UDC 622.73

P.I. PILOV, L.J. GOROBETS, Dr.t.Sc.
(Ukraine, Dnepropetrovsk, National Mining University),
N.S. PRYADKO, PhD
(Ukraine, Dnepropetrovsk, Institute of Technical Mechanics NASU and SSAU)

REGULAR DEPENDENCE OF ACOUSTIC SIGNALS FROM DISPERSION AT JET GRINDING ORES

In operating conditions of jet grinding installations acoustic laws of material dispersiveness change are revealed during thin grinding. Complex acoustic and technological criteria of ground product quality improvement are offered with specific power inputs decrease.

Statement of a problem. Fine grinding is used for disclosing minerals of fine impregnation ores. Thus it is necessary to avoid impregnation over grinding because of spending redundant energy and the over grinding product does not correspond to industrial technical requirements. The establishment of optimum conditions of thin grinding is an actual problem on one hand because of significant power consumption of producing high dispersion products (fraction less than 60-40 microns), and on the other hand necessities of exception over grinding valuable minerals

At realization of the jet grinding closed cycle there is an extraction from a mill obviously ungrinding a product which is divided in the qualifier into a ready product according dispersion and larger, non-standard, directed in a mill for grinding. In conditions of production required dispersion is determined on rest R on a control sieve. A parameter of thin grinding efficiency is named the mill productivity G divided by new surface S of the ground product. Thus with the purpose of power input decreasing for superfluous material over grinding in thin grinding process management it is important to establish minimally possible a product specific surface S_{sp} size at required rest R on a control sieve. In plant conditions the decision of this problem is not achievable because of absence of technologically possible and duly quality monitoring of received product dispersion in grinding installations. For this reason wide enough range of dispersion change with getting quality requirement rest R of ground product takes place. For example, for fine dispersed zircon concentrate limits of change S_{sp} is 1400-2500 sm^2 /g at $R \leq 0{,}5-2{,}5\%$.

In this article the problem of acoustic monitoring application is considered on the example of jet mill work for dispersion monitoring during a grinding cycle and finding of acoustic and technological criteria complex of process optimization.

In works [1-3] the technique of acoustic monitoring of a jet mill acting zone for the control of a material loading and ground particles size is approved. Acoustic activity is measured with the help of the sensor connected with a brass waveguide setting inside a mill chamber. Grinding zone acoustic characteristics depending on jet mill productivity G and a product dispersion degree S_{sp} are determined. There have been established by researches the dependences of grinding zone acoustic parameters (signal amplitude and activity) from a grinding stage and mode.

The developed system of jet grinding acoustic monitoring allows establishing quality control of a ground material and a received product. The amplitude size changes of acoustic signal (AS) depend on the particle size containing in jet. And the increase of the particle size at one order (from 0,3 up to 3 mm) rises amplitude more than the same order on stages of jets loading and an grinding operating modes with other things being equal [4, 5].

For maintenance of required product dispersion a ways of its quality control are offered on the following law basis:

– Changes of acoustic activity of signals with the maximal amplitude at various grinding stages;

– Changes of a small amplitude signal share from a classification mode and product dispersion.

Researches have allowed establishing logarithmic dependence of the maximal AS amplitude from the ground product particle size. In the below table and on fig. 1 the dependences established during various materials jet grinding in JGP-20 (jet grinding plant with productivity of 20 kg/h) are shown.

Dependence of maximal amplitude A_{max} (mV) on size d (mkm) of grinding product particles (ρ–density, g/sm^3)

№	Materials	Type of dependence	Correlation coefficient, r
1	Chamotte	$\lg A = 1{,}1 \lg d - 0{,}21$	0,91
2	Slag	$\lg A = 1{,}55 \lg d - 1{,}3$	0,9
3	Quartz	$\lg A = 0{,}8 \lg d + 0{,}99$	0,88
4	Zircon	$\lg A = 2{,}1 \lg d + 0{,}76$	0,99
5	Technical carbon	$\lg A = 0{,}99 \lg d - 0{,}26$	0,95
6	General dependence	$A_{max} = d \cdot 10^{0{,}4\rho + 0{,}04}$	0,81

