УДК 658.56

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SYNERGETIC APPROACH TO THE DESCRIPTION OF REALIZATION OF THE PRODUCT AT THE STAGES OF DESIGN, MANUFACTURING AND OPERATION

Application of synergetics as new scientific paradigm to management is discussed. The necessary settings for the development of organization as a complex system in the framework of the theory of synergetic management are analyzed. Within the limits of the model of endogenous scientific and technical progress the problem of efficiency increase of integration into the general system at all stages and levels of life cycle of a product is considered. A synergistic model, which allows to present evolution of life cycle on the basis of joint behavior of designing, making and using systems is constructed. On the basis of phase portraits kinetics of continuous transition between modes of realization of life cycle of the product which answer various parities of times of change of a gain of scientific and technical result and the production functions of using and making systems is investigated.

Keywords: *synergetic model of product life cycle, self-organization.*

Introduction

In modern industrial systems finished product is a result of a joint interaction of many economic, technical and social processes, both on national, and international, and, sometimes, at global levels («global sourcing»).

High level of functional, aesthetic and ecological properties of production (at economic feasibility observance) is in many respects connected with the realisation of the system approach in the organisation and management of product life cycle (PLC). Application of information technologies, which cover and unite all stages of PLC provides reduction of time of working out of a new product, development of its manufacture and its putting up for the market. The new technological and technical decisions, which are realised in production and reflect achievements of various branches of knowledge, lead to association of efforts at PLC stages of a wider range of the enterprises, each of which concentrates on its own basic competence. It creates conditions for maintenance of qualitatively new set of properties and measure of utility of products, and also an increase of technical and economic indicators of its manufacture and operation.

Efficiency of PLC functioning is in many respects connected with presence of corresponding objective laws of management, which are capable to consider condition and changes of the internal and the external environment. Problems of management of such dynamic systems are rather relevant and require new theoretical approaches. A present economic crisis is an acknowledgement to that. At present time more and more decisions, connected with management of various technical systems, are based on deep analogy to the processes, which proceed in natural systems (physical, chemical, biological).

PLC research in frameworks of the synergistic approach, which represents the interdisciplinary course, is rather perspective. It allows to describe a self-organization of strongly nonequilibrium systems in a uniform way in various science directions and appendices [1, 2].

Statement of the problem

According to the model that is introduced in the international standards of ISO 9000 Series, PLC can be presented by a combination of levels of designing, manufacture and operation. Each of these levels represents a system, which can have an independent character of application of the results. However, their integration into the general system provides possibility of essential increase of technical and economic indicators of a product.

The PLC system condition is defined by a set of conditions and means providing joint functioning of economic, technical and social processes, testing on itself unequal influence of an environment and possessing different response time. The majority of mathematical models of processes which are in use nowadays consist of the following elements (see fig. 1): set of possible entrance influences (any streams of resources - material, financial, personnel and information); set of possible target influences (production, service, etc.); the set characterising a condition of the system during the given period (the workplaces that serv for transformation of streams of resources into finished goods).

In these conditions to define quantitatively dependence between an input and output of the production, having reconstructed internal structure with sufficient completeness, is rather difficult. On the other hand, the description of functioning of modelled process as a system can be received on the basis of processing of the statistical data.

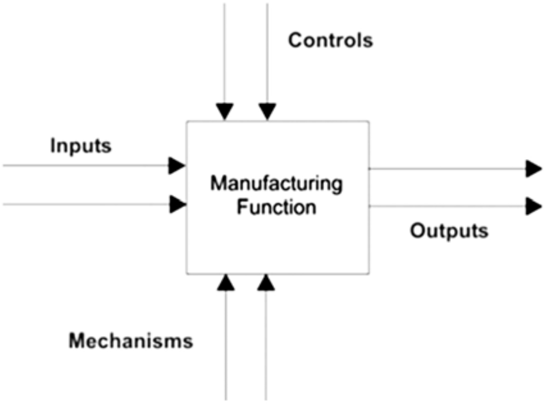


Fig. 1. Model of PLC processes

In such situation PLC management turns into a problem, which demands an application of special means of the analysis, planning and management. One of such means is an economic-statistical modelling in which models of the production functions (PF) are used most often [3].

