RELIABILITY ANALYSIS OF E_SR_C 1400 BUCKET WHEEL EXCAVATORS OPERATING IN OLTENIA LIGNITE OPEN PIT MINES

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1. ANALYSIS OF MECHANICAL FAILURES

The analysis of mechanical failures occurring in excavators ESRC 1400-1430 × 7-630, that operate in the **Oltenia Lignite Open Pit Mines,** was based on the information collected on faults from 8 excavators monitored during operation in 2010 year.

Fault analysis was performed on the main subassemblies of excavators, aiming to highlight the type of defect, the damaged component, the number of defects per subassembly and per entire excavator and also on the times when the excavator is out of order as a result of repairing.

The main types of failures by elements and components occurred during the analyzed period are at:

- the bucket wheel drive: drive gearbox failure (attack pinion) and the bearings of the first stage; gearbox lubrication system failure; screw fixation loosening of the gearbox semi-carcasses and of the gearbox as a whole; screw fixation loosening of the electric motor to gearbox; cardan shaft breaking;
- the bucket wheel: cracks in stator ring and wheel; breaking of buckets, ear catchers, bolts and wedges, teeth; lubrication system failure of main shaft. To be noted that teeth wear is not considered a failure, unless this is a premature one;
- the crawler track mechanism: breaking of tracks shoes (the most frequent); breaking of the connecting pins; connecting pins going out of holes as a result of improper fixation; premature worn of the spurs; tracks stretching system failure; failure of tracks gearbox drive; breakage of the coupling between the motor and the gearbox (the most common);
- the excavator inner belt conveyor system: destruction of coupling staples(the most common); the failure of idlers; the destruction of shock absorbing idlers; the deterioration of belt wipers; the breakage of the coupling between the motor and gearbox; drive and return drum failure by breaking the axles and bearings; deterioration of discharges and bunkers; jammed parts; deterioration of visiting and maintenance platforms for the belts.

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- the transfer feeder: the premature destruction of belts staples; uncoupling of tracks; breaking of shoes and connecting pins of the tracks; tracks stretching system failure; jammed parts;
- the boom lifting - lowering mechanism: breakage of boom supporting ropes; rope driving pulleys failure; unbalancing tensions in ropes; failure of the coupling between the motor and the gear drive winch;
- the mechanism for swiveling the excavator's superstructure: destruction of the drive gears; un-calibration of control clutches.

One usual way of fault analysis is using the Pareto diagrams that helps to obtain a distribution (quantity or percentage) of the defects in the operation of excavators, for a certain period of time, in descending order of occurrence frequency and importance weight.

Such a diagram allows to analyze all types of faults and, based on this, to rank the problem solving, giving priority to most serious problems. Based on this, the remedial and elimination of faults are established in the order of importance, percentage, frequency. Therefore, we can say that drawing the Pareto diagrams is the first phase in an action for improvement.

An analysis with Pareto diagrams shows that most times, eliminating the first 2-3 causes one can result the elimination of 60-70% of the deficiencies. Although it may seem simple, these diagrams are recognized as extremely useful in analyzing and evaluating faults in a cause-frequency basis. They are used when the types of faults or causes are well known, for a first association, connection, relationship between faults and their causes.

Following the logical sequence of steps found in the literature, the Pareto diagrams were drawn-up, which bring out the frequency of mechanical failures occurring in excavators ESRC-1400.

Based on the information taken from excavator's operation records there were centralized the types, frequency and total number of faults occurring during the period specified for each subset defective part, presented in Table 1.

Table.1. necessary data for drawing-up the Pareto diagram

Code	**Subassembly failed**	**No. of faults**	**Total cumulated**	**Percent from total**	**Percent cumulated**
A	Tracking system	76	76	29,23	29,23
B	On board belt conveyors	73	149	28,08	57,31
C	Transfer feeder	28	177	10,77	68,08
D	Bucket wheel	26	203	10,00	78,08
E	Swiveling mechanism	24	227	9,23	87,31
F	Bucket wheel drive	18	245	6,92	94,23
G	Boom lifting - lowering mechanism	12	257	4,62	98,85
H	Other subassemblies *	3	260	1,15	100
	Total	260	-	100	-

In figures 1, a) and b) the Pareto diagrams are presented in absolute frequency, and in Figures 2, a) and b, the same diagrams are shown based on cumulative frequency.

