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AN ANALYSIS OF RANDOM MECHANICAL FAILURES OF BUCKET WHEEL EXCAVATOR
ANALIZA SLUČAJNIH MAŠINSKIH OTKAZA ROTORNOG BAGERA

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Keywords
- bucket wheel excavator
- mechanical failures
- reliability
- mean time between failure (MTBF)

Abstract

In this article random mechanical failures of bucket wheel excavator at open cast mine "Tamnava Zapad" are analysed. Random mechanical failures of mining equipment may represent an important factor in coal production because these types of failures occur unpredictably. Some of the reasons for the occurrence of such failures are undetectable defects, unexplainable causes, and unavoidable failures. In addition, here we have failure of equipment that has a large investment and productivity value. Statistical regularity of the component failure distribution of this system is analysed based on dispatcher's reports about EBS system failures in the period 2003–2011. The proposed distribution is analysed by theoretically, using suitable tests. By using statistical distribution we get the expected uptime of the bucket wheel excavator, for each year, which represents an important factor in maintenance programs and periodic inspections/repairs on bucket wheel excavator and mining components, in general.

Ključne reči
- rotorni bager
- mašinski otkazi
- pouzdanost
- srednje vreme između otkaza (MTBF)

Izvod

U ovom radu su analizirani slučajni mašinski otkazi rotornog bagera na površinskom kopu „Tamnava Zapad“. Slučajni mašinski otkazi rudarske opreme mogu predstavljati značajan činilac u proizvodnji uglja, jer se ova vrsta otkaza događa nepredvidivo. Neki od razloga dešavanja otkaza su neprimetni defekti, neobjašnjivi uzroci kao i otkazi koje je nemoguće izbeći. Pored toga, u pitanju je otkaz opreme koja poseduje veliku investicionu i proizvodnu vrednost. Na osnovu dispečerskih izveštaja o otkazima sistema BTO u periodu 2003–2011. god., analizirana je statistička zakonitost raspodele otkaza delova datog sistema. Predložena raspodela je testirana sa teorijskom, odgovarajućim testovima. Korišćenjem statističke raspodele se dobija očekivano vreme ispravnog rada bagera, za svaku godinu, što predstavlja važan činilac u cilju sagledavanja održavanja kao i periodičnih kontrola i popravki na delovima rotornog bagera i rudarske opreme, uopšte.

INTRODUCTION

In coal production, various and numerous mechanization is used where the key place is occupied by continuous action systems which consist of: bucket wheel excavators, haulage systems with belt conveyors, stackers, material transfer equipment, reclaimers and facilities for coal processing. The bucket wheel excavator is one of the most complex technical systems in the industry in general. First, it is characterized by a complex hierarchy of construction structure, high investment value, as well as productivity /1/.

Serial connection of this system requires high reliability of components. In order to achieve this, maintenance of each component must be adequate to assure the required level of system's reliability, /2/. Operational conditions for systems at open cast mines are difficult and investment value of the system is high. This is why it is necessary to aim at the highest time and capacity utilization possible, /3-6/. Mine equipment life time can be defined as working duration of equipment, which is the period in which the equipment is in a functional state.

Reliability is the probability that a component or system shall perform a required function for a given period of time when used under the stated operating condition /7/. Although it is difficult to predict the time at which a piece of equipment fails due to the unscheduled critical failure, the time-dependent failure events demonstrate some statistical rules and the patterns of trend. Duane has proposed the power law model on the failures of a complex repairable system; the accumulated mean operating time between failures (MTBF) is linearly related to the operating time on log-log scale, /8/. Barabady and Kumar /9/ used various statistical distributions, including Weibull, exponential, normal, and log-normal distribution to analyse the reliability of a crushing plant, in order to identify the bottlenecks in the system and to find the components or subsystems with low reliability for a given designed performance.

Even though scheduled preventive maintenance programmes are generally implemented and periodic inspections/repairs on their construction equipment are carried out, it is still a difficult task to predict the occurrence of a specific failure event for a piece of equipment in the short or long term. According to a survey in the United States, approximately 46% of the major equipment repairs are due to an unscheduled failure. As a result of such breakdowns, the equipment unit has to be pulled out of production and repaired on site, or brought to a shop for repair. In addition to the impact on the project, other problems arise from these unexpected failures, including high costs for emergency repairs on a remote jobsite. However, there is a slight improvement in their prediction, which represents a significant saving in time and cost.

