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THE POSSIBILITIES OF USING OF GROUP TECHNOLOGIES FOR MANUFACTURING THE PARTS OF UNIVERSAL-ASSEMBLED DEVICES

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The manufacture of parts and assembly units of the aerospace industry is characterized by a small product range, but a significant changeability of their shape and size. In these circumstances, the use of the elements of universal assembly devices (UAD) allows to reduce the number of special devices significantly. Based on the results of a complex research on the analysis of design and manufacturing technology of elements of UAD, and on the known principles of construction of group technologies the algorithm for the formation of technological groups of UAD details of the "prism support" type was developed. The 3D-model of the complex details, the classification of surfaces proposed for it and the database on all 16 details of the group are the basis for the development of an algorithm for a route group technological process (GTP). In the new GTP and control program it is proposed to combine in one operation practically all draft types of processing: milling, drilling, thread cutting on the multi-task machine with the palletization of complex details on a technological plate. The effectiveness of the constructive-technological decisions is confirmed by the reduction in the number of operations and equipment (from 7 to 4 machines) thus reducing the labor content and cost. The use of the developed techniques of development the GTP allows significant expansion of the possibilities for automation of technological preparation of production, simplifies the development of control programs, reduces the labor content of the preparation of technological documents and its translation into digital form.

Keywords: group technology process, universal assembly device, complex detail, labor content, production cost.

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ВОЗМОЖНОСТИ ИСПОЛЬЗОВАНИЯ ГРУППОВЫХ ТЕХНОЛОГИЙ ДЛЯ ИЗГОТОВЛЕНИЯ ДЕТАЛЕЙ УНИВЕРСАЛЬНО-СБОРНЫХ ПРИСПОСОБЛЕНИЙ

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Для изготовления деталей и сборки узлов аэрокосмической отрасли характерна небольшая номенклатура изделий, но значительная сменяемость их по форме и типоразмерам. В этих условиях использование элементов универсально-сборных приспособлений (УСП) позволяет существенно сократить количество специальных приспособлений за счет использования стандартных элементов в рамках определенных групп деталей. По результатам комплекса работ по анализу конструкций и технологии изготовления элементов УСП и на основании известных принципов построения групповых технологий разработан алгоритм формирования технологических групп деталей УСП типа «призма опорная». Сформированная 3D-модель комплексной детали, предложенная для неё классификация поверхностей и база данных по всем 16-ти деталям группы (включенным в состав комплексной по общности конструктивных и технологических признаков) являются основой для разработки алгоритма построения маршрутного группового технологического процесса. В новом групповом технологическом процессе предлагается совместить в одну операцию практически все черновые виды обработки: фрезерование, сверление, нарезание резьбы на многоцелевом станке с ЧПУ с установкой комплексной детали на технологическую плиту. Управляющая программа для механической обработки резанием комплексной детали легко адаптируется к изготовлению любой детали группы. Эффективность принятых конструктивно-технологических решений подтверждается сокращением количества операций, оборудования (с 7 до 4 станков) и межоперационных переходов в структуре процесса механической обработки резанием, а значит, снижением трудоемкости и себестоимости. Таким образом, предложены и обоснованы конструкторско-технологические приемы повышения эффективности механической обработки деталей универсально-сборных приспособлений за счет применения групповых технологических процессов. Использование разработанных ме-

тодик построения групповых технологических процессов позволяет значительно расширить возможности для автоматизации технологической подготовки цифрового производства, упрощает процедуру разработки управляющих программ для многоцелевых станков с числовым программным управлением.

Ключевые слова: групповой технологический процесс, универсально-сборные приспособления, комплексная деталь, трудоемкость, себестоимость.

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Introduction. In the conditions of small- and medium-scale production in the manufacture of parts in small batches (which is typical for enterprises of the aerospace industry), with a large change in form and size, there are significant losses of time caused by adjustment of machine tools in the transition from manufacturing one part to another. In these conditions it is expedient to use the group method of processing [1; 2]. It is known that this method takes into account not only the similarity of structural features of details, but also precision, technological, instrumental, organizational and planned characteristics [3–7]. A key position in the construction of group technology is the stage of designing an integrated part. The solution of the problem of creating a complex part is accompanied by the fact that in the classification of parts the possible methods and sequence of machining of technological surfaces (installation, guiding, supporting) are already taken into account, as well as the necessity of observing the well-known principles of engineering technology – the agreement of the basic design, technological, measuring bases [8; 9]. Route technological process should provide the possibility of processing any part of the group without significant deviations from the general technological scheme. Since the research is aimed at increasing the efficiency of manufacturing components of specialized universal assembly devices, it is necessary to note a number of significant features of such specialized equipment. Its application is justified if the range of products produced using UAD is small [4]. It is this type of production that is typical for manufacturing parts and assembling products of the aerospace industry in a small amount, but with a high turnover in shape and size. A similar approach is used in the manufacture and use of equipment at the factory of Airbus (UK) [5], where the range of products produced in the enterprise is ten. At the same time, the use of UAD can significantly reduce the number of devices needed in the presence of a wide range of manufactured products, by using standard elements within certain groups of parts (fig. 1).

