Chapter 1

New methods for improving quality and reliability in mechanical engineering

1.1. Application of process and functional approaches to quality management in the machine-building organization

Wiliam Zaloga[1], Kostiantyn Dyadyura[2], Iryna Rybalka[3]
Sumy State University, Sumy, Ukraine
E-mail: [1]*zalogav@gmail.com*, [2]*dyadyura@pmtkm.sumdu.edu.ua*, [3]*rybalka.ira@gmail.com*

Abstract. The analysis of existing approaches to the construction of process models taking into account the functionally oriented management to ensure the appropriate quality of the products is carried out. The basic principles of process modeling are determined. The method of decision-making in the hierarchical structures of the system of enterprise processes is proposed. The results of the theoretical research can be used in the implementation of quality management systems based on international ISO standards and the description of processes by organizations.

Keywords: process, business process, process model, quality management system, functional approach, process approach.

1. Introduction

The ISO 9000 standards contain recommendations and tools for companies and organizations (regardless of the scope of their activities) who want their products and services to constantly meet the customer's requirements, and the quality is constantly improved. These standards are based on a number of principles for quality management such as customer orientation, motivation and involvement of senior management, process approach and continuous improvement [1]. The process approach is used as the base one [2]. According to the requirements of ISO 9001: 2015, the organization must determine the processes necessary for building a quality management system [3-5].

The problem is that the quality management system at each enterprise is, as a rule, unique and characterized by the content and importance of the hierarchical structures of the processes entering it, their input and output information, energy and material flows, quality indicators and their boundary values. The complex of interrelations between processes in each organization is complex and multifaceted [6-8]. Clients, competition, economic and political changes create new conditions for the existence of organizations and require flexibility and quick reaction in their management [9]. Until now, the methods of quality assurance applied at most machine-building enterprises were based, as a rule, on rigid multistage control of the product quality (functional approach) and services, and very insignificantly concerned improving the quality of production management systems based on the process approach (Fig. 1), which is the most important sign of perfect quality management and is used as a base in the International Standards ISO series 9000 [10-13]. For practical implementation in accordance with the requirements of ISO 9001: 2015, the organization must:

a) determine the required input data and the expected output of these processes;

b) determine the sequence and interaction of these processes;

c) identify and apply criteria and methods (including monitoring, measurements and relevant performance indicators) necessary to ensure the effective implementation and management of these processes;

d) identify the resources required for such processes and ensure their availability;

e) designate responsibilities and authority for the processes [14].

Under conditions of uncertainty in the external and internal environments characteristic of most modern enterprises, the formation of an optimal hierarchical structure of business processes that allow transforming “entrances” into “exits” and often al-most uncontrollable [15, 16], for the adoption of rational (optimal) management solutions to continuously improve quality is a complex scientific and practical task. This is especially relevant for enterprises, for example, machine building, which are involved in the life cycle (LC) – designing, manufacturing, servicing and recycling – of complex technical products such as compressor equipment. For them, a common scientific methodology is necessary both for the analysis and for synthesis of the system of processes at the stages of the LC of complex technical products, and for analysis and synthesis of systems for integrated process control, taking into account the corresponding dynamic, parametric and energy laws.

The purpose of this work is to analyze the existing approaches to process and functional management, as well as the formation of a process model of modern ma-chine building organizations (based on the example of an enterprise for manufacturing modern compressor equipment) based on the requirements of ISO 9001: 2015.

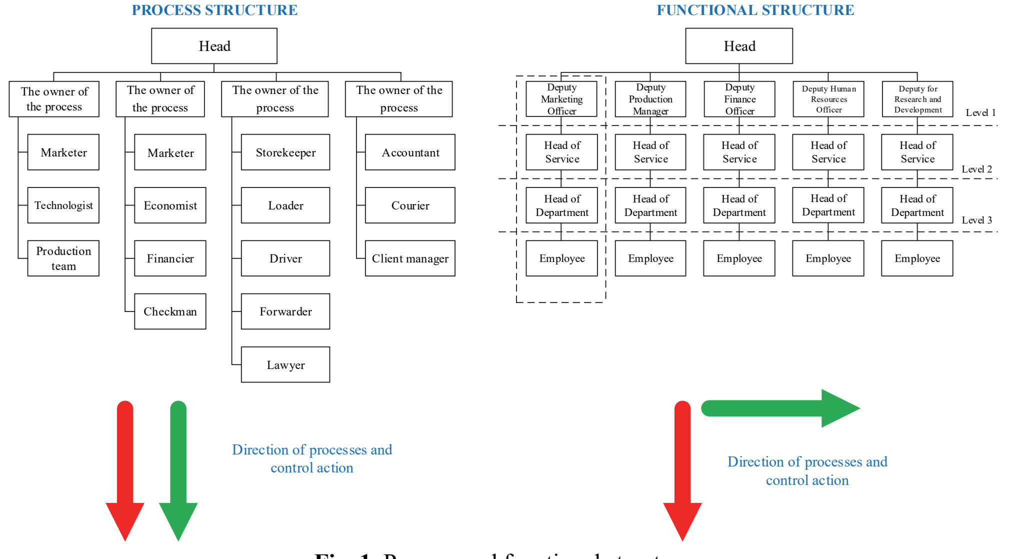

Fig. 1. Process and functional structures

2. General: major recent advances

As a part of a complex technical system (STS), in general, three different components can be distinguished [17] – a complex of technical means (CTM), software (SW) and operational personnel (OP) as shown in Fig. 2.

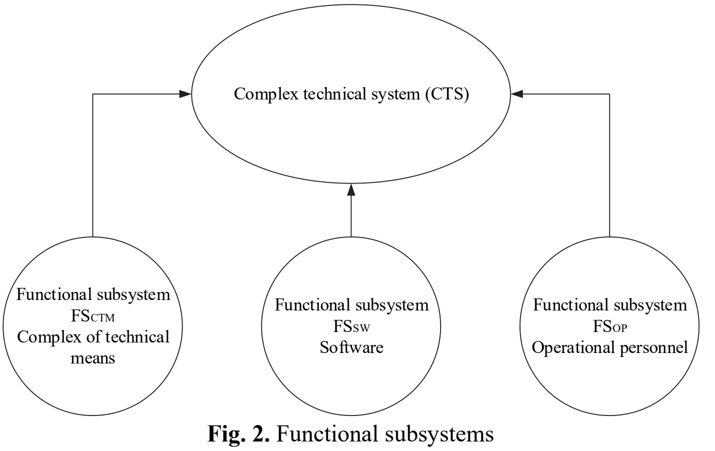

Fig. 2. Functional subsystems

Designing, manufacturing and operation of compressor equipment, predetermines a community, which includes documented information, hardware and software, as well as personnel that are interconnected within a single system through information, energy and material flows. The components of the CTS compressor equipment are shown in Fig. 3.

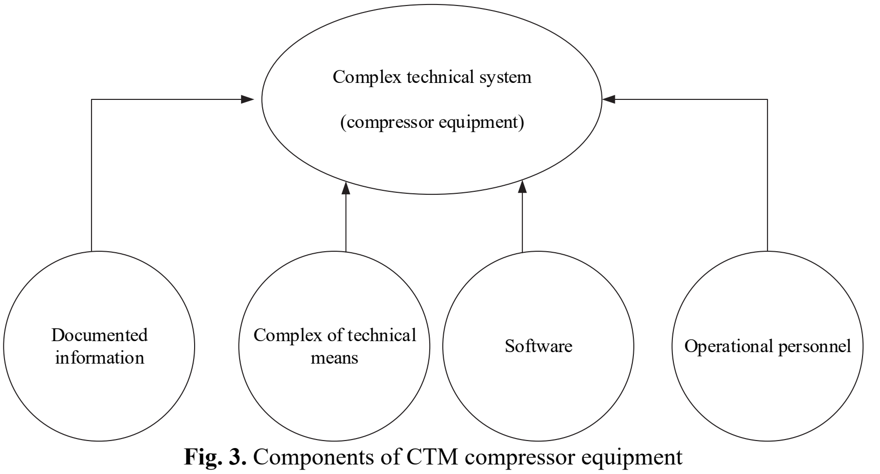

Fig. 3. Components of CTM compressor equipment

To ensure the quality of CTS (compressor equipment), it is necessary to ensure the appropriate quality of output data for each phase of the LC STS, which is realized through the identification and monitoring of KPI (Key Performance Indicator) key performance indicators of the LC processes. Highlighting indicators is most convenient for the process depicted in IDEF0 notation (Fig. 4), when the figure shows the inputs, outputs, control (process execution rules) and mechanisms (equipment, personnel).