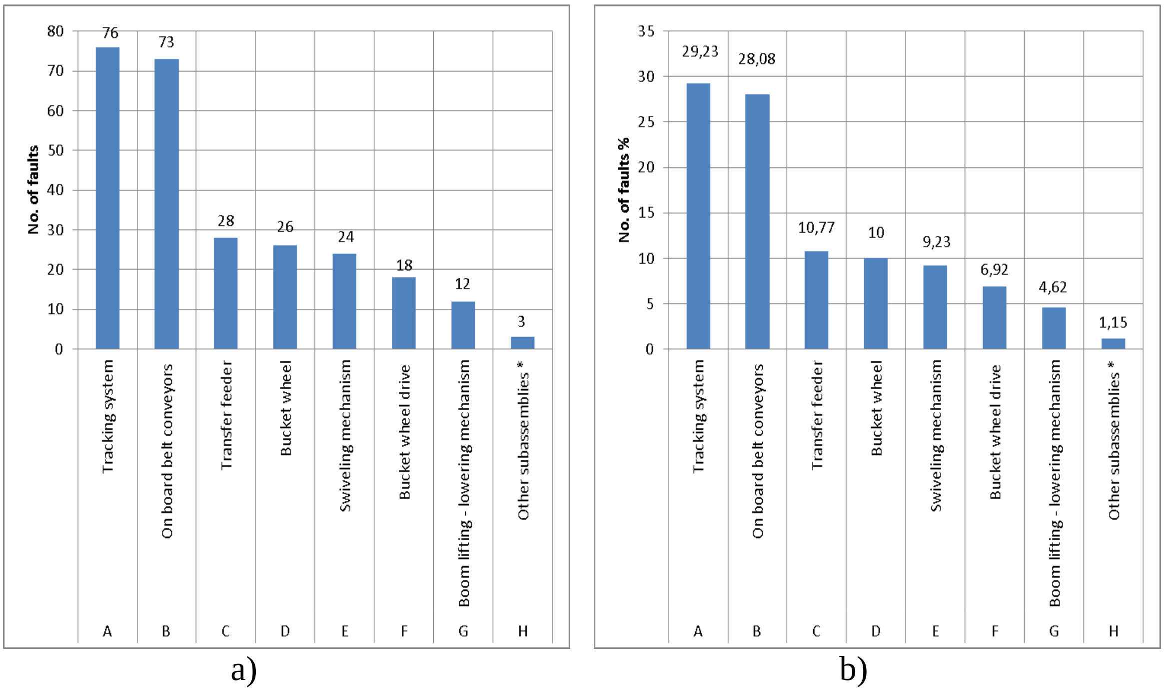

Fig.1. Pareto diagram in absolute frequency of failures expressed in no. of failures, a) and percentage, b)

