Application of the methods of chaos theory and nonlinear dynamics to diagnostic of technical objects

D. Marhenko, A. Zhidkov

Volodymyr Dahl East-Ukrainian National University e-mail:.zhand.cmw@ukr.net

Received June 03 .2015: accepted June 19.2015

Summary. The paper proves the possibility of using the methods of chaos theory and nonlinear dynamics to separate the useful signal during diagnosing diagnostic of technical objects.

Key words. Chaos theory, nonlinear dynamics, diagnostic, technical objects.

INTRODUCTION

The assessment of condition of technical objects is the most important scientific - technical task. For a current state of Ukrainian economy the extension of service life or forecasting of planned removal from service of the objects of national economy, has huge national economic value. It is known that a lot of technical objects in Ukraine depleted their planned resource, however they continue to operate because of the lack of funds for their repair or replacement. For example, today at the plants of Ukraine more than 230 thousand Lifting constructions are being operated, 84% from which have already worked out their rated life [1].

Their further safe operation is possible only after carrying out expert inspection (technical diagnosis) at the heart of which the assessment of technical condition is. The problem of an objective (quantitative) assessment of technical condition is actual and gives as considerable economic effect, because it is about further continuation of operation in case of the positive expert report, as it prevents appearing of man-made and dangerous situations (accidents) in case of the termination of further operation at the negative expert report. Getting a quantitative assessment of technical condition allows us to define more objectively the opportunity and terms of further safe operation, to reduce costs for maintenance of their working capacity. It is especially actual to diagnose objects of the increased danger to which bridges, pipelines, carrying and lifting machines and etc. belong [2].

Researches testify that destruction of constructions because of fatigue damages is one of the main cases of constructions premature failure from the operation. The fatigue failure process is multistage and complicated. The rate of this process is influenced by various factors. However, the mechanism of fatigue failure is identical to a wide range of materials and types of loadings. Most of the researchers tend to the model of material fatigue failure [3] which describes development of the fatigue failure process as the increase of the part of the distended metal layer on the surface of a product and in full. Therefore, to estimate a residual resource, it is necessary to diagnose a part of the distended metal in the most loaded zones of the technical object.

Diagnostics of the material condition of the technical object can be carried out with the use of various methods of nondestructive control. For metal constructions the most common are ultrasonic, different types of magnetic, x-ray, acoustic emission and other methods. A common problem, for all types of diagnostics, irrespective of physical sense of the process, is the low level of a useful signal from the sensor which can be compared with noise level. And if, considerable improvement of measuring devices in the sensitivity and selectivity field of sensors is extremely difficult [4], so modern methods of processing of the received signal allow to increase considerably the quality of diagnostics.

The aim of the work: the usage of nonlinear mechanics, chaos theory and the theory of fractals for extraction of a useful signal during diagnostics of technical objects

MATERIALS AND METHODS

Development of modern mechanics (both theoretical and experimental) mainly relies on the concept of the sets having nonintegral dimension. The concept of fractional (fractal) dimension was firstly formulated in the works of Hausdorff [5] and Bezikovich [6] which the researches of outstanding mathematicians of the end of XIX - the beginning of the XX century such as the Cantor, Weierstrass, Peano, Koch, Sierpinski [5-8] preceded. Splash in works on fractals affected such fundamental directions as non-equilibrium thermodynamics [10, 11] and cosmology [8, 9], the theory of dynamic chaos [10, 11] and hydrodynamic turbulence [12, 13, 14], research of phase transitions [15, 16].

Adequate mathematical concept of the kinetics process, is given by diffusive formalism [17, 18]. Thus establishment of coherent communication in ensemble of initial reagents leads to the collective effects not allowing to consider the process in the usual way. During the process of formation of fractality the mode in which it is necessary to consider establishment processes of the modulated structure in the field of minimally stable structural elements corresponding to the regularities of second order phase transition [19] is realized. The synergetic approach is used for the adequate description of this stage [20].