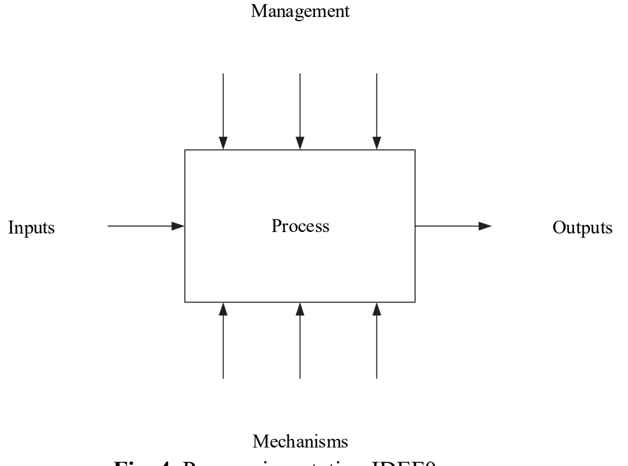

Fig. 4. Process in notation IDEF0

Key performance indicators and performance indicators, being derived, when using such a scheme characterize the overall process (Fig. 5).

The algorithm for developing the process indicators is as follows:

1. Identify the process and its result.

2. Identify inputs-resources (resources processed in one process cycle) and inputs-mechanisms (resources ensuring multiple execution of the process-equipment, personnel).

3. Identify the inputs and controls (rules and requirements for the process).

4. Knowing the result that must be obtained, it is necessary to evaluate it quantitatively – to generate the outcome indicators. They can be either simple or calculated (by formula or otherwise).

5. Based on the inputs of the process, you can generate cost indicators.

6. Based on the mechanisms of the process, you can generate additional cost indicators.

7. The correctness of the process, in addition to the cost of performing activities, also reflects the performance indicators.

8. Performance indicators are calculated as the ratio of the result obtained to the time.

9. Calculation of key performance indicators is carried out on the basis of pre-selected KPI performance and KPI costs. Performance indicators, thus, are integral characteristics of activity.

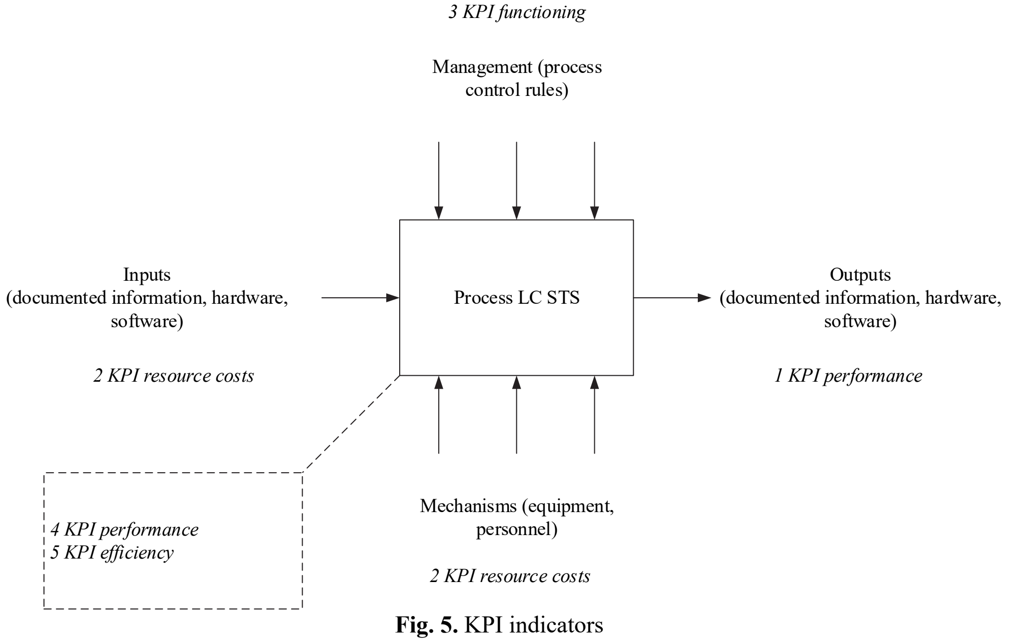

Fig. 5. KPI indicators

These components (Fig. 3) affect the effectiveness of the implementation of the LC is not isolated, but in close relationship with each other, which is expressed in the ability of one to correct the other two by the effectiveness of the implementation of its functions. Between the components, the space-time relations act.

The organization's processes are divided into main, providing, management processes and development processes, the definitions of which are presented in Table 1.

The main factors of the complexity of these processes are:

– the dynamic nature of the functioning of processes;

– the processes that take place both within the organization and when it interacts with the external environment, are non-linear, synergistic (dissipative);

– the natural evolutionary processes occurring in the organization are degradative, have a latent stage of development and are aimed at the destruction of the system;

– the time of the course of degradation processes considerably exceeds the time of the course of specific processes.

Every community of objects, processes and phenomena is characterized by the structure and interconnection of its components and can be represented in the form of a graph in which nodes correspond to components, and arcs to their connections.

Basic notations in modeling business processes (notation is a stable set of rules that describes the business process as part of the methodology):

– structural models (control) – IDEF0 notation, VAD notation (ARIS, MS Visio);
– Workflow models – "process" and "procedure" notations, notation of eEPC (ARIS, MS Visio);
– models of executable processes – notations BPMN 2.0, notations S-BM, CFFC;
– data flow models – DFD notation [18, 19].

Table 1. Table classification of processes

Types of processes	Definitions	Organization processes
Basic processes	• Processes that create a product that is valuable to the external consumer. • Processes that create added value to a product or service.	Sales Design and development Service maintenance Supply Production
Providing processes	• Processes whose consumers are the main processes. • Processes that create and maintain an organization's infrastructure.	Financial and Economic Management Human Resource Management Maintenance management Legal support Business Security Management Managing documented information Knowledge Management Communications Management Logistics Management IT security
Processes management	• Processes, the main purpose of which is to manage the activities of the organization. • The processes that ensure the survival and development of the organization regulate its current activities.	Strategic management Business Process Quality Management Management of risks
Processes (projects and programs) development of	• Irregular and innovative activities to improve and develop the organization. • Activities aimed at the long-term perspective.	Project management

Consider the IDEF0 notation. The IDEF0 submission form provides an opportunity to see and understand the interconnection of processes without going into details. Processes can be represented in the form of a hierarchical, tree structure with characteristics of links (branches), reflecting the utility, the probability of obtaining a result and the connection with previous and subsequent processes.

With the help of the graphical language IDEF0, the studied system appears as a set of interrelated functional blocks. Modeling of business processes using IDEF0 tools, as a rule, is the first stage of studying the system. Today, this technique of describing business processes has become the most widespread in the world and adopted as a standard in many countries [20-24]. The decomposition of processes in the form of IDEF0 is shown in Fig. 6.

The decomposition of variants is carried out by a set of characteristics. Criteria for choosing options are economic indicators (minimum cost, costs) or technical solutions that form a benefit function (utility). Description of business processes involves:

1) the definition of the owner of the business process, the boundaries of the business process, clients and outputs of the business process, suppliers and inputs of the business process, resources;

2) a description of the technology of the business process;

3) development of indicators of the business process, the results of the business process, customer satisfaction of the business process;

4) a description of the work of the owner of the business process for analyzing, improving the business process, reporting to a superior manager.

