Model of HPGR-based Comminution Circuit Performance

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Summary

Article concerns the issues of modeling and optimizational approach for ore comminution circuits performance. The circuit under the analysis is based on HPGR devices operating on a fine crushing stage. In order to determine the HPGR-based comminution circuit performance a suitable model was built. The target function in presented model considers the issue in terms of the flotation operation effectiveness.

Keywords: comminution, optimization, high-pressure grinding rolls

Introduction

Mining practice shows that together with progressive ore exploitation the run-of-mine material with lower grade of a useful mineral is extracted nowadays. Industrial operations of the feed material size reduction are the most energy-consuming processes in ore processing technological circuit and amount from 30 to 45% of total costs in mining industry (Tromans 2008). In order to limit the energy-consumption of comminution operations, it aims at reducing the grinding operations in favor of intensifying the fine crushing stage. To achieve that, modern crushing devices, increasing the size reduction ratio at lower energy consumption and high capacity, are being applied. Considering the above, issues concerning the modeling of work of HPGR-based comminution circuits are significant in terms of optimization the entire technological circuit operation (Saramak et. al 2010).

It is essential that the modernization in mineral processing should cover not only the selected operations, but the entire technological circuit, and modernization of individual processing operation should be supplemented through adjusting the circuit's performance to the new conditions. The circuit's upgrade should be also applied in the places, which may give potentially the highest improvement of its effectiveness performance.

The stage of ore mechanical enrichment (crushing and grinding operations) is the one of a major importance in terms of achieving potential energetic benefits. It especially applies to the situation where older crushing devices are replaced by new ones, more technologically advanced (i.e. HPGR, vertical mills). Optimizational approach to HPGR-based circuits performance should start from the analysis of potential benefits from application of the high-pressure roller press into a specific technological circuit. A key role here plays the type of feed material and required quality of the final product (concentrate). For a specific ore type two basic properties determine its size reduction effectiveness: a particle size distribution and moisture content (Saramak 2011, Fuerstenau and Abouzeid 2007).

Operation model of HPGR-based crushing circuit

Kolmogorow (1941) and Epstein (1948), proved that for a multi-stage comminution process, the particle size distributions of crushing products can be well described with using a log-normal distribution function:

$$\Phi(d) = 1 - \exp\left[-c\left(\frac{d}{d_{\max} - d} \right)^n \right], \quad 0 \le d \le d_{\max} \qquad (1)$$

where:

d – particle size;

c, n, d_{max} – parameters determined on the basis of the empirical data (d_{max} – maximum particle size in crushing product);

$\Phi(d)$ – cumulative particle size distribution curve.

The above formula is also usually true for high-pressure comminution process in HPGR. A key operating parameter of HPGR is the pressure, which, in turn, can be tied with the quality of comminution products. The influence of the pressure (P) on the crushing product size reduction ratio (d) can be determined with using of an exponential function:

$$d = AP^B, \quad B < 1 \qquad (2)$$

where:

A and B – coefficients.

It also appears that the course of *n*, *c* and d_{max} parameters can be described as functional relationships of pressure P. A selection of respective pressure level in press results in particular values of *n*, *c* and d_{max} which, in turn, give us the information about the particle size distribution of crushing products (Saramak 2013):

$$n = A_1 \cdot P^{A_2} \tag{3}$$

$$d_{max} = A_3 \cdot P^{A_4} \tag{4}$$

$$c = A_5 \cdot P^3 + A_6 \cdot P^2 + A_7 \cdot P + A_8 \tag{5}$$

where:

A_1 to A_8 – coefficients.

Combining equations (1) to (5) together it is possible to make HPGR crushing product's particle size distribution of the operating pressure value (equation 6).

It is rather recommended to build a model based on the function of crushing product particle size distribution, than to use the size reduction ratio in qualitative description of comminution products. In such a model (6) it is possible to control the basic technical parameter of the press in order to obtain a specific quality of crushing product and, as a result, to determine the operational conditions of downstream beneficiation processes.

