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Improvement of Constructive-Technological Approaches Reducing Innovative Obsolescence of Industrial Technologies in the Context of Industry 4.0

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***Abstract*. The article is dedicated to the improvement of constructive-technological approaches in the design and manufacture of engineering products, innovations, their management and implementation in enterprises, innovation strategy and policies for its achievement, as well as methods for alternative solutions against the rapid obsolescence of innovations in the field of technology in the conditions of the Fourth Industrial Revolution (FIR) and globalization. Emphasis is on the stages in the design of the technological process for mechanical processing of engineering products, as well as the optimization of dimensional-accuracy connections. Schemes describing the optimization have been developed, and the approach will be programmatically implemented in subsequent development.**

Keywords: Constructive-technological approaches, Industry 4.0, Innovative obsolescence, Technological process.

I. Introduction

The development of a new product is a complex task for the solution of which it is necessary both to reach the necessary technical level of the finished product and to reduce as much as possible the costs of materials and the time for development, production, maintenance, repair. This is possible by creating a new technology for construction and dimensioning at the stage of development of the structures of the products. A primary role in ensuring the technological feasibility of the product structures belongs to the designer. He is the one who provides the necessary quality indicators of the constructed product and constructive properties that predetermine the level of resource costs in the creation, production, maintenance, and repair of the product. The set of all these properties of the product determine its technology [9].

Achieving the necessary manufacturability of the structure is a complex problem that has long been the subject of attention of many scientists and practitioners.

The general rules for analyzing the manufacturability of the construction of the products, as well as rules for ensuring this manufacturability, are considered in several standards [8].

However, currently there are great difficulties in the technological control of the construction documentation,

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i.e. specific practical requirements for the technologist for its implementation have not been developed. First of all, this is related to the fact that at the stage of development of the construction documentation, the functional requirements for the pro-duct are mainly fulfilled: the dimensional chains are determined and fixed, based on the purpose of the product and its necessary performance, and at the stage of technological analysis, they are also determined the relationship between all dimensional parameters in the production process of the product is fixed.

The functional connections in the product are primary in terms of technological and metrology. This means that the dimensions included in the dimensional chains when performing a functional analysis are mandatory for the remaining dimensional relationships.

In many cases, individual dimensions such as functional dimensional relationships are applied to drawings in such a way that they become technologically difficult or impossible to implement. Unfortunately, this often happens only at the technological design stage. Therefore, the main task of the techno-logical control of the construction documentation is the determination of such dimensions. It should be borne in mind that the technological control does not appear only in the recalculation of the dimensional chains.

The inspection of a new development is a complex study of the new construction by specialists from all divisions of the production system. This accelerates the finishing works of all elements of the structure from the point of view of purpose, reliability, cost and appearance [3].

The final check of the product's manufacturability is done at the completion of the design work, testing and analysis of the test samples of the product. This is the last opportunity to change the construction without seriously interfering with the master plan. The costs of the project at this stage are much smaller than the changes introduced later - during the pro-duction or operation of the product.

The work on the compilation and analysis of the dimensional chains must be done until the work on the construction documentation is completed. The designer must consider the influence of the functional dimensional chains and the related technologies, and the specialist must implement the technological control [2].

There are often cases when the constructor, based on the remarks of the technologist, must not only refine, but also redo the construction. As a rule, the technologist's attempt to make changes to the structure is met with objections from the designer. They are justified by the fact that the reconstruction of individual details leads to limitations in already developed mechanisms, and the subject of the given product is already finished. But in the practice of enterprises, there are often cases when the requirements of the technologist, made to the manufacturability of the detail at the stage of techno-logical control of the design documentation, are not initially accepted by the designer, which must be corrected in the drawings after the product has already been released into production. Therefore, the construction can be considered complete only after careful consideration and agreement with the technologist.

The product, first, is an object of exploitation and is evaluated by users mainly according to the relevant purpose. But before it becomes an object of exploitation, the product is considered as an object of production, which is subject to completely different requirements, called in general - processability. Therefore, the designer must proceed to the final design of the drawing after making sure not only of the operational qualities of the product, but also of its technology, i.e. in its possibilities for production in the specific production conditions [4].

