WEAR OF THE CYLINDER LININGS OF DRUM SAG MILL

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ABSTRACT. A basic technical parameter of drum mills is the volume of the drum. This parameter changes during operation due to the intensive wear of the mill linings. On the one hand, with the increase of the volume, the productivity of the machine increases too, but on the other this also leads to a change in the speed regime, which affects the grinding quality. The semi-autogenous mills mostly use a cascade and a mixed speed mode motions which depend mainly on the diameter of the drum and the height of the lifters of the cylinder lining. In the present paper an attempt has been made to determine the wear of the lifters of a semi-autogenous mill grinding gold-copper ores with high abrasion and solidity. For this purpose the wear of the mill was periodically measured for several years with a laser scanner, the wear of several cylinder linings of the mill drum was also monitored, while recording the quantity of processed ore and the time of new linings mounting to reach this wear. The necessary number of statistic data has been collected and processed, which, after using the respective computer programmes, presents the quantity of the outworn material from the linings as a function of the grinding time and the quantity of processed ore. For this purpose adequate mathematical models have been obtained, describing the relation between the worn-out steel quantity of the mill linings and the amount of processed ore and the time to achieve to this wear. The results are presented in a graphic manner and the relevant conclusions are made.

Keywords: mill, semi-autogenous, lining, reliability, failure

ИЗНОСВАНЕ НА ОБЛИЦОВКИТЕ НА ЦИЛИНДЪРА НА ПОЛУАВТОГЕННА БАРАБАННА МЕЛНИЦА

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РЕЗЮМЕ. Основен технически показател на барабанните мелници е обемът на барабана. Този параметър се променя по време на експлоатация поради интензивното износване на облицовките на мелницата. От една страна при увеличаване на обема се повишава и производителността на машината но това води и до промяна на скоростния режим който влияе на качеството на смилане. Полуавтогенните мелници използват най често каскаден и смесен скоростен режим които зависят основно от диаметърът на барабана и от височината на лифтерите на облицовката на цилиндъра. В настоящата разработка е направен опит да бъде определено износването на лифтерите на барабанна полуавтогенна мелница смилаща медно златни руди с висока абразивност и здравина. За целта износването на облицовките на мелницата са измервани периодично посредством лазерен скенер в продължение на няколко години, като е проследявано износването на няколко облицовки на цилиндъра на барабана на мелницата и едновременно с това е записвано количеството преработена руда, и времето на поставяне на нова облицовка до достигане на това износване. Събрани са и са обработени необходимия брой статистически данни, които след използване на съответните компютърни програми дават престава за количеството износен от облицовките материал във функция от времето за работа на мелница и количеството преработена руда. За целта са получени адекватни математически модели описващи връзката между износеното количество стомана от облицовките на мелницата и количеството преработена руда и времето за достигане на това износване. Резултатите са показани и графично и са направени съответните изводи.

Ключови думи: мелница, полуавтогенна, облицовка, надеждност, отказ

Introduction

Causes and consequences from the wearing of the lining lifters of a drum mill type SAG 8.5x5.3.

The sliding intensity of the crushing media onto the surface of the drum linings depends mainly on the lining profile and the coefficient of friction between the crushing media and the linings.

It has been proven that the wear of the drum mills linings is greater in mills with high sliding intensity and specific normal contact pressures between the crushing mass and the lining of the drum. It is known that the amount of the grinded by friction product is proportional to the contact area of the friction surfaces. The calculations show that the surface of friction with the balls is only about 2% of the total surface of the balls inside. This allows to claim that the amount of material erased as a result of friction between the grinding bodies and the drum lining is, for example, 2% of the total amount of the grinded product. Thus, it may be concluded that the impact of the linings on the quantitative side of the crushing process because of the friction of grinded mass is negligible. At the same time, the friction significantly increases the wear of the drum linings. As the productivity of the mill for a finished product is proportional to the used useful power, the friction reduction will increase proportionally the mill productivity and the specific energy consumption and lining will be decreased.

If the grinding mass moves without a friction and the speed of the grinding particles, that move on a circle trajectory, is equal to RPMs of the drum $\left(\omega_m = \omega_б\right)$, the power of the drum shaft will be:

$$P_б = M_б . \omega_m , kW \quad (1)$$

where:

$M_б , N/m$ - torque of the drum.

In the case of movement of the grinding bodies with slippage in order to preserve the initial filling mode, it is necessary to increase the rotation speed of the drum with a value determined by the slippage.

