Realisation of energy saving potential at mining enterprises on the basis of optimal intramill filling

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Abstract. The authors present the development of an automated system for controlling the loading of the output mill of pebbles and scrap of the beneficiation plant of JSC Lebedinsky GOK on the basis of measurement of bearing vibration signals. The object of our research is a universal ore-pebble ball mill (MSHRGU 4500x6000). The aim of the work is to develop, on the basis of the analysis of domestic and foreign experience, a mechanism for increasing productivity and minimising specific energy consumption of the ball mill by optimising the intramill filling. The proposed system will ensure the technological process of the mill in the modes of maximum loading with no overloading, which will increase the efficiency of production by reducing specific energy consumption.

1 Introduction

One of the most important areas for realising the energy saving potential in the country is the implementation of a targeted energy saving policy in the sphere of production and consumption of energy resources, including by improving the level of energy resources management.

The problem of energy saving is currently universal. In this regard, a wide range of theoretical and applied research is presented in the foreign literature, which examines various aspects of energy conservation management and energy efficiency improvement in modern conditions [1 - 8].

This problem is especially relevant for mining enterprises, which are the largest consumers of fuel and energy resources, some of which they receive from suppliers and some of which they produce at their own facilities The share of the energy component in the cost of production of mining and processing enterprises reaches 27-32%.

The processes of crushing and grinding of mineral raw materials are the most widespread and, moreover, energy-intensive technological processes, consuming about 20% of the total

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electricity generated in the country. In this regard, the problem of energy saving in rock crushing is becoming increasingly important.

Grinding is the process of gradually reducing the particle size of a material and is a typical technological process related to mechanical grinding. The feed material is fed into ball mills for grinding.

Practice shows that optimal intramill filling allows to extract maximum efficiency from the closed grinding cycle: high ore throughput, required ore size reduction, energy saving.

The ball mill section (universal ore-pebble ball mill – UOPBM-4500x6000) is a problematic place of production with low productivity and significant energy losses of the enrichment plant of JSC Lebedinsky Ore Enrichment Plant. In this regard, the problem of optimisation of the grinding process within the ninth technological section of the enterprise acquires an important practical significance.

The problem of minimising the energy consumption of ball mills has been covered in the works of Russian and foreign scientists. In particular, Vinogradov V.S., Golovkov B.Yu., Reibman L.A., Kolpikov G.G. consider in detail the design, technical features, operating modes of ball mills, causes of mill overloading, and also develop a methodological basis for the construction of monitoring and control systems for ball mills [9, 10].

K.Ya. Ulitenko proposed variants of using vibroacoustic analyser of mill loading (VAZM) for construction of control systems of volumetric filling of mills [11, 12]. The signal of volumetric filling of mills is formed on the basis of measurement and frequency analysis of three signals: vibration, noise, active power of the mill drive. VASM is used as an additional information criterion to control and prevent the onset of overloading of mills. The disadvantages of this approach are the complexity of setting up the device.

A group of foreign scientists developed a variant of using vibration sensors installed on the rotating body of the mill barrel, with the transmission of information from the sensors via wireless radio frequency modem [13]. This variant of the control system construction provides the use of the vibration signal in the frequency domain. The proposed approach is complicated by the need to use rechargeable batteries to power the vibration sensors, since there is no possibility of direct power connection to the sensors installed on the rotating barrel.

Among other works of foreign researchers, let us highlight the approach of developing an expert control system for the mill - hydrocyclone object using fuzzy logic [14] and an intelligent, neural network system for selecting the setting actions for the mill control system based on a fuzzy regulating device [15].

At the same time, the developments proposed in the papers [14-15] seem to us difficult to implement in production due to the complexity and multifactor nature of the developed systems, the lack of expert specialists in these areas at the enterprises.

The object of our research is the universal ore-pebble ball mill (UOPBM-4500x6000).

The aim of the work is to develop, on the basis of the analysis of domestic and foreign experience, a mechanism for increasing productivity and minimising specific energy consumption of ball mills by optimising intramill filling.

