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AN ANALYSIS OF OPERATIONAL RELIABILITY OF THE WORK OF A TECHNICAL OBJECT

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Summary. The principle of entropy growth for an analysis of stability of the work of technical systems is analyzed, including the consideration of stochastic processes and the functional phenomena.

Key words: entropy, operational reliability, technical object

The structure of mechanical devices, as a rule, possesses spatial and time properties which do not easily give in to known methods of mathematical formalization. The major characteristics of modern technical systems is their nonlinearity, stochasticity, presence of a big number of subsystems, irreversibility. Some subsystems have a determined stochastic character and, consequently, the optimization of each subsystem does not mean an optimization of all the system. The open feature of some subsystems leads to constant fluctuations, i. e. to casual deviations of sizes from their average value.

It is necessary to emphasize, that joint action of the determined and stochastic forces translates technical system from an initial condition into new, quite often unstable conditions.

It is possible to allocate three types of the system: determined, chaotic and determined chaotic.

Irregular or chaotic movement is called the determined chaos, nonlinear systems for which dynamic laws unequivocally define evolution in time of a condition of a system, provided that the previous processes are known.

The theory of existential chaos manages to be constructed first of all when dynamics of a nonlinear field can be considered as dynamics of a complex of cooperating stable and astable structures.

Let us notice, that to nonequilibrium and unstable systems, it is possible to carry what, for a long time, has been in operation and has become much less reliable.

By virtue of extreme disorder and possible sharp variability in time and space of all sizes of noquilibrium, non-stationary and stochastic systems, it is necessary to use new research methods for studying similar processes.

The significant results are such from which accident in time follows, that, as a rule, is connected with action of external factors, and casual distribution of a field in space can be a consequence of only determined laws operating change of variables along coordinates, and rather poorly depends on casual imperfections.

For mechanical conservative system the condition of stability of balance is defined by the theorem of Lagranza-Dirichle according to which balance is steady if in position of balance potential energy of a system is minimal. For the systems which are being in movement, a condition asymptotic or exponential stability is defined by Lyapunov's criterion.

For the decision of the specified problems the effective method can be the one based on the principle of modern non equilibrium thermodynamics and the theory of information.

A significant contribution to development of the new approach to the analysis of unstable systems was brought by Prigozhin and his school [1979]. Prigozhin has proved that those irreversible, unique processes are a source of the order. Joint actions of the stochastic and determined forces translate a system from initial conditions into new ones, thus defining which new configurations are realized.

Despite the stability in relation to entry conditions, the determined-stochastic systems possess significant stability in relation to arising functions.

Measure of uncertainty of a condition of a system is entropy, defined as mathematical expectation of the logarithm of the given condition (Bolzman's formula)

$$S = - k \cdot \ln W, \tag{1}$$

where:

W – so-called thermodynamic probability which specifies the possible number of realization of the given condition.

The formula (1) is similar to probability of information capacity (Hartley's formula).

$$I = - k \cdot \ln P, \tag{2}$$

where:

P – probability of a condition of system.

At fluctuation entropy changes from equilibrium value S_o up to $S_o + \Delta S$. Therefore the probability of the considered fluctuation is defined by expression (Einstein's formula).

$$W = \left\{ \frac{\Delta S}{k} \right\}, \tag{3}$$

where:

k – Bolzman's constant .

It is necessary to emphasize, that the concept of thermodynamic probability is allocated formally and, as a rule, does not coincide with the usual concept of probability.

The probability of any size of *and* can be analyzed only in that case when this size can change within the limits of this system. It means, that function *W () da* means the valid probability of definition of value *and* within the limits of from *and* up to *and* + *da*.

Within the limits of such representation interdependence of probability and entropy is defined by the equation.

$$W(a)da = \frac{e^{(1/k)S(a)}\,da}{\int e^{(1/k)S(a)}\,da}. \tag{4}$$

Except for Bolzman's constant k, this equation contains only the data given on macroscopical sizes.

For stochastic processes there can be mentioned fluctuations of the phenomena. For fluctuations of several parameters, for example *and* and *b*, the likelihood formula looks like this:

$$W(a,b) = const\; e^{\frac{1}{k}S(a,b)} da\, db.$$

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From the resulted parities it is possible to draw a conclusion, that the probability of fluctuation is fully proportional to the entropy of the closed system. From here follows, that W is proportional

$$W \exp \Delta S,$$

where:

ΔS – change entropy at fluctuation.