The task of the specialist carrying out technological control is to demand timely help from the designer to improve the technology of the product. He is obliged, together with the designer, to deal with the construction and determination of the dimensional chains. For each structure, several functionally equivalent dimensional chains can be formed in the development process. From these, the designer must select that dimension chain for which the constituent units of the dimension chain have the largest deviations. It is expedient to solve such a task by means of optimization methods, where it is best to take the value of the product during production as optimality criteria. If in technological design it is necessary to change the dimensional chain, this task can be solved by converting the required dimensions by applying the theory of dimensional chains [7]. Considering the complexity of finding the optimal functional relationship and the search for a compromise solution in practical development, it is expedient to solve such a task using modern computer technologies.

No matter how experienced the technologist is, he cannot always determine the most expedient techno-logical solution. Therefore, the collective discussion is the most essential and principled moment of the technology. This requires the selection of the optimal design option to be carried out during the development of the TA, especially in its initial stage [4].

An important moment in the construction of the products is the choice of the construction bases. The design bases, determining the mutual arrangement of the details of the product, must relate to the technological bases. The production of products with the smallest error occurs only in this case, when the dimensions set by the designer, determined by the design bases, coincide with the technological ones. Thus, there is no need to introduce intermediate dimensions, which always reduce the accuracy of the closing units. Therefore, when constructing new products, we must strive to eliminate the design and assembly bases with the technological ones, which is feasible with the corresponding configuration and dimensional relationships in the constructed product. Therefore, the designer, when choosing construction bases, is obliged to match them with the technological bases, and to analyze their features and their influence on the accuracy of the dimensions of the finished products.

In practice, this means that already during the development of the construction of the part, the designer is obliged to mentally outline the technology to produce the designed part, to foresee the establishment of the calculated dimensions directly from the main technological bases [6].

The analysis of the existing systems for manufacturability to date is carried out in accordance with the existing standards.

The processing of manufacturability takes place in accordance with the Unified Standard for Design Documentation (USDD) "General rules for ensuring the manufacturability of the design of the products" and the Bulgarian State Standard (BSS) "Technological control of the design documentation".

Working out the feasibility of certain details of a product must be done by a technologist with sufficient experience and practice through a general analysis of the drawings presented by the designer.

This analysis is accompanied by certain difficulties caused by the following:

- For the technologist's analysis, no information about the features of the new product is presented. On what equipment will a certain part be produced - existing or new? What methods of reducing the labor intensity (for example by 20%) compared to a previous product (if it is a question of improving a product) does not appear to her. There are no promising technologies, there is no collective discussion of these issues.

- The analysis begins with an assembly drawing, in which the technologist meets with the designer, and the preparation of the product is studied. The drawings of the parts are distributed by groups by type of blanks. For details where at a given stage the method of obtaining the workpiece is unknown, the workpiece is mentally represented by similitude.

The analysis of dimensioning of the detail drawings is not done, that is, this question does not arise due to the insufficient experience of the technologist. The collective discussion of any questions on the analysis of the construction of the details and the technology of their processing is not done.

Often the designer is not given to realize his idea, i.e. the available equipment cannot provide the required accuracy of the manufactured part. The method of obtaining the blank of the part and the planned labor intensity are determined by analogy with previously produced products.

At the stage of scientific and research work, the product is technologically analyzed by an experienced technologist, designers of devices and calibers, but this activity is superficial. Serious processing begins only at the stage of technology development when the order is signed according to the relevant order.

In the casting department, the drawings of the details are analyzed to determine the possibilities of obtaining the castings, the thickness of the wall and the possibilities of filling the casting with metal are analyzed, and the issue of the placement of the pouring system is resolved. The analysis of the dimensioning of the part is done only by eye on the dimensions of the workpiece. Guidelines for the analysis of materials in the sizing of details are not made.

The analysis of the existing system for processing manufacturability shows that many specialists in the enterprise - designers, technologists are distracted from the main work for various changes and corrections, and are engaged in secondary work, for example, forming remarks.

For the assessment of the level of quality in preparation for production and the corresponding design and technological documentation of the production technology, a statistical analysis of the observations as quantitative and cause-and-effect structure in several productions is made, and it starts from the moment of mastering the new product.

A sufficiently large number of remarks on the considered products are technological and prevail over all other remarks accepted by the standard for enterprises. In reality, they are the most numerous, i.e. remarks on reduction of material intensity, processing of the technological process, expanded production capabilities, improvement of control and collection, alignment with current pro-duction, reduction of labour intensity, etc., referred in a number of cases to "miscellaneous", can be attributed to "technological".

