МОДЕЛЮВАННЯ, ОПТИМІЗАЦІЯ, СТРУКТУРНИЙ АНАЛІЗ І СИНТЕЗ ТЕХНОЛОГІЧНИХ КОМПЛЕКСІВ

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B. Palchevskyi, DThSc., Professor
Lutsk National Technical University, Ukraine

PRINCIPLES OF CREATION OF INTELLECTUAL COMPUTER AIDED DESIGN OF TECHNOLOGICAL EQUIPMENT

It was considered the principles of creation and operation of intelligent CAD system for the design of technological equipment. It was performed the features of the formation of a knowledge base for industrial application area of functional modules. It was shown the examples of working of heuristic algorithms for designing.

Designing, optimization, synthesis, heuristic algorithm, search area, technological equipment, workflow.

1.Two types of computer-aided design of technological equipment

Design of any technical object – is the creation, transformation and presentation in accepted form of image of its non-existent object. The image of the object can be created in the human imagination as a result of a creative process or generated by some algorithms in the interaction between human and computer.

Engineer-designer solves the problems of different levels of complexity by creating technological machines. If he works on the same type of technological devices for which the special design methods are designed, then he needs to provide the parameters of the machines according to the requirements, that are contained in the specifications. The task is complicated if a new technological machine is designed, that requires creative usage of earlier experience. A part of work should be performed without anything in the process of designing of such machine, creating a new construction.

Engineer-designer solves the problems of different levels of complexity, creating the new technical products. There are two levels of designing of technical objects:

- prototyping;
- searched design.

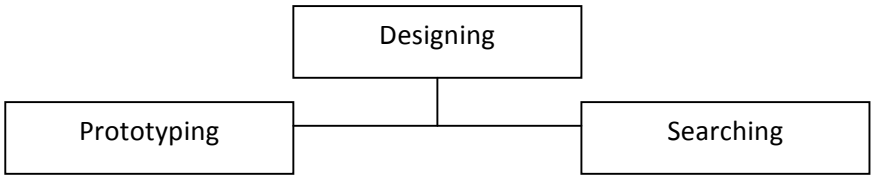

Fig.1. Levels of designing of technical objects

Technical object is a result of prototyping, that consists of typical elements similar to the prototype, but that adapts to the new conditions of usage. An original construction is the result of searched design, which is derived by the heuristic search methods using such information technology as mathematical modeling, optimization synthesis etc.

Of course, the fate of the non-standard actions is higher at the searched design than at the prototyping. Therefore, the separation of the processes of the real design to these levels is largely conditional. However, such separation allows to select two system classes among computer-aided design (Fig. 2):

1. The first-class (traditional CAD) is primarily focused on the usage of ready-made solutions. Classic CAD is used in those cases when the sufficient experience is gained at the designing of objects of this class.
2. The second-class system (intelligent CAD) supports by special means that part of the work of the designer, which is associated with the searching for unconventional solutions. Intelligent CAD systems are needed when there are no methods of designing, or the object fundamentally is new and requires considerable costs of creative work.

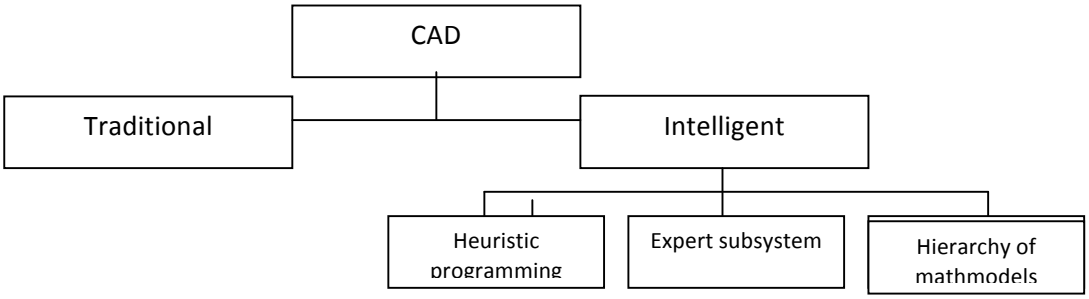

Fig.2. Types of CAD

Traditional CAD. Using the traditional CAD, the designing task is entered in the control program that organizes with the help of information retrieval system the searching for technical solution – counterpart in the database. If these are found, they are presented to a designer. If there is no ready-made solution, then a system using standard procedures of designing, which are usually stored in the form of software libraries, conducts the necessary procedures and gives the received solution to the designer. He appreciates it and with a positive solution gives the command for the preparation and the issuance of documentation on the designed object.

The concept of "rapid prototyping" is usually used at the development of the technological equipment. The prototype should demonstrate the suitability of technological methods for this task. If everything is okay, the designer extends the knowledge about the prototype from a problem area. If something is wrong in searching of a new prototype, the developers can make a conclusion about the unsuitability of methods of "rapid prototyping" for this task. When the knowledge is increased, the prototype can reach such point when it successfully solves all the tasks of designing. The converting of the prototype to a final product usually leads to redesign of its structure.

This structure of CAD – simple. The database, in which the searching for solutions – analogues is occurred, stores the information about the previously found designed decisions, about the typical units, knots and details, about the normative documentation, the properties and applications of various materials etc. With the complexity of tasks that are solved in the design process it is also complicated. Thus, the traditional CAD is a combination of hardware and software tools that provide an automation of all major stages of designing of objects, the analogues of which have already mastered by the industry.

Intelligent CAD (ICAD). The most difficult level of designing – one that is commonly referred to inventive or the level of searched design. Engineer creates the new objects, analogues of which did not previously exist.

