CHAPTER 3. SYSTEMATICITY OF PRODUCTION TECHNOLOGIES

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3.1. Technological preparation of production

Technological preparation of production (TPP) – stage of technical preparation of production, which is a set of interrelated measures, ensuring the full technological readiness of the enterprise to produce a product of a given quality in a timely manner, according to production volumes and costs.

Technological readiness of production assumes existence at the enterprise of complete sets of the design and technological documentation and means of the technological equipment necessary for realization of the set volume of release of products with the established technical and economic indicators.

Technology development – this is a complex multivariate task, solving which, in addition to technological considerations, one must take into account the requirements of the economy and organization of production, the specific production environment, features and requirements for product quality, etc.

The versatility of the technological process is always associated with overcoming significant difficulties. Each developer of the technological process, analysing many factors, eventually comes to a certain technological solution. However, it cannot be guaranteed that the decision itself is the most favourable, as the development process had many unknown factors from the beginning, and in some cases certain hypotheses and assumptions were used. Extensive use of computers to solve such problems allows in a short time not only to take into account many simultaneously acting factors, but also to work out a single solution.

Information technology is widely used because the variability (turbulence) of the modern market requires fast and reliable information and its processing. This, in turn, makes information technology the basis for adapting the company to change. Information technology becomes the basis for the development and modernization of production.

When developing product manufacturing technologies, it is necessary to save material and labour resources, make the most full use of equipment and provide reserves that allow in the shortest possible time to either sharply increase or decrease the output of products.

Technological preparation of production is the most time-consuming and responsible stage of production preparation.

As a component of the system technology of PLC, technological preparation of production is a set of processes and procedures, usually performed with the help of CAM systems, which contains the following tasks:

– analysis of initial data, existing technologies, equipment and production facilities of the enterprise;

– analysis of manufacturability of new products;

– development of technical tasks for the design of technological processes of production and non-standard technological equipment and its manufacture;

– development of advanced route and route-operational technological processes of manufacturing parts, assembly, adjustment and testing of individual components and the product as a whole;

– development and implementation of rational methods of technological control;

– identification and analysis of technological dimensional relationships;

– development of plans for placement of equipment, jobs, machine lines, etc.;

– release of research and installation batch of products with testing of the developed technology and means of work, implementation of technological and design control;

– final adjustment of technological processes, special tools and start of production;

– development of service regulations;

– development of control programs of machines, industrial works, assembly and control and measuring machines;

– determination of safety and environmental safety requirements;

– determination of economic efficiency of technological developments;

– registration of the corresponding technological documentation.

One of the development directions of the process of technological preparation of production in conditions of increasing competition is the automation of products design and technological processes of their manufacture. However, on this way there are a number of problems arising.

Methods and formal procedures for automated development of technological processes for processing workpieces of body parts are still insufficiently developed, including such difficult-to-formalize procedures as the definition of base schemes, route selection and basic technological operations, selection of accuracy conditions, etc.

Therefore, technological decision-making is often based on the experience and intuition of the developer, or on the TP-analogue for the same type of parts.

In non-automated production preparation, technological processes are developed as a set of technological documentation, in automated – the developed description of TP is placed in a computer database, and the relevant technological documentation is only a reflection in the external sphere of internal representation of TP. In this case, the TP stored in the database is a source of information for solving not only other tasks of TPP, but also a number of production management tasks.

There is no clear boundary between the end of design and the beginning of technological preparation. In the design process, the designer and technologist must work in close contact to ensure high manufacturability in the early stages of creating a new product.

With this aim, some Western firms are creating joint design and technology departments of production preparation and are introducing positions of design-technologist, and some universities have begun training such specialists.

The content, volume and system of organization of technological preparation for the production of products depend on the type of production, the degree of novelty, complexity and manufacturability of new products, as well as the level of specialization of production.

The degree of detailing of the work is determined by the serial number of products. The higher the serial number, the more detailed the technological preparation of production should be.

Simultaneously with the development of the technological process in the framework of organizational and material preparation of production, methods of its organization are developed, and also norms of expenses of materials on details, nodes and products as a whole are defined.

3.2. System principles of technological processes development

The complexity of solving technological problems is the need for systematic consideration of the simultaneous action of many factors on the initial parameters of product quality.

Therefore, technological processes must be developed, taking into account a set of principles for the construction and implementation of technical systems.

1. The principle of progressivity: the technological process should be based on the latest scientific and technical achievements that provide the greatest increase in productivity, efficient use of resources and a high level of automation.

2. The principle of dynamism: the structure of the technological process should allow its operational change when changing the object of production.

3. The principle of systematicity: TP is considered in relation to the external environment, in close connection with other solutions. The TP is seen as part of the production process, and the overall goal of the TP is consistent with the purpose of the electoral process, and all operations, transitions, and equipment are subject to this goal. All performed operations are considered not in isolation, but in interrelation, because the final characteristics of the treated surfaces or joints are formed not only on the finishing operations, but under the action of the whole set of performed actions.

The machine is not a mechanical connection of parts, but a single whole, where all the components are closely interconnected, i.e., form a system.

A machine can be described as a system of components of its design (parts d_i) and mechanical connections K_i between them:

$$M = \left(\bigcup_{i=1}^{n} d_i, \bigcup_{i=1}^{n-1} K_i \right),$$

where n – the number of parts in the product;

K_i – mechanical connection of the i-th part.

The i-th detail di is described by the set of all its geometric elements E= $\{e_i\}$ and the set of their geometric coordinating connections G= $\{g_i\}$, i.e.

$$d_i = \left(\bigcup_{j=1}^{m} e_i j, \bigcup_{j} g_i j \right),$$

where m_i – the number of elements in the i-th part.

The element of the part ei is described by the set P={Pк} of the surfaces that form this element and the geometric connections between them

$$e_j = \left(\bigcup_{k=1}^{q_j} P_{jk}, \bigcup_{k} g_{ik} \right),$$

where P_{jk} – k-th surface included in the j-th element;

g_{jk} – geometric connection of the k-th surface of the j-th element.

Then the machine can be described as follows:

$$M = \left(\bigcup_{i=1}^{n} \bigcup_{j=1}^{m_i} e_{ij} \bigcup_{i} \bigcup_{j} g_{ij}, \bigcup_{i=1}^{n-1} s_i \right).$$

The system is also the technological process of manufacturing the machine. The elements of the first level are operations, the second − institutions, etc., which are in some connection between themselves and the machine (part). On the other hand, the technological process is an element of the supersystem of the production process.