A distinctive feature of the technological preparation of the manufacture of UAD parts is the need for simultaneous creation of routing, operational technological processes and a control program for multi-purpose machines that are part of the production structure of the enterprise. Therefore, the efficiency of the use of group technologies for the manufacture of the entire range of parts included in the UAD requires the creation of a database of their three-dimensional models in conjunction with the corresponding technological processes and control programs for the manufacture of products manufactured using UAD [6].

The main drawback of the existing traditional approaches of such design and technological preparation of production is the high laboriousness in the development of individual 3-D models and technological processes for each part of the UAD and complicates the procedure for technological changeover when replacing one part for another [7–9]. For these reasons, the use of group technologies for manufacturing the range of UAD parts is topical and practically significant, especially in the specific production conditions of small-scale production of aerospace enterprises.

Analysis of the nomenclature of UAD details and the creation of a 3-D model of an integrated part. As initial data for determining the prospects for the use of group technologies in the conditions of modern digital production, drawings of the main parts of universally assembled devices (UAD) used at JSC "ISS" Reshetnev Company". For the development of group technological processes, the most representative (by structural and technological features and applicability) details of the hull group of the prism type are selected. Fig. 1 shows an example of the integrated use of such elements of UAD for gluing the skeleton of the satellite.

As a result of a complex of works on the analysis of structures and technology of manufacturing elements of UAD "Prism support" carried out jointly with the specialists of ISS-Reshetnev Company, the main technical requirements for the accuracy of the executive dimensions of the parts (tolerance fields for the dimensions of the mounting surfaces, U-shaped grooves, prismatic surfaces, connecting surfaces, the accuracy of the relative position of the surfaces in terms of flatness, parallelism and perpendicularity, surface roughness from Ra 0.32 to Ra 0.63) were determined. The need for additional chemical-thermal treatment of these details – cementing to a depth of 0.6–1.2 mm and quenching (hardness of HRC 57–63) – was also taken into account. It imposes correspondingly stringent requirements on the technology of their machining after quenching. In a generalized form, the results of the analysis of the accuracy characteristics are presented in table.

The existing technology of surface machining at the five-axis machining center HERMLE C-40 with the use of imported cutters Ø10-EC-D6 10-22C10H72 (ISCAR) provides the actual roughness Ra0.32-0.63 (according to the requirements of the design documentation (DD) Ra 0.32 is necessary); the actual value of the asymmetry tolerance of the grooves (12H7) with respect to the sides 0.01–0.025 (according to the requirements of the DD 0.01 is necessary). Therefore, in order to achieve the required parameters of the accuracy of the dimensions and surface roughness, it is also necessary to grind to the H7 grade with a surface grinding machine – FS 420 SD of increased accuracy. For the manufacture of all elements of UAD in accordance with the requirements of the DD, it is necessary to equip the machine tool with a precision flat grinding machine type BLOHM PLANOMAT HP 408 with Easy Profile CNC with micron feeding on all axes (cost ~ 500,000 EURO).

Therefore, one of the main research tasks is to study the possibilities of increasing the accuracy of machining due to the use of group technological processes and promising precision forming methods with basing on a technological plate.