In a general form it is possible to present the production function by the following dependence:

$$y = f(x_1,\dots,x_n)\,, \tag{1}$$

where y – an output indicator; $x_1,\dots x_n$ - indicators of industrial resources.

Number of factors of the production functions $n < 10$. Usually PF (1) is created by selection of the most suitable functions of a certain parametrical class $y = f(x_i;a_1,a_2,\dots,a_k)$, where $a = (a_1,\dots,a_k)$ vector of parameters.

More often in economic literature PF are expressed in a multiplicate $y = a_0 x_1^{a1} x_2^{a2}$ or an additive $y = a_0 + a_1 x_1 + a_2 x_2$ forms.

Here a_1 and a_2 – the indicators of the production function that characterise sensitivity of the throughput to the change of the costs of industrial resources, a_0 – the factor, which considers dimension of indicators and neglected random factors of manufacture. These indicators are received on the basis of available statistical, expert and other data types about technology and production behaviour in the past and the future. Thus the method of their estimation unequivocally is not defined and depends on the purposes of PF creation, features of the modelled process and the initial data.

The analysis of the existing methods shows that it is the most rational at PF formation (y) to pass on to dimensionless indicators $x_1,\dots x_n$. For this purpose it is necessary to convert all indicators (x_i) into a dimensionless scale x′, where each individual indicator will be defined under the formula (2) [4]:

$$d_i = e^{-(e^{-x'_i})}\,. \tag{2}$$

At unilateral limitations $x_i \le x_{imax}$ or $x_i \ge x_{imin}$ x'_i looks as follows (3):

$$x'_i = k\frac{x_i - x_{max}(x_{min})}{x_{max}(x_{min})} + m\,, \tag{3}$$

where k, m – the factors, which allow to set a various curvature of the curve (fig. 2).

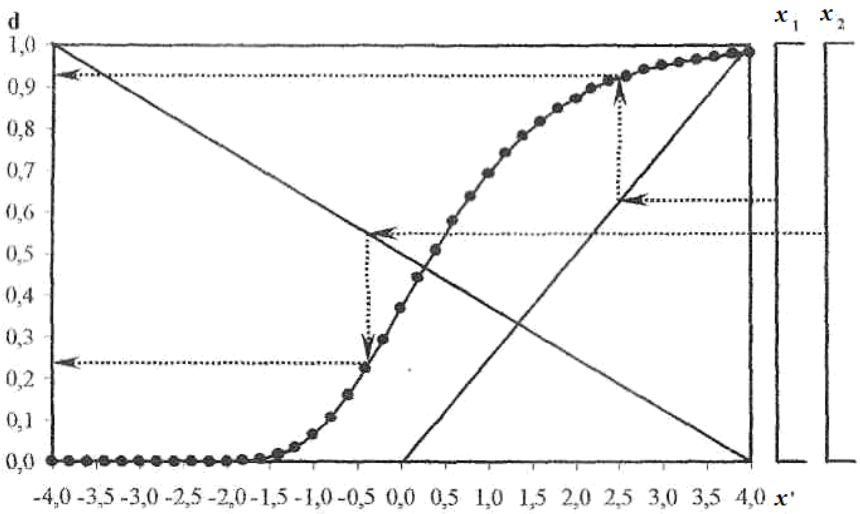


Fig. 2. Graph of the Harrington's desirability function

It allows to consider separate, most important features of the modelled process and the initial data.

Consequently PF is formed as a generalised function representing a geometric mean of separate parameters

$$y = \sqrt[q]{d_1 \cdot d_2 \cdot \dots d_q}\,, \tag{4}$$

where q – number of studied parameters of optimisation.

The special scale (table 1) allows to find either desirable level of PF.

Table 1

Scale of PF desirability

Level of PF	y
Maximum possible level of PF	1.00
High level of PF	1.00 – 0.80
Good level of PF	0.80 – 0.60
Sufficient level of PF	0.60 – 0.37
Admissible level of PF	0.37
Inadmissible level of PF	0,37 - 0
The most undesirable level of PF	0

Thus the production functions can be applied both independently and as a part of the more complex economic and mathematical models.

The most known model which allows to consider processes of PLC is P.Romera's model [5] – the model of the endogenous scientific and technical progress, based on the idea of accumulation of the human capital.

