RELIABILITY AND MAINTAINABILITY CALCULUS OF VIBRATING DRAINAGE SCREENS IN COAL PROCESSING PLANT

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Abstract: The paper determines the operational reliability and maintainability characteristics of drainage screens used in Jiu Valley energetic coal preparation. The assessment is based on information gathered by studying the machineries during operation over a 2 years period, transposed in statistical series which allow the determination, using specific methods, of reliability and maintainability indicators. The assessment allows the establishment of the level of quality of these machineries, proposing and implementing a series of solutions to increase their operational efficiency.

Key-words: coal, vibrating screens, reliability, maintainability, maintenance, indicator, statistical series

1. FOREWORD

Following the coal extraction process in the mines of Jiu Valley, there are cases where the coal mass comprises waste intercalations which need to be eliminated before sending the coal to the central heating plant. Waste elimination is realized through a complex preparation process resulting therefore in a homogenous mass of coal. The vibrating drainage screens are installed on the technological line and are destined for separating water through draining reducing therefore the water content of coal to approximately 15 … 20 %

Figure 1 represents a general view of the analyzed screen highlighting the screening surface. [14].

The operational survey of all four screens have emphasized the number of failures appeared highlighting as well the elements, which broke down, information comprised in table 1. [15].

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The data presented in the table highlight the overwhelming proportion of failures 81.94%, respectively 92.56%, are due to the screening surface which means not only the screen itself but also the metallic construction supporting the screen, and mainly its connection to the structure.

The failures are the wear and premature tear of the metallic screening surface and the wear and tear of the metallic structure and its welding spots.

The main intervention is welding and adding plates and profiles for strengthening the metallic construction.

Fig. 1. General view of the vibrating screen

Table 1. **The operational survey of all four screens** [15]

No.	**Screen code**	**Defected element**	**No. of failures**	**Total no. of failures**	**Failures' percentage %**
1	10.04 10.05	screening surface	179	216	81.94
2		coupling	34		15.74
3		spiral spring	2		0.93
4		electric	3		1.39
5	10.11 10.12	screening surface	87	94	92.56
6		coupling	4		4.26
7		spiral spring	1		1.06
8		ball bearing	1		1.06
9		electric	1		1.06

2. METHODOLOGY FOR TESTING THE FUNCTIONS OF DISTRIBUTION

The methodology proposed for testing the functions of distribution for the random variables, performance time, *TBF* and corrective maintenance time *TMC*, imply the following steps [1], [5], [7], [10]:

1. The determination of the empirical repartition functions, $\hat{F}(t_i)$ and $\hat{M}(t_{ri})$
2. The determination of the parameters of the functions of distribution:

- λ, the failure rate for the operating time, *TBF* and μ, the repair rate, for the corrective maintenance time, *TMC*, measured in $1/h$, the characteristics of the exponential distribution, symbolized *e*;
- the average m_n and standard deviation of σ_n of operating time measured in *h*, the characteristics of the normal distribution, symbolized *n*;
- the average repair time, m_{rlg}, the median repair time, t_{rmed} and the standard deviation σ_{rlg} of the repair time, measured in, *h,* characteristics of the lognormal distribution, symbolized *lg*
- the form parameters, β_1 and the real scale ones, η_1, of the operating time,

β_{1r} and η_{1r} parameters of the repair time, (β_1, β_{1r} - adimensional, η_1, η_{1r} expressed in *h*), determined using the method of the mean square errors specific to Weibull distribution, W_m;
- the form parameters β_2, the scale parameters, η_2 and the initialisation ones, γ, for the performance time, respectively β_{2r}, β_{2r}, γ_r for the repair time, (the adimensional parameter γ), estimated using the moments method, specific to Weibull's three-parametric distribution, W_m;

3. The determination of the punctual values of the theoretical functions of distribution, $F_e(t_i)$, $F_n(t_i)$, $F_{Wp}(t_i)$ and $F_{Wm}(t_i)$, respectively $M_e(t_{ri})$, $M_n(t_{ri})$, $M_{lg}(t_{ri})$, $M_{Wp}(t_{ri})$ and $M_{Wm}(t_{ri})$, using the values of the parameters determined at (2);

4. The modelling possibility of the (experimental) empirical distribution of the random variables of the mentioned theoretical distributions is tested based on the statistical data, using Kolmogorov-Smirnov test;

5. If more tested distributions may be accepted, the distribution where the value of the maximum deviation between the empirical and theoretical distributions is the smallest.