If the body is not in balance with Wednesday,

$$\Delta S = - R_{\min} \cdot T_0, \tag{6}$$

where:

$R_{\min}$ – size of the minimal work;

T_0 – temperatures of environment.

In that case

$$W \sim exp\left(-\frac{R_{min}}{T_0}\right). \tag{7}$$

Considering, that

$$R_{\min} = \Delta E - T_0\, \Delta S + p_0\, \Delta V,$$

where:

ΔE, ΔS, ΔV – change of energy, entropy and volume of the given small part of a body at fluctuation, and

T_0 and p_0 – parameters of an environment, follows.

$$W \sim exp\left(-\Delta E + T\Delta S - p_0 \Delta V / T\right). \tag{8}$$

In such a way this formula can be obtained for any fluctuations, both small, and significant.

For any space of conditions of system change, entropy can be presented as the sum of two components.

$$dS = dS_e + dS_i, \tag{9}$$

where:

dS_e – change entropy owing to influence of an environment;

dS_i – change entropy owing to the internal processes occurring in a system.

The condition of a system is defined by a parity composed in the formula (9). From this formula it follows, that the condition of balance of system takes place at $dS_e = - dS_i$.

The steady stationary condition is supported under condition of indemnification of an increment entropy in unit of time, caused by irreversible internal processes, which has been compensated by constant inflow of negative entropy (nonentropy) in volume of system. For this purpose it is necessary to raise the level of the organization of processes in a technical system, to increase its level of automation and efficiency.

For research of a degree of perfection of determined -stochastic systems it is expedient to use Kolmogorov's entropy $S_к$ – the major characteristic of the stochastic phenomena in space of any dimension . Specifying for speed of loss of the information, $S_к$ eventually gives data on change of a condition of a system. It means, that $S_к\big|_{n+1} - S_к\big|_n$ describes loss of information on a system in an interval of time n from up to $n + 1$.

At deterioration of the equipment and necessity of its replacement energy spent on the creation of the equipment is equal

$$E = \sum_{i=1}^{n} M_i \left(\frac{l_{доб}}{\eta_{доб}} + \frac{\Delta G}{\eta_{вос}} + \frac{l_{обр}}{\eta_{обр}} \right) + W_{пр}, \tag{10}$$

where:

M_i – weight of i-th detail;

$l_{доб}$ – specific minimal work on extraction of raw material;

ΔG – Gibb's energy (specific) reactions of restoration;

$l_{обр}$ – specific work of processing of a detail;

η – corresponding to efficiency of processes;

$W_{пр}$ – expenses exergy on processing, assembly, transport of elements of a system;

n – quantity of details in an element of a system.

Recently, the graph-theoretic method of the optimum analysis and synthesis of technical systems of various functional purposes is widely used in the engineering practice. As to energy change, the systems work on return and mixed cycles. Special interest is given to work. In recent years this method has been extended by the analysis in terms of modern applied thermodynamics.

Flow columns, whose tops display elements of system, and arches – physical streams, are evident and convenient for the carrying out of alternative calculations and parametrical optimization that form a basis for creation of a package of applied programs.

The problem of optimization – to minimize value of criterion function

$$Z = \sum_i \sum_j Z_{ij} X_{ij} \tag{11}$$

for all *ij*, belonging to a network,
where:

Z_{ij} – weight of an arch, i.e. expenses in the block (cycle) which correspond to the given arch with the accepted boundary conditions. Thus $X_{ij} = 1$ if the arch ij enters into a considered way, $X_{ij} = 0$, otherwise.

It is necessary to note, that Kolmogorov's entropy is defined with average time on which it is possible to predict a condition of system with dynamic chaos. It specifies that $S_к$ is that size which characterizes chaotic movement, hence, a degree of destruction of the investigated object. In the case of a strange attractor it is possible to define it as an attractor with positive entropy.

Let's emphasize, that a strange attractor is an attractor with complex structure.

In summary we shall notice, that highly effective work of the machine and stability of its regime conditions meets the requirements of a minimum dissipation energy. This principle can be formulated so: for set of conditions, including a condition of system as a whole, stability of work and the minimal dispersion of energy is characterized by the minimal entropy growth. This position (Prigozhin's theorem) expresses property of inertia of nonequilibrium systems and represents a variational principle of irreversible processes .

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