According to this model PLC can be presented as the block diagramme shown in fig. 3.

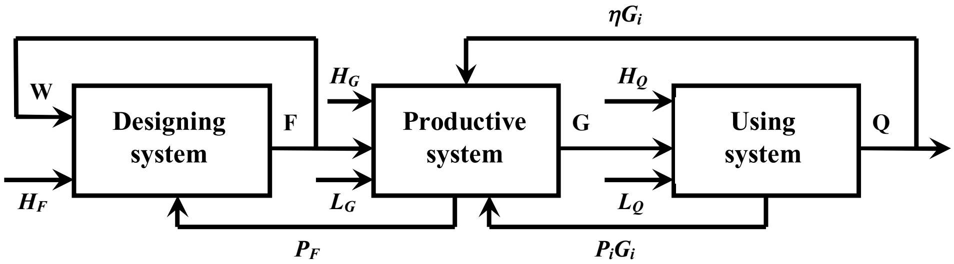


Fig. 3. The block diagramme of the model of endogeneous scientific and technical development of the life cycle of a machine-building product

The product is originally created at a design stage - engineering and design preparation of the manufacture. It is possible to present the results of this stage by the production function F which is proportional to already available store of designs W and realisations (an existing fund of knowledge), including complex of preproduction works (research and development), and to the involved volume of human capital H_F. At a production phase the information, containing in the design and technological documentation (engineering documentation and technical documentation, accordingly), by means of technological actions will be transformed to properties of a product. Functioning in system resources, technology and organisation conditions define potential possibilities and a condition of the process of production. Efficiency of transformation of resources into production can be expressed by the production function G (cost of the output of the end product), which includes industrial capital costs H_G and labour inputs L_G.

Made product G_i (product cost (means of production)) is put into operation, where on the basis of labour inputs L_Q in the form of cost of tangible assets (machinery and equipment, buildings, constructions, the earth, stocks of raw materials, half-finished products and finished goods), which are applied in production, and the involved human capital H_Q (the accumulated expenses for the general education and special training of experts, public health services, labour moving, etc.) is used by the customer for a release of the end production Q (cost of the output of the end product).

In the offered work, the phenomenological scheme is investigated. In the frameworks of this scheme evolution of self-organizing systems can be represented in a self-coordinting way, and possible variants of continuous transition between modes of PLC realisation can be considered. Our approach is based on the Lorentz's three-parametrical system, answering the elementary field representation of the self-organizing system.

Synergistic representation of life cycle of the product

As shows a research of complex systems [6], representation of the self-organizing system is reduced to the self-co-ordinated description of time dependences of parameter of the order, the interfaced to it field and the operating parameter. As efficiency of realisation of PLC is defined at its operation, then it is necessary to accept the production function of maintaining (using) system Q as an order parameter. Accordingly, the conjugate field represents the production function of making system G, and the operating parametre F characterises a gain of scientific and technical result.

As a result the problem is reduced to an expression of the specified quantities' change rates $\dot{Q}, \dot{G}, \dot{F}$ through their values Q, G, F.

Considering that the behaviour of parametre of an order $Q(t)$ is the core and subordinates behaviour of the conjugate field $G(t)$ and the operating parameter $F(t)$, we will accept an expression for its change rate $\dot{Q}$ in the linear form

$$\tau_Q \dot{Q} = -Q + A_Q G . \quad (5)$$

Here the first summand in the right part considers a relaxation of the production function of the using system to zero value for time τ_Q, the second - describes linear reaction of the change rate $\dot{Q}$ to field increase G ($A_Q > 0$ - a communication constant).

The equation for the conjugate field is accepted as

$$\tau_G \dot{G} = -G + A_G QF, \tag{6}$$

where the first summand again has a relaxation nature with the characteristic time τ_G , the second - represents a positive feedback of the production function of the using system and a gain of scientific and technical result with the change rate of the conjugate field ($A_G > 0$ - the communication constant). This communication causes increase of the conjugate field (the production function of making system), which is at the bottom of self-organising.