The task of the researches is development of the approach which is based on the analysis of collective effects in the synergetic scheme which would allow to add the concrete mechanism of structurization on the basis of the formalism of the fractal Brownian motion to the analysis and to consider the multilevel plan of structurization as gradual development of cluster fractal structure.

RESULTS

The rules (an algorithm) of the kinetic picture of structurization will be formulated according to the discrete method of cellular automata [19].

We will model the process with a two-dimensional hexagonal lattice (L×L size). In the cells of the lattice there are integral numbers (Fig. 1). If the number exceeds one, the cell (a structural element) is unstable that is expressed in decreasing of the number by 2 in it with simultaneous increase the numbers in two cells adjoining this one from below by 1.

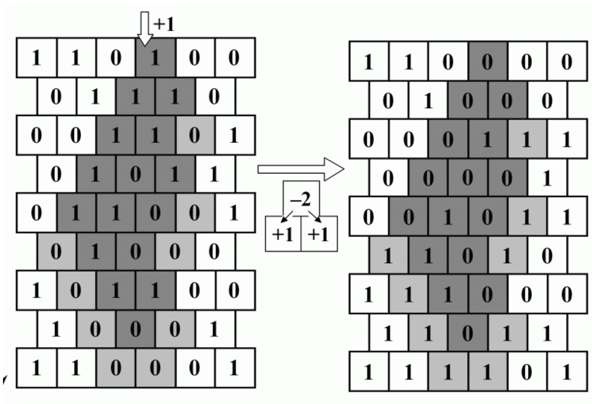

Fig. 1. Cellular automaton

If disturbance of the medium is insufficient, so indignation can't extend far, and activity decays quickly. If, on the contrary, disturbance reached a limit near some value at which concentration of minimally stable structural elements (SE) is equal to a percolation threshold, i.e. to the appearance point of the infinite coherent cluster from them, so any disturbance can extend over the system to infinite distance, and the system behaves as an integral whole.

Rank parameter (a number coherently connected with the SE) starts accepting nonzero value at the transition of the control parameter through the critical value that means the appearance of complete characteristics in the system [20]. The critical point divides chaotic (subcritical) and ordered (supercritical) states therefore in it any small influence can have essential impact on the system.

In the description of the state of the system structure in terms of the minimally stable elements (MSE) MSE share is like a control parameter, and a rank parameter is probability that some cell belongs to infinitely big cluster from them, i.e. that impact on it will extend to infinite distance that corresponds to the picture of establishment of the modulated structure [18] corresponding to regularities of second-order phase transition [20].

As it is known from the theory of phase transitions, such state is formed critically - the ordered phase develops as a self-similar structure in which there is no typical scale [20]. Formally the quality of self-similarity is expressed by uniformity of distribution function $P(x)$ on the x amplitude, responsible for collating [17, 19]:

$$P(x/x_c) = x_c^{\alpha} P(x) . \quad (1)$$

According to (1) changing of the scale of x_c of a random value x leads to the multiplicative change of probability of its realization P characterized by an exponent. Entering the scaled variable $y \equiv x/x_c$ and distribution function $P(y) = y^{\alpha} P(y)$, it is possible to copy (1) as:

$$P(x) = x^{-\alpha} P(y) , \quad (2)$$

from which follows that in the limit of big and small values of a stochastic variable x when the function $P(y) = y^{\alpha} P(y)$ can be constant, distribution $P(x) = x^{-\alpha} P(y)$ takes the power form [16-20].

The presented kinetic picture corresponds to the field concept of structurization which is written out from the first principles that proves accessory of the structurization process in polymeric material to same universality class with second-order phase transition.

These ideas rely on the idea that original structure will be transformed in the final one not in a direct way, but through intermediate stages. Achievement the most thermodynamically favorable state in the system is realized according to the branch scheme, according to filling of local minima of thermodynamic potential. In turn each of the minima, distinguishable at this scale, at further increase finds thinner structure of minima which have smaller depth and corresponds to the closer one-dimensional long-period structures (Fig. 2).