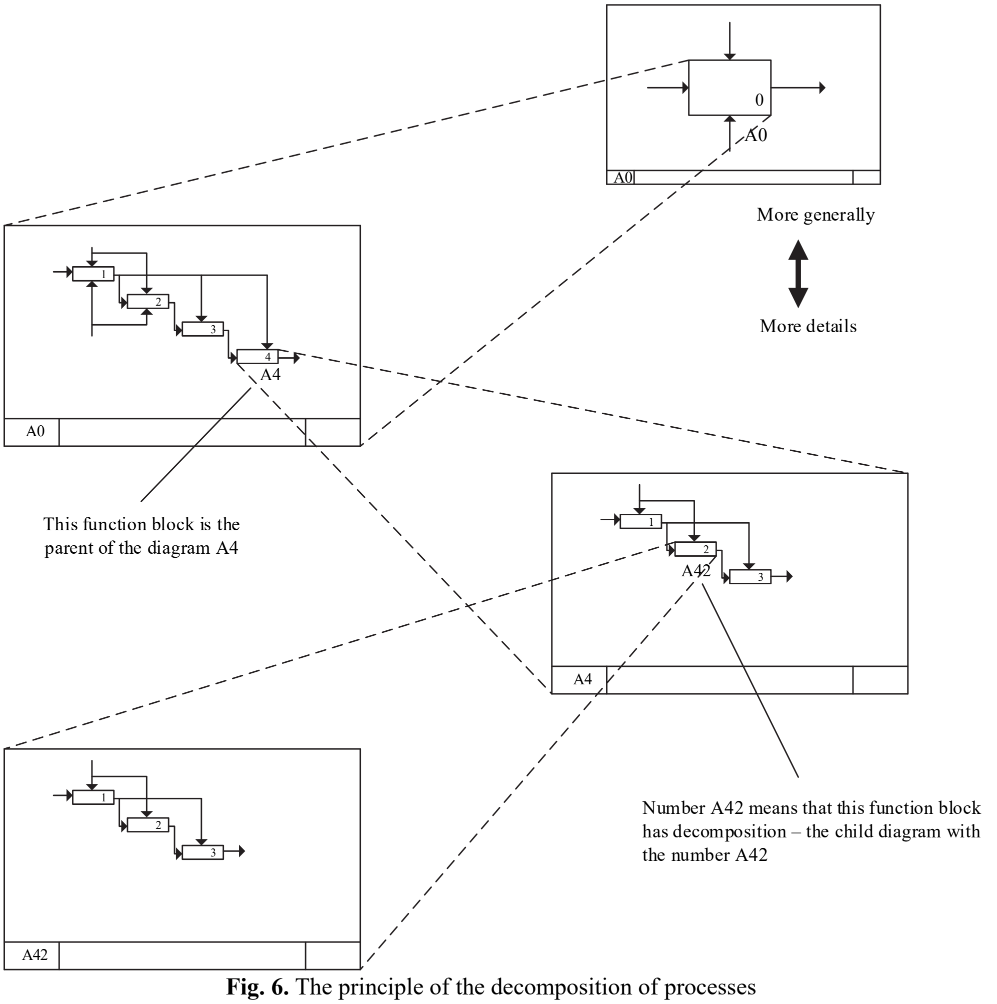

Fig. 6. The principle of the decomposition of processes

In describing and optimizing the organization's processes, two possible tasks can be solved:

– increase transparency and effectiveness of the organization;

– automation of business processes.

As criteria for evaluating the results of the description of processes, the following can be adopted:

– availability of verified descriptions of business processes;

– solution of problems identified during the implementation of business processes;

– the degree of coordination of units;

– the degree of minimization of possible variations as a result of the implementation of the corresponding business process, i.e. The business process is executed stably without failures.

Let us consider the choice of the best variant of describing processes under uncertainty conditions using vector optimization [25]. Among the various ways to optimize complex systems, which include the systems of business processes in enterprises, the formation of many possible solutions is paramount [26].

The problem of step-by-step vector optimization is formulated as follows. Let there be N variants of processes with numbers $n = \overline{1, N}$. Each variant of the process is characterized by M number of indicators qnm, where $m = \overline{1, M}$. We assume that the exponents are normalized in such a way that $q_{nm} \in [0; 1]$, and the maximal quality of the process corresponds to $max q_{nm}$. Then to each variant of the process there corresponds a quality vector $\bar{Q}\ [q_{n1}, q_{n2}, q_{n3}, \cdots, q_{nm}\ ]$.

Due to the fact that the systems of processes in the enterprise are multifunctional and the functions performed by them can differ significantly, when considering many issues, we use a functional approach. At the same time, a group of technical, program and ergatical (personnel) elements participating in the performance of this function are distinguished from the composition of all elements for considering the processes by some (j-th) function [27].

This group of elements forms the j-th functional subsystem (j-th FS or FS_j) of the system under consideration. It is this FS_j that is to be analyzed when considering the characteristics of the system with respect to the j-th function it realizes.

The composition of the FS_j (as well as the composition of the system as a whole) generally consists of three components:

– group of j-th functions of technical means participating in the implementation (j-th functional subsystem CTM – FS_{CTMj});

– group of software tools participating in the j-th function realization (j-th functional subsystem SW – FS_{SWj});

– group of ergatic means participating in the j-th function realization (j-th functional subsystem OP – FS_{OPj}).

On the basis of participation in the performance of a function, functional subsystems are distinguished, constructive features can be allocated to constructive subsystems, information subsystems, information subsystems, etc. Analysis of the functioning of the system is greatly simplified if its structure is constructed in such a way that the subsystems distinguished by functional and constructive characteristics coincide.

The system of functions forms the characteristics of the functional subsystems of the X_{FPS}. In this case, the functions can be divided into main and auxiliary. The main ones are those that directly form other functions, the auxiliary ones are only involved (help to form).

Between the hierarchy of functions (transformations) and the hierarchy of functional subsystems, there is a correspondence [28]. The interrelationship between the set of functions (F) and the set of groups of means (FS_{CTM}, FS_{SW}, FS_{OP}) is determined by the levels of the hierarchy. At each decomposition level, the μ function $F_{lj}^{\mu} \in F^0$ corresponds to a number $\{FS_{lj}^{\mu}\}_Y$ of types of means (j is the index of the function at the level of the hierarchy; l is the number of functions at the hierarchy level). The type of the facility provides $FS_j \in \{FS_{lj}^{\mu}\}_Y$ the principle possibility of performing the function $F_{lj}^{\mu} \in F^0$. Thus, we are given a multiple map of the system F on the subsystem of the FS.

The system of funds based on the principle interconnection levels: forming a plurality of elementary means $FS = \{FS^0, FS^1, \ldots, FS^{\mu-1}\}$, each of which ensures the performance of a single elementary function of the set $F = \{F^0, F^1, \ldots, F^{\mu-1}\}$.

