DETECTION OF CHANGES IN THE STRUCTURE OF A SYSTEM ACCORDING TO CHANGES OF ITS FLICKER NOISE

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The results of computer simulations of a chaotic motion of elementary particles in the systems with chaotic or ordered structure are presented. The conclusion about the possibility to use the flicker noise of a system for the qualitative estimation of its inner structure and changes in the structure is made.

1. Introduction

In the course of the deep study of the nature, especially of biological and physicochemical processes, the structure organization peculiarities of explored systems become more important. The X-ray analysis of a structure, which is used for diagnostics of the inner structure of a system, needs a special equipment. Moreover, such a method of diagnostics can be used not always, as it is connected with the necessity of dismantling the explored system.

In addition to the traditional methods of diagnostics, the new methods of exploring the inner structure are elaborated and substantiated. One of such methods is the diagnostics of a quality of objects by the level of their flicker noise (FN) [1–4], whose spectral density $S(f)$ is inversely proportional to the frequency: $f : S(f) \sim \frac{1}{f}$. Nowadays, using the measured levels of flicker noise, the quality and the reliability of passive components of different electronic devices and integrated circuits such as thin-film conductors, contacts, tape resistors, *etc.* are predicted [1]. The reason to use FN consists in its dependence on the inner object structure.

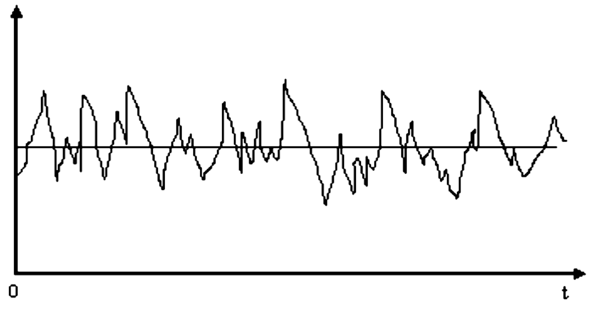

Fig. 1. Variation of $S(t)$ in time

FN is measured not only in electronic circuits. Spectra of the $\frac{1}{f^\alpha}$ type, where $0.5 \leq \alpha \leq 1.5$, are observed in radio technical devices, some biological systems, and geophysical processes [5–8]. The appearance of FN in absolutely different systems can be explained in the way that the changes which occurred in these systems are presented in terms of the dynamical variable $S(t)$, and $S(t)$ can have any sense: the measured parameter of physical objects, rate of chemical changing in the condensed phase, changing the intensity of electromagnetic or acoustic signals, variation of activity indicators of heart's muscle, seismic or volcanic activity, size of a population in ecosystems, motion intensity of a city transport, speed of changing the wage, and so on. The temporal behavior of $S(t)$ is presented in Fig. 1, i.e., it has the form of fluctuations around some average value $\overline{S(t)}$.

While determining the spectrum of $S(t)$ by using the autocorrelation function and the Fourier transformation, the specific nature of a process or phenomenon described by the dynamic variable $S(t)$ is not significant: in Fig. 1, $S(t)$ is an abstract quantity which can reflect any process.

In work [4], there is examined the perspective to use the chaotic series of different dynamical variables which are found during exploring the processes and the structures of different nature and are presented mostly in the form of time series or spatial rows and maps for obtaining the information about the state of the explored system, specificity of its evolution, and peculiarities of the organization of its structure. It is stressed on the analysis of the flicker noise dependence of the signal power spectrum which is formed by a δ -function sequence [9]. It is proposed to determine the information about the processes running in the system during the interpolation of the resulting power spectrum which is found on the basis of experimental values of the time series, by using the equation [4]

$$S(f) = \frac{S(0)}{1 + (2\pi f T_0)^n} , \tag{1}$$

where $S(0)$, T_0 and n are phenomenological parameters ("the passport parameters"), which help to distinguish the explored complex structures or the dynamics of the explored evolution of open dissipative systems. The parameter n characterizes the "memory loss" velocity (the correlation connections) in the sequence of splashes on time intervals; the parameter T_0 has the sense of the correlation time; $S(0)$ is the spectral density on medial frequencies. When $n = 4$, there is a turbulent diffusion in the explored system; when $n = 5/3$, there is the completely advanced turbulence, etc. [4]. The comparison of values of the "passport parameters" obtained in the analysis of the time series with their values defined in special cases enables us to qualitatively present the character of those complex processes which cause the evolution under study.

A method of flicker-noise diagnostics (flicker-noise spectroscopy – FNS-method) offered in [4] has also obvious defects: the determination of the parameters T_0 and n, at which expression (1) would approximate an actual spectrum with satisfactory precision, is inconvenient.