Like any other system of artificial intelligence, intelligent CAD (ICAD) incorporates the knowledge base, in which all the necessary information for its work about the subject area is stored, in which the task of designing is solved. In this knowledge base that experience is collected, that is gained by designers and expert information about possible ways of a searching design, that is based on the methods of designing, that are typical for professionals working in this field. As you can see, setting and solving of any problems are related to the "immersion" in the appropriate application area. Thus, solving the problem of designing of technological equipment for packaging products, we involve to the applied field such objects as specific types of packing, packed stuff, auxiliary packed means, functional devices such as dispensers, sealing devices etc., time intervals, and general concepts "dose", "type of packing", "packed material" etc. All items and events that form the basis of a common understanding, that is necessary to solve the project task of information, which is called subject area.

Subject area consists of the real or abstract objects. They are in certain relations to each other. Relations between objects are expressed by judgments.

Nowadays there is a shift of attention of researches from creating of functioning CAD, that independently decide the project tasks, to the creation of human-machine systems that integrate into the human intelligence and capabilities of computers to achieve the goal of designing of a technical object with given features. This is the principle of creating of intelligent CAD. Intelligent CAD is a human-machine design system, in which the possibilities of a human and a computer are combined and complement each other. This allows to bypass the critical points of the designing process by the way of shifting on a person those functions that are inaccessible for computers.

2. Procedures and the objective of procedure of designing in intelligent CAD

The design of technological equipment is based on the ideas of **functional-modular designing**, in which the technological machines of modular architecture are arranged from the certain functional modules (FM), and their virtual models – from a database of electronic models of FM.

Their usage allows to organize the designing process from the initial facts through the certain rules and procedures to achieve the goal, which was formulated in the technical task (Fig.3).

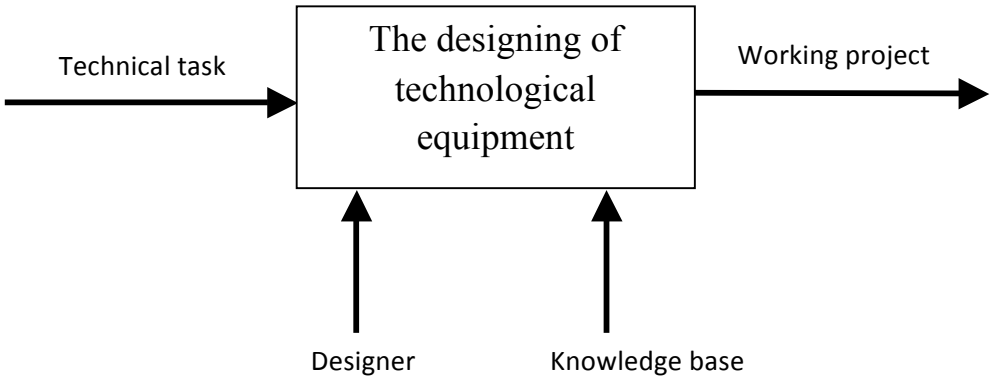

Fig.3 Procedural CAD model of technological equipment

Different procedures, stages and levels of the designing are integrated in modern CAD in order to achieve a goal of designing, which provides a continuous cycle of designing, from the stage of preparation of technical task and development of technical proposal to the creation of working and technical projects. Not only routine tasks are automated, but also heuristic and creative, such as the procedures of search designing, structural synthesis and optimization.

The exact methods do not exist for many tasks, which people are able to decide. The only reproduction of that rules and techniques on the computer in this case is remained, that are used by the person in dealing with similar problem. These specific for human rules and methods are called heuristic methods. Since they are not accurate methods, then they do not always provide the desired result. But heuristic methods include the wealth of experience of the human skills, which professionals would like to convey to the intelligent systems. They are also used when exact methods cannot be used because of the need for realizing of enormous calculations.

The general formulation of the design problem is formulated as follows: given function, it is necessary to develop a description of the object that will implement the given function and will satisfy with a certain set of restrictions and conditions. Therefore, the main procedures of designing, which are used in intelligent CAD, are a system analysis, synthesis and modeling. From these the main math procedures and stages of designing are composed in different combinations.

Synthesis is a procedure of designing that aims to connect the various elements, features, aspects, etc. of the object as a whole, a system. The project solutions that get a new quality of its own elements are created as a result of the synthesis. The technological machines and lines, components, algorithms, technological processes and operations, the physical principles of operation can serve as the synthesized design decisions.

Analysis is to determine the properties of the described object and comparing them with given. Analysis allows to evaluate the extent of satisfying of the project decision to the specified requirements and its suitability to perform a given function.

A typical design procedure of analysis is optimization, which leads to an optimal for a particular criterion project decision.

The combination of the synthesis procedure and the procedure of analysis of object forms a complex procedure of optimization synthesis that solves the task of synthesis of optimal structure of the workflow in the machine at the designing of technological equipment, finding the best optimal principles of its structure, the synthesis of optimal structure of a machine from the set of given FM.

Modeling is used at all stages of designing as during the conduction of the procedure of optimization synthesis of workflow and at the procedure of optimization synthesis of the structure of the technological equipment. The modeling allows to solve the main problem of the designing – to determine the relationship between the structure of the designed object and characteristics of its efficiency.

The procedures of analysis, synthesis and modeling in the design process are closely linked, forming metaprocedures that are aimed at creating an acceptable or optimal project decision. These metaprocedures reflect some models of creative activity, that are studied in the psychology of thinking. The usage of ideas in CAD became possible only with the development of information technology. The main metaprocedures include the following models of creative activity:

1. labyrinthine;
2. associative;
3. model.

The essence of **labyrinthine model of creative activity** is the assumption that the transition from the initial data of the task to its solution lies through the labyrinth of possible alternative ways. Since not all ways lead to the desired goal, then it is necessary to make step-by-step control of the correctness of the selected way. Numerous procedures of searching, such as a well-known method of a discrete optimization of "branches and bounds" belongs to the programming of this metaprocedure.