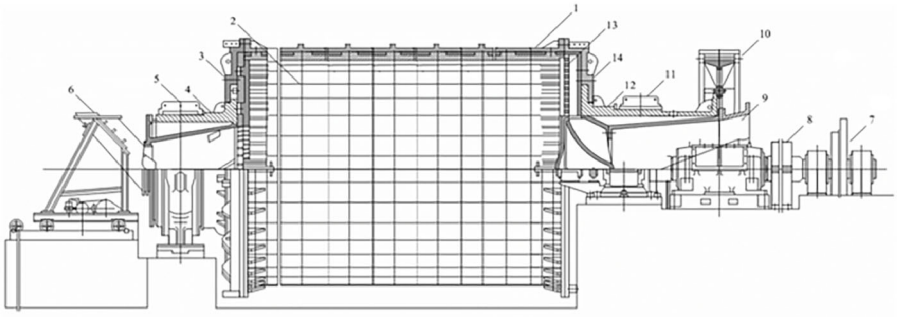
2 Materials and methods

Control of the intramill filling parameter is a complex task, since the grinding process is complex and multifactorial. Methods of system analysis, mathematical statistics, mathematical modelling of dynamic processes, decision-making theory, methods of modern theory of automatic control systems, numerical methods of optimization are used in the work. The methodological and theoretical basis of the work was formed by scientific works of domestic and foreign authors in the field of the theory of beneficiation (grinding of ore

materials), the theory of automatic control, the theory of identification of systems, optimal control, modelling of dynamic processes.

3 Results and discussion

Grinding of ore gall and scrap removed from enrichment shops №1 and №2 of the enrichment plant of JSC Lebedinsky Ore Enrichment Plant takes place in mills UOPBM-4500x6000. The technological process of grinding of gale and scrap is a single grinding in a mill without recycling, where hard-to-crush material (gale and scrap) is crushed with balls of 150 mm diameter to the required size distribution at the output. The capacity of the mill UOPBM-4500x6000 for input raw material is 150-250 tonnes per hour.



1 – drum; 2 - armour plates and lifters; 3 - front end cover; 4 - front journal; 5 - ront bearing; 6 – charger device; 7 - electric motor; 8 - toothed clutch; 9 - uncharger device; 10 - toothed ring; 11 - rear bearing; 12 -rear journal; 13 - grate; 14 - rear end cap

Fig. 1. Ball ore-pebble mill UOPBM - 4500x6000.

Ore-pebble ball mill UOPBM-4500x6000 is shown in Figure 1.

Ore-pebble ball mill UOPBM-4500x6000 is a single mechanical structure mounted on front and rear bearings 5 and 11, including the following elements: drum 1, front and rear end caps 3 and 14, front and rear trunnions 4 and 12.

The drum is rotated by the electric motor 7 through a toothed clutch 8, drive pinion and a toothed ring gear 10 mounted on the rear journal.

The mill drum is lined with lifters and armour plates 2. The armour plates of the drum lining are bolted. The end walls of the drum are lined with armour plates in two rows.

Lifts - lining elements for protection of the drum or feed (discharge) wall of the mill from mechanical impact of grinding bodies and grinding materials, positively influences the grinding performance. Lifts and armour plates are mated by inclined bevels.

In order to conduct technological mode with low pulp level in the mill, the mill design uses discharge grate 13 and discharge lifts for the purpose of forced unloading of the grinding unit. In the discharge zone of the mill drum, a discharge grate 13 is installed, with holes having a diameter of 20 mm, in a design version with increasing hole diameters towards discharge. The grate is bolted to the drum. The space between the discharge grate 13 and the rear end cover 14 is divided into sector chambers by lifters, with the possibility of discharging the crushed material into the rear trunnion 12 and further into the discharging device 9.

Loading of ore gall and scrap into the mill is carried out through the feeding device 6.

In order to intensify the feeding of slurry and scrap into the mill, a feeding spiral sleeve is installed in the front journal 4. To return the pulp from the mill seals, a special spiral device is installed in the rear trunnion 12.

Since ore slag and scrap, which are taken out of the beneficiation shops, are difficult to grind material with high specific weight, giving increased load on the unit, at the beneficiation plant of JSC "Lebedinsky Ore Enrichment Plant", at the ball mills UOPBM-4500x6000 are installed electric motors with increased power of 2500 kW [9, 10].

According to the technology of the ninth technological section, grinding is carried out in two ball mills UOPBM-4500x6000 (Figure 2).

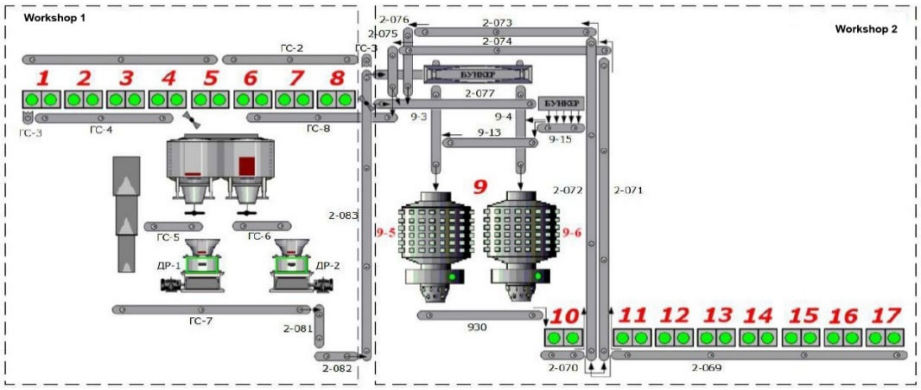


Fig. 2. Technological scheme of mills UOPBM-4500x6000 №9-5, №9-6.