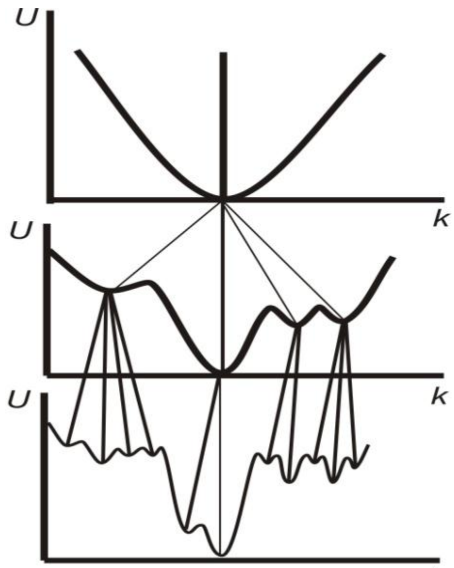

Fig. 2. Structure of a charge pattern of the thermodynamic potential [14]

As these minima correspond to stable elements of the microstructure, so such assumption means master-slave hierarchy of their behavior during structure evolution: reorganization of rough details is provided with corresponding change of the small ones. Graphically it is represented, if we match each minimum with a point in ultrametric space. Then system evolution reacts on the "movement" on the points of a Cayley hierarchical tree (Fig. 3) representing a geometric image of ultrametric space.

The most densely located tree points are connected with the smallest structure elements, going to a frame we pass to larger ones. Branches of the tree react on the elementary acts of structure reorganization when coordinated and interdependent behavior of its details at one level leads to spontaneous reorganization on the higher one (accretion of several branches in one point).

The fractal topology of the mechanism structurization means that the set of parallel channels of structurization which existence is supposed in model of the branch process (Fig. 3) acts independently. Such a situation corresponds to the charge pattern of the system (Fig. 1) having hierarchical structure.

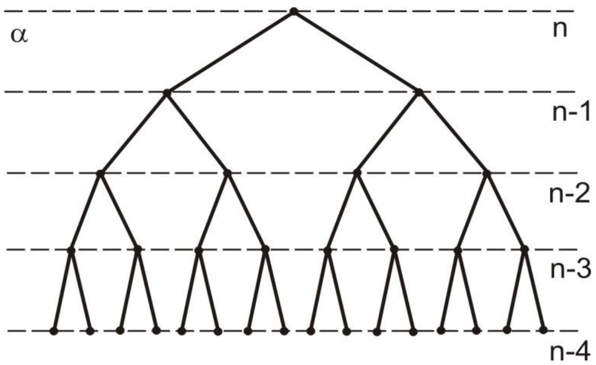

Fig. 3. Cayley tree [17]

Let's trace structural transformations in the system, modeling structurization dynamics by fractal Brownian process [17].

For the description of the phenomena having fractal characteristic [20] the generalized Brownian motion which, by definition, is written in the form of fractional integral was added to the work:

$$B_H(t) = \frac{1}{\Gamma\left(H + \frac{1}{2}\right)} \int_{-\infty}^{e} h(t-\tau)\,dB(\tau). \quad (3)$$

where: $dB(\tau)$ is an increment of the Wiener process; $\Gamma\left(H + \frac{1}{2}\right)$ – gamma function; H – the Hurst parameter.

Impulse response function is equal to:

$$h(t-\tau) = \begin{cases} (t-\tau)^{H-1/2}, & 0 \le \tau \le t; \\ (t-\tau)^{H-1/2} - (-\tau)^{H-1/2}, & \tau < 0. \end{cases} \quad (4)$$

Using impulse response function of the power kind (4) in the equation (3) leads to the strong correlated dependence of the process $B_H(t)$ on its previous values, and also points at self-similar character of the fractal Brownian motion. On the basis of the correlation $h(bt - b\tau) = b^{H-1/2} h(t-\tau)$, and on the dependence for the Wiener process $dB(b\tau) = b^{1/2} dB(\tau)$ from the equation (3) we receive $B_H(bt) = b^H B_H(t)$:

$$B_H(t) = b^{-H} B_H(bt), \quad (5)$$

that confirms self-similar character of structurization if we model it with the fractal Brownian motion.