In order to obtain a quality machine, it requires consistency of these systems, which is achieved through a systems approach.

Based on the structure of the TP, its development should be carried out with mandatory parametric and structural optimization.

Optimization – a process of finding the extremum of some quantitative value of the developed object, represented as a function.

If this function characterizes the positive property of the TP or its component (operation, transition), then it is necessary to look for its maximum value, if the negative – the minimum.

The optimization process is the basis for the development of new, more efficient and less expensive technological processes and is carried out through structural or parametric optimization.

Structural optimization means to minimize the complexity of TP due to high-performance structures.

The structure of the operation consists of transitions and their structures. When forming transitions, their number, sequence and mode of execution, time rate, intermediate (technological) tolerances, or connection requirements, etc. are determined. The formation of the structure of the operation also includes the ordering and distribution of the total set of transitions into subsets, taking into account the presence of heat treatment, minimizing the number of installations of workpieces or parts, idle movements of working units of equipment.

The initial conditions for the formation of the structure of the operation are the obtained sets of transitions of processing of elementary surfaces or assembly of elementary connections and the exact parameters set by the technical conditions that must be provided in the process of processing or assembly.

Criteria for evaluating options for the structure of the operation are the artificial processing time or the cost of its execution, the values of which are reduced by reducing the number of transitions and their simultaneous execution or combination of elements of the main and auxiliary time.

Parametric optimization involves minimizing a number of characteristics of process parameters, primarily energy costs, cutting or pressing force, heating temperature, maximizing the thickness of the cut, etc.

Tasks of both structural and parametric optimization are different at different hierarchical levels of the system "technological process".

The main purpose of the technological process (TP), or its component – technological operation (TO) is to provide the specified (required) quality characteristics of the product in the most productive way at minimal cost.

Hence the two criteria for assessing the optimality of technology: maximum productivity and minimum cost.

4. The principle of the shortest path: the highest (all things being equal) accuracy is achieved with dimensional or kinematic chains with the least number of components. For example, the processing of surface modules should be performed with a minimum number of technological transitions and operations, in addition, it usually leads to increased productivity and reduced costs.

5. The principle of conformity: the sequence of performed technological transitions or operations on processing of the same surface should be such that the values of quality indicators at the input of each subsequent transition (operation) correspond (equal) to the values of the same indicators at the output of the previous transition (operation) and regulatory conditions.

Adherence to this principle allows to ensure the normal course of the process at all stages of the technological process. Thus, the task of the preliminary transition is to prepare the surfaces of the workpiece for subsequent processing.

6. The principle of clarification: each of the following operations or transitions must be more accurate than the previous ones, i.e., provide higher quality indicators of parts or their assembly.

7. Technical principle: the reliability of ensuring the quality of the machine in the production process should be ensured not by the qualification of the worker, but by the structure and content of the technological process, the perfection of the applied processing methods (assembly), equipment and facilities.

8. Economic principle: to ensure the fullest use of technical capabilities of equipment and process equipment, while minimizing the cost of living and materialized labour for a given volume of production and production conditions.

Among several possible equivalent variants of technological process of manufacturing of the same product, it is necessary to choose the most productive and most profitable variant.

With the same productivity options choose the most profitable, and with the same profitability − the most productive. At the same both indicators choose the most profitable, provided that the performance of these options is not lower than required.

It should be remembered, that lowering costs or increasing productivity on individual operations does not always lead to lower costs due to possible increases in costs on other operations. Therefore, issues of economic efficiency should be considered systematically throughout the process.

9. The principle of combining bases: technological bases should choose structural elements, from which the drawing is set direct dimensions and conditions that coordinate the position of the treated surface. At the same time the highest accuracy of the sizes and relative turns as they are received directly is reached. Violation of the principle requires the determination of technological dimensions, or special processing methods.

10. The principle of sustainability (constancy) of bases: all (or most) processing operations should be performed from the same bases.

This increases the accuracy of the relative position of the treated surfaces, as it eliminates the error of the relative position of the bases used for processing, simplifies the manufacture and operation of devices through the unification of the base and clamping elements.

11. The principle of the decisive operation: operations where probable defects due to material defects or processing difficulties must be performed at the beginning of the process.

This allows to get rid of further inappropriate processing of substandard parts. Thus, at the beginning of the process, the surfaces from which the thickest layer of material is removed should be treated, as this better shows the internal defects of the original workpiece (shells, inclusions, cracks, hairs, etc.). In addition, the internal stresses are redistributed the most and the workpiece grooves more intensely. Therefore, in the subsequent stages of processing, its shape is more stable and easier to ensure the required accuracy.

12. The principle of advantage: surface treatment is carried out according to their value. So, first of all it is necessary to process those surfaces which will serve as bases for the subsequent processing. Surfaces that are the basis for an operation must be treated in the previous operation.

13. The principle of one establishing: surfaces with the exact relative location are processed from one establishing. In this case, the error of installation of the workpiece does not affect the accuracy of the relative location of the treated surfaces.

14. The principle of differentiation of operations: the technological process consists of a large number of simple operations, each of which consists in processing surfaces with one tool sequentially on one or different machines.

Differentiation of processing allows to provide high indicators of quality, thanks to simplicity of operations, provides the big flexibility at transition to release of other products as to reconfigure the simple machines applied in this case, is much easier, than the difficult ones.

The disadvantages of processing differentiation include the increase in auxiliary time and errors due to repeated permutations of workpieces from one machine tool to another.

15. The principle of concentration of operations: technological process consists of a group of complex operations performed simultaneously by many tools on a single-, multi-position machine tool or automatic line with simultaneous processing of one or more workpieces.

Compared to differentiation, the concentration of processing (assembly) can reduce the number of units of equipment required for its placement and reduce the number of service personnel, but requires the use of more complex machine tools and the use of highly skilled workers.

TP can be built on sequential, parallel and parallel-sequential concentrations.

Sequential concentration of operations is characteristic of non-automated production and consists in alternate processing of blanks by many tools on universal equipment. This concentration has low productivity due to high idle time, manual control of the machine tool, manual installation, clamping and reinstallation of the workpiece and tool change. To increase the productivity of a sequential concentration of processing allows automation of the work cycle.

