ATLANTIS PRESS
Advances in Engineering Research (AER), volume 157
International Conference "Actual Issues of Mechanical Engineering" (AIME 2018)

Method of workpiece group's creation and selection of parts representatives in digital manufacturing

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***Abstract*— For modern high-efficiency digital production, the main requirement is its ability at any time to break evenly the manufacture of products and in a short time with minimal costs to start producing any number of new products. The fulfillment of this task largely depends on the efficiency of the technological planning of production, which makes it possible to integrate the manufacturing of a new product into existing technological processes at a minimal time to market with the minimum costs using available technological equipment, fixtures, tools, etc. When developing new products, engineers are trying to design parts similar to those already developed and manufactured at the enterprise, but this does not always work. In addition, there are questions concerning determining the load of equipment when introducing new products. All these issues in manufacturing help to solve the methods of bringing the release program. This article presents a technique for splitting the multinomenclature machine-building production into groups of parts, selecting the details-representatives, calculating the manufacturing times for the details of the above-mentioned output program, and comparing the times obtained by calculation with the processing times of the workpieces on the machines by the example of manufacturing the "Transition plate" parts.**

Keywords*— *digital manufacturing; technological planning; technical renovation of machine-building enterprises; production and technological systems; multinomenclature production; classifier; part-representative.

I. INTRODUCTION

Modern machine-building enterprises are characterized by the transition from the release of a relatively constant range of products to the production of customized products [1]. Changing the paradigm leads to the need to ensure the flexibility and readjustment of the production system, which are realized in the framework of technological planning of production or technical renovation [2]. This requires a comprehensive study of technological and organizational tasks. Solution of these problems on a single basis allows getting the idea of creating the digital manufacturing.

In most cases, the term "digital manufacturing" refers to the information (electronic) model of high-tech production, includes information about all processes occurring in the production. The information model is represented by a whole range of automated systems: CAD, CAE, CAM, product data management (PDM) and others, integrated into the product lifecycle management (PLM) system [3].

The effectiveness of any production, including the "digital", largely depends on the effectiveness of technological planning of production [4]. One of the important directions in the process planning is the identification of models of technological equipment, its quantity and uniform loading for the fulfillment of a given program of production. The difficulty is that with a large range of products, this process is very laborious and multivariate. Unfortunately, modern software products do not allow this to be done in an automated mode [5]. This article offers a method for solving this problem.

II. THE ORETICAL BASIS

The quality of process planning for the designing or modernization of production is largely determined by the reliability and completeness of information on the technological processes of products manufacturing.

The collection and processing of technological information about manufactured products is a laborious task, various methods of bringing the program of production and grouping of products [6] are used to reduce it.

This research was made under financial support of Russian Ministry of education and science, project task N9.2731.2017/4.6.

The essence of these methods is to determine the laboriousness of manufacturing products according to a limited nomenclature - representative products and recalculation of the time of manufacturing of other parts belonging to the group under the program of release.

The analysis of existing methods based on the grouping of parts on the basis of utility items [7], structural and technological features [8], surface modules [9], and grouping in accordance with the All-Russian Classifier of Products and Design Documents OK 012-93 showed insufficient efficiency for the grouping of products of the nomenclature of subject-closed shops, which makes up thousands, tens of thousands of positions [10].

The practical use of these methods in the design of multinomenclature production workshops is limited by the following factors [10]:

- a significant number of different types of parts;

- Inadequate formalization of rules for determining characteristics for grouping products,

- insufficient formalization of rules for determining the values of characteristics for grouping,

- insufficient formalization of the methodology for calculating the coefficient of reduction,

- a great deal of time consuming to technological processes planning for manufacturing representative products.

It is necessary to find a "golden mean" that allows grouping and selecting the details - representatives with minimal resources and at the same time obtain information about the manufactured nomenclature of the enterprise as close as possible to reality.