Last equation of evolution of the system describes the relaxation of the gain of the scientific and technical result, F which is playing a role of the operating parameter:

$$\tau_F \dot{F} = (F_e - F) - A_F QG. \tag{7}$$

Unlike (5), (6) the first summand in (7) describes a relaxation of parameter F not to zero, but to final value F_e, which is set by external influence (τ_F - corresponding characteristic of relaxation, $A_F > 0$ - a communication constant). According to (7) negative feedback of the conjugate field and parameter of an order with speed of a gain of scientific and technical result, according to a principle of Le-Shatele, results to reduction of this parameter.

According to [7] system of synergistic equations (5) - (7) is the elementary field scheme representing effect of self-organising. For the analysis of this system it is convenient to make use of dimensionless variables by scaling time t, the production function of the using system Q, conjugate field G and internal status parameter F

$$\tau_Q,\ Q_c \equiv (a_G a_F)^{-1/2},\ G_c \equiv \left(a_Q^2 a_G a_F\right)^{-1/2}, \quad F_c \equiv (a_Q a_G)^{-1}. \tag{8}$$

Then the behaviour of PLC processes is represented by dimensionless system of the equations

$$\dot{Q} = -Q + G, \tag{9}$$

$$\sigma \dot{G} = -G + QF, \tag{10}$$

$$\delta \dot{F} = (F_e - F) - QG, \tag{11}$$

where relations of characteristic times $\sigma \equiv \tau_c / \tau_Q$ and $\delta \equiv \tau_F / \tau_Q$ are entered.

Within the frames of the elementary picture the evolution of self-organizing systems is represented by adiabatic approach $\tau_{G,}\tau_F << \tau_Q$, according to which the conjugate field $G(t)$ and the operating parameter $F(t)$ change so quickly that they have time to be arranged under slow change of parameter of an order $Q(t)$. Thus system evolution has the monotonous character described by the equation of Landau-Halatnikov. According to [8], for reflexion of nonmonotonic evolution of system, it is necessary to weaken a standard principle of hierarchy [9], accepting that not one, but two variables possess the greatest time of relaxation. As a result a system of two differential equations represent a transition and the problem comes to research of possible scenarios of continuous transition.

Continuous transition

The elementary picture of continuous transition, which is traditionally related to the second kind, is realised provided that characteristic time of parameter of an order τ_Q does not depend on its value *Q*. In adiabatic approach characteristic time of change of the production function of the using system much more surpasses corresponding scales for the production function of the making system and a gain of scientific and technical result

$$\tau_{G,}\tau_F << \tau_Q. \tag{12}$$

As dimensionless rates $\dot{Q}, \dot{G}, \dot{F}$ have an identical order, conditions (12) allow to neglect the left parts of the equations (10) and (11) that lead to parities

$$G = F_e \frac{Q}{1+Q^2},\ F = \frac{F_e}{1+Q^2}. \tag{13}$$

Substitution of the first of equalities (13) by (9) gives the equation of evolution of system in the form of the equation of Landau-Halatnikov:

$$\dot{Q} = -\frac{\partial V}{\partial Q}. \tag{14}$$

Its kind is defined by synergistic potential, which is measured in units Q_c^2:

$$V = \frac{Q^2}{2} - \frac{F_e}{2} \ln\left(1 + Q^2\right), \tag{15}$$

At small values of intensity of external influence F_e dependence $V(Q)$ has monotonously increasing type with a minimum $Q_0 = 0$, which answers inefficient realisation of PLC.

With growth of F_e to the values exceeding critical level of F_c, there appears minimum

$$Q_0 = \sqrt{F_\ell - 1}\,, \tag{16}$$

which answers the effective realisation of PLC.

The consideration shows that the use of the system (9) - (11) allows to present the self-co-ordinated picture of transition between various modes of realisation of PLC.

Kinetics of transition between modes of realization of life cycle of the product

Let's consider three cases of nonmonotonic behavior of PLC.

Case $\tau_G << \tau_Q, \tau_F$

To start a research of nonmonotonic behavior of PLC, we will begin with a case in which the lower-range value has time of relaxation of the production function of the making system that follows changes of generating function of the using system and a gain of scientific and technical result. Then fluctuations of the conjugate field can be neglected, believing that in (10) $\dot{G} = 0$.