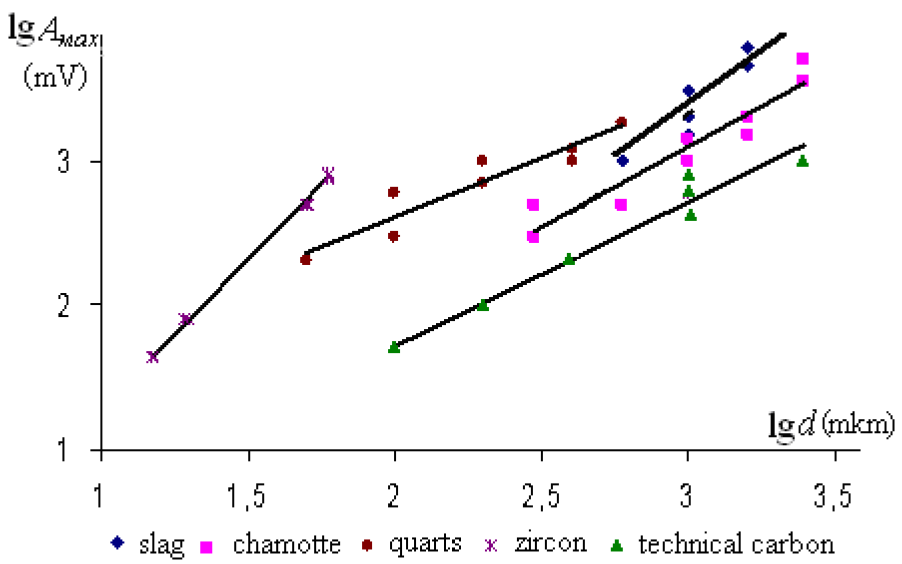

Fig. 1. Dependence of maximal amplitude on size *of* grinding product particles

On the basis of the designed graphs three-parametrical dependence of the maximal amplitude $A_{мах}$ (mV) from the ground product particle size d (mcr) and material density (g/sm^3) is established. From the table follows, that there is directly proportional dependence between the size of maximal amplitude and product particles, whereas between amplitude and density there is exponential one. Thus, knowing two sizes – the characteristic particle sizes d of the ground product and material density it is possible to predict acoustic signal amplitude $A_{мах}$ expected in a grinding zone according to established dependences with the shown correlation factor.

Dispersion effect was estimated on the basis of a signal share definition with small amplitude in the measured AS account. In conformity with the experimental data dependence of a small amplitude (less than 40 mV) acoustic signal share (%) in a grinding zone on product dispersion parameter S_{sp} (sm^2/g) is established [3, 4] at jet grinding of chamotte, slag and limestone in mill JGP-20. According to an estimation of product specific surface S_{sp} in a range of 1500 – 6800 sm^2/g there were observed of signal activity changes with amplitude A_{-40} in a range $6 \cdot 10^3 \le \dot{N}_{(A_{-40})} \le 2 \cdot 10^5$ imp/c, that had 88-99 % of total acoustic signal activity in grinding zone.

The purpose of this article is development and research of complex acoustic criteria of an ground product quality estimation on the basis of the material dispersion analysis during thin grinding. Further the analysis of the acoustic and technological grinding information about a number of loose firm materials in laboratory mill and also results of industrial acoustic monitoring approbation of zircon jet grinding in Volnogorsk Mining and Smelting Plant (VMSP) are made.

The contents of researches. Experimental researches are carried out on laboratory jet mill JGP-20 and industrial JGP-2000 (VMSP), which productivity were 20 kg/h and 2000 kg/h, accordingly. The laboratory mill productivity on a ready product at grinding quartz sand was G = 3-5 kg/h at compressed air pressure P = 0,3 MPa and rotation frequency of the qualifier rotor was n = 2000 min^{-1}. The industrial mill productivity at zircon concentrate grinding was 0,6-1,1 t/h at P = 0,5-0,6 MPa, n = 84-180 min^{-1}.