In the present work, the grouping of parts is considered when solving the problems of technical renovation of machine-building enterprises, which in the automatic and semi-automatic mode allows the grouping and selection of representative parts.

The method of breaking up the nomenclature into groups, selecting the details - representatives and calculating the given program of output are presented in the following order of implementation:

A. Step 1. Collection and structuring of information about the product nomenclature.

Collection of general information for each product by analyzing the designing documentation - drawings and specifications. All data are structured and entered in the form of a table, i.e. a database is formed with the following structure:

1. Name CE / D - name of the assembly unit (CE) / component (E) in the product, which is assigned by the manufacturer.

2. CE / D code - CE / D code in the product, which the manufacturer assigns to the enterprise.

3. The annual program of release.

4. Brand of material.

5. Mass of the part.

6. Overall dimensions of the part.

7. Kind of assortment of stock.

8. Workpiece weight.

9. Overall dimensions of the workpiece.

10. The number of parts obtained from the first billet.

Data on the parameters of parts and workpieces (the grade of the material, the mass of the part and the workpiece, the overall dimensions of the workpiece, the type of the assortment) can be recorded automatically in the form of uploading information (using applications); for this, all the capabilities of modern graphical editors are available when developing new products. As an example in Fig. 1, information about a detail drawn by the designer in the graphics editor "SolidWorks" is presented.

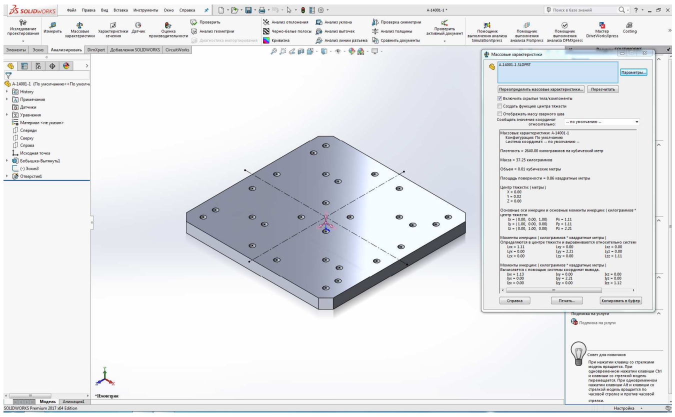

Fig. 1. 3D model of the part and its parameters in the graphics editor "SolidWorks"

The above-mentioned information on parts and workpieces can be entered manually by the operator if the documentation is provided in paper form or drawn in a graphical editor that does not allow downloading the information from the program.

After the formation of the database in the form of a table, it is possible to pre-form groups by parameters such as the annual output program, the material grade, the mass of the part, the overall dimensions of the part, the kind of assortment of the workpiece, the mass of the workpiece. It is necessary to make a selection by sorting the collected information.

We will give some recommendations on the division of nomenclatures into groups that showed the simplicity and effectiveness of their use.

We recommend the following mass ratios Mpr and annual output Npr of the representative's product to the corresponding indicators in the group [11]:

$$0,5M_{мах} < M < 2\,M_{мin}; \quad (1)$$

$$0,1N_{мах} < N < 10\,N_{мin}; \quad (2)$$

where Mmax, Mmin, Nmax, Nmin are respectively the largest and lowest values of mass and annual output of products belonging to the corresponding group. If these relations are not fulfilled, it is extremely important to perform an additional breakdown of the products into groups.

Sorting by dimensions and weights of parts and blanks is made on the ranges according to the pre-selected technological equipment, which in the future can be adjusted.

You can determine in which type of part the prism, shaft, disc, and tube will be even at this stage, filling out the columns of the sample - "Length", "Width or diameter outer", "Height or diameter inner", with the appropriate information

B. Step 2. Determining the design features of assembly units / parts when grouping.

Analysis of techniques for determining the design features of products proposed by other authors showed their bulkiness, i.e. requiring considerable time to determine which type will be assigned to a particular part. As a rule, during the execution of design work there are short deadlines and a small team of highly paid specialists is working, so the "golden mean" will be the most optimal. According to the authors of the article, the classification proposed in the publication [10] is the most successful. It showed its simplicity and effectiveness.