3. Results

The possibility of forming various variants of the characteristics of the X_{FPSi} of the functional subsystem of processes is provided by a directed selection from the set $\{FS^0\}$ of a set of elements $FS_i \subset FS^0$, which ensures the fulfillment of a set of functions $\{F^0\}$:

$$X_{FS_i}: [\{F_i^0\} \to \{FS_i^0\}; \{F_i^1\} \to \{FS_i^1\}; \ldots; \{F_i^N\} \to \{FS_i^N\}],$$

with parameter constraints:

$$X^1_{FS_{min}} \leq X^1_{FS} \leq X^1_{FS_{max}}, \quad X^1_{FS} = \{X^1_{FS_1}, X^1_{FS_2}, \dots, X^1_{FS_{k1}}\},$$
$$X^2_{FS_{min}} \leq X^2_{FS} \leq X^2_{FS_{max}}, \quad X^2_{FS} = \{X^2_{FS_1}, X^2_{FS_2}, \dots, X^2_{FS_{k2}}\},$$
$$\vdots$$
$$X^N_{FS_{min}} \leq X^N_{FS} \leq X^N_{FS_{max}}, \quad X^N_{FS} = \{X^N_{FS_1}, X^N_{FS_2}, \dots, X^N_{FS_{k\mu}}\},$$

for given connections of the set F and FS:

$$\{F^0\} \times \{FS^0\} \rightarrow \{\Theta^0\},$$
$$\{F^1\} \times \{FS^1\} \rightarrow \{\Theta^1\},$$
$$\vdots$$
$$\{F^j\} \times \{FS^j\} \rightarrow \{\Theta^\mu\},$$
$$\vdots$$
$$\{F^N\} \times \{FS^N\} \rightarrow \{\Theta^N\},$$

and the connections inside the set F and FS:

$$\{F^1\} \times \{F^2\} \rightarrow \{f^2, \nu^{1-2}\},$$
$$\{F^2\} \times \{F^3\} \rightarrow \{f^3, \nu^{2-3}\},$$
$$\vdots$$
$$\{F^\mu\} \times \{F^{\mu+1}\} \rightarrow \{f^{\mu+1}, \nu^{\mu-(\mu+1)}\},$$
$$\vdots$$
$$\{F^{N-1}\} \times \{F^N\} \rightarrow \{f^N, \nu^{(N-1)-N}\},$$
$$\{FS^1\} \times \{FS^2\} \rightarrow \{\varepsilon^{1-2}\},$$
$$\{FS^2\} \times \{FS^3\} \rightarrow \{\varepsilon^{2-3}\},$$
$$\vdots$$
$$\{FS^\mu\} \times \{FS^{\mu+1}\} \rightarrow \{\varepsilon^{\mu-(\mu+1)}\},$$
$$\vdots$$
$$\{FS^{N-1}\} \times \{FS^N\} \rightarrow \{\varepsilon^{(N-1)-N}\},$$

where i is the index of the characteristic of the functional subsystem of the X_{FSi} $0 \leq i \leq M$; M is the number of characteristics of X_{FSi}; μ – hierarchy level index; N – number of hierarchy levels; $X_{FS_{min}}$, $X_{FS_{max}}$ – ranges of parameters of functional efficiency relative to the j-th level of the hierarchy; k_j – the number of parameters of functional efficiency at the j-th level of the hierarchy; Θ – connection of F and FS; f – connection of levels of the hierarchy of the system F; ν – connection within the levels of the system Φ; ε – communication within the levels of the FS system.

Thus, the functional subsystem of processes can be represented in the form of a set of hierarchically organized sets: elementary functions F^N, groups of means (FS_{CTM}, FS_{SW}, FS_{OP}) participating in the realization of the function at each level and the corresponding characteristics of the X_{FS} (Fig. 7). The set of elementary functions F^N with respect to Θ^N bonds defines a set of groups FS^N_{iN} and elementary means ($FS_{CTM_{iN}}, FS_{SW_{iN}}, FS_{OP_{iN}}$). Inside the set FS^N over the links Θ^N, many characteristics X^N_{FS} ($X^N_{FS_i} \in X^N_{FS}$) are formed, which ensure the efficiency of performance of functions in conditions of constraints on parameters [29, 30].

Each element of the system of means $FS_i \in FS^0$ can be described in addition to the links Θ and ε by the readiness characteristics r and the containment C:

$$FS^0 = \bigcup_{\mu=1}^{N} FS^{\mu}(\Theta^{\mu}, \varepsilon^{\mu}, r^{\mu}, C^{\mu}). \quad (1)$$

Many characteristics X_{FS}^{N} can be represented by two subsets: $X_{FS_i}^{r}$ that includes the types of subsystems of elements ready for operational use, and a subset $X_{FS_i}^{r^*}$ that includes the types of subsystems and elements not ready for immediate use at the time t:

$$X_{FS_i} = X_{FS_i}^{r} \cup X_{FS_i}^{r^*}. \quad (2)$$

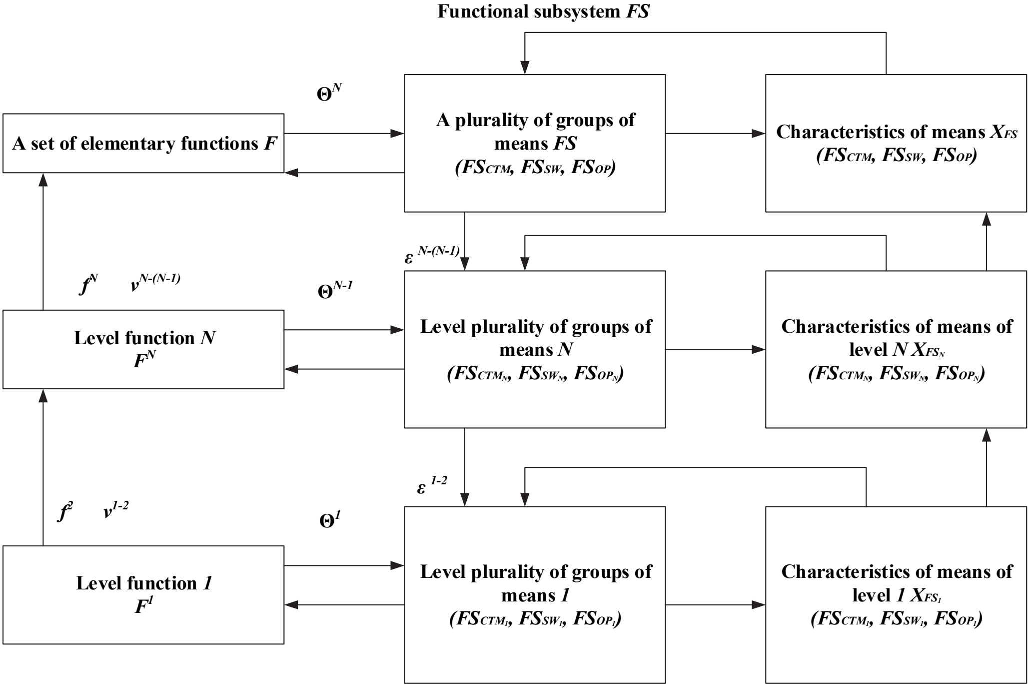

Fig. 7. Structure of the functional subsystem

4. Discussion

In this case, two types of business process models are considered: process and functional structures (see Fig. 1).

Differences and advantages of functional and process approaches:

1) the process approach shows:

– orientation to the client (on the result), i.e. CRM-approach;

– submission to the owner of the process;

– priority – performance of functions important for other participants in the process, active cooperation with participants in the process;

– higher management flexibility;

– focus on costs (cost of the process), its duration, quality;

– transparency of operations. It is easy to track ‘failures’;

2) with a functional approach:

– orientation to the manager;

– submission to the head of the unit;

– priority – the performance of functions in which the unit itself is interested;

– propensity to "bureaucracy", as a consequence – loss of managerial flexibility, low speed of decision-making, loss of information;

– the contradiction between the objectives of the functional units;

– opacity of activity. The shifting of responsibility.

In our opinion, it is not only impossible to contrast the process and functional approaches to the management of an organization, but, conversely, the quality management system should be viewed as a system of interaction between process-oriented and functionally-oriented management.

In the process of implementation of processes under the influence of internal and external factors, a gradual and continuous (evolutionary) change in the structure of processes takes place.

In this case, the system of processes is proposed to be investigated in several directions:

– representation of complex systems of processes as an interconnected set of sub-systems of different hierarchical level, constructing a hierarchy of optimization tasks with appropriate information exchange in time and levels, i.e., the so-called hierarchical approach;

– development of special approaches and methods for accounting for information uncertainty, analysis and decision making;

– the development of gaming approaches, including games with non-conflicting interests and the adoption of collective decisions;

– development of methods for multicriteria optimization, methods of peer review, etc.

5. Conclusions

It is shown that due to the application of the process approach to the management of the organization it is possible to improve its activity to a considerable extent. Practical implementation of the process approach in the quality management system allows:

– make a list of the main business processes and draw conclusions on the rational use of resources, the number and load of personnel, etc., on the basis of the data obtained;

– identify missing and duplicated business processes and make appropriate adjustments;

– determine the list of functions of each division of the organization;

– establish interrelationships between departments and the functions performed in them.

