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L.V.Chirkova, K.T.Ermaganbetov, E.T.Arinova

Ye.A.Buketov Karaganda State University
(E-mail: ket3853@mail.ru)

Issues of dynamic chaos in technical discipline

In article the description of experience of introduction to the content of technical disciplines of achievements of modern physics on the example of concept of dynamic chaos is given. In article the formation technique at students of understanding of a role of unstable, critical conditions in evolution of a matter is considered. Examples of studying of dynamic chaos in a training course «Electromagnetic oscillations and waves» are given. The role of nonlinear restriction in dynamic self-oscillatory systems on the example of the classical lamp generator of Van-der-Poll is considered and at a statement of the principles of operation of lasers. Examples of application of chaos in communication systems are given.

Key words: dynamic chaos, unstable states, formation technique, self-oscillatory systems, laser, telecommunication systems.

The present stage of development of science is characterized by growth of scientific information. Thus there is a strengthening of processes of integration of different sections of fundamental science.

As one of important achievements of science consider understanding of a role of unstable critical conditions in evolution of a matter in recent years. Today the accent is postponed from studying of equilibrium conditions of system for research of conditions of instability, and also for studying of mechanisms of emergence new and reorganizations of structures, self-organization [1]. Thus, today it is possible to say that there is a formation of a new scientific paradigm.

In this regard there was a problem to revise the maintenance of traditional training courses of a natural-science and technical profile taking into account achievements of modern physics. The solution assumes introduction to subject matters (such, as, for example, physics, physical electronics, quantum radio physics and others) knowledge of achievements of modern science, of the new phenomena and concepts, a statement of traditional questions from science positions at the present stage.

Authors of this article have experience in the solution of this complex challenge [2, 3]. At a statement of various sections of such disciplines as electromagnetic oscillations and waves, physical electronics, quantum radio physics, microelectronics, authors of article set as the purpose formation at students of understanding of a role of the phenomenon of instability, nonlinearity in the course of evolution of a matter.

We will in more detail consider the matter in practice of studying of dynamic chaos in a training course «Electromagnetic oscillations and waves».

This training course is intended for students of an educational program of the radio technician, the electronic engineer and telecommunication. The purpose of a training course is development of the main data on oscillatory and wave processes, their deep community, and also about application of electromagnetic oscillations and waves for transfer and reception of information. During a statement of a training material the electromechanical analogy is used. This analogy allows seeing a community of laws to which oscillatory and wave processes which have the different nature, an origin submit.

During a training course the electromagnetic oscillations and waves which are trained get acquainted with the main, basic unit of knowledge on which the main subjects among which — electronics, quantum electronics, the theory of transfer of electromagnetic waves, analog circuitry, microelectronics, etc. are under construction subsequently.

Already in introduction (first) lectures on this training course such concepts as the determined system, system which results of action unambiguously are defined by the operating impacts made on it are given.

When speak about determinacy, mean unambiguous interrelation of cause and effect. Generally dependence of future $x(t)$ state from initial $x(t_0)$ can be written down in a look $x(t)=F\left[x(t_0)\right]$, where F — the determined law which carries out strictly unambiguous transformation of an initial state $x(t_0)$ to future state $x(t)$ for any $t > t_0$.

Then linear and nonlinear systems are considered. Thus it is emphasized that in linear systems processes correspond to the principle of superposition and are described by the linear equations.

It is important that linear systems usually are idealization of real systems. Thus simplifications can belong both to parameters of system, and to the movement in it. During a training course examples of linear systems are given. All types of continuous environments (gas, liquid, a solid body, plasma) at distribution to them of wave indignations of small amplitude when parameters of these Wednesdays can be considered constant and not dependent from amplitudes of waves concern to them.

Then trained in a training course acquaint with concept of oscillatory linear system and give examples of such electric systems. For example, electric oscillatory contours and chains, a self-induction, capacities which resistance don't depend on the currents proceeding on them or on tension attached to them. Carry also parametrical oscillatory systems which parameters change under the law set from the outside to linear oscillatory systems.

