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SELECTION AND CALCULATION OF THE MAIN SYSTEM COMPONENTS OF OPTIMAL CONTROL OF TECHNOLOGICAL PROCESSES PRODUCTION AND PROCESSING

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Purpose. The aim of the research is to increase the energy efficiency and the iron content in the concentrate during the ore enrichment process presented through mineralogical and technological species, by developing the principles and approaches to the distributed optimal control of interrelated processes concentrating production on the basis of dynamic spatial-temporal model.

Methodology. Analysis of domestic and foreign experience; systematization of the existing approaches and methods to optimize the control of ore enrichment process; methods of mathematical statistics and probability theory for processing the results of experiments; methods of analytical design and computer simulation in the synthesis and analysis of automated systems; methods of system analysis and optimal control methods in the development of process control algorithms; numerical simulation methods for the synthesis and analysis of mathematical models of optimal automated control system; computer information and software technology for the implementation of the developed algorithm for automated control software.

Scientific novelty. Developed the method for automating control processes of nonlinear dynamic objects of the technological line iron ore enrichment, which differs from the existing ones, that the technological line processing of iron ore is represented as a structure with lumped inputs: consumption of ore and water in the processing units; and distributed over the entire production line output - distribution functions of the iron content by grade of ore particle size, which allowed to redistribute the load between the stages of enrichment and to reduce electricity consumption by 2.34%.

Practical significance. The obtained results include the development of: algorithms and programs of the automated energysaving control of ore enrichment process; software and hardware means formation of information base of automated process control over technological processes of ore enrichment.

Key words: system, processes, production, ultrasonic control, error, pulp.

Introduction. In modern conditions at the mining and processing plants are processed several types of ore processing. The system of mining operations does not allow to produce the same type of ore for a long time, which leads to instability of the mineral composition of the raw material supplied to the enrichment. One of the ways to reduce the negative impact of variability of the raw iron-ore on energy consumption process equipment is to increase the accuracy of object identification processing control of production, that will improve the process control quality. The final results of the processing plant depend on a complex of interrelated processes. That requires an appropriate approach to modeling the technological processes that take into account their combination and ensures optimization of the entire structure [1-6]. The analysis showed that the problems of managing interrelated processes of production and processing is advisable to solve on the basis of distributed optimal control methods based on dynamic spatial-temporal models performing the operational characteristics measurement of the technological iron ore flow through ultrasonic radiometric methods.

Materials and methods. To solve the problem of the automatic control parameters of ore solid slurries is proposed the method, which consists in measuring the intensity of the high frequency volumetric ultrasonic waves transmitted at a fixed distance in the measuring container during periods ore slurry flow to affect the suspension with ultrasonic vibrations and in their absence [7-12]. In this case, the calculated ratio of the measured values allows to determine the parameters of the solid phase of the ore slurry. Also, during the measurement are formed gamma radiation and low-frequency volumetric ultrasonic waves in the ore slurry flow and are measured the intensity gamma-radiation and low-frequency volumetric ultrasonic waves transmitted at a fixed distance in the presence of the reference fluid in the measuring chamber and the ore slurry flow during effect on the slurry flow with ultrasonic vibrations and in their absence. At the same time, the intensity of ultrasonic vibrations during their effect on the flow of suspension is changed under the relevant law.

Functional scheme of automation, designed according to the stated principle of operation, is shown in Fig. 1

