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FORECAST AS METHODOLOGY FOR EQUIPMENTS RELIABILITY INCREASE

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ABSTRACT

The assessment of certain equipment reliability in the stage of its design has a forecast character. The factors with influence onto this quality feature are numerous. The impact of each among them is hard to be precisely determined – sometimes unpredictable things do happen. A methodology dedicated to forecast the machine-tools safe functioning indicators is presented in this paper. It lays on three methods already proved in prospective analysis practice: the morphological method, the extrapolation method, and the statistic method.

KEYWORDS: safe functioning, forecast, morphological analysis, trends extrapolation.

1. INTRODUCTION

The necessity of machine-tools reliability forecasting is coming from the need of quantitatively and qualitatively assessing the trends of machine-tools safe functioning indicators, during a given time interval.

If speaking in general, then a system safe functioning is under control when at least one of the following parameters, characterizing the duration of functioning without failures, is known: *i)* the safe functioning function, $p(t)$; *ii)* the failures rate, $\lambda(t)$, and *iii)* the density of functioning without failures time distribution, $f(t)$.

The forecast of safe functioning indicators should be concerned about the synthetic analysis of the approached system, meaning the study of its future evolution by starting from the whole entity and going down to its component elements or about the morphological analysis, which goes reverse, from the analysis of system constitutive elements, towards its entire vision.

In the case of an intuitive approach, we have to deal with experimental elements concerning the existing machine-tools, while the theoretical approach grounds on systemic abstractions, used for building and studying reality models and their dynamics.

The methodology for safe functioning indicators forecast is based on some classical methods, as the morphological method, the trends extrapolation method, or the statistical method.

2. SAFETY INDICATORS FORECAST BY MORPHOLOGICAL METHOD

The morphological method consists in decomposing the machine-tool in systems, sub-systems and parts, followed by finding the safety indicators for each element and revealing the relations between them. The ranking criteria that could be applied to a machine-tool morphological model are presented below.

Table 1 – Ranking criteria

System level
Architectural structure Main sub-system Component elements
Morphological model
Kinematical structure Connections between elements Works drawings
Examples
Numerical controlled lathe Gearbox Spindle

The machine-tool, regarded as system, consists in serial or parallel connections of elements. In the case of a serial connection, the safety indicator having the minimum value of all is the most likely safety indicator of the whole ensemble – the same way as the strength of a chain is the one of its weakest link.

If the serial system is made from *n* identical elements, and if the failure probability of each element is defined by the probability density function $F_R(x)$, and x is meaning the intensity of loading the considered element, then the probability of the element good functioning is:

$$P_1(n) = 1 - F_R(x)\,. \qquad (1)$$

By admitting that the elements failure probabilities are independent, the probability of all elements good functioning is:

$$P_t(n) = [1 - F_R(x)]^n\,. \qquad (2)$$

As consequence, the machine-tool (considered as serial system) failure probability is:

$$P_t(n) = 1 - [1 - F_R(x)]^n\,. \qquad (3)$$

For example, let us consider the machine-tool lack of precision due to its slides. Here by x we mean the variable characterizing the deformation that makes the machine tool to loose its proper functioning.

We admit a random distribution of deformations along the elements defining the slides. Therefore, by increasing the number of elements, the value of ratio between deformation and slides total length will go towards a limit $f(x)$, meaning a failure density.

We further suppose that one of the slides, having the length l_1, is affected in average by n failures. If this slide is divided in sections of l length, then the probability that one among the failures occurs in one among the sections is $1/l_1$, hence the probability of the opposite event – the probability of not having this failure – is $1 - 1/l_1$. The probability that anyone of these n failures does not appear in the considered section is $(1 - l/l_1)^n$, representing the probability of its good functioning.

