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Dmitry Svirsky *

ŠTRUKTURÁLNA SYNTÉZA AUTOMATIZÁCIE PRE KOMPAKTNÉ VÝROBNÉ SYSTÉMY

COMPACT MANUFACTURING SYSTEMS STRUCTURAL SYNTHESIS AUTOMATION

V článku sa uvažuje o problémoch navrhovania moderných výrobných systémov podľa konceptu „štíhlej výroby". Je uvedená definícia kompaktného výrobného systému (CMS), a z toho vyplývajúce pôvodné princípy získania priemyselnej kompaktnosti. Na základe týchto princípov ponúka autor techniku skonštruovania CMS sformulovanú do integrovaného algoritmu. Výsledok výrobného a operačného cyklu semiotického modelovania bol stanovený na základe autorovej verzie simultánneho predvedenia, ktoré sa realizuje v CAD stredisku vo Vitebskej štátnej technickej univerzite. Prediskutovaná je konfigurácia počítačovej siete strediska, ako i model dát o súčiastke. Na konci článku sú predstavené projektované a vytvorené CMS: kompaktná dielňa podniku, CMS reverzného inžinierstva, CMS rýchleho prototypovania založeného na metóde automatizovaného laserového rezania; CMS prípravy výroby (Rýchle prototypovanie & výroba nástrojov); Stredisko CAD

In the paper the problems of collective designing of modern industrial systems in the „Lean Production" concept are considered. The definition of compact manufacturing system (CMS) is given, and the original principles of industrial compactness maintenance have resulted. On the basis of these principles the author offers the technique of designing CMS, formalized up to an integrated algorithm. The result of industrial and operating cycle semiotic modeling was fixed in a basis of the author's version of simultaneous designing, which is realized at the CAD Centre at Vitebsk state technological university. Both the configuration of the Centre computer network and a model of the design data are discussed. At the end of the paper the examples projected and created CMS are resulted: the compact shop of the machine-building enterprise; the CMS of Reverse Engineering; the CMS of the Rapid Prototyping on the basis of automated laser cutting; the manufacture preparation CMS (Rapid Prototyping & Tooling); the CAD Centre.

1. Introduction

During each industrial system operation two opposite tendencies are detected. One of them consists of lowing production costs at the expense of production stabilization by the mass release of homogeneous goods. On the other hand, the quick response on the change in a market situation and achievement of competitive advantages requires the strategy of maximum increase of a production variety within the existing limitations resources of the manufacturing framework. It is the tendency of artificial rise variety of possibilities for a maximization of probability of a choice optimal (concerning the received profit) business solution. As a result, any industrial firm has transition and stationary phases of its operation, which are sharply distinguished from each other by a level of variety (or stability). Increase of a relative share of expenses of resources at a transition stage in a production cycle and actualization of a problem of rational use of all industrial potential of the firm are objective features of the present stage of global industrial development.

The task of effective rise of a production variety with the fixed technical structure of manufacturing was solved traditionally by the flexible manufacturing systems application. However, the known structural, morphological and space-temporary redundancy of flexible manufacturing systems causes not only a quick response to the change of the orders stream, but also (in some more greater degree) to high cost of creation and operation of manufacturing systems. The attempts at essential lowering expenses of the equipment without narrowing of a range of manufacturing system technological possibilities have resulted in the concept of compact manufacturing. The compact manufacturing system (CMS) is a human-machine complex combining a curtailing in space and time with a minimum level of a structural and resource redundancy, supported by highly intellectual tools of computer aided designing and management [1].

2. General principles of CMS creation

The main principles of CMS organization are the following [2]:
I - Conformity structure of CMS to its purpose;
II - Localization of functional invariant;
III - Recursive decomposition of CMS hierarchical structure;
IV - Functional sufficiency of the CMS components;
V - Optimal parity of expenses on a functional invariant and variable adapter;

* **Docent Dr. Ing. Dmitry Svirsky**
Computer Aided Design Centre at Vitebsk State Technological University, Moscowski ave. 72, Vitebsk, 210038, Belarus,
Tel.: +375-212-22 70 41, Fax: +375-212-25 74 01, E-mail: svirsky@vstu.unibel.by

VI - Evolutionar local change of structure CMS at the expense of the equalizer adaptive reorganization;
VII - Reflection of stages of system development in its structural components.

