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PRINCIPLES OF FUNCTIONAL-ORIENTED TECHNOLOGY MANUFACTURING PRODUCTS ENGINEERING PRODUCTION

Наведені принципи, переваги та недоліки концепцій об'єктно-орієнтованого та функціонально-орієнтованого технологічного проектування виробничих процесів машинобудування. Для реалізації паралельного інжинірингу, впровадження PLM-технологій запропоновано використання системи реологічного імітаційного моделювання процесів різання (CAF-системи). Це дасть можливість прогнозування основних кваліметричних експлуатаційних властивостей виробу вже на стадії технологічної підготовки машинобудівного виробництва.

The article presents the principles, advantages and disadvantages of the object-oriented and functional-oriented process concepts in designing industrial processes engineering. For the implementation of the concurrent engineering, PLM-technologies the usage rheological simulation of cutting process (CAF-system) was proposed. It enable to predict the key performance qualimetric properties of a product already the stage of functional process design parameters of the structure and operations processing machine products manufacturing

Problem statement recent research and analysis. In order to implement computer technology engineering and manufacturing computer aided design engineering analysis and complex technological preparation of manufacture (CAD/CAE/CAPE/CAM), and project management system (PDM – Product Data Management) should be applied. Firstly, these systems provide full cycle of a product from a conceptual idea to its implementation, and, secondly, create a design and technological environment for simultaneous operation of all participants in the creation of engineering products with a single virtual model of the electronic device. This organizational system denoted by the acronym CAPE (Concurrent Art-to-Product Environment) – a support system of parallel design (or parallel engineering) [1]. Following this concept, we can drastically reduce the cycle of a product improving the technical level projects to avoid inconsistencies and errors in manufacturing equipment and the product because all data are interrelated and controlled. The first official standard that appeared in this area, known as ISO/IEC 12207: 1995 Information Technology – Software Life Cycle Processes [2]. The new version, which appeared five years ago is called ISO/IEC 12207: 2008 Systems And Software Engineering – Software Life Cycle Processes [3]. Also, in the last 6-7 years there were appeared standards, which are determined by the parted requirements for individual processes lifecycle product engineering: ISO/IEC 16085: 2006 Systems and Software Engineering – Life Cycle Processes – Risk Management, ISO/IEC 15939: 2007 Systems and Software Engineering – Measurement Process, ISO/IEC 26702: 2007 Systems Engineering – Application and Management of the Systems Engineering Process and others.

Taking into account the conditions of the most loaded parts of the product, it is a particularly important opportunity for effective design, purpose and design standards of precision technology of their manufacture. That means that using concurrent engineering we can implement recurrent and iterative cross-correlation functional stages of pre-production: 3D product modeling (CAD-system), simulating the conditions of their future operation (CAE system), designing the structure and parameters of their production technology (CAPE-system) and programming CNC machines (CAM system). In this chain there is a gap- automated system that implements the relationship between technology products shaping the terms of use. Basics of such a system (Computer Aided Forming – CAF-System) are presented in [4, 5, 6, 7, 13, 14].

Cross-functional process can be considered in the implementation with involving of multiple systems at the same time at the upper level. In terms of system integrators methodology [8, 9, 11], it is these processes finally realizes the PLM-systems, and this is where most problems occur. Therefore, it is a good idea to use such a process hidden greatest potential to improve the quality of engineering products. Any complex hierarchical organization, reaching a certain size, has a problem that the local criteria of individual subsystems begin to dominate to ensure extreme values of the global objective function. Actually, this is not a new idea: "hack walls between units" – a call for a re-engineering model early 90s. [9] Another thing is that the proposed reengineering classical approach to the implementation of the iterative design process through a single radical transformation was not entirely successful. The modern concept of concurrent engineering has brought new perspectives on how to do it, but the goal remains the same. In order to illustrate the cross-functional problems the metaphor of silage tower is often use "functional silo". The analogy is as follows: after the peasant laid sloping hay to silage tower, he can only get a small part of it – to the upper layer. Similarly, resources, information, knowledge, processes in a hierarchically organized system of technological preparation of production are buried in the preliminary stages of the realized design – most of the information available to developers from other departments and works to achieve the main goal of the project. Purely functional view of things leads to a distorted view of what criteria should be used to produce the result of a single phase of the production machine. For example, in the design phase structure and process parameters that the system is implemented CAPE (Computer-Aided Process Planning), the main criterion is to ensure productivity and abstracted quality – accuracy of the parts and sizes of surface roughness. And of these functional parameters, such as the surface layer wear resisting most critical surface parts, residual deformation, the contact parts of rigidity, etc. – for the system are accessed. This is the result of CAE systems. However, for the CAE system these data are not available, since the modelling of the above features, the information that can be obtained as a result of computer-aided formation is as follows: surfaces microtopology, the stress-strain state of blanks and others. But in terms of PLM-concept the situation is the opposite: it is part of a global objective function to ensure effective operational performance products (in terms of value engineering products for the consumer process "from order to payment"), and the structure and parameters of the process – it is only an auxiliary internal information system. Clearly, information technology is necessary because without it would be hard to realize production process. However, the criteria adopted by the stage of CAPE systems can't be global. CAPE Operation system is just one example of classical sequential technological process of production failture.

