METHODOLOGY FOR DETERMINING THE REPLACEMENT PERIOD FOR LIFTER BARS

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Abstract: The timely replacement of the drum mill liners brings about an increase in the quality of the milled product and reduces the milling costs. Therefore, an approach has been chosen to determine the replacement period for semi-autogenous mill liners in view of minimizing costs. A methodology has been developed to determine the service life of the milling lifter bars, whereby factors such as energy consumption, yield of the calculated class, productivity, price of liners, replacement costs and downtime loss are included. Costs are determined in terms of the type and quantity of the processed ore, balls, and backwater consumption that feed the mill. In the case under consideration, it has been found that it is economically most advantageous to replace the liners of the mill drum approximately every 4 months.

Keywords: lifter bar; liner; replacement period; energy cost;

1. INTRODUCTION

The individual components of the processing machines vary in terms of service lifetime. The faultless operation of machines and the extension of their service life is achieved through the timely replacement of the worn-out parts. These measures lead to a decrease in production costs but sometimes they result in a deteriorating production quality. In order to optimize production costs while maintaining the production quality, it is necessary to develop a methodology for determining the replacement period for some of the components that includes various factors, such as production safety, productivity, unit price, energy consumption, and others.

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2. SUBJECT OF STUDY

An object considered in the article is the mill liners which are changed in accordance with the wear of the lifter bars. This is a major component that yields a relatively large share in the formation of the production cost of the mineral processing plants.

3. MODELS TO DETERMINE THE DURATION OF WORK OF LINERS

In the case of mills, much of the decisions for capital replacement are taken in accordance with the engineering (Minin and Hainov, 2013 and Djordjevic, N.at all, 2004) and the economic safety requirements (Liao et al., 2006). In order to obtain higher economic benefits, deterministic economic models are recommended to use so as to determine the lifespan of the individual components of each machine (Kalala et al., 2008, Cleary, 2001, Yahyaei et al., 2009, Bearman and Briggs, 1998). These models are based on the depreciation term, on the estimate of the downtime costs, as well as on the consequences of failures and are applied by different authors. The disadvantage of the models described is the lack of information about the production quality, i.e. the reduction in particle size according to the wear of lifter bars.

Other researchers (Santarisi and Almomany, 2005) offer linear substitution strategies based on mathematical models of the wear of cement mill cladding. Their conclusions mainly concern the fact that the optimum replacement interval increases productivity (tons/hour) with reduced specific energy consumption and with a reduction in the price per unit of the cement produced.

The review shows that it is necessary to develop a determinate model of liner replacement based on a broad perspective that includes the economic decision to influence maintenance in terms of quality and quantity of the mill production. For this purpose, it is necessary to perform an LCP (life cycle profit) or loss analysis based on the technological parameters. The maximum profits, the minimum losses, or maximizing the profitability of the mill can serve as criteria.

A model has been developed for maximizing gross profit (Dandotiya, 2011). However, profit depends not only on the technical parameters of production, but also on the market situation; therefore, this is not a suitable criteria for a longer period considered. The current research uses the model by Yun and Choi (Yun, Y.W, C.H. Choi, 2000), who suggest optimum replacement intervals in a repair system via the introduction of a random time horizon. They model a system according to a pre-determined period, wherein the optimum replacement interval is related to the minimizing of the expected costs. In this case, repairs are not carried out between two replacements. Also, their methodology does not include factors such as production efficiency, energy consumption, and metal recovery.

4. METHODOLOGY FOR DETERMINING THE PERIOD OF LIFTER REPLACEMENT

The present study offers the methodology and the subsequent data simulation that aim to minimize the life cycle cost by determining the optimum replacement interval. The life cycle model is based on a detailed analysis of the mill efficiency, the liner wear, and maintenance statistics. Practical data was used without taking into account the measurement of wear between two successive replacements.

4.1. Output modeling data

4.1.1. Factors influencing the model

The mathematical model is associated with determining the time for liner replacement and includes the following factors: product quality related to tons of ore produced; price for liner maintenance; ore density (the ratio of tons of balls, ore and water); and the amount of electricity consumed. For all these elements to be compatible, they are referred to the price per ton of ore produced. It has been established that the efficiency of the grinding process for each type of ore depends on the size of the lifter bars; therefore, in the model, their height is a basic parameter that leads to more efficient decision-making.