By consideration of nonlinear systems the attention of students is focused that properties of such systems depend on processes which in them happen. Fluctuations of nonlinear systems are described by the nonlinear equations. To students examples of nonlinear electric systems are given: the electric systems containing a ferroelectric material which dielectric permeability depends on intensity of electric field etc. In such systems communication between electric charges and intensity of the field created by them; communication between tension on the ends of the conductor and force of the current proceeding on it; communication between the current and intensity of the magnetic field (magnetic induction) created by it in a magnetic are nonlinear. Each of these nonlinear communications leads to that the differential equations describing behavior of nonlinear systems are nonlinear.

In a educational course it is highlighted that all physical systems are nonlinear. One of the most important features of nonlinear systems is violation of the principle of superposition in them.

Considering specifics of an educational program, students are acquainted surely with that distortion of a form of harmonious external influence in nonlinear systems and inapplicability of the principle of superposition allow to carry out with their help generation and transformations of frequency of electromagnetic oscillations (straightening, multiplication of frequency, modulation of fluctuations etc.). Thus, already at the first lectures intersubject communications of subject matters of an educational program are realized.

Then concepts of the determined nonlinear system and dynamic chaos, as difficult, irregular and unpredictable (on big intervals of time) behavior of the determined nonlinear systems are entered. The attention of students in a training course is paid to world outlook value of this opening. This discovery is that the determined system can possess all properties of casual process. It radically changes the established idea of possibility of the long-term forecast of processes of evolution.

Chaotic processes in the determined nonlinear systems — one of fundamental problems of modern natural sciences. It is convincingly proved [4, 5] that in such systems the reason of generation of difficult oscillatory processes consists not in a large number of degrees of freedom or existence of fluctuations. Exponential instability of the modes is the reason. Possibility of the similar phenomena was understood and assumed by A.Poincare. In the book «Science and Method» (1908) he wrote that in unstable systems «absolutely insignificant reason escaping us on the trifle causes considerable action which we can't provide … The prediction becomes impossible, we have before ourselves the phenomenon casual».

As a striking example of the chaotic movement it is possible to use demonstration of chaotic fluctuation of a mathematical pendulum at which the point of sub weight makes the chaotic movements.

Further it is important to enter concept of dynamic system. It is the mathematical model corresponding to real systems (physical, chemical and so on) which evolution is defined by an initial state [3]. It is important that evolution of dynamic system can be shown by means of phase trajectories in phase space.

Then students are told about two classes of dynamic systems — conservative and dissipative. These systems in turn can be divided into two types: determined and not integrated.

At the determined systems of a trajectory of the movement are steady. They can't be changed considerably small indignations. The behavior of such systems in the past and the future is defined by a state [4] now.

Existence of not integrated systems for the first time was predicted by A.Poincare. These are dynamic systems which behavior is unstable. Any small indignation quickly leads to cardinal change of a trajectory. (Here it is necessary to emphasize that quickly is understood in time scale for this system).

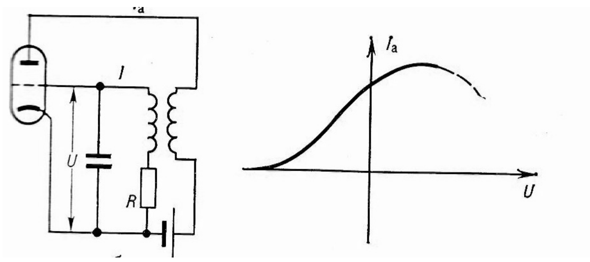
When studying linear and nonlinear oscillatory processes phase portraits of typical oscillatory systems are considered. It allows creating knowledge of students of special points of phase trajectories of dynamic systems: center, saddle, steady and unstable systems, knot and focus. On the basis of the analysis of a phase portrait of a mathematical pendulum the concept of a separatrix is entered.

Passing to consideration of a question of dynamic chaos, it is necessary to try to give its definition. When speak about chaos, mean that change in time of a condition of system is casual and non-reproducible. That is process can't be predicted and it is impossible to repeat.