3. ESTIMATING THE RELIABILITY PARAMETERS

The time of actual operation of the screening surfaces are represented by the statistical series formed of n=48 values, in operation hours, until a failure appears: 15; 28; 31; 35; 39; 42; 54; 74; 78; 85; 102; 124; 126; 151; 162; 170; 174; 177; 180; 199; 208; 213; 231; 246; 252; 254; 266; 270; 278; 286; 286; 290, 294; 297; 326; 343; 392; 405; 412; 425; 430; 433; 444; 483; 503; 512; 533; 612. [15]

The values of the parameters of the functions of distribution for the screening surfaces presented in table 2 were determined using methods to the statistical. [1], [7], [10], [12]

Table 2. **The values of the parameters of the functions of distribution**

Distribution/Method	λ, 1/h	m_n, h	σ_n, h	β_1	η_1, h	β_2	η_2, h	γ
Exponential/The mean square errors method	$4 \cdot 10^{-3}$							
Normal/The maximum likelihood method		249	155					
Weibull 2 parameters Wp/The mean squares errors method				1.34	283			
Weibull 3 parameters Wm/The moments method						1.64	278	$6 \cdot 10^{-9}$

Table 3 presents the analytical expressions of the functions of reliability, the values of the maximum deviations from the empirical distribution, D_{max} and the critical values of the Kolmogorov-Smirnov (K-S) test, $D_{\alpha,n}$, allowing therefore a quantity and quality comparison of the assessed laws of distribution.

Table 3. **The functions of reliability for the screening surface**

Distribution	Reliability function, R(t)	Max. departure, D_{max}	Hazard α	Critical value, $D_{\alpha,48}$	Validation
Exponential	$e^{-0.0044 \cdot t}$	0.2270	0.01	0.2305	Yes
Normal	$\frac{1}{2} - \Phi\left(\frac{t-249}{155}\right)$	0.0830	0.20	0.1513	Yes
Weibull 2 parameters	$e^{-\left(\frac{t}{283}\right)^{1.34}}$	0.0941	0.20	0.1513	Yes
Weibull 3 parameters	$e^{-\left(\frac{t-6 \cdot 10^{-9}}{278}\right)^{1.64}}$	0.0888	0.20	0.1513	Yes

The diagrams in figures 2, 3, and 4 present the variation of different reliability indicators considering the operational time.

The grouping tendency, even the layering, of the curves of reliability for the normal and Weibull's laws of distribution, result from Figure 2, confirming therefore the close values of the maximum distances between the experimental and the theoretic distributions. It is also confirmed once again that any of these distributions expresses with sufficient precision the closest reliability indicators considering the real situation.

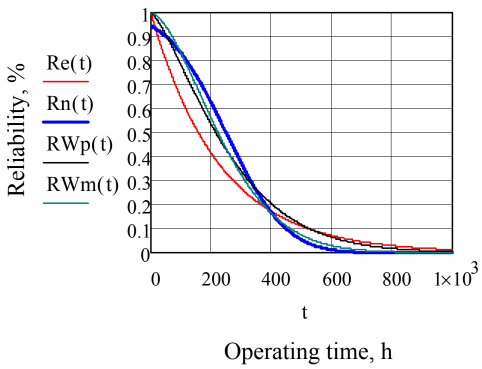

Fig. 2. The diagram of the functions of reliability

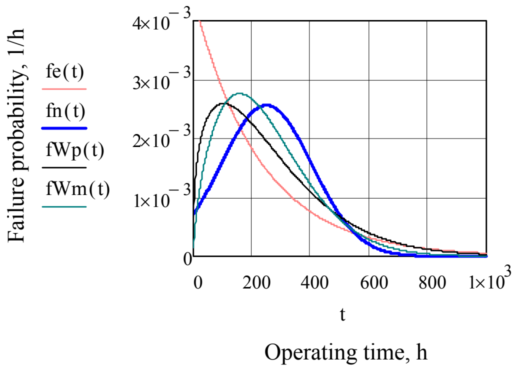

Fig. 3. The diagrams of the functions of failure probability

Decreased relative values of the reliability of the screening surfaces also result from these representations, resulting into a 60% chance for the surface not to break down after 200 hours of effective operation. It therefore means that with a 60% confidence level (a 40% risk level being a high risk level), for approximately 12 days of operation of the screen, the screening surface will break down, or, during a month, two defects may appear.

If an 80% reliability is imposed, which is a reasonable value in techniques it results a no defect operational time t_{80}=92 *hours*,, meaning that after approximately seven days of operation the repair action of the screening surfaces need to be undertaken.