Quality of the output product and percentage of metal recovery. The quality of recovery decreases at a reduced size of the lifter bars because the mill revolutions are increased, the material is kept for a shorter period, and the pulp produced is with a larger grain size (Yahyaei et al., 2009, Schena et al., 1996). The purpose of determining the replacement period is to increase the percentage of metal extraction (recovery is achieved at a later stage - floatation), which leads to an increase in profitability and to lowering of price per unit produced.

Changes in the mill volume due to wear. In this case, the automatic control of the material feed rate is based on the instantaneous mill load. Liner wear leads to an increase of mill volume by up to 17%, which raises the throughput or capacity of the mill. As a result, the amount of the milled product is reduced.

Variations in the energy consumption. According to Djordjevic et al. (2004), Minin and Hainov, (2013) the relatively high lifter bars consume less power than outworn lifter bars under identical conditions (process parameters, such as: angular speed; mill filling with ore, water, balls; type of ore).

Density of the ore (pulp). According to the multivariate analysis, it is established that the most important parameter causing wear of lifter bars is the ore density (Wijaya, 2010). Ore density changes inversely with wear, which indicates to a directly proportional relationship between the density and life of the lifter bars.

Maintenance of the liner. Repair, inspection and accident downtime lead to high costs due to unproduced production.

The percentage of ore extraction is not included as a factor because it also depends on the floatation process.

Several assumptions are made in the techno-economic model to ensure that there are no variations in the life cycle due to changes in productivity levels. They are:

1) the total time with a lower level of pulp in mill is much shorter than the service life of the liner;

2) the wear of the liner itself is not measured as, in relation to the lifter bars, it is very insignificant in terms of percentage;

3) the wear of the liner was studied for a single kind of ore containing gold and copper;

4) the profile of the liner and the design of the lifter bars are not taken into account in the model.

4.1.2. Model parameters.

This section briefly describes the parameters employed in the mathematical model.

Suitability of the liners. The technical suitability of the liner bars shall be tested throughout the lifetime at regular intervals. In this case, the data is taken on a daily basis.

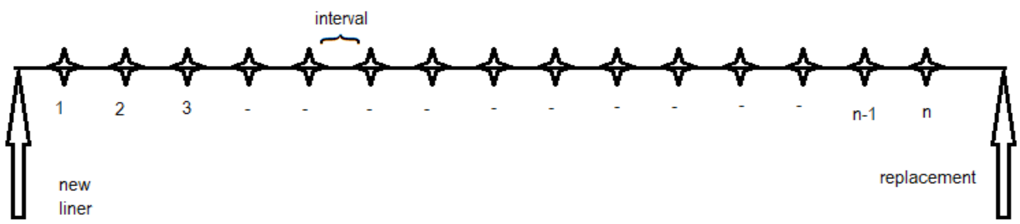

Fig.1. Measurement period

Costs. Costs are calculated for the entire exploitation period of the liner.

Total costs = [operating costs (energy costs) + replacement costs + costs for consumables], where

$$\sum_{i=1}^{n} E_i \cdot C_{energy} \qquad (1)$$

where:: E_i is the number of intervals, n is the duration of one cycle, and C_{energy} is the electricity costs [in BGN].

Replacement costs. Replacement costs of liners include the price of liners and the installation of a new inner liner, with each Ith interval being:

$$\frac{C_{rep}}{T_{cycle} + T_{rep}} t \qquad (2)$$

where: T_{cycle} is the time for one cycle, T_{rep} is the repair time (interruption and replacement), and t is the duration of sampling intervals [measured in days], C_{rep} is the replacement cost.

In the case of an SAG mill, the cost of the liner is 37% of the total milling costs, see Catalog Manual (2002). Since interruptions happen only during repair operations, then in the case T_{cycle}= 0:

Costs for consumables, balls, etc. during the life cycle.

$$\sum_{i=1}^{n} E_i \cdot C_{cons} \tag{3}$$

Where C_{cons} - is consumables per ton of ore [in BGN].