Flotation is considered as a base beneficiation process for many sulphide ores of base metals. The material particle size is one of a key feature influencing the effects of flotation, and it can be different for various types of ore. In general, particles below and above of a some value causes a significant decrease in flotation effectiveness (Brożek and Mlynarczykowska 2010). Therefore the enrichment process of sulphide copper ores should be so designed in order to maximize the weight recovery of the certain particle size fraction. Considering Polish conditions of copper processing, the most favourable feed for flotation operation in terms of particle size is between 0.02 to 0.07mm, while the content of particle fractions finer than 0.02mm should be minimized (Trahar, 1981).

The final product of comminution circuit is, in general, a composition of three particle size fractions: particles below a minimum size which generally constitute the waste, particles between some minimum and maximum size, constituting the optimal feed for flotation operations, and finally fraction over the maximum size, which is recycled to the circuit. Particles within the size range from minimum to maximum have the most favourable flotation abilities so technological process should be run in a way enabling the highest yield of these particles in the flotation feed. Considering the above the technological model (i.e. aiming at maximization of the useful component recovery) for ore comminution circuit optimization assumes the following form of target equation 7.

Searching the model solution

In order to solve the model presented in equation (7) following steps should be done:

a. It is necessary to determine the relationship between the value of operating pressure in HPGR and particle size distribution of HPGR product. Up to date investigations show that the relationship will have an exponential form (2), but the coefficients values changes for various types of feed material;
b. There should be also determined the specific values of minimum (min) and maximum (max)

$$\Phi(d) = f(P) = 1 - \exp\left[-\left(A_5 \cdot P^3 + A_6 \cdot P^2 + A_7 \cdot P + A_8\right)\left(\frac{d}{\left(A_3 \cdot P^{A_4}\right) - d}\right)^{\left(A_1 \cdot P^{A_2}\right)} \right] \tag{6}$$

$$M = \max\left\{ \begin{array}{l} \gamma_{\min-\max\_i} \cdot \beta_{\min-\max\_i} \cdot Q_i + (1-w)\cdot\left[1-\left(\gamma_{\min-\max\_i} + \gamma_{0-\min\_i}\right)\right]\cdot \mu_{>\max\_i} \cdot Q + \\ -\gamma_{0-\min\_i} \cdot \vartheta_{0-\min\_i} \cdot Q_i - w \cdot \left[1-\left(\gamma_{\min-\max\_i} + \gamma_{0-\min\_i}\right)\right]\cdot \mu_{>\max\_i} \cdot Q \end{array} \right\} \tag{7}$$

where:

i – number of technological operation

$\beta_{min-max}$ – useful mineral grade in the product particle size within the range (minimum – maximum),

ϑ_{0-min} – useful mineral grade in the product particle size within the range (0 to minimum),

$\mu_{>max}$ – useful mineral grade in the product particle size above maximum,

$w = \dfrac{\gamma_{0-\min}}{\gamma_{0-\min} + \gamma_{\min-\max}}$ – a proportion in which the particle size coarser than maximum is divided between classes below minimum and within the range minimum-maximum in size reduction operations.

particle sizes, which constitute the most favourable flotation feed for given type of material;
c. The values determined in point a) and b) are the input data for calculation the yields of specific particle size classes.

As a result of the above procedure not only the weight recoveries of flotation concentrate can be determined, but also the yield of tails and the volumes of material stream recycled to crushing operations.

Apart from the comminution degree, the main benefit resulting from HPGR applications into industrial processing circuits are the energy savings. Plant practice shows that industrial application of HPGR resulting in lower energy consumption ranging between 15 to 25 percent (Morley 2003). This results in decreasing the grindability of HPGR product measured by Bond's index and, as a result, lowering the energy consumption of grinding stage. Additionally a part of finest HPGR product can be directed to flotation operations, bypassing the grinding stage (Fig.1).

It is possible to calculate the energy consumption for such a circuit, but it needs to be pointed out that both HPGR and Ball Mill operate in closed circuit (equation 8).

The model (12) considers only the energy savings, but some additional gains can be obtained through the lower consumption of grinding media, due to the withdrawing of mills from the circuit (total number of ball mills can be reduced due to the lower capacity ($Q – Q_1$) of the grinding stage).