This approach gives relation

$$G = QF, \tag{17}$$

which consideration in the remained equations (9 - 11) leads to a new system

$$\dot{Q} = -Q(1 - F), \tag{18}$$

$$\dot{F} = \delta^{-1}\left[F_e - F\left(1 + Q^2\right)\right]. \tag{19}$$

From here it is visible that in precritical area ($F_e < 1$), when intensity of external influence is less than critical value $F_c = 1$, point D represents a steady vertex, and point O is absent at all. As a result our system switches to D - the mode of inefficient realisation of PLC, according to the phase portrait given in fig. 4, a.

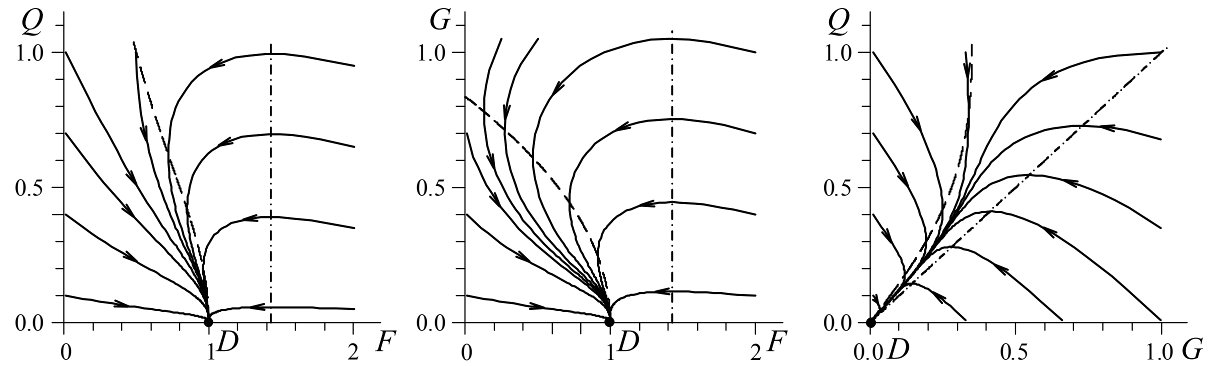


Fig. 4. Phase portraits of low-efficient PLC ($F_e = 0.7 F_c$):
а – $\tau_G << \tau_Q = \tau_F$; б – $\tau_Q << \tau_G = \tau_F$; в – $\tau_F << \tau_G = \tau_Q$;
hereinafter the shaped line specifies points in which phase trajectories have a vertical tangent, a stroke-dotted - the horizontal

Growth of parameter (20) leads to a twisting of trajectories around point *D* that shows the tendency to oscillatory mode of PLC, which appears with an increase of a lag of changes of the operating parameter as against the order parameter.

As evident from the phase portrait given in fig. 5, this tendency is realised in full at transition in area where intensity of external influence exceeds critical value.

Here point *D* transforms to a saddle and the additional point *O,* which answers an effective mode of realisation of PLC, appears. At the values of parameter δ, limited by magnitude

$$\delta c = F_\ell^2 \big/ \left(8\left(F_\ell - 1\right)\right), \tag{20}$$

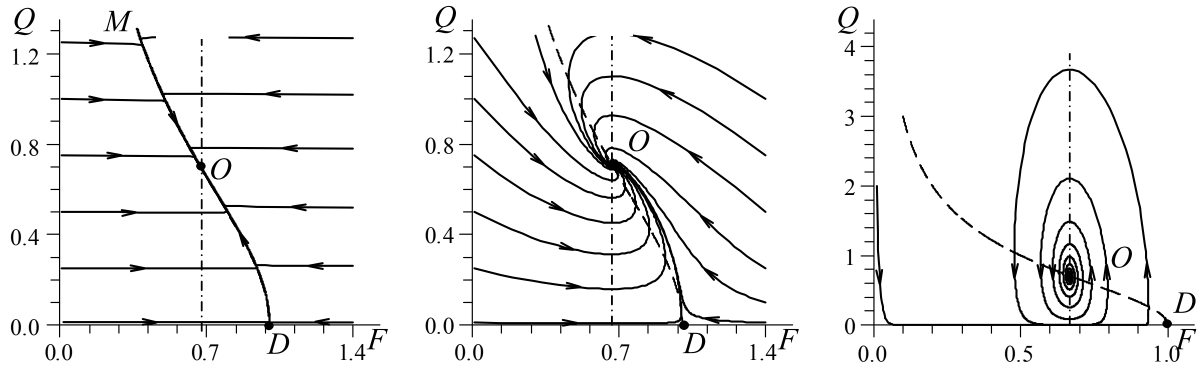
this point represents a steady vertex, and with its growth to values $\delta > \delta_c$ - steady focus.