The distinctive features of the acoustic signal analysis strategy have been in the following. There were considered the AS in a grinding zone at the registration frequency of 400 kHz. For the chosen time interval (about 1-100 mc) maximal amplitude (A_{max}), total and particular acoustic radiation activity ($\dot{N}_{\sum}$, $\dot{N}_{A_{\max}}$) of a grinding zone were calculated. Thus in definition of signal maximal amplitude with share more than 1 % (more than 10 AS) was taken into account. At $\dot{N}_{\sum}$ estimation jet "noise" signals with amplitude about 1-2 mV were excluded. The share of signals with small amplitude (A_{-40} – A_{-10}) was defined.

Experience of jet grinding researches of materials with different initial size (unit and shares of mm) shows, that acoustic signals with larger amplitudes characterize the content in jet more coarse-grained fractions.

On fig. 2 there is shown connection of maximal amplitude with a dispersion parameter S_{sp} for various materials which initial sizes are less than 2-3 mm, density is in a range of 1,4-4,7 g/sm^3 ground in mill JGP-20. Amplitude spectrum at the jet unloading stage is analyzed as at this stage size A_{max} can characterize the particle sizes of circulating loading.

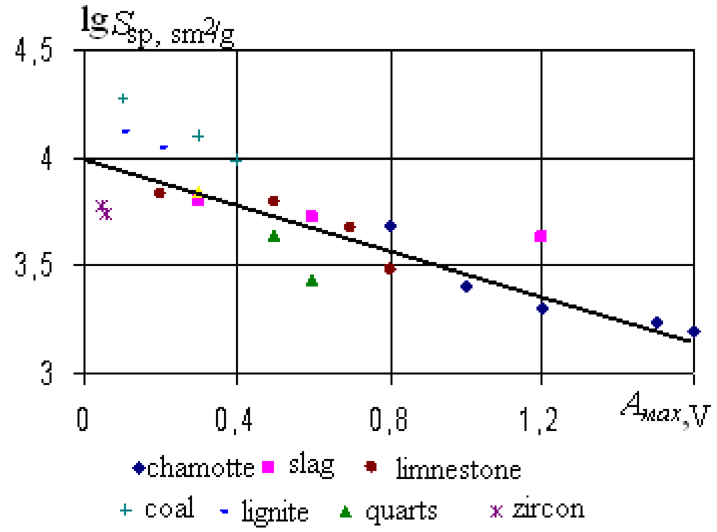

Fig. 2. Dependence of AS maximal amplitude at dispersion changes of ground particles (at jet unloading)

Dispersion of the jet grinding product, measured on specific surface size S_{sp} on device T-3 Tovarova, has shown the following results: chamotte – S_{sp} = (0, 17-0,28) m^2/g, limestone – S_{sp} = (0,3-0,68) m^2 /g; light coal – S_{sp} = (0,97-1,88) m^2/g, lignite – S_{sp} = (1,11-1,32) m^2/g, zircon – S_{sp} = (0,55-0,59) m^2/g.

Results of researches have shown, that accumulation process of acoustic signal with small amplitudes (about 5-20 mV) in spectra characterizes the primary maintenance of small sizes particles in jet, i.e. the prevailing of material dispersion effects in grinding kinetics. The connections of acoustic parameters with specific surface *Ssp.* of the ground products are established on the experimental data of jet mill JGP-20.

On fig. 3 acoustic signal distributions at the unloading stages of zircon grinding zone in laboratory (curves 1-3) and industrial VMSP (curves 4-6) mill are shown.