Costs of stay. The costs of stay or loss of production cannot be compensated and can lead to a breach of standard operations and to inefficiency. Downtime costs (or the so called production loss) are the most critical parameter in the decision-making model; i.e. the duration of the milling stops regardless of whether they are for liner inspection or replacement. Depending on the duration of the shutdown, the energy costs and the production efficiency costs vary, too. Therefore, in the particular case, the cost per hour is assumed to be constant for each cycle of time, with the downtime cost for each i^{th} sampling interval being as follows:

$$\frac{C_{DR}}{T_{cycle} + T_{rep}} t \tag{4}$$

Where C_{DR}- is the stay costs [in BGN].

In the model, it is assumed that downtime losses for the planning horizon are reduced to the price of unprocessed gold and copper:

$$\begin{aligned} C_{DR} &= \left(T_{rep} \cdot C_{Cu} + T_{rep} \cdot C_{Au}\right) \frac{T_{max}}{T_{cycle} + T_{rep}} = \\ &= \left(T_{rep}.Q_r \cdot I_z \cdot C_{Cu1} + T_{rep}.Q_r \cdot I_z \cdot C_{Au1}\right) \frac{T_{max}}{T_{cycle} + T_{rep}} \end{aligned} \tag{5}$$

Where T_{max} is the maximum time for 10 years which is equal to the days of work and stay; C_{Cu1} and C_{Au1} are the prices of copper and gold per kilogram; I_z is the percentage of gold or copper content in the ore; Q_r is the amount of ore per day.

As production losses, liner prices, metal prices on the stock exchange, etc. may vary over the years, to reduce the prediction error for a longer period of time, the expression is simplified and reduced to a loss minimization model:

$$C = \sum_{i=1}^{n} E_i \cdot C_{energy} + \sum_{i=1}^{n} E_i \cdot C_{cons} + \frac{C_{rep}}{T_{cycle} + T_{rep}} t + \frac{C_{DR}}{T_{cycle} + T_{rep}} t \tag{6}$$

The optimization approach is based on a comparison of gross costs at different replacement intervals.

To justify the model, the horizon concept is introduced for a planned period (days, months): The lifetime of the liner from its installation to its removal. This is employed to calculate the LCC. The optimization used in this case is based on two scenarios L (long) and S (short) with a data interval for one liner cycle. The S scenario contains fewer days T_s, whereas the L scenario contains more days T_l; consequently $T_l > T_s$. A longer time T_{max}, including time is selected that comprises several L or S scenarios.

The comparison is performed over a given time horizon of T_{max} in order to determine the best interval for loss minimization. T_{max} is at the threshold of the lifespan of the liners and includes the installation time and the operation time. To determine the number of cycles N, the dependence is used:

$$N = \frac{T_{max}}{T_{cycle} + T_{rep}} \tag{7}$$

Where T_{max} is the maximum study period; T_{cycle} is the mill operation time; T_{rep} the shutdown time for liner replacement.

In order to optimize the life cycle, as well as to reduce the cost of staying, it is advisable to make a diagram of cost minimizing, including downtime loss, per production unit. For this purpose, time intervals have been introduced for a period of 10 years or 120 months, both of which are close to the L scenario. The L interval is assumed to be 150 days and the S interval is 135 days. To compare two L and S scenarios, the gross loss is calculated for T_{max} days.

5. RESULTS

For the verification of the techno-economic model, data was obtained from a semi-autogenous mill for processing ore with gold and copper content, but due to the confidentiality of the data used those have been scaled. Based on these, models were developed to determine the correlation between the liner wear and the process parameters for the entire lifetime of the liners. Through variations in the liner life cycle over a longer period of time, a decision was made related to the optimum replacement period.

All costs per ton of ore produced are visualized by the graphs in Fig. 2 with their variation in days within a period of 150 days, of which 147 days are the operation of the mill and 3 are for the liner replacement. In the graph, R_b are the costs of balls, R are the total costs (including water), R_{liner} are liner costs, and R_e are the electricity costs.