For the increments of this process expected value and dispersion on the basis of (3) taking into account properties of the Wiener process:

$$M\{dB(T)\} = 0,\ M\{dB(\tau_1)dB(\tau_2)\} =$$
$$= M\{n\tau_1)n(\tau_2)\}d\tau_1 d\tau_2 =$$
$$= N_0 \delta(\tau_2 - \tau_1) d\tau_1 d\tau_2,$$

are correspondingly equal:

$$M\{B_H(t) - B_H(t_0)\} = 0 \quad (6)$$

$$M\{[B_H(t) - B_H(t_0)]^2\} \sim (t - t_0)^{2H}, \quad (7)$$

Scaled correlation function of stationary increments of the fractal Brownian motion for two adjoining nonoverlapping time intervals (t_0, t_1) and (t_1, t_2) will be defined:

$$r_H(t) = \frac{M\{[B_H(t_1) - B_H(t_0)][B_H(t_2) - B_H(t_1)]\}}{M\{[B_H(t_1) - B_H(t_0)]^2\}};$$

or at $B_H(t_0) = 0$

$$r_H(t) = \frac{M\{B_H(t) - B_H(2t)\} - M\{B_H^2(t)\}}{M\{B_H^2(t)\}}. \quad (8)$$

Adding and subtracting in each of the multipliers of the first term of sum (8) $B(2t)$ and $B(t)$ correspondingly, after multiplication and reduction of similar terms we receive:

$$r_H(t) = M\{[B_H(t) - B_H(2t) + B_H(2t)][B_H(2t) -$$
$$- B_H(t) + B_H(t)]\} / M\{B_H^2(t)\} - 1 =$$
$$= \frac{M\{B_H^2(2t)\}}{M\{B_H^2(t)\}} - \left[\frac{M\{B_H(t)B_H(2t)\}}{M\{B_H^2(t)\}} - 1\right] - 2. \quad (9)$$

Taking into account that the correlation in square brackets in the expression (9) on the basis of (8) is equal to $r_H(t)$, and also considering (7), we have finally:

$$r_H(t) = 2^{2H-1} - 1. \quad (10)$$

If we multiply (10) by $M\{B_H^2(t)\} \sim t^{2H}$, we will get the correlation function of increments on the intervals $(0, t)$ and $(t, 2t)$ of the fractal Brownian motion [18]:

$$K_{2H}(t) \approx (2^{2H-1} - 1)t^{2H}.$$

This expression points at the strong correlation dependence of increments increasing with growth of t.

The correlation function for the fractal Brownian motion will be written down in the shape of:

$$K_{2H}(t_1,t_2) \sim 1/2[(t_1^{\ 2H} + t_2^{2H} - |t_1 - t_2|^{2H}]. \quad (11)$$

Correlation coefficient for stationary increments of the fractal Brownian motion on the intervals $(t_n, t_n - T)$ and $(t_{n+k}, t_{n+k} - T)$ the defined duration T spread over the time kT where k - a shift parameter, can be written down as the expression:

$$r_H(k,T) \sim \frac{1}{2}\left[(k+1)^{\alpha+1} - 2k^{\alpha+1} + (k-1)^{\alpha+1}\right]$$

where: $k=1$ that corresponds to correlation dependence for the increments process on the adjoining time intervals, and also considering a correlation $\alpha = 2H-1$, we receive (10). At big values of k the correlation coefficient is approximated by the expression:

$$r_H(k,T) \sim \frac{1}{2}\alpha(\alpha+1)k^{\alpha-1} = = H(2H-1)k^{2H-2}, \quad (12)$$

It follows from this expression that the more parameter is, the more extended dependence $r_H(k,T)$ has.

