Mathematical modeling of making mechanical engineering products based on an information model

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Abstract. The paper dwells upon computer-aided mechanical engineering. We herein propose a concept of choosing operations for producing a standard airframe part based on a product image and industrial environment object classifiers. Such industrial environment objects and their inter-relations are described as a set-theoretic model.

1 Introduction

Any mechanical-engineering enterprise, if it is developing and launching a new product, has to do design and pre-production engineering (DE and PPE), which involves work of numerous narrowly-specialized professionals.

In modern aerospace engineering, when designing the process of making a part we need a sophisticated approach as aircraft parts have to meet specific requirements different from those in mechanical engineering.

When designing any process, the following foundations must be laid:

a) high quality has to be assured to guarantee reliable operation and long service life;

b) manufacturing time has to be minimized.

Each process is developed after this or that design is tested for manufacturability per GOST 14.201—83.

2 Relevance and scientific significfnce

In modern process designs, processes are developed as documentation sets. In case of computer-aided pre-production engineering, such process desciptions are stored in a data base [1].

Operation selection is a multi-option problem. When selection operations, a number of factors are considered such as the product design and its conditions like dimensional allowances and the mutual positioning of structural elements. When choosing operations, the technologist has to optimize the sequence, to carefully set the parameters, the intermediate dimensions, removable stock, time norms, allowances, etc. This is why

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formalizing this stage as a part of PPE is still a relevant problem for state-of-the-art digital-enabled enterprises.

3 Statement of problem

The development and implementation of information technology in various industries made the concept of "digital enterprise" a sign of innovativeness that enables enterprises described that way to make highly competitive products with great consumer properties at a minimum cost. In a virtual enterprise (i.e. before a product is made), designers and technologists can take into account all the risks and analyze numerous different options to optimize the manufacturing sequence of making a semi-finished product into a finished one.

The authors hereof propose the following algorithm for designing a mechanical-engineering process based on a digital product model:

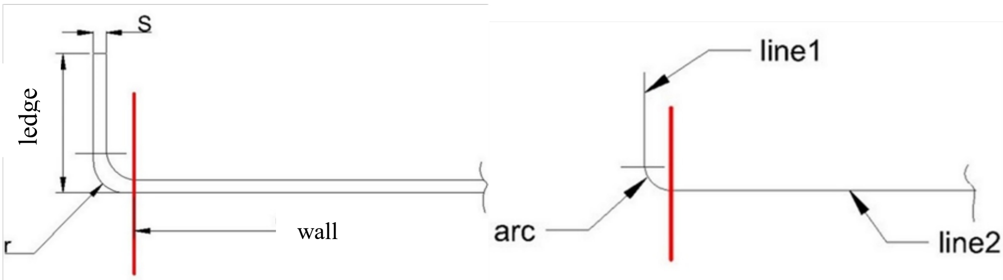
1) generate an information model (image) of your product:
a. recognize its structure
b. generate a set of structural elements (SE) with a list of important parameters
2) test the model for manufacturability
a. run quality tests
b. run quantity tests
3) design the process:
a. select the type of process;
b. select a workpiece;
c. select a set of technological bases;
d. define the sequence of forming each SE;
e. generate operations (the manufacturing sequence);
f. choose equipment;
g. choose tooling;
4) calculate part manufacturing time norms;
5) select the optimal process.

4 Theory

4.1 Phase 1. Information model

Information models are developed in accordance with the specific design and process-planning problems. Papers [2, 3, 6, 12] propose analyzing a CAD-generated digital product model as source data for defining the set of structural elements. When developing an information model, structural elements are selected based on the same source data as used for representing such elements in the digital model. Those include three basic data groups:

– geometric data of the objects contained in the digital model (DM) of a product;
– differential and integral properties of the geometric objects contained in the DM of a product;
– data on the DM object inter-relations.



a) c)

(a) cross-section outline bounding the border surface; (c) basic outline (thickness ignored) divided into its component lines.

Fig. 1. Border parameters

Thus, after recognition is complete we have generated a formalized information model which can be used for semi-automatic criteria-based manufacturability testing provided there is a formalized database of technological recommendations, which testing is affected by the impact of other industrial objects.

4.2 Phase 2. Manufacturability testing

Papers [5, 6, 7, 13] propose comprehensive manufacturability analysis for a specific set of structural elements contained in the information model; it is suggested such analysis should be based on operation, tooling, and equipment data. This takes into account not only elements obtained by generating the elements of the entire part, but also such elements that were obtained early in design. If necessary, the set of structural elements might be altered by the designer's decision based on the manufacturability testing results [10].

4.3 Stage 3. Generation of operations

Consider a standard airframe part, a wall consisting of the following structural elements: billet, flanging (type 1), border, and undercutting, see Figure 2.

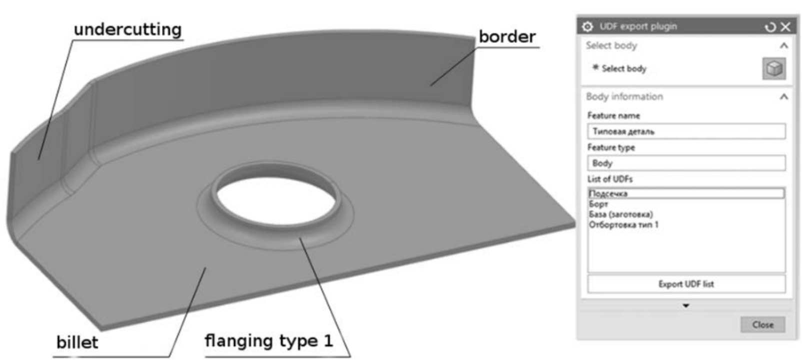


Fig. 2. The UI example and typical 3D model

First, we compile a table, see Table 1. Each line contains the name of an SE and its manufacturing options. The manufacturing sequence, the presence of superficial inter-relations with other SE, and other factors are thereby taken into account. In this case, operations are limited to the known methods of manufacturing this specific SE.