The essence of it is as follows. Within the preliminary grouping, when analyzing product drawings, all the many details of the nomenclature are divided into 4 groups:

Group 1. Standard parts (parts, the design of which is regulated by regulatory documents GOST, OST, etc.);

Group 2. Typical parts - parts that are close in design to standard parts;

Group 3. Same type - details of a typical design of the same type;

Group 4. Special parts - unique parts that have a design that can not be attributed to any of the selected groups.

The details of each group are classified according to their own classifier of this group.

Currently, this step of splitting products into groups is difficult to perform in an automated mode, so it is performed by the operator in a manual mode.

After filling in the information about the products described in Steps 1 and 2, one can perform sequential sorting and selection by groups. In the groups, there are similar (by design, material, dimensions, etc.) products.

After that, there is a need to go to Step 3.

C. Step 3. Selecting a detail-representative from the group.

The next step of this method is to work with each of the groups individually.

The essence of the work is as follows. Each detail is considered separately. The part is divided up into simple geometric elements, and then their analysis is performed on the identity of the surfaces, the purity of the processing and the accuracy. After analyzing the parts and finding identical surfaces, a part data table is compiled.

The contents of the detail data table columns are the following:

Part surface number defines the number of parts surfaces that have excellent dimensions and geometric shape.

The number of similar surfaces shows the number of surfaces identical to each other in the part.

Accuracy - accuracy quality of the dimension of a given surface.

The purity of the resulting surface shows the purity (roughness) of the surface obtained by Ra.

The program calculates the arithmetic mean values of purity and accuracy for the resulting surfaces.

After carrying out calculations for each part and determining the arithmetic average of the purity and accuracy of the resulting surfaces, the data for all details are entered in the table.

The contents of the columns of the selection table of the detail-representative from the group by weight coefficients are:

mass of the material to be removed - the values of the difference in the mass of the workpiece and its workpiece are indicated;

the average value of the accuracy class is the arithmetic mean of the tolerance for the surface over all surfaces of one part;

the average value of the surface roughness (Ra) is the arithmetic average of the purity of the surface obtained over all surfaces of one component;

score by weight - a score, which is assigned by the mass of the material being shot. Points are distributed according to the following principle, the larger the mass of the layer being removed, the greater the score.

A score on the average value of the accuracy class is a score that is assigned according to the tolerance of the received surface. Points are distributed from a lower tolerance value to the larger one within the group.

A score on the average value of surface roughness (Ra) - a score that is assigned by the roughness of the resulting surface. Points are distributed from a lower tolerance value to the larger within the group.

The total score is the sum of the scores based on the weight of the material being taken, the accuracy and roughness of the resulting surface.

The program compares the values and selects the part with the highest value of the total score. The detail with the maximum score will be the detail-representative.

If the points of two or more parts coincide during the addition, the program checks the annual output program for this part and accordingly assigns the maximum score of the detail having the maximum output program - this part is accepted as the detail-representative.

D. Step 4.Process planning for the production of the detail-representative and calculation of the output programm.

After selecting the detail-representative from the group, a process planning for its production is developed with the information on the technological structure, the necessary equipment and the time of its manufacture are determined.

The time for manufacturing other parts from the group is calculated by calculating the time of manufacturing the detail-representative for the refinement coefficient by the formula:

$$T_{pt\ i} = T_{pt\ det.repr.\ i} \times k_{red} \qquad (3)$$

where $T_{pt\ det.repr\ i}$ - unit time for the operation for the i-th part;

k_{red} - coefficient of reduction (specifying coefficient);

$$k_{red} = k_M \times k_s \times k_k \times k_r \qquad (4)$$

where k_M is the mass coefficient, takes into account the difference in the mass of the extracted chip volume of the i-th component M_i and representative part M_{red}, is determined by the formula:

$$k_M = \sqrt[3]{\left(\frac{M_i}{M_{red}}\right)^2}. \qquad (5)$$

In the procedure [11], coefficient k_M is calculated by the mass of the parts, and we think that this is not true. It is necessary to compare the weight of the removed chips, since it takes time to work on the machine.