This conclusion can be used for the characteristic of behavior of the temporal sequence of parameter changes, defining concentration of the reagents in the studied polymeric system through the statistics having self-similarity characteristics of the fractal Brownian motion.

If we define increments of the fractal Brownian motion on the intervals $(t_n, t_n - T)$ as X_n, the aggregative clustering process created as sequence of the weighted averages from increments on m identical nonoverlapping intervals with the duration T, is described by a correlation [20]:

$$X^{(m)} = \{X_k^{(m)};\, k = 0, 1, \ \ldots\} = = \left\{\frac{X_1 + \cdots + X_m}{m}, \ldots, \frac{X_{km+1} + \cdots + X_{(k+1)m}}{m}\right\}.$$

In the aggregative process of increments, when $m \to \infty$ the coefficient of correlation $r_H(k,T)$ keeps the structure and practically doesn't depend on the parameter m, and dispersion changes according to the correlation:

$$D^{(m)}(t) \sim m^{\alpha-1}, \quad (13)$$

This statistics – dispersion of increments is the convenient characteristic during processing of experimental data for the analysis of the considered process.

The studied process will be presented as a model of casual process with increments of a random variable [17].

If $p_x(x,T)$ is the conditional probability that an event x happens, if the event T happened and probability density of this event is $p_T(T,t)$ so the unconditional probability to find the random variable in x is equal to:

$$p(x) = \int_0^\infty p(x,T)\, p_T(T,t)dt. \quad (14)$$

Our aim is to receive a function for unconditional distribution of random walks radius vector $R = \sum_{i=1}^{N} r_i$ at conditional probability of Gaussian distribution $p_x(x,T)$, i.e. to find the function $p_T(T,t)$.The solution of this problem is formulated in the generalized two-parameter Levi functions [17]:

$$L(x;\alpha,\gamma) = \frac{1}{\pi} \times \times \operatorname{Re}\int_0^\infty \exp\left[-ixz - z^\alpha \exp\left(\frac{i\pi\gamma}{2}\right)\right]dz. \quad (15)$$

We will look for distribution of a random variable in the following class of functions [17]:

$$\varphi(0) = \frac{q}{r_N^\alpha} - \frac{q}{r_1^\alpha}. \quad (16)$$

if radius vector *r* incidentally moves from the position *l* to the position N after N -jump.

The same scalar $\varphi(0)$ will be added according to the equation [17]:

$$\varphi(0) = \sum_{i=1}^{N-1}\frac{q}{r_N^\alpha} - \frac{q}{r_1^\alpha} = \sum_{i=2}^{N}\frac{q}{r_i^\alpha} - \sum_{i-1}^{N-1}\frac{q}{r_i^\alpha} \quad (16a)$$

By convention probability density of distribution is equal to:

$$\varphi(0) = \int \delta(\varphi - \varphi(0)) P_N(r_1 \ldots r_N) dr_1 \ldots dr_N,$$

where: $\delta(x)$ is delta function, and $P_N(r_1 \ldots r_N)$ is probability to find a particle after the first jump in the point r_1, after the second – in a point r_2, etc. If Fourier transform of delta function is added [17], then:

$$W(\varphi) = \frac{1}{2\pi}\int_{-\infty}^{\infty} dK \int_V \ldots \int_V P_N(r_1 \ldots r_N) dr_1 \ldots dr_N \times. \times \exp\left[iK\left(\varphi - \sum_{i=1}^{N}\frac{q}{r_i^\alpha}\right)\right] \quad (17)$$