In order to significantly improve the competitiveness of domestic engineering to the creation of a new system of automated pre-production (ASTPV) that implements a set of related cross-functional subsystems, providing thus the whole life cycle of the product. Feature ASTPV new methodology that implements PLM-concept design is called functionally-oriented technologies engineering. Definition of the basic principles of these technologies are outliner in this article.

Description of main idsas. The classic algorithm design process involves performing a series of sequential interrelated steps noniterative downward structural and parametric synthesis (Table 1). Technology downward projecting means that technology starts working on the project at a high level of abstraction, followed by a part. First, based on the input (macrogeometric representation of the parts configuration, material, its size-weight characteristics, precision geometric dimensions and relative surfaces, physical-mechanical properties and functional state of surface parts, the type and organizational form of production) is formed by machining path product, and then determined the structure of manufacturing operations are assigned processing modes and projected technological equipment, instruments and so on. This classification design in the context of the global objective can be considered object-oriented. That is the main criterion for the formation of the optimal structure and parameters of the process to ensure a minimum manufacturing cost object production (product), subject to formal quality (accuracy, roughness physical and mechanical properties of individual surfaces) and maintain the set production program of manufacturing products based on technological continuity of existing production [12]. This technology is completely abstracted from the problems of functional (operational) the nature of the object, believing that the appointment of standards of precision and quality – is the prerogative of the developer! And the dialogue between developers and technologists in this case is solely for reasons of product technology, but in any case not in the context of the conditions of its future operation, maintenance, technology services and so on.

Table 1

General characteristics of object-oriented technology engineering

Input for the design	Input information	The principle of construction of the structure and process parameters	The advantages of object-oriented design	The problems of object-oriented design
Makrogeometric part configuration	Design documentation, system CAD, system MacroCAE	Method of analysis: an algorithmic search for structural prototype design and technological features and the correction parameters according to the input data for the design	The simplicity and adequacy of the formalization of input data	Failure to take into account the functional properties of parts in its future operation
Part material				
Dimension and weight characteristics			Well-established theoretical base for making optimal technological solution	
Accuracy of geometric dimensions				
The accuracy of the part surfaces relative position			Algorithmic simplicity of technological design	Structural rigidity: the lack of iterative and recursive relations to other phases of an integrated system of technological preparation of production
Physical and mechanical functional state of part surface				
Type and organizational production form	Organizational and project design documentation, the program output		A large number of software products that implement the principle prototyping technology solutions (CAD and CAM systems)	Adequacy of the design concept of PLM Failure to implement the principle of concurrent engineering

In automated production inputs for object-oriented design process documentation provided by CAD systems and MacroCAE is design. In this case, the MacroCAE (Macro Computer Aided Engineering) means the classical system engineering analysis product that allows using computational methods macro simulation processes (including thermodynamics) to evaluate how the product will behave computer model of simulated operating conditions adequate for really.

