Methodology of the formalized approach of the automated construction of the manufacturing route of a mechanical engineering product

A S Govorkov¹, I V Fokin², M V Lavrentyeva³, Yu I Karlina⁴

¹Institute of Aircraft Machine Engineering and Transport (IAM&T), Irkutsk National Research Technical University, Irkutsk, Russia
²Irkutsk Aviation Plant (IAP), an affiliate of Irkut Corporation
³Irkutsk Branch of Moscow State Technical University of Civil Aviation, Irkutsk, Russia
⁴Irkutsk National Research Technical University, 83, Lermontov St., Irkutsk, 664074, Russia

E-mail: govorkov_as@istu.edu; nikofrogi777@mail.ru; mira.amazon@gmail.com; karlinat@mail.ru

Abstract. The research refers to the field of automation of technological preparation of production in mechanical engineering. There is a concept of technological operations selection at manufacturing of a standard component of an airframe of an airplane glider on the basis an image of a product and objects’ classifiers of an industrial environment. Presentation of the objects of the production environment and their communication are performed in the presented theoretical and multiplicity model. The development of technological processes is considered; 3D models of the part are used in the process of TP design. The concept of the technique of automated construction of the manufacturing route on the basis of dependencies between the objects of the production environment “KE-TO-STO-Equipment” is presented.

1. Introduction
Modern mechanical engineering can be characterized as a complex system, constantly striving to modernize existing systems and create new ones to produce its wide range of used equipment and manufactured products. These aspects raise the issue of technological adaptability of the enterprise to change the requests from the customer in the conditions of modern competitiveness. The primary problem in this case is an increase of automation of technological preparation of production (TPP), beginning from an estimation of adaptability at working out of 3D model, till establishing of finished technological documentation.

For any machine-building and aircraft building enterprises there is an acute problem of reduction of design and technological manufacturing. In the age of information technologies, the development of production automation is one of the most top priorities. However, many engineering tasks still differ in their complexity and automation in one click is impossible, so the stage-by-stage formalization of the order of manufacturing routes is relevant.

Existing systems of the automated designing of technological processes (CAD TP) allow to reduce terms on working out TP, but as a rule work in a manual/semi-automated mode and basically these
means do not have the account of technological equipment of the given enterprise. In connection with the above mentioned drawbacks there was a question of necessity of creation of new methods of TP construction, having formalized data and knowledge of experts-technologists and designers, for fast response to changing market demands.

It is possible to achieve this goal to the greatest extent by developing a system of automated design of multiclass TP. At the heart of which lies full formalization of all stages of TPP, using all design procedures which are carried out at the enterprise using relevant information on the used equipment.

The concept of TP design is presented in general terms at the level of technological operations, and includes the need to develop the structure of the operation and the definition of the service station of the enterprise.

2. Results
As a result, there is a system with the possibility of creating new TPs with automated technology analysis and building an integrated manufacturing route.

The basic scheme of the method described above is presented in Figure 1.

Designers using CAD modeling tools perform 3D modeling of the part, laying in the model - material, geometric dimensions, roughness, tolerance, etc. This information is used by the technologists in the future for writing the working TP, where the choice of this or that equipment depending on the part's KE takes place. Thus it is possible to tell that having formalized this information, having added the mathematical description of a route; it is possible to automate procedure of construction of the expanded route of manufacturing.

![Figure 1. Workflow of CAD on the proposed methodology](image)

Let us consider a typical part of an airframe - a wall, which consists of the following structural elements: wall, flanging (type 1), board, undercutting (Fig. 2).
Figure 2. Stiffener wall

When identifying the simplest parts that have 2-3 KE in its composition, there may be a large number of options for TD, due to the peculiarities of engineering.

But this is not all, the part has a KE-board, which is performed on press equipment and can also be performed in several ways.

Figure 3. Variable TP execution field

As can be seen from the 3 drawings of the “board” variants, several variants are possible, but each of them has its own peculiarities.

At an initial stage of designing the table is formed (tab. 1). Each row corresponds to the name of the KE and each column describes the variants of its production. At the same time, the sequence of KE manufacturing, the presence of interrelated surfaces with other KEs and other factors are taken into account. In this case, the number of technological operations is limited only by the currently known methods of production of the KE.
In order to implement a maintenance sample for each KE it is necessary that all technological operations have their own identification coding. To solve this problem, the authors suggest using the coding of the "All-Russian Classifier of Technological Operations in Mechanical Engineering and Instrument-Making" in their work.

The procedure of formation of the theory of cognition concept can be classified as recognition of an object from all available set of objects. In this case, what is recognized is not what is in the model, but what should be recognized to satisfy specific purposes. In such statement of a problem the basic elements of designing should be designated:

1) \( C = \{ c_i \}, \ i = 1, n \) – multiple purposes of TP design;
2) \( P = \{ p_i \}, \ i = 1, m \) – multiple TP criteria;
3) \( X = \{ x_i \}, \ i = 1, k \) – multiple technology options;
4) \( V = \{ v_i \}, \ i = 1, I \) – Many technological solutions of TP.