The mills are fed from hoppers of hard-to-grind product. Feeding of raw materials to the mills UOPBM-4500x6000 №9-5 and №9-6 is performed by conveyor transport 9-15, 9-3, 9-13 and 9-4.

In the unloading of ball mills there are hoppers for withdrawal of scrap and spent balls from the process, which are sent for reworking by means of belt conveyors №930, 2-070, 2-077. Depending on the level of filling of hoppers with ore pebbles and scrap, one or two mills of the technological section can operate [9, 10].

The efficiency and energy efficiency of the ball mill depends on the mill control mode of grinding material feeding.

1. Low mill loading mode. In this mode the movement of grinding bodies (balls) and crushed ore mass in the mill drum has a cascade-waterfall (mixed) character. The underloading mode is inefficient: low productivity of the mill on iron ore concentrate of regulated size and high specific power consumption for grinding are observed.
2. Pre-loading mode of mill loading. In this mode, the movement of grinding bodies (balls) and crushed ore mass in the mill drum has exclusively waterfall character, i.e. this mode is characterised by the greatest trajectory of falling of grinding ball medium and crushed ore mass. Pre-loading mode is the most energy-efficient: the maximum-high productivity of the mill for iron ore concentrate of the regulated size is observed, because the energy spent on grinding is maximum and at the same time the specific power consumption for grinding is minimal.
3. Mill overloading mode. In this mode grinding bodies (balls) and the grinding ore mass under the action of friction and centrifugal forces adhere to the entire inner surface of the mill drum, i.e. the mode has a centrifugal character. The energy spent on grinding is minimal, the balls stop colliding with the ore medium to be ground, the mill productivity is minimal, even the slightest additional ore feeding into the mill leads to overfilling of the mill drum and emergency stop of the mill. Overloading of the mill is unacceptable, as it takes a lot of time to manually empty the mill drum (a very labour-intensive process), there is a high risk of breakage of

expensive mill equipment, there may be long emergency downtime for repair of the grinding unit.

The purpose of energy-efficient ball mill control is: to conduct the technological process in the pre-loading state, as in this mode the maximum productivity of the mill on iron ore concentrate of the regulated size is provided, specific power consumption is minimised.

Maintaining the optimal pre-loading mode of the mill (40-45% of full filling) is a complex and urgent task, its solution is complicated by the following factors:

- the ball mill is subject to external, constantly changing disturbing factors (variability of material size and grindability at the inlet, wear of the lining armour, amount of changing ball load);
- the value of the in-mill filling of the mill can only be estimated by indirect methods, there is no possibility of direct measurement;
- the quality of the technological process depends on the experience of the process operator and the experience of the process engineer.

The experience of domestic concentrators shows that successful implementation of existing solutions has a one-time (individual) character with no possibility to create a template solution for replication to other (any) mills without long-term adjustment and testing on a particular technology.

Vibro-acoustic analyser of mill loading VAZM is the most widespread existing solution for assessment of overloading states of ball mills [11, 12]. But in the practice of domestic enterprises is not widespread use of information about the degree of mill loading from the analyser VAZM for the implementation of automatic subsystems of mill loading control in view of the complexity of setting the device.

The signal of vibration amplitudes of ball mill bearing units directly correlates with the value of the mill loading level with material (in this case, ore pebbles and scrap), therefore, for ball mills, the method of measuring mill loading on the basis of measuring the vibration of mill bearings is a key way to increase the productivity of grinding units, reducing the specific energy consumption per processing [13, 16, 17].

A piezoelectric sensor is chosen as a vibration measurement device, which is mounted on the mill bearing unit housing vertically on a stud.

The criterion of indirect estimation of the value of intramill loading of the mill will be the output signal of vibration acceleration of the piezoelectric accelerometer.

The values of intensity of vibration amplitudes of the ball mill bearing units and the value of the ball mill loading level with ore pebbles and scrap are inversely proportional to the values.

Depending on the level of loading of the ball mill with ore pebbles and scrap, as well as grinding medium (balls), the amplitudes of vibration vibrations in bearings change, i.e. as the level of loading of the mill with grinding medium (ore pebbles and scrap) increases, the signals of vibration amplitudes of bearings will decrease, respectively, as the level of loading of the mill decreases, the amplitudes of vibrations in bearings will increase.

