SYSTEM APPROACH TO THE PROBLEM OF COMPLICATED TECHNOLOGY RELIABILITY

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The assertion that the basic objects of the science represent the systems is the simple statement of the fact. The statement is rather meagre but allowing to draw the conclusion that the modern methods of investigation should take into consideration the factors systematization (including generality and emergent properties) both in the natural and artificial sciences which appear as an independent principle not deducible from another theoretical prerequisites deductively (1, 2). The more thorough conclusions are impossible to get from the mentioned fact without the study of concrete objects. The systems classification can be made under the different basis, and in the present report the authors limited themselves by dividing the systems into artificial and natural ones. The main aim of the report is to demonstrate the effectiveness of the systematic approach to the problems of prediction of durability and reliability of complicated technical systems (CTS). By definition, CTS is a system presupposing the availability of subsystems any of which can fulfil some functions independently. Meanwhile, the degree of subsystems coordination is characterized by the efficiency function of the system and CTS themselves (supposing hierarchical patterns) permit some quantity estimations of complexity. The report considers the stationary CTS which are characterized by the quantity of hierarchy levels. Namely, the system made of N elements (units, components) has the structure consisting of *n* hierarchical levels of informational complexity. The number of levels is defined with the following relation: $n = c + ln\ (N+1)$, where c = 0.5772… – Euler constant; e=2.71828… - the base of the natural logarithms. Original and derived elements of CTS (N_i) are distributed in hierarchical levels: $N_i = e^{n-i}$, where $i = 1,2…n$, and i is the number of structure hierarchical level (the first level is the lowest level of hierarchy). The average volume of information (q_i) in each CTS element of the *i* hierarchical level is represented by the exponential dependence: $q_i = e^{i-1}$. The average volume of information for every level is determined from the relationships of (N_i) and (q_i) of CTS (w): w=$q_i\ N_i$=const. The volume of information which each CTS element contains is called *the information capacity* of the element. It forms the zones in the information flow with the total amount of $m = 2^{\sqrt{w}}$ (**).

The task has the marked practical orientation – the estimation of the reliability and development of diagnostic means of CTS having five and more complexity levels. Actually the task under consideration was originally formulated as a technical problem for the chief mechanic department of Nerungrinsky coal mine the largest one in Yakutia (RF): to ensure the designed efficiency of the shovel fleet of the "Komatsu" PC-5500 and PC-8000 class that have the sixth level of complexity. The machines of the mentioned company traditionally are characterized by quality and reliability, but in the conditions of Nerungrinsky mine they puzzled the operative people with "unaccountably considerable" number of malfunctions (see Fig. 1-3).

Table of symbols:

A group – organization reasons;
A1 subgroup – lack of expendable materials;
B group – wear of the units and structure elements;
C group – lack of spare parts;
C1 subgroup – lack of spare parts for frequently failing components;
D group – factory defect;
E group – mistake or malfunction of on-board computer;
G group – operational mistake;

I group – mechanical-repair service mistake; K group – malfunction due to the mistakes in repair and setup; L group – undetermined cause.

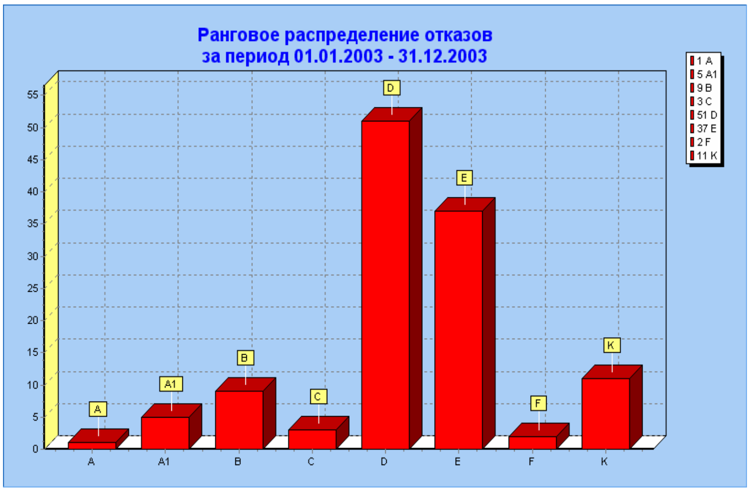

Fig. 1. Class distribution of malfunctions within the period 01.01.2003 – 31.12.2003