Although traditional reliability theory can be applied to the heavy equipment in service, there are practical obstacles which make it difficult to apply these reliability modelling techniques originally developed from the manufacturing industry. This is because the construction environment is highly uncontrollable with constantly changing weather conditions, job nature, and operating conditions, all of which have an impact on equipment reliability, /10/.

In this paper unscheduled mechanical failures of bucket wheel excavator at open cast mine "Tamnava – Zapad" are analysed.

CLASSICAL MATHEMATICAL MODELS

The Weibull distribution most frequently provides the best fit of life data. This is due in part to the broad range of distribution shapes that are included in the Weibull family. Many other distributions are included in the Weibull family, either exactly or approximately, including normal, exponential, and Rayleigh.

Exponential distribution

The exponential distribution plays an essential role in reliability engineering because it has a constant failure rate. This distribution is applicable to the case where a used component that has not failed is as good as a new component – a rather restrictive assumption. It should therefore be used carefully, since there are numerous situations where this assumption (known as the 'memoryless property' of the distribution) is not valid. If the time to failure is described by an exponential failure time density function, then:

$$f(t) = \frac{1}{\theta} e^{-\frac{t}{\theta}}, \quad t \geq 0,\ \theta > 0 \tag{1}$$

and this will lead to the reliability function:

$$R(t) = \int_t^\infty \frac{1}{\theta} e^{-\frac{s}{\theta}} ds = e^{-\frac{t}{\theta}}, \quad t \geq 0 \tag{2}$$

where $\theta = 1/\lambda > 0$ is a *mean-time-between-failures* parameter (MTBF) and $\lambda \geq 0$ is a constant failure rate.

The hazard function or failure rate for the exponential density function is constant, i.e.

$$h(t) = \frac{f(t)}{R(t)} = \frac{\frac{1}{\theta} e^{-\frac{1}{\theta}}}{e^{-\frac{1}{\theta}}} = \frac{1}{\theta} = \lambda \tag{3}$$

The failure rate for this distribution is λ, a constant, which is the main reason for this widely used distribution. Because of its constant failure rate, the exponential is an excellent model for the long flat 'useful life' portion of the *bathtub* curve. Since most parts and systems spend most of their lifetimes in this portion of the bathtub curve, this justifies frequent use of the exponential distribution (when early failures, or wear out, is not a concern).

During the useful life region the item hazard rate remains constant with respect to time. Some of the main reasons for the occurrence of failures during this region are undetectable defects, higher random stress than expected, abuse, low safety factors, and human error, /11/.

Suppose that the reliability function for a system is given by $R(t)$. The expected failure time during which a component is expected to perform successfully, or the system *mean-time-to-failure* (MTBF), is given by:

$$\text{MTBF} = \int_0^\infty R(t)dt = \int_0^\infty e^{-\frac{t}{\theta}} dt = \theta = \frac{1}{\lambda} \tag{4}$$

EXPERIMENTAL RESULTS

An important topic in the field of lifetime data analysis is to select and specify the most appropriate life distribution that describes the times to failure of a component, subassembly, assembly or system. This requires the collection and analysis of the failure data obtained by measurements in order to fit the model empirically to the observed failure process, /12/. Random failures of the bucket wheel excavator 'Glodar 1', which is a part of the continuous excavator-belt conveyors-stacker (EBS) system, is analysed in the period 2003-2011, having in mind following components:

- Excavator SchRs 900/6×25 – 'Glodar 1'
- Belt wagon BRS 1600/(28+50)×9 – 'BW1'
- Belt conveyors
- Stacker ARS 1400(22+60)×21

The observed period of BWE failures is 500 h, because over 90% of mechanical failures happen during this period.

By analysing random mechanical failures of the bucket wheel excavator 'Glodar1' in the period 2003 to 2011, it is concluded that, for every year, times between failures have an exponential distribution. As an example, the relative frequency of the bucket wheel excavator 'Glodar 1' failures for the year 2011 is presented in Table 1 and in Fig. 1.

Table 1. Relative frequency of BWE 'Glodar 1' failures in 2011.