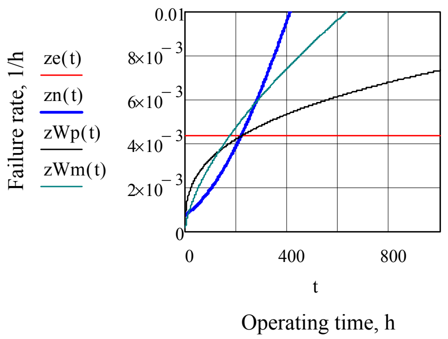

Fig. 4. The diagram of the functions of the rate of defects

Analysing the variation in time of the rate of defects of the screening surface, a strongly increasing tendency is observed, for every 200 hours of operation its value being $z(200)=4\cdot10^{-3}$ *defects/hour*, which is a very high value.

The reliability assessment carried on the screening surface leads at least to the following conclusions:

- the reduced reliability of the screening surfaces is due to the improper use of screens by processing a mixture of coal and waste in considerable quantities and dimensions, exceeding therefore the operational prescriptions implied by the documentation. The operational principle of the screen as well as the material processing technology leads to shocks and vibrations creating therefore premature defects namely mechanical aging of the machinery;
- in order to increase the life span of the construction of the screens it is required to reconsider the design and construction technology of the screening surfaces, namely to increase the mechanical wear resistance leading to shocks and vibrations as well as reconsider the construction material of the screening surface.

4. ESTIMATING THE MAINTAINABILITY PARAMETERS

The practical time of repairing the screening surfaces is represented by the statistical series which comprises n = 48 values, in repair hours until the elimination of the defect: 0.50; 1.00; 1.50; 2.25; 2.33; 2.33; 2.33; 2.58; 2.67; 2.75; 2.83; 2.84; 3.00; 3.08; 3.25; 3.75; 4.17; 4.17; 4.42; 4.50; 4.58; 4.66; 5.67; 6.17; 6.58; 6.58; 6.75; 6.83; 7.91; 8.59; 8.67; 8.83; 10.00; 10.67; 11.25; 11.58; 11.75; 12.34; 12.41; 16.50; 16.75; 17.50; 29.25; 29.50; 32.58; 32.92; 33.33; 34.76. [15]

Table 4 presents the values of the parameters of the theoretical functions of distribution for the repair time of the screening surfaces, used in expressing the maintainability indicators. [1], [7], [10], [12]

Table 5 presents the analytical expressions of the maintainability functions, the values of the maximum deviation from the empirical distribution, D_{max} and the critical values of the Kolmogorov-Smirnov (K-S), $D_{\alpha,n}$, test allowing the quality and quantity comparison of the laws of distribution considered in the study.

Table 5 shows that all five distributions are validated but the lognormal theoretical distribution best approximates the experimental function (empirical), with the maximum distance being the smallest of them all. Figures 5, 6, and 7 represent the variations in time of the functions of maintainability, of the density of portability of the repair time or reset, respectively the repair intensity.

Table 4. **The values of the parameters for the functions of distribution**

Distribution	μ, 1/h	m_{rn}, h	σ_{rn}, h	t_{rmed}, h	σ_{rlg}, h	β_{1r}	η_{1r}, h	β_{2r}	η_{2r}, h	γ, h
Exponential	0.09									
Normal		9.6	9.56							
Lognormal				6.22	0.96					
Weibull 2 parameters Wp						1.22	9.82			
Weibull 3 parameters Wm								1.00	9.62	$3 \cdot 10^{-9}$

Table 5. The maintainability functions for the screening surface

Distribution	Maintainability function $M(t_r)$	Max. departure, D_{max}	Hazard α	Critical value, $D_{\alpha,48}$	Validation
Exponential	$1-e^{-0.098 \cdot t_r}$	0.142	0.20	0.151	Yes
Normal	$\frac{1}{2}+\Phi\left(\frac{9.60-t_r}{9.56}\right)$	0.187	0.05	0.192	Yes
Lognormal	$\frac{1}{2}+\Phi\left(\frac{1}{0.96}\cdot ln\frac{t_r}{6.22}\right)$	0.089	0.20	0.151	Yes
Weibull 2 parameters, Wp	$1-e^{-\left(\frac{t_r}{9.82}\right)^{1.22}}$	0.118	0.20	0.151	Yes
Weibull 3 parameters, Wm	$1-e^{-\left(\frac{t_r-3.2 \cdot 10^{-9}}{9.62}\right)^{1.005}}$	0.151	0.10	0.173	Yes

Figures 5 and 6 show the grouping tendency, even layering, of the maintainability curves and the density of probability of the repair time for the exponential distribution, log-normal and Weibull's and bi and three-parametric laws, which confirm the close values of the maximum distances between the experimental and the theoretical distribution.

