RELIABILITY AND POSSIBILITY OF FAIL-SAFE OPERATION OF A DRUM MILL TYPE SAG 8,5x5,3

Ivan Minin, Petko Nedyalkov

University of Mining and Geology "St. Ivan Rilski", 1700 Sofia; minin_ivan@abv.bg; petko.nedyalkov@mgu.bg

ABSTRACT. The distribution of failures of an element or machine from a specific technological line is an attempt to describe mathematically their life expectancy. The distribution mode affects the analytical appearance of this distribution. The present paper tries to determine the distribution of failures of the basic elements of a drum semi-autogenous mill used to grind copper and gold ores and to determine the probability of fail-safe operation of this machine. In the present case, the chosen mill has three basic elements, and in case of damage of each one of them it stops working and has to start repair activities for its replacement. That is why, the mill is seen as a system of three elements that are consequently connected. This means that if any one of its components is damaged, there is a failure. The required number of statistics have been gathered and processed, which, after using some elements of the reliability theory, describe the performance regarding the reliability of its separate elements and the mill as a whole. The probability of faultless operation of the whole mill for a given quantity of processed ore is determined by the probability multiplication theorem, thus predicting machine failures and the amount of replacement lining plates necessary for one year ahead. The results obtained after processing the statistics unambiguously prove the right choice of this machine for the exploitation conditions.

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

НАДЕЖДНОСТ И ВЕРОЯТНОСТ ЗА БЕЗОТКАЗНА РАБОТА НА БАРАБАННА МЕЛНИЦА ТИП SAG 8,5x5,3

Иван Минин, Петко Недялков

Минно-геоложки университет "Св. Иван Рилски", 1700 София

РЕЗЮМЕ. Разпределението на отказите на един елемент или една машина от дадена технологична линия е опит да се опише математически продължителността им на живот. Начинът на разпределението се отразява на аналитичния вид на това разпределение. В настоящата разработка е направен опит да бъде определено разпределението на отказите на основните елементи на барабанна полуавтогенна мелница използвана за смилане на медни и златни руди и да бъде определена вероятността за безотказна работа на тази машина. В настоящия случай избраната мелница има три основни елемента, като при повреда на всеки един от тях - спира да работи и започват ремонтни дейности по подмяната му. Ето защо мелницата се разглежда като система от три елемента, които са последователно свързани. Това означава, че който и от елементите й да се повреди, има наличие на отказ. Събрани са и са обработени необходимия брой статистически данни, които след използване на някои елементи от теорията на надеждността, описват поведението по отношение на надеждността на отделните й елементи и на мелницата в съвкупност. Вероятността за безотказна работа на цялата мелница за дадено количество преработена руда е определена от теоремата за умножение на вероятностите, като по този начин могат да бъдат прогнозирани отказите на машината и количеството на резервните облицовъчни плочи необходими за година напред. Получените резултати след обработката на статистическите данни недвусмислено доказват правилният избор на тази машина за условията и на експлоатация.

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

Introduction

The investigated semi-autogenous tumbling mill type SAG 8.5x5.3 grinds material with high abrasion, hardness and strength. The period of gathering the statistical data was 5 years and shows that the machine went out of service mainly due to wear on the drum linings. They cannot be recovered, but have to be replaced. The drum linings have different wearing in different areas, which depend mostly on the size of the ore fractions in the respective area. The drum of the mill is essentially divided into three elements on which linings are mounted - a feed cover, a cylinder and a discharge cover, as the ore is largest in size in the area of the feed cover and decreases towards the cylinder and the discharge cover of the mill. This also results in quicker wear of the linings of the feed cover than in the other two zones. Figure 1 gives the configuration of the drum linings of a semi-autogenous mill, where 1 shows the lifters of the feed cover linings, 2 – the lifters of the cylinder linings, and 3 - the lifters of the discharge cover of the mill. Figure 2 is a cross-sectional view of a 3D computer model of the overall linings of the mill drum.

The main question that may be set in the present study is how the performance of a machine for the deriving of mineral grains (semi-autogenous drum mill) can be described using the probability and reliability theory and how the failures can be predicted in order to plan the necessary spare parts and upcoming repairs.

The plants in which such machines are in exploitation often are overloaded with spare parts due to the fact that these machines are single and they determine the productivity of the whole company in order to reduce the layovers during the repairs.

