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Contributions to Production Systems Functional Reliability Analysis

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ABSTRACT

In this paper production systems functional reliability is studied, by using graphical methods. The method that has been used estimates reliability indicators values based on probability networks. A comparative analysis between machine-tool different parts reliability is also presented, together to its influence onto the entire equipment reliability.
***Keywords**: reliability, parametric method, probability network.*

1. Data Acquisition Method

Analysis of functional reliability, the main subject of this paper, supposed a manipulation of data collected from "Exploitation reports" stored at the Equipments maintenance department from "PROMEX" Company from Brăila. The analyzed batch of machine-tools satisfied the following conditions:

- homogeneity, meaning that all turning machines are SNA 500 type and are coming from the same manufacturing generation;
- exploitation conditions, specific to manufacturing by cutting departments (FE 300 and FE 400), were similar: various operations (exterior and interior turning, threads cutting etc.) comparable working regimes (hard cutting or finishing) pieces having different physical and mechanical characteristics (steel, cast iron, aluminum, bronze, brass etc.);
- operating staff has, generally speaking, medium qualification (II, III and IV categories);
- equipment loading (production level) quite equal and distributed onto two daily turns.

To simplify data collecting process, the supposition that turns worked on stationary regime was made; as consequence, the following criteria were fulfilled:

- the equipment has finished its lapping period;
- defects appearance periodicity is relative constant and reduced during each observation period;
- behavior regime during exploitation is of the type without memory, meaning that the status and the way of functioning at a given moment are not depending on the past (present defects are not under the influence of anterior ones).

Under these conditions, it is possible to substitute the data collected from a single machine-tool, during a very long period (longitudinal summing) by a sample composed by a number great enough of homogeny equipments ($N_u > 25$, as mentioned into dedicated literature) that are studied during shorter periods of their exploitation (transversal summing).

2. Calculus of Functional Reliability in the Case of a Turns Batch

The times of god functioning between two successive defects of each turn, (t_i), were collected in the case of the same observation period (a calendar year). It has been considered that a turn, once repaired, works at the same technical parameters as a new one. Thus, the $N_e = 136$ events, recorded in the case of $Nu = 34$ turns, could be considered as being produced by 136 equipments being pursued until the first defect took place.

Functional reliability study, in the case of the turns batch characterized by a breaking out probability variable during time, was realized by using the statistic model defined through Weibull repartition law. In this case, analytical expression of reliability indicator, R(t), has the shape

$$R(t)=e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}, \qquad (1)$$

where: γ means the position parameter;
η – real scale parameter of probability network;
β – parameter of network shape.

Continuous random variable is represented by the time of good functioning between two successive reparations, t_i.

To do data statistic analysis, they were grouped in intervals having the same width, h. More precise, the good functioning time had the extreme values t_{min} = 30 hours and t_{max} = 1280 hours. These were divided into 13 intervals (Table 1), whose width was found by using Sturges relations:

$$h=\frac{t_{max}-t_{min}}{1+5{,}5\lg N_e}\cong 100 \text{ hours.} \qquad (2)$$

Table 1

Crt. No.	Interval Limits, $t_i - t_{i+1}$	Interval Medium Value, $(t_n)_{med}$	The Number of Events during the Interval, N_n	ΣN_n	Empiric Repartition Function, $F^*(t_i)$
1	0-100	50	17	17	0,123
2	100-200	150	22	39	0,287
3	200-300	250	16	55	0,404
4	300-400	350	22	77	0,556
5	400-500	450	25	102	0,750
6	500-600	550	16	118	0,868
7	600-700	650	4	122	0,897
8	700-800	750	0	122	0,895
9	800-900	850	3	125	0,919
10	900-1000	950	5	130	0,956
11	1000-1100	1050	3	133	0,978
12	1100-1200	1150	2	135	0,993
13	1200-1300	1250	1	136	1

