Theoretical Considerations Regarding Spare Parts Reliability Evaluation Based On An Integrated Management System

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Abstract: - Due to the fact that a series of parts and subsets have a large proportion in the amount of expenses of a company, their operation monitoring is imposed in order to control their influence on the operational costs and therefore taking a series of decisions in order to increase their reliability. Monitoring their operational behavior has to be made during the entire life span of these spare parts, starting with their entering the company until taking them out of operation, the scope being that of determining their operational reliability. Therefore, in an Integrated Management System, it is imposed to implement not only the procedure of following the operation of spare parts during the defects notification period, procedure which only handles the means of solving the defects which may appear by the suppliers, but also a procedure for the evaluation of the reliability of parts supplied.

Key-Words: - reliability, Integrated Management System, biparametric Weibull distribution, Kolmogorov – Smirnov test

1 Theoretic considerations

Operational reliability represents the reliability determined by the results regarding the operational behavior during a certain period of time, of a large number of products used by the beneficiary. That is to say, reliability is the quality of the product extended in time. The objectives of a reliability study are:

- Knowing the defect (establishing the causes as well as the means of repairing them);
- Defects' physical analysis of defects;
- Quantitative and qualitative appreciation in time of the behavior of products and systems considering the influence of internal and external factors;
- Determination of mathematic models and determination and prognosis methods of the reliability based on trial operations and operational analyses of products and systems;
- Establishing the means of ensuring, maintaining and increasing the reliability during the design, creation, and operation phases of products;
- Establishing reliability data selection and processing.

2 Spare parts reliability evaluation steps

An Integrated Management System, together with the procedure of following the operation of products during the warranty period also contains a series of procedures for the evaluation of the reliability of the supplied products.Therefore, the steps to take for the evaluation of the reliability of spare parts are the following:

- Choosing the product, sample or lot, which will be the basis of the determination of reliability;
- Establishing the data collection and information systematization system;
- Statistic analysis of malfunctions based on observation results;
- Identifying the malfunction repair procedure, determination of parameters of theoretic distribution of malfunctions and estimation of reliability parameters; testing the repair chosen procedure;
- Final result analysis, conclusions, measures, forecast.

3 Evaluation of supplied spare parts' reliability

The reliability determination method, based on acquired data processing by following the operational behavior of products, is characterized by minimum expenses concerning the acquisition and

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process of information, but require as well either a long period of time of supervision or the supervision of a large number of products during a short period of time. The success of such a reliability analysis depends mostly on the correctness of information regarding the behavior of products.

In what the volume of the sample is concerned, the larger it is the more real are the result of the analysis. A sample with a number of elements is considered insignificant for the balance of the reliability of complex products. If there aren't enough exemplars of the specified product, data for a longer period of time are gathered for general statistics.

Data processing is meant to stabilize statistic information, obtained through a series of specific operations, which may be found in the following paragraphs.

3.1 Appointing the team of experts

The team will evaluate the reliability of the parts or of group of spare parts, according to specific responsibilities, time spent for the analysis, and the report presentation date regarding the evaluation of the reliability of spare parts.

3.2 Delimitation

The volume of the sample is being established, i.e. population or statistic group to be observed.

Delimitation represents a division of the studied phenomenon, being also necessary either because of a large number of units or because the destructive characteristic of experiments. Therefore, a delimitation corresponding to a partition of reality is made, such as for the analysis of the phenomenon to be made on a reality level following the extension to the entire population.

3.3 Data acquisition

Continuous operation of spare parts is observed during the entire time of the analysis, being monitored.

3.4 Filling in the continuous operation chart of the product, with all the events related its operation. Therefore, the following will be noted for each breakdown in the operation of the machinery:

- Name of the defect,
- Date and time of the defect,
- Machineries starting time,
- Duration of the defect,
- Operation period between two events.

From an informational content point of view, this document comprises general data as well as data regarding the information which is gathered based on observation. It is really important to consider whether the products may or may not be repaired. For repairable spare parts the chart may have the following content:

a. General data referring to:

Name of the place where the monitored product is used, Name of the product, The identification code of the product, Manufacturing year of the product, Starting operation date of the product, Name of the supplier.

b. Data comprising breakdown information:

Date and time of the breakdown: month, day, and hour of breakdown; The number of operational hours until the breakdown: the number of hours during operation or other parameters (km, number of cycles, etc.);

Cause of the defect: it will be specified if the defect is due to normal wear, breaking, corrosion, etc. If it's a visible effect the cause may be found right away. If it is the other way around, then we proceed with the total or partial dismantling of the product, mentioning the name of the malfunctioning element or elements;

The conditions in which the malfunction had appeared: it will be specified the factors leading to the malfunction such as overrun, wrong manipulation, etc.;

The means of remedying the malfunction: it will be specified the means of remedying the malfunction (replacement of parts with new or refurbished spare parts, adjustment operations, etc.);

The period of time for the remediation: the number of hours, and minute will be specified for the remediation of the malfunction;

Out of operation period: is marked by the number of hours and minutes when the product was out of operation, since the appearance of the malfunction until the new operation;

Cost of repairs: the cost of materials and man hours;

Observations: technical revision or the category of repairs (current or capital) or recommendations for the improvement of operation in order to avoid the appearance of similar malfunctions, will be specified;

Comprises the signature of the person filling in the chart.