If the length of the slide section increases, then the failures number $n(x)$ also increases on such a manner as the product $n(x)\cdot l_1$ tends to $f(x)$. In this case, the good functioning probability becomes:

$$\lim\left[1 - \frac{l}{l_1}\right]^{n(x)} = \lim\left[\left(1 + \frac{1}{-l_1/l}\right)^{-l_1/l}\right]^{-\frac{n(x)}{l_1}\cdot l} = e^{-f(x)\cdot l}\,. \qquad (4)$$

The failure probability of an element of l length is:

$$P_1(x) = 1 - \exp[\,f(x)l\,]\,. \qquad (5)$$

If $l = 1$, the failures density $f(x)$ will be:

$$f(x) = -\ln[1 - P_1(x)]\,. \qquad (6)$$

In the case of parallel associations of elements, the safe functioning indicators evaluation is more complicate. When all the terms from a sum are equal, its average value is the sum of its terms standard deviations:

$$\overline{X} = n\overline{x}\,, \qquad (7)$$

$$\sigma^2(X) = n\cdot\sigma^2(x)\,, \qquad (8)$$

$$\sigma(X) = \sqrt{n}\cdot\sigma(x)\,. \qquad (9)$$

3. SAFETY INDICATORS FORECAST BY TRENDS EXTRAPOLATION METHOD

Machine-tools safe functioning indicators are dynamical and change their values in time. This evolution is due to the improvement of the existing technical solutions or to the use of new ones.

The graphical illustration of the safe functioning indicators dynamics can be regarded as a family of curves determined by the variation of constructive and technological parameters, during a given time interval (Fig.1). The character of the connection between these curves is given by the enveloping curve, having the equation $I(t,y) = 0$. Here by t we denoted the time variable, while by y we meant the safety indicator.

The envelop equation results by eliminating c parameter of curves family equation $f(t,y,c) = 0$ from the system

$$\begin{cases} f(t,y,c) = 0; \\ \dfrac{\partial f(t,y,c)}{\partial c} = 0. \end{cases} \qquad (10)$$

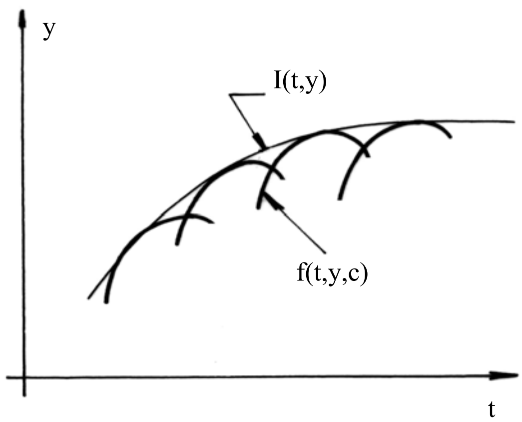

Fig.1. Safety indicators dynamics

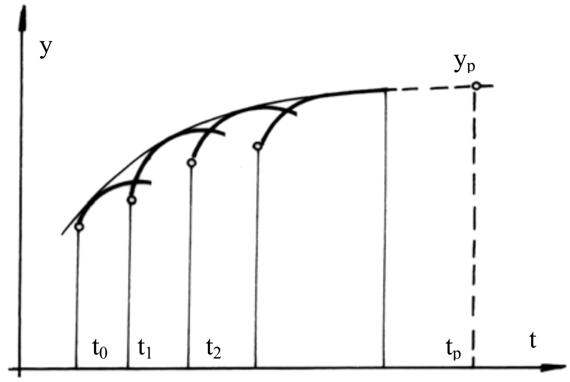

Fig. 2. Safety indicator forecast

During the considered time interval, *c* takes a certain number of values, which are time discrete functions: $c_0(t_0)$, $c_1(t_1)$, ... $c_k(t_k)$.

The safety indicator forecast means to calculate $y_p = \varphi(t_p)$, where t_p is the time interval covered by the forecast (Fig.2).

If a machine-tool safety indicators are determined by the characteristics vector $Y_n = \{y_1(t), y_2(t), \ldots y_n(t)\}$, then the following temporal stages can be revealed:

- Initial characteristics, at t_0 moment,

$$Y_0 = \{ y_1(t_0),\ \ y_2(t_0), \ldots y_n(t_0)\}; \tag{11}$$

- Current characteristics, at analysis moment, t_a,

$$Y_a = \{ y_1(t_a),\ \ y_2(t_a), \ldots y_n(t_a)\}; \tag{12}$$

- Hypothetical future characteristics, at forecast moment, t_f,

$$Y_p = \{ y_1(t_f),\ \ y_2(t_f), \ldots y_n(t_f)\}. \tag{13}$$

The evolution trend of the considered machine-tool is then reflected by the evolution matrix:

$$Y_e = \begin{pmatrix} y_1(t_0) & y_2(t_0) & \cdots & y_n(t_0) \\ y_1(t_1) & y_2(t_1) & \cdots & y_n(t_1) \\ \vdots & \vdots & & \vdots \\ y_1(t_m) & y_2(t_m) & \cdots & y_n(t_m) \end{pmatrix}. \tag{14}$$

Although the method has a global character, concerning the entire machine-tool, it can be used to realize a deeper analysis, at parts level. On long term, the forecast does not have a high degree of accuracy, because the interactions between machine-tool sub-systems, as consequence of their separate quality enhancing, cannot be precisely anticipated.