Let any jump can be made in any point of space equally, then

$$P_N(r_1 \ldots r_N) = \frac{1}{V^N} / \quad (18)$$

Now it is convenient to present probability density (18) in the next form:

$$W(\varphi) = \frac{1}{2\pi}\int_{-\infty}^{\infty} dK \exp(iK\varphi) \times$$

$$\times \prod_{i=1}^{N} \left\{ 1 - \frac{1}{V} \int_V \left[1 - \exp\left(iK \frac{q}{r_i^{\alpha}} \right) \right] dr_i \right\}, \quad (19)$$

and the task is resolved to finding of the only integral:

$$I_{\alpha,G} = \frac{1}{V} \int_V \left[1 - \exp\left(-iK \frac{q}{r^{\alpha}} \right) \right] dr \cong .$$

$$\cong \frac{d(Kq)^{G/\alpha}}{V} \int_0^{\infty} (1 - \cos y) \frac{dy}{y^{G/\alpha + 1}}, \quad (20)$$

where: α – an exponent in the law (16), G – number of spatial measurements, d – the result of integration in corners.

The integral (20) converges, if $0 \le \frac{G}{\alpha} \le 2$, i.e. in the window of definition of Levi distribution [16]. The integral to the right (20) is calculated by parts:

$$I_{\alpha,G} = \frac{\pi d (Kq)^{G/\alpha}}{2GV \sin\left(\frac{\pi G}{2\alpha}\right) \Gamma\left(\frac{G}{\alpha}\right)} = BK^{G/\alpha},$$

where: B – a constant, $\Gamma(x)$ – Euler gamma function.

In (19) all integrals are identical therefore it is possible to go to an exponential limit, when $N \to \infty$:

$$(1 - I_{\alpha,G})^N = (1 - \frac{NBK^{G/\alpha}}{N})^N \to \exp(-NBK^{G/\alpha}).$$

According to [18], considering that jumps happen evenly, i.e. with constant speed $N = \gamma T$, we add designations:

$$\varphi(0) = B^{\alpha/G} = \frac{q}{V^{\alpha/G}} [\frac{\pi d}{2D \sin(\frac{\pi G}{2\alpha}) \Gamma(G/\alpha)}]^{\alpha/G},$$

$$x = K\varphi_0, \beta = \varphi / \varphi_0.$$

As a result from (19) we have an expression for density function of a random variable $\varphi(0)$ (16) in the form of time-dependent Levi distribution:

$$W(\beta) = \pi^{-1} \int_0^{\infty} \cos(\beta x) \exp(-\gamma t x^{G/\alpha}) dx$$

The Levi law of motion distribution is characterized by slowly descending asymptotics, i.e. by a significant amount of big fluctuations [21, 22].

One-dimensional discrete analog of Levi jumps on the fractal lattice simulated by a spanning set of Malderbrota-Given fractal used in the percolation theory will be considered [19]. Probability of the particle to appear on the l point after n steps $P_n(l)$ and probability distribution of jumps on lengths $f(l)$ are designated:

$$P_{n+1}(l) = \sum_{m=-\infty}^{\infty} f(l - m) P_n(m). \quad (21)$$

As a function $f(l)$ we will choose the following one:

$$f(l) = \sum_{n=0}^{\infty} a^{-n} (\delta_{l,-b^n} + \delta_{l,b^n}), \quad (22)$$

where: $\delta_{n,m}$ – Kronecker symbol. Then structural function for such random walk is equal to:

$$\lambda = \int f(l) \exp(ikl) dl = \sum_{n=0}^{\infty} a^{-n} \cos(kb^n). \quad (23)$$

It is also noticed that structural function λ satisfies to the functional equation:

$$\lambda(k) = a\lambda(kb).$$

Therefore, when $k \to 0$ it has to behave powerlike with the exponent $D = \ln a / \ln b$. As continually the particle diffusion leaves the point so the sum of probabilities of the motion on W_+ and against W_- fields, has to equal to one: $W_+ + W_- = 1$. From here we have an expression for probabilities of the motion on and against the field:

$$W_{\pm} = (1 \pm \alpha)^{b^n} / \left[(1+\alpha)^{b^n} + (1-\alpha)^{b^n} \right].$$