Thus, when analyzing the existing systems for mechanical processing from the point of view of the technological nature of the product, during the design in the enterprise, they show that the study of the construction documentation, the sequence of the processing, are methodologically poorly developed. At the stage of scientific and research work (R&D) the processing of surfaces in relation to manufacturability. The main burden in mechanical processing is the technological preparation, which takes up a limited amount of time, during which the technologists manage to develop and shape only one techno-logical option. This leads to a decrease in the quality of technological solutions, and the entire burden of the final processing of the technological processes is placed on the last stage - the assimilation of the product in the workshop when the technological equipment is also prepared. Any change in the construction-technological documentation at a given stage leads to additional costs associated with corresponding correction, and in many cases also with the design of new technological equipment and their preparation in emergency cases, which is extremely undesirable and affects the time for assimilation of the product.

The purpose of this article is to improve the constructive-technological approaches, leading to the reduction of the innovation obsolescence of industrial technologies, by redesigning the technological process for mechanical processing based on the optimization of dimensional-accuracy relationships. To develop logical

schemes, which at the next stage will be further developed into software.

II. MATERIALS AND METHODS

2.1. Design and dimensional analysis of technological processes, approaches, and methods

Determining the required number of operations and their implementation in the development of a new technological process (TP) - is solved with the help of the use of complex interrelated tasks, the solution of which is possible only with the use of highly experienced scientific workers.

The following factors influence the structure of the TP for the processing of machine-building products:

- The design of the products and the technical conditions for their production.
- The method of obtaining and the technological characteristics of the starting blanks - (overall dimensions, wall thickness, material and hardness, etc.).
- Organizational-production factors (period of assimilation and implementation, etc.).
- Factors related to the work of the workshops (thermal, galvanic, assembly, etc.).

When choosing the structure of the TP, it is necessary to ensure minimum costs for means and materials and for transportation, as well as to consider various possibilities for automation and concentration of processing, ensuring synchronicity of operations.

Studying the type and volume of the works performed during the design of a new TP allows to distinguish seven main stages, differing in content and execution methods, fig. 1:

- Study of the drawings of the details and preparation of the source data in the design of the TP.
- Preliminary design of a schematic diagram and options for processing.
- Size analysis of the planned options and their specification.
- Assessment of TP variants according to criteria and selection of the optimal variant.
- Forming the final selected version of the TP.
- Implementation of the most economically expedient technological process.

Of the listed stages, the fourth one is the most complex - the dimensional analysis, where the dimensional calculations are performed, expressing technologically the technical conditions of the manufactured parts, to ensure their prescribed quality during production.

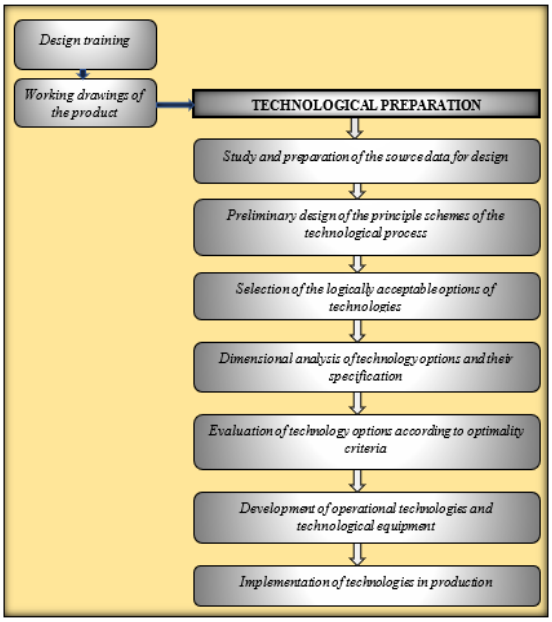

Fig. 1. Stages in the design of a technological process.

The implementation of the fourth stage is started after the three previous stages have been developed, when the logical evaluation of the principle schemes of the several processing options has also been developed.

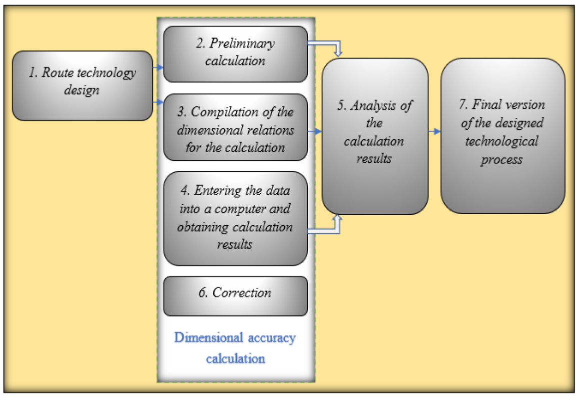

Fig. 2. Stages in the design of a technological process for mechanical processing of engineering products.