The mode of forecasting is reduced to the arithmetic average determination of the required number of nods and elements on the basis of a previous year.

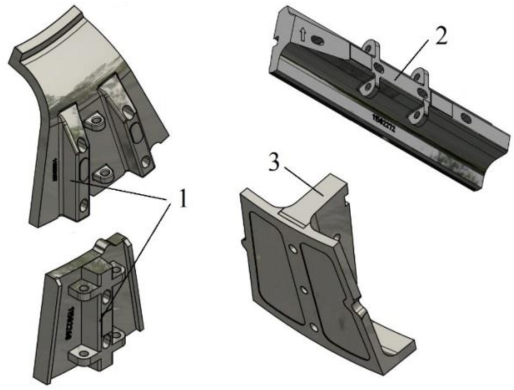

Fig. 1. Configuration of the linings of a mill type SAG

The best solution in this case is to determine the parameters of the machine operational safety based on the reliability theory. A major problem for such a study would appear during the gathering of the statistics when spare parts and nods from different manufacturers and of different quality are delivered for the machine. In the present study this problem is avoided.

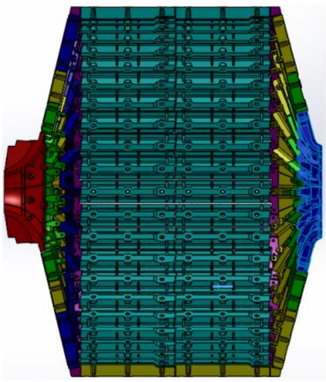

Fig. 2. A cross-section of a 3D computer model of the overall linings of a drum mill type SAG

The present study it is expected to prove the fact that the reliability theory can also be used to solve similar engineering tasks in the mining industry.

The aim of the present study is to investigate the regularities of the alteration of the quality indicators in time by examining the influence of external and internal impacts on the operation of a machine for the deriving of mineral grains - a drum semi-autogenous mill, to create methods and means for prediction of technical conditions and to increase the reliability of such machines under operational conditions.

Theory

The reliability theory widely uses the statistical Weibull distribution function (Waloddi Weibull, 1887 - 1979, KTH Royal Institute of Technology, Stockholm, Sweden) despite the fact that it is based on and uses heavy mathematical and software appliance.

The Weibull probability distribution (density) function /pdf/ is defined as a three parameter function:

$$f(\tau)=\frac{\beta}{\eta}\cdot\left(\frac{\tau-\gamma}{\eta}\right)^{(\beta-1)}\cdot\exp\left[-\left(\frac{\tau-\gamma}{\eta}\right)^{\beta}\right] \qquad (1)$$

, where:

- $\beta>0$ - shape (slope) parameter;
- $\eta>0$ - scale parameter;
- $\gamma\in(-\infty,\infty)$ - location parameter, often $\gamma=0$

, and integral (cumulative/CDF/) distribution function is:

$$F(t)=\int_{-\infty}^{t} f(\tau)\,d\tau=1-\exp\left[-\left(\frac{\tau-\gamma}{\eta}\right)^{\beta}\right], \qquad (2)$$

The two parameter Weibull function is derived at zeroing location parameter $\gamma=0$, so the function looks like:

$$f(\tau)=\frac{\beta}{\eta}\cdot\left(\frac{\tau}{\eta}\right)^{(\beta-1)}\cdot\exp\left[-\left(\frac{\tau}{\eta}\right)^{\beta}\right] \qquad (3)$$

$$F(t)=\int_{-\infty}^{t} f(\tau)\,d\tau=1-\exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right], \qquad (4)$$

Survival function *S(t)* or reliability function is defined as admission life period to exceed some time interval *P(T>t)* , so the function is:

$$S(t)=1-P(T\le t)=1-F(t)=exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right] \qquad (5)$$

, and the hazard function is defined by:

$$h(t)=\frac{f(t)}{S(t)}=\frac{f(t)}{1-F(t)}, \qquad (6)$$

$$h(t)=\frac{\beta}{\eta^{\beta}}\cdot t^{(\beta-1)} \qquad (7)$$

So the reliability functions are defined, but the computational problems appear at the parameter estimation method about Weibull statistics (Weibull 1951, Murthy 2004). One of the easiest method is achieved in median rank regression estimator /**MRE**/ using the equation:

$$\sum_{k=i}^{N}\binom{N}{k}\cdot Z_i^{k}\cdot(1-Z_i)^{(N-k)} \qquad (8)$$

, approximated with Bernard algorithm to:

$$F_T(t_i)\cong Z_i\cong\frac{i-0.3175}{N+0.365} \qquad (9)$$

, where:

$N, number$ - total number of data;

i - data point ascending rank;

After some transformations shown below:

$$1 - F_T(t) = exp\left\{-\left(\frac{t}{\eta}\right)^{\beta}\right\} \quad (10)$$

$$\ln\left\{\ln\left[\frac{1}{S_T(t)}\right]\right\} = \beta \cdot \ln\left(\frac{t}{\eta}\right) = \beta \cdot \left[\ln(t) - \ln(\eta)\right] \quad (11)$$

, one can achieve:

$$y = \beta \cdot x - \beta \cdot \ln(\eta) = A_1 \cdot x + A_0 \quad (12)$$

or:

$$\left| \begin{array}{l} \beta = A_1 \\ \beta \cdot \ln(\eta) = -A_0 \end{array} \right. \Rightarrow \left| \begin{array}{l} \beta = A_1 \\ \eta = exp\left(-\frac{A_0}{A_1}\right) \end{array} \right. \quad (13)$$

According to these formulas one can easily create non-iterative algorithm in Excel as it is shown in the next section. Usually, the MRE algorithm is represented as a graph of the type on Fig. 3 - 5. The advantage of this method is the ability to work with small amount of data, it is fast and has a simple non-iterative algorithm.

- the mean time to failure /MTTF/ or the expected time to failure as an mathematical expectation:

$$MTTF = E = \eta \cdot \Gamma\left(\frac{1}{\beta} + 1\right) \quad (14)$$

, where **Γ** is Gamma function.

Data and results

The particular estimation about parameters of failure data for SAG mill lining plates is described. The data is represented as the point at lining plate changing according cumulative productivity Q_{int}, which is easy to recalculate in relative productivity:

$$Q_i = Q_{Ci} - Q_{Ci-1}, t \quad (15)$$

, respectfully in average hour productivity $Q_h, t/h$ the working hours are:

$$t = \frac{Q_i}{Q_h}, h \quad (16)$$

The median rank is calculated by equation (9), and the parameters regression according equation (13) is shown on Fig.3 - 5 which represent regression:

$$\left| \begin{array}{l} ln(t) \\ ln\left\{ln\left[\frac{1}{S(t)}\right]\right\} \end{array} \right. \quad (17)$$

The survival function S(t) and the hazard function h(t) shown on Fig. 6 and 7, are calculated in equidistant points in the observed interval, respectively.