Associative model of creative activity is the basis of metaprocedure of associative searching of problem solving. It is based on the assumption that the solving of new problems are somehow based on already solved the problem, similar to the one that should be solved. New task is considered as already known, although different from it. But this metaprocedure led to that for its effective usage we should involve the results, which are based on the knowledge of a particular subject field. It is necessary to specify the source data and technical specifications, the class of acceptable decisions (class of projects) and the method of choice of any project from a class of acceptable decisions for a given technical specification and input data. Computer-aided design is reduced to setting of a specific technical condition and acceptable input data and applying of an algorithm of transition to a class of decisions. CAD rapid prototyping is based on this model.

Model metaprocedure of creative activity is based on the assumption, that the human brain uses the model of problematic situation, in which it must make a decision. For the solving the metaprocedures are applied, that operate with a set of knowledge from that problem area to which belongs this problem. The searching in a set of existing knowledge of information, related to this problematic situation is used in the model metaprocedure.

These metaprocedures form the core of intellectualization of modern computer-aided design systems. Intelligent CAD incorporates the knowledge base, in which all the necessary information of applied area is stored, in which the task of designing is solved. That stored experience by designers, and expert information about possible ways of searched design are collected in this knowledge base.

3. Plans of designing in intelligent CAD

The functioning ICAD has a purposeful character. This is a decision of project task by planning of achieving the desired goal - working draft of a machine - from some fixed initial situation, given by the technical task of designing. An action plan as a sequence of design procedures, i.e. partially-ordered set of actions of designing should be as the result of solving the problem. The searching of action plan in ICAD occurs only when it is faced with unusual situation, for which there is a known set of actions, that lead to the desired goal, e.g. at the designing of a new technological machine.

Such systems can generate technical solutions, based on the information about technological task, which they have to perform. When the task of designing is entered to the entrance of system, it with the help of ICAD attempts to bring the process of designing to the standard procedures, which are implemented in classic CAD. If this attempt is unsuccessful, the logical unit sends the task to the input of an expert system, oriented on a decision of designed task in this subject area. Interacting with the knowledge base ICAD, expert system looks for solution.

All the tasks of building of an action plan for the designing can be divided into two types, to which correspond different models of designing:

- *the designing in space of states (SS-design)*
- *the designing in space of tasks (PR-design)*

The designing in space of states. The object of designing passes successfully through some intermediate states under the influence ICAD. The designing is to find a way from the initial to the final state. The space of designing can be represented as a graph whose vertices correspond to states and arcs – design procedures. Typically, these graphs are not given, but are generated according to the needs of designing.

There are blind and directed searched methods towards designing. Blind has two types: search in depth and search in breadth. Each alternative is explored to the end, without considering other alternatives at the searching in depth. All alternatives are explored on the fixed level at the searching in breadth and only after that the transition to the next level is carried out. Both blind methods require a large time cost and therefore become necessary the directed search methods. *The method of branches and bounds* refer to these methods. The shortest way is selected and extended by one step from the incomplete ways, that are generated in the process of searching. These new incomplete ways are considered together with old and again the shortest of them is extended by one step. The process is repeated to the first reaching of target vertex, the solution is remembered. Then from the incomplete ways, that were left, the longest are excluded than a completed way or equal to it, and those that were left extend by the same algorithm as long as their length is less than a completed way. As a result, all incomplete ways are excluded or among them the completed way is formed, shorter than previously obtained. The latest way begins to play the role of a standard and so on.

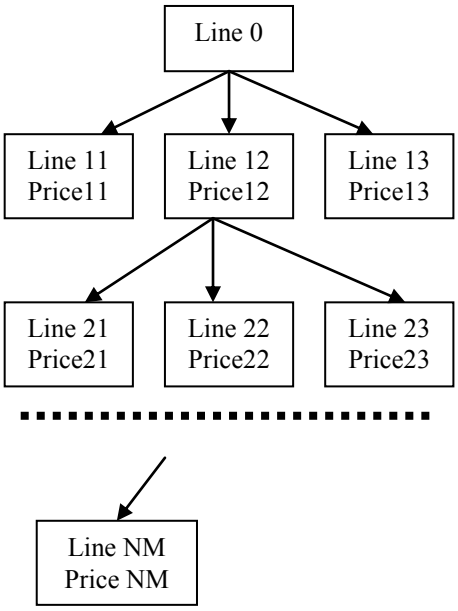

Fig.4. Scheme of "branches and bounds

If, for example, CAD is intended for the designing of functional-modular structure of the technological equipment. Intermediate states will be states of equipment with incomplete set of functional modules. The initial state is the set of structures with different constructions of functional modules for the performing of the first operation or transition, and the last – a set of structures with their full range.

Each element of graph represents a state of technological equipment with attached functional module corresponding hierarchical level (mechanisms of working position or some technological machines) that can be characterized by various parameters (accuracy, productivity, reliability, cost, energy-saving etc.).

The arcs of the graph represent the design procedure of selecting and joining of one functional module.

Let the problem lies in the selection of equipment for automatic line that will perform a necessary complex of operations with a given productivity, so that its cost will be minimal. The finding of optimal solution is very consuming process, considering a large number of models of existed equipment.

The usage of method "branches and bounds" for the optimization of the structure of technological complex is in the following. The states of the structure of lines are described in the form of tree with ramifications for each subsequent operation (Fig. 4). Line - is an array that contains a list of equipment and Price - array that contains the price of each item of this equipment. Each ramification of the tree is a design procedure of selecting of the equipment variant, which contains the lines. The level of a branch location for height of the tree specifies the operation, which the given equipment performs. Formally, the task is to find the cheapest way from the initial state (upper level)

to the final (lower level). The found variants are remembered in the searching. If at some level N way will be more expensive than in already found variant, then this branch and all their subbranches are not considered. The model of equipment for the realization of the first operation is selected at the first step, then of the second and for all other operations. Then the first variant of the structure is, which satisfies the initial condition. We take its value for the maximum $value_{max}$. The accumulated value from $value_{max}$ is considered in the further searching on each ramification. If the received value is less, then the searching continues, otherwise a return to the previous ramification is carried out and the searching in other branches of a tree. If the searching has come to the end of tree $value_{max}$, this value is assigned to the received variant. Next, the previous steps are repeated until all branches will not be bypassed.