Parallel concentration of operations is carried out in one position due to the use of combined, typesetting tools (multi-cutter holders, a set of drills, countersinks, reamers, taps in the multi-spindle head; a set of cutters, grinding wheels), aggregate machine tools that allow to process a workpiece by several sets of tools simultaneously from its different sides in one position. However, the use of a large number of cutting tools in one position is not economical due to the large loss of time for their adjustment. Increasing the number of tools and complications of the machine reduce its reliability: the number of failures increases, increases the time for their elimination. In order to increase the period of stability of the cutting tool, it is necessary to significantly reduce the cutting mode.

Parallel-sequential (mixed) concentration is carried out by simultaneous processing of several surfaces of the workpiece or assembly in several consecutive positions: workpieces or assembled products change positions, and tools are installed in rotary heads or drums.

16. The principle of phasing: to achieve a given goal, TP is divided into phases (stages).

Stage – a completed part of the process in which the object of labour passes into another qualitative state. For example, the metal in the original workpiece, the original workpiece in the part, the part is included with other parts in the assembled node.

To reduce the error, processing is divided into roughing, clean off and finishing, which allows more efficient use of equipment and skills of workers.

To reduce the complexity and labour intensity of a development, TP is also divided into successive stages. At the initial stages, the preliminary outlines of the process are performed, at the subsequent stages they are specified on the basis of detailed technological calculations. The end result for all tasks is found by gradual approximations, specifying the solution of some tasks after the solution of others.

17. The principle of decomposition: to determine the content of the component of the higher level, divide (grind) the object into smaller components (elements).

To do this, first record the initial and final state of the process or object to be decomposed. Then determine the content of the finite elements.

So, for example, for assembly processes the final element is a detail, and elementary (final) technological action – connection of two details. The component (element) of the upper level is the assembly unit, i.e. some local connection of parts.

For tools (machine tools, installations, assembly machines) the finite elements of the decomposition are a certain position of the workpiece (part) in one cycle of technological action of this content. The upper level is the local technological system and its cycle.

Each of the stages of TP can also be divided into a number of operations, which in turn are a set of technological and auxiliary transitions and moves.

Thus, making decisions at each system level, the object under study is consistently detailed.

18. The principle of sequence: the execution of phases, stages, levels and other components of the design process must be performed sequentially.

The transition to solving the tasks of the next level is possible only after the complete solution of the tasks of the previous level. It is impossible to solve tasks in parallel at several levels, because the results of solving the previous stages are used in the following.

The highest level is the level of general assembly or manufacture of parts, the lowest − the level of content development and sequence of work and auxiliary moves.

19. The principle of completeness: technological solution must contain all the necessary and sufficient information for the development of design and technological measures to achieve this goal.

20. The principle of inversion: change to the reverse of any functions, methods or order of processing (assembly). This means to rearrange technological operations, elements of a structure or bases.

So, for example, taking a pre-treated hole of the hub of the pulley, treat the rim surface. Applying the inversion, one can process the outer surface of the rim, and then, based on it, to process the hole in the hub. The accuracy of the relative location of these elements (concentricity) will not change.

Installation of the sleeve in the housing with tension can be done either by heating the housing or by cooling the sleeve to a certain temperature. However, the quality of planting does not change in principle.

When developing technological equipment, constructive inversion is used, for example:

– change of roles of details: to make the leading detail entered, directing – such as directed, covered – covering, motionless – mobile and on the contrary;

– inversion of the shape, for example, make the inner cone outer, convex spherical surface – concave;

– moving structural elements from one part to another, for example, a key from the shaft to the hub, etc.

21. The principle of sequential exclusion: sequential exclusion from the set of technological solutions, those that are unacceptable for these production conditions.

22. The principle of safety: the technological process must ensure safety of labour and the environment. To do this, it is necessary to use technical means and organizational methods to ensure the safety of workers and environmental protection (environmental safety).

For this, it is necessary:

– exclude dangerous approaches and ways of mechanical processing and assembly;

– provide for the protection of moving parts of equipment and protective devices, as well as safety and signalling devices in operations with increased risk of injury, means to reduce noise and vibration;

– mechanize and automate dangerous technological and auxiliary operations;

– be guided by current regulations on safety and environmental safety;

– all organizational measures for occupational safety and personal protective equipment must be reflected in the technological documentation.

23. The principle of parallelism: simultaneous (parallel) execution of stages (operations, transitions) of TP, their combination in time.

For example, simultaneous processing of several surfaces of the workpiece (parallel execution of technological transitions, parallel node and general assembly, etc.).

The implementation of this principle significantly reduces the duration of the manufacturing cycle of products and reduces the required working capital.

If it is inexpedient to introduce full parallelism of production because of small serial number and impossibility of full loading of the equipment, it is necessary to organize at least partial parallelism.

24. The principle of proportionality: ensuring the proportional capacity of the various jobs of the main, service and auxiliary processes.

The level of proportionality is determined by the coefficient of proportionality $k_{пр}$

$$k_{пр} = \frac{ПЗ_{min}}{ПЗ_{max}},$$

where $ПЗ_{min}$, $ПЗ_{max}$ – respectively, the minimum and maximum throughput (or parameter: variability, load, power) of workstations in the technological chain.

The bandwidth of the i-th workstation $ПЗ_i$ is determined by the dependence:

$$ПЗ_i = C_{пр_i} \cdot F \cdot k_{зм},$$

where $C_{пр_i}$ – accepted quantity of equipment,

F – working time fund,

$k_{зм}$ – coefficient of variability of equipment operation.

Proportionality can be ensured through such organizational and technological measures:

– revision of the design of the part in order to ensure the proportionality of the complexity of operations;

– view processing modes;

– development and organization of equipment replacement, site redevelopment;

– reloading workstations with other similar processing.

The increase in the degree of proportionality of individual processes contributes to the continuous flow of the production process, and the decrease – to the emergence of "bottlenecks" (limiting) places of the process.

25. The principle of continuity: no interruptions in the technological process and the use of labour resources. For example, the next operation should begin immediately after the end of the previous one without any breaks (or minimize them) in time while ensuring the continuous operation of workers and equipment.

The level of continuity is determined by the coefficient

$$k_{cn} = \frac{T_{wk}}{T_c},$$

where T_{wk} – duration of working time, hours;

T_c – duration of the cycle (process), including idle or lying objects of labour between workplaces, on workplaces, etc., hours.

Increasing the level of continuity helps to reduce the production process.

This is the most important direction of production intensification that is achieved:

– at the workplace – reduction of auxiliary time (intraoperative breaks) in the course of performance of each operation;

– at the site and in the shop – by reducing the interoperation transfer of semi-finished products from one workplace to another.