In the first case the effective mode of realisation of PLC is reached at the expense of monotonous change of intensity of external influence and the production function of maintaining system, in the second case the mode of fading fluctuations of these values is realised.

The carried out consideration shows that at

$$\tau_Q << \tau_F$$

in above-critical areas there is an oscillatory mode of transition of system to a mode of effective realisation of PLC: according to fig. 5, c, reduction of the production function of maintaining system leads to the increase in a gain of the scientific and technical result, which growth then causes an increase of the specified roduction function, which, in turn, is reducing subsequently the gain of scientific and technical result.



а б в

Fig. 5. Phase portraits of the mode of PLC effective realisation ($F_e = 1.5 F_c$):
а – $\tau_G << \tau_Q = 100\tau_F$; б – $\tau_G << \tau_Q = \tau_F$; в – $\tau_G << \tau_F = 100\tau_Q$

The inverse limit $\tau_F << \tau_Q$ answers the adiabatic approach that represents a standard picture of transition. According to the phase portraits shown in fig. 5, reduction of parameter to $\delta \to 0$ leads to gathering of all trajectories at a diagram area *MOD*, which position does not depend on microscopic details of the system. From fig. 5a it is clear that before getting to this area the gain of scientific and technical result quickly changes, and then slowly evolves on it (thus the effect of delay reveals the more strongly, the lesser is the nonadiabatic parameter). From the formal point of view the *MOD*-area answers the drawing range which is traditionally designated as a channel of a big river.

Case $\tau_Q << \tau_G, \tau_F$

Now let's consider a case when the production function of the maintaining system changes so quickly that it has time to follow changes of the production function of the making system and changes of the gain of the scientific and technical result.

Then in the equation (9) it is possible to put $\dot{Q} = 0$ that leads to relation

$$Q = G. \quad (21)$$

Its substitution in the system ((10), (11)) gives a new system

$$\dot{G} = -G(1 - F), \quad (22)$$

$$\dot{F} = \tau^{-1}\left[F_e - \left(F + G^2\right)\right], \quad (23)$$

where time t is measured in units τ_G and the relation of characteristic times is introduced

$$\tau \equiv \tau_F / \tau_G. \quad (24)$$

The carried out analysis and the view of phase portraits (fig. 6) show that at great τ values, when the gain of the scientific and technical result changes much more slowly than the production function G, the system gets to a mode of fading fluctuations (fig. 6, c). With the reduction of τ to values $\tau << 1$ the smooth mode of evolution (fig. 6a) is reached. As in the previous case, in adiabatic limit $\tau \to 0$ system evolution takes a universal character that is expressed by availability of *MOD*-area (fig. 6a), getting on which, the system slowly moves to the stationary point *O*, which answers the effective mode of PLC realisation.

Case $\tau_F << \tau_Q, \tau_G$

As the gain of the scientific and technical result changes most quickly here, so, assuming in (11) $\dot{F} = 0$, we find relation

$$F = F_e - QG, \quad (25)$$

and the equations (5) and (6) become

$$\dot{Q} = -Q + G, \quad (26)$$

$$\dot{G} = \sigma^{-1}\left[F_\ell Q - G\left(1 + Q^2\right)\right], \quad (27)$$

where the relation of characteristic times is entered

$$\sigma \equiv \tau_G / \tau_Q. \quad (28)$$

The phase portrait has special points D(0,0) and $O\left(\sqrt{F_e - 1}; \sqrt{F_e - 1}\right)$ (fig. 7), the second of which is realised only for the mode of the effective PLC realisation at the value of intensity of external influence $F_\ell > 1$.

At $F_\ell < 1$ point *D* represents the steady vertex answering an inefficient mode of PLC realisation, and with transition into the above-critical area $F_\ell > 1$ it is transformed to a saddle. At the values of parameter σ that belong to an interval (σ_-, σ_+), where

$$\sigma_\pm = \left(3F_e - 4\right) \pm \sqrt{8\left(F_e - 1\right)\left(F_e - 2\right)}, \quad (29)$$

point *O,* which answers the effective mode of PLC realisation, represents a drawing focus, and out of it – a drawing vertex.