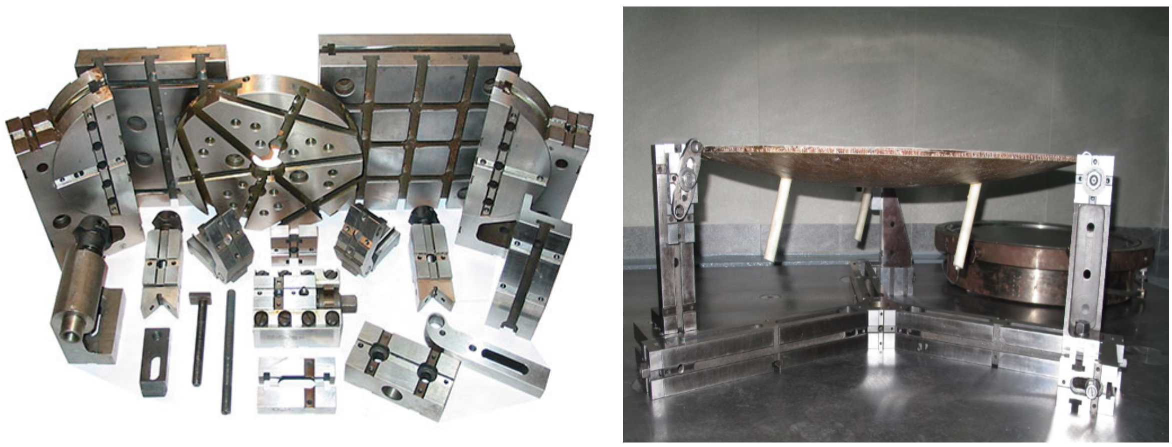
Based on the known principles of group technologies formation, an algorithm for creation of technological groups of parts of UAD of Prism type was developed (fig. 2).

When combining the UAD parts into groups, we proceeded from the condition of similarity of the surfaces to be machined or their combinations, while the group often includes parts of various shapes and sizes, but any of them by the range of linear and angular dimensions and arrangement of the surfaces, the methods for obtaining them during machining by cutting corresponds (has analogies) and can be built into the structure of the complex part. The analysis of structural and technological features and surfaces, the features of the existing technological processes of machining at the enterprise, made it possible to form a complex part from a number of similar parts. Fig. 3 presents a model of a complex detail of ”prism” type, consisting of a number of elementary surfaces (1–45).

Proceeding from the existing at the enterprise routing technological process of machining, the main surfaces of the complex part can be defined as: execution surfaces – 7, 8; basic design bases – 1–6; auxiliary (connecting) design surfaces – 10–45; free (technological) surface – 9.

Fig. 4 shows the data on the main geometric parameters that were necessary and used in the development of the group process and control programs for processing the main surfaces of the complex part.

The resulting 3D-model of the complex part, the proposed classification of surfaces and the database created for all 16 parts of the group selected according to the similarity of design and technological features, were taken as a basis for the development of an algorithm for constructing a route (group) process.



a *b*

Fig. 1. Elements of UAD: *a* – a set of parts and assemblies of the UAD;
b – a reflector on the tooling of UAD elements

Рис. 1. Элементы УСП: *а* – набор деталей и сборочных единиц УСП;
б – рефлектор на оснастке из элементов УСП

Precision requirements to parts of “prism” type

	Accuracy degree/ limit deviation	Roughness, Ra	Shape accuracy
Main execution surfaces (dimensions)	js6	0.32	⏥ 0.008 ⊥ 0.02
U-shaped grooves	7H	0.63	⊥ 0.02
Holes	7H		◎ 0,08 A *
Angular surfaces of the prism	90° ± 5'	0.32	

*Alignment in relation to the reference surface of the central hole Ø13 (base A).

Justification and development of a group technological process of machining parts of UAD of Prism type. The service purpose of parts of the group, their design, the material of workpieces, the classification of surfaces and the accuracy requirements were taken into account when selecting and justifying the routing technological processes of group processing.

The analysis of the existing technological processes for the production of a group of UAD of the Prism type made it possible to establish that, in spite of the common shape and size, there is a considerable loss of time during their manufacture due to the readjustment of the machines during the transition from the manufacture of one part to another. The routing technology adopted at the enterprise assumes a considerable number of re-installations, inter-operational transitions, sometimes even in one technological operation of shaping, for example, milling planes, grooves, drilling holes.