Experimental studies in the development and debugging of the system of automatic control of vibration of the bearings of mills UOPBM-4500x6000 in the conditions of the ninth technological section of the enrichment plant of JSC "Lebedinsky Ore Enrichment Plant" allowed to identify and evaluate a fairly accurate inversely proportional regularity between the transient characteristics of the amplitudes of vibration oscillations in the bearings of the mill and the level of intramill mill filling of the grinding material.

As a measuring device of the system of automatic control of vibration of mill bearings the vibration converter 645B01 - PCB Piezotronics (measuring range of vibration acceleration: 0,0-49 m/s^2; frequency range: 3-5000 Hz; output signal 4-20mA) is chosen.

In this paper we have carried out research to determine the most informative range of vibration acceleration value from the vibration transducer sensor at different operating modes of the ball mill:

The analysis of spectral characteristics of vibration acceleration signals from sensors allowed to reveal that:

- the most informative signal from the vibration transducer is concentrated in the frequency range of 1500-3000 Hz
- the amplitude of the vibration acceleration signal on the bearing on the loading side of the mill is twice as high as on the bearing on the unloading side. Accordingly, on the front bearing the sensitivity of the signal to changes in the mill filling is twice as high.

Analysis of transient characteristics of vibration accelerations from the vibration transducer showed:

- the highest amplitude of the vibration acceleration signal from the sensor corresponds to the mode when the mill is empty (ore gale and scrap are completely absent), as the trajectories of falls and the force of impacts on the lining of balls in the mill will be maximum;
- the amplitude of the vibration acceleration signal from the sensor decreases when the mill is filled with grinding media (ore gale and scrap).

Accordingly, in order to conduct the technological process of the mill in the most efficient mode (maximum productivity, minimum specific power consumption), it is necessary to automate the process of mill loading in order to maintain the level of the vibration acceleration signal from the vibration transducer within the experimentally set limits.

The structure of the developed automated process control system (APCS) of ball mill UOPBM -4500x6000 for effective process control and automatic overload protection is shown in Figure 3.

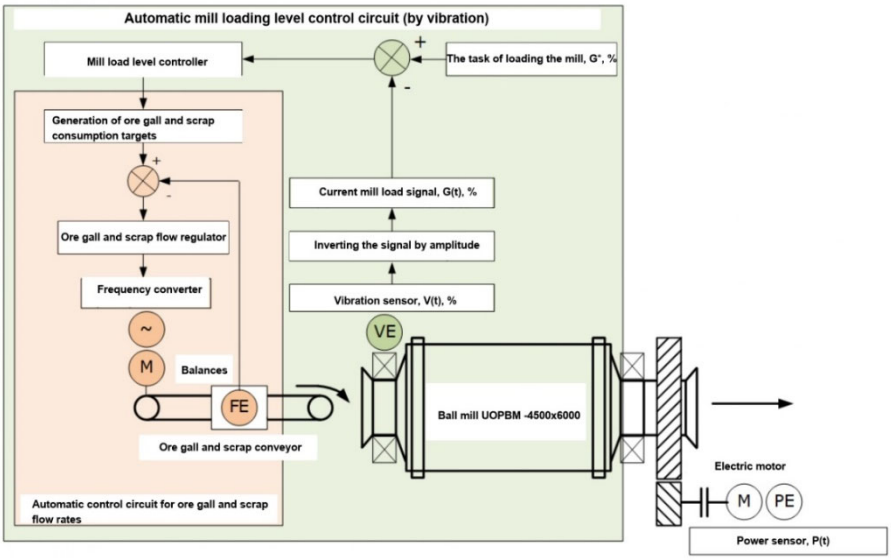


Fig. 3. Structure of the automated process control system of the ball mill UOPBM -4500x6000 (VE - vibration sensor; FE - flow sensor; PE - power sensor; M - electric motor; ~ - frequency converter).

The criterion for determining the preload state of the ball mill using the vibration acceleration signal from the vibration transducer from the front bearing of the mill is formalised.

In order to obtain the transient characteristic of the change in the dynamics of the mill loading level G(t), %, we use the inversion of the front bearing vibration signal V(t), % in amplitude, since the vibration signal of the front bearing and the mill loading level are inversely proportional values.

