubbles size distribution is required. These parameters are strongly dependent on the various operational, technical, physical and chemical factors, the effects of which should be considered in flotation process modeling [2,3].

It is known that for the pulp solid phase particle size distribution may exist the optimal gas phase bubbles size distribution in the flotation process.

Thus, the task of research is to form and maintain a specified gas bubble size distribution which would correspond to the ground ore particle size distribution.

Materials and methods

To form the required gas bubble size distribution function, which would conform with the pulp solid phase particle size distribution in the flotation process, it is proposed to affect on the pulp flow with high-energy ultrasonic wave with given frequency and amplitude, resulting in a gas bubbles concentration change, and redistribution of their size. Character of redistribution depends on the size of the bubbles themselves, the frequency and amplitude of the incident radiation. Increasing the frequency and amplitude to the values at which the transition cavitation starts, bubble size will decrease due to crushing of larger bubbles. When decreasing the amplitude and frequency the bubbles will rise due to coalescence of smaller bubbles [4].

To solve this task, let’s form the control action based on the dynamic effects of high-energy ultrasound using phased array technology, the main feature of which is computer-controlled driving pulses amplitude and phase of the individual piezoelectric elements in multi-element transducer to control the parameters of the ultrasound beam, for example, angle, focal length, focal spot size [5,6].

Taking into account the above in the proposed method using the ultrasonic phased array mounted on the external wall of the flotation machine chamber, in the working area, at each current moment of time we generate the high energy ultrasound effect with a given frequency 0.7 - 2.5 MHz, (because the value lower than 0.7 MHz does not give a stable effect of bubble size changes, which is caused by the extreme nature of cavitation, and a value above 2.5 MHz is not affect the change of necessary indicators) and the pressure amplitude of 10^2 - $5{\cdot}10^6$ Pa, (because the value lower 10^2 Pa not sufficient to effectively control the gas phase, and the values above $5{\cdot}10^6$ Pa not give quality indicators growth), wich focused on the window in the interchamber septum. The gas bubbles which formed in the aeration step, after impeller dispersing are exposed to focused ultrasound, which leads to variations in their concentration and desired size redistribution in the pulp flow.

To focus precisely on the window in the interchamber septum it is necessary to calculate the parameters of a phased array and to construct its directivity pattern.

The acoustical pressure of the array was calculated by modeling every element of the array as an independent simple source and summing the contribution of each simple source at each point in the field. The acoustic pressure *p(x,y,z)* at a specific point *(x,y,z)* in the field due to a simple source was calculated using the Rayleigh-Sommerfeld equation [7,8]

$$p_i(x,y,z)=\sqrt{\frac{2W\rho}{cA}}\left(\frac{fS}{d}\right)e^{\left\{\left(\phi-\frac{2\pi d}{\lambda}\right)i-d\alpha\right\}} \quad (1)$$

where W - is total acoustical power output from the array, ρ – is density of the medium, c – is speed of sound in the medium, A – is active transducer aperture, f – is frequency, S – is area formed by source, d – is distance from the source to the point *(x, y , z)*, φ – is phase of oscillation, λ – is wavelength, and α – is attenuation in the medium.

The active aperture (the total length of the array) is calculated by the following formula [6].

$$A=n\cdot e+g\cdot(n-1) \quad (2)$$

where A - is active aperture; g – is gap between nearest elements; e – is width of one element (typically $e<\lambda/2$); n – is number of elements.

Active aperture projection onto a plane seen along the refracted rays (effective active aperture A_{eff}) is given by

$$A_{eff} = \frac{A \cdot \cos \beta_R}{\cos \alpha_I} \quad (3)$$

Recommended passive aperture is determined by probe frequency and the focal depth range as follows

$$W = 1.4[\lambda(F_{\min} + F_{\max})]^{0.5} \quad (4)$$

Its contribution to the focal depth (near-field length) is given (for nonfocused probes) by formula (5)

$$N_0 = \frac{(A^2 + W^2)(0.78 - 0.27W / A)}{\pi\lambda} \quad (5)$$

Array pitch of p is determined by the formula:

$$p = e + g \quad (6)$$

where g – is the element gap; e – is the element width.

The maximum width of a single element, which is determined by the maximum beam refracted angle by electronic control e_{max} can be represented as follows

$$e_{\max} = \frac{0.514 \cdot \lambda}{\sin \alpha_{R_{\max}}} \quad (7)$$

Note that the beam width is dependent on the focal length and the angle of entry.

A focused beam is characterized by the focusing factor or normalized focus depth

$$S_{ac} = \frac{F_{ac}}{N_0} \quad (8)$$

with $0 < S_{ac} < 1$ and $F_{ac} < N_0$, and F_{ac} – is the actual focal depth.