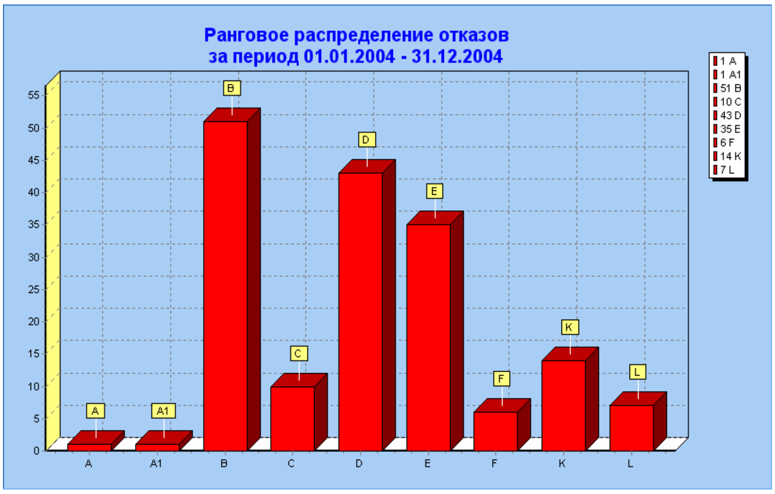

Fig. 2. Class distribution of malfunctions within the period 01.01.2004 – 31.12.2004

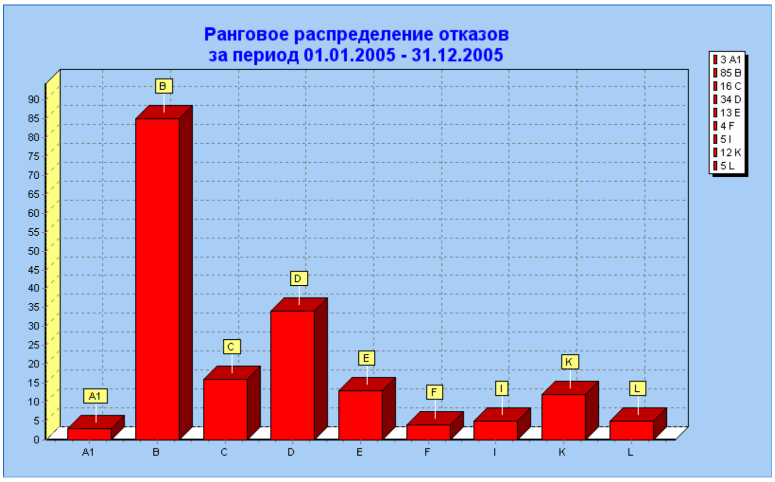

Fig. 3. Class distribution of malfunctions within the period 01.01.2005 – 31.12.2005

The unusual structure of malfunction graphs proved the initial hypothesis: the function of malfunction distribution does not belong to the class of exponential distribution.

$$P(x) = \frac{\alpha}{2\lambda\sigma\Gamma(1/\alpha)} \exp\left(-\left| \frac{x - X_ц}{\lambda\sigma} \right|^{\alpha} \right), \qquad (1)$$

where $\lambda = \sqrt{\frac{\Gamma(1/\alpha)}{\Gamma(3/\alpha)}}$; $\sigma -$ mean-square deviation;

$X_ц$ – centroid of distribution coordinate,

$\Gamma_{(z)}$ – gamma function;

α – some characteristic for this distribution constant – its exponent.