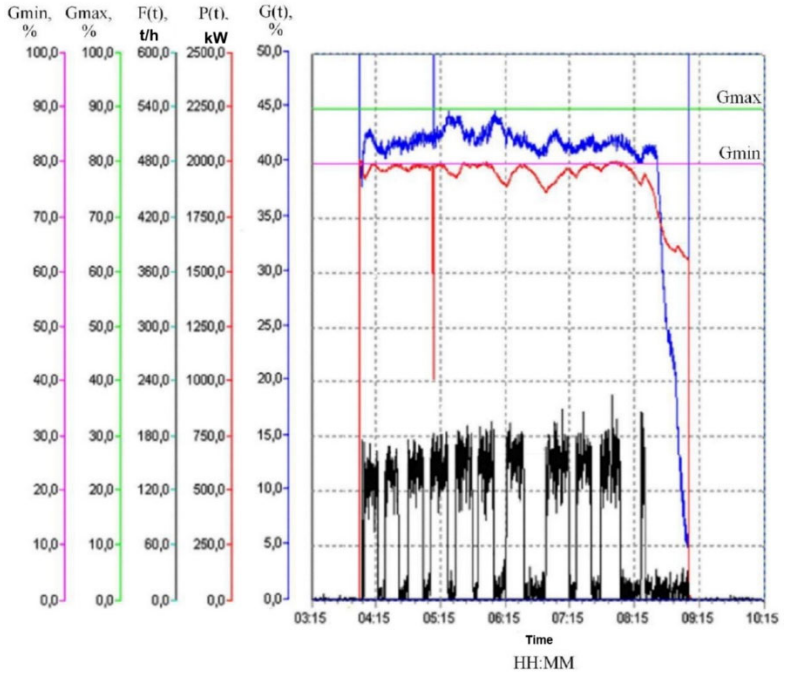


Fig. 4. Dynamics of transient characteristics of signals of ball mill UOPBM -4500x6000 in pre-overload mode: mill load level G(t), % by vibration; active power of the mill motor P(t), kW; instantaneous flow rate of pebbles and scrap into the mill (conveyor scales on conveyors 9-3, 9-4) F(t), t/hour; lower limit of effective mill operation Gmin, %; upper limit of effective mill operation Gmax, % (criterion of mill overload protection).

Using information on the dynamics of the mill loading level G(t) by vibration, the range of the most energy-efficient mill operation (vibration amplitude 20-10% corresponds to the real volume filling of the mill 40-45%) was experimentally found, the limit on the maximum mill loading level G(t) was found (vibration amplitude 10% corresponds to the maximum permissible real volume filling of the mill 45%), when exceeding which the ball mill enters into overload (Figure 4).

The maximum value of the mill loading signal G(t) by volume is 45% (in terms of time tentatively at 5:30 and 6:00) and corresponds to the maximum permissible value of the mill loading level, as shown in Figure 4.

4 Conclusion

Ferrous metal production occupies an important place in the country's economy. Extraction and primary processing of ferruginous ores is carried out at mining and processing plants and is one of the important steps in obtaining high-quality products in metallurgical production.

Energy-intensive power plants, the most powerful of which are mills, are widely used in beneficiation production.

The authors have carried out research on studying the technology of ore gall and scrap grinding in mills UOPBM-4500x6000, which has a number of specific features, as the ground material has increased hardness and heterogeneous granular composition. The operating modes of the mill UOPBM-4500x6000 have been analysed: low loading mode, pre-overloading mode, overloading mode. Experimentally (multiple stops of the mill under load, visual control of the mill drum filling, routine ball load) it was determined that the optimum pre-loading mode, specifically for mills of hali and scrap UOPBM-4500x6000 is achieved at intramill filling by the volume of the drum 40-45%.

The authors proposed a reasonable choice of the type of vibration sensor and their installation locations; the selection of working amplitude and frequency ranges of signals was made; calibration of the vibration signal scale for correct display of the mill loading signal by volume was carried out.

The developed system of control of intramill filling using vibration in the bearings of the mill UOPBM-4500x6000 possesses scientific novelty, because:

- the system is significantly less expensive and easy to set up, being an alternative to the existing on the market loading analyser VAZM;
- automatic control of the mill loading of the mill UOPBM-4500x6000 in real time mode was realised according to the parameter of intramill filling with the use of vibration in the mill bearings;
- this automated process control system (APCS) of the ball mill UOPBM-4500x6000 does not require installation of new software and expensive equipment and can be realised by the capabilities of the existing automation system.

The use of the method of mill overload protection using vibration signals in bearings allows minimising the risks of overloading and long emergency downtime of the ball mill UOPBM-4500x6000.

Implementation of the developed automated control system of loading of the mill for the output of pebbles and scrap of the enrichment plant of JSC Lebedinsky Ore Enrichment Plant will allow to ensure efficient output of pebbles and scrap, increase production efficiency by reducing specific energy consumption.

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