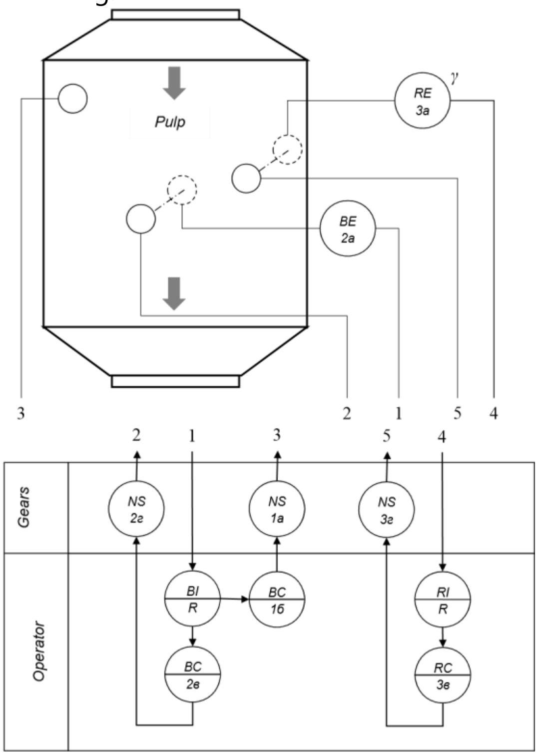

Figure 1. Functional scheme of automation control product processing industry

Scheme of automation control product processing industry (Fig. 1) consists of three circuits. The circuit 1 is designed to generate directed high-energy ultrasound and consists of elements: 1A - control device (BC); 1B – switchgear (NS) of ultrasonic phased array. The contour 2 is designed for measurement of the pulp density on the basis of the ultrasonic signal to determine the concentration of ore particles in the pulp. The circuit consists of the following elements: 2A – transducer ultrasonic signal transmitter (BE); 2B – indicating and recording secondary transducer of the ultrasonic signal (BIR); 2C – control device (BC); 2D – switchgear (NS) source of ultrasonic vibrations. Contour 3 is designed to measure the iron content in the ore particles on the basis of gamma radiation. The circuit consists of the following elements: 3A – primary transducer of gamma-radiation signal (RE); 3b – indicating and recording secondary transducer of ultrasonic signal (RIR); 3b –control device (RC); 3G – switchgear (NS) source of ultrasonic vibrations.

Consider the research results of the effect of such parameters of ultrasonic phased array as a distance between elements, a wavelength and the number of elements, on control and the efficiency of ultrasonic radiation. Ultrasonic phased array is considered as a set of point sources of ultrasound, located equidistantly (*d*) from each other. The ultrasonic pressure field is calculated using Huygens ' principle with properly selected values of phase and amplitude for the case $r >> d$ [13].

$$(r,\theta,\tau)=\frac{\rho_0 r_0 \sin\left[\left(\frac{\omega\Delta\tau-kd\sin\theta}{2}\right)N\right]}{\sin\left[\left(\frac{\omega\Delta\tau-kd\sin\theta}{2}\right)\right]}\exp$$

$$\left[-j\left(\frac{\omega\Delta\tau-kd\sin\theta}{2}\right)N-1\right]\cdot\exp[j(\omega\tau-kr)]$$

where r_0 - the infinitely small radius of pulsating ultrasonic radiation point-sources; p_0 - the pressure amplitude of ultrasonic radiation point-sources; k - the wave number; ω - the angular frequency; N - the number of ultrasonic radiation pointsources; j - the imaginary unit.

Diagram of a point element ultrasonic phased array is shown in Fig. 2.

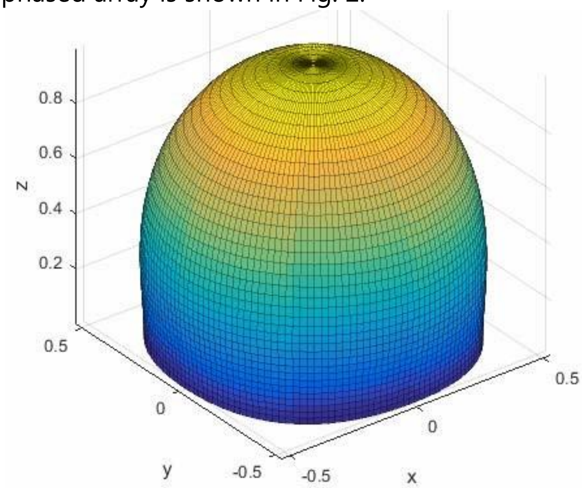

Figure 2. Diagram of a point element ultrasonic phased array

The required time delay between adjacent sources is needed to direct ultrasonic radiation at an angle θs is given by [14].

$$d\sin\theta_s/C, \qquad (2)$$

where c - the speed of a sound in the propagation medium (the standard fluid and ore pulp respectively).