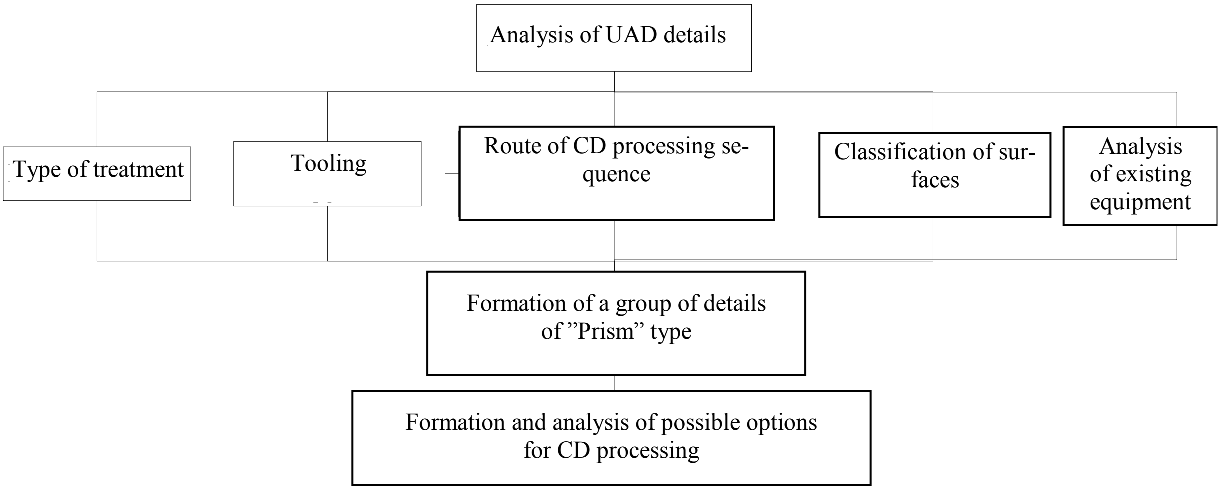
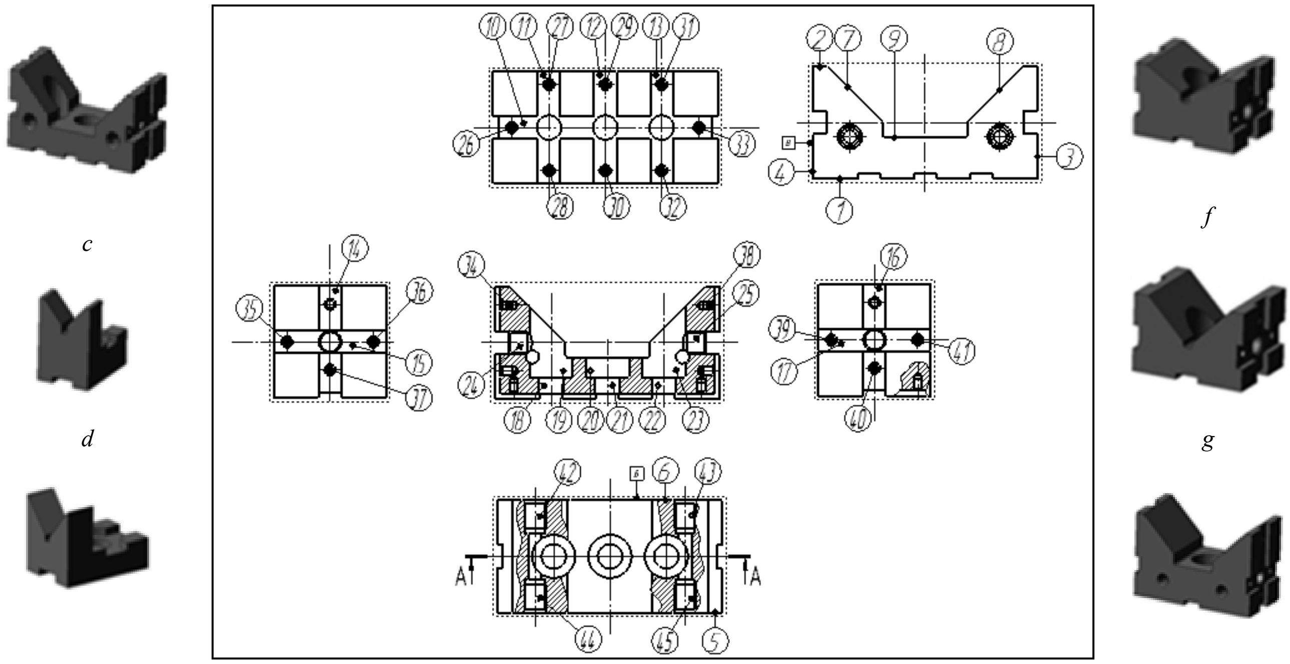


Fig. 2. The design algorithm for the group technological process

Рис. 2 Алгоритм проектирования для группового технологического процесса

b e



a

Fig. 3. Model of complex part and typical parts of the group: *a* – complex part with designated surfaces; *b*–*g* – details of the group

Рис. 3. Модель комплексной детали и типовые детали группы: *а* – комплексная деталь с обозначением поверхностей; *б*–*ж*– детали группы