Summary and conclusions

The effect of the circuit modernization through the application of HPGR press presented the above doesn't take into account any technical issues connected with circuit modification which makes possible a suitable separation of the Q_1 mass stream. Rebuilding the circuit will also require taking into consideration additional streams of the material, (i.e. the HPGR recycle stream), what results in increasing

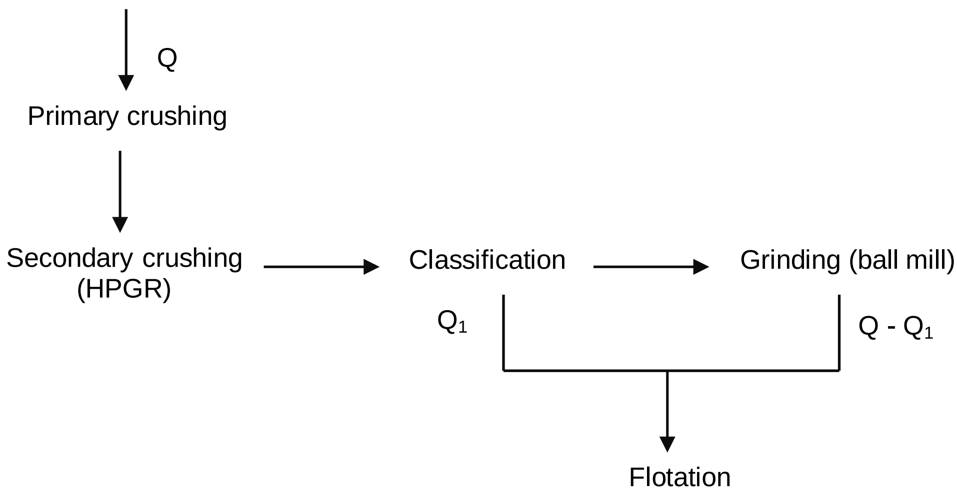

Fig. 1. Scheme of material flow in HPGR-based comminution circuit:
Q – circuit's capacity, Q_1 – material stream directed to flotation with bypassing the grinding stage

Rys. 1. Schemat przepływy materiału w rozdrabniania z HPGR:
Q – wydajność układu, Q_1 – materiał kierowany do flotacji z ominięciem mielenia

$$P(kWh) = E_{SP\_prim\_crush} \cdot Q + \cdot E_{SP\_HPGR} \cdot (Q + Q_{HPGR}) + E_{SP\_BM} \cdot (Q - Q_1) \quad (8)$$

where:

Q – circuit's capacity
$E_{SP\_prim\_crush}$ – unit energy-consumption for primary crushing stage
E_{SP_BM} – ball mill unit energy-consumption
E_{SP_HPGR} – HPGR unit energy-consumption
Q_{HPGR} – HPGR recycle material stream
Q_{BM} – ball mill recycle material stream
Q_1 – material stream bypassing the grinding stage

the energy-consumption of the circuit. The increase, however, will be rather of insignificant importance comparing to the energy savings achieved after the new crushing device application.

A solution of the target function (7) can be obtained utilizing the mathematical programming theory, due to the model nonlinearity. The obtained results allow for determination the values of HPGR technical parameters, which maximize either the profit or concentrate grade at presence of the model limitations, depending on the defined problem.

Based on the results of investigations presented in the paper one can say that it is possible to build a simulation model of ore processing plant operation, relying on technical parameters of comminution devices (Tumidajski 2012). The parameters, in turn, can be combined with the comminution process effects through the parameters in approximation functions of theoretical particle size distributions.

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Model pracy układu rozdrabniania z prasą walcową

Artykuł dotyczy zagadnień związanych z modelowaniem i optymalizacją pracy układów rozdrabniania rud. W analizowanym układzie występuje wysokociśnieniowa prasa walcowa zainstalowana na drugim stopniu rozdrabniania. Aby określić efektywność pracy układu technologicznego przeróbki rud został zbudowany odpowiedni model matematyczny pracy układu rozdrabniania, w którym funkcja celu została powiązana z efektywnością procesów flotacyjnych.

Słowa kluczowe: rozdrabnianie, optymalizacja, wysokociśnieniowe prasy walcowe