As a result of the introduction of the process approach and the description of the processes, the order and responsibility for performing the work will be fixed, the failures in the implementation of processes will be eliminated, and the quality of the process performance will be improved.

The reorientation of organizations to process management will allow producers compressor equipment to survive and develop in the conditions of the modern world.

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Viliyam Zaloga received Ph.D. degree in Information Science and Engineering Institute from University, City, Country, in 2014. Now he works at Company. His current research interests include control, dynamics and fault diagnosis. The scientific field is mechanical processing of materials, modeling of working processes of high technologies, standardization and certification of industrial winery

Kostiantyn Dyadyura is a Doctor of technical sciences, Professor, head of the Department of Applied Material Science of Sumy State University. The scientific field of machine elements includes both individual machine elements and machine elements in a product technology context. This relates specifically to machine elements with a product development and design application, focusing on condition monitoring. It is to unite theoretical and practical results of research, developmental and process work to form emergence properties of goods (of different industry branches) on the stages of their life circle taking into consideration self-consistent interaction of processes while designing, manufacturing and operating as an open system, self-organization of which influences the results of satisfaction of requirements.

Iryna Rybalka is a postgraduate student of the Department of Manufacturing Engineering, Machines and Tools from Sumy State University, Sumy, Ukraine. She current research interests include integrated management systems, implementation of international standards.

1.2. Current trends in mechanical engineering

Stepan D. Postil
University of the State Fiscal Service of Ukraine, Ukraine
E-mail: *sdp_irp@ukr.net*

Abstract. World science and industry face challenging problems that can be solved on the basis of the following: a) integration of specific scientific disciplines in inter-, multi- and transdisciplinary scientific areas; b) development of specific technologies into technological chains of new generation; c) integration of specific modules and components into hierarchical systems of higher level and development of megasystems. Innovative knowledge-based economy serves as critical characteristic of modern scientific and technical, industrial, socio-economic and all social processes. High-Tech Computer-Aided Engineering, "Simulation Based Design" (in development to "Digital Manufacturing"), integrated comprehensive systems and technologies to supporting life cycle of products act as the basis of engineering. The abstract presents science-based computer engineering of bimetallic casting which is based on the methods and algorithms of numerical problem solving with respect to heat exchange, nonlinear problem of thermoelasticity and inverse problems of heat conduction, that make it possible, based on the results of a natural experiment, to adapt a mathematical model to the conditions of the process under study. The experience of economically developed countries shows that one of the main conditions for economic growth and innovative development of the economy is development of the market engineering. The role of Ukraine in international engineering is insignificant, but the positive trend of our country is development of domestic engineering companies that have competitive advantages.

Keywords: engineering of products, innovation, computer-aided engineering, systems and technologies of computer design, integrated comprehensive systems and technologies, life cycle of products, bimetallic casting.

As of today the key point of engineering is its creative nature, presence of a common fund of technologies and inventions; the leading role of science (IT is in the first instance) in creation of new products and technics in general; system-based nature of activity. The abstract gives better outline of new integration trends that are related to deepening of design process understanding and change in technology of engineering [1].

The first key in this process is simulation of all aspects of human activity, i.e. social, organizational, technical, educational, recreational, etc. That is, the subjects of the activity move on to detailed forecasting of their future and to their most rapid implementation. In the process of such implementation, in materialization of ideas the role of engineering activity is significant, that organizes this process and implements the specific project based on innovative technologies. At the same time, the place and welfare of countries as well as the individuals depend ultimately on mastering and development of new.

Engineering, in the first instance, serves as the information process, the process of new information generation. This process in terms of quantity has an avalanche-type character since with transition to each new information level the number of possible combinations increases and, accordingly, the power of new sets of objects or their information substitutions. There is a need for proactive development of simulation and communication tools as compared to the means of material implementation of the project in the article. The main mean of systematic representation of new developments and forecasting of possible consequences is mathematical simulation.

Globalization of markets, competition, educational and industrial standards, financial capital and high-tech innovations requires faster growth rate, short cycles, low prices and high quality than ever before. Rapid, intense development of information and communication technologies and high-tech computer technologies has been observed.

Global science and industry face more complicated comprehensive challenges that cannot be solved using traditional ("highly targeted") approaches. This leads to integration of the separate scientific disciplines in inter-, multi- and transdisciplinary scientific areas; to development of separate technologies in technological chains of new generation; to integration of individual modules and components in hierarchical system of higher level, and to development of mega-systems, that is, multiscale comprehensive scientific and technological systems that maintain the level of functionality that can be achieved through their individual components [2].

Intense blurring of sectoral boundaries, convergence of sectors and branches of economy, blurring of the boundaries between fundamental and applied science take place through the need to solve comprehensive scientific and technical problems, emergence of megaproblems and mega systems, diversification and intensification of activity. The most frequently this is done on the bases of outsourcing and outstaffing, as well as with effective cooperation of companies and institutions, both within the sector of economy and and from different sectors. For example, generation of high-tech clusters from scientific and educational organizations and industrial companies, from large state-owned companies to small innovative companies. A distinctive feature of the current stage of development is producing through modern nanotechnology of new functional materials and smart-materials, the materials with given physical and mechanical and controlled properties, alloys, polymers, ceramics, composites and composite structures, that on the one hand, are "materials-structures" and on the other hand, they are the integral part or the component of a macrostructure (a car, an aircraft, etc.).

Innovation is a critical characteristic of modern scientific, technical, industrial, socio-economic and social processes. The consistent pattern of transition from predominantly reproductive to inoovative type of development has been observed in the world. The future of Ukraine to the certain extent depends on mastering of innovative mechanisms of development: whether it moves towards accession to the number of developed countries or it will remain a stagnating country on the fringes of scientific-and-technological and social progress [3].

The basic principles of establishment of modern organizations, companies and institutions with innovative knowledge-based economy should be pointed out: 1) optimization of interactions between different areas of innovation process (education, science and industry); 2) priority ranking of long-term objectives; 3) a model of continuous improvement of processes after Shewhart-Deming; 4) kaizen principles; 5) "war for talents" from McKinsey international consulting company; 6) the knowledge creating company); 7) learning organization; 8) "firing rate" from Toyota; 9) learning through problem solving; 10) "education throughout the life"; 11) inter-, multi-, transdiscipline; 12) capitalization of "know-how" and key competencies; 13) "invariance" of multidisciplinary suprasectoral computer technologies [4, 5].

The principle of optimization of interactions between different actors of innovation process (education, science and industry) can be implemented under the corresponding state policy as an intermediary. As the analysis shows, in Ukraine innovative transfer of technology has always been a weak point in the National innovation system, which insufficiently ensures commercialization of scientific achievements and technological developments. The reason for this is administrative-command tradition of managing Ukrainian educational and scientific areas, as well as maintaining of managerial organizational forms that serve the "linear" model of innovation cycle [6, 7].

Determination of the goals is a rather labor-intensive and responsible process, which consists of the following main stages: identification and analysis of trends within the environment; selection of the goals of the organization in general; building up of the hierarchy of the goals; identification of the individual goals. The basic rule when defining the goals, especially general ones, is involvement of the employees of the organization in their development.

Continuous Process Improvement Model or the Shewhart-Deming cycle PDCA (Deming Cycle is often used – Plan, Do, Check, Act) allows to manage effectively the activities in various areas on a system-wide basis. This is achieved through the following principles: a) sustainability of the goal through allocation of resources in such a manner as to maintain the long-term goals and high competitiveness; b) strict improvement of all processes; c) practice of leadership;

d) promotion of effective bilateral ties within the organization and elimination of the barriers between units, services and divisions; e) practice of personnel training and retraining; e) stalwart devotion of senior management to continuous improvement of quality and effectiveness; e) implementation of educational programs and support of self-improvement of the employees under the “knowledge is a source of successful advancement in achievement of competitiveness” slogan [3].