The principle (I) in the concentrated form expresses that, first, the purpose (Z) is the main sister creation factor; secondly, the object in view can be achieved, to some extent, by creation and/or use of set of the CMS structures {St}; thirdly, the achievement of the objective is carried out by selected CMS structure by means of execution hierarchically organized functions (F):

$$Z \Rightarrow \{F\} \Rightarrow \{St\}$$

The principle (II) allows, on the basis of principle (I), separate common essential (invariant) units of the multipurpose CMS purposes objectives, functions and structures sets:

$$Inv\ \{Z\} \Rightarrow Inv\ \{F\} \Rightarrow Inv\ \{St\}$$

The principle (III) provides presence of invariant and adaptive modules at each level of hierarchy structure of system:

$$St\ (CMS) = \bigcup_{i=1}^{N} Inv_i \cup adp_N$$

The principle (IV) regulates a degree of parametric implementation of any hierarchy level functions above the necessary minimum value for CMS purpose achievement, since any exceeding of this value leads to the unjustified increase of expenses at CMS creation and maintenance:

$$L_f = [L_f] \Rightarrow L_E = L_{E\ opt}$$

The principle (V) determines the best variant of an allocation of resources at the implementation of the constant and variable parts of the CMS according to their functional importance:

$$\frac{L_3\ (Inv)}{L_3\ (adp)} = \frac{R\ F_{inv}}{R\ F_{adp}}$$

The principle (VI) of the evolutionary approach to the decision of tasks of development and modernization CMS allows to carry out permanent a structural adaptation of CMS to varied external conditions:

$$St\ (CMS)_0 \Rightarrow St\ (CMS)_1 \Rightarrow \ldots \Rightarrow St\ (CMS)_T$$

The principle (VII) together with principle (VI) determine the CMS structure in each given moment of its functioning time:

$$f: [St\ (CMS)_0 \Rightarrow \ldots \Rightarrow St\ (CMS)_T] \rightarrow St\ (CMS)_T$$

3. CMS design stages

The process of creation of CMS as a complex technical system consists of three main stages: CMS macro-design; CMS structural and parametric synthesis; CMS adaptive structural adjustment.

The macro-designing stage includes marketing and a CMS macro-technical shape creation. The task of marketing research is the definition of the nomenclature of production of CMS normal (profitable) operation during the designed period. The search of potentially profitable production is carried out by finding "areas of activity" in the space of economic activity and forecasting of dynamics of their change.

As a result of the primary analysis of the market on the basis of the different information sources some set of the goods whose production probability will be highly profitable during the designed period comes to light. Simultaneously, the capacity of target segments of the market is predicted.

The selected sorts of production are analyzed with the purpose of definition of a degree of their technological generality. The standard technological processes of their manufacture are compared (Fig. 1). The importance of technological generality is expedient for estimating with the help of the relative given expenses on operation:

$$K = C_{Mi}\ t_i\ /\ \sum\ (C_{Mi}\ t_i),$$

C_{Mi} - given minute expenses for operation, ti - absolute duration of operation.

The secondary analysis of the market will further be carried out with the purpose of creation of the best set connected (by technological invariants) sorts of production. The CMS profile