Обозначение призм	H, мм	B, мм	L, мм	α	b, мм	h1, мм
15275-7033-1201	45	60	45	90	5	17
1202	60	90	45	90	30	27,5
1203	45	60	45	120	30	27,5
1204	60	90	45	120	5	27,5
15276-7033-2946	60	120	60	90	30	22
2947	60	120	60	120	30	22
15277-7033-2441	30	30	45	90	5	15,5
2442	40	30	45	90	5	27,5
2443	40	45	52,5	90	5	15,5
2444	45	60	52,5	90	5	15,5
2445	65	75	60	90	5	15,5
2431	30	30	45	120	5	15,5
2432	40	30	45	120	5	15,5
2433	40	45	52,5	120	5	15,5
2434	45	60	52,5	120	5	15,5
2435	65	60	52,5	120	5	15,5

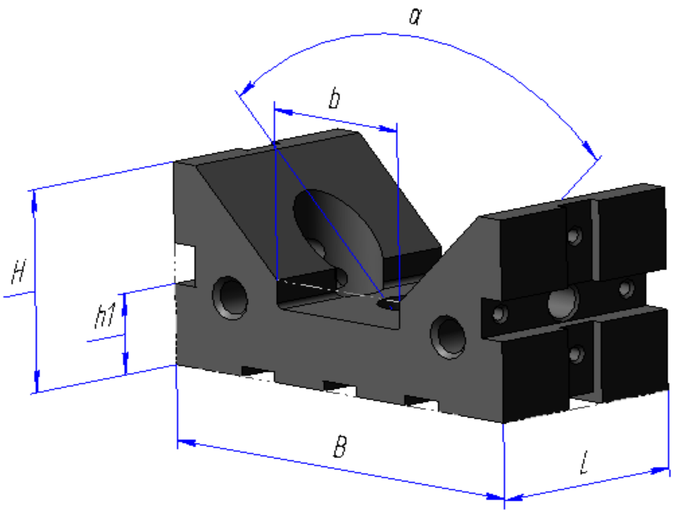


Fig. 4. Parametrized model and table for the dimensions of the complex part

Рис. 4. Параметризированная модель и таблица типоразмеров комплексной детали

Taken together, this leads to an increase in labor intensity, a violation of the principle of constancy of the bases, and hence to a possible decrease in the accuracy of processing, and therefore to inclusion of additional finishing operations in the route technological process. In addition, the output cycle is disrupted, the inter-operational costs of auxiliary time increase and the utilization factor of the equipment decreases (according to the enterprise data from 0.28 to 0.42). Together, the effect of these factors leads to an increase in the cost of parts included in the UAD. The cost of one complex part of the UAD 107-7099-0100-04 ”Prostavka” can reach 43–48 thousand rubles, the estimated cost of a typical part of the UAD of the ”Prism” type ranges from 4–12 thousand rubles (a similar level of selling prices is given in the materials of some firms of manufacturers of equipment, such as Shunk, Iscar and the Tool ”Favorite” [10–12].

In the developed new group technological process, it is proposed to combine almost all roughing operations of milling, drilling, threading on a multipurpose CNC machine with the installation of a complex part (and therefore any other part of the group) into a single operation on the technological plate (fig. 5) on surfaces of the planes of the base 1 and fixing using a nut 4 and a pin-bolt 3 through the calibrated hole (surface 21).

A reliable orientation of the workpiece relative to the axis of symmetry is provided by making a fit along the surfaces of the hole 13H7 and the pin bolt 13h6. Additional fixation from the rotation (in addition to the clamping force of the nut) under the action of cutting forces is realized on the mating surfaces of the grooves on the workpiece and counter-protrusions on the technological plate. Since the sizes of the base holes ∅13 (surface 21 on the complex part) and the guiding grooves (surface 12 on the complex part) on the base plane for all the parts of the group included in the structure of the complex part coincide, the technological plate is unified, and the principle of complete interchangeability is in action. The process of machining all free surfaces by cutting (2–9, 14–17, 24–45) is performed without re-setting on one milling-drilling-boring operation with basing on the surface 1 on the technological plate, which in turn is clamped in the vice of the machine table, but does not interfere with all the shaping movements of the tools.