Table 1. SE manufacturing operations

Name	Operation options $j = 1 \ldots . n(m)$				
	1	*2*	...	*n*	*m*
Billet (SE_1)	O_1	O_{j+1}	…	O_n	–
Flanging (SE_2)	O_1	O_{j+1}	…	O_{m-1}	O_m
Border (SE_3)	O_1	–	–	–	–
Undercutting (SE_4)	O_1	O_{j+1}	–	–	–

To sample operations for each SE each operation must bear an ID code. To that end we propose using the encodings of the Russian Classifier of Mechanical Engineering and Instrumentation Operations.

From the perspective of the knowledge theory, the designing process can be attributed to the recognition of an object in a space of the entire set of objects. In this case, we recognize not something that actually exists but something that has to exist for our purposes. In this formulation, designing consists of the following components:

1) $C = \{c_i\}$, $i = \overrightarrow{1,n}$ is the set of process design goals;
2) $P = \{p_i\}$, $i = \overrightarrow{1,m}$ is the set of process parameters;
3) $X = \{x_i\}$, $i = \overrightarrow{1,k}$ is the set of possible solutions;
4) $V = \{v_i\}$, $i = \overrightarrow{1,l}$ is the set of process solutions.

The components of the designing process are interrelated. There is a correspondence between the set of goals and the set of parameters, as well as between the set of parameters and the set of solution options. If for our design we choose a subset C_c in the set C, then we compose correspondences in the set X to find the subset X_c comprising the image of the set C_c. Mapping X_c onto the set of estimates enables us to find an optimized-for-goals solution.

In the structure of an enterprise, we can identify the following sets of similar parameters, presented in a hierarchic order. The top level includes the sets of such parameters, the structure of which is shown in Figure 3 as it exists in the industrial environment. Fundamental is the set of product specific solution parameters (D_{TP}). It includes four subsets without common elements:

– product parameters as a part of the solution, $D_P \in D_{TP}$;

– operation D_{TO}parameters as a part of the solution $D_{TO} \in D_{TP}$, $D_{TO} \cap D_P = \emptyset$;

– tooling D_{CTO} parameters as a part of the solution $D_{CTO} \in D_{TP}$, $D_{CTO} \cap D_P = \emptyset, D_{CTO} \cap D_{TO} = \emptyset$;

other parameters of the solution $D_{\Pi P}$, not included in the subsets a D_p, D_{TO} *and* D_{CTO}, so that $D_{\Pi P} \in D_{TP}$, $D_{\Pi P} \cap D_P = \emptyset$, $D_{\Pi P} \cap D_{TO} = \emptyset$, $D_{\Pi P} \cap D_{CTO} = \emptyset$.

Therefore, the set of all parameters of a product solution is the merger of five mutually disjoint sets:

$$D_{TP} = D_P \cup D_{TO} \cup D_{CTO} \cup D_O \cup D_{\Pi P}. \quad (1)$$

In the set D_P of product parameters, identify the subset $D_{КЭ}$ of the *parameters* of such structural elements that the product consists of. Note that $D_{КЭ} \in D_P$. Besides, when designing a solution for making a product, we add the set of equipment parameters D_O so that $D_O \cap D_{TP} = \emptyset$. However, when selecting and analyzing the objects of a solution, what matters is not just the set D_O, but also the subset $D_{O\text{тех}}$ *of significant technological parameters* of the equipment, which is defined as follows:

$$D_{O\text{тех}} \in D_O \cap D_{TP} = \emptyset. \quad (2)$$

In the set D_{TO}, specify the subset $D_{TO\text{п}}$ of transition parameters paired to at least one parameter of an equipment element. Note that $D_{TO\text{п}} \in D_{TO}$, and the sets $D_{\text{КЭ}}$ and $D_{TO\text{п}}$ may or may not have common elements, which depends on the design of the product as well as on the set $D_{O\text{тех}}$.

Formally, the process can be represented as a simplified set of the elements of the structural model, where each element has a specific function and is structurally, functionally, and information-wise related to other elements.

The high dimensionality of design problems in case of complicated systems and objects makes it advisable to use a block-hierarchy approach, where the designing process is divided into inter-related hierarchical levels.

With that approach, a process can be described mathematically as the function Φ that demonstrates the reshaping of the machined part S. The entire shaping process can be shown as a transition from the workpiece state S_0 to the finished-part state S_K, which is achieved by a specific sequence of operations.

4.4 Phase 3.f Equipment selection

Equipment is selected specifically for each operation. This problem is soluble based on operation type data, manufacturing precision, the standard process of choice, and the dimensions of the part to be made.

5 Conclusions

The paper proposes a model for designing a process for image-based manufacturing of products associated with NX models. When generating the manufacturing sequence, one has to find the optimal operations and the sequence in which the part's structural elements should be made. These problems are soluble by analyzing the structure of a 3D model, the interrelations between its SE with due account of all design and technology-related pecularities; such analysis generates the image of the product. This image enables one to design a sketch-based manufacturing proccess (sequence) when creating and linking a CAD model in NX.

The desire to automate the initial design stages results in the development of expert systems capable of creating solutions with the skill of a qualified designer/technologist working in the field.

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