Therefore, the structural function during diffusion by means of Levi jumps is equal to:

$$\lambda(k; E) =$$

$$= \sum_{n=0}^{\infty} a^{-n} \left[\cos(kb^n) + i \sin(kb^n)(W_+ - W_-) \right]. \quad (24)$$

As well as during usual diffusion, the second term of sum at the small $k \to 0$ has drift speed:

$$V = i\partial\lambda(k; RE) / \partial t|_{k \to 0} = \sum_{n=0}^{\infty} (b/a)^n \times$$

$$\times \left\{ \left[(1+\alpha)^{b^n} - (1-\alpha)^{b^n} \right] / \left[(1+\alpha)^{b^n} + (1-\alpha)^{b^n} \right] \right\} \cong$$

$$\cong \sum_{n=0}^{\infty} (b/a)^n th(ab^n), \quad (25)$$

where: $th(y)$ – a hyperbolic tangent. For calculation of speed we will use the Poisson equation:

$$\sum_{n=0}^{\infty} f(n) = 1/2 f(0) + \int_0^{\infty} f(t) dt + 2 \sum_{m=1}^{\infty} f(t) \cos(2mt).$$

In our case $f(t) = (b/a)^t th(\alpha b^t)$. Made two replacements $t' = t \ln b$ and $z = \exp t'$ we will have for the function $f(z)$:

$$f(z) = z^{-D} th(\alpha z).$$

It follows that:

$$V(E) = \alpha / 2 + \alpha^{(d-1)} \times$$

$$\times \left[\sum_{m=-\infty}^{\infty} \int_1^{\infty} th(z) z^{-\gamma_m} dz + \int_0^{\alpha} th(z) z^{-\gamma_m} dz \right]$$

where: the exponent $\gamma_m = D + 2\pi m i / \ln b$.

It is easy to see that the second term of sum in brackets is small in comparison with the first in the parameter α. Thus, we receive nonlinear dependence:

$V \sim R^{1-D}$ which shows what events we should expect from the system.

Projecting the given analysis technique on identification of useful information in a signal with the high level and noise density it is possible to increase considerably the quality of technical objects diagnostics. It opens prospects for identification of dangerous object conditions at the stage preceding its destruction.

CONCLUSIONS

1. As dynamics of the difficult system evolving in time is observed usually as a dynamic series of some characteristic which creates a database for the analysis and identification of dynamic behavior of the system by means of the methods of nonlinear dynamics, so such analysis will allow to find useful information in the signals from the sensor with the high level and noise density during technical objects diagnostics.

2. To trace the state function of the studied system according to the change of the concentration of reagents which are directly connected with this function. Identification of the area of initial data at which choice it is possible to expect self-organization with formation of the periodic space-time modes, represents rather a complex problem as its decision demands carrying out extensive studies. At this stage of the researches we were limited to study of the self-oscillating modes especially as these modes define, apparently, the characteristics of the structural organization of initially disordered polymeric medium.

3. We got the evidence of essential possibility of mode realization of the deterministic chaos in the studied process when fluctuations of the parameter connected with concentrations of reagents in the studied medium form fractal structures.