Continuity of work within the operation is ensured, first of all, by the improvement of tools – the introduction of automatic readjustment, automation of auxiliary processes, the use of special equipment and devices.

Reduction of inter-operational breaks – the choice of the most rational methods of combination and coordination of partial processes in time. One of the prerequisites for reducing inter-operational breaks is the use of uninterrupted vehicles, the use in the production process of a rigidly interdependent system of machines and mechanisms, the use of rotor lines.

This is one of the main trends in the development of technical systems.

Many of these principles conflict with each other, so some compromises are needed to overcome or reduce emerging contradictions.

3.3. Methods of technological processes development

There are the following methods of TP development:

– method of analogy (method of reuse of a single TP);

– method of addressing (method of using unified (standard and group) TP;

– TP synthesis method.

The method of analogy is based on the use of ready-made solutions. The search is carried out among the TP operating at the enterprise, steps:

1. Find an analogue for this part.
2. Find a single TP for an analogue part.
3. Adjust this TP: make small changes in the structure of operations or their sequence, in the selected technological equipment, processing modes, basing schemes, tool sizes, etc.

A single process, obtained by analogy with existing processes, as a rule, is not structurally optimal, because the main use of random TP, not always the best, and the quality of the complexity of its development depends on the quality of the analogue and the quality of adjustment.

This method is used for parts that do not have a unified TP.

The method of addressing is based on the use of unified TP (UTP), which uses advanced technological equipment and advanced forms of organization.

In the first stage, the address (binding) of the part to the unified TP is performed, based on the comparison of the addressed part and the reference part for which there is a UTP. Based on this comparison, a conclusion is made about the possibility of using a unified TP.

After selecting the UTP, it is analysed and refined for the part for which it was selected. This excludes individual operations that are not required for this part and analyses the possibility of using the remaining operations.

The method of technology synthesis is used when there are no ready-made solutions to the route and content of operations. The manufacturer's task is to choose a rational version of the TP for the existing conditions according to certain criteria.

The use of standard solutions can dramatically reduce development time and cost. The developer is exempt from routine work: calculations, search for equipment models, sizes of cutting tools, etc.

In flexible automated production, each of the various blanks requires its own technological process. The choice of a specific option in specific conditions requires the availability and constant analysis of relevant information, which is achieved by automating the process of TP development based on the modular principle of formation of the TP structure (modular technology).

The method of modular technology (MT) is based on the development of technological processes in the form of a set of unified technological solutions, each of which provides the manufacture of a specific structural element of the part.

This method allows you to synthesize the technological process from a set of previously formed design and technological solutions. The method is based on preliminary grouping of parts, the presence of a library of typical machining cycles for CNC machines, unification and standardization of structural elements and presentation of the control program for CNC equipment in the form of a set of subroutines for individual tool transitions (software modules).

For each elementary surface with the help of software-technological module form a processing plan and control program for the CNC machine. These modules are combined into a set, which is used for structural synthesis of TP operations.

Modular (elementary) technology is a further development of single, standard and group technologies and has absorbed their advantages.

Modular technology allows you to formalize and reduce the time to develop technology for a particular set of parts. In combination with the method of group technology, it facilitates the receipt of alternative options for TP in the formation of variable-daily task for FPS using SADTP.

Any product is a set of elementary surfaces (ELS) inextricably linked. A structural element in the form of a single or several surfaces, by means of which a part performs a corresponding service function, is called a surface module (SM).

According to the functional feature, the surface modules are divided into three classes: basic (MBS), working (executive) (MWS) and binder (MCS) (Figure 3.1).

According to structural and geometric features of SM are divided into external and internal, flat, cylindrical, conical, etc.

Structural elements, which are technical systems of low complexity, are very diverse in shape and size.

Designing parts by layout with a surface module requires a different design of the drawing, which must indicate the SM, the code of each surface module according to their classification, the dimensional relationships of the SM, which determine their size and position.

This simplifies the information needed to develop technological processes for manufacturing parts and assembling products. The drawing of the part in this case can be represented as an assembly unit, in which the parts are SM with dimensional connections that determine their position (Figure 3.2).

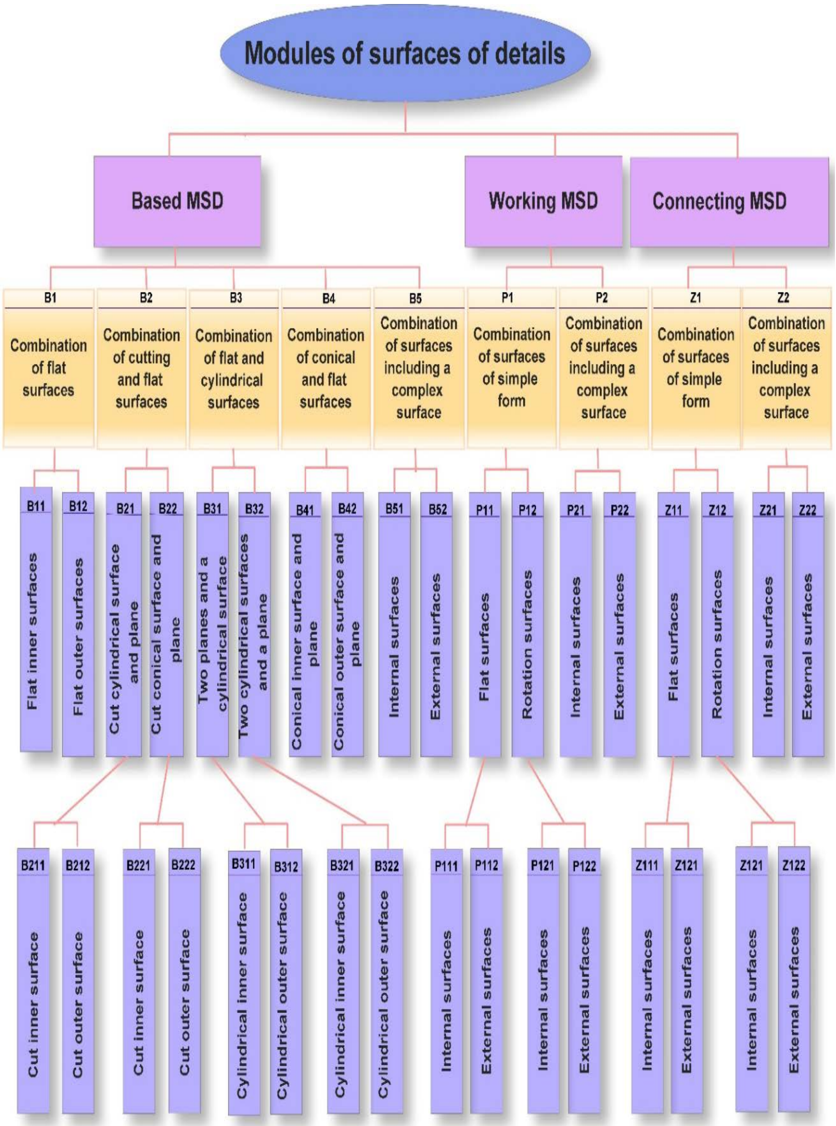


Figure 3.1 – Modules of surfaces on a functional basis

In order to be able to use CAD / CAM systems, a 3D representation of the part is required.