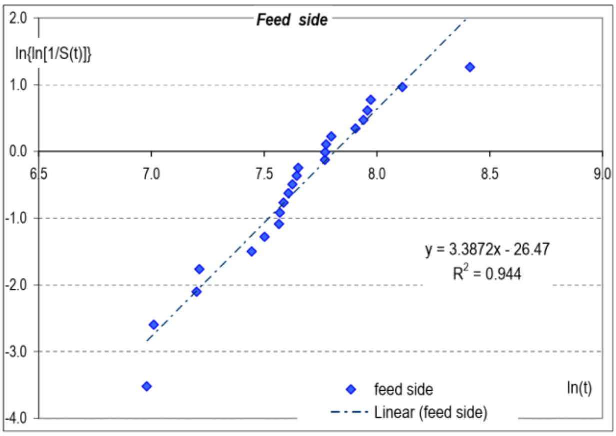

Fig. 3. Feed side maintenance MRE regression

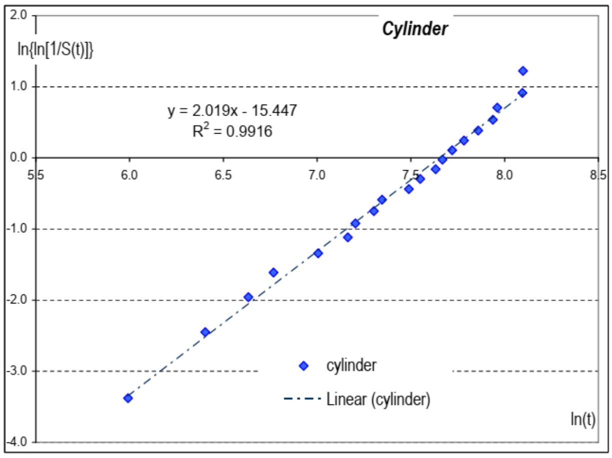

Fig. 4. Cylinder maintenance MRE regression

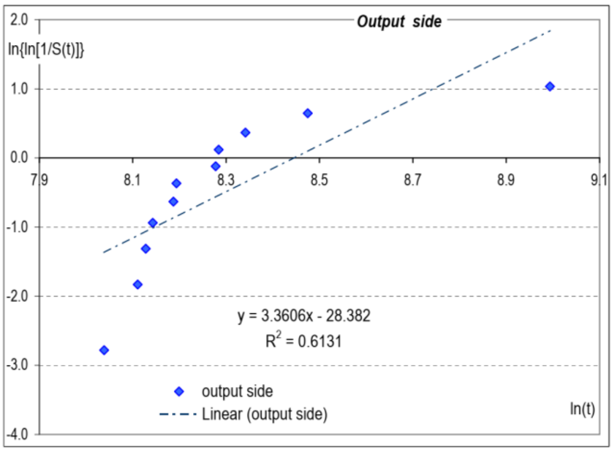

Fig. 5. Output side maintenance MRE regression

Conclusions

So far many researchers (Murthy 2004) found that these dependences follow Weibull models. In comparison with the exponential model (Minin 2017) Weibull fit uses some advantages focused on the reliability over the life cycle of a product. In case of hazard thinking the formula describing hazard function about the maintenance cycle follows formula (6) and it is time dependent in comparison to the time independent hazard function derived from the exponential (Minin 2017) distribution. The derived survival function S(t) is shown on Fig 6, it is clearly seen that probability of survival for all parts of mill liners is dramatically decreasing between 1800 and 4200 working hours. The derived hazard function h(t) from data is shown on Fig. 7.

Table 1. *Parameters results*

	Feed side	Cylinder	Output side
β	3.3872	2.019	3.3606
η	2476.8	2102.4	4654.2
MTTF	2224.66	1862.87	4178.70

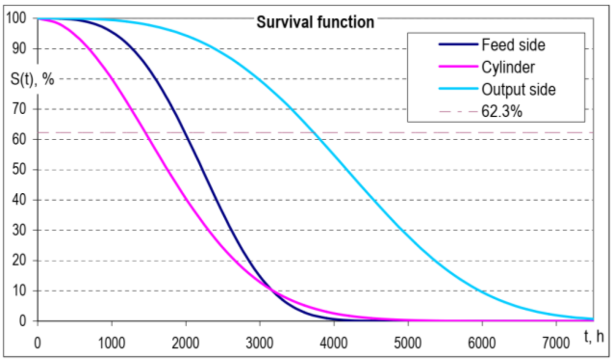

Fig. 6. Survival functions based on fitted Weibull models

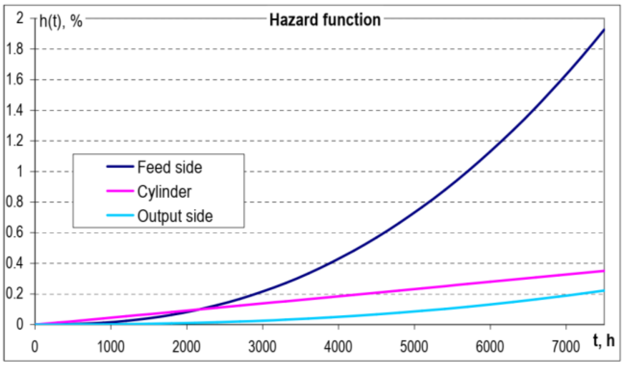

Fig. 7. Hazard functions based on fitted Weibull models

Particular data from SAG maintenance cycles are processed and from them the parameters of Weibull reliability function are estimated. The median regression estimation method with good regression significance is used. The resulting parameters of fitted Weibull function are shown in Table 1.

References

Minin, I., D. Mitev. 2017. Determination of the function of reliability and the possibility of failure-free operation of a jaw crusher type CJ615:01. – *Journal of Mining and Geological Sciences, 60*, III, 11–17.

Murthy, D. P., M. Xie, R. Jiang. 2004. *Weibull Models*. John Wiley and Sons, Inc.

Weibull, W. 1951. A statistical distribution function of wide applicability. – *Journal of Applied Mechanics, 18*, 293–296.