The designing in space of goals and objectives of an object. The space of designing is formed by the decomposition of the design task, that is given by the technical task on the subtask (goals and sub-goals). It is necessary to find a variant of the decomposition of original task on the subtask, which leads to the problems whose solution is already known.

For example, for CAD is known how the dosage of the product is carried out, how its serving is realized, sealing, cutting of package. If CAD needs to choose hardware for the serving of the product, its dosing, packing in the package and its welding, the solution of PR-designing will be the presenting of this problem in the form of task decomposition, that form the workflow of a machine as a set of technical functions "deliver product", "dose "and so on. That is, the process of designing lies in a sequential reduction of the original problem to more common as long as only basic tasks will not be received, for which solutions are known. For the technological equipment these tasks represent the elementary functions, for which a system has a set of hardware – functional modules.

Partially the ordered set of such solutions will be the solution of the original problem. An unbundling of the assignment to an alternative set of subtasks conveniently is presented in the form of AND / OR-graph. In this graph every vertex, except the final, has a conjunctive bound subvertices (AND-vertices) or disjunctive bound (OR- vertices). The initial vertex (root and / or - the graph) represents the original problem. The final vertices are decisions.

4. The structure of intelligent CAD

The development of modern CAD of technological equipment occurs in the direction of giving them intelligent functions. The knowledge base and the database are included in the structure of intelligent system in the most general form.

Knowledge Base, together with the database – are necessary component of software complex of intelligent CAD (Fig. 5).

The functioning of intelligent CAD is based on the knowledge of the applied field, which are stored in its memory. The concept of knowledge appeared with the development of intelligent CAD, and this knowledge combined many features of procedural and declarative information. The procedural information is materialized in the programs, which are carried out in the process of a decision of tasks, declarative information – in the data, with which these programs work. The contents of memory creates the information base. Therefore, we can say that knowledge - is specially the organized data.

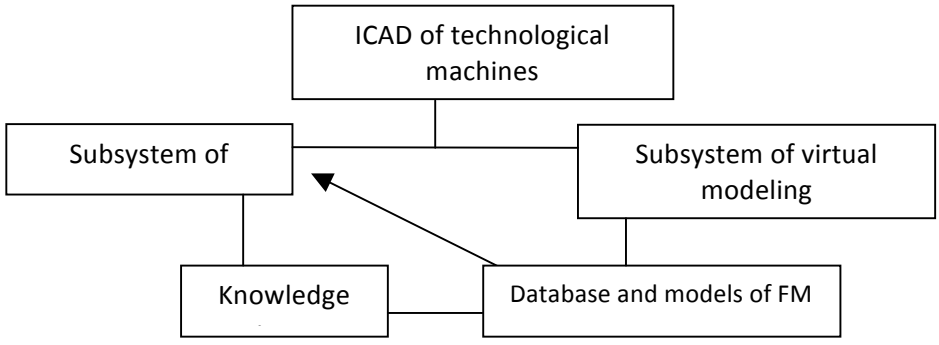

Fig.5. Structure of intelligent CAD

An indicator of intelligent system in terms of knowledge representation systems is the ability of system to use at the right time needed (relevant) knowledge. Systems, that don't have means to find relevant knowledge, face with a problem of "combinatorial explosion". We can argue that this problem is one of the main reasons, which restrict the sphere of usage of intelligent CAD.

When the task for designing is entered to the input of intelligent CAD, it is understood as a system with the help of interactive tools, is specified in the user and is converted in a special internal representation. After that the attempt is done to bring the design process to standard procedures, which are implemented in traditional CAD. If this attempt is unsuccessful, the logical unit sends the task to the input of an expert system, which is oriented on the solution of designing in the subject area. Interacting with the knowledge base, an expert system looks for solution.

The increasing of intelligent system of designing is carried out by using:

1. heuristic algorithms,
2. expert systems,
3. hierarchy of mathematical models at all levels of designing.

The using of heuristic algorithms in solving problems of designing is well established itself in the creation of new technological machines that confirms the existed belief about that the intelligent CAD is practically an expert system. Therefore, the structure of intelligent CAD includes the knowledge base and database. Their usage allows to organize the process of designing from the initial facts through the certain rules and procedures to the achievement of the goal, which was formulated in the technical task.

Database (working memory) is used to store source and intermediate data of the solved task in the present moment.

Knowledge Base (KB) of intelligent CAD is used to store long-term data, that describe this area, and rules, that describe the appropriate transformations of data of this area.

5. The searching of technical solution in intelligent CAD of technological equipment

5.1. The features of modeling in the designing

Methods of solving problems that are based on the reduction of them to the searching depend on the applied area in which the problem is solved, and on the demands, that are presented by the user to decision. In terms of methods of solution the features of applied area can be characterized by the following parameters:

- size, which determines the amount of space, in which we should find a solution;
- the completeness of model, which is used to describe this area. Usually, if the model is not complete, then the several models are used to describe the area, that complement each other;
- the determination of data about the solved task, that characterize the measure of accuracy and completeness of the data. The completeness of data is understood as sufficiency of input data sufficiency for the solution to the problem.

Thus, the complexity of the problem, determined the above set of parameters, is varied from simple tasks of low dimension with constant specific data and the lack of restrictions on the result and the method of its obtaining to the challenges of high dimension with variables, erroneous and incomplete data and arbitrary restrictions on the result and the way of its obtaining. From general considerations it is clear that all problems can not be solved by any one method.

Existed methods of problem solving that are used in intelligent CAD can be classified as follows:

- methods of searching in one space - methods for using in the following conditions: a areas of small dimension, the completeness of model, accurate and complete data;
- methods of searching in hierarchical spaces - methods for working in areas of large dimension;
- methods of searching at inaccurate and incomplete data;
- methods of searching that use several models, and are intended for working with areas for an adequate description of which one model is not enough.