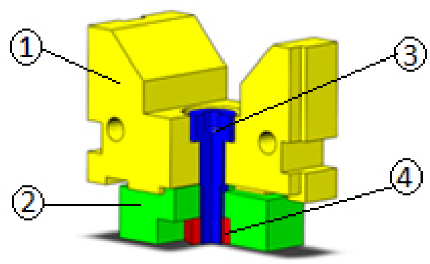


Fig. 5. The scheme of basing of a complex part on a technological plate: *1* – part; *2* – technological plate; *3* – pin bolt; *4* – nut

Рис. 5. Схема базирования комплексной детали на технологической плите: *1* – деталь; *2* – технологическая плита; *3* – штифт-болт; *4* – гайка

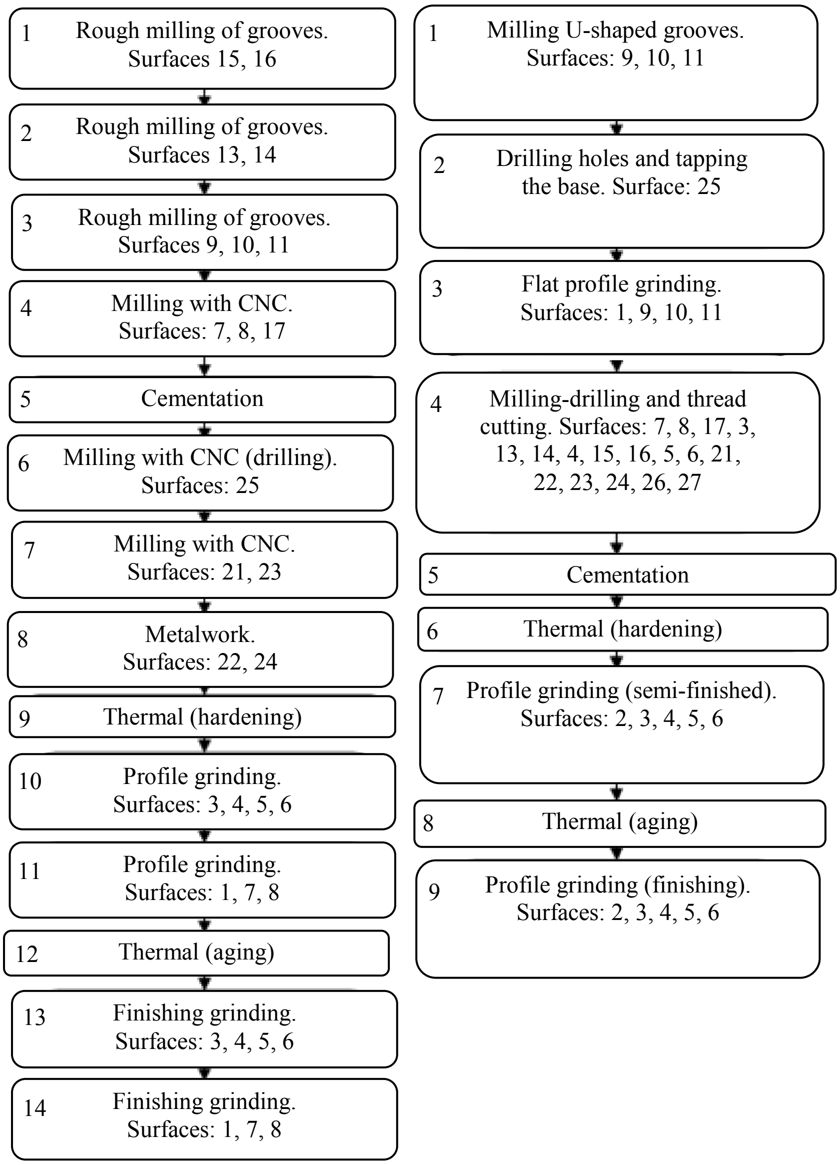
In addition, it is proposed to use new designs (developed in SFU jointly with JSC "ISS") for high-speed turning and milling tools equipped with interchangeable geometrically-complex elements [13–15] on the basis of nanostructured hard alloy composites [16–18] at finishing machining of prism planes. The application of the new cutting geometry and kinematics of rotary cutting, combined with the use of dispersed hard alloy carbide composites with ultra fine carbide grain, allows the grinding operations to be replaced with fine milling without compromising the quality of the surface treatment. The structure of the routing group technological process in comparison with the basic one applied at the enterprise is shown in fig. 6.

Efficiency of the adopted design and technological solutions (in accordance with the block diagrams of the routing technological processes of processing parts 7033-4734 ”prism support”: a) basic – according to the technology of the enterprise; b) the new one, based on group technology) is clearly supported by a reduction in the number of transactions in the structure of the process, which means a reduction in labor intensity and cost of production.

Formation of the structure of transitions in the manufacture of individual parts of the group within the group process is illustrated graphically by the data shown in fig. 7.

Based on the results of the complex design and technological work conducted jointly ISS-Reshetnev Company a variant of the group technological process for a complex part of the UAD of ”prism support” type and a control program for the machining of its main surfaces with installation on a technological plate were developed.