On the basis of system decomposition an elemental base of technological support for the manufacture of MP at the modular level is created – technological process modules, equipment, tooling, machine tools and control and measuring devices, etc., through which modular technological support is built. This opens the way to the systematic application of the modular principle in the construction of machine-building production.

Element (modular) TP is a process built from typical elementary technological actions (transitions) (TED) of surface module (SM) processing or implementation of elementary connections (EC). This allows the development and use of standard elementary actions (TEA). To implement such actions, it requires modules of technological equipment (PEM), elementary tool settings (ETL), installation and clamping elements (ICE) of devices, elementary measuring instruments (EMI) (Figure 3.3).

According to the modular principle of construction of the operation, the part is considered as a certain system of elementary surfaces – surface modules,

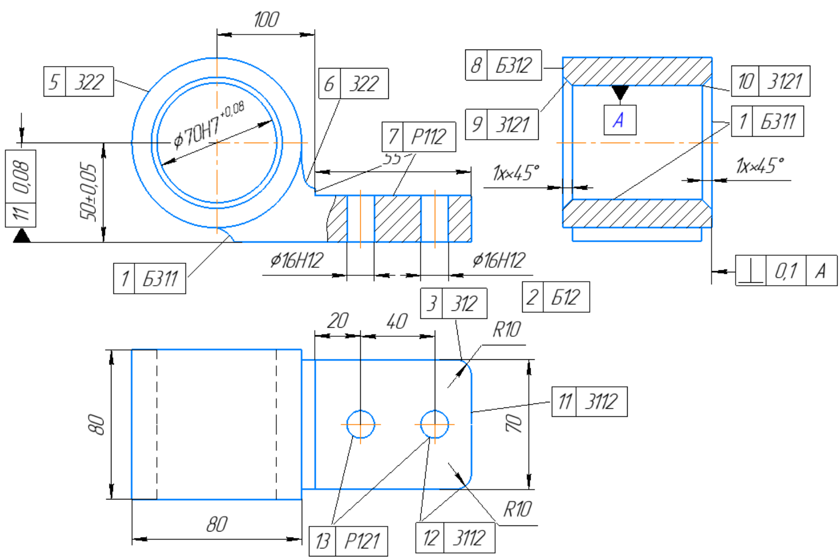


Figure 3.2 – Drawing details as an assembly unit of surface modules

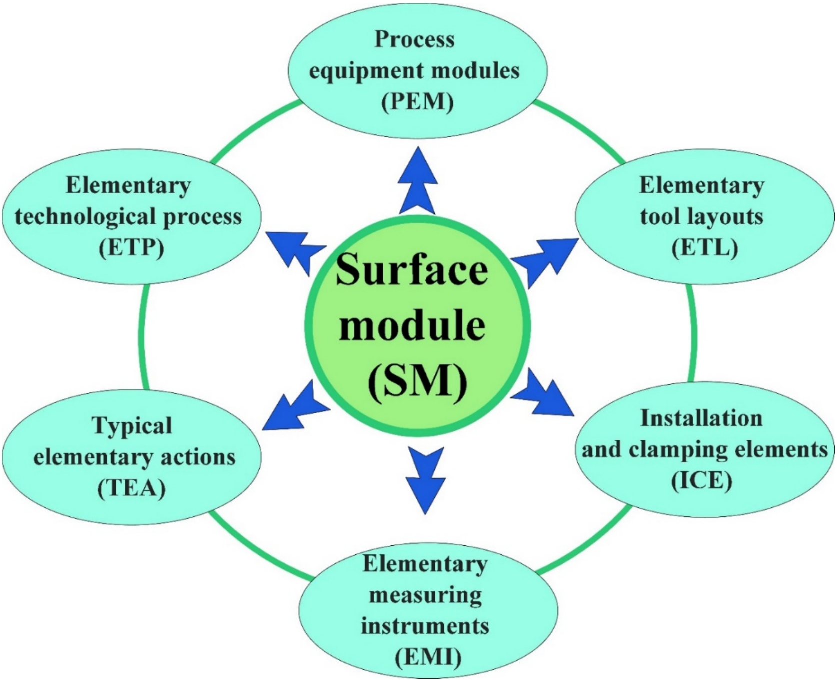


Figure 3.3 – The scheme of the element base of manufacturing SM

processed according to typical technological schemes using standard cycles (technological schemes). Technological scheme – a set of sequentially performed moves, necessary to ensure the required accuracy and quality of the surface.

Each operation is a set of technological schemes (elementary TP) of drilling, turning and other transitions (Table 3.1).

The structure of the operation is usually formed according to this scheme:

– for each elementary surface (module of surfaces) details define the technological scheme of processing;

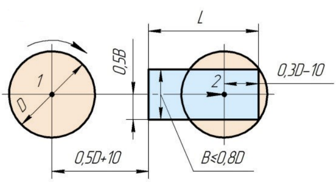
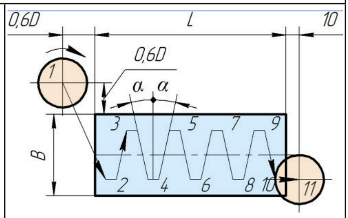
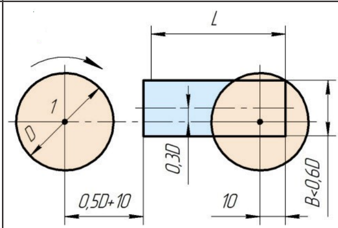
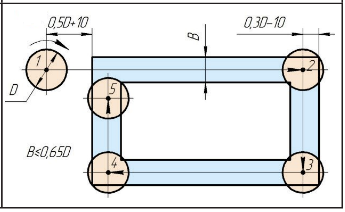
– for each of the processing transitions provided by the technological scheme, the cut and auxiliary tool is chosen;