Necessary condition of emergence of dynamic chaos is nonlinear restriction of growth of indignations in system and instability. The deviation from balance will grow until the mechanism of nonlinear restriction takes effect.

The role of nonlinear restriction in dynamic systems is accurately shown in self-oscillations. As we know, understand not damped oscillations in dissipative nonlinear system as self-oscillations. These fluctuations are sustained due to energy of an external source. Parameters of fluctuations (amplitude, frequency, a range of fluctuations) are defined by properties of the system and don't depend on final change of entry conditions [6, 7].

In the elementary self-oscillatory systems allocate oscillatory system with attenuation, the amplifier of fluctuations, the nonlinear limiter and a link of feedback. As an example of self-oscillatory system it is possible to consider the classical lamp generator of Van-der-Paul (fig. 1 a).



a) в)

Figure 1. The scheme of the generator of Van-der-Paul with an oscillatory contour in a chain of a grid (and);
the characteristic of a lamp (in)

The amplifier (active element) is the lamp. The oscillatory contour with losses consisting of capacity With of inductance of L and resistance of R, represents dissipative oscillatory system. The chain of feedback is formed by a chain the cathode — a grid and inductance of L.

Small own fluctuations which incidentally arise in an oscillatory contour, via the coil L operate anode current of a lamp. At positive feedback certain energy is brought in a contour. If it exceeds energy of losses in a contour, amplitude of fluctuations grows in a contour.

Anode current of a lamp not linearly depends on tension on a grid (fig. 1 c). Dependence of I (U) is approximated by a cubic polynom [6]:

$$I(U) = -gU + gU^3, \ (1)$$

where g — conductivity.

The active nonlinear element with small amplitudes strengthens indignation (conductivity is negative, that is $I(U) = -gU$).

With a growth of amplitude of fluctuations the energy coming to a contour decreases. With some amplitude of fluctuations energy becomes equal energy of losses. The mode of stationary self-oscillations is as a result set. In this case the external source (a source the anode battery is) offsets all losses of energy. Thus, self-oscillatory systems are essentially nonlinear. Nonlinearity defines receipt and expenditure of energy of a source and doesn't allow fluctuations to increase infinitely: with big amplitudes of fluctuations $I(U) \approx gU^3$. Thus, nonlinear attenuation is the restriction mechanism.

Mathematically the mode of functioning of dissipative dynamic system is the attractor is the limit trajectory located in limited area of phase space. All relatives to it a trajectory aspire to this limit trajectory.

After completion of consideration of systems with one degree of freedom the teacher draws a conclusion that such dynamic systems can or make periodic fluctuations, or beyond all bounds come nearer to balance position, or beyond all bounds move away from balance position.

The question of a role of nonlinear restriction arises again in a training course of quantum electronics by consideration of the principles of operation of lasers. The laser is an example of nonlinear optical system. Nonlinearity of properties of the laser is shown in effect of saturation which limits possibility of strengthening of radiation to the active environment. At an explanation of this effect an analogy to nonlinearity of an intensifying element in the generator of harmonic oscillations is drawn. This analogy allows showing to students that the fundamental physical principles are shown in work of self-oscillatory systems of various natures. Thus at students idea of a universal role of nonlinearity in establishment of fluctuations is formed.

By consideration of a question of chaos the teacher pays attention of students to that circumstance that the main feature of chaos is dynamic instability of the movement. The concept of the chaotic movement repeatedly changed in recent years. Researches of nonlinear dynamic systems showed possibility of dynamic chaos in such systems. The reasons of unpredictability and an irregularity are own dynamics of system, but not influence of noise and external factors.

Emergence of chaos requires existence of local instability and hashing of phase trajectories. Local instability is called sensitivity to indignation of entry conditions as it consists in an exponential divergence of phase trajectories at small changes of entry conditions.

In dynamic systems with several degrees of freedom phase trajectories are concentrated in limited area of phase space. It is caused by nonlinear restriction. Hashing of phase trajectories happens as a result any small vicinity of an initial state evolves so that moves on all area of a trajectory.