The power of the drum shaft in this case will change and will be defined as:

$$P_б^{'} = M_б . \omega_б , kW \quad (2)$$

The power, that is lost at the slippage of the ball mass, is:

$$P_з = P_б^{'} - P_б = Mб.(\omega_б - \omega_m), kW \quad (3)$$

The power loss at a slippage could be given as:

$$Pз = P_{mp} + P_u , kW \quad (4)$$

where:

P_{Tp} - power loss by the rupture of the lining by friction, kW ;

P_u - useful power used to crush material through abrasion in the lining, kW .

The ratio of the values in the above given equation will vary depending on the contact area of the grinding load with the linings of the mill and the resulting pressures at the contact points.

The investigated drum semi-autogenous mill grinds material of high abrasion, hardness and solidity and operates in a mixed speed mode characterised by high slippage intensity of the material on the drum mill linings. Despite the fact that the machine goes out of its operational capacity, with the wear of the drum linings the technological parameters of the machine are gradually changing (Parashkevova, D., Lyubenov, K., 2011). Some of them, such as productivity, are improved due to the increase in drum volume while others, as the yield of the estimated class, are worsened by the change in speed mode and the reduced coefficient of balls fill and large fractions of ore. In addition, the energy consumption and the cost of the final product are increased (Hristova, T., 2018).

The main question that may be posed in this study is whether it is possible to find a relation between the run off of the drum mill linings and the wear rate of the lifters, when measuring and monitoring the wearing of the drum mill linings and using mathematical statistics methods.

This can be used for the proper control of the machine technological parameters with the continuous increase of the drum volume due to the continuous wear of the drum lifters.

Summary

The aim of the present research is to study the patterns of changing the lifters volume of a semi-autogenous drum mill and to obtain an adequate mathematical model, describing the relation of their wear to the mileage of the lining, which can be obtained by means of different programme packages such as MatLab, MuPAD, MathCAD and others (Ivanov. A. 2019). These programmes will serve to create methods and means for predicting the rate of wear under operational conditions.

Investigation on the wear of SAG mill lifters

In order to carry out an investigation of the lifters wear in the lining mileage, it is necessary to choose a method and mode for its measurement.

Due to the complexity of the configuration of the mill linings and the large diameter (Figure 1), it is estimated that the wear of the linings will be monitored and measured using a laser scanner of type “FARO Laser Scanner Focus3DX130” with the following principle of operation and basic parameters:

1. The scanner uses a laser light that is reflected back in the scanner by the object. The distance to 130 m is measured with an accuracy of millimetres through the phase difference between the transmitted and the received light.

2. Vertical scan angle. The mirror deflects the laser light in a vertical direction toward the same object. The maximum angle is up to 270˚ and relies directly to the distance measurement.

3. Horizontal angle. The laser scanner rotates at 360˚ horizontally. The horizontal angle is coded along with the distance measurement.

4. The maximum error in the scanning at 130m is 5mm, as it decreases proportionally for objects nearby.

5. Maximum scanning time for an object - up to 30 minutes.

The scanning takes place under very severe conditions - high temperatures and humidity in the mill drum, because the mill ceases its operation for a short period of time as this is not sufficient for its cooling.

The laser scanner is placed inside the drum on a tripod (Figure 2).

As a result of the scan a cloud of points is obtained (at about 10,000,000 in number) with recorded coordinates, which is a basis for creating a computer model (Figure 3), describing the inside surface of the linings at the exact time of the measurement.

Then, using the software of the scanner, a lining for which the wear of the lifters to be monitored once or twice a month is cropped out.

The results of each scan are overlaid on previous scans for each lining. Finally, cuts in predetermined places are made, to show the wear of the linings throughout their operational life (Figure 4).

Fig. 1. A linings configuration in a drum SAG mill

Fig. 2. The laser scanner during a measurement

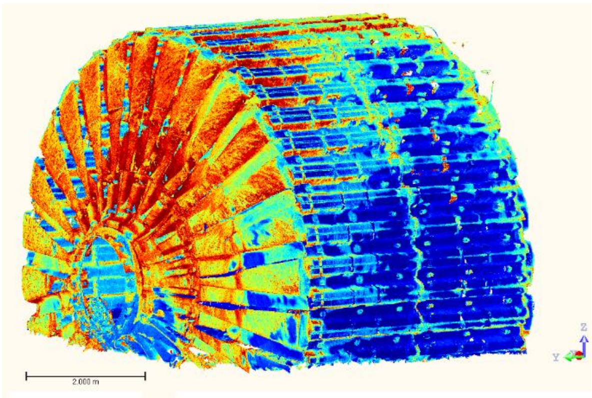

Fig. 3. A model of the scanned inner surface of the mill

Results

By means of the AutoCAD programme, the surface areas of each wear are calculated between two scans (Figure 5). The graphical dependencies of Fig. 4 can also be automatically interpreted using MathCAD (Stoyanov, A., 2016).