Fig. 8 shows the setups and trajectories of the tool moving on the preparation operations of the base surfaces a) milling the base plane, grooves and drilling holes; b) rough milling of the technological groove and surfaces of prisms; c) trajectories of the tool moving with installation of the workpiece on the technological plate. As an illustration of the use of group technologies in digital form, a fragment of the control program for one of the transitions (rough milling of the base 1) of machining of the complex part on a five-axis machining center HERMLE C-40 is given.



a *b*

Fig. 6. Routing technological processes: *a* – basic; *b* – novel

Рис. 6. Маршрутные технологические процессы: *а* – базовый; *б* – новый

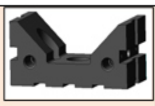
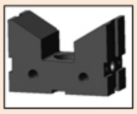
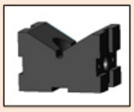
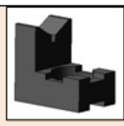
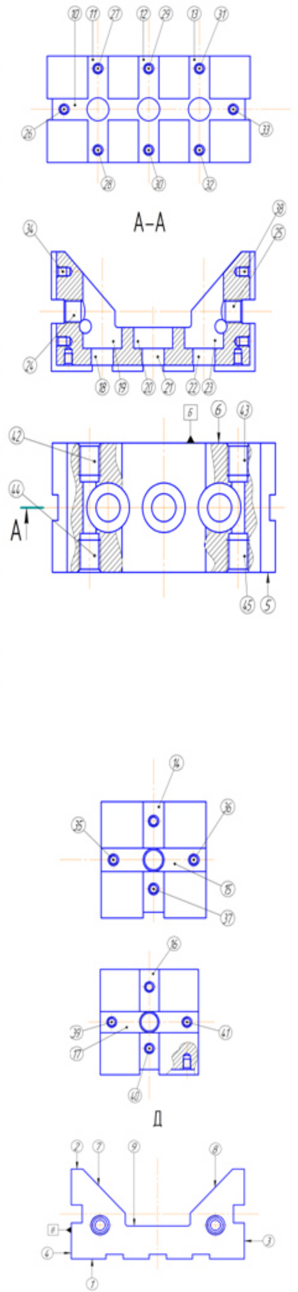
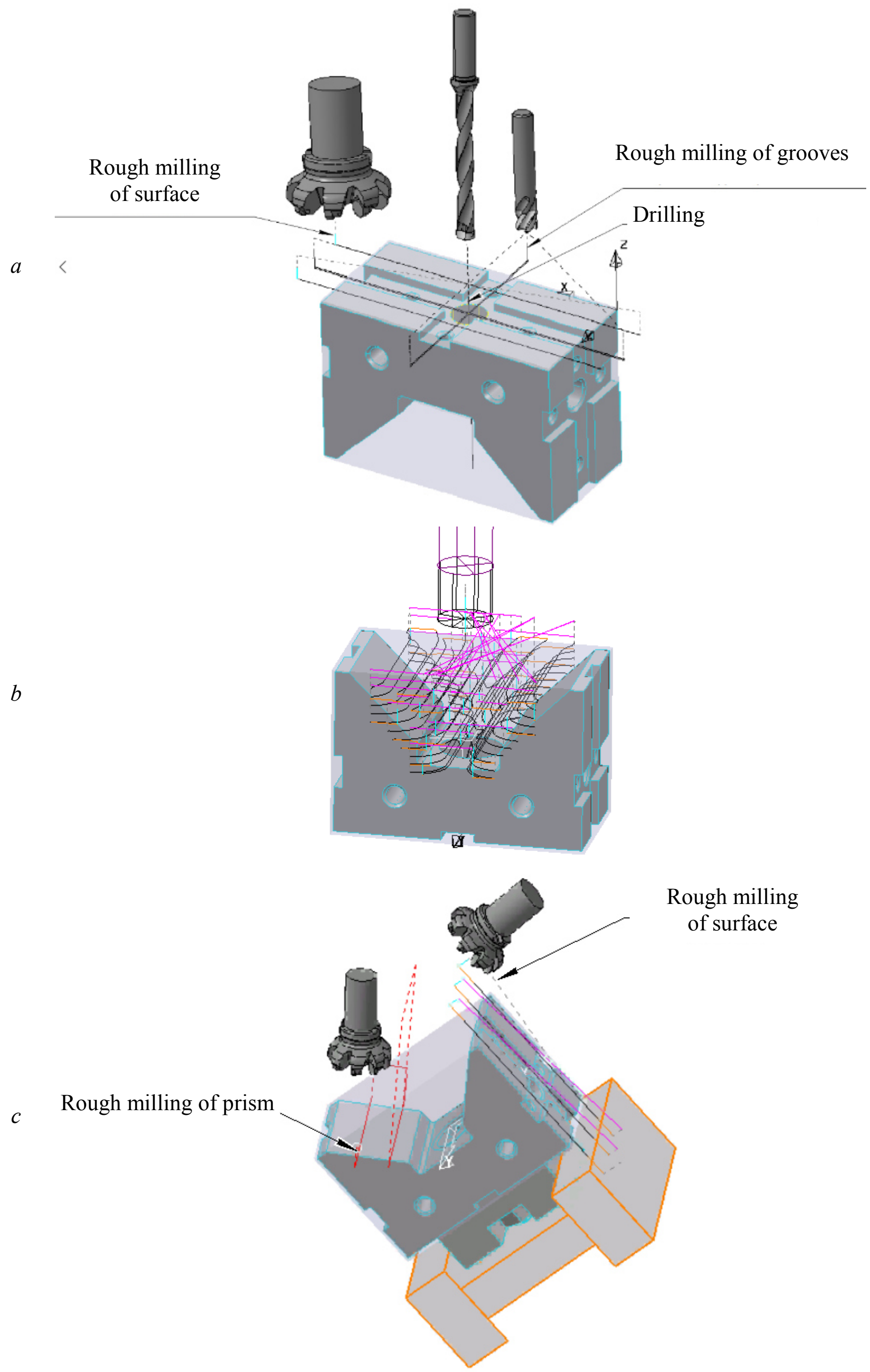
Эскизы деталей						Комплексная деталь
Переходы						
Фрезеровать поверхность основания: 1	●	●	●	●	●	
Фрезеровать П-образные пазы. Поверхности: 11,13	●					
10	●	●	●			
12	●	●	●	●	●	
Сверление отверстий на основании. Поверхности: 27,28,31,32	●	●	●	●	●	
21,26,29,30, 33	●	●	●			
Сверление главных отверстий. Поверхность: 21	●	●	●	●	●	
18,22	●					
Плоско – профилешлифовальная Поверхности: 1	●	●	●	●	●	
12	●	●	●	●	●	
10	●	●	●			
11,13	●	●	●	●	●	
Фрезерно-сверлильно-резьбонарезная. Поверхности: 2,3,4,5,6,7,8,9,21	●	●	●	●	●	
14,15,16,17,24,25,34,35,36,37,38,39,40, 41	●	●				
19,23	●					
42,43,44,45	●	●				
Цементация, термическая(закалка)	●	●	●	●	●	
Плоско - профилешлифовальная Поверхности: 2,3,4,5,6	●	●	●	●	●	
Термическая(старение)	●	●	●	●	●	
Плоско-профилешлифовальная Финишное шлифование. Поверхности: 2,3,4,5,6	●	●	●	●	●	