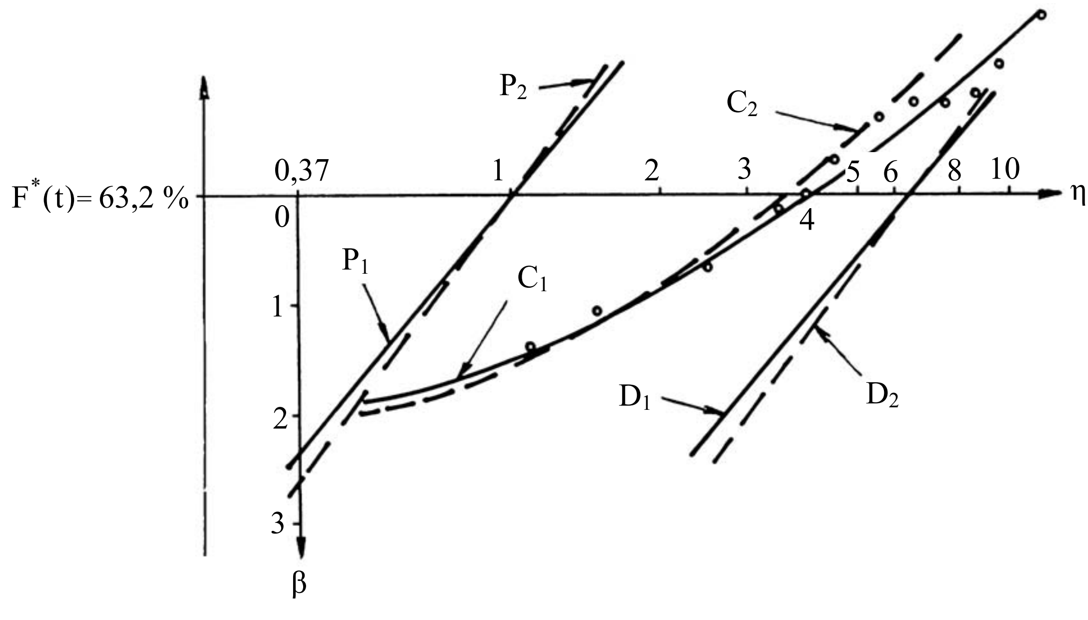

Fig. 1 – Graphic Representation of Empiric Repartition Function of the Functioning Time, $F^*(t_i)$, (curves C_1 and C_2)

The parameters of Weibull repartition law were determined by using the graphical method, with the help of Alen Plait diagram. The diagram was drawn after transforming relation (1) into a linear one, by applying two times the logarithm function,

$$\ln\ln\frac{1}{R(t)}=\beta\ln(t-\gamma)-\beta\ln\eta. \qquad (2)$$

When γ = 0, relation (2) will become

$$\ln\ln\frac{1}{R(t)}=\beta\ln t-\beta\ln\eta. \qquad (3)$$

Between the terms $\ln\ln[R(t)]$ and $\ln t$ there exist a linear relation that allows the construction of probability network (Figure 1). Thus, the curve C can be drawn, as defined through couples of points $[t_i, F^*(t_i)]$. By t_i were denominated the functioning times values, increasingly arranged if referred to abscises logarithmic scale, while $F^*(t_i)$ means the empiric repartition function of functioning time.

So, γ parameter value may be found graphic or by interpolation, by using the relation

$$\gamma = \frac{t_1 \cdot t_n - t_m^2}{t_1 + t_n - 2 \cdot t_m}, \tag{4}$$

where t_1 and t_n means the functioning time extreme values;

t_m – the abscise of empiric repartition function with medium value.

Linearization of C curves (Figure 1) can be realized by summing to each abscise the constant value of γ parameter. Thus, D straight lines can be drawn.

The value of scale parameter, η, is given by the abscise of intersection point between D straight line and the line corresponding to the ordinate $F^*(t)$=63,2 %. The particularity of this point is given by the equality t = η and corresponds to a reliability minimum value, R(t) > 36,8%.

Through the point having (1; 63,2) co-ordinates, a straight line, P, parallel to D can be drawn. The intersection between P line and the parallel to ordinates axis that passes by the point having (0,368; 63,2) co-ordinates defines the value of shape parameter, β.

As it follows from above, in the case of the entire batch of events (N_e=136), it were drawn the curve C_1 and the straight lines D_1 and P_1, which leads to the following expression of reliability indicator:

$$R_1(t) = e^{-\left(\frac{t-250}{635}\right)^{2,4}}. \tag{5}$$

By using the same procedure, but only for the events included into the first 5 intervals (Table 1), that contain 75% from the total number, din total, there were drawn: the curve C_2 and the straight lines D_2 and P_2. With their help, the equation of reliability function was reformulated as

$$R_2(t) = e^{-\left(\frac{t-272,5}{645}\right)^{2,65}}. \tag{6}$$

By using the equations (5) and (6), the values of functional reliability were calculated to entire batch of turns, for the moments t_k=500 hours and t_q=1000 hours. Conform to results presented in Table 2, the error introduced by relation (6) is smaller than 5%.