– from the resulting set of tools remove identical, repetitive, combine tools of the same purpose, and replace tools of similar size, if possible, by one, combining technological transitions performed by the same tool;

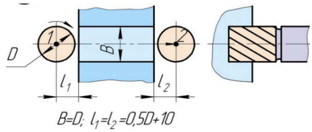
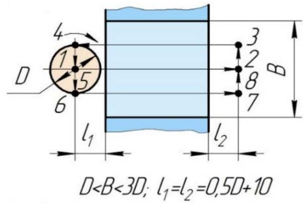
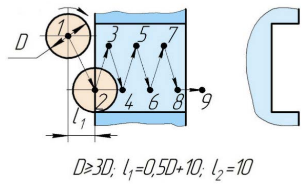
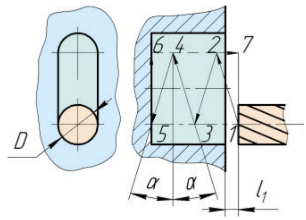
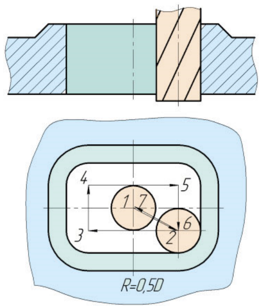
– determine the sequence of technological transitions of this operation, based on ensuring the required accuracy and reducing the auxiliary time to replace the tool and perform auxiliary moves;

– establish acceptable options for processing the elementary surfaces of the workpiece.

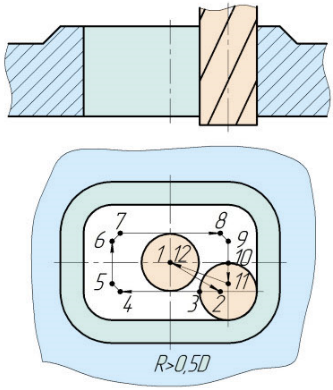
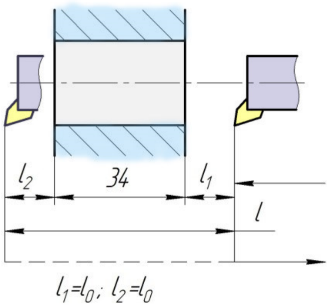
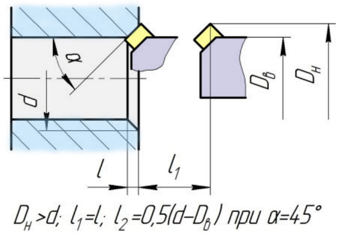
Table 3.1 – Technological structures of mechanical processing

Surface module	Element type	Size	Scheme of elementary technological action
Milling ETP			
Flat outer surfaces	Open plane D – diameter of a mill	B<0,8D	
Milling ETP			
Flat outer surfaces	Contour open plane	0,8D<B<1,6D	
		B<<0,6D	
		B≤0,65D	

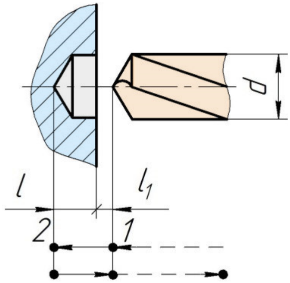
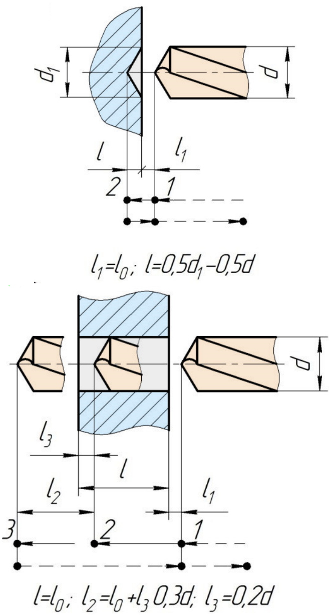
(Continuation of Table 3.1)

Surface module	Element type	Size	Scheme of elementary technological action
Flat inner surfaces	Groove	B=D	
		D<B<3D	
		B>3D	
	Well	B=D	
Flat inner surfaces	Window	R=0,5D	

(Continuation of Table 3.1)

Surface module	**Element type**	**Size**	**Scheme of elementary technological action**
Flat inner surfaces	Window	R>0,5D	
Boring ETP			
Cylindrical inner surfaces	Hole	D	
Conical inner surfaces	Chamfer	lxα	

(End of Table 3.1)

Surface module	Element type	Size	Scheme of elementary technological action
Drilling ETP			
Cylindrical inner surfaces	Deaf hole	l<d	
Cylindrical inner surfaces	Through hole	l>d	

The choice of module processing method depends on:
– processing performance;
– workpiece material;
– rigidity of the machine;

– the possibility of chip removal;
– the complexity of the programming process;
– the magnitude of the departure of the tool;
– possibilities of processing on old multi-spindle machines;
– the number of tools used;
– flexibility of the processing method (for example, processing of different nomenclature of holes);
– no need for lubricating coolant, etc.

Elementary (modular) TP (ETP) of processing of surface modules are classified and coded according to the SM code (Table 3.2).

Table 3.2 – The structure of the ETP of processing SM

SM Code	Elements codes				
	A	**B**	**H**	**M**	**K**
Transition number	**The name of transition**	**Type of transition and its accuracy**	**Type of cutting tool and its dimensional characteristics**	**A fragment of the control program for the machine tool**	**Typical route stage**
1	AB1		H1	M1	K1
2	AB2		H2	M2	K2
…	…		…	…	…
n-1	ABn-1		Hn-1	Mn-1	Kn-1
N	ABn			Mn	Kn

To create modules of technological equipment (MTO) it is necessary to know the technological capabilities of machines for the manufacture of SM and for each model of the machine to establish a list of SM that can be made on it. For this:
– the kinematics of the machine determines the list of elementary surfaces that can be made on it;
– the designs of the SM formed from these surfaces are defined;
– the position of each SM in the working zone of the machine on which it is possible to process it is defined;
– for each design of SM the ranges of the sizes, accuracy and roughness achievable on the given machine are defined;
– the resulting set of SM is encoded accordingly.