For un-repairable spare parts, the chart may comprise the following:

a. General data:

The name of the place the product is monitored, The name of the product, The identification code of the product, The name of the supplier, The name or code of the contract.

b. Data comprising information concerning malfunctions:
Operation/installation date; Quantity, number of benchmarks put in operation; Measuring unit; Dismantling date; Number of operation hours until the malfunction; Installation / dismantle confirmation document (minutes of meeting, observation, etc.); Date of the confirmation document; Reason for the replacement; Observations; Comprises the signature of the person filling in the chart.

3.5 Data centralization

This operation consists in the acquisition of all data following to be processed. The operation is required when the steps 3.2 and 3.3 are realized distributiveli, i.e. in more experimental and observation places. The data centralization degree influences the compatibility of information to the model and the real situation.

3.6 Ordering

In order to obtain element referring to the statistic significance, experimental data are rearranged in an ascending manner. The result of such an operation is the acquisition of a statistic series.

3.7 Organization

The acquired statistic series obtained in step 3.6 is classified according to the following categories: (S1) – for which all the values are disjunctive values; (S2) – for which some of the values are repeated; (S3) – for which statistic data are grouped in intervals of disjunctive values. Statistic series are organized according to tables 1, 2 and 3.

Table 1 Data organization for series type (S1)

No.	Value
1	t_1
2	t_2
…	…
i	t_i
…	…
n	t_n

$t_1 < t_2 < \ldots < t_i < \ldots < t_n$;

$t_i \neq t_k \quad \forall i,k = 1,2,\ldots,n$; $i \neq k$, $n = N =$ sample volume = the number of the values obtained by measurements.

Table 2 Data organization for series type (S2)

No.	Value
1	t_1
2	t_2
…	…
i	t_i
…	…
ν	t_ν

$t_1 < t_2 < \ldots < t_i < \ldots < t_\nu$;

$t_i \neq t_k \quad \forall i,k = 1,2,\ldots,\nu$; $i \neq k$, $\nu < N$, $N =$ sample volume.

Table 3 Data organization for series type (S3)

No.	Value
1	$[d_0, d_1)$
2	$[d_1, d_2)$
…	…
i	$[d_{i-1}, d_i)$
…	…
m	$[d_{m-1}, d_m)$

3.8 Frequencies and empirical distribution functions determination

The Absolute frequency and, n_i and the relative frequency, f_i are determined. The empirical distribution function, $F_n(t)$, is given by the values of the relative frequencies smaller or equal to a value t. Therefore, for the data organized in operation 3.5, it results:

a) for the series type (S1) the frequencies are not determined because these are equal to all the values which may appear,

$$n_i = 1;\; f_i = \frac{1}{N};\; \forall i = 1,2,\ldots,N \qquad (1)$$

The empirical distribution function is determined with the relations:

- for $N \leq 10$,

$$\hat{F}(t) = \frac{i}{N+1},\; t_{i-1} \leq t < t_i,\; i = 1,2,\ldots,N, \qquad (2)$$

Determined based on the progression;

- for $N > 10$

$$\hat{F}(t) = \frac{i - 0,3}{N + 0,4},\; t_{i-1} \leq t < t_i,\; i = 1,2,3,\ldots,N, \qquad (3)$$

Results in considering the median;

b) For the statistic series type (S2), table 4 is filled in for the determination of the frequencies.

Table 4 Frequencies for the statistic series type (S2)

No.	Values	Absolute frequency, n_i	Relative frequency, f_i
1	t_1	n_1	$f_1 = n_1 / N$
…	…	…	…
i	t_i	n_i	$f_i = n_i / N$
…	…	…	…
ν	t_ν	n_ν	$f_\nu = n_\nu / N$
		$\sum_{i=1}^{\nu} n_i = N$	$\sum_{i=1}^{\nu} f_i = 1$

The empirical distribution function is determined here with the following relation

$$\hat{F}(t) = \sum_{j=1}^{i-1} f_j, \quad \text{pentru} \quad t_{i-1} \le t < t_i,\ i = 2,3,\ldots,\nu \quad (4)$$

c) For the statistic type (S3), the absolute frequency, n_i, is determined for the value interval $[d_{i-1}, d_i)$ being given by the characteristic value number found in the specified interval. Conventionally, it is considered the values corresponding to the frequencies are given by:

$$t_i = \frac{d_{i-1} + d_i}{2} \quad (5)$$

The empirical distribution function is determined with the relation

$$\hat{F}(t) = \sum_{j=1}^{i-1} f_j + \frac{t - d_{i-1}}{d_i - d_{i-1}} f_i, \quad \text{pentru} \quad d_{i-1} \le t < d_i \quad (6)$$

where $d_i - d_{i-1}$ represents the length of the interval, while $i = 1,2,\ldots,m$.