REFERENCES

1. **Andrienko N.N., 2011.**Where to go, where to turn? / N.N. Andrienko, V.L. Root, SJ Polnarev // Lifting facilities. Special equipment. – №7-8. – 20-21. (in Russian).
2. Law of Ukraine "about high-risk facilities." / The Verkhovna Rada of Ukraine. – Ofits. look. – K.: Parley. kind of, 2001. – 6. (Biblioteka ofitsiynih Vidanov). (in Ukrainian).
3. **Bolotin V.V., 1984**. Predicting resource of machines and structures / V.V. Bolotin. – M.: Engineering, 400.
4. **Lobanov L.M. 2004**. Evaluation of welded joints of magnetic structures (koertsimetricheskim) method to predict the residual life of the individual / L.M. Lobanov, J.K. Bondarenko, Yu Bondarenko // Technical diagnostics and non-destructive testing. – №1. – 3-6. (in Russian).
5. **Hausdorff F.** Dimension und äuß eres Maß, Math. Annalen 79, 157 (1919).
6. **Krzysztof Danilecki, 2007.** Application of time density characteristics in optimization of parameters of an engine with sequential turbo-charging. TEKA Kom. Mot. Energ. Roln. – OL PAN, 2007, 7A, 23-34.
7. **Paytgen X.O., Richter I.H., 1993.** The beauty of fractals. Images of complex dynamical systems. – M.: Mir. - 176. (in Russian).
8. **Morozov A.D., 2002**. Introduction to the theory of fractals / A.D. Morozov // Moscow-Izhevsk: Institute of Computer Science, 160. (in Russian).
9. **Mandelbrot B., 2002**. Fractal Geometry of Nature / B. Mandelbrot. – M .: Institute of Computer Science. – 656. (in Russian).
10. **Malinetskii G.G., Potapov A.B., 2002**.Modern problems of nonlinear dynamics. – M.: Editorial URSS. – 371. (in Russian).
11. **Prigogine I, Stengers I., 2003**. Time, chaos, quantum. On the solution of the paradox of time. Trans. c Eng. – M.: Editorial URSS. – 356 p. (in Russian).
12. New in synergy: Looking to the third millennium / Information: unlimited possibilities and possible limitations. Ed. **G.G. Malinetskii, S.P. Kurdyumova**, **2002**. – M: Nauka. – 480. (in Russian).
13. **Knyazev E.N.** complex systems and nonlinear dynamics in nature and society [electronic resource]. Access: http://www.synergetic.ru/society/index.php?article=kn3
14. **Berge, Pomo P., Vidal K., 1991**. Order to the chaos. – M.: Mir. – 257. (in Russian).
15. **Schuster G., 1988**. Deterministic chaos. Introduction. – M.: Mir. – 240. (in Russian).
16. **Lichtenberg A., Lieberman M.A., 1984**. Regular and stochastic dynamics. – M.: Mir. – 528. (in Russian).
17. Non-stationary structure and diffusion chaos // **T.S, Akhromeeva, S,P, Kurdyumov, G,G, Malinetskii, AA Samara**, **1992. –** M.: Nauka. – 285. (in Russian).
18. **Belotserkovsky O.M., Oparin A.M., Chechetkin V.M., 2002**. Turbulence. New approaches. – M.: Nauka. – 286. (in Russian).
19. **Buda V.P., Savin S.P., Green L.M., 2011**. The observations of intermittency and generalized self-similarity of turbulent boundary layers: on the way to determining the characteristics of the transfer. \\ UFN, t. 181, № 9. – S.704-742. (in Russian).
20. **Klimontovich Y.L., 1995**. Statistical theory of open systems. – M.: Janus. – 382. (in Russian).
21. **Bartelemy P., Bertolotti J., Wiersma D., 2008**.A Levy ight for light // Nature. – V. 453. – 495-498.
22. **Zbigniew Burski, Joanna Tarasińska, 2007.** Correlation analisys of an influence of a piston's gabarit-mass modification in a s-402|3 engine on vibration in condition of limitary clearance. TEKA Kom. Mot. Energ. Roln. – OL PAN, 2007, 7A, 17–22.

ПРИМЕНЕНИЕ МЕТОДОВ ТЕОРИИ ХАОСА И НЕЛИНЕЙНОЙ ДИНАМИКИ К ДИАГНОСТИКЕ ТЕХНИЧЕСКИХ ОБЪЕКТОВ

Д. Маргенко, А. Жидков

Аннотация. В статье доказывается возможность использования методов теории хаоса и нелинейной динамики, чтобы отделить полезный сигнал при постановке диагноза диагностики технических объектов

Ключевые слова: теория хаоса, нелинейная динамика, диагностика, технические объекты.