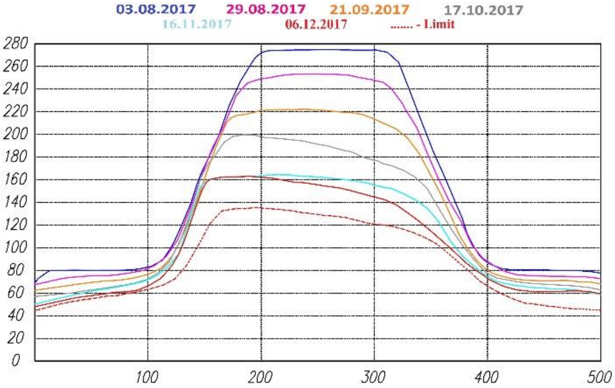

Fig. 4. The linings wear in the middle part of the drum in the period 3rd of August, 2017 – 6th of Dec, 2017

These areas are multiplied by the lining length of each one of the lifters and thus the volume of the worn-out material from the respective lining is obtained. However, in order to obtain the exact volume of the worn material between two scans, it is necessary to subtract the volume of the holes of the clinchers, attaching the lining to the mill drum, from the resulting volume.

For the final calculation of the total volume of the worn out material from the mill drum, the resulting values are multiplied by the number of the lining rows. In order to obtain the quantity of worn material from the mill linings in weight units, the volume is multiplied by the density of the steel.

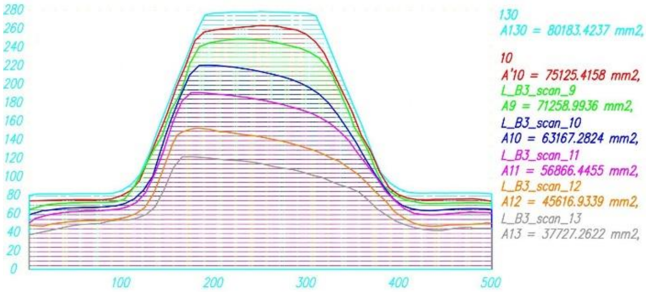

Fig. 5. The linings wear in the middle part of the drum in the period 3rd of August, 2017 – 6th of Dec, 2017

The calculations are drafted by means of the following formula:

$$M = \left[n(A_{NEW} - A), L - V_1 \right] . \rho, kg \qquad (5)$$

where: M, kg is the calculated mass of the abraded material of the lining due to the wear;

- n - the number of rows of drum linings;
- A_{NEW} - the initial surface area of the section of the new lining;
- A - the measured surface area of the section after the processing of the scan results;
- L - the inner length of the mill drum;
- ρ - the density of the steel of the linings;
- V_1 - the volume of the holes of the clinchers, attaching the lining to the mill drum.

The obtained data, a result of the study, is presented in Table 1.

The last column shows the values of the quantity of the processed ore from the moment of new lining mounting to the moment of the measurement of the linings wearing.

The data processing (the data from Table 1) is performed through a statistical analysis. The whole matrix is processed in order to obtain a mathematical model giving the dependence of the amount of worn material on the tons of processed ore in the mill.

Table 1.

№	$A_{NEW} - A$	V	M	Q
	m^2	$m3$	kg	t
1	0.0068	1.010	7928.11	335642
2	0.0094	1.387	10893.56	465570
3	0.0223	3.307	25960.72	586266
4	0.0268	3.982	31260.36	625224
5	0.0364	5.404	42423.77	738401
6	0.0051	0.750	5892.27	105947
7	0.0089	1.324	10396.42	231538
8	0.0170	2.525	19822.78	396555
9	0.0233	3.460	27162.88	572485
10	0.0346	5.129	40267.88	753279
11	0.0425	6.300	49458.88	878000
12	0.0075	1.108	8697.85	167361
13	0.0146	2.172	17056.56	305377
14	0.0197	2.919	22918.92	428799
15	0.0278	4.122	32364.28	562412
16	0.0335	4.968	39005.44	705556
17	0.0468	6.948	54542.27	903122
18	0.0046	0.6796	5335.21	212577
19	0.0103	1.5319	12025.26	381737
20	0.0169	2.5088	19693.71	530653

The results of the experiment were statistically processed using the STATGRAPHICS programme. The programme is suitable for finding target functions to determine the influence factors in stochastic systems. Such are the objects in the mining industry as mills and crushers (Hristova T., 2018, Nedyalkov P., 2010). The results of the statistical analysis of the linings wear are shown in Table 2.