According to the theory of classical Systems Engineering [8] for any top-down design uses an algorithm based on the method of analysis. In this case, the effective formalization abstracted heuristic procedures implemented problem-oriented search for structural prototype design and technological features with further adjustment of its parameters according to the input on the design. Obviously, this traditional concept of technological design has several advantages:

- simplicity and adequacy of the formalization of input data;
- the presence of extensive theoretical knowledge base for making optimal technological solution;
- algorithmic simplicity of technological design;
- the presence of the large number of software products that implement the principle prototyping technology solutions (CAD and CAM systems).

However, it is the most effective methodology in a manual design. A copy of the classical algorithm decision-making process significantly limits the potential of an integrated automated pre-production, does not allow the implementation of complex PLM-concept. Most problems for object-oriented design are the follows:

- inability to take into account the stage of technological design parts functional properties in terms of its future operation;

– structural rigidity: the lack of iterative and recursive relations to other phases of an integrated system of technological preparation of production;
– assonance PLM concept design;
– inability to implement the principle of concurrent engineering.

Scheme of the information nets between subsystems in the implementation of object-oriented design process shown in Fig. 1 [7]/

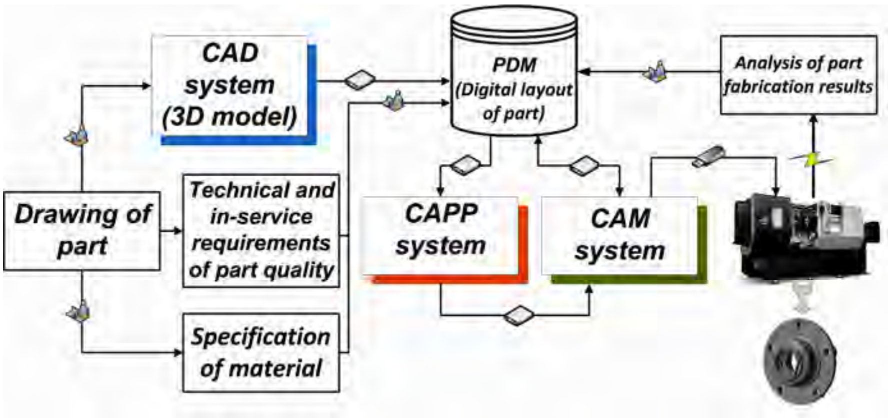

Fig. 1. Scheme of the existing integrated system design and technological process planning

Functionally-oriented technological design provides priority to ensure high performance of products subject organizational, technical and economic constraints [10]. In a manual design, a partial account of the operational characteristics of the individual (the most important, and most load) of the product is the result of previously conducted experimental studies. Clearly, experimental studies in the case of need for rapid technological solution is highly undesirable due to significant complexity and lack of a differentiated analysis of the impact of individual factors on the outcome of the design. For example, analysis of the impact of the cutting tool geometry, its vibrations in all directions, deformation phenomena (including residual) have a significant impact on microtopology of surface. However, in order to analyze their impact you can only be differentiated using a comprehensive simulation capabilities rheological and analytical modeling [4, 14] and experimentally we can only confirm the adequacy of their overall impact on the formation of microgeometry finally.

It is clear that in a real engineering practice predicting functional characteristics of the product and the associated assignment standards of accuracy and quality of individual surfaces are performed by the Developer priori. However, even experienced developers fail to systematically assess the impact of such important factors as microtopology of surfaces, residual stress and deformation of the surface layer on the performance of wear, fatigue strength, and corrosion surfaces resistance and more. As the production experience, 50–70 % of existing defects finished engineering products resulting from errors in structural work, 20–30 % due to lack of technological products, and only 5–15 % – the fault of the workers [1].

The algorithm of functionally-oriented design process is a classic example of iterative design rising from recurrent connections. The technology of concurrent engineering is a technology development-through design. In a parallel design information flow to provide intermediate or final product specifications are available for approval at various stages of project development.

This problem is solved on the basis of predictive (from Lat. Praedictīvus – "predictable") tools, i.e., programs that provide communication phases functionally logical, technical (design) stage design and technological preparation of production. However, predictive tools used at the level of individual project procedures and the level of the whole project (if we're talking about avant-stage design). Due to this, going back design make a possibility to receive a product with higher performance.