4. SAFETY INDICATORS FORECAST BY STATISTICAL METHOD

Forecast of machine-tools behavior depends on numerous factors, as cutting regimes, geometrical elements or materials mechanical properties. Machine-tools behavior is characterized, for example, by deformations, strains, stresses or accuracy.

Bayes formula enables to pass from a known dataset, regarding machine-tool or their component sub-systems reliability, assessed on the base of failures intensity probability $P(\lambda_i)$ and failures probability $P(S/\lambda_i)$, to the establishment of future failures probability, $P(\lambda_i/S)$:

$$P(x = \lambda_i / S) = \frac{P(s/\lambda = \lambda_i) \cdot P(\lambda = \lambda_i)}{\sum_{j=1}^{n} P(s/\lambda = \lambda_j) \cdot P(\lambda = \lambda_j)}. \tag{15}$$

5. NUMERICAL APPLICATION. CONCLUSIONS

Let us suppose that when designing a new machine-tool, by analyzing the known dataset, we found $\lambda = \lambda_1 = 10^{-3}$ hours. We hypothetically admit that, if new operating conditions do occur, we will find $\lambda = \lambda_2 = 10^{-2}$ hours. We estimate the probabilities $P(\lambda = \lambda_1) = 0.9$ and $P(\lambda = \lambda_2) = 0.1$; then, for a duty *t* of 100 hours, Bayes reliability results as:

$$\begin{aligned} \hat{P}(t = 100) &= P(\lambda = \lambda_1)e^{-\lambda_1 t} + \\ &+ P(\lambda = \lambda_2)e^{-\lambda_2 t} = 0.856 \end{aligned} \tag{15}$$

The new machine-tool functioning is firstly tested, on an experimental model, during a time interval T = 300 hours, then the real probabilities are calculated:

$$P(\lambda = \lambda_1 / T) = \frac{0.9e^{-\lambda_1 T}}{0.9e^{-\lambda_1 T} + 0.1e^{-\lambda_2 T}} = 0.992, \tag{16}$$

$$P(\lambda = \lambda_2 / T) = \frac{0.1e^{-\lambda_2 T}}{0.9e^{-\lambda_1 T} + 0.1e^{-\lambda_2 T}} = 0.008. \tag{17}$$

It results that, with only one experimental determination, an assessment more precise with 10% than the one from the design beginning was obtained. The statistical method is more accessible and it is used in machine building for elements whose safety indicators values are experimentally determined.

We apply now the forecast methodology in the case of a vertical lathe SC 14 – NC, on the base of information furnished by the back shop. This lathe structure was divided into the following sub-systems: driver, column/cross rail, tool-holder slay, hydrostatic sustentation, lubrication, electrical driving, display &

numerical positioning, measuring, control & warning. The connections between them are illustrated in Fig.3.

Statistics show that failure frequencies in hydraulic, mechanical and electrical sub-systems are in ratio of 3:2:1. Also from statistics regarding elements reliability, the following values of the safety indicators and specific requirements have been found:

- *Driver*: antifriction bearings with failure intensity, λ_m, lower than 10^{-5}; gearbox lapping for 50 hours.
- *Column/cross rail*: operating without failures at a displacement with 0.01mm precision for more than 2000 hours; slay/slide couple wear lower than 0.06 mm/year.
- *Hydrostatic sustentation*: λ_m lower than 10^{-7}, enabled by doubling pumps and pockets number.
- *Lubrication*: 65% from functioning safety is due to oil quality, who needs to be replaced after 500 – 600 hours of duty.
- *Electrical driving*: $\lambda_m = 10^{-5}$, with special requirements for the electromagnetic clutches.
- *Display & numerical positioning, measuring, control & warning*: $\lambda_m = 10^{-5}$.

