Adaptive control of ore pulp thinning in ball mills with the increase of their productivity

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Abstract
A method for adaptive control of the pulp thinning in a ball mill on the surface of the solid feed and boundary ratio of solid / liquid of the classifier sands, which allows to increase significantly the grinding efficiency is presented
Key words: ADAPTIVE CONTROL, PULP THINNING, SOLID SURFACE, MIXING, BALL MILL

Ukraine has one of the leading places in the world production of ferrous metals. The main raw materials are products of the ore beneficiation factories where about 50% of the total cost of the enterprise electricity and a considerable amount of steel balls and fettling is spent on the ore grinding.
Grinding results are strongly dependent on the solid/liquid ratio in the mill [1], which is not provided at the desired level [2]. In the modern process control system for the all mills the simplest approach is being used, which is designed for open cycle grinding, which does not satisfy the process requirements.

The leading industry experts indicate the need to implement the pulp thinning stabilization system in the ball mills to the technological process ACS [3]. In [4, 5] an approach for solving the problem of solid/liquid ratio stabilization in the mill is proposed. However, the issue of material averaging along the technological unit drum, which provides the efficiency of the balls remained unsolved. The possibility of this problem solving is proved in [6].

The purpose of this article is to provide the conditions for effective mixing of the material during pulp thinning in the mill and its productivity increasing by qualitative averaging of large and fine fractions.

The pulp density in the ball mill discharge related to the drum pulp density via its probability factor R_P [8], which is in the range of 0 ... 1. The theoretical value of R_P = 0 corresponds to a complete separation of the pulp solid and liquid phases as well R_P = 1 – to the ideal mixing. If the residence time of the solid corresponds to a residence time of the liquid in the drum, then the ball mill serves as the effective mixer [9]. A. Linch in [10] claims that grinding aggregate may be viewed as the aggregate consisting of a number of cross-sections, and each including the same amount of material. Then, the first section of the ball mill can be presented in accordance with [8]

$$R_{\Pi} = \frac{Q_{T1} \cdot T_{T1} + Q_{B1} \cdot T_{B1}}{(Q_{T1} + Q_{B1})T_{T1}}, \qquad (1)$$

where Q_{T1}, Q_{B1} – are the volumetric flow rate of the solid and water, which are fed in and out from the first portion of the ball mill drum, respectively; T_{T1}, T_{B1} – residence time of the solid phase and water in the first section of the drum, respectively.

The solid phase residence time in the drum first section and its length is determined by the speed of the pulp flow. The pulp liquid phase residence time in the drum first section can vary within wide limits. The water with a high flow rate is fed to a single point of the drum first section and is stored therein. Such water (not coupled with a solid) is easily passes by gravity to the neighboring drum section, thereby significantly reducing the liquid phase residence time in the first section. The value changes of R_P from the water residence time in the mill drum first section are given in Table 1 below.

Table 1. The values of R_P probability coefficient when changing the pulp liquid phase residence time in the mill drum first section

The value of the circulating load, %	The residence time of water in the drum mill first section, sec								
	72	108	144	180	216	252	288	324	360
50	0.674	0.715	0.756	0.796	0.837	0.878	0.919	0.960	1.0
100	0.700	0.738	0.775	0.812	0.850	0.888	0.925	0.962	1.0
150	0.716	0.751	0.787	0.822	0.870	0.893	0.928	0.964	1.0

The original ore can retain significant amounts of water at preliminary wetting. The classifier sands may also retain the significant amount of additional water during their limit value thinning. The remaining water should be fed into the mill central part by sprinkling. Such streams are effectively averaged by connecting on the mill inlet, since the liquid sands pass the wetted ore pieces easily as well the sprinkled water facilitates the process.

Thus, on the mill inlet the R_P directly takes the value close to unity and occurs specific material averaging, which can be improved by feeding of the additional balls at short intervals, for example, about 20 minutes after a certain ore amount processing.