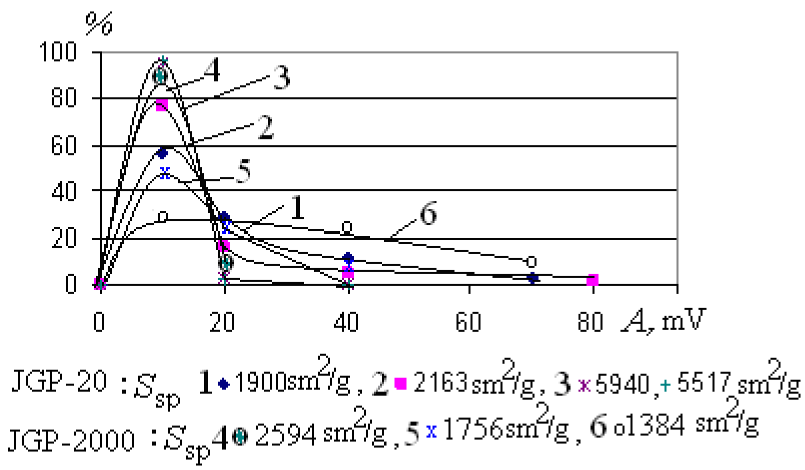

Fig. 3. Amplitude distribution of grinding zone acoustic signals for different dispersion of ground zircon

Comparative graphs specify that increase of powder dispersion is accompanied by growth of small amplitude signal share (less than 10-20 mV) in AS distributions. So, for grinding in JGP-20 growth of product dispersion from 1900 sm^2/g up to 5900 sm^2/g is accompanied by a share increase of signals with amplitude A =10-20 mV from 60 % to 98 %. In industrial grinding conditions this change range is for small amplitude signal share 28-85 % and for S_{sp} 1300-2600 accordingly.

On fig. 4 connections of dispersion S_{sp} with relative share of value A_{-40} and A_{-10} of small amplitude signals are shown.

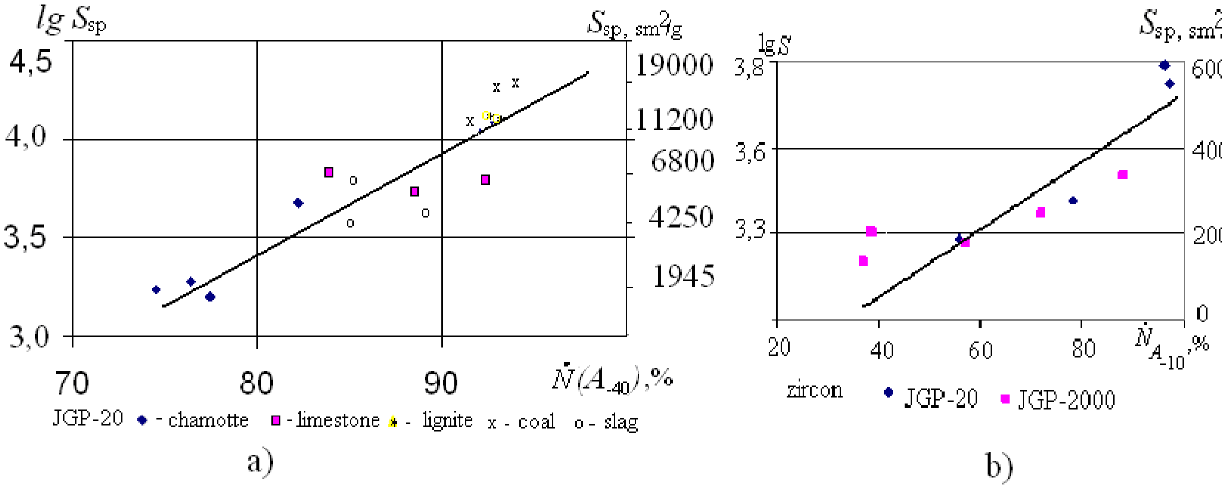

Fig. 4. Connections of product dispersion S_{sp} with relative share of value $\dot{N}_{A\_40}$ and $\dot{N}_{A\_10}$ of small amplitude signals of JGP-20 (a, b) and JGP-2000 (b) grinding zones

At density of 2,8-3,0 g/sm^3 connection of a dispersion parameter S_{sp} (sm^2/g) with acoustic parameter $\dot{N}_{A\_40}$ (%) of a share small amplitude signals in total acoustic activity of a grinding zone are described by the equation $\lg S_{sp} = 0.057 \cdot \dot{N}_{(A\_40)} - 1{,}12$ with correlation factor R = 0,87.