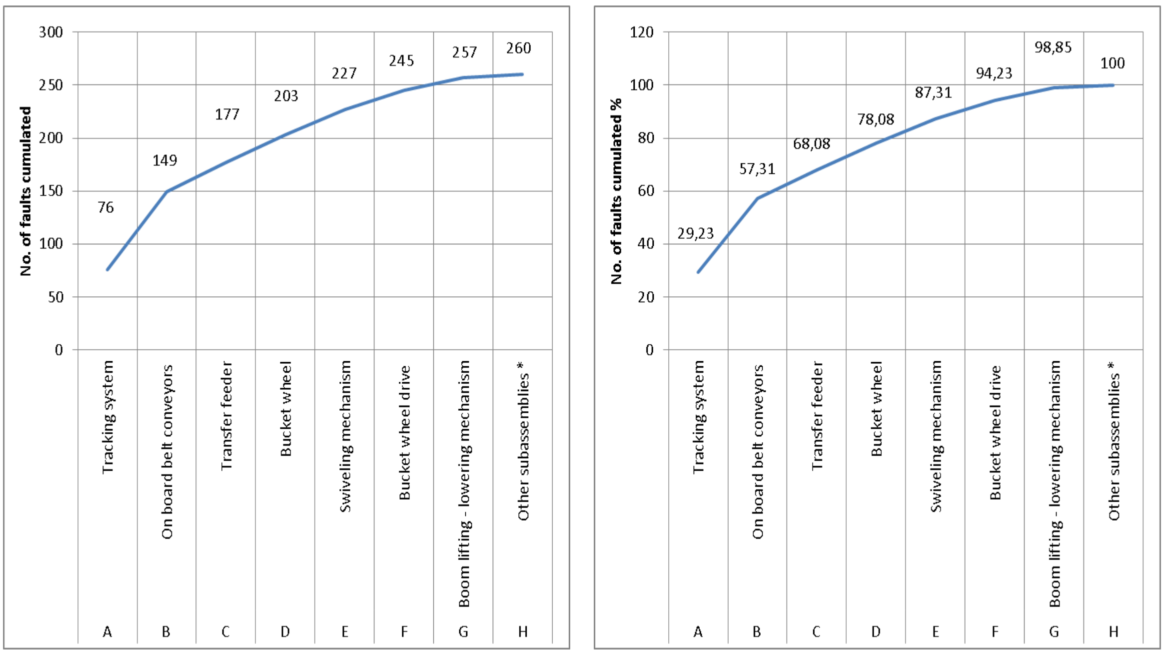

Fig.2. Pareto diagram in cumulative frequency of failures expressed in no. of failures, a) and percentage, b)

From the analysis of Pareto diagrams results that approximately 60% of the defects occurring in operation of the excavators are caused by two subassemblies, respectively the excavator tracking system and the on board belt conveyor system.

In order to increase the failure safe operation of the excavator and the reduction of maintenance costs, it is necessary to upgrade the two previously mentioned subassemblies.

The operational behavior in of the tracking mechanism of the excavator is very well highlighted by the present reliability study conducted to reveal the availability of all excavators, seen from the point of view of this subassembly.

2. STUDY OF THE RELIABILITY OF THE TRACK MECHANISM OF ESRC 1400 EXCAVATOR

In order to establish the moments of failure of the tracking mechanism, two databases were used:

- records for faults situation, outlining the day and time the fault occurred;
- records with the descriptions of the actual operation times, by days, of each excavator, which only takes into account the time that the excavator operated in coal or overburden, and the nature of all causes of downtimes of excavators.

Analyzing and interpreting the two databases, we obtained the string consisting of n = 71 values, ordered ascending, which represents the number of actual operating hours of effective functioning of the driving mechanisms until the failure, for the eight excavators, during a year : 10; 12; 13; 14; 15; 15; 16; 17; 17; 17; 18; 18; 25; 26; 28; 28; 29; 32; 33; 33; 35; 42; 43; 45; 50; 51; 54; 61; 64; 66; 69; 73; 92; 98; 100, 101; 105; 109; 113; 133; 137; 140; 151; 152; 156; 157; 162; 163; 170; 194; 202; 229; 320; 339; 341; 354; 370; 386; 406; 411; 540; 540; 612; 622; 638; 698, 749; 773; 801; 836; 1044.

This set of values can be considered an S1 type of statistical series in which all values are disjoint, for which, by default, we can be observed a large dispersion of values, the difference between the extreme values being very high. The values of the empirical repartition function, $\hat{F}(t_i)$ are shown in Table 2.

Table 2. Values empirical repartition $\hat{F}(t_i)$ function

1	0,009804	13	0,177871	25	0,345938	37	0,514006	49	0,682073	61	0,850140
2	0,023810	14	0,191877	26	0,359944	38	0,528011	50	0,696078	62	0,864146
3	0,037815	15	0,205882	27	0,373950	39	0,542017	51	0,710084	63	0,878151
4	0,051821	16	0,219888	28	0,387955	40	0,556022	52	0,724090	64	0,892157
5	0,065826	17	0,233894	29	0,401961	41	0,570028	53	0,738095	65	0,906162
6	0,079832	18	0,247899	30	0,415966	42	0,584034	54	0,752101	66	0,920168
7	0,093838	19	0,261905	31	0,429972	43	0,598039	55	0,766106	67	0,934174
8	0,107843	20	0,275910	32	0,443978	44	0,612045	56	0,780112	68	0,948179
9	0,121849	21	0,289916	33	0,457983	45	0,626050	57	0,794118	69	0,962185
10	0,135854	22	0,303922	34	0,471989	46	0,640056	58	0,808123	70	0,976190
11	0,149860	23	0,317927	35	0,485994	47	0,654062	59	0,822129	71	0,990196
12	0,163866	24	0,331933	36	0,500000	48	0,668067	60	0,836134		

The empirical repartition function values above were calculated with the formula:

$$\hat{F}(t_i) = \frac{i - 0{,}3}{n + 0{,}4} \tag{1}$$

where, i is the rank number and n is the total number of values in the string.