Unlike considered above cases the oscillatory mode practically is not shown here.

According to the phase portraits shown in fig. 7, universality of kinetic behaviour of system is shown both at $\tau_G << \tau_Q$, and at $\tau_G >> \tau_Q$.

In the first case the exit onto a universal area occurs at the expense of the fast change of the production function of the making system G(t) at almost invariable production function of the maintaining system Q(t) (fig. 7, a), and in the second case the return picture is observed - the production function of the maintaining system changes very quickly, and the production function of the making system almost does not vary (fig. 7, c).

In the intermediate area $\tau_Q \sim \tau_G$ versatility is shown only at small initial values of one of the production functions (fig. 7, b). Unlike above considered cases in this one the universal area has not falling down, but accruing character.

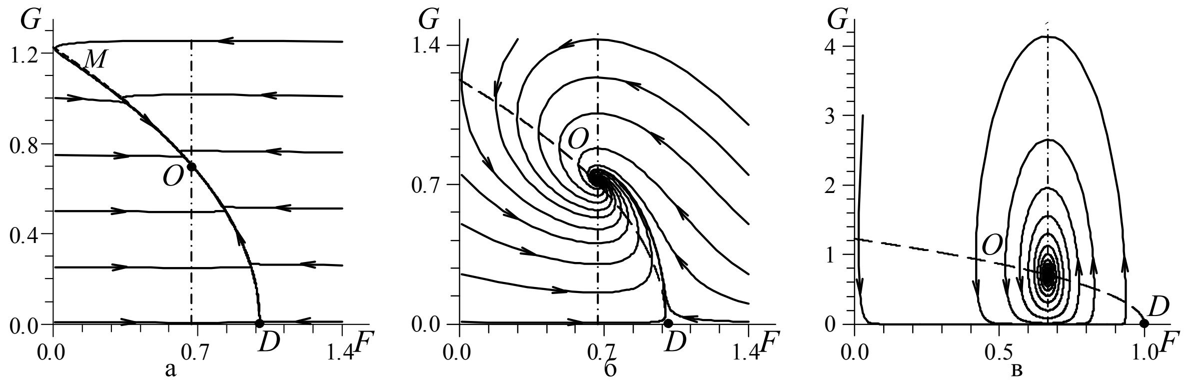


Fig. 6. Phase portraits of the mode of effective PLC realization ($F_e = 1.5 F_c$):

а – $\tau_Q << \tau_G = 100\tau_F$; б – $\tau_Q << \tau_G = \tau_F$; в – $\tau_Q << \tau_F = 100\tau_G$.

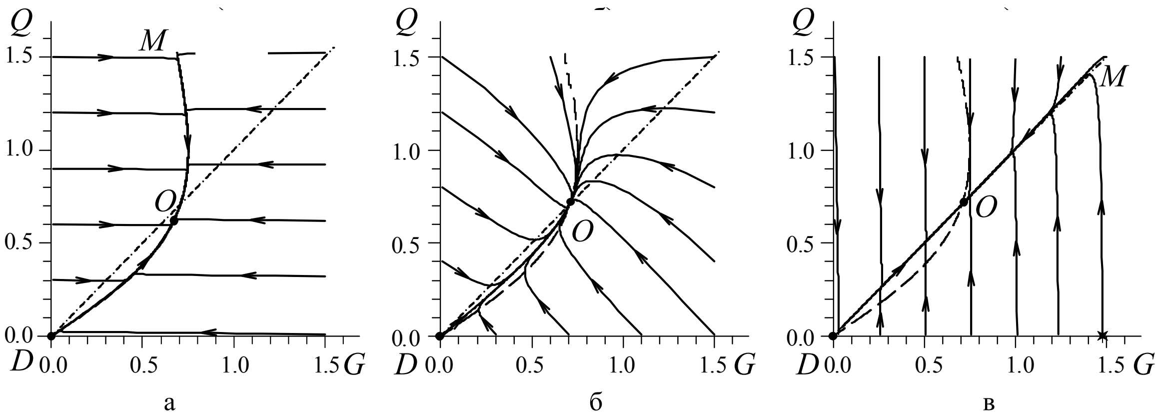


Fig. 7. Phase portraits of the mode of effective PLC realisation ($F_e = 1.5 F_c$):

а – $\tau_F << \tau_Q = 100\tau_G$; б – $\tau_F << \tau_Q = \tau_G$; в – $\tau_F << \tau_G = 100\tau_Q$

Conclusion

According to the model given in the international standards of series ISO 9000, PLC may be presented by the combination of the levels of designing, manufacture and operation. Each of these levels represents a system, which can have an independent character of application of the results.