k_s - quantity factor, takes into account the difference between the annual program for the release of the i-th part of N_i and detail-representative N_{red}, is determined by the formula:

$$k_s - \left(\frac{N_i}{N_{red}}\right)^m \qquad (6)$$

where m is the exponent, depending on the overall dimensions of the products (m = 0.2 ... 0.33).

Toughening the requirements for the accuracy or roughness of the machined surfaces leads to an increase in the machine-tool capacity of the machining of parts due to an increase in the number of transitions or a reduction in the cutting regimes.

k_m - the accuracy factor, depends on the average accuracy parameter of the parts surfaces.

The average qualification is determined by the formula:

$$\bar{T} = \frac{\Sigma(T_i n_i)}{\Sigma n_i} \qquad (7)$$

where T_i is the i-th qualite; n_i - number of sizes of the i-th quality;

k_r - coefficient of roughness, depends on the average roughness parameter of the parts surfaces;

The average value of the roughness parameter of surfaces is determined by the formula:

$$\overline{Ra} = \frac{\Sigma(Ra_j n_j)}{\Sigma n_j} \qquad (8)$$

where Ra_j is the *j*-e value *Ra*; n_j is the number of surfaces having value *Ra*;

After carrying out the calculations and determining the reduced time for the production of the details of the group members, the data are recorded in the table.

III. PRACTICAL IMPLEMENTATION.

Practical implementation of this technique was carried out on the production site of one of the Russian machine-building enterprises for the manufacture of transition plates (in Fig. 2) for shaker types of the mod. BF-45UA-E, BF-70UA-E and BF-70UA-E-T.

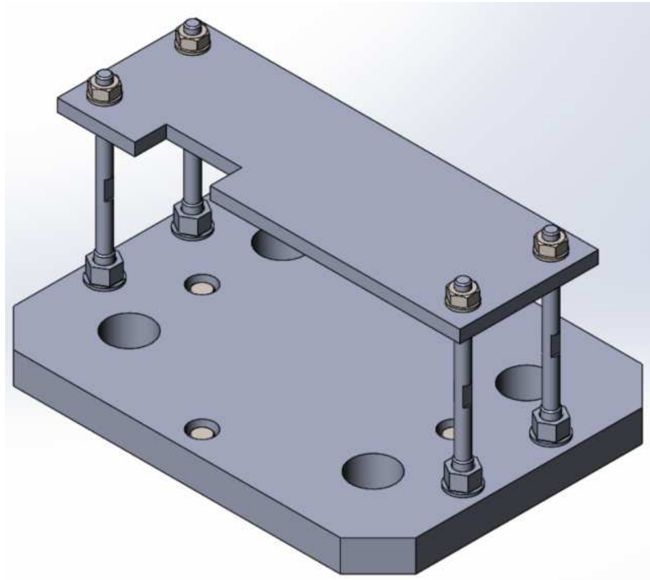

Fig. 2. A transition plate for the shaker table

A. Step 1. Collection and structuring of information about the product nomenclature

The results of collecting information on the product nomenclature in question are presented in the form of a table (Fig. 3.)