Considering the nature of the subassembly in the study, it is assumed that the times of failure, considered between two consecutive failures are distributed following a Weibull distribution law, as this will be confirmed or infirmed using concordance tests.

The probability density of failures for tri-parametric Weibull distribution is expressed by the relation:

$$f(t;\eta,\beta,\gamma) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right] \tag{2}$$

where β is the shape parameter, η is real scale parameter and γ is the initializing parameter.

The parameters of a tri-parametric Weibull distribution can be calculated using the method of moments. The shape parameter β is obtained by solving the equation

$$CV = \frac{\sqrt{\Gamma\left(\frac{2}{\beta}+1\right) - \left[\Gamma\left(\frac{1}{\beta}+1\right)\right]^2}}{\Gamma\left(\frac{1}{\beta}+1\right)} \tag{3}$$

where CV is the coefficient of variation, which is obtained using the relation

$$CV = \frac{s}{m} \tag{4}$$

where s is the standard deviation and m is the mean value of the string.

The scale parameter η is calculated with

$$\eta = s / C_\beta \tag{5}$$

and initializing parameter γ with the relation

$$\gamma = m - \eta\, K_\beta \tag{6}$$

In these relations K_β and C_β are coefficients dependent on the shape parameter β, which are calculated from the relations:

$$K_\beta = \Gamma\left(\frac{1}{\beta}+1\right) \tag{7}$$

$$C_\beta = \sqrt{\Gamma\left(\frac{2}{\beta}+1\right) - \left[\Gamma\left(\frac{1}{\beta}+1\right)\right]^2} \tag{8}$$

For the data above, with the mean value m = 207,225352 and standard deviation s = 249,051756 the parameters of the Weibull distribution are obtained are: β = 0,836403; η = 188, 528901; $\gamma = 2{,}3607\times10^{-6}$; K_β = 1,099170; C_β = 1,321027.

By calculating the elements needed to define the distribution and verification of the Weibullian character of the analyzed product behavior using the Kolmogorov-Smirnov concordance test, we obtain the maximum distance, D_{max} =

$0{,}085254 < D_{\alpha,\, n} = D_{80,\, 71} = 0{,}124985$, $D_{80,\, 71}$ being the Kolmogorov-Smirnov test feature for a confidence level of 80% and n = 71 values, so that the Weibullian character of failure times distribution is validated.

The tri-parametric Weibull distribution parameters characteristics are calculated with the equations:

- Reliability function:

$$R\left(t;\eta,\beta,\gamma\right) = \exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right], \% \tag{9}$$

- The non-reliability function:

$$F\left(t;\eta,\beta,\gamma\right) = 1 - exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right] \tag{10}$$

- Intensity or rate of failure:

$$z\left(t;\eta,\beta,\gamma\right) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \tag{11}$$

- average uptime:

$$m = \gamma + \eta\,\Gamma\left(1 + \frac{1}{\beta}\right) \tag{12}$$

- median of uptimes:

$$t_{med} = \gamma + \eta\left(-ln\,0{,}5\right)^{1/\beta} \tag{13}$$

In Figures 3, 4, 5 and 6 are shown the variations of the reliability indicators specific to the tracking mechanism of the rotor excavators.

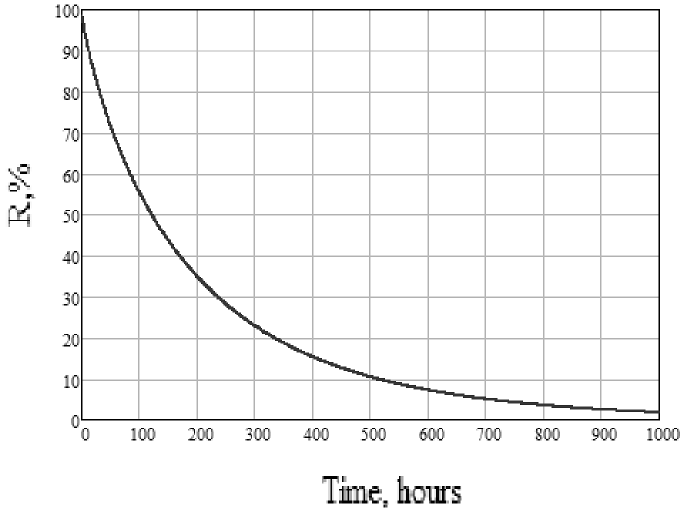

Fig. 3. Variation of the reliability function for the track mechanism of the excavator