An optical focus point is defined by

$$F_{opt} = \frac{R}{1 - (v_{test \cdot piece} / v_{lens})} \quad (9)$$

where R - lens curvature radius.

The optical focusing factor is defined by

$$S_{opt} = \frac{F_{opt}}{N_0} \quad (10)$$

The net pressure due to all the elements was determined by summing the effects of each simple source:

$$P_{net}(x, y, z) = \sum_{i=1}^{n} p_i(x, y, z) \quad (11)$$

The net power deposition at point (x,y,z) was the result of the attenuation [5]

$$q(x, y, z) = \frac{\alpha P_{net}^2(x, y, z)}{\rho c} \quad (12)$$

The total energy at a point (x, y, z) is given by [8,9]

$$I(x, y, z) = \frac{p^2(x, y, z)}{2\rho c} \quad (13)$$

where $I(x, y, z)$ - intensity at the point (x, y, z), $W \cdot m^{-2}$

The phase of each element of the array was determined by

$$\phi_i = \frac{360°}{\lambda}(d_i - d_0) - 360° n \quad (14)$$

where φ_i is phase of element i in degrees, d_i is distance from the center of element i to the focus, d_0 is the focus depth, n is an integer used to maintain $0 <= \varphi_i <= 360°$.

3. Results

Normalized directivity pattern for a rectangular array with Z = 16 elements equally spaced from each other d = 0,6 mm in the plane (Fig. 1) used in the simulation with software and hardware tools TAC (Transducer Array Calculation) [10] is presented on Fig. 2.

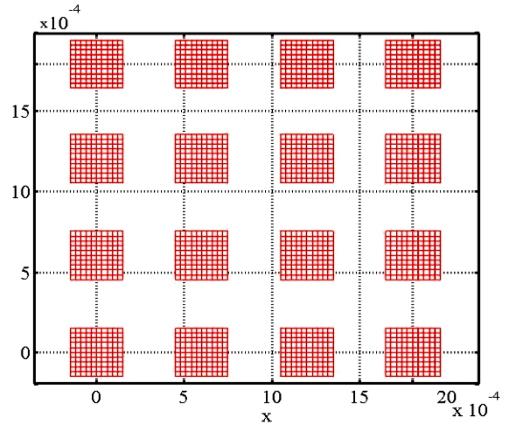

Figure 1 Phased array configuration

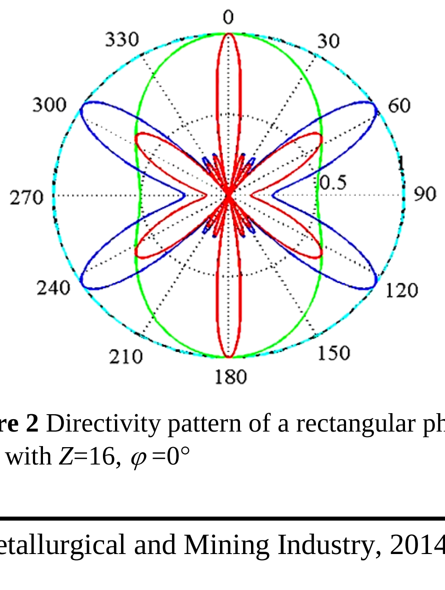

Figure 2 Directivity pattern of a rectangular phased array with Z=16, φ =0°

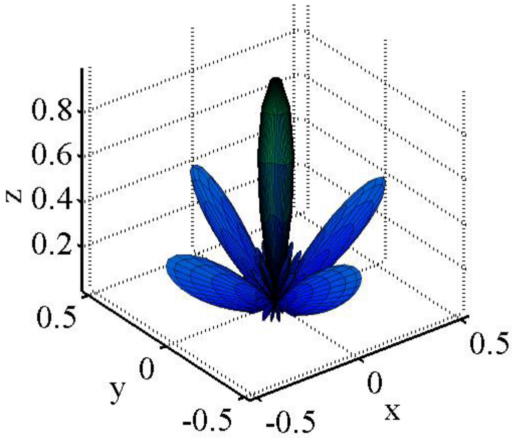

Figure 3 Directivity pattern of entire arrangement

Taking into account the above, for the method implementation we form the ultrasonic action with certain amplitude and frequency using phased array at each current moment of time in a flotation machine working zone that will provide the required gas bubble size distribution in the pulp flow.

Conclusions. Simulation results of the high energy ultrasound impact on the pulp gas phase using ultrasonic phased array allow to form the required gas bubble size distribution function, which will conform with the pulp solid phase particle size distribution in the flotation process. Thus, the proposed flotation control method allows to implement efficient control of the pulp gas phase composition, improve the quality of the concentrate and the efficiency of the beneficiation process.

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