Kaizen principles of Continuous Process Improvement of the Company Activity constitute central concept of Japanese management. The main components of Kaizen technologies are as follows: a) total quality control (TQC); b) process-oriented management; c) “standardized work” concept as the optimal combination of the employees and the resources; d) “just-in-time” concept; e) PDCA-cycle; f) 5-W / 1-H (Who-What-Where-When-Why / How) and 4-M (Man-Machine-Material-Method) concepts. It is critically important that everybody should be involved in Kaizen, from top management to ordinary employees, that is, “Kaizen is the cause of each and everyone” [8].

Thanks to implementation of the principles of McKinsey in the modern world, those organizations have revenues that are the most attractive in the labor market and do everything to attract, to assist development and to retain the most talented employees. The basis of success is appointment of the competent employees to the key positions within the organization. The shortage of the staff will force the companies to start creating their own sources of engagement and education of talents: partnership with the universities, the internship programs, career enhancement system and continuous education.

In the management model based on the “the company is the creator of knowledge” principle the main role is the “knowledge” The main provisions of this approach as follows: a) knowledge is the main competitive resource; b) organizational training; c) the theory of the knowledge creation by the organization is based on the methods of interaction and transformation of formalized and unformalized knowledge; d) the spiral of creation of knowledge that extends “up and in breadth” e) the knowledge creation team as a rule is composed of “knowledge officers”, “knowledge engineers” and “knowledge practitioners” [9].

In the present-day conditions “stiff competition” of the organization becomes an obstacle for rapid respond to external changes and effective use of limited internal resources, therefore the organization must have such internal structure to allow it to adopt continuously to constant changes of the external environment. The main components of the learning organization are as follows: general vision, system-based thinking, skills of personal development, intellectual models, group learning based on regular dialogues and discussions.

Universal principles of Toyota can be used in any industry to form a perfect organizational structure which is capable of doing everything necessary to shorten the time period from the moment of the Customer’s request and up to payment for the work performed. The following practical ideas are relevant for every business, which is focused on strict improvement and enhancement: a) making management decisions based on a long-term concept; b) standardized tasks are the basis for continuous improvement and empowerment of the employees; c) education of the leaders who have profound knowledge of their business, live with the company’s philosophy and can share the knowledge about it to the others; d) it is mandatory to respect all partners and suppliers, to set them difficult tasks and help improve; e) making decisions slowly, jointly and carefully considering all options, but implement them quickly and immediately [10].

The principle of “learning through problem solving” provides for development of the system of regular participation of students and employees in joint implementation of real projects customized of the companies of domestic and world industry. This is achieved within the framework of the activities of virtual project-oriented teams based on proactive acquisition and application of modern key competencies, in the first instance, technologies of computer engineering [11].

The principle of “lifelong learning” facilitates development of comprehensive and interdisciplinary training or professional retraining of skilled and competent world-class experts in the area of computer engineering based on the corresponding advanced technologies.

The principle of inter-, multi-, transdiscipline means transition from field-specific sectoral qualifications to a set of key competencies, that is, capabilities and preparedness to conduct the certain activity (scientific, engineering, design, accounting, technological, etc.) that meets high requirements of the world market.

Implementation of the principle of "know-how" and the key competencies within the conditions of globalization and hypercompetition will allow confirming constantly high level of performed research work, to create new scientific and technological results through systematic capitalization and multiple replication in practice of both sectoral and inter-, multi-, transdisciplinary "know-how". This approach is fundamental for creation and dissemination of key competencies and advanced technology within the organization.

The principle of "invariance" of multidisciplinary suprasectoral computer technologies allows to create significant and unique scientific and educational projects by systematic capitalization and multiple application in practice of numerous inter-, multi, transdisciplinary "know-how", to establish rational effective schemes and algorithms of engineering (polytechnic) system of transfer, which is critically important for setting up of innovative infrastructure of the future.

It should be noted that at the present stage of civilization development any available resources, including information, cannot provide long-lasting competitive advantages. Today, success in global competition between the separate companies, regions and countries depends primarily on ability to create new knowledge and, on the basis of them, to develop new technologies, new products, identify continuously new problems and invent innovative ways for their solving. The leading role in creation of a "knowledge triangle" (education-research-innovation) belongs to the universities, that must act as the catalysts of innovation processes and, ultimately, the generators of welfare and well-being. The University as an organization is intended not just to transfer knowledge to students, but also to produce new knowledge and through involvement of students to permanent scientific research it must teach them to analyze critically, to think and act independently, freely, creatively, to formulate and solve new problems on their own, to develop and study throughout the life [4, 6].

The cornerstones of modern engineering are, first of all, high-tech computer engineering technologies: MultiDisciplinary and MultiScale and MultiStage Research and Engineering – multidisciplinary, multi-scale (multi-level) and multistage research based on inter-, multi-, transdisciplinary, sometimes so-called "Multiphysical" ("MultiPhysics"), computer technologies [1]:

1. MultiDisciplinary Concept means transition from the separate disciplines, for example, thermal conductivity and mechanics, based on thermomechanics, electromagnetism and computational mathematics to multidisciplinary computational thermo-, electro-, magnetomechanics.

2. MultiScale Concept means transition from single-scale models to multi-scale hierarchical nano-, micro-, meso-, macromodels.

3. MultiStage Concept means application of MultiDisciplinary and MultiScale concepts when creating new materials with special properties, development of competitive systems, structures and products of new generation at all technological stages of engineering (for example, casting – stamping / forging / ... / deformation – welding, etc.).

The second base of modern engineering is "Simulation Based Design" which means computer design of competitive products (products), based on effective and comprehensive application of the methods of numerical simulation and advanced computer technologies with the use of modern visualization tools [12]:

1. CAD, Computer-Aided Design. Currently three main CAD subgroups are distinguished:

• Mechanical CAD (MCAD – Mechanical CAD), being the most advanced technologies with the corresponding segment of the market;

• Printed circuit boards CAD (ECAD – Electronic CAD/EDA – Electronic Design Automation);

• Architectural and construction CAD (CAD/AEC – Architectural, Engineering and Construction).

2. FEA, Finite Element Analysis - numerical analysis, in the first instance, of the problems of mechanics of deformable solids, statics, oscillations, stability of dynamics and strength of machines, structures, devices, equipment, installations and constructions, that is, the entire spectrum of products and products of various sectors of industry. With the aid of various methods of numerical simulation, the problems of heat exchange, electromagnetism and acoustics, construction mechanics, technological problems (in the first instance, the problems of plastic processing of metals), the problems of fracture mechanics, mechanics of composites and composite structures are solved effectively.

3. CAE, Computer-Aided Engineering means a high-tech computer-aided engineering based on effective use of multidisciplinary suprasectoral CAE systems based on modern computing methods. When implementing CAE-systems, rational mathematical models are developed and applied that have high level of adequacy to real objects and real physical and mechanical processes, effective solving of multidimensional research and industrial problems are solved that are described by non-stationary nonlinear differential equations in private derivatives.

In XXI century, the main concept of computer-aided design of competitive products ("Simulation Based Design") is developed intensively by forces of the leading vendor companies of CAE-systems and industrial companies [5].

Evolution of the main approaches, trends, concepts and paradigms from "Simulation Based Design" to "Digital Manufacturing" can be represented as follows:

1. Simulation Based Design / Engineering (design and technical advisory services on development and preparation of production process, ensuring the normal course of the process and sales of products).

2. Multi-Disciplinary Simulation Based Design/Engineering (multidisciplinarity, the tasks become complex, they require knowledge of related disciplines to solve them).

3. Super Computer Simulation Based Design (widespread use of HPC technologies (High Performance Computing), supercomputers, high-performance computer systems and clusters within hierarchical cyber infrastructures for solving complex multidisciplinary tasks, multimodal and multiple-option calculations);

4. Super Computer (Multi Scale/Multi Stage and Multi-Disciplinary and Multi Technology) Simulation Based Design/Engineering (application of concepts: multi-scale/multi-stage and multidisciplinary and multi-technology).