Similarly, on the basis of system decomposition by the finite element method, databases from other components of technological equipment and typical elementary connections are created.

Various modules of the unified auxiliary and cutting tools necessary for full realization of technological possibilities of multipurpose machines on processing of various SM are developed.

Creation and application of the modular tool meeting requirements of operation of multipurpose machines is connected with overcoming of essential contradiction between quantity of its component elements and maintenance of necessary accuracy and rigidity of a design as errors from deformation of the auxiliary tool make 60% and more of an production error.

Therefore, the layout of the auxiliary tool in the development of the operation and the prepared equipment must be accompanied by the establishment of a rational ratio of the dimensions of its layout, providing the required accuracy and rigidity.

Based on the results of the structural synthesis of the components of the set of technological bases, a technical task for the development (selection) of technological equipment is developed.

A feature of the technological preparation of production on a modular basis is the replacement of special devices with universal prefabricated technological equipment, which is accompanied by a set of interchangeable installation and clamping parts and assemblies (modules) for specific operations.

Upon completion of use, the device is disassembled, and the components are repeatedly used in new configurations and combinations.

Details and assembly units of the set on a functional basis are divided into groups: basic, body, installation, guides, clamping, fastening, pneumohydraulic drives, locking elements and fittings, auxiliary. The unity of the design of the components of such universal prefabricated devices (UPD) is ensured by their functional interchangeability of each dimensional group.

Connection and fixing of elements are carried out by fingers, bolts, pins and nuts.

In the presence of databases of elements of a product and technological equipment, TP of manufacturing of a detail is constructed as follows (Figure 3.4):

– SM details are defined;

– the sequence of formation of all SM is determined;

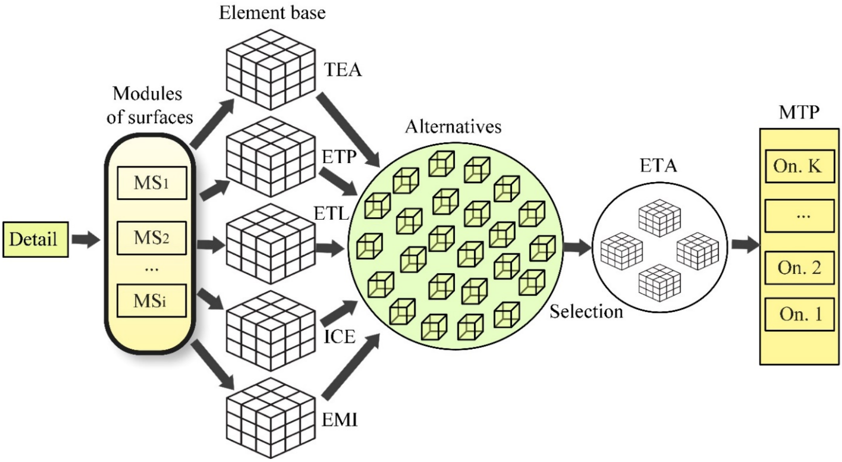


Figure 3.4 – Scheme of development of modular TP

– modules (elements) of technological equipment (TEM) for realization of elementary technological actions (ETA) are called from the corresponding databases;

– TEM are unified to reduce diversity;

– ETA are combined into operations.

The route of the modular process of manufacturing the part is built so that the manufacture of all surfaces of each of the surface modules was carried out in one operation and preferably for one institution. This guarantees high accuracy of the relative position of its surfaces and avoids the accumulation of errors in the relative position of the surfaces of the modules in comparison with their processing in various operations.

The organization of machine-building production on the principles of modular technology allows:

– by an order of magnitude and more to reduce the time and complexity of technological preparation of production through the layout of TP of typical elements;

– reduce the cost of technological equipment by reducing its diversity and the possibility of recompositing for the transition to the manufacture of other products to raise the level of repeatability of equipment;

– reduce the number of overlays, settings and their complexity in the transition to the manufacture of new products;

– to increase the productivity of technological processes of manufacturing products in terms of multi-item small-scale production through a combination of transitions, the use of advanced methods of assembly and processing of workpieces, typical for large-scale production, reducing the cost of preparatory and final time;

– for the manufacture of products in large series to quickly move to the production of new products by creating new technological means of the layout of existing modules;

– to improve the quality of manufacturing products by building their technological processes from the tested modules;

– raise the level of quality of design solutions for the reduction of labour skills, etc.

Since the technological process is part (subsystem) of another system (supersystem) − the production process, to obtain a higher quality product requires consistency of system components. This consistency is ensured by technological processes developed on the basis of a systems approach.

Implementation of the system approach in the application of the modular principle is its use during the production chain: product − technological process − technological system − workplace, when each section is built from the appropriate modules.

However, this requires the creation of clear and unambiguous relationships between SM and technological processes, the creation of a classification of TP for processing SM, as well as a classification of technological equipment, which is associated with a variety of difficulties.

3.4. Analysis of the object of production

The main tasks that need to be solved by the technological process are formulated on the basis of careful study and analysis of the object of production.

For this purpose, are consistently considered:

– non-purpose functions of the machine (assembly unit);

– part as an element of the assembly unit and the machine;

– functional purpose of the part and its structural elements;

– dimensional connections between the main elements or surfaces of the part (executive surfaces, main and auxiliary bases);

– material of the part and its properties;

– requirements for reliability and durability of the machine and parts as its component;

– mode and conditions of operation of limiting surfaces or elements of a detail;

– durability of limiting surfaces or elements of a detail and the mechanism of their destruction at operation.

The performance of the machine depends not only on its design, but to a greater extent on the technology of manufacturing parts and assembling them into a product. Therefore, a clear definition of the purpose of the machine, the specification of its functions, as well as identifying the scope and operating conditions, the causes of incapacity is necessary for the sound development of manufacturing processes of all its parts.

After clarifying the purpose of the machine analyze the part for its role in the machine and its functions. It is necessary to determine the functional role of each element and the surface of the part.

To executive surfaces, usually put forward the greatest requirements, and they follow from functional purpose and working conditions of the car, assembly unit, details.

The location of the coordinate axes of the part, usually coincides with the main bases, because only they determine the position of this part in the machine. The positions of all other surfaces (auxiliary bases, executive and free surfaces) should be structurally oriented relative to the main bases.

The free surfaces do not perform the working functions provided by the function of the part, and do not come into contact with the surfaces of other parts of the machine. Therefore, they are usually not processed or processed inaccurately.