It is set some production environment of functional modules, in which action of intelligent of CAD is to achieve technical solution, given by technical conditions, from some initial situation, given by technical task, with the help of action plans

$$P_0 = \{p_i\},$$

where $p_i = 1,...,n$ - project procedures.

To set technical conditions in such production environment - it means to specify the properties $c_j \in C_0$ of functional modules $\Phi M_k \in A_0$ and the relation between them $r_m \in R_0$. The model of production environment of functional modules for such action of intelligent CAD can be presented as

$$M_0 = \langle A_0, P_0, C_0, R_0 \rangle,$$

and a task of planning of design procedures in the production environment M_0 can be formulated as follows: thy given technical task and technical conditions, it is necessary to build from the implemented procedures $p_i \in P_0$ a design plan P_0, which is applied to technical task, allows to achieve technical conditions.

In the solving of this task the problem usually is because the searching of designed plan is difficult due to the high dimension of space of searching. Thus, the models of production environment of functional modules need more general for intelligent CAD due to M_0.

The process of designing of technological machine provides the functional design, on which a functional model of workflow in machine is created and a structural design, on which a model of machine structure is created on the basis of workflow. Obviously, the functional description is more general because each technical function can be implemented by many variants of constructions of machine elements. And conversely, each variant of the construction of machine element can implement only a single function - it is the one for which it was created. It follows from this reasoning that the functional model is more general than structural. This model superficially describes the properties of functional modules - only their functional purpose.

Let C1 – set, that is derived by coarsening of properties of functional modules $c_j \in C_1$, P_1 - set of procedures of the construction of simplified technical solution, $A_1 \le A_0$; $R_1 \le R_0$. Then the simplified model of production environment of functional modules can be represented as

$$M_1 = \langle A_1, P_1, C_1, R_1 \rangle,$$

but the setting of tactical task of designing and its solution - as a set $P_1 = p_1 ..., p_{in}$. Some functional modules and project procedures become vague due to the specified coarsening in a simplified model of the production environment of functional modules M1. However, this simplification that is caused by the "coarsening" of the senses of intelligent CAD, allows significantly to reduce the dimension of space of the solutions searching. Further coarsening of model of production environment M2 present the functional modules, $\Phi M_k \in A_2$, whose properties $c_j \in C_2$ and relations $r_m \in R_2$ between them the generalized concepts are determined.

Such models allow to find solutions at the early stages of designing. In the next steps the models are complicated, that allows to use a string of models with different levels of description detailing of the production environment of functional modules. The product and its model are considered as given, analysis of which is used to build a model of the workflow in the machine as a set of basic technological functions.

The next step is to find the matching to the basic functions of technical means of their implementation and the formation from them the structural model of technological machine. Among the tasks – objectives of selecting of FM we will select class of elementary for which the obvious will be a choice of appropriate FM. The last we will assume complex, and present their solutions in the form of a partially ordered set of elementary solutions. Therefore, for the transition from the initial to elementary task the typical tasks are used - typical technological schemes of a machine. First, the semantic structure of input data is defined for a given initial task, namely the strategic task is set, such as making of a certain product or its part and is formed a hypothesis of its solving in the form of a project of machine workflow and its technological scheme.

Thus the logical sequence of steps of designing is received, each of which is ended by the construction of more accurate model of the production environment, and the results of a previous in the form of appropriate models are used as follows (Fig. 6).

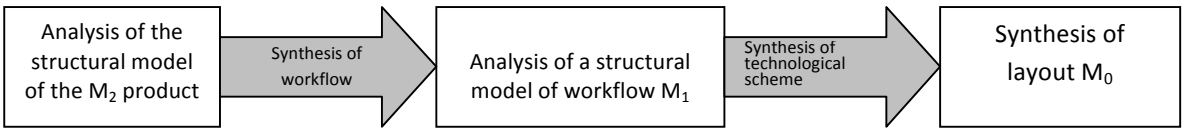

Fig.6. String of models in the designing

5.2. Stages of intelligent CAD of technological equipment

Each stage of the designing is led to forming of descriptions of the designed technological equipment that relates to its various hierarchical levels. The basic stages of designing are distinguished in terms of sequence of performance:

- avan-designing, where the reasoning of source data for the designing is carried out, the results of which are made in the form of technical conditions, technical task and the technical proposal;
- functional designing, during which the optimization synthesis of workflow of technological equipment is carried out, technological and principle schemes are designed;
- structural designing, during which the structure of the projected object is formed, its component parts, which are usually completed blocks - functional modules (FM), the spatial and functional relations between them are determined;
- designing, during which the technical solution for design and engineering, economic and operational indicators is optimized. The working project is developed at this stage of designing, i.e. the technical documentation that is necessary for the manufacture and operation of technological equipment.

The intelligent CAD includes appropriate heuristic algorithms for the implementation of these stages of designing:

1. an algorithm of decomposition of a design task for subgoals;
2. an algorithm for analyzing the structure of the product and building of sequence of realization of technological transformations of product, and from them - a sequence of basic functions within the workflow of equipment;
3. an algorithm of the placement of functions on the working positions of a machine and a choice of types for these positions of FM – the flowsheet of machine;
4. an algorithm of optimization synthesis of the machine structure (layout).

Let's consider their work on the examples.

5.3. An algorithm of decomposition of a design task for subgoals

This is analysis of the initial data and the formulation of goals. This stage is performed in the space of objectives and lies in the consistent construction of the initial task to more common. The partitioning of the global objective for subgoals lasts as long as you will see an opportunity to link goals of the lower levels with the means that provide the performance of these goals, i.e. the combination of goals of lower levels to the transferring of functions, which are performed by the device.