Results of the data analysis of a jet mill acoustic monitoring allow offering criterion of process optimality, as product of maximal amplitude A_{max} on total acoustic activity $\dot{N}_{\Sigma}$ of a grinding zone $K_{opt} = A_{\max} \cdot \dot{N}_{\Sigma}$ (V /c). Such form of this criterion characterizes acoustic effect of kinetic energy transformation of particle accelerated by jets into particle impact acoustic energy as in acoustic monitoring A_{max} and $\dot{N}_{\Sigma}$ are the proportional parameters to speed and number of fixed particle impacts at a wave guide, accepted by the gauge. Thus, the offered criterion value is proportional to "relative ration" (to number and force of impacts) of particle destruction in acts of jet grinding and can make an optimization basis of this process.

According to the above-stated results the next acoustic technological parameter complex can make a optimization basis of jet grinding mode and product quality:

– Criterion of grinding efficiency $K_{eff} = G / \dot{N}_{\Sigma}$, (g/imp);

– Criterion of dispersion efficiency $K_S = G \cdot S_{sp} / \dot{N}_{\sum} = K_{eff} \cdot S_{sp}$, (sm^2/imp);

– An acoustic parameter of grinding power consumption E_N^{gr} (imp/g) – inverse value of K_{eff};

– An acoustic parameter of dispersion power consumption E_N^{disp} (imp/sm^2) – inverse value of K_S.

Stability of high values of criteria K_{eff} and K_{opt} characterizes a condition of peak efficiency achievement of jet grinding process. The recommended level of acoustic criteria for an estimation of an industrial jet mill acting has got for grinding zircon to 45mkm ($S_{sp=}$2300-2600 sm^2/g), K_{eff} = (1-2,3) *10^{-3} g/imp, K_{opt} =*19-61* V/c; at grinding to 63mkm (S_{sp} =1500-2050 sm^2/g) K_{eff} =(2 – 4)*10^{-3} g/imp, K_{opt} = 32-139 V/c.

Application of acoustic monitoring for quality assurance of the ground product has shown the following results. The gauge was put in an output zone of gas suspension from the qualifier and registered signals which could make it possible to judge quality and quantity of the ready product loading to cyclone. During product quality assurance the interval of allowable change of acoustic activity of signals with maximum permissible values of amplitudes (no more than 2 мВ) is revealed: $A \geq A_{contr}$ = 2 mV.

In particular, for the ground zircon (-63 micron) in VMSP optimum quality (fig. 5c) is achieved at practically full absence of occurrence cases of the AS with amplitude above A_{contr} = 2 mV, allowable quality is observed at activity not above $\dot{N}_{contr}$ = 80c^{-1}, and inadmissible quality (fig. 5a) is in case of regular excess of signal activity with control amplitude more $\dot{N}_{contr}$ =100c^{-1}, or occurrences in the amplitudes spectra value which are equal to (5-10) A_{contr}.

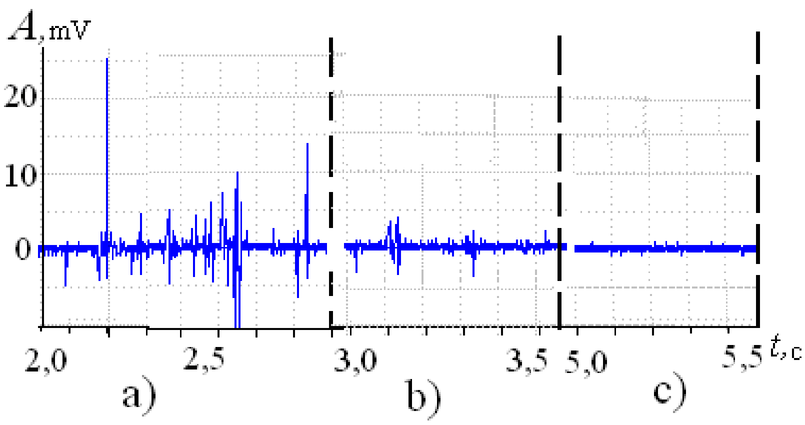

Fig. 5. Acoustic signals in case of quality changes of ground products:
a) inadmissible quality: $R_{63} > 3\%$;
b) allowable quality: R_{63} =1,5%;
c) optimal quality: R_{63} = 0-0,5%

As a result of acoustic research the block diagram of a jet grinding product quality control (fig. 6) which includes acoustic criteria definition for product dispersion optimization is offered.