5. Super Computer (Material Science and Mechanics) (Multi ** 3) Simulation Based Design/Engineering (simultaneous computer-aided design and engineering of materials and structural elements, among them: harmonious combination of mechanics of materials and structures);

6. Super Computer (Smart Mat and Mech) and (Multi ** 3) Simulation and Optimization Based Design/Engineering (application of Smart-materials/"intelligent" materials, application of various types of optimization (parametric, multidimensional, structural, topological, multicriterion, etc.), rational optimization of technological processes, etc.)

7. SuperComputer (SmartMat and Mech) and (Multi ** 3) Simulation and Optimization Based Product Development (design, engineering and optimization extends to manufacture of products and transition to Virtual Products/Products Development.

8. Digital Mock-Up/Digital Manufacturing ("digital prototype" means a virtual, digital 3-D model of the product and all its components, which allows to exclude from the product development process creation of expensive prototype models, it allows to "measure" and simulate any characteristics of the object in any conditions of operation/"digital production" as the main components of "smart" plants and factories).

Integrated comprehensive systems and technologies to support the life cycle of products are also being developed, the evolution of which can be represented by the following stages [12]:

1. CAD/CAM-technologies (Computer-Aided Design/Manufacturing) that integrate CAD and CAM-systems and provide integrated solution of the tasks of computer aided design and technological design, including the means of 3-D parametric modeling, release of drawings, as well as technological production preparation aids, in the instance, with the aid of computer numerical control (CNC) or, recently, with Rapid Prototyping, RP or Additive Technologies (AD).

2. Concurrent Engineering (CE) means "competitive" design/parallel design/joint design) which is joint work of experts from different functional units of the company at the earliest stage of the product development to achieve high quality, functionality and processability in the shortest possible time with minimum costs. CE is basically expression of the desire to increase competitiveness of products through reduction of the life cycle of the article, as well as improvement of quality and price lowering.

3. Product Data Management Systems (PDM) are sometimes referred to as systems for collaborative work with engineering data.

4. In addition to application of CAD/CAM/CAE/PDM systems, starting from 1990s ERP (Enterprise Resources Planning) systems are used in the industry, they are enterprise resource planning and management systems. At the beginning of the century, the most serious attention was paid to Manufacturing Enterprise Solutions (MES) system, they are enterprise production planning and management systems at the level of production unit, SCM systems (Supply Chain Management, SCM), CRM systems (Customer Relationship Management, CRM).

5. The problems as to organization of teamwork on the projects and effective product information management throughout its life cycle attracted attention from the 1980s. Different approaches were proposed to address those issues, for example, the Unites States Department of Defense proposed the methodology of computer-aided acquisition and logistics support (CALS) and IBM Corporation introduced the concept of Computer Integrated Manufacturing (CIM). Perhaps those initiatives were ahead of time, but due to a number of reasons, they did not become widespread and did not cause stimulate enthusiasm among users.

6. At the end of the last millennium, IBM developed the new concept – Product Lifecycle Management (PLM). The demand for PLM products began to grow, despite the recession and global economic crisis. The main purpose of PLM-technologies is unification and effective interaction of isolated automation areas that were formed as a result of implementation of various systems (CAD, CAM, CAE, PDM, ERP, MES, SCM and CRM) within the single information space, as well as for implementation of end-to-end engineering, technological and commercial production cycles, from inception of an idea, creation of product, its operational use, and, finally, its disposal".

It is critically important that the basis of PLM-technologies form CAD-, CAM-, CAE- and PDM-technologies, due to the joint use of which traditional and consistent approach to development of new products is replaced by a modern integrated approach. This approach ensures simultaneous computer-aided design of the product with the aid of CAD system, execution of various engineering CAE calculations (computer engineering) and technological preparation of production with the help of a CAM system based on joint use of the project data from the earliest stages of design and engineering analysis, simultaneously by different groups of experts using the PDM-system.

The following presents is a high-tech computer-aided engineering of bimetallic casting (SAE system) that is based on reliable methods and algorithms of numerical solution of heat transfer problems, nonlinear thermoelasticity problem and inverse heat conduction problems, which make it possible, based on the results of a natural experiment, to adapt a mathematical model to the conditions of the process under study [13].

Using these algorithms, a multipart analysis of casting solidification process was performed, in the course of which thermal and geometric parameters of the system varied and the basic parameters of optimal casting regime were determined. Developed software tools release the researcher from conducting expensive and labor-intensive experiments on liquid metal and allow analyzing new technologies and new processes of casting.

The significant reserve for increase of metal use efficiency in machine structures is application of cast products and multilayered products within the structures of castings, including those obtained on the basis of worn parts.

Reconditioning of parts by filling of liquid metal into a solid base in diecasting die is carried out if the following processes related to heat exchange are in place: preliminary heating of the worn part (metal-base) using an induction heater; solidification of filled liquid metal; cooling of obtained bimetallic casting and diecasting die.

An important condition to form a high-quality casting is obtaining of metallic linkage between connecting parts. In the course of interaction of filled metal with the metal base of diffusion melting process the process of diffusion saturation of the surface layer is always preceded. After the certain concentration the alloying element is reached, the surface layer of the metal base is melting. The depth of diffusion layer for this temperature can be determined approximately by saturation time and diffusion coefficient of alloying element.

In the course of worn parts in diecasting die reconditioning in castings there is significant nonuniformity of temperature fields. The degree of nonuniformity of the temperature is determined by thermal interaction of build-up layer with metalize, conditions of heat transfer of casting with the environment, initial thermal state of the system, etc. The thermal stresses resulting from this nonuniformity can lead to the formation of various types of cracks.

An additional point is that insufficient metal junction may appear between built-up layer and metal base. Thus, the reconditioning of parts should be carried out under such values of technological parameters that ensure welding of bimetallic layer (built-up layer-metal base) and permissible level of emerging thermal stresses in the casting.

In connection with this, there was a need for mathematical simulation of heat transfer processes within the system of interacting bodies in the course of bimetallic casting formation.

The process of worn parts reconditioning is accompanied by the displacement of boundary of transformation phase as a result of metal crystallization and during mathematical description, it belongs to the class of Stefan's task.

The mathematical model of the task of casting hardening includes the parabolic equation of heat conductivity:

$$c\rho\frac{\partial t}{\partial \tau} = \mathrm{div}(\lambda\,\mathrm{grad}\,t) + \Pi, \qquad P = \{G \times [0 \times \tau_{\mathrm{k}}]\}, \tag{1}$$

initial conditions:

$$t_{|G} = \varphi, \tag{2}$$

conditions of heat exchange on full external border G:

$$L(t_r) = \psi, \tag{3}$$

on the S surfaces of field links objects G:

$$\lambda\vec{\Delta}t_{|S^-} = \frac{\lambda_S}{\delta_S}\Delta t_{|S} = \lambda\vec{\Delta}t_{|S^+}, \tag{4}$$

and on the interphase border Stefan's approach is used in classical formulation:

$$\lambda\vec{\Delta}t_{|z^-} - \alpha\Delta t_{|z^+} = \rho\chi\frac{dz}{d\tau}, \qquad (5)$$

where G is the area in some spatial coordinates; τ is the time; λ_S – effective heat transfer coefficient through gas gap with δ_S value; L operator can correspond to the border-line conditions of type I, II or III. In this case, the inputs in the system of Eqs. (1)-(5) functions:

$$\Phi = \{c, \rho, \lambda, \Pi, \chi, \varphi, \psi, \delta_S, \lambda_S\}, \qquad (6)$$

are considered as set for entire field P, in which the temperature and the problem (1)-(5) are determined which is considered to be a direct heat conduction problem if phase transformations are in place.

Given the known difficulties (nontranparancy of molten metal, its high temperature, aggressiveness, etc.) it is not always possible to accurately determine physical or geometric characteristics of the system. The situation might arise when at least one of the functions (6) is not determined or it is determined not in all field of the temperature definition and it is necessary to find this function on the basis of other known functions and some additional information about the temperature or heat flow in the cylinder P:

$$L_\partial(\mathrm{P}) = g. \qquad (7)$$

Such a heat conduction task (1)-(7) is considered to be inverse. Since the additional information is taken from the experiment, the methods of solving the inverse problem of heat conduction allow us to adapt the mathematical model to the conditions of the process.