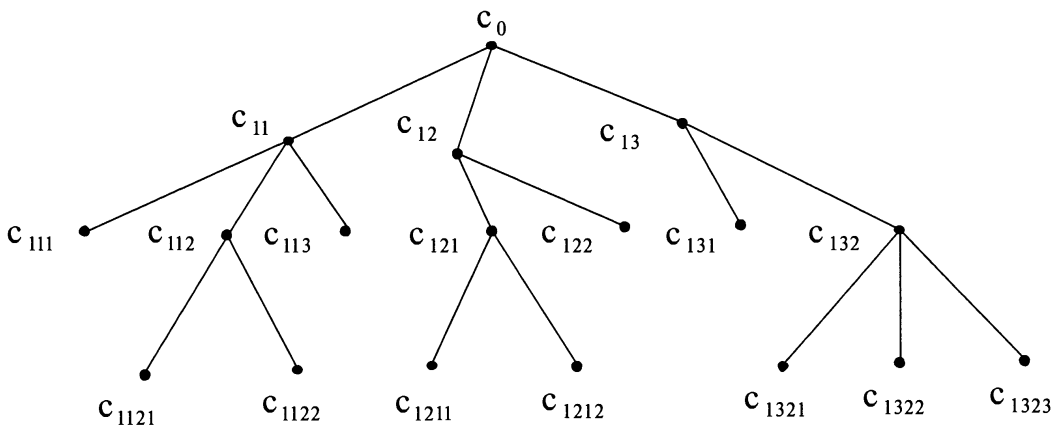

Fig.7. Formulation of goals

The intelligent CAD builds the solution of complex output tasks from the decisions of elementary tasks. The intelligent CAD usually can't find the solution for such object of designing as technological machine. It is provided the performance of the next stage of functional designing of workflow in a machine.

Indeed, if we'll define the global goal of designing as a implementation of service function of a machine, i.e. the manufacture of product with the parameters at certain limitations, then decomposition of this goal into subgoals will be reduced to the receiving of a set of technological functions, for each of which the technical means of its implementation will be known. The structure of workflow is formed from this set at the functional designing.

5.4. Functional designing

It begins from the analysis of the product which should be produced on the technological equipment. This product represents a combination of details and connections between them in the case of the assembly unit, and in the case of separate detail - a combination of surface or structural elements from several surfaces and geometric relations between them.

Let's consider, as an example, analysis of the structure of individual detail. The functional, designed and technological constraints influence on the sequence of surface processing of details, that allow to distinguish three groups of contradictions in the ratios of precedence, i.e. in ratios "which surface must be made before the one that is considered", namely:

- **functional ratios of precedence** that are imposed by the terms of the functioning of a detail;
- **designed ratios of precedence** that are imposed by the terms of the spatial arrangement of surfaces in detail;
- **technological ratios of precedence** that are imposed by the terms of processing of a detail.

To determine the logical sequence of processing we will write functional, geometric and technological ratios of precedence that are imposed on the surfaces of details in the form of a matrix of precedence.

The surface, which should be previously processed

S -surface, which is processed	S1	S2	S3	S4	S5	**Bo** Degree of surface dependence
S1						0
S2	1					1
S3	1					1
S4		1	1			2
S5				1		1
Degree of surface imitation	2	1	1	1	0	

Then the sequence of technological transitions of surface processing of a detail (fig. 8).

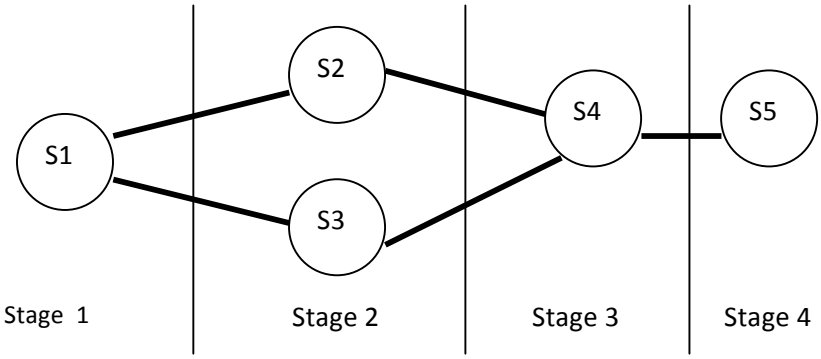

Fig.8. The sequence of surface processing of a detail

Let's consider this procedure for the real detail, for example at optimizing of the structure of the process of mechanical processing of the body support.

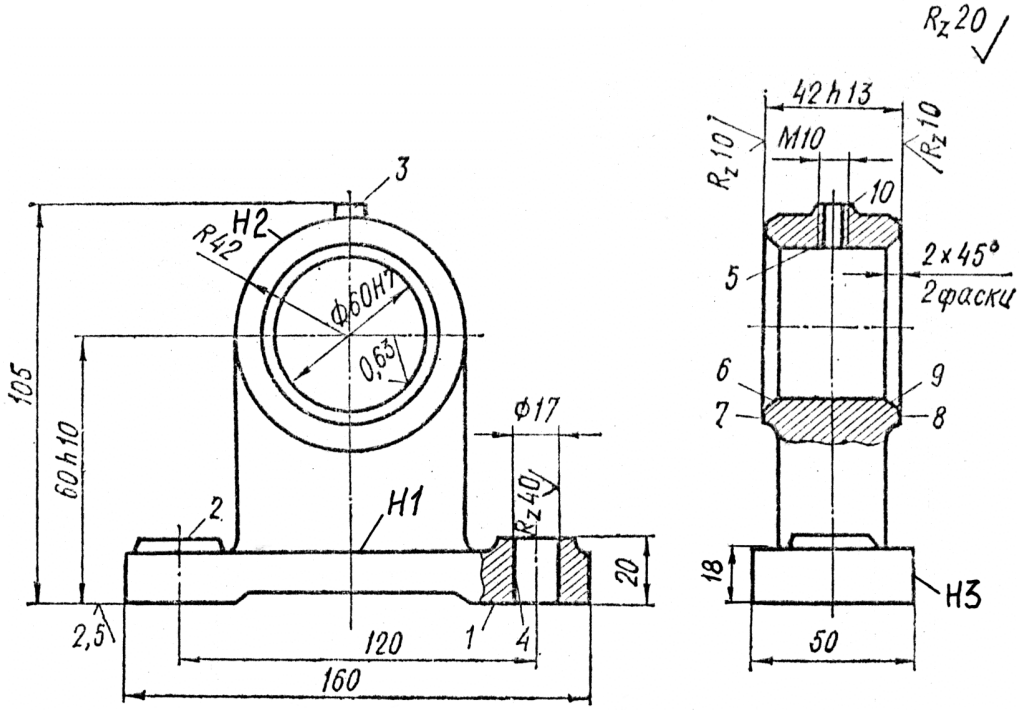

Fig. 9. The body support (Gray iron - GI-18)