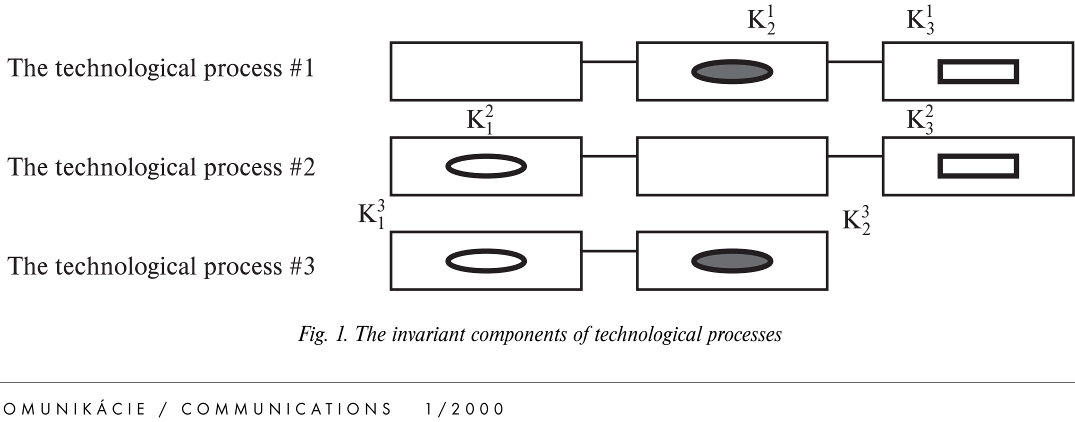

Fig. 1. The invariant components of technological processes

thus is formed. At the last stage of the macro designing the CMS general specification is formed.

The structural synthesis is carried out on the basis of the principles of CMS creation considered earlier and the use of results of the previous design stage. The structure of CMS equipment complex has brightly expressed its modular character. During the choice of CMS equipment the task of parametric synthesis is solved. The numerical values of parameters nominals are determined by functional-cost analysis of the whole system.

I. CMS MACROSTRUCTURAL SYNTHESIS

I.1. CMS structure formation

1. Search of areas of activity in the whole space of economic activity.
2. Analysis of character and prospects of that activity (fast or slow growth or recession).
3. Definition of a set of potentially favorable production (products and services).

I.2. CMS technical shape formation.

4. Search of typical technological processes of manufacture of the selected kinds of production.
5. Analysis of a degree of similarity of structure of typical technological processes of manufacturing of different kinds of production.
6. Formation of competing sets of production.
7. Choice of the best set of production.
8. CMS industrial program formation.

II. CMS STRUCTURAL SYNTHESIS

9. Planning organizational structure of generalized technological processes and CMS.
10. Allocation of CMS technical means functional invariant.
11. Optimization of technical parameters of the CMS process equipment invariant (base).
12. Analysis of dynamics of the adapter structure change in a complex of CMS technical means.
13. Optimization of functional and technical parameters of the CMS process equipment.

III. ADAPTIVE STRUCTURAL ADJUSTMENT

14. Market conjuncture operative monitoring.
15. Reconstruction of the adapter of CMS technical means.

Fig. 2. The integrated algorithm of CMS structural synthesis

After CMS input in operation the process of its design continuous in form of its perfecting so as the varying conditions of the external (market) environment make necessary adaptive structural adjustment of the industrial system. The procedures of the third design stage in general, repeat the first two stages, however their results have more local character, being limited by changes of structure and parameters of the adapter, not mentioning the unit of a technological invariant. During CMS operation the information on a parity functional and cost parameters of invariant and adaptive units is stored. It allows to select more precisely the best parity of expenses at the implementation of CMS functional units with the help of the principle (VII). The integrated algorithm of CMS structural synthesis is given in Fig. 2.

4. The CMS concurrent design intelligence system

The designing of such complex technical system as CMS requires simultaneous work of a large team. The acceptance of the agreed solutions usually increases common project operating time owing to the realization of various procedures on coordination of share intellectual efforts and integration of individual solutions. In this situation the problem of the design process productivity rise without loss of quality of designing is solved at the expense of wide use of modern information technologies and computer network systems [3]. The participants of design conferences working in a dialogue with the computer have access in a real time scale to anyone to necessary information and program resources of firm and also possibility of dialogue with the colleagues both inside and outside of collective. For intensification of processes of thinking and information interchange it is possible to use associative units (basic psychological images). Such possibility is opened by hypermedia technology which allows to link not only word but also it is possible to store files of any type of data (figures, sounds). There is a possibility of simples and reliable connection with each other of data items irrespective of their format, that especially it is important with creation and use of design databases. The participants of collective designing are joined by a local network and have access to the global network. Many procedures such as search, collection and preliminary analysis of the commercial information and formal forecasting at a marketing research stage, search of standard technological processes, primary grouping (classification) of production is expedient to carry out with the help agent-based systems. The intellectual agent will form the active information filter connecting the global network with a local network of collective designing. A similar methodological approach was applied in research Centre of computer aided design (CADC) at Vitebsk State Technological University (Fig. 3).