The name of the Assembly units/Detail	The code of the Assembly units/Detail	The annual program of production, pieces	Detail information					Data for the workpiece					
			Material grade	Weight, kg	Overall dimensions, mm			Type of variety	Weight, kg	Overall dimensions, mm			The amount of detail obtained from the 1st workpiece
					Length	The width or the diameter of the outer	The height or diameter of the inner			Length	The width or the diameter of the outer	The height or diameter of the inner	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Plate	A-13983-1	300	AMr6	3,68	425	425	20	Sheet	10,59	427	427	22	1
Plate	A-13978-1	273	AMr6	3,69	425	425	20	Sheet	10,59	427	427	22	1
Plate	A-13992-1	160	AMr6	5,15	355	355	20	Sheet	7,4	357	357	22	1
Plate	A-13998-1	402	AMr6	32,86	755	755	30	Sheet	48,41	757	757	32	1
Plate	A-13994-1	510	AMr6	10,13	425	425	30	Sheet	15,4	427	427	32	1
Plate	A-14000-1	350	AMr6	27,99	755	755	30	Sheet	48,41	757	757	32	1
Plate	A-14001-1	270	AMr6	37,25	600	600	40	Sheet	40,18	602	602	42	1
Plate	A-14010-1	270	AMr6	26,14	755	755	25	Sheet	40,85	757	757	27	1
Plate	A-14022-1	108	AMr6	30,28	755	755	27	Sheet	45,39	757	757	29	1
Plate	A-14011-1	218	AMr6	4,96	597	347	20	Sheet	12,14	599	349	22	1
Plate	A-14012-1	210	AMr6	27,14	600	600	30	Sheet	30,62	602	602	32	1
Plate	A-14013-1	247	AMr6	4,85	597	347	20	Sheet	12,14	599	349	22	1
Plate	A-14039-1	178	AMr6	4,13	425	425	15	Sheet	8,18	427	427	17	1
Plate	A-14023-1	120	AMr6	7,95	550	350	16	Sheet	9,23	552	352	18	1
Plate	A-14008-1	300	AMr6	10,43	720	350	15	Sheet	11,41	722	352	17	1
Plate	A-13990-1	193	AMr6	13,97	420	420	32	Sheet	15,98	422	422	34	1
Plate	A-14041-1	123	AMr6	3,16	380	160	20	Sheet	3,41	382	162	22	1

Fig. 3. A structure of information about the product nomenclature in question

B. Step 2. Determining the design features of assembly units / parts when grouping.

Fig. 4 shows the breakdown of parts by design features.

The name of the Assembly units/Detail	The code of the Assembly units/Detail	Selection of products by design features			
		Standard	Typical	Similar	Special
1	2	15	16	17	18
Plate	A-13983-1			O1.	У1.2
Plate	A-13978-1			O1.	У1.2
Plate	A-13992-1			O1.	У1.2
Plate	A-13998-1			O1.	У1.2
Plate	A-13994-1			O1.	У1.2
Plate	A-14000-1			O1.	У1.2
Plate	A-14001-1			O1.	У1.2
Plate	A-14010-1			O1.	У1.2
Plate	A-14022-1			O1.	У1.2
Plate	A-14011-1			O1.	У1.2
Plate	A-14012-1			O1.	У1.2
Plate	A-14013-1			O1.	У1.2
Plate	A-14039-1			O1.	У1.2
Plate	A-14023-1			O1.	У1.2
Plate	A-14008-1			O1.	У1.2
Plate	A-13990-1			O1.	У1.2
Plate	A-14041-1			O1.	У1.2

Fig. 4. Breakdown of parts according to constructive features

Figure 5 shows the representatives of the parts that belong to the same group.

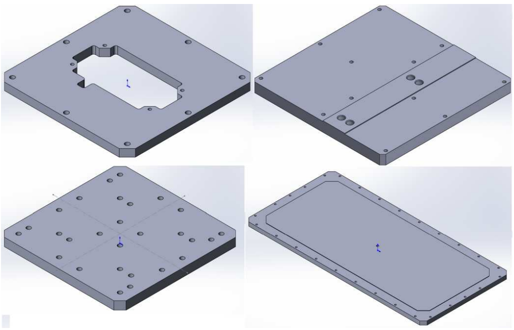

Fig. 5. 3D models of parts belonging to the same group

C. Step 3. Selecting the detail-representative from the group

After carrying out calculations for each part and determining the arithmetic mean of the purity and tolerance for the surfaces obtained, the data for all details are entered in the table in Fig. 6.