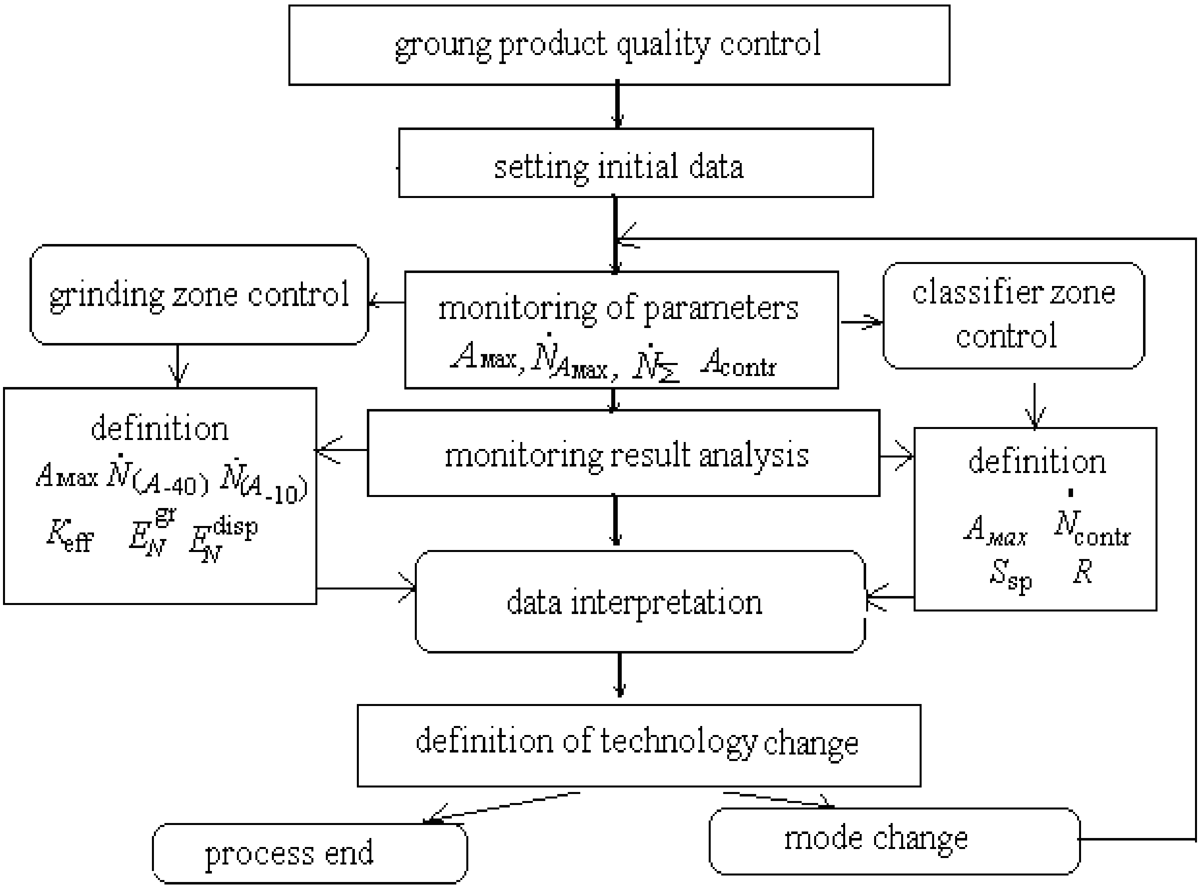

Fig. 6. Block diagram of monitoring and acoustic criteria definition
for dispersion optimization of jet grinding product