The calculations show that for the processed 55,3 10^3 kg, 6 ore balls with a diameter of 90 mm, 8 balls with a diameter of 75 mm, 11 – of 65 mm and 19 – of 50 mm should be loaded into the mill [11]. These additional balls improve the pulp mixing, being in the first drum section (significant time in its inner region). Since balls segregation along the drum and its radius is slow, the additional grinding bodies are in the area of the first drum section length almost until the next loading of the same batch.

The effectiveness of the balls in the mill increases greatly immediately and is improved as far as material moving to discharge

At the same time, the mill productivity is significantly increases both by including 1/4 ... 1/3 of the drum length, and by the grinding improve on drum remain part and by the technological aggregate productivity increasing under the conditions of constant weight restoration of worn grinding media.

The material flows preparation adaptive control is advisable to carry out on the basis of developed means of solid / liquid ratio providing in a ball mill. It is made by the research outlined in the works about the automatic control stochastic system of the pulp thinning, increasing its accuracy [12], its dynamics [13] and the controlled variable identification block [14].

The control action at the inlet of the ball mill – water flow rate should be divided into three streams: to sands, to the loaded ore surface and directly into the mill with sprinkling in the central part. It is necessary to dilute the sands automatically until the possible boundary value of solid / liquid ratio in the function of their consumption.

The water should be supplied on the incoming ore in its surface consumption function. Research has established that the solid surface consumption in the ball mill is equal to

$$S_T(t) = \frac{6}{\delta_P gL} \cdot \frac{F(t) \cdot \upsilon(t)}{d_C}, \qquad (2)$$

where *F(t)* – is the linear load on the conveyor belt; *υ(t)* – is the ore velocity; d_C – is the average ore particle size in the bulk material flow; δ_P –is the ore density; *g* – is the free fall acceleration; *L* –is the conveyor scales base distance.

To implement (3) it is necessary to take into account *F(t)*, *υ(t)*, d_C. The indicators *F(t)* and *υ(t)* are measured during the ore flow rate determining. The average particle size should be measured. This could be done on the basis of research results which outlined in [15-18, 19].

Conclusions

Thus, this study shows that by the adaptive control of:

- the water flow rate to the ball mill in the ore surface function;
- the water flow rate in the boundary dilution function of the classifier sands and
- the residue water sprinkling to the technological unit central part under its flow rate, defined by the solid/liquid ratio system in it,

it is possible increase greatly the grinding efficiency, reduce the consumption of power, balls, fettling and useful product losses.

References

1. Malyarov P. *Osnovy intensifikatsii protsessov rudopodgotovki* [Bases of intensification ore benefication processes]. Rostov-on-Don: Rostizdat, 2004.
2. Morozov V., Topchayev V., Ulitenko K. *Razrabotka i primeneniye avtomatizirovannykh sistem upravleniya protsessami obogashcheniya poleznykh iskopayemykh* [Development and application of ACS of treatment process of mineral products]. Moscow, Ruda i metally, 2013.
3. Ivanov A., Kuvayev V., Kuvayev YA. (2010). Promising direction of automation and ore grinding and reduction process, *Mining Journal*, No 11 p.p.74-76.
4. Kondratets V. (2013). Obespecheniye identifikatsii sootnosheniya ruda/voda v melnitsakh s tsirkuliruyushchey nagruzkoy [Securing of identification of correlation ore/water in the mills with circulating load], *Vestnik IrGTU*, No11 p.p. 95-102.
5. Kondratets V., Serbul O. (2013). Obgruntuvannya sistemi kompyuternoi ídentifíkatsii ta regulyuvannya rozridzhennya pulpi u kulovikh mlinakh z tsirkulyuyuchim navantazhennyam [Grounding of computer systems identification and regulation of pulp dilution in the ball mils with circulating load], *Visnuk of Kryvyi Rih National Universuty*, No 34, p.p.45-50.
6. Kondratets V., Karchevska M. Modelyuvannya rozpodílu krupnogo tverdogo z metoyu identifikatsii zavantazhennya kulovikh mliniv, Proceedings of the International Scientific Conference [Intellectual systems for decision making and problems of computational intelligence (ISDMCI'2014)] Yevpatoriya, Ukraine, March 18-22, 2009, Vol 1, Kherson: KHNTU, 2009, p.p.68-70.
7. Kondratets V., Serbul O., Matsuy A. *Avtomatizatsiya protsesiv keruvannya rozridzhennyam pulpu pri podribnenni rudu barabannumu mlunamu* [Automatization of control process of pulp dilution during ore crushing by barrel mill], Kirovograd, KOD, 2013.
8. Prokofev E., Trop A., Arshynskyy V. (1968). Uproshchennaya model protsessa mokroho yzmelchenyya v melnytsakh napravlennoho deystvyya, Voprosy avtomatycheskoho upravlenyya protsessamy obohashchenyya [Simplified model of wet crushing process in the directed action mills. Questions of automatic control of concentration process], *works of Vakhrushev Sverdlovsk mining university*, No 52, p.p. 21-28.
9. Kellsall D. (1965). Study of breakage in a small countinuons opencircult wet ball mill. *Canad Mining J*, No10, p.p. 25-29.
10. Lynch A. *Mineral crushing and grinding circuits*. Amsterdam, Oxford, New York: Elsevier scientific publishing company, 1977
11. Kondratets V., Reva O., Karchevska M. (2008). Teoretychne doslidzhennya ustalenykh i perekhidnykh rezhymiv roboty kul ta futerivky v mlynakh. [Theoretical investigation of long-standing and transient conditions of balls