The results of computer modeling of a chaotic motion of fundamental particles presented in [5] allow us to assert that, for the formation of the flicker component of a spectrum of noises, the internal structure of the explored system is most important. In [10], the hypothesis on the appearance of the flicker component of a spectrum of noises in nonequilibrium systems is substantiated, and the empirical expression for the spectral density of noises is given as

$$S(f) \sim \frac{a e^{f\tau}}{e^{f\tau} - 1} , \tag{2}$$

where a is the spectral density in the range of medial frequencies, and τ is the time of relaxation of the system.

In contrast to (1), expression (2) enables one to unambiguously find a relaxation time τ of the system on the basis of the experimentally determined $S(f)$. It is obvious [5] that τ is a structurally sensitive quantity. Moreover, using τ and its change, it is possible to make conclusions about features of the internal structure of the system under study and its change.

The purpose of our numerical experiments is to define the correlation between the parameters of the spectral density of FN and the peculiarities of the inner structure of a system, whose FS is examined.

2. Experiment

For the computer modeling of the chaotic motion of particles, we used the method described in [5]. As objects of the investigation, we chose the systems with ordered and disordered structures. The plane triangle with the sides, whose ratio is 1:2, corresponds to the ordered structure. This triangle contains 20 vertical opaque partitions with equal length, which are placed in a certain order. The chaotic position of those partitions corresponds to the disordered structure.

In [10], there is presented the method of defining the time relaxation τ if the spectrum $S(f)$ is known: if we set $f = f_0 = \frac{1}{\tau}$ in (2), $S(f_0) = 1.58a$. It was also discovered that the parameter a depends only on the motion speed of elements (balls) of the system, whereas the relaxation time τ is a structurally sensitive value. During the computer modeling, the dependences of the parameters a and τ on the motion speed of balls ($v_1 = (10 \pm 5)$ m/s, $v_2 = (100 \pm 50)$ m/s), the place of structure elements [uniformly ordered and disordered (chaotic) positions of the elements], the size of the structure elements ($l_1 = 0.1$ m and $l_2 = 0.2$ m), the distance between elements, and the number of elements ($n_1 = 20$ and $n_2 = 40$) were studied. The corresponding structures and the spectral densities of noises are presented at Figs. 2–5. The values of the parameters a and τ, which were found with the use of the presented spectral densities of noises, are given in Tables 1–4.

3. Computer Simulation

1. Determination of the dependence of a and τ on the motion speed of balls in the systems with chaotic (Fig. 2,a) and ordered structures (Fig. 2,b).

2. Determination of the dependence τ from size of the inner structure elements of chaotic (Fig. 3,a) and ordered (Fig. 3,b) systems.

3. Determination of the dependence of τ on the distance between structure elements.

4. Definition of the dependence of the parameters a and τ on the number of the inner structure elements.

According to the analysis of power spectra presented at Figs. 2–5, it becomes evident that the parameter a in (2) characterizes the degree of saved thermal energy ($a \sim kT$), but the energy related to the system structure is characterized by the relaxation time τ. So, in the systems that have equal saved thermal energy ($a = 0.174 \div 0.185$, Tables 1–4), the energies related to the