Preliminary according to the technical project necessary technological parameters (P, n, t) are established and initial allowable acoustic criteria of a jet mill acting are set from a database on the basis of the experimental data of a certain material grinding

During grinding monitoring spectra of acoustic activity and AS amplitudes are measured, the general number of signals and number of signals with small amplitudes ($\dot{N}_{(A\_40)}$, $\dot{N}_{(A\_10)}$) for the chosen intervals (t, c, mc) time, maximal amplitudes are determined. At operation presence of ready product weighing and the mill productivity control a values of the offered criteria and parameters are calculated: K_{opt}, K_{eff}, E_N^{gr}, E_N^{Disp}. On the comparison basis of criteria current sizes to their initial values it is judged a jet loading, process efficiency and power consumption, about ground product quality and about the further actions on technology regulation.

If the current criteria size chosen for the control of jet loading by material, is beyond allowable values, the signal either on a mill stop (ending of grinding), or on additional, next loading of an initial material portion (in case of experience continuation). At inadmissible change of the criteria which control product quality, the signal on change of a classification mode is set, and then updating of energy carrier parameters are changed (if it’s necessary).

Conclusions. Acoustic monitoring process of jet grinding in operating conditions of laboratory and industrial jet mills has allowed revealing the following laws of connections of the acoustic and technological parameters which control product dispersion and grinding efficiency.

– There is correlation, logarithmic linear, directly proportional connection of the maximal amplitude and the size of product particles with other things being equal: a kind and density of material, energy carrier parameters.

– The parameter of ground product dispersion S_{sp} is connected by logarithmic linear, inversely proportional dependence on characteristic (representative) value A_{max}. During the analysis of amplitude spectra at a stage of jet unloading this value can characterize the sizes of circulating loading particles.

– Product dispersion S_{sp} is related to an acoustic signals share with small amplitude (less than 40mV) in a working jet mill zone by a logarithmic linear directly proportional dependence at grinding chamotte, slag, quartz sand and coal. At zircon grinding similar connection of S_{sp} with signal share $\dot{N}_{(A_{-10})}$ of smaller amplitude (less than 10mV) is established.

– Peak efficiency of jet grinding process is realized under condition of achievement of stably high values of criteria K_{opt}, K_{eff}.

– A condition of achievement of optimum quality of the ground zircon (-0,063 mm) for industrial grinding in VMSP are exception of cases of acoustic signals occurrence with amplitude above some control size (2 mV) on gas suspension output from the qualifier.

The established acoustic laws form control system basis of jet mill work with use of the block diagram of monitoring and calculation of acoustic criteria for optimization of jet ground product dispersion offered in the article.

References

1. Акустические и технологические характеристики процесса измельчения в струйной мельнице / П.И. Пилов, Л.Ж. Горобец, В.Н Бовенко, Н.С. Прядко // Известия вузов. Горный журнал. – 2009. – № 4. – С. 115-121.

2. Закономерности акустического мониторинга струйного измельчения полезных ископаемых / П.И. Пилов, Л.Ж. Горобец, Н.С. Прядко и др. // Збагачення корисних копалин: Наук.-техн. зб. – 2011.– Вип. 44(84). – С. 25-32.

3. Горобец Л.Ж., Прядко Н.С. Акустические характеристики гранулометрических распределений частиц в процессе измельчения кварцевых песков // Автоматизація виробничих процесів у машинобудуванні та приладобудуванні. – 2011. – №45. – С. 336-340.

4. Горобец Л.Ж., Бовенко В.Н., Прядко Н.С. Акустический метод исследования процесса измельчения // Обогащение руд. – 2013.– № 3. – С. 18-24.

5. Пилов П.И., Прядко Н.С. Описание удельной поверхности продуктов измельчения на основе функции распределения дисперсности // Збагачення корисних копалин: Наук.-техн. зб. – 2013. – Вип. 53(94). – С. 57-64.

Надійшла до редколегії 03.09.2013 р.
Рекомендовано до публікації д.т.н. І.К. Младецьким