Input for functionally -oriented design process includes (Table 2):
– geometry and dimensions of each surface functional parts;
– sheet material of parts (including its analytical dependence of dislocation kinetics, the curve of the thermal strain hardening, fracture criteria, etc.)
– mikrotopology of surface layer for each surface functional parts;

– residual stresses obtained by thermodynamic force and the load, which is accompanied by a process of changing the geometric shape, size and physical condition of mechanical parts during the formation of functional surfaces;
– deflected and thermodynamic state of the workpiece in the chipforming zone;
– residual deformation of each functional surfaces arising in the process of part machining.

Table 2

Characterization of functionally-oriented engineering technology

<table>
<tr><th>Input for the design</th><th>Input information</th><th>The principle of construction of the structure and process parameters</th><th>The advantages of functionally-oriented design</th><th>The problems of functionally-oriented design</th></tr>
<tr><td>Geometry of each functional parts surface</td><td rowspan="2">Design documentation, CAD system</td><td rowspan="11">Method of synthesis: an algorithmic synthesis of optimal structure and parameters of manufacturing operations, based on the results of predictive simulation of rheological modeling of the stress-strain and thermodynamic state of the workpiece in the process of forming</td><td rowspan="5">The formalization of recursive relations between the results of technological design and conditions of the product allows an optimum set of its functional performance qualimetric</td><td rowspan="3">Difficulty macrogeometryc parameterst parts settings for structure formation process</td></tr>
<tr><td rowspan="3">Specifications parts material (including analytical dependence of dislocation kinetics, curve of the thermo-hardening, fracture criteria, etc.)</td></tr>
<tr><td rowspan="2">Specialized database</td></tr>
<tr><td rowspan="2">The need for structural integration and provide a common format STEP data exchange between different CAD/CAE/CAPP/CAF/ /CAM systems (CAPE technology) (ISO 10303)</td></tr>
<tr><td rowspan="3">Surface layer microtopology of the each functional parts surface</td><td rowspan="7">Design documentation, system CAF, CAD System, CAE System (MacroCAE, MicroCAE, NanoCAE)</td></tr>
<tr><td>Full compliance with the PLM concept</td><td rowspan="2">The relative difficulty of formalizing input for the design</td></tr>
<tr><td rowspan="5">Provide system integration automated technological preparation of production (CAD / CAE / CAPP / CAF / CAM) by the concurrent engineering</td></tr>
<tr><td>Residual stresses (I, II i III typies)</td><td rowspan="2">The need for an automated technological system shaping the product (CAF – system)</td></tr>
<tr><td rowspan="2">Stress-strain and thermodynamic state of the workpiece in the chipforming area</td></tr>
<tr><td rowspan="2">The need for substantial improvement of existing CAE systems (MicroCAE, NanoCAE)</td></tr>
<tr><td>The deformation of the surface layer of the surface functional</td></tr>
</table>

Obviously, it is only possible to base on a thorough analysis of the impact of structure and process parameters on the engineering of machined surfaces. Formally, this phase is the result of CAE-systems, but information for its operation can only be obtained from the analysis of the results of the CAF-system. But the analysis phase forming (CAF) is performed later than the stage of engineering analysis (CAE). Therefore, no implementation of iterative relationship between individual stages of an integrated training system to make the process of functionally-oriented design is not possible! Moreover, the problem is that classical CAE systems are not designed to solve problems of analysis tribotechnical, micro-and nano-deformation processes such as wear resistance, contact stiffness, fatigue strength, corrosion resistance and so on. The theoretical basis of such studies are analytically and experimentally established, but the need for the implementation of systems engineering analysis as MicroCAE and NanoCAE in engineering practice was not yet found, because the author proposed approach to functional-oriented technologies for the first time.

According to the theory of classical Systems Engineering [8], for any design characteristic ascending sequential algorithmic synthesis of optimal structure and parameters of separate technological transitions, operations, are based on the results of the predictive simulation of rheological modeling of the stress-strain state and thermodynamic product during its formation.

Benefits of functionally-oriented design to object-oriented are quite evident (Table 2):

– formalization of recursive relations between the results of technological design and conditions of the product allows an optimum set of its functional qualimetric indicators;
– providing system integration and hybridization automated technological process planning (Integer Computer-Aided Manufacturing – CAD/CAE/CAPP/CAF/CAM systems) by means of concurrent engineering.