Table 2.

Parameters	Value	Standard error		P-value criterion
Q	0.0269311	0.00631809		0.000
Q^2	3.6136E-9	9.11302E-9		0.000
	Sum of squares of the model	***Degrees of freedom***	***F-value criterion***	***Significance of F***
Model	1.56724E10	2	473,58	0.000
Residual	2.97841E8	18		
Total	1.310446	20		
Multiple correlation coefficient			98.135 %	
Adjusted coefficient of multiple correlation			98.0314 %	
Standard error			4076.76	
Average Absolute Error			3162.78	
Statistics of Durbin - Watson			0.5439	

Thus, 6 models have been obtained, the parameters of which are given in Table 3.

However, it should be taken into consideration that a minimum error is also obtained, caused by the error of the scanner (up to 1 mm) and by the wet mill scanning error. In this case, there is a thin layer of pulp on the linings.

Nevertheless, it can be assumed that the error is within the tolerance limits and is less than 3%.

Table 3

Model №	P criterion	Significance of F	R^2 %	$R^2_{(adj)}$ %
1	<0.05	0	90.28	89.7
2	<0.05	0	96.5	96.5
3	<0.05	0	93.1	92.8
4	0	0	96.2	96.2
5	>0.05	0	93.5	93.3
6	0	0	98.1	98

Among all of the models obtained, the one with the best values of confidence probability is model 6. The multi-correlation coefficient and the corrected multi-correlation coefficient is over 98%.

The value of the confidence probability (P-Value) criterion for the model and the control parameters is below the critical 0.05, i.e., it can be assumed that the model is adequate with a high confidence probability of over 98%.

The equation of the model without a constant in natural variables is:

$$M = 0,027Q + 3,61.10^{-8}Q^2, kg \qquad (6)$$

The relation of the model to the experimental data is shown in Figure 6.

The model is shown in a graphic manner cx Figure 7.

Taking into account the equation of the model and solving it in relevance to m at M = 1kg, it is obtained:

$$3,61.10^{-8}Q^2 + 0,027Q - 1 = 0 \qquad (7)$$

$$Q_{1kg} = \frac{-0,027 + \sqrt{0,027^2 + 4.3,61.10^{-8}}}{2.3,61.10^{-8}} = 37,5t \qquad (8)$$

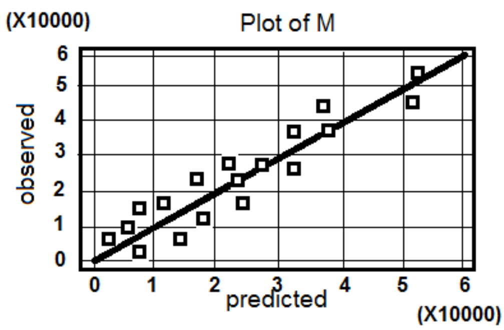

Fig. 6. A compliance of the model with the experimental data

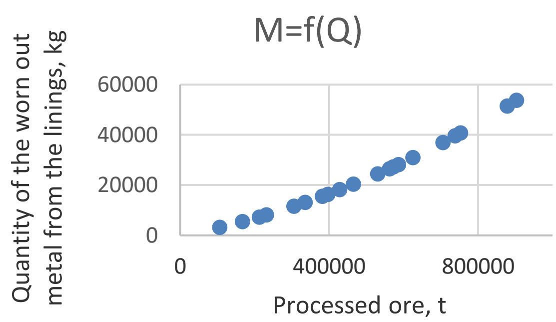

Fig. 7. A graph showing the wear of the linings as a function of the processed ore

Conclusion

As a conclusion, the following statements can be made:

1. There is a functional dependence between the wear of the mill drum linings and the amount of ground ore.

2. The function is parabolic (Figure 3) and this is probably due to the fact that with the wear of the lining lifters the slipping area of the ore onto the inner surface of the mill cylinder increases on the one hand, and on the other, the volume of the mill and the amount of ore in the drum increases, which also leads to an increased wear.

3. The results of the study can be used in the planning of the supply of spare linings of semi-autogenous mills.

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