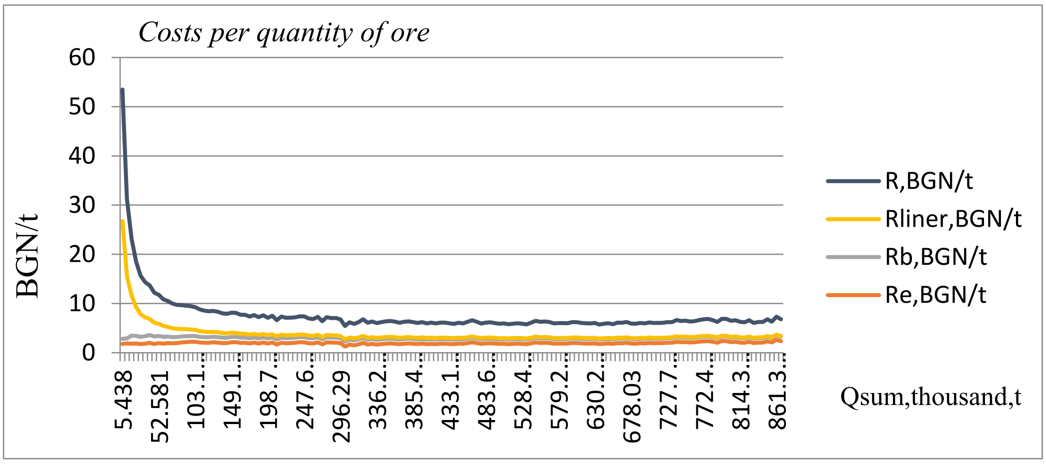

Fig. 2. Costs versus amount of ore

It is clear from the graph that for the amount of ore of 128,439 thousand tons the price of liner becomes lower than the price of electricity per ton of ore. At the end of the period, the energy cost and total cost increase. It is economically more profitable to replace the liner before the cost rises. Fig. 3a) shows these costs and for better visibility Fig.3.b) gives the costs for the end of the period.

The graph shows that the costs that are on the increase are those for electricity and the total costs. For the sake of clarity, they are outlined against the entire period of liner operation.

The calculations show that costs are on the rise after 120 days. To clarify the moment to replacement, the optimization approach is applied. For this, we assume that Tmax = 120 months, and we choose the horizon periods: 150 days for the first variant and 135 days for the second variant. It is estimated that 120/5 = 24 liners are replaced within 10 years in the first variant. The second variant is two weeks shorter and the number of liners replaced within the same period will be 26.6. Costs are calculated after the dependence (6) or for variant one - BGN 13383,0864 thousand over a period of 10 years, with the duration of liner operation of nearly 5 months. For a period of operation of 4.5 months, the amount is BGN 12254,4033 thousand.

For the entire period of operation, the T_{max} costs are calculated on the basis of the following dependence:

$$C_{zag} = \left(\sum_{i=1}^{n} E_i.C_{energy} + \sum_{i=1}^{n} E_i.C_{cons} + C_{rep} + C_{DR} \right) \frac{T_{\max}}{T_{cycle+T_{rep}}} = \\ = \left(\sum_{i=1}^{n} E_i.C_{energy} + \sum_{i=1}^{n} E_i.C_{cons} + C_{rep} + C_{Cu} + C_{Au} \right) N \quad (7)$$

The variation in gross cost is determined by a simulation program for (n = 1, 2, 3 ... Trisk), where Trisk represents the maximum number of days in operation of the liners before their thickness is reduced to the hazardous zone, i.e. one which implies a risk of damaging the mill. Also, the discounted rate is not taken into account due to the short technical life cycle of the liner as compared to the lifespan of the whole mill.

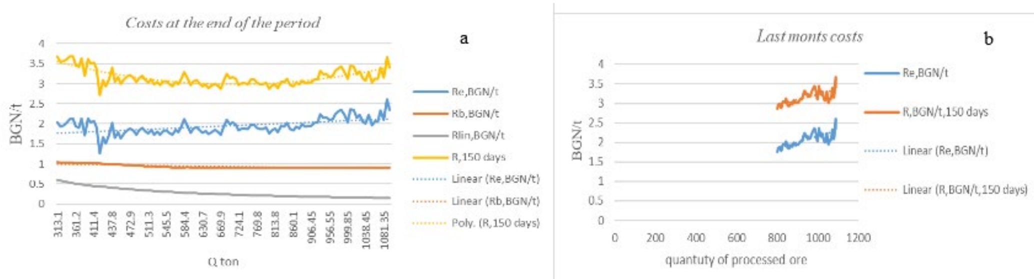

Fig. 3a). Costs for the last month and **3b)** Total costs and electricity costs at the end of the period

The cumulative cost curve for a horizon of 150 days looks like this (Figure 4). It is obvious that the minimum is approximately on day120 and it is economically more profitable to replace the liner during this period. At minimum costs for variants of 2 to 150 days, the last days of the cycle are shown in Fig. 5.