However, besides the positive features there are many problems in implementation of functionally-oriented design, including:

– complexity macrogeometric parts settings for technological process structure formation;
– the necessity for structural integration and provide a common format STEP data exchange between different CAD/CAE/CAPP/CAF/CAM systems (CAPE technology) (ISO 10303);
– difficulty of formalizing input for the design;
– the necessity for an automated technological system shaping of the product (CAF – system)
– the need for substantial improvement of existing CAE systems (MicroCAE, NanoCAE).

Scheme of the information nets between subsystems in the implementation of functionally-oriented design process are shown in Fig. 2 [7].

The basis of functional-oriented technology is integrated to ensure the effectiveness of the products of mechanical engineering, which greatly depends on the quality of manufacture of parts [12]. Particularly noteworthy are the products that are functional surfaces to be in service increased mechanical, temperature and tribological load.

Physical properties of the functional surfaces of all types and for different purposes, are formed by mechanical processing, specifies the shape and size of the micro-geometrical parameters of the surface layer. Formation a surface parts layer of the special pay much attention. This is due to the fact that the destruction of parts of the operation usually starts from the surface where the surface layers are most subject to stress and adverse environmental effects. Thus, the state of the surface layer is dependent performance properties parts: wear resistance, fatigue strength, corrosion resistance and so on. With increasing depth and degree of deformation wear resistance and fatigue strength of machine parts operated at normal temperature increase. However, parts of the heat-resistant steels and alloys, such as gas turbine blades that operate at high temperatures (800 °C) are detrimental deformation that reduces resistance to fatigue. Residual stresses arising during processing of the surface layer of parts without affecting durability. Do not depend on the magnitude and sign of residual stresses and fatigue properties of high-temperature alloy parts that operate at high temperatures. However, a different role of residual stresses in parts that undergo cyclical variable loads over time under normal temperature. In this case, the presence of the surface layer of parts compressive residual stress endurance limit its increase, while the tensile stress significantly reduced fatigue resistance. In addition, the height of roughness, the direction of the strokes processing step form and roughness, size bearing surface, ie parameters that define the micro (topology) surface finish, have a decisive impact on the performance properties of machines.

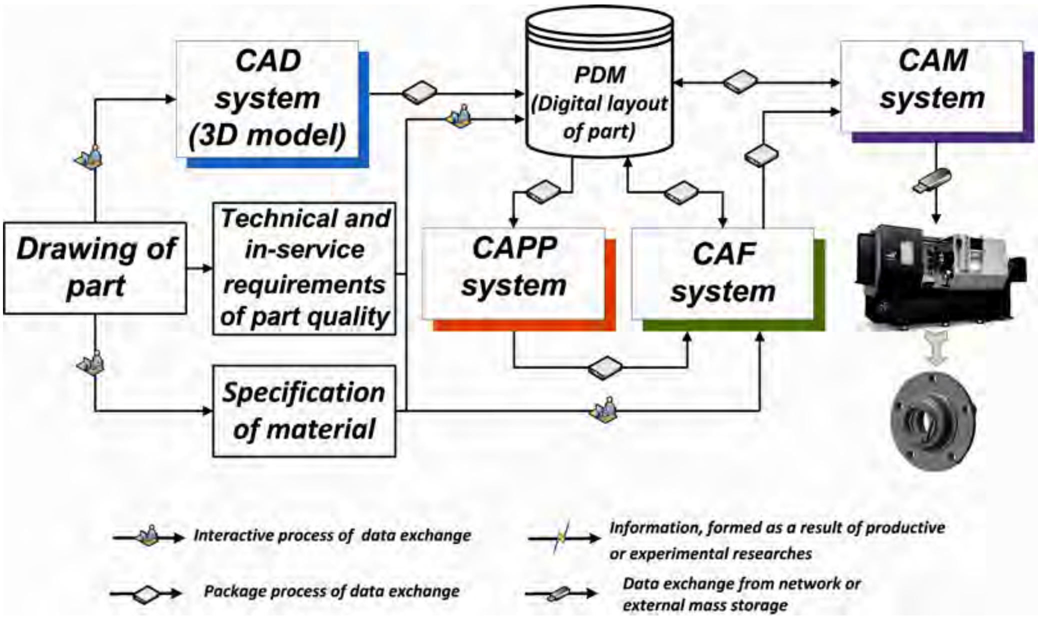

Fig.2. Scheme of the integrated system functionally-oriented technological preparation of engineering process planning