It is also confirmed once again that anyone of these four distributions precisely expresses the closest maintainability indicators towards the real situation.

It is also observed from the same representations the increased relative gaps between the normal distribution and the other laws of distribution considered within the study although the normal distribution is validated by the Kolmogorov-Smirnov (K-S) test.

It also results the reduced values of the maintainability of the screening surface, the probability that the surface be repaired or reset after five hours of repair activity being of only 40%. If an 80% maintainability is imposed, which is a reasonable accepted value in techniques, a repair and reset time of t_{80}=15 *hours* has to be considered, which is an extremely large value, considering the construction of the screening surface and its elements.

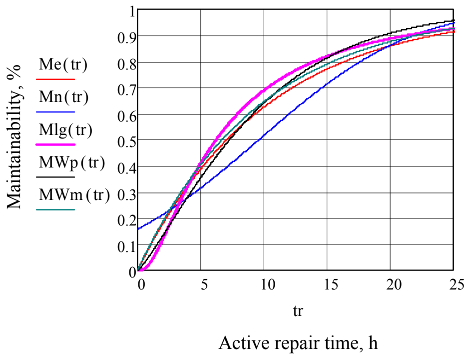

Fig. 5. Diagrams for the functions of maintainability

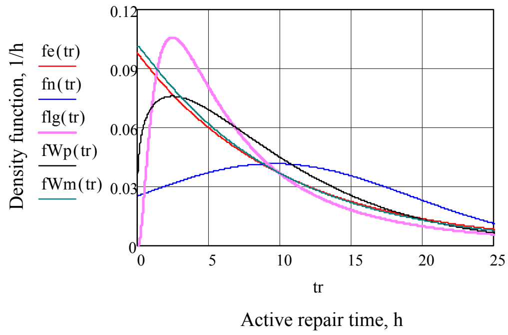

Fig. 6. Diagrams for the functions of probability density

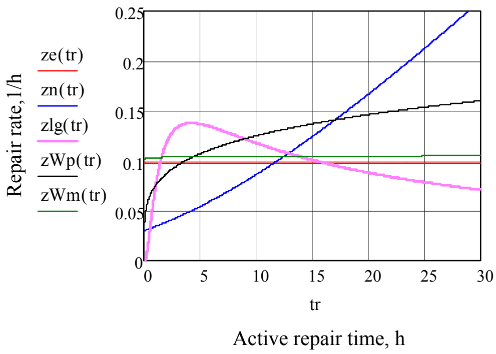

Fig. 7. Diagrams for the functions of the repair rate

Analysing the time variation of the intensity or the repair rate of the screening surface it is observed that there is an increased tendency as the time increases followed by a stabilising tendency, the normal distribution expressing discordances.

The increased corrective maintenance time is mainly due to a lack of maintenance management. The affirmation is based on the argument that the maintenance strategy chosen for the operation of the screens is that of corrective maintenance based on defects repair activities in order to bring the product within the quality conditions and to remove sudden defects or flawed operation.

Obviously, this kind of actions have a purely corrective characteristics and comprise the following:

- ensuring, during the appearance of the defect, the required specialised staff;
- the diagnostic of the defect, namely discovering the nature and cause of the defect;
- localisation of the defect;
- ensuring the material base, namely spare parts, tools and machineries required for the repair, consumables;
- repairing the defect, by partial of total replacement of one or several elements or part, which have contributed to the defect;
- checking the correctness of the maintenance operations.

Each one of these elements contributes to the creation of a substantial time fund, which unjustifiably extends the reset into operation of the machinery. The reduction of the repair time of the screening surface, respectively reducing the time the screens are not in operation may be realised by adopting a maintenance strategy planned ahead which based on the results of the reliability and maintenance analysis implies that after two calendar weeks, besides productive changes, a thorough control should be made of the state of the screening surface and of its metallic structure and work should be done in the weak spots observed meaning the reconsideration or adoption of a new maintenance strategy.

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5. CONCLUSIONS

The paper makes an analysis of the reliability and maintainability characteristics of vibrating screens composing the technological coal preparation lines.

The proposed and applied methodology allows the testing of the functions of distribution in such a way that it adopts that theoretical distribution which best characterises the functionality of the product. The determined reliability indicators prove the reduced quality level of the screening surfaces imposing therefore their redesign. The maintainability indicators are also uncorresponding being necessary the adoption of a preventive-planed maintenance system.

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