The process of optimization synthesis of the process of mechanical processing includes:

1. The defining of restrictions on the sequence of formation of surface details, that are imposed by the construction of a detail, by the technology of mechanical processing and by the conditions of operation of a detail in the node.
2. The generation of variants realization of each technological operation of processing and selection of the optimal variant of the process structure.
   Matrix of the surface precedence of body support has the following form.

	R1	R2	R3	1	2	3	4	5-c	5f	6	7	8	9	10	P0	P1	P2	P3	P4	P5	P6
R1															0						
R2															0						
R3															0						
1	1														1	0					
2				1											1	1	0				
3				1											1	1	0				
4		1	1	1											3	1	0				
5c				1			1								2	2	1	0			
5f				1			1	1							3	3	2	1	0		
6									1		1				2	2	2	1	1	1	0
7				1			1								2	2	1	0			
8				1			1								2	2	1	0			
9									1			1			2	2	2	1	1	0	0
10				1			1								2	2	1	0			

Here the result is the structure of the workflow and the flowsheet is built on its basis, which completes the functional stage of designing (Fig. 10).

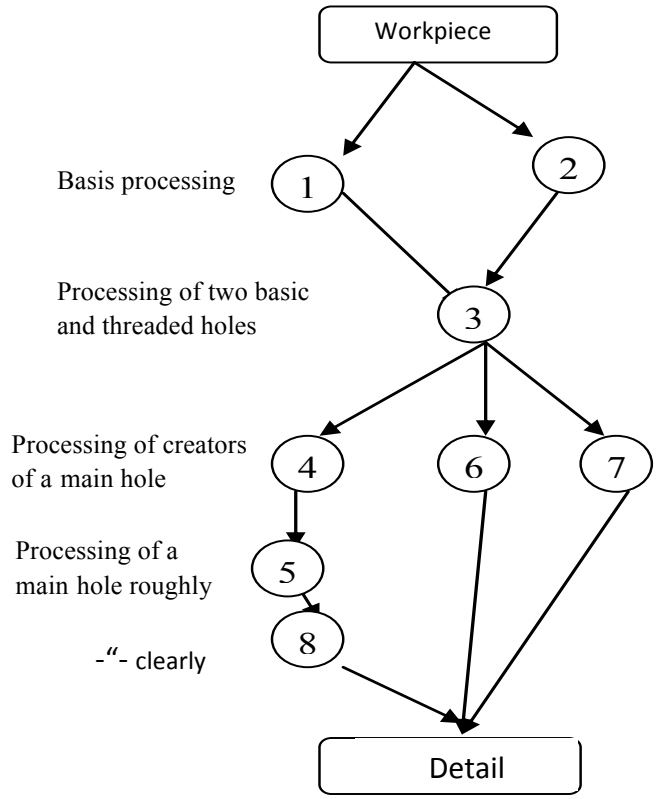

Fig. 10. The structure of process of mechanical processing of body support

5.5. The structural designing

It is a set of tasks, connected with the transformations of the functional model of workflow components in a set of components of a machine structure. The guiding principle is modular in the structural designing of technological equipment, which involves the separation of functional modules of various degrees of complexity, which are in spatial and functional relations.

Two problems are appeared:

1. the finding of optimal placement of functions on the functional modules;
2. the finding of optimal placement of functional modules in the workspace.

Let's consider, as an example, the structural designing of the technological machine for the packaging of bulk materials. Technological operation of packaging includes such technological transitions (x_1 - x_5), the sequence of which is given by the workflow and by the flowsheet of a machine (Fig.11):

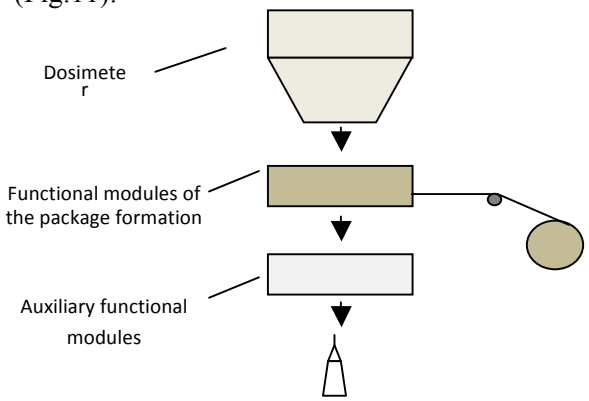

Fig.11. The flowsheet of a machine for the packaging of bulk products

- the formation of the workpiece of package – funnels (x_1) from the polymer film;
- the dosing of substance mass x_2);
- the longitudinal welding of package (x_3);
- the transverse welding of package with a dose of substance in it (x_4);
- the drawing of workpieces of package – funnels on a step (x_5).

It is possible to use different functional modules from the set $A_i = \{x_{i1}, x_{i2}, ...\}$ for the implementation of the i-th transition, which differ in characteristics (reliability, speed, energy consumption, cost, etc.), the problem of synthesis of packing machine structure is a multivariate . It can be solved by methods of discrete programming that allow to find the optimal composition of functional modules for the selected criteria.