CADC specializes on realization of educational, practical and theoretical operations on creation and maintenance CAD systems of products, technological processes and industrial equipment of mechanical engineering and light industry. It is quite possible to examine CADC as the manufacturing system and the common technique of designing CMS is applicable. The CADC specificity as the CMS consists only that it production (knowledge, programs and data) has intellectual and information character. It is necessary especially to mark that CADC is the powerful tool of CMS collective designing on the basis of application of network computer information technology.

Nowadays the employees of the Centre develop a compact system of new products of light industry manufacturing. It is based on technologies of reverse engineering, rapid prototyping and manufacturing.

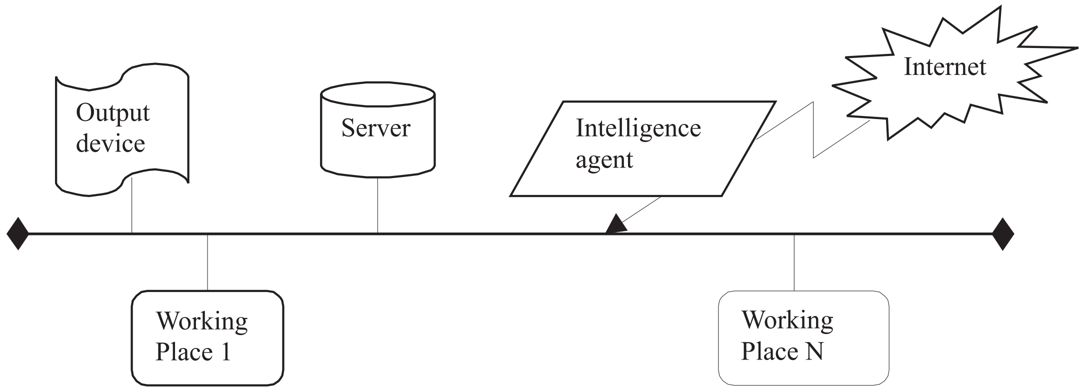

Fig. 3. CAD Centre network configuration

5. The CMS examples

5.1 Cybernetic simulation of CMS (compact shop of the machine-building enterprise) hierarchical structure

The industrial system can be presented as "a black box" with output variable Y (production); an entry variable X (resources) and unguided effects or disturbance f (changes of the orders stream) (Fig. 4). Examining thus CMS as the object of a control it is possible to apply a known method of control with disturbance compensation. It consists that in a control system the special block of disturbance compensating - the equalizer is entered (Fig. 5). The modern theory of invariance allows to determine the conditions of independence (invariance) output variable Y from revolting effects f. Really, with addition to the industrial system of the equalizer, in which the disturbance f will be transformed in $-f$ and effects on CMS, the compensation turns out, since $f - f = 0$. In result, despite of the constants of the orders stream change, the main (invariant) CMS part functions in the stable (given) mode of the greatest efficiency.

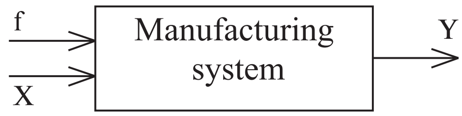

Fig. 4. Classical model of the manufacturing system

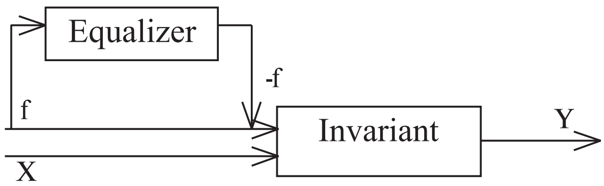

Fig.5. CMS cybernetic model

So the CMS structure consists only of two functional, structural and space isolated units: an invariant and adapter (equalizer). Last of them realizes compensating (adapting) functions-technologies.