Analyzing the functions of non-purpose surfaces of parts build diagrams of dimensional chains, which characterize the relationship of design (main and auxiliary) bases between themselves and the executive surfaces. This will allow in the future a more reasonable approach to the choice of technological bases and the establishment of the sequence of surface treatment of parts.

3.5. Assessment of the level of a technological process

The quality of technological preparation of production is provided by a set of special measures, which are carried out at all stages of TPP to ensure the requirements for the quality of products drawn up in the design documentation.

Usually, these include:

– selection of equipment capable of ensuring the manufacture of parts of appropriate accuracy in size, shape and surface quality;

– selection of devices capable of ensuring the manufacture of parts of appropriate accuracy in size, shape and quality of surfaces without excessive deformation of the workpieces during processing;

– selection of technological processes and equipment for assembly, which include damage to the components of the product and ensure the quality of assembly.

Technology assessment helps the company to better understand its essence, identify sources of competitive advantage and assess its competitive status.

There are the following types of technologies:

– The latest technology – any new technology that has high potential;

– Advanced technology – still quite new, but is not widespread in the market;

– Modern technology – a recognized technology with high demand;

– Not a new technology – a useful technology for which demand is beginning to fall;

– Outdated technology – low demand or complete rejection in favour of the new.

The quality of TP is determined by its level established by certification.

Certification is performed in two stages: first the level is assessed, and then the actual certification. Based on this, a database of technological processes of the enterprise is formed.

At the stage of assessing the level of technological processes the following is performed:

– compiling a list of technological processes;

– compiling a list of advanced technological equipment;

– compiling a list of advanced technological methods;

– establishment of normative values of evaluation indicators;

– calculation of the TP level;

– development of an action plan to increase the level of TP.

Certification of technological processes is performed to objectively assess the degree of compliance of their main parameters with the best world and domestic achievements and to obtain information for the development of a plan of organizational and technical measures to ensure stable production of products of the highest quality category.

The level of the technological process is determined by the formula:

$$P_{TP_i} = \sum_{i=1}^{n} K_i \frac{\Pi_i}{\Pi_i^n},$$

where K_i – weighting factor of the indicator ($\sum K_i = 1$);

Π_i, Π_i^n – respectively, the indicator and the normative value of the i-th indicator, which characterizes one of the properties of the TP;

i – serial number of the indicator;

n – number of indicators.

The level of TP is characterized by the following properties (indicators):

– labour productivity ($П_{ПП}$);

– progressiveness of technological equipment ($П_{ПС}$);

– degree of mechanization and automation ($П_{МА}$);

– efficiency of materials use ($П_{ВМ}$) etc.

Labour productivity indicator $П_{ПП}$:

$$П_{ПП} = О_{ПР}/Ч_{ВП},$$

where $О_{ПР}$ – volume of output for the year, thousand UAH;

$Ч_{ВП}$ – number of production staff, persons.

Indicator of productivity of technological equipment $П_{ПС}$:

$$П_{ПС} = ТР_С/Т,$$

where $ТР_С$ – labour intensity of manufacturing the product on advanced technological equipment, norm-hour;

Т – total labour intensity of product manufacturing, norm-hour;

Indicator of mechanization (automation) of TP:

$$П_{МА} = Т_{МА}/Т_{заг},$$

where $Т_{МА}$ – time of installation of mechanized (automated) operations (transitions), min;

$Т_{заг}$ – total labour intensity of operations (transitions).

Indicator of use of materials $П_{ВМ}$:

$$П_{ВМ} = М/Н,$$

where M – product weight, kg;

H – material standard for the product, kg;

The coefficients of weight of the indicators are taken as follows:

$$К_{П_{пп}} = К_{П_{пс}} = 0,3;\ К_{П_{МА}} = К_{П_{ВМ}} = 0,2.$$

Evaluation of the developed technological process of assembly can be carried out on the following indicators:

– the load factor of the assembly workplace;

– productivity of the assembly workplace (hourly, replacement);

– the average load factor of the assembly line;

– the complexity of the assembly process;

– total complexity of technological processes;

– the cost of the technological process of assembly compared to alternative.

The level of technological perfection of assembly is usually estimated by the coefficient of complexity of the assembly process $К_{ск}$:

$$К_{ск} = \frac{Т_{ск}}{Т_{мех}}$$

where $Т_{ск}$ – complexity of assembly work;

$Т_{мех}$ – complexity of machining.

The smaller the value of $К_{ск}$, the better the machining of workpieces and higher technological culture of assembly work.

Normative values of indicators, as a rule, are established by directive branch organizations depending on type of manufacture, specific features of branch, on the basis of the analysis of world and domestic technological achievements, data of the related enterprises, studying of the forecast of development of technological processes of production of similar products.

The level of TP set used in the manufacture of the product (assembly unit on the site, in the shop or in the enterprise as a whole is calculated by the formula:

$$P_{TP}^{\Sigma} = \sum_{i=1}^{m} a_i P_{TP_i}$$

where P_{TP_i} – level of the i-th TP;

a_i – weighting factor of the i-th TP ($\sum_{i=1}^{m} a_i = 1$);

i – sequence number of the TP;

m – the total number of technological processes.

The coefficient a_i is calculated as the share of labour intensity of the i-th TP in the total labour intensity of product manufacturing (assembly unit) or in the total labour intensity of manufacturing at the enterprise (shop, site).

The assessment of the quality of TP and competitive positions of the enterprise carried out during the inventory is supplemented by the identification of strengths and weaknesses of the enterprise in relation to competitors and ends with the development of measures to improve the situation.

For development of measures the analysis of the factors influencing quantitative characteristics of this or that indicator of level of TP is carried out, establish and define perspective directions of their improvement.

Based on the TP level map, the TP category is determined.

The highest category ($1{,}0 \geq P_{TP} \geq 0{,}92$) includes TP, which in their indicators correspond to the best world and domestic achievements or exceed them.

The first category ($0{,}92 > P_{TP} \geq 0{,}70$) includes TP, the indicators of which are at the level of modern production requirements.

The second category ($0{,}70 > P_{TP}$) includes TP, the indicators of which do not meet modern production requirements, significantly inferior to the achieved level of technology.

If the level of technological processes of product manufacturing corresponds to the highest or the first categories − the product can be submitted for quality certification. Product certification is not performed if the level of its production corresponds to the second category.

The frequency of TP certification is determined by many factors and is set according to the competitive situation but at least once every five years.