The design components are interrelated. Among a considerable quantity of the purposes and set of parameters, and also between set of characteristics and set of variants of the technical decision exists conformity. If for designing a certain subset of the set is chosen, then on the basis of the composition of matches the set is determined by a certain subset that makes up the image of the set. Representation on set of assessments gives the chance to find the rational variant of the technological decision which best meets the chosen purposes of designing.

In the organizational structure of any plant, the following sets of similar criteria can be identified in the sequence of their formation. At the highest hierarchical level there are many criteria, the composition of which in the production sphere is shown in Fig. 3. The basis is made by set of parameters of technological decisions for considered product \( D_{TP} \). It includes four subsets that have no common elements:

- product parameters in the technological solution, \( D_p \in D_{TP} \);
- parameters of technological operations \( D_{TO} \) as part of the technological solution, \( D_{TO} \in D_{TP} \);
- Parameters of technological equipment \( D_{SS} \) as part of the technological solution, \( D_{SS} \in D_{TP} \);
- Other parameters \( D_{PR} \), not included in the subsets \( D_p, D_{TO} \) and \( D_{SS} \), so that \( D_{PR} \in D_{TP} \).

Thus, the set of all parameters of a constructive solution of a product is association of five mutually not crossing sets:

\[
D_{TP} = D_p \cup D_{TO} \cup D_{SS} \cup D_0 \cup D_{PR}.
\] (1)

Table 1. Technological operations for the manufacture of KE

| Name                  | Possible TO \( j = 1 \ldots n(m) \) |
|-----------------------|-------------------------------------|
| Wall (KE1)            | TO1, TO1+1, ... , TO\( n \)         |
| Flanging (KE2)        | TO1, TO1+1, ... , TO\( m \)         |
| Base (KE3)            | TO1, TO1+1, ... , TO\( m \)         |
| Undercutting (KE4)    | TO1, TO1+1, ... , TO\( m \)         |

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Inside the set \( D_p \) of all parameters of the product under consideration, let's select a subset \( D_{KE} \) parameters of structural elements directly included in the product. It is important that \( D_{KE} \in D_p \). In addition, when developing a manufacturing solution for a product, many parameters of \( D_0 \), such as \( D_0 \cap D_{TP} = \emptyset \). However, when selecting and analyzing the composition of TP objects, not the whole set of \( D_0 \), but just the subset \( D_{Otech} \) significant technological parameters the elements of the equipment defined by the following equation:

\[
D_{Otech} \in D_0 \cap D_{TP} = \emptyset.
\] (2)


Within the $D_{TO}$ set, let's select a subset of $D_{TOn}$ parameters of technological transitions, which have interfaces with at least one technological parameter of the equipment element. It should be noted that $D_{TOn} \in D_{TO}$. $D_{KE}$ and $D_{TOn}$ may or may not have common elements depending on the design and technological features of the product and the composition of the $D_{tech}$ set.

Technological process formally can be presented in the form of high quality structural model, each element in which carries out concrete function and thus is in constructive, functional, information communication with other elements.

Significant dimensionality of questions of designing of difficult technological concepts and objects creates expedient block-hierarchical approach, at its use the process of designing will be presented in the form of interconnected hierarchical levels.

Using this method, TP can be described mathematically as a function of the function $F$ of the workpiece shape $S$. The entire forming process can be represented as a transition from the state of the workpiece $S_0$ to the state of the workpiece $S_K$ by performing a set of some sequence of operations.

The choice of equipment composition is made for each technological operation of the route. The solution of this problem is based on the type of operation, accuracy of production, selected typical TP and overall dimensions of the manufactured part.

3. Conclusion

This paper describes the basic scheme of TP development on the basis of 3D model of the product, which is associated with the model in the NX system. When constructing the manufacturing route, the problems of determining sequences are solved such as the production of the KE in the workpiece and a reasonable selection of the optimal technological operations. For the purpose of the decision of these problems the structure of 3D-model of a workpiece with the further its analysis is recognised and classified, interrelations between all KE taking into account both constructive. Moreover, technological dependences of a workpiece and information image of a product are under construction. The given shape allows to form "rough" technological process (route) of manufacturing at a stage of sketch modelling and coordination CAD of model in system NX.

The desire to automate the initial design periods leads to the development of expert systems capable of forming reasoned solutions at the level of a qualified designer/technologist working in the field.

Use of the given concept - assuming use of the formalised procedures of formation of rules, with possibility of their editing and change of structure of rules and other actions providing necessary completeness and accuracy of performance of design and technological workings out with use of expert system renders effect of decrease in labour input on final cost of a product. Expected economic effect at the expense of decrease in labour input of CCI makes 10-40%, for the inquiry the plane MS-21-300 ($\approx$96 million USD) for unit.

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