The directivity of the ultrasonic radiation onThe results of the calculation delay time in the actuation of point elements ultrasonic phased array is shown in Fig. 3. the basis of an equation (1) defined as

$$\left| \frac{\sin\left[\frac{\pi d(\sin\theta_s - \sin\theta)}{\lambda} N\right]}{N \sin\left[\frac{\pi d(\sin\theta_s - \sin\theta)}{\lambda}\right]} \right|. \quad (3)$$

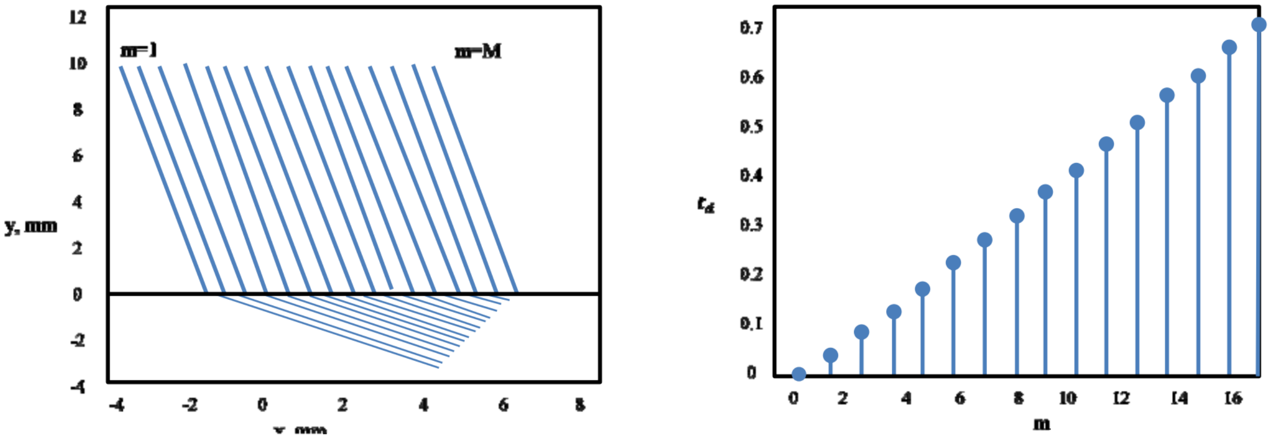

Figure 3. The delay time (in ms) of the ultrasonic phased array point-sources

Optimal parameters of the ultrasonic phased array are selected on the basis of the following parameters, characterizing the diagram directivity of the ultrasonic phased array (Fig. 4)

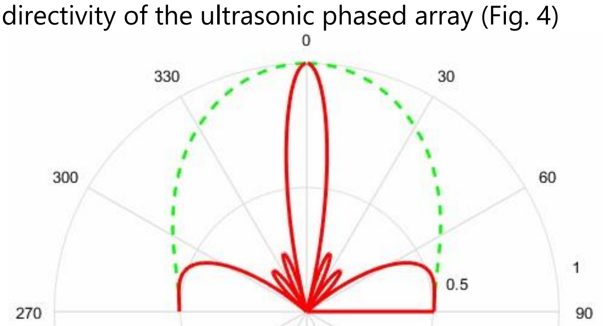

Figure 4. The diagram directivity of the ultrasonic phased array: --- – total; --- – point element

The width value (sharpness) of the main lobe of the diagram based on the formula (3) is determined from the equation

$$q = \frac{1}{\pi}\left[\sin^{-1}\left(\sin\theta_s + \frac{\lambda}{Md}\right) - \sin^{-1}\left(\sin\theta_s - \frac{\lambda}{Md}\right)\right] \quad (4)$$

In this case, the best directivity corresponds to the smaller value of the parameter q. It should be noted that in the case where the value of the equation λ/Nd approaches zero, then the value also tends to zero. Thus, the best directivity can be achieved by applying a greater number of point radiating elements or increasing the distance between the elements.

On the basis of the equation describing the increased width of the main lobe of the radiation diagram it can be concluded that the increase in the number of elements of the ultrasonic phased array improves its efficiency. However, studies [1114] show that the value of the index q is dramatically reduced by varying the number of elements in a phased array to 8 pieces. The number of elements exceeding 32 does not bring significant improvement of the parameter q. Thus, the optimal number of elements in terms of the improvement in directivity of the phased array, as well as manufacturing costs, is 16 elements.