Interval (h)	Middle of interval (h)	Relative frequency of failures
0–72	36	18
72–144	108	5
144–216	180	5
216–288	252	2
288–360	324	2
360–432	396	1
432–504	468	1

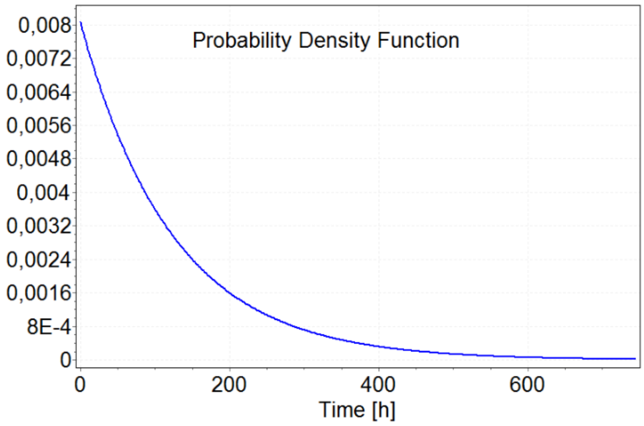

Figure 1. Failure density function of BWE Glodar 1 in 2011.

As is known, the characteristic of exponential distribution is the constant failure (hazard) rate, i.e. the failure rate is not time dipendent (Fig. 2).

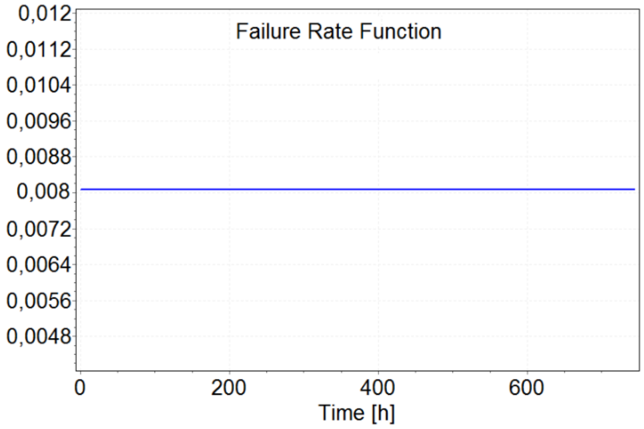

Figure 2. Failure rate function of BWE Glodar 1 in 2011.

A comparison of the observed (exponential) distribution with the theoretical one is carried out in two tests.

The common techniques are the Kolmogorov–Smirnov *'d'* test and the Anderson-Darling test. The results are shown in Fig. 3. The results show that the exponential distribution with significance level $\alpha = 0.05$ passes all tests.

Exponential [#12]					
Kolmogorov-Smirnov					
Sample Size Statistic P-Value Rank	7 0,2008 0,89184 2				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,38148	0,43607	0,48342	0,53844	0,57581
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size Statistic Rank	7 1,8741 13				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	Yes	No	No	No	No

Figure 3.Test distribution results, BWE Glodar 1 in 2011.

Equally, the derived exponential distributions for each year in the period from 2003 to 2011, pass all the test, too.

Failure number values are shown in Table 3, as well as the calculated failure rate λ and mean time between failures (MTBF) for every year.

Table 3. Number of failures, failure rate λ and mean-time-between-failure, by the years.

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011
Number of failures n_i	229	71	105	130	114	201	126	36	34
Failure rate λ_i	0.01577	0.01256	0.01066	0.01061	0.01121	0.01497	0.01263	0.00684	0.00828
MTBF (h)	63.42	79.61	93.83	94.27	89.17	66.8	79.17	146.25	120.71

CONCLUSION

Preventive maintenance (i.e. preventive replacements of parts) is applied when the technical system and its subsystems (parts) have the increasing rate of failures in relation to the use of the system. In the case of a constant rate of failure, preventive replacements would not affect the security of the achieved level of reliability, and maintenance costs would increase.

In this case, when the failures are random, the optimal procedure would be the replacement of parts in case of a failure.

The uptime of the system whose failures are affected only by independent random factors has an exponential distribution. Thus, we conclude that the factors affecting the uptime of the bucket wheel excavator are mutually independent.

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