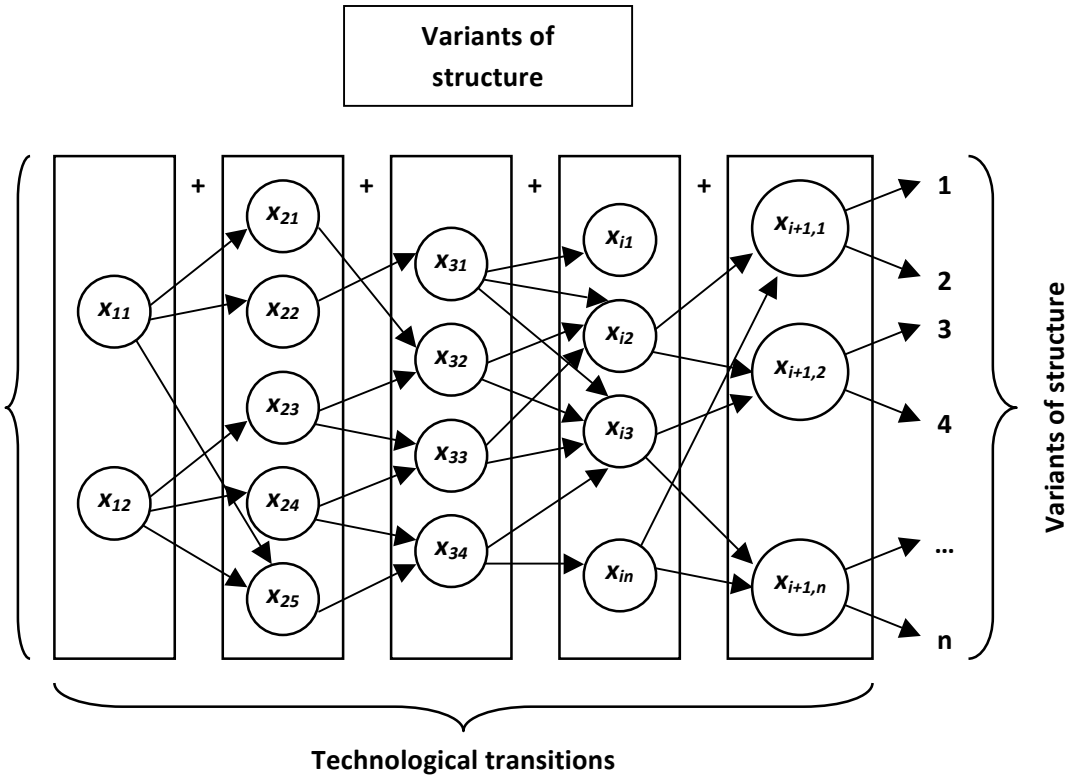

Fig.12. Model of a procedure of optimization synthesis of functional-modular structure of packing machine at a given flowsheet

The next design procedure – a location of selected set of functional modules in the layout of a machine, their distribution over positions. Such limitations as a number of functions are taken into account, the number of functions, which are performed by a functional module, the number of connections, the total occupied area, and the number of functional modules. Thus, at the strategic level, each tactical situation (output data or desired result) is measured by the presence of semantic structures.

For example, the semantic structures are expressed at the designing of layout of the technological machine by the terms "horizontal placement of positions", "circular placement of positions", "difficult position from several functional modules" and so on. The designed tactic tasks from the strategic level by the way of decomposition of typical tasks are decided at the tactic level, e.g. the formation of technical means for realization of particular transition.

Some modifications of machines layouts will differ by kind of functional modules and by their number.

5.6. The designing and development of working project

After the ending of optimization synthesis of functional-modular structure of technologic machine the subsystem of virtual modeling using 3-D models of typical functional modules allows you to build a virtual 3-D model of the designed machine and to create automatically its design documentation, which is required for manufacturing and operation.

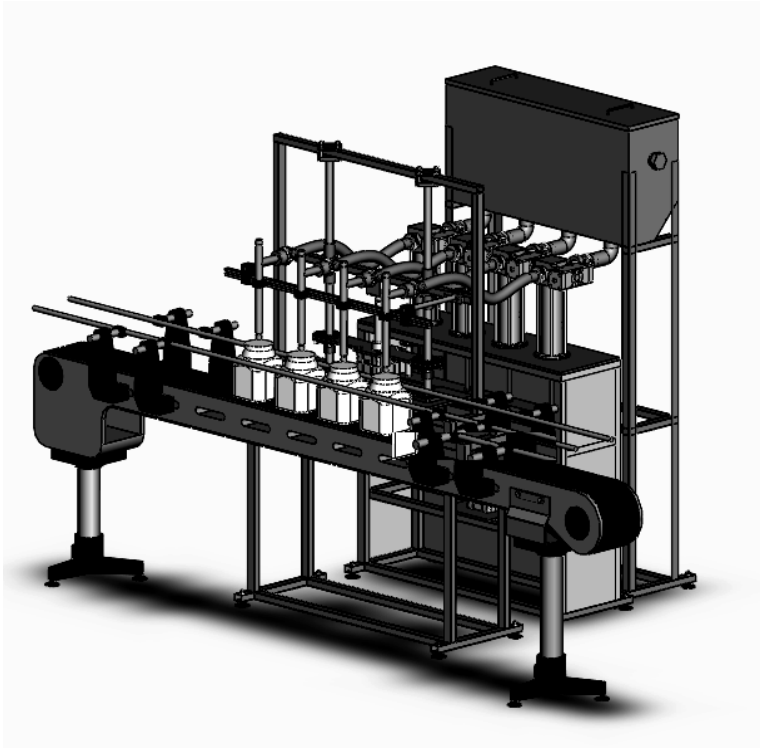

Fig.13. 3D-model of technological machine for packaging of viscous products

Conclusion

As you can see, in the intelligent CAD the heuristic algorithms of optimization synthesis of workflow in a machine are used, of flowsheet and of machine layout with using of expert knowledge for building procedures of synthesis and evaluation of technical solutions.

1. Пальчевський Б.О. Інформаційні технології проектування технологічного устаткування. − Луцьк: Видавн-во Луцького НТУ, 2012. − 572 с.