The distance between the elements is also a significant parameter that affects the directivity index q of the ultrasonic phased array radiation. In the paper [12], it is shown that the best value of directivity corresponds to a larger distance between the elements in phased array. However, it should be noted that along with the improvement of the directivity value q, also increase side- lobes of the directivity. This is confirmed by the shown in Fig. 6. results of calculating the diagram directivity of ultrasonic phased array with 16 elements (4×4) while changing the distance between the elements from 0.4 mm to 0.7 mm in increments of 0.1 mm.

Therefore, it is necessary to find a compromise value for the distance between the elements of the phased array, which, on the one hand, ensures an optimal radiation directivity, and on the other, provides a reduction in side-lobe. From the equation (3) subject to $H(\pi/2)=1$ we find the distance between the elements of the phased array $d_{cr}=\lambda/(1+\sin\theta_s)$

As a result, obtained the optimal distance between the elements of the ultrasonic phased array d_{cr}=0,47 mm.

The arrangement of the elements of the ultrasonic phased array is shown in Fig. 5.

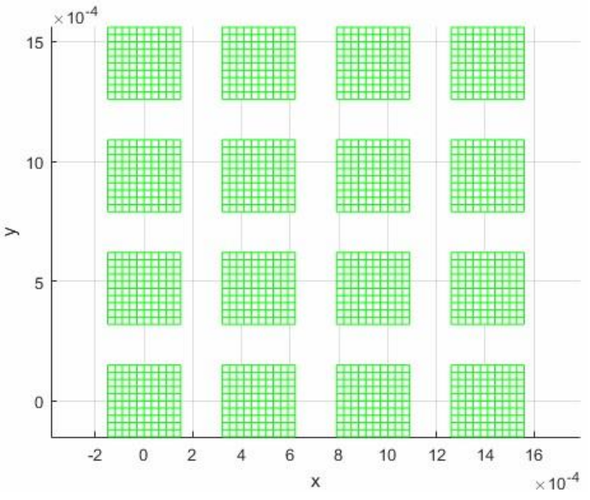

Figure 5. The arrangement of elements of the ultrasonic phased array when the distance between the elements d_{cr}=0,47 mm

Three-dimensional representation of the diagram directivity of the ultrasonic phased array is shown in Fig. 6.

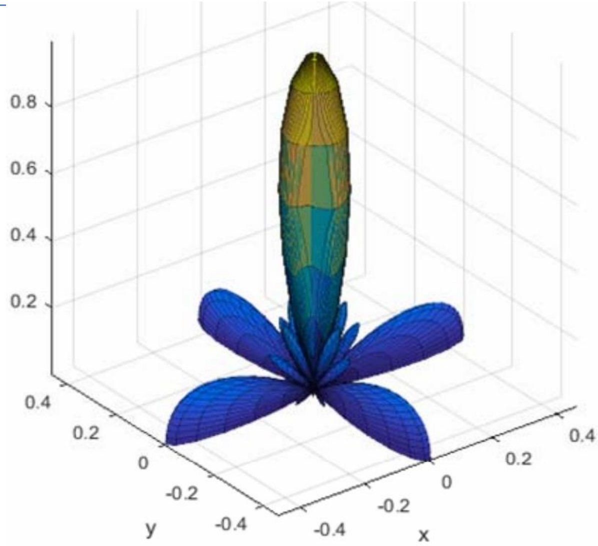

Figure 6. The diagram directivity of ultrasonic phased array when the distance between the elements d_{cr}=0,47 mm

Results. The results of laboratory tests of the developed device for ultrasonic control pulp parameters showed that the reconstruction error of the distribution function of the crushed material particles by size in standard deviation is 0,7-0,85%; the reconstruction error of the distribution function of the useful component content in the particles of the crushed material by size in standard deviation is 0,67-0,74%.

Conclusions. Developed a method of evaluating the distribution function of the useful component by grade of particle size iron ore pulp using a high-frequency and low-frequency ultrasonic radiation and gamma radiation, which differs from existing ones that in the process of the measurement is carried out displacement of the particles of a given grade size in the measurement area by acting on the pulp with ultrasonic radiation of high intensity; the measurement results are compared with the reference substance characteristics, which improves the measurement accuracy by 1.23%.

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