The name of the Assembly units/Detail	The code of the Assembly units/Detail	The annual program of production, pieces	Weight of material to be removed, kg	The processing time of the workpiece on the machine Tм, min	k_m	k_s	$k_к$	k_r	k_{red}
1	2	3	23	34	39	40	41	42	43
Plate	A-13983-1	300	**6,91**	8,0457	0,9653	1,0309	1	1,1	**1,0947**
Plate	A-13978-1	273	6,9	8,0380	0,9644	1,0309	1	1,1	**1,0936**
Plate	A-13992-1	160	2,25	3,7215	0,4603	1,0000	1	1,1	**0,5063**
Plate	A-13998-1	402	15,55	13,0549	1,6487	0,9794	1	1,1	**1,7762**
Plate	A-13994-1	510	5,27	6,3919	0,8072	0,9794	1	1,1	**0,8696**
Plate	A-14000-1	350	20,42	15,9557	1,9735	1,0000	1	1,1	**2,1708**
Plate	A-14001-1	270	2,93	4,3387	0,5479	0,9794	1	1,1	**0,5903**
Plate	A-14010-1	270	14,71	12,8500	1,5894	1,0000	1	1,1	**1,7483**
Plate	A-14022-1	108	15,11	13,0796	1,6178	1,0000	1	1,1	**1,7795**
Plate	A-14011-1	218	7,18	7,8392	0,9900	0,9794	1	1,1	**1,0666**
Plate	A-14012-1	210	3,48	4,8604	0,6138	0,9794	1	1,1	**0,6613**
Plate	**A-14013-1**	**247**	**7,29**	**7,3500**	**1,0000**	**1,0000**	**1**	**1**	**1,0000**
Plate	A-14039-1	178	4,05	5,4853	0,6785	1,0000	1	1,1	**0,7463**
Plate	A-14023-1	120	1,28	2,5647	0,3172	1,0000	1	1,1	**0,3489**
Plate	A-14008-1	300	0,98	2,1503	0,2660	1,0000	1	1,1	**0,2926**
Plate	A-13990-1	193	2,01	3,4545	0,4273	1,0000	1	1,1	**0,4700**
Plate	A-14041-1	123	0,25	0,8728	0,1080	1,0000	1	1,1	**0,1187**

Fig. 6. Selection of the detail-representative from the group by weight coefficients

The program compares the values and selects the part with the highest value of the total score. Based on the results of the calculation, a maximum total score of 46 was obtained for the part "Plate A-10013-1". It will be the representative of the group.

D. Step 4. Process planning for the production of the detail-representative and calculation of output program.

The workpiece "A-10013-1" is developed for the workpiece "Plate", which determines the time for manufacturing it.

Then calculations are made for the rest of the group's details according to the given release program. The results of the calculations are shown in Fig. 7.