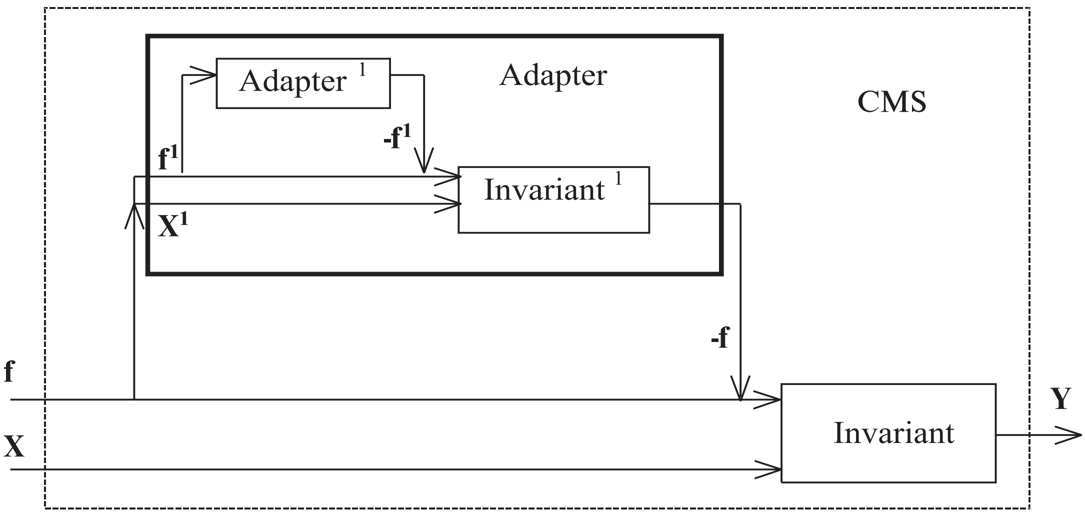

Fig.6. Recursive model of CMS hierarchical structure

The existence in the system organization the invariant and adapting components is characteristic of all levels of CMS hierarchical structure (Fig. 6). At an organizational level the inverse form of a marketing research adapts an existing configuration of the industrial system (as invariant) for the usual conjuncture of the market. At a functional and technological level quasi-optimal technological processes adapt an available CMS equipment complex (invariant) for production, which manufacture is theoretical profitable. At a structural and arrangement CMS level, for example, with operation of the automatic line for moulding or punching, the system of the changeable equipment operating manufacture adapts the high-efficiency specialized equipment (invariant) for change of a configuration of products. At a level of technical devices technological equipment to the machine tool (invariant) or the stamps to a press (invariant) execute the function of the adapter in realization of technological processes, no less than changeable original parts in relation to standard (normalized) units in modular stamps. In the technological complexes (Rapid prototyping systems etc.) the function of the adapter is executed by the computer in relation to universal program to controlled process equipment (invariant) realizing high technologies.

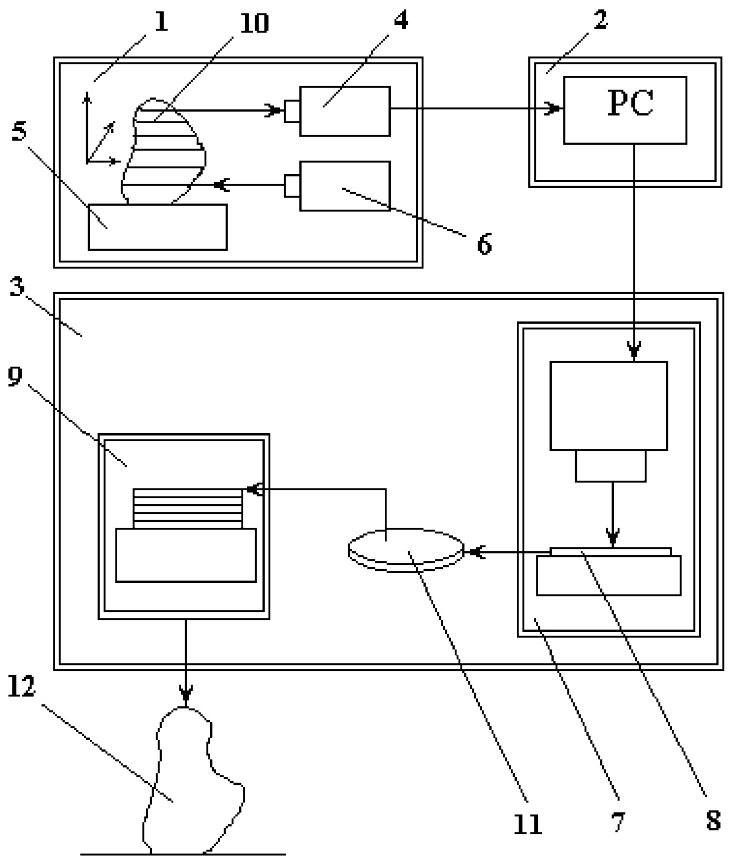

Fig. 7. A compact reverse engineering system configuration
1. The information input module; 2. The information processing module; 3. The industrial module; 4. The video camera; 5. A coordinate table; 6. A projector; 7. A laser cutting installation; 8. A cutting material; 9. An assembly unit; 10.Initial (analogue) object; 11. A cutout layer; 12. A ready object.