For $d_0 < t \le d_m$, relation (6.6) becomes

$$\hat{F}(t) = \sum_{j=1}^{i-1} f_j + \frac{f_i}{2},\ i = 1,2,\ldots,m \quad (7)$$

Table 5 Frequencies for the statistic series (S3)

No	Value Interval	Conventional Value	Absolute Freq. n_i	Relative Frequency, f_i
1	$[d_0, d_1)$	$t_1 = \frac{d_0 + d_1}{2}$	n_1	$f_1 = \frac{n_1}{N}$
…	…	…	…	…
i	$[d_{i-1}, d_i)$	$t_i = \frac{d_{i-1} + d_i}{2}$	n_i	$f_i = \frac{n_i}{N}$
…	…	…	…	…
m	$[d_{m-1}, d_m]$	$t_m = \frac{d_{m-1} + d_m}{2}$	n_m	$f_m = \frac{n_m}{N}$
			$\sum_{i=1}^{m} n_i = N$	$\sum_{i=1}^{m} f_i = 1$

3.9 Presenting the information obtained as appearance frequencies and as empirical distribution functions

The graphic representations of experimental data may show the type of the theoretic distribution followed by the random variable.

3.10 Determining the statistic indicator describing the behavior of the characteristic as random phenomenon

The following will be determined:

- Average values showing the central tendency of the characteristic, respectively the simple and ponderous arithmetic progression;
- The median of the values series, M_e;
- Module, M_o;
- Dispersion, D;
- Average square average deviation, s;
- Variation coefficient, CV.

3.11 Determining the theoretic distribution function corresponding to the empirical function established in at 3.8

Extrapolation is mainly used in order to determine the theoretic distribution function, which may determine the appearance of an error. It is therefore determined the corresponding theoretic model which will be the base while estimating the studied characteristics.

Passing on to the empirical model, obtained by the appearance or truncate the reality, to generalizing results is sustained by Glivenco-Cantelli theory, according to which in case of a big enough volume population, the event that the deviation of the empirical distribution function $\hat{F}(t)$ from the theoretic function $F(t)$ be zero represent the only event, i.e.

$$P\left(\lim_{N\to\infty} \sup_{t\in R} \left|\hat{F}(t) - F(t)\right|\right) = 1 \quad (8)$$

where R represents the array of real numbers.

In order to adopt the theoretic model of the distribution there is the need to apply the accordance tests between the empirical and theoretic distributions.

3.12 Determining the parameters of the theoretic functions and reliability indicators

It is determined, based on adequate methods, parameters defining theoretic distributions which describe the studied phenomenon. Based on these parameters, the reliability indicators will be determined.

Speaking of a statistic analysis of random values, respectively the frequency of appearance of malfunctions during the operation of the machineries, choosing a distribution law was necessary.

In the case of machineries and installations with an increased degree of complexity, in order to determine the reliability of their components, the biparametric Weibull distribution law of the malfunction frequency, using the least square method.

This distribution model uses three parameters:

- The form parameter β;
- The distribution parameter λ;
- The scale parameter η;

The form of the reliability function is:

$$R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{9}$$

In order to apply the least square method, the input data group and form a series type (S3), and in order to establish the length of an interval the Sturges relation is used,

$$\Delta d = \frac{d_{max} - d_{min}}{1 + 3{,}322 \lg N} \tag{10}$$

where: d_{min} is the minimum value of the statistic series; d_{max} - is the maximum value of the statistic series.

4 Determining the empiric distribution parameters

The study was made considering the teeth of bucket wheel excavators in Berbeşti, Roşia, Peşteana and Olteț quarries belonging to the National Company of brown coal Oltenia. The following simplifying hypotheses were considered:

- The teeth were installed on the same type of excavator in the same quarry;
- It has been considered that the teeth were kept under the same force independent on the nature of rock they sank into;
- The wear does not depend on the nature of the rock they operate in, considering the war due to the abrasive phenomenon is equivalent to the wear due to coal cutting phenomenon;
- The entire set is replaced at once.

The estimation of reliability parameters was made considering that until they fall off the set of teeth follow the Weibull distribution law, using the least square method.