Mechanical processing, causing deformation of the surface layer and the change of surface roughness has a significant influence on the corrosion resistance of the metal. In addition, creating strain components accompanied by the penetration of corrosive environments inside the metal through the ferrite surface defects that plastically deformed. It may neutralize the development of corrosion processes and help to reduce fatigue strength of parts. To take into account peculiarities of operation of individual parts in a machine or process system and software set, you must limit their operational capacity to implement the algorithm deciding the choice of structure and process parameters based on the predictive capabilities CAF-system [5, 13].

The result of CAF-system is a complex stress-strain behavior, strength and thermodynamic parameters of cutting, changes in the angle shift and pattern of phase transformations on the treated surface material. This allows you to make a forecast of important performance parameters such as microtopology surface finish, residual stresses 1 and 2 type, physical and chemical state of the surface layer, etc.

In Figure 3 the algorithm fusion technology based on iterative and recursive relations. The process of designing such technologies based on the following stages:

- form a digital layout of the product;
- formalization and simulation environment to ensure the efficient operation of products;
- simulation of rheological modeling of stress-strain, thermodynamic and structural-phase state of the most critical parts of surfaces during their formation;
- models predict functionally-oriented properties of the product;
- structure and process parameters and the process of object-oriented technology;
- adjustment of structure and synthesis technology based on the principles of functional-oriented technologies;
- providing the necessary boundary properties or details depending on the characteristics of its use in the car or technological system.

Performance of individual stages of designing distributed and connected recurrent connections between automated systems such as CAD, CAE, CAPP, CAF and CAM.