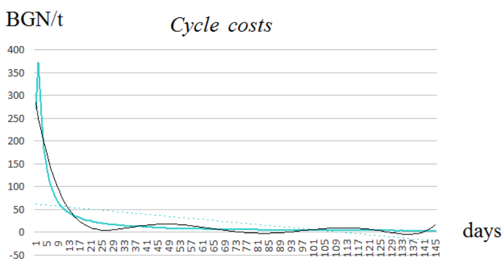

Fig. 4. Cost curve for a 150-day

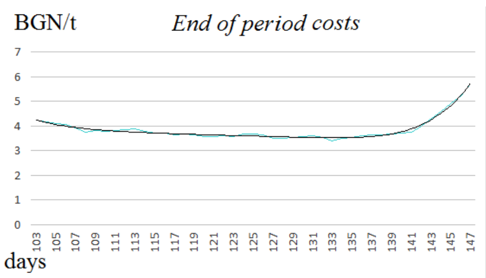

Fig. 5. Total costs to end of the period for the first variant of a 150-day cycle period

With 120-month planning Tmax, which is consistent with the proposed Optimization Maintenance Policy, the results of this study show (see Fig. 5) that around day 141, the cost curve reaches a minimum, and then rises. This indicates that it is appropriate to replace the liner after 138 days or after 8,000,000 tons of processed ore. If a 10% error is included due to the replacement of the type of liner, or to ore characteristics, or to the change in the price of metals on the exchange, etc., then it is normal to change the liner after 140 days. Despite the long horizon, the sensitivity of the model results ranges from 1-2% for the various optimum scenarios.

Fig. 6 compares to two variants with cycles of 150 and 120 days, respectively. There are snown two L and S scenarios with the corresponding curves. The total area of the loss curves in the S scenario is less than the total area of the curves in the L scenario. This is due to better process efficiency and to the lower power consumption in the initial phases of the life cycle of the liner bars. At the same time, the S scenario has more substitute times than the L scenario, which leads to more downtime costs, but despite everything, the total costs over a 10-year period remain lower. Therefore, the life cycle is optimised based on the minimisation of the loss curve for a given time horizon.

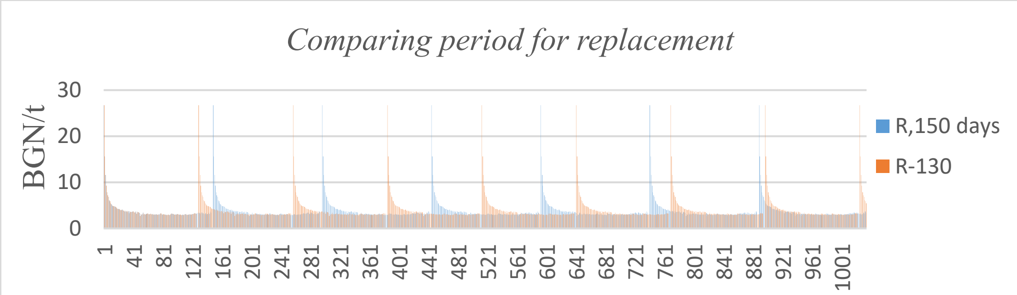

Fig. 6. Location of the cycles for both variants

6. CONCLUSION

In conclusion, the following inferences can be drawn:

1. The timely replacement of lifter bars will not only reduce the costs per ton of ore but will increase the quality of the milled product.
2. By economic criteria, this should be done earlier, around day 136 or, in this case, after 800,000 tons of processed ore with these liner bars.
3. For greater precision of measurements, it is necessary to monitor the liner wear with a laser scanner that also measures the shape of the lifter bars at least twice a month.
4. When replacing the liner manufacturer or the liner configuration, the study hereby should be repeated.
5. The results of this study are valid for the type of processed ore during the specified period.

When establishing the boundary wear by economic criteria, all metal, electricity, and liner prices used in the model, along with the liner replacement, were determined at the beginning of 2015.

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