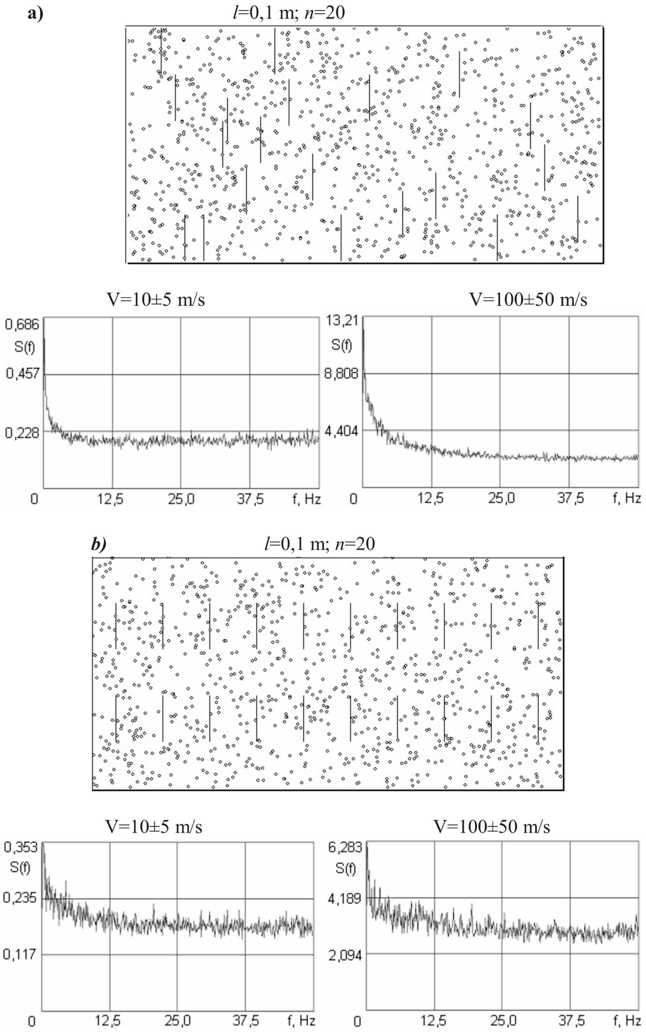

Fig. 2. Systems with chaotic (a) and ordered (b) structures and the power spectra which correspond to the motion of balls with a speed of (10 ± 5) and (100 ± 50) m/s

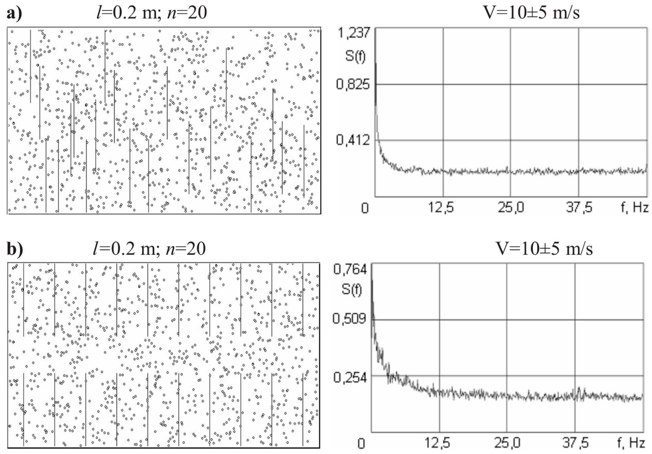

Fig. 3. Systems with chaotic (a) and ordered (b) structures and the increased size of elements and the corresponding power spectra

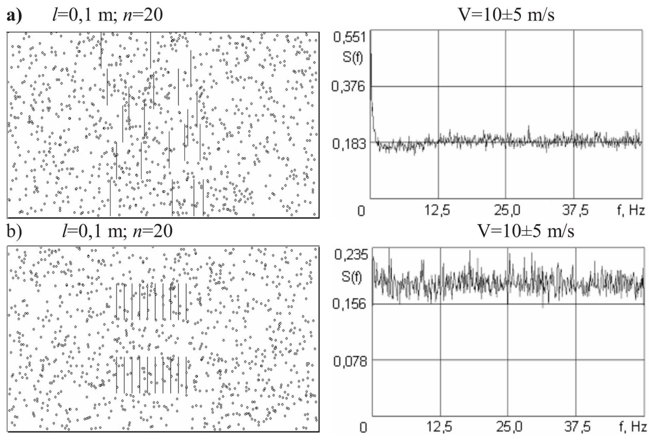

Fig. 4. Systems with chaotic (a) and ordered (b) structures and the decreased distance between elements and the corresponding power spectra

structure are different: the chaotic structures which are characterized by the relaxation time τ_x save the greater energy than the ordered structures, whose relaxation time is τ_n ($\tau_n > \tau_x$, Figs. 2–5, Tables 1–4); structures with the greater number of elements and with the bigger size of these elements save the greater energy as well

T a b l e 1. Dependence of the parameters a and τ on the motion speed of balls

$S(f)$	v, m/s	a, J	τ, s
Fig. 2,a	10 ±5	0.183	1.03
	100 ± 50	2.16	0.40
Fig. 2,b	10 ± 5	0.183	1.90
	00 ± 50	2.30	0.72

(Figs. 2–5, Tables 1–4). In general, if the relaxation time τ decreases the greater energy related to the system structure will be saved. The relaxation time also depends on the motion speed of balls (as it depends on the

T a b l e 2. Dependence of the parameters a and τ on the size of structure elements

$S(f)$	a, J	τ, s
Fig. 3,a	0.184	0.77
Fig. 3,b	0.181	0.81

T a b l e 3. Dependence of the parameters a and τ on the distance between structure elements

$S(f)$	a, J	τ, s
Fig. 4,a	0.183	2.44
Fig. 4,b	0.180	3.55

temperature), and this dependence is the inversely proportional one: $\tau \sim \frac{1}{\sqrt{\nu}}$. The flicker noise dependence is considered in [7, 11].