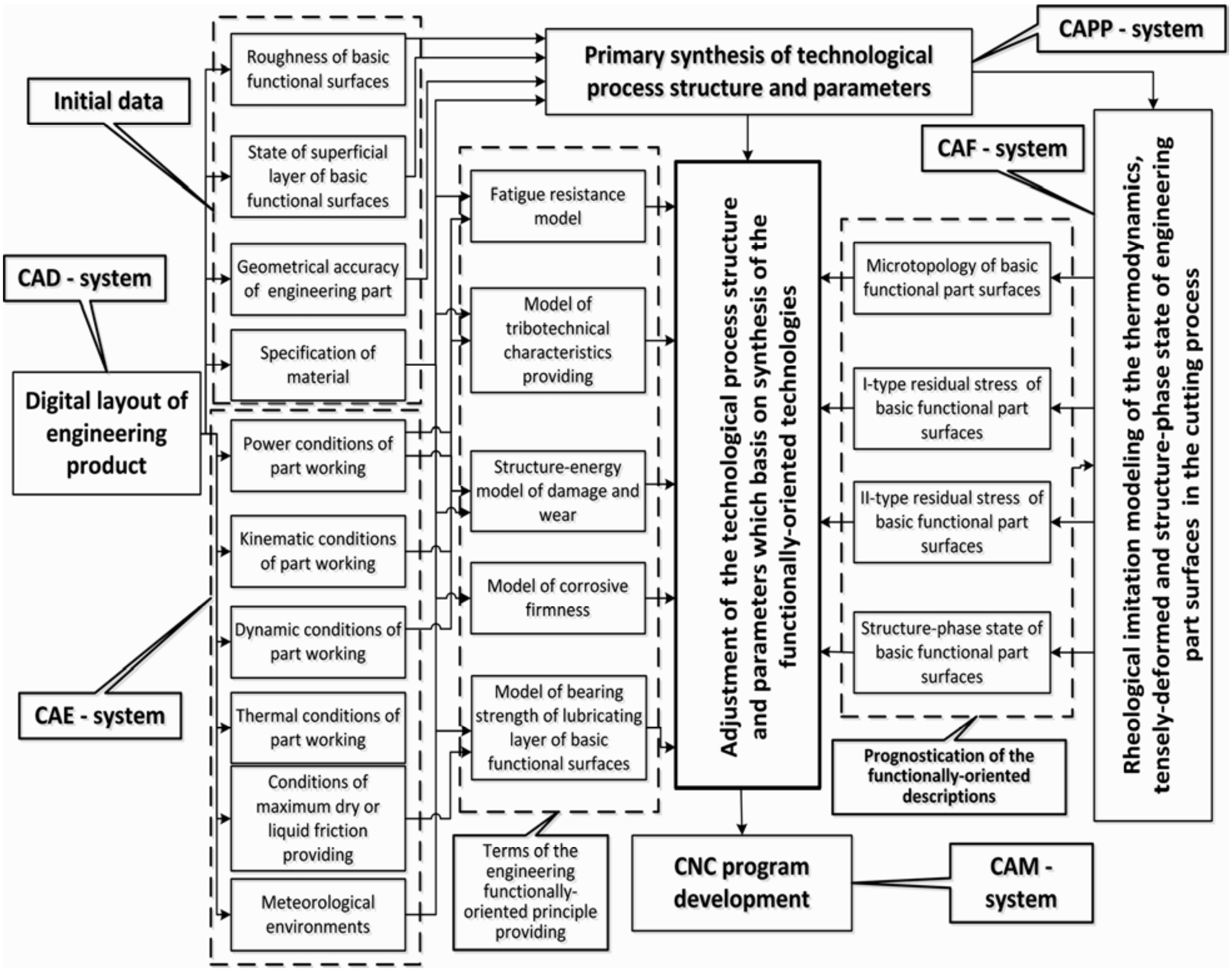

Fig. 3. The structure and logic chart of technological preproduction with functionally-oriented principle of planning

Conclusions. 1. The implementation of an integrated system for automated process planning of engineering production can be divided into two concepts for technological design – object-oriented and functional-oriented design. These concepts are not only on the criterion of choosing the optimal structure and parameters of technological processes, but also the algorithm implementation. Thus, for object-oriented design characteristic analysis method: an algorithmic search for structural prototype design and technological features correction parameters according to the input on the design is given. In a functionally-oriented design using algorithmic synthesis method: designing optimal structure and parameters of separate technological transitions, operations, based on the results of the predictive simulation of rheological modeling of the stress-strain and thermodynamic state product.

2. Given the positive and negative features of both design concepts, we can recommend the use of the algorithm of choosing the optimal structure and parameters of technological processes on the concept of functionally-oriented design only for parts that are functional surfaces to be in service longer mechanical, temperature and tribological load. Such details are the most defining operational quality of the product as a whole. For parts that do not meet these conditions of operation, it is advisable to use an algorithm that implements the concept of object-oriented design. So you can significantly optimize the criterion of complexity of the process of technological preparation of production, thus implementing PLM technology.

3. Introduction of a functional-oriented technologies enables more effective implementation of PLM concepts in engineering on the basis of the parallel design. The main feature of this design is that the primary in determining the structure and parameters of the process is the conversion of complex functional and performance properties of the product (accuracy and quality of the surface layer, residual stresses, etc.)

and the requirements of the process of effective cutting (chip formation, heat dissipation, vibration, etc.). Using CAF – a system that seamlessly complements the existing integrated CAD/CAE/CAPP/CAM system is predictive ability of simulation and installation depending qualimetric main indicators of product structure and process parameters, which is the basis of functional-oriented design.

4. Classical systems engineering analysis – MacroCAE (Macro Computer Aided Engineering) allows calculation methods using simulation macrophizycal processes to assess how behave computer model of the product in a simulated operating conditions. These CAE systems are not designed to solve problems of analysis tribotechnical, micro-and nano-deformation processes such as wear resistance, contact stiffness, fatigue strength, corrosion resistance and so on. The theoretical basis of such studies analytically and experimentally established, but the need for the development of systems engineering analysis as MicroCAE and NanoCAE in engineering practice has not existed since the proposed approach to functional-oriented technologies proposed for the first time. Therefore, the concept of functionally-oriented design is necessary to significantly improve the existing CAE systems (subsystems addition MacroCAE MicroCAE and NanoCAE).

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