By consideration of evolution of locally unstable dissipative dynamic system the teacher pays attention of students that initial phase volume in such system decreases because of energy loss over time. At the same time there is a growth of indignations in system that is connected with local instability. As a result phase volume in some directions stretches, in other directions — contracts. Evolution of dynamic system is defined by entry conditions. These conditions can be set only with a final accuracy. Therefore for a prediction of behavior of system it is necessary to consider evolution in time of close entry conditions. However local instability and the mechanism of hashing lead to that the determined prediction becomes impossible — originally close entry conditions bring to various final condition of system over time. Such behavior of system is called as dynamic chaos.

There are some typical scripts of transition of no equilibrium dynamic system for the determined chaos. Are the most known — the cascade of doubling of the period, a combination and the quasiperiodic modes. As an example in a training course the first of the listed scenarios which call Feygenbaum scenario is considered: transition to chaos in many dynamic systems results from the infinite cascade of bifurcations of doubling of the period. The interval between consecutive bifurcations is considered as a geometrical progression. One of examples of systems in which the scenario of transition to chaos via the cascade of doubling of the period works is the electro optical bistable device (fig. 2).

The device represents the electro optical lock captured by feedback [8].

Work of this scheme is described by a recurrence relation

$$Q_n = P\sin^2\left(\varphi_0 + Q_{n-1}\right), \tag{2}$$

Here $P = \beta I_{вх}$ и $Q = \beta I_a$ — dimensionless intensity; β — the constant coefficient depending on parameters of system; φ_0 — constant phase; index n=1,2,3,.. defines a present situation of time $t = n\tau_{oc}$; τ_{oc} — delay time in a feedback chain.

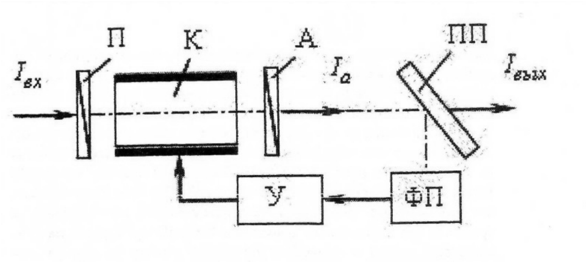


Figure 2. Electrooptical bistable device. П, And — a polarizer and the analyzer,
To — a crystal, software — a translucent plate, At — the amplifier, FP — a photodetector [8]

Stable states $Q_{n-1} = Q_n = Q^{cm}$ are defined as solutions of the transcendental equation

$$Q^{cm} = P\sin^2\left(\varphi_0 + Q^{cm}\right). \tag{3}$$

They can be found a graphic way (fig. 3), having constructed function graphs $f(Q) = Q$ and $F(Q) = P\sin^2\left(\varphi_0 + Q^{cm}\right)$.

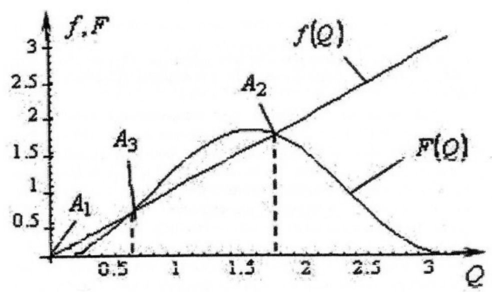


Figure 3. Graphic solution of the equation (3) [9]

Follows from figure 3 that for the set scheme parameters P and φ_0 three stable states are possible $Q_1^{cm}, Q_2^{cm}, Q_3^{cm}$, corresponding to points of intersection A_1, A_2, A_3. Two states (attractors A_1, A_2) are steady, to them all phase trajectories from some area of phase space (attraction area) are attracted. Third state (repeller A_3) — unstable, for it the exponential division of the trajectories beginning in the field of a repeller is characteristic.

Thus, the considered scheme is bistable and depending on initial value of intensity Q_0 will come to one of the steady states Q_1^{cm} or Q_2^{cm}.