and mills lining, Technique in agricultural productivity, industrial engineering, automatization]. *Proceedings of Kryvyi Rih National University*, No 21, p.p. 187-196.

12. Kondratets V., Serbul O. (2010). Pidvyshchennya tochnosti stokhastychnoyi SAR rozridzhennya pulpy v mlyni z tsyrkulyuyuchym navantazhennyam filtruvannyam syhnaliv. [Accuracy increase of stochastic ACS of pulp dilution in the mill with cyclic load of signal filtration. Technique in agricultural productivity, industrial engineering, automatization]. *Proceedings of Kryvyi Rih National University* No 23, p.p. 78-84.
13. Kondratets V., Serbul O. (2010). Teoretychne doslidzhennya dynamiky SAR rozridzhennya pulpy v mlynakh z tsyrkulyuyuchym navantazhennyam, [Theoretical investigation of ACS dynamics of pulp dilution in the mill with cyclic load. Technique in agricultural productivity, industrial engineering, automatization]. *Proceedings of Kryvyi Rih National University.* No 24, p.p. 56-62.
14. Kondratets V., Serbul O. (2012). Rozrobka ta doslidzhennya bloka identyfikatsiyi rozridzhennya pul′py v mlyni z tsyrkulyuyuchym navantazhennyam, Tekhnika v silskohospodarskomu vyrobnytstvi, haluzeve mashynobuduvannya, avtomatyzatsiya [Development and investigation of identification block of pulp dilution in the mill with cyclic loads. Technique in agricultural productivity, industrial engineering, automatization]. *Proceedings of Kryvyi Rih National University*. No 25(2), p.p. 282-287.
15. Morkun V., Porkuyan O. (2007), Kontrol hranulometrycheskoho sostava zhelezorudnoy pulpy na baze kombynyrovannoho yspolzovanyya obemnykh UZV i voln Lyava, *Visnuk of Kryvyi Rih Technical Universuty*, No 17, p.p. 224-230.
16. Morkun V.S, Morkun N.V, Pikilnyak A.V. (2014). Ultrasonic phased array parameters determination for the gas bubble size distribution control formation in the iron ore flotation, *Metallurgical and Mining Industry*, No3, p.p. 28-31.
17. Morkun V.S, Morkun N.V, Pikilnyak A.V. (2014). The gas bubble size distribution control formation in the flotation process, *Metallurgical and Mining Industry*, No4, p.p. 42-45.
18. Morkun V.S, Morkun N.V, Pikilnyak A.V. (2014). Simulation of high-energy ultrasound propagation in heterogeneous medium using k-space method, *Metallurgical and Mining Industry*, No3, p.p. 23-27.
19. Morkun V., Morkun N., Pikilnyak A. The study of volume ultrasonic waves propagation in the gas-containing iron ore pulp, *Ultrasonics*, No 56C, (2015): 340-343.