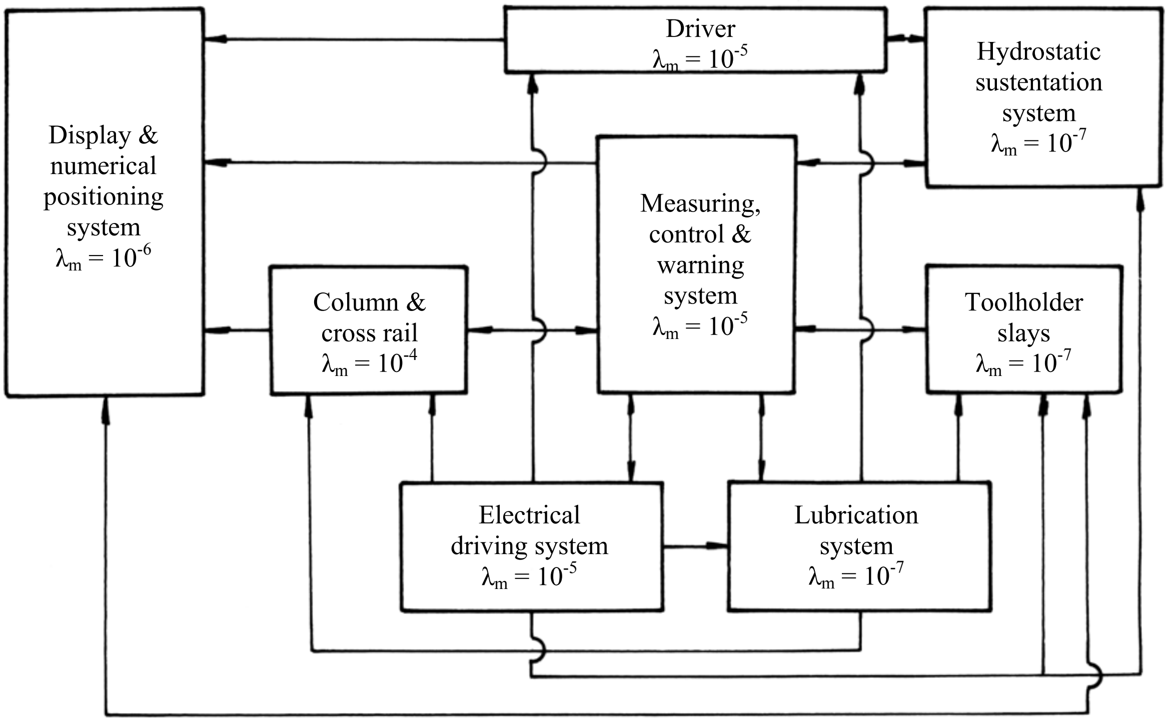

Fig. 3. Interconnections in assessing a vertical lathe reliability

Under the enounced conditions regarding the operational and technological requirements, the forecast of machine-tool global indicators is:

- Average operating duration, without going out of precision restrictions: 6000 hours;
- Operating duration to the first normal overhaul: 2000 hours;
- Operating duration to the first capital overhaul: 6000 hours;
- Presumable operating duration to the first casualty: 1000 hours;
- Precision reserve at the beginning of machine-tool exploitation: 65%;
- Average failures intensity for an operating time interval of 6000 hours: $\lambda_m = 0.5 \cdot 10^{-3}$;
- Failures intensity: $\lambda = 0.6 \cdot 10^{-4}$.

REFERENCES

[1]. Caba, M., *Fiabilitatea şi siguranța în exploatare a utilajelor*, Editura OID, Bucureşti, 1992.

[2]. Cătuneanu, V., Potențiu, F., *Optimizarea fiabilității sistemelor*, Editura Academiei, Bucureşti, 1989.

[3]. Fleşer, T., *Mentenanța utilajelor tehnologice*, Editura OIDICM, Bucureşti, 1998.

[4]. Mărăşescu, N., *Sisteme de înaltă fiabilitate bazate pe tehnici de diagnoză şi predicție*, Teză de doctorat, Galați, 1999.

[5]. Oprean, A., Dorin, A., Drimer, D., *Fiabilitatea maşinilor unelte*, Editura tehnică, Bucureşti, 1979.

[6]. Stoian, C., Frumuşanu, G., *Fiabilitatea şi mentenanța utilajelor*. Editura Cartea universitară, Bucureşti, 2005.

[7]. Zhao, M., *Availability for Repairable Components and Series Systems In A predictive Maintenance Program,* IEEE Transactions on Reliability, vol. 43, nr. 2, 1994, pag. 329-334.