Bistability is observed in the limited range of change of intensity of entrance radiation $P_1^{кр} < P < P_2^{кр}$. At achievement of critical value of entrance intensity $P_2^{кр}$ ~1,97 (для $\varphi_0 = 0$) attractor A_2 turns in a repeller, and in his vicinity there are two new attractors A_4 and A_5, that is in system there is a bifurcation. Thus new steady states consistently replace each other on each subsequent iteration (2 cycle).

2 cycle is observed and in the limited range of change of entrance intensity $P_2^{кр} < P < P_3^{кр}$. At achievement of critical value $P_3^{кр}$ in system there is a bifurcation again: attractors A_4 and A_5 turn in repeller, and in the vicinity of each of them there are two new attractors. There is 4 cycle. At further increase of intensity of

entrance radiation consistently arise 2^k -cycles, in each of which there is a doubling of the period in comparison with previous (the cascade of doubling of the periods). After infinite number of doubling of the period in system there comes the difficult chaotic state.

Computer modeling [9] shows that in the considered system the dynamic chaos comes at $P > P_x = 2,35$ (для $\varphi_0 = 0$). Emergence of chaos is result of global loss of stability of system.

The given example of nonlinear electro optical system allows to demonstrate necessary conditions of emergence of bistability, to show characteristics of dynamics of nonlinear systems and to explain physical sense of a number of the new concepts which are widely used in modern science.

At a material statement about dynamic chaos the attention of students is focused that the understanding of the nature of dynamic chaos is necessary not only for formation of scientific outlook. It is necessary in order that chaotic processes could be operated for the purpose of their application in various areas of science and equipment. Researches of the last years [11] showed that in chaotic systems it is possible to realize adaptive management easily. In other words, chaotic systems are easier arranged under the changing external conditions.

In a training course the attention is paid to a material statement about application of chaos in communication systems. In this case the chaos can be used as a data carrier, as the dynamic process providing transformation of information to a new look.

The chaos belongs to broadband signals. Similar signals possess big information capacity in comparison with narrow-band fluctuations. The wide strip of frequencies increases information transfer speed, and also increases resistance of system to the revolting factors. The broadband and super broadband communication systems based on chaos have potential advantages before traditional systems. Advantages consist in simple hardware realization, power efficiency and a high speed of information transfer. Chaotic signals can serve for masking of the transmitted data without use of expansion of a range that is at coincidence of a strip of frequencies of the information and transferred signals.

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Л.В.Чиркова, Қ.Т.Ермағанбетов, Е.Т.Аринова

Техникалық пәндердегі динамикалық хаос

Мақалада «динамикалық ретсіздік» ұғымы негізінде техникалық пәндердің мазмұнына физиканың қазіргі заманғы жетістіктерін ендіру тәжірибесі талданған. Материяның дамуындағы орынсыздықтар мен критикалық күйлердің алатын орындары туралы түсініктерді арнайы пәндерді оқу барысында студенттердің жадында қалыптастыру әдістері қарастырылған. Мысал ретінде «Электрмагниттік тербелістер мен толқындар» курсында динамикалық ретсіздік құбылысын талдау үдерісі келтірілген. Динамикалық–автотербеліс жүйесінде бейсызық шектеулердің алатын орны талданған. Автотербеліс жүйесінің мысалы ретінде классикалық Ван-дер-Пол шам өндіргіші ұсынылған. Кванттық электроникада лазерлердің жұмыс ұстанымындағы бейсызық алатын орны талданған. Коммутация жүйелерінде ретсіздік құбылысын пайдалану мысалы берілген.

Л.В.Чиркова, К.Т.Ермаганбетов, Е.Т.Аринова

Вопросы динамического хаоса в технических дисциплинах

Описывается опыт введения в содержание технических дисциплин достижений современной физики на примере понятия динамического хаоса. Рассматривается методика формирования у студентов в ходе изучения дисциплин специальности понимания роли неустойчивых, критических состояний в эволюции материи. Приведены примеры изучения динамического хаоса в курсе «Электромагнитные колебания и волны». Рассмотрена роль нелинейного ограничения в динамических–автоколебательных системах на примере классического лампового генератора Ван-дер-Поля и при изложении принципов работы лазеров. Приведены примеры применения хаоса в коммуникационных системах.

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