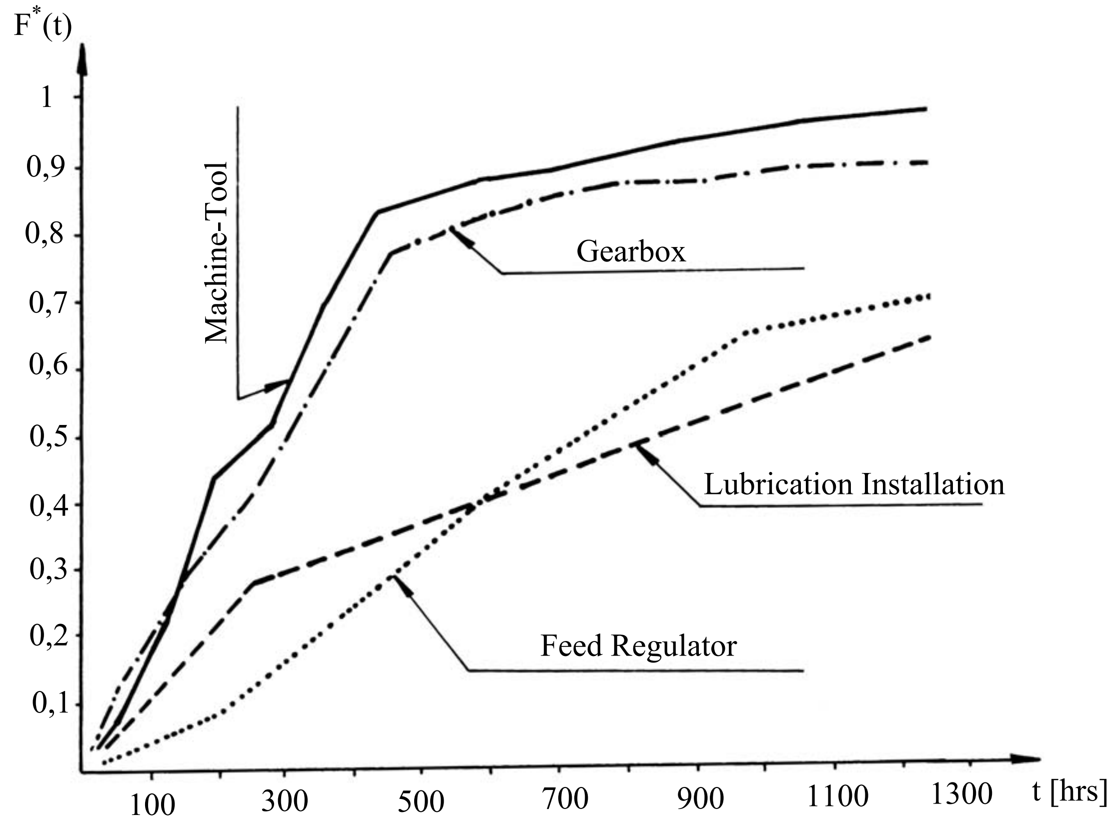

Fig. 2 – Graphic Representation of Empiric Repartition Functions of Functioning Time, $F^*(t_i)$, in the Case of Machine-Tool Parts and also in the Case of Entire Equipment.

Table 2

t	t_k= 500 hrs	t_q=1000 hrs
$R_1(t)$	0,901	0,238
$R_2(t)$	0,920	0,242

As consequence, experiments duration can be reduced by 2.5 times, from 1280 hours to only 500 hours. The number of recorded observations also decreases from 136 to 102.

The method gives the possibility to obtain correct results and has the advantage of reducing the time necessary to decide about maintenance actions to increase machine-tool reliability parameters.

3. Compared Analysis of Batch Turns Parts Exploitation Reliability

When designing machine-tools, there are often used typeset parts. These are conceived having as purpose different values of provisional reliability. This way, the reliability of turns batch was studied by having in view machine-tool behavior during exploitation, as ensemble and, in particular, as parts: gearbox, feed regulator, lubrication installation.

By using data extracted from evidence files, the curves of functioning time empiric repartition functions $F^*(t_i)$ were drawn, in the cases of analyzed parts and also global, to entire equipment. By making a comparison between curves shape, the influence of provisional reliability level considered, when designing parts, onto entire machine-tool exploitation reliability was evaluated (Figure 2).

It was noticed that in the cases of about 85% from total number of observations, the influence of gearbox defects is predominant on which concerns equipment global reliability. Thus, the values of good functioning medium time between two successive defects are:

- 257 hours, to entire machine-tool;
- 323 hours, to gearbox;
- 1028 hours, to feed regulator;
- 1400 hours, to lubrication installation.

We can observe that, when good functioning time has values smaller than 500 hours, gearbox reliability increase leads to a substantial improvement of entire machine-tool reliability.

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Rezumat

În cadrul lucrării, este studiată, prin metode grafice, fiabilitatea funcțională a sistemelor de producție. Procedeul utilizat estimează valorile indicatorilor de fiabilitate cu ajutorul rețelelor de probabilitate. De asemenea, este prezentată o analiză comparată a fiabilităților subansamblelor dintr-o maşină-unealtă şi influența acestora asupra fiabilității întregului utilaj.

Résumé

Dans ce travail, il s'agit d'étudier, à l'aide de méthodes graphiques, la fiabilité fonctionnelle des systèmes de production. La méthode utilisée estime les valeurs des indicateurs de fiabilité à l'aide des réseaux de probabilité. En même temps, il est présentée une analyse comparative pour la fiabilité des sub-ensembles d'une machine-outil et leur influence sur la fiabilité d'outillage tout entier.