5.2 CMS of the Reverse Engineering

The developed technique of concurrent design has found practical application with Reverse Engineering CMS creation and operation on the basis of the automated laser technological unit. It may be used for the recursive copying (or reverse engineering) of irregular surfaces during the new forms of industrial, architectural and art design computer aided creation process. The information-input module 1, information processing and control module 2, and industrial module 3 are included in this system configuration (fig. 7). It is offered to use video-system for 3D objects digitizing. The modern video systems combine low cost with sufficient accuracy and provide high efficiency and speed of transfer of the information in the processing module.

The configuration of offered video system includes a video camera, projector, rotary table and personal computer. The projector is equipped with a slide with the image of a coordinate grid with the units, which located from each other on equally distance. The digitizing process includes a shooting of object, on which light strips of the slide inserted in the horizontal located projector are imaging, by the video camera established by angle to a horizontal plane. The 3D-stage information is imported from the video camera to the computer. In the computer the software organizes the information in digital models of objects. The object digital model making elements are the scanning object surface points coordinates in the chosen spatial system of coordinates.

The module of information processing and management is functional invariant of all system. The interrelation between system making modules is carried out by it. Also in this module the computer model is developed.

The industrial module carries out the objects manufacturing. It realizes Rapid Prototyping technologies. The technology of level-by-level synthesis is most productive. This process is automated. The flat elements are cut out on coordinate table automatically. The flat elements correspond to the layers of the computer model. The layers parallel connection allows monolithic products making. The method of flat elements cross connection of allows 3D object skeleton assembly.

5.3 Rapid Prototyping CMS (on the laser cutting basis)

Use of universal laser physical-technical effect and easily adapted to the orders stream changes program-technical complex (on the basis of the personal computer) allows to make a wide gamma of industrial products (table 1).

Laser CMS application area — Table 1.

The products type		The products sort	Industry or other sphere of activity
Plane		Patterns, templates	Tailoring, foot-wear, dry goods
		Incrustation	Furniture, art
		Layings	Repair firms, shop
Relief		Signboards,	Art, advertising
		Stamps	Graphic arts, dry goods
Volumetric	Modular	Special furniture	Furniture
		Exhibition stands	Advertising, design
	Shells	Components for sport vessel and airframe	Sport, tourism
		Foundry models	Moulding
	Continuous	Matrixes, form	Products from plastic and ceramics production
		Stamps	Pilot production
		Models, card	Cartography, training appliance

Structure of the laser industrial system consists of:
- CO_2-Laser (power consumption 800 W);
- The optical channel;
- Control system (personal computer), allowing to carry out direct conversion of the graphics information about a detail (standard file of graphics exchange *.dxf) in signals of handle of coordinate desktop;
- Coordinate desktop.

The made system has the following technological parameters:
- Processed materials: plastics, wood, textiles, natural and artificial leather;
- Overall dimensions of products Up to 1700 x 1200 mm;
- Width of a source material Up to 20 mm;
- Technological accuracy Till 0.05 mm;
- Technological speed Up to 24 M/mines;
- Overall dimensions of installation 3000 x 2000 mm.

The application laser CMS for manufacturing of the complex 2D, 2,5D and 3D object of the machine-building, light and other industries allows to reduce sharply (up to 5 ... 8 times) time and cost of designer and technological preparation of competitive production manufacturing.

This CMS may be used for Rapid Manufacturing of the moulding equipment (stamps).

6. Conclusion

The "Lean Production" concept can be practically realized in compact industrial systems. The maintenance of manufacture compactness becomes possible by use of the CMS designing principles, which are offered in the paper.

The developed technique of the CMS automated structural synthesis is based on a wide use of modern information technologies. Now it is applied at the Centre at Vitebsk State Technological University for CMS simultaneous designing for different industries.

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