At the same time, this class is wide enough as the distribution is characterized by the three parameters α, σ and $X_ц$; it includes: Cauchy distribution at $\alpha<1$, Laplace distribution at $\alpha=1$, normal at $\alpha=2$, trapezoidal at $\alpha>1$ and even distribution at infinite α. Thus, standard methods of classic reliability theory applied in technics, did not clarify the situation. Direct application of the ideas from Neumann's works about building "reliable systems of unreliable elements" was also impossible because of operative people's insufficient information awareness of design solutions. Due to the causes mentioned the method of kinetic [run-on] analysis was used being suggested by the basic concepts of "the sciences of the artificial" – differentiation between the external and internal conditions of CTS functioning. As a model one we have chosen B. Gomperz's class equation (1)

$$\frac{dn(t)}{dt} = -(k_e + k_g(t)) \cdot n(t).$$

Here n is the number of cycles of failure-free operation of high-end technology.

Equation (1) contains two significant quantities: k_e – "ecological" ratio of malfunction rate by external reasons, and k_g – "genetic" ratio of malfunction by internal reasons ("rate constant"). If the assumption of external medium invariance is valid, k_e does not depend on t. On the contrary, k_g reflects the increase with the lapse of time of the probability of CTS failure by internal "genetic" reasons. That is why this quantity is the increasing function of time: $k_g = k_g(t)$. The task of the kinetic analysis [3, 4] is to evaluate the value of k_g ratio and find the form of function $n(t)$ by the statistic data on the number of failure-free operation cycles.

First of all, let's make a phenomenological system function, find the analytical relation of $n(t)$ to k_e and k_g solving the equation (1) with the initial condition $n(0)=n_0$:

$$n(t) = n_0 \exp(-k_l t - \int_0^t k_g(t)dt) \qquad (2)$$

Now we should compare the theoretical relation (2) with the experimentally made function $n(t)$ and select the ratios k_e and k_g for the theoretic and experimental curves to be close to the defined reliability:

$$k_g(t) = \alpha \cdot e^{\beta t}. \qquad (3)$$

So the two values α and β (constant for each CTS class) occurred; they can only be positive. Exponential increase of the ratio proves to be significant. It is evident that this equation is adequate every time when the failure probability does not change with the lapse of time, i.e. there is no ageing of system components.

Now let's consider another borderline case: $k_e = 0$ (there are no external cause failures), and $\kappa_{ё}$ increases exponentially. Then it follows from the equation (2) that:

$$n(t) = n_0 \exp\left(-\frac{\alpha}{\beta}\left(e^{\beta t} - 1\right)\right).$$

Thus the natural explanation of the catastrophic growth in the number of malfunctions was obtained. The next natural step is building and adaptation of the predictive malfunction model. As such unit as the swivel block hydraulic actuator is a subsystem, the first step of adaptation was building the diagnostic algorithm of failures of this very component. The mathematic model of hydraulic actuator malfunctions was built in the following way. The values of α and β ratios were evaluated by the failure statistics by Gauss's method and by the putative form of the curve (Gomperz's type). Comparing these values with the ratios obtained for the analogous shovels working in the Republic of South Africa, we found out that the CTS ageing rate in the conditions of Yakutia is twice as more rapid. After that using the known working hours the nearest failure forecast was made. The error was less than 70 working hours. The value of the error can be considerably lower (and the prognosis more exact) if the rate of components material ageing is taken into consideration. So, in the network of kinetic reliability theory it was established that using the conventional components and increasing the dissipated power from W_0 to W_t the wear rate grows as $(W_t/W_0)^{1/3}$, so the regularities found can be applied to the more powerful CTS PC-8000.

Summary: a) Similar to "large" living organisms the shovels of PC-5500 class (so as all the modern machinery) do not possess the absolute reliability in principle;
b) The peculiarity of operating CTS in the extreme temperature conditions is doubling the "ageing" rate of the whole system. Meanwhile, the ageing rate of components materials is accelerated insignificantly.
c) The failure prognosis of CTS is effective even in phenomenological models. The basis for the prognosis is the system function of the number of working cycles *n(t)* with the defined α and β.

Literature

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