Now, the dimensional analysis of the TP is carried out on the basis of existing theories, in which the calculation of the operational tolerances is done by their "overlay" on the size of the finished part. The calculation of operational sizes according to the existing methodology does not allow to cover the entire complex of existing size chains. That is why, at the design stage, it is not possible to ensure all the requirements made to TP to ensure the qualities of the manufactured engineering products. Changing the operating dimensions in many cases requires designing and manufacturing machine-building pro-ducts with additional technological equipment [5].

At the stage of creating a technological route and dimension-accuracy calculation of the dimensional chains when acquiring a new product in one of the technological departments of a given plant, details of low complexity, mainly rotary details, were selected for the design of a new TP. A group of leading technologists and researchers from TU-Sofia, Plovdiv branch was created to develop a technological route and further control the dimensions of the part.

2.2. Design of the technological routes

The design of the technological routes for the mechanical processing of details and the technological calculations of the dimensional chains are carried out by technologists according to existing methods. The following stages can be distinguished, through which the time for their implementation can be determined:

1. Designing a technological route and performing the necessary calculations of the dimensional chains.

2. Carrying out a dimensional analysis according to the technology of the route.

2.1. Studying the technological process.

2.2. Construction and control of dimensional chains.

2.3. Carrying out dimensional calculations.

3. Duration of the performed works.

4. Analysis and comparison of the loss of time for the design of the technological process according to the methodology existing in the enterprise and with subsequent control of the methods for dimensional analysis.

2.3. Design of the technological process

The design of the TP based on the constructed dimensional schemes and optimization of the dimensional-accuracy relationships allows specifying the final version of the TP and solving the following main tasks:

- Calculation of the dimensions of the blanks with the minimum necessary tolerances, which ensures a reduction of the cost of material.
- Design of TP with a minimum number of operations and transitions, which reduces labour intensity in the production of the product.
- Creation of a new process, during the implementation of which minimal corrections are required during its assimilation.
- Design of TP, stably guaranteeing high quality and economy in production without techno-logical waste.

Solving all tasks without building technological dimensional chains, their analysis and performing the necessary dimensional calculations is practically impossible.

The dimensional analysis of TP is based on a few general rules and propositions of dimensional chain theory [1, 5].

The dimensional analysis of TP has three varieties, which differ in the way of composing and solving the dimensional chains:

- Analysis of the new TP, when only drawings of the details are presented as source documents.
- Analysis of the new TP, when there are not only drawings of the details, but also a known way of obtaining or a drawing of the starting workpiece (mixed task).
- Analysis of the current TP (verification task), when any TP does not provide the necessary indicators in terms of quality, material consumption or other elements. Dimensional analysis establishes the relationship of the dimensional parameters of the various operations, followed by a decision on the dimensional chains and determines the tolerance sizes provided for the operations and determines the possible ways to improve the process.

Carrying out the overall analysis of the dimensional chains is accompanied by the implementation of a series of activities:

- The determination of the basic tolerances of all operating dimensions.
- The determination of the necessary and enough technical requirements of the operations.
- Determination of minimum tolerances.
- The design of the operating schemes of the technological process.
- Detection and fixing of the interrelationship of all parameters of the dimensions along the length of the shape-changing workpiece.
- Revealing the dimensional chain.
- Check calculation of the possibilities to ensure the dimensions of the drawing and the technical requirements.
- Checking and ensuring the optimal methods for determining the sizes of the operations.
- Determining the nominal values of the dimensions of the operations by solving the dimensional chain (manually or by computer).
- Calculation of average and maximum tolerances.
- Determination of the thickness of the layers of wear-resistant coatings (cementation, nitriding, chroming, and other types of saturation) and decorative coatings on surfaces and other tasks.

The complexity of performing all these works is related to the analysis of the dimensions of the TP and optimization of the size-accuracy relationships [10].

The dimensional analysis, the optimization of dimensional-accuracy relationships and the selection of the optimal variant of a technological process, ensuring the prescribed quality and economy of the processed parts, require a large volume of calculations [12].

When creating a design variant of the route and operational technology, all operational dimensions and their tolerances are determined, the accuracy of implementation of all design dimensions is checked. The maximum allowances for machining are also determined. After analyzing the operational pro-cessing technology and the accuracy of the structural dimensions, the search for ways to increase the accuracy in processing is resorted to [11].