4. Conclusions

If the relaxation time τ, which can be defined from (2) using the spectral density $S(f)$ of the time change of the parameter $S(t)$ (Fig. 1), and a change of the relaxation time are known, it is possible to make conclusion about the inner structure of the system and its evolution especially if, at the initial time moment, the elements of the structure were placed uniformly and ordered in the system volume (Fig. 2). The increase of the relaxation time (a decrease of FN) means that

1) the distance between structure elements decreases (Fig. 2,b, τ=1.90 s, Fig. 4,b, τ=3.55 s);
2) the size of structure elements decreases (Fig. 3,b, τ=0.81 s, Fig. 2,b, τ=1.90 s);
3) the number of structure elements decreases (Fig. 5,b, τ=0.90 s, Fig. 2,b, τ=1.90 s).

The reason for a decrease of the relaxation time (an increase of FN) can be the following:

1) the distance between structure elements increases (Fig. 4,b, τ=3.55 s, Fig. 2,b, τ=1.90 s);
2) the size of structure elements increases (Fig. 2,b, τ=1.90 s, Fig. 3,b, τ=0.81 s);
3) the number of structure elements increases (Fig. 2,b, τ=1.90 s, Fig. 5,b, τ=0.90 s);
4) the system structure becomes chaotic (Fig. 2,b, τ=1.90 s, Fig. 2,a τ=1.03 s).

If, at the initial state, the inner structure elements were placed chaotically in the system, the increase of the relaxation time (a decrease of FN) can be a result of

1) the ordering of structure elements (Fig. 2,a, τ=1.03 s, Fig. 2,b, τ=1.90 s);
2) a decrease of the distance between structure elements (Fig. 2,a, τ=1.03 s, Fig. 4,a, τ=2.44 s);
3) a decrease of the size of structure elements (Fig. 3,a, τ=0.77 s, Fig. 2,a, τ=1.03 s).

The decrease of the relaxation time (an increase of FN) in the system with chaotic structure can indicate

1) an increase of the distance between structure elements (Fig. 4,a, τ=2.44 s, Fig. 2,a, τ=1.03 s);

T a b l e 4. Dependence of the parameters a and τ on the number of structure elements

$S(f)$	a, J	τ, s
Fig. 5,a	0.176	0.60
Fig. 5,b	0.174	0.90

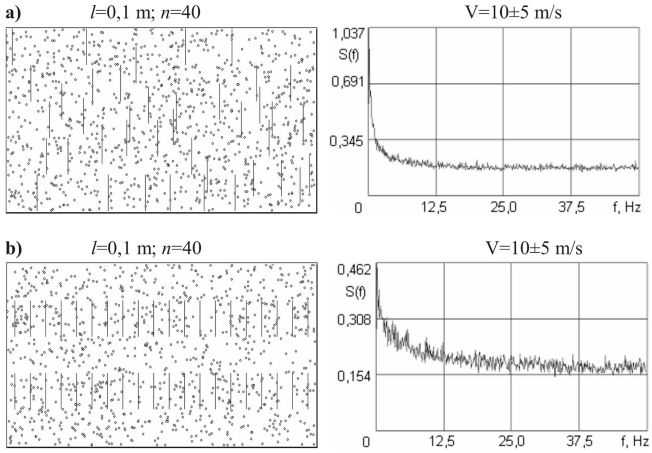

Fig. 5. Systems with chaotic (a)) and ordered (b) structures and the increased number of elements and the corresponding power spectra

2) an increase of the size of elements (Fig. 2,a, τ=1.03 s, Fig. 3,a, τ=0.77 s);
3) an increase of the number of structure elements (Fig. 2,a, τ=1.03 s, Fig. 5,a, τ=0.60 s).

Thus, the computer analysis of the chaotic motion of particles has proved that noises of the $1/f$ type are structure-sensitive noises: the degree of FN depends on the order of elements of the inner system structure: with increase of the order of arrangement of elements of the inner structure of the system, the degree of FN decreases (the resulting degree of FN become near the thermal noise in the system). So the obtained characteristics of FN can be used for the estimation of changes which took place in the inner structure of the system without both its dismantling and the influence of testing signals on it. It is worth also noting that the presented conclusions are referred to the fluctuations (Fig. 1) which occur on the macro- and microscales.

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ВИЯВЛЕННЯ ЗМІН У СТРУКТУРІ СИСТЕМИ ЗА ЗМІНАМИ ЇЇ ФЛІКЕР-ШУМУ

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Р е з ю м е

Наведено результати комп'ютерного моделювання хаотичного руху елементарних частинок в системах з хаотичною та упорядкованою структурою. За результатами аналізу зроблено висновки про можливість використання флікер-шуму системи для якісної оцінки її внутрішньої структури та змін у структурі.