However their integration into the general system provides qualitatively new set of properties and a measure of utility of products, as well as an increase of technical and economic indicators of its manufacture and operation.

Condition of the PLC system is defined by set of conditions and means of joint functioning of the economic, technical and social processes, which are unequally influenced by the external environment and which possess various persistence-levels.

In such situation management of PLC turns to a problem that requires application of special means of the analysis, planning and management with the help of production functions.

In the offered work the phenomenological scheme is investigated. In the frameworks of this scheme evolution of self-organizing systems can be represented in a self-coordinting way, and possible variants of continuous transition between modes of PLC realisation can be considered.

The conducted researches show that Lorentz's system ((9 – (11)) allows to present in the self-coordinating way the basic features of transition from the mode of inefficient realisation of PLC to the mode of its effective realisation.

The phenomenological description is reached due to dependence of synergistic potential V(Q) from the production function of the maintaining system. In case of continuous transition this dependence is defined by the characteristic value of intensity of the external influence F_{ℓ}: a monotonously increasing dependence V(Q) with a minimum in a point $Q_0 = 0$, which answers inefficient realisation of PLC, is received at $F_{\ell} < 1$.

And at $F_{\ell} > 1$ there is a minimum $Q_0 \neq 0$, which corresponds to a mode of effective realisation of PLC. The kinetic picture of transition has been presented by the phase portraits shown in fig. 4 – 7.

On the basis of the phase portraits the processes of continuous transition between the modes of realisation of PLC, which possess various parities of times of change of production functions of the making and maintaining systems and time of change of a gain of the scientific and technical result have been investigated. It is shown that critical increase of two first times leads to an oscillatory mode if the parameter «the gain of the scientific and technical result» changes much more slowly than other values. Otherwise the evolution of the system is defined by a universal area of a phase trajectory.

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Поступила в редколлегию 1.04.2015

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СИНЕРГЕТИЧНИЙ ПІДХІД ДО ОПИСУ РЕАЛІЗАЦІЇ ПРОДУКЦІЇ НА ЕТАПАХ ПРОЕКТУВАННЯ, ВИГОТОВЛЕННЯ І ЕКСПЛУАТАЦІЇ

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У статті розглядається застосування синергетики, як нової наукової парадигми менеджменту. Аналізуються необхідні параметри для розвитку організації як складної системи в рамках теорії синергетичного управління. В рамках моделі ендогенного науково-технічного прогресу, розглядається проблема підвищення ефективності інтеграції в загальну систему на всіх етапах і рівнях життєвого циклу продукту. Побудована синергетична модель, що дозволяє представити еволюцію життєвого циклу на основі спільної поведінки проектування, виготовлення та використання систем.

Ключові слова: *синергетична модель життєвого циклу продукції, самоорганізація.*

СИНЕРГЕТИЧЕСКИЙ ПОДХОД К ОПИСАНИЮ РЕАЛИЗАЦИИ ПРОДУКЦИИ НА ЭТАПАХ ПРОЕКТИРОВАНИЯ, ИЗГОТОВЛЕНИЯ И ЭКСПЛУАТАЦИИ

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В статье рассматривается применение синергетики, как новой научной парадигмы менеджмента. Анализируются необходимые параметры для развития организации как сложной системы в рамках теории синергетического управления. В рамках модели эндогенного научно-технического прогресса, рассматривается проблема повышения эффективности интеграции в общую систему на всех этапах и уровнях жизненного цикла продукта. Построена синергетическая модель, позволяющая представить эволюцию жизненного цикла на основе общего поведения проектирования, изготовления и использования систем.

Ключевые слова: *синергетическая модель жизненного цикла продукции, самоорганизация.*