This search can be fulfilled by the application of relevant design methods directed in the following directions:

- Increasing the stability of the technological system. This can be done at the expense of the stability of the machine (choice of another machine), the workpiece (change of the pro-cessing method), the tool (replacement of the tool or change of its attachment) [14].
- Reduction of cutting forces at the expense of changing the size of the feed.
- Reducing the error from static tuning, etc..
- Use of more accurate processing methods.
- Increasing the accuracy of the dimensions of the blanks (changing the methods of obtaining them).
- Reducing the error from establishing the blanks, respectively the error during processing.

After introducing the relevant changes in the processing conditions, it is necessary to specify the tolerances and allowances for mechanical processing and the nominal operating dimensions [15].

At this stage, the main issue is resolved - the technological provision of the technical conditions to produce the part. The following condition must be met:

$$\sum n_i \to 3 \qquad (1)$$

the sum of operations and transitions of each TP must be minimal:

$$\sum m_i \to 3 \qquad (2)$$

the sum of the number of units in the size chain of the missing size - the increment can possibly be equal to 3 (the size of the previous operation, the size of the current operation, an increment between them). The optimal TP will consist of such elementary technological blocks, where the design, technological and measurement bases will coincide:

$$\sum z_i \to min \qquad (3)$$

the amount of operating allowances should be minimal.

$$[\delta_A] \geq \sum \delta_i \qquad (4)$$

The sum of the tolerances of the operating dimensions making up the units of the dimensional chain of the missing structural dimension must not exceed the tolerance of this dimension. In solving the above question, the task "Analysis of calculation results" is used [4, 13].

Therefore, at this stage, the issues of technological assurance are decided (this term is introduced in the practice of design of TP and in the process of processability together with others such as, for example, processability, accuracy, economy, etc.), i.e. a check is introduced to ensure the technical conditions for the production of details according to proposed techno-logical routes and to optimize the dimensional relationships of the drawings of the details, blanks and technological sketches.

These calculations are made as many times as possible while adjusting the output data until the technical conditions described in the drawing are satisfied.

If the change of the source data does not lead to positive results, it is necessary to make a route processing technology and prepare a proposal for recommendations for correcting the working drawings.

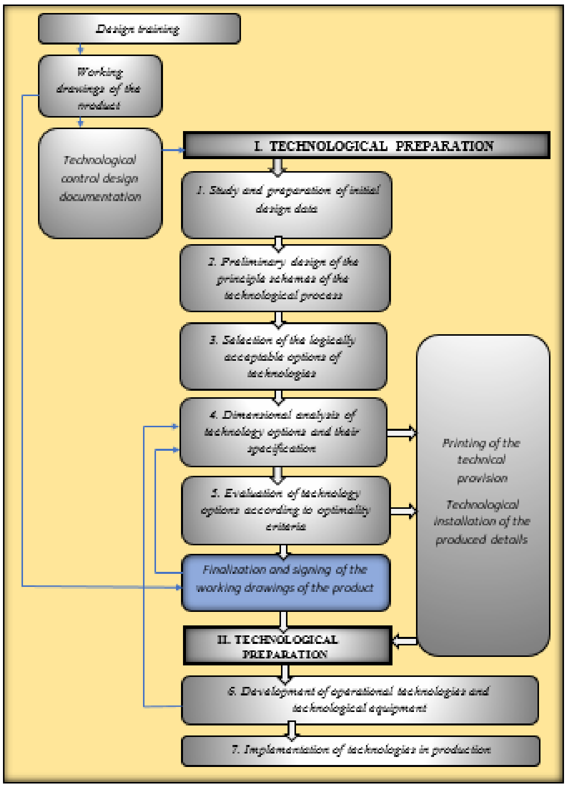

Fig. 3. Stages in the design of TP based on the optimization of dimensional-accuracy relationships.

III. CONCLUSONS

All this gives us reason to conclude that now there are opportunities for analysis and control of design-technological documentation, which is a prerequisite for the creation of an optimal TP with high quality.

The development proposed a methodology for a complex analysis of the construction-technological documentation, and selection of a variant of the technological process. This process must provide the technical conditions for the preparation of the product and its economic justification. This is done at the technology design stage, based on data from the analysis and optimization of dimensional-accuracy relationships.

The results of constructive-technological approaches, leading to the reduction of the innovation obsolescence of industrial technologies, by redesigning the technological process for mechanical processing based on the optimization of dimensional accuracy relationships, are proposed and their logical schemes are presented. On this basis, in a subsequent stage, it is necessary to further develop the idea into a software application for the industry.

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