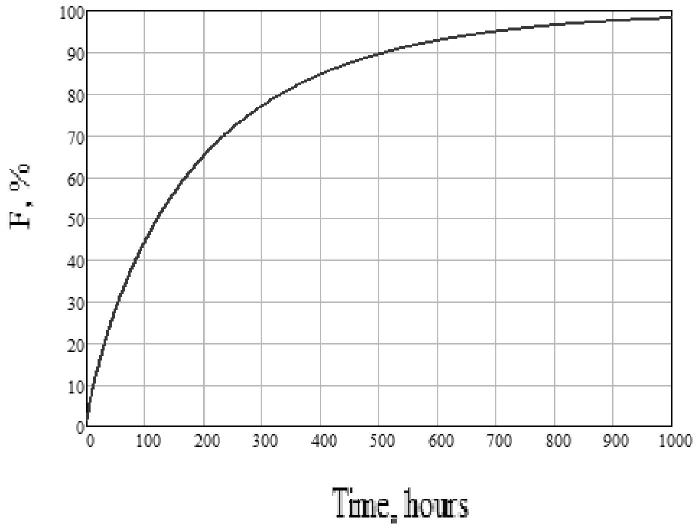

Fig. 4. Variation of the non-reliability function for the track mechanism of the excavator

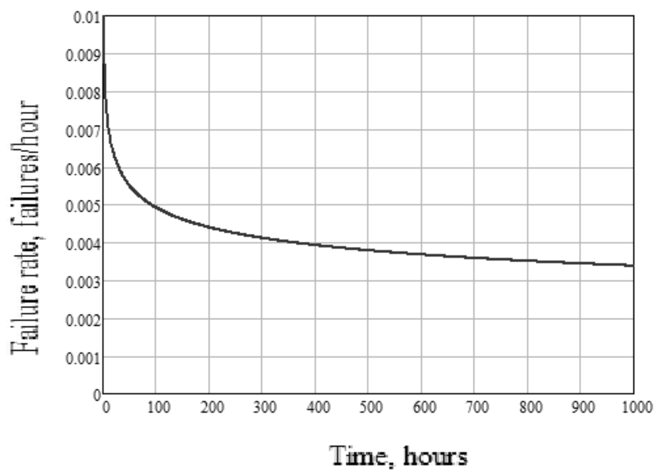

Fig. 5. Variation of the intensity of failure

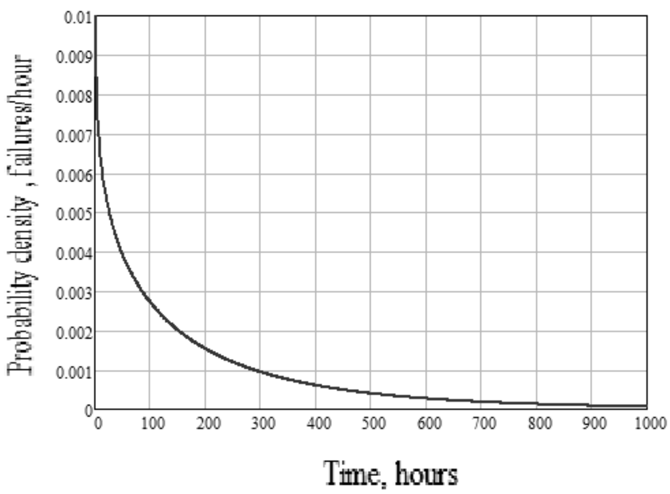

Fig. 6. The variation of the density of probability of time to occurrence of faults

The average time of fault-safe operation of the track mechanism of the excavator is 207 hours, and the median time of good functioning is 121 hours.

Since the probability density diagram of occurrence of failures is strongly asymmetric, the median time of good functioning better characterize the functionality of the moving mechanism, giving a good functioning of 121 hours, which is a very low value.

Considering that an excavator functions on average 15 hours a day, is expected that every 8 days the moving mechanism has a malfunction, which shows a very low level of reliability.

This is well evidenced by the analysis of reliability diagrams, which show that the probability of the moving mechanism no get damaged after 100 hours of actual functioning is only 60%, which is an extremely low value.

The low reliability of the moving mechanism requires its modernization with priority in order to increase the use of the excavator.

5. REFERENCES

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