The resulted intervals, the empiric distribution function and the necessary measures for the determination of the parameters of the biparametric Weibull distribution are presented in Table 6.

The determination formulas used for the parameters of the biparametric Weibull formula are the following:

Form parameter:

$$\hat{\beta} = \frac{n\left[\sum_{i=1}^{n} \ln\ln\frac{1}{\hat{R}(t_i)}\ln t_i\right] - \left[\sum_{i=1}^{n}\ln\ln\frac{1}{\hat{R}(t_i)}\right]\left(\sum_{i=1}^{n}\ln t_i\right)}{n\left[\sum_{i=1}^{n}(\ln t_i)^2\right] - \left(\sum_{i=1}^{n}\ln t_i\right)^2} \tag{11}$$

The distribution parameter:

$$\hat{\lambda} = \exp\left\{\frac{\left[\sum_{i=1}^{n}\ln\ln\frac{1}{\hat{R}(t_i)}\right]\left[\sum_{i=1}^{n}(\ln t_i)^2\right] - \left(\sum_{i=1}^{n}\ln t_i\right)\left[\sum_{i=1}^{n}\ln\ln\frac{1}{\hat{R}(t_i)}\ln t_i\right]}{n\left[\sum_{i=1}^{n}(\ln t_i)^2\right] - \left(\sum_{i=1}^{n}\ln t_i\right)^2}\right\}; \tag{12}$$

The estimated scale parameter is:

$$\hat{\eta} = \frac{1}{\hat{\lambda}^{\frac{1}{\hat{\beta}}}} \quad (13)$$

Introducing the above values in relations (11), (12) and (13) the estimated values of the parameters of the biparametric Weibul distribution are determined:

- the coefficient of form $\hat{\beta} = 1{,}513614904$;
- parameter $\hat{\lambda} = 0{,}000123$;
- the scale parameter $\hat{\eta} = 382{,}50$ hours.

Distributions verification and validation

The use of Kolmogorov-Smirnov test verifies if the chosen distribution is according to the experimental data. The parameters of the theoretic distribution are $\hat{\beta}$ and $\hat{\eta}$.

The necessary determination methods for the application of the test, for the two variants, are presented in Table 7.

Statistics d is determined using the following relation:

$$d = \max_{1 \le i \le n} \left\{ \left| F(t_i) - \hat{F}(t_i) \right| \right\} \quad (14)$$

k is determined using the following relation:

$$k = d\sqrt{n} \quad (15)$$

From the verification tables of Kolmogorov – Smirnov test, variant II, $P(k)$ measure is determined, i.e. the accordance probability between the experimental function and the theoretic one. It is appreciated that for $P(k) > 0{,}05$ the accordance is corresponding.

Table 7 Necessary measures for the application of Kolmogorov-Smirnov test, for tooth bucket 1400M II, Berbeşti Quarry

i	$\bar{d}_i$	$F(\bar{d}_i)$	$\hat{F}(\bar{d}_i)$	$\left\| F(\bar{d}_i) - \hat{F}(\bar{d}_i) \right\|$
1	50	0.04493	0.050	0.005070
2	150	0.215311	0.200	0.015311
3	250	0.408651	0.400	0.008651
4	350	0.582821	0.550	0.032821
5	450	0.721654	0.683	0.038320
6	550	0.823209	0.750	0.073209
7	650	0.892611	0.967	**0.074060**

The value $d = 0{,}07406$ results from the analysis. Relation (15) gives the following result:

$$k = 0{,}07406 \cdot \sqrt{30} = 0{,}4056 \quad (16)$$

$P(k)$ measure is determined from the verification tables of Kolmogorov – Smirnov test, variant II.:

$$P(k) = 0{,}9972 >> 0{,}05 \quad (17)$$

And therefore the proposed accordance between the empiric and theoretic function is true.

5 Conclusions

- The determination of the reliability of products and applying it within the supply of results is laborious and difficult if there is a lack of observation in their operation and of an informational system for data processing.
- The reliability forecast also allow the evaluation of maintenance tasks in case of repairs and the amount of spare parts which should be provisioned in order to face random defects of a machine park. On the other hand, during the same previsions, the same components recording progressive wear and need to be systematically replaced the statement of a maintenance schedule.
- The reliability studies bring an important support for the maintenance services in all the problems related to the determination of the maintenance politics. The scope of this optimization may be either the minimization of maintenance costs (personnel and spare parts stock), or the maximization of the availability of the products, for given costs.
- Based on the data obtained during operation, using specific methods in the theory of reliability, the empiric parameters of the biparametric Weibull distribution have been determined, and characterizes the operational behavior of analyses teeth and the correctitude of the distribution was validated through accordance for the considered cases.

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