On the basis of the mathematical model of the heat conduction problem in the system of linked objects (“Surfacing”, “Thermal insulation”, “Diecasting die”, “Environment”) an algorithm and a software complex with the use of the difference method [14] have been developed.

Simulation experiments were carried out on the research of heat transfer processes on reconditioning of parts by filling of liquid metal on the worn surface of the part (metalbase).

In implemented technological line on reconditioning of parts (running roller) of a track type tractor, heat transfer processes run under the following conditions: 1) inductive heating of the metal base is carried out outside the diecasting die; 2) solidification of molten mass takes place without shielding; 3) cooling of the die-casting die and casting is carried out by air.

It is assumed that with a view to obtain high quality casting, the process of reconditioning of the running roller in the diecasting die, the inner surface of which is covered with thermal insulation layer, is carried out by liquid metal with overheating temperature of about 100 to 200K. At the same time, it is accepted that liquid metal at the time of metal base preheating completion is filled quickly enough and it hardens at the constant temperature T_t.

The defining parameters of the technological process can include the temperature of preheated surface of metal base T_m, the temperature of liquid metal T_j and the amount offilled metal D, which is spent on reconditioning the unit surface of the worn part. In order to develop optimal modes of reconditioning of worn surface of the running roller of the track type tractor, computational study of the process was performed, depending on its determining parameters.

The following was determined in the course of computational study of reconditioning process of the running roller of the track type tractor: temperature distribution within the system of objects and the coordinates of phase transformation borders, the gap and the heat transfer coefficient between the casting and diecasting die as well as the temperature of the free surface of the thermal insulation.

A good match of design and of the calculated and experimental temperatures on external surface of metal base and inside building-up where the temperature is maximum shows sufficient accuracy of the mathematical model which is used.

For quality eating of metallic compounds of bimetallic pair, kinetics of solidification of liquid metal on the metal base was studied, depending on the key parameters of the technological process.

The results of calculating examination of the parts reconditioning process showed that molten metal was located near external surface of the metal base for some time in a liquid state. This time will be called as welding time of bimetallic pair. In the course of this time diffusion meltdown of metal base is carried out.

Based of the finding of experimental research the depth of qualitative diffused layer makes the order of b = 0.2-0.4 mm.

Apparently, the optimal level of diffusion meltdown of metalbase corresponds to the depth of the surface irregularities and microcracks. Having in our dispodal b value, we can determine the minimum time (saturation time) required to create the required connection.

As the optimal criteria of the parts reconditioning, stress intensity is used which determines permissible level of the emerging thermal stresses and S ratio, which characterizes welding of bimetallic pair (meltdown – metalbase).

Correlation S is obtained on the basis of comparison of calculated and experimental data:

$$S = \frac{N * T * M}{1 - M}, \quad (8)$$

where dimensionless quantities are $N = \frac{T_j - T_t}{T_t}$, $T = \frac{T_m}{T_t}$ and $M = \frac{D}{D_j}$; D_j – input of liquid metal at full wear of a rim part.

S value, obtained on the basis of relation (8) was used for the a-priori estimation of the parameters of the process of obtaining bimetallic casting by filling with cast iron under composition (on the mass): 2.8-3.2 °C; 1.6-2.2 Si; 0.7-0.9 Mn; 0.2-0.4 Cg; 0.2-0.4 Cu; less than 0.05 S; less than 0.1 R on a solid metal base, made of steel grade 45.

When input of liquid metal equals to M = 0.22-0.57, its overheating equals to N = 0.1-0.25 and preliminary heating of external surface of metal base reaches the value of T = 0.74-0.97, then the qualitative weldability of bimetallic pair will be achieved if the following condition is fulfilled: $S \geq 0.04$.

Stressed state of bimetallic casting was determined by the solution of unlinked nonlinear thermoelasticity problem. The solution of the problem was carried out in movements by the method of installation [14]. In the course of numerous calculations, distribution of strain, stress and intensity of stresses were calculated. The value of permissible stress has been determined under the literature sources at the maximum temperature in each of the layers of the bimetallic casting, in which it takes minimum value and determines critical state of metal.

Calculations have shown that under the influence of substantially irregular temperature field in bimetallic casting the significant temperature stresses arise that depend on the temperature value difference along interconnection of the article. Based on the results of numerous experiments it can be concluded that in order to reduce the level of emerging thermal stresses in bimetallic casting, it is necessary to select metals as close to mechanical characteristics as possible and avoid high temperature differentials through the thickness of the article.

Studied problem with respect to formation of qualitative diffusion layer in bimetallic castings is also relevant in the processes of obtaining multilayer castings by filling of the next portion of liquid metal onto solidified metal after pre-filling.

Developed methodology allowed to carry out computational studies of thermal state of multilayer casting, obtained by layered filling of liquid metal on a pre-filled and solidified basis, and to obtain practical recommendations related to optimal modes of their formation.

The most active participants of the engineering projects are the countries of Europe and North America, but all these countries give ground to the United States. The trends in development of international engineering can be include the fact that among the exporters of engineering services the small companies dominate and the services themselves have national or regional nature [2].

Europe possesses a well-developed engineering consultancy service. There are all categories of companies that provide engineering services of all kinds in the region. The main lines of engineering services export from the EU are the EU countries themselves, the USA, Switzerland, Japan, that is, the most highly-developed countries. A small share of export falls to Russia, China, India, Turkey, Africa. Import of the EU is almost the same as export. For developed countries there is a widespread implementation of works and provision of services in the form of comprehensive engineering, that is, full range of services and supplies required for new production.

The market of engineering in Ukraine is in fact only at an early stage. More than 80 % of domestic engineering companies have a market share of less than 0.3 %. This low indicator can be explained. First, in Ukraine, the demand for comprehensive engineering services is still insufficient. Second, lack of experience causes rise to a large number of errors in implementation of projects. The current problems of Ukraine also include shortage of skilled personnel, poor work performance, obsolete legislative framework, imperfect system for determination of the costs of the project design work, corruption phenomena at the stage of approval and examination of documents, low level of project design works automation and many others [1].

To ensure further development of engineering and advisory activities in Ukraine, the following main organizational and economic measures should be implemented: 1) establishment of world-class competence engineering centers to permit Ukraine to reduce its dependence on foreign experts; 2) holding of professional international level forums; 3) adaptation of know-how to the specific conditions of Ukraine by local engineering companies; 4) setting up of the system of professional education and training of specialists in the area of engineering and ensuring of free access to professional literature; 5) regulation of legislative framework; 6) improvement of quality of engineering services by attracting the specialists from the certain sectors of science and industry.

The priority components should be as follows: a) building up of the National system of "digital" and STEM-education (focused on the scientific component of education and innovative technologies, and it actively develops creative component of personality and critical thinking); b) introduction of special training for cyberphysical productions and their continuous professional development; c) development of new approaches to acquisition of knowledge and skills at workplaces, including use of digital education methods.

Conclusions

In the context of international development, the engineering services become more widespread since they increase significantly the efficiency of invested capital. The experience of economically developed countries shows that one of the main prerequisites for economic growth and innovative development of the economy is precisely development of engineering market.

The role of Ukraine in international engineering at this stage is insignificant, but the positive trend is development of domestic engineering companies having competitive advantages in our country.

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Stepan Postil obtained Ph.D. in technical sciences degree at the Institute of Technical Thermophysics of the National Academy of Sciences of Ukraine in 1989. At present he works at the University of the State Fiscal Service of Ukraine, he is the Associate Professor of the Department of Intellectual Management and Computer Systems. He is the author of more than 90 scientific and scientific-pedagogical papers. Current scientific interests include: numerical solution of tasks of mathematical physics, databases, interdisciplinary information modeling using CASE-technologies.