The name of the Assembly units/Detail	The code of the Assembly units/Detail	The annual program of production, pieces	Weight of material to be removed, kg	The processing time of the workpiece on the machine Tм, min	k_m	k_s	$k_к$	k_r	k_{red}
1	2	3	23	34	39	40	41	42	43
Plate	A-13983-1	300	**6,91**	8,0457	0,9653	1,0309	1	1,1	**1,0947**
Plate	A-13978-1	273	6,9	8,0380	0,9644	1,0309	1	1,1	**1,0936**
Plate	A-13992-1	160	2,25	3,7215	0,4603	1,0000	1	1,1	**0,5063**
Plate	A-13998-1	402	15,55	13,0549	1,6487	0,9794	1	1,1	**1,7762**
Plate	A-13994-1	510	5,27	6,3919	0,8072	0,9794	1	1,1	**0,8696**
Plate	A-14000-1	350	20,42	15,9557	1,9735	1,0000	1	1,1	**2,1708**
Plate	A-14001-1	270	2,93	4,3387	0,5479	0,9794	1	1,1	**0,5903**
Plate	A-14010-1	270	14,71	12,8500	1,5894	1,0000	1	1,1	**1,7483**
Plate	A-14022-1	108	15,11	13,0796	1,6178	1,0000	1	1,1	**1,7795**
Plate	A-14011-1	218	7,18	7,8392	0,9900	0,9794	1	1,1	**1,0666**
Plate	A-14012-1	210	3,48	4,8604	0,6138	0,9794	1	1,1	**0,6613**
Plate	**A-14013-1**	**247**	**7,29**	**7,3500**	**1,0000**	**1,0000**	**1**	**1**	**1,0000**
Plate	A-14039-1	178	4,05	5,4853	0,6785	1,0000	1	1,1	**0,7463**
Plate	A-14023-1	120	1,28	2,5647	0,3172	1,0000	1	1,1	**0,3489**
Plate	A-14008-1	300	0,98	2,1503	0,2660	1,0000	1	1,1	**0,2926**
Plate	A-13990-1	193	2,01	3,4545	0,4273	1,0000	1	1,1	**0,4700**
Plate	A-14041-1	123	0,25	0,8728	0,1080	1,0000	1	1,1	**0,1187**

Fig. 7. Calculation of the given release program

IV. CONCLUSION.

In conclusion, let us make a comparative analysis of the times obtained by the proposed method with the times obtained in the actual manufacture of parts at the production site of one of the Russian machine-building enterprises; the results of the comparison are shown in Fig. 8.

The name of the Assembly units/Detail	The code of the Assembly units/Detail	The annual program of production, pieces	The processing time of the workpiece on the machine Tм, min (calculated)	The processing time of the workpiece on the machine Tм, min (with machine)	The percentage of inaccuracy of the estimated time relative to the processing time on the machine
1	2	3	34		
Plate	A-13983-1	300	8,0457	**9,2**	-12,5467799
Plate	A-13978-1	273	8,0380	**8,84**	-9,072289461
Plate	A-13992-1	160	3,7215	**4,6**	-19,09739872
Plate	A-13998-1	402	13,0549	**15,8**	-17,3740056
Plate	A-13994-1	510	6,3919	**7,2**	-11,22427327
Plate	A-14000-1	350	15,9557	**18,4**	-13,28408331
Plate	A-14001-1	270	4,3387	**4,8**	-9,609431335
Plate	A-14010-1	270	12,8500	**11,7**	9,829335957
Plate	A-14022-1	108	13,0796	**12,9**	1,392233916
Plate	A-14011-1	218	7,8392	**8,8**	-10,91774797
Plate	A-14012-1	210	4,8604	**4,2**	15,72434655
Plate	**A-14013-1**	**247**	**7,3500**	**7,8**	**-5,769230769**
Plate	A-14039-1	178	5,4853	**6,2**	-11,52746294
Plate	A-14023-1	120	2,5647	**3,6**	-28,75802761
Plate	A-14008-1	300	2,1503	**3,2**	-32,80467061
Plate	A-13990-1	193	3,4545	**3,9**	-11,42224959
Plate	A-14041-1	123	0,8728	**1,25**	-30,17511192

Fig. 8. Comparative analysis of the times obtained by the proposed method with the times obtained in the actual manufacture of parts

The machine time obtained by the proposed method showed deviations in the range from 2 to 32 percent of the processing time of the blanks "Transition plate" on metal cutting machines at the production site of one of the Russian machine-building enterprises. On average, the deviation was 14%.

This technique allows you to automate the process of splitting into groups of parts lists and selecting representative parts from them, which directly affects the quality of design decisions and shorten the terms of design work.

The proposed method of grouping of parts and selection of details-representatives in the design of multi-nomenclature machine-building production is considered as one of the solutions aimed at the creation of digital engineering production.

Acknowledgment

This research was made under financial support of Russian Ministry of education and science, project task N9.2731.2017/4.6

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