Fig.7. The structure of operations of group technological processes

Рис. 7. Структура операций группового технологического процесса

Virtually all rough milling, drilling, tapping operations are proposed to be combined in one operation on a CNC multi-purpose machine with the installation of the part on the technological plate. This will allow processing of all free surfaces without re-setting in one operation, thus realizing the principle of constancy and unity of bases known in engineering technology.

It eliminates the need for reinstallations and improves the accuracy of processing and the relative location of surfaces.

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%
…
N30 G0 G90  G94 G21
N31 G17 G80 G40
N32 G0 G91 G28 Z0.0
N33 (TOOL TYPE: ENDMILL )
N34 (TOOL ID: "FR_30" )
N35 (TOOL DIAMETER
:30.0  )
N36 (TOOL LENGTH:160.0 )
N37 T3 M6
N38 S1500  M3
N39 G90 G54
N40 (TOOLPATH:
CHERNOVOEFREZEROVAN
IETORCA(1))
N41 (ALLOWANCE: 0.5)
N42 (WORKPLANE: UST1 )
N43 G0 X105.0 Y10.0
N44 G43 Z9.067 H3
N45 M8
N46 Z4.067
N47 G1 Z0.0 F500.
N48 X-15.0 F1000.
N49 G0 Z9.067
N50 X105.0 Y35.0
N51 Z4.067
N52 G1 Z0.0 F500.
N53 X-15.0 F1000.
N54 G0 Z9.067
N55 M9
…
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Fig. 8. Schemes of adjustment: *a* – milling and drilling of basic surfaces;
b – rough milling of technological surfaces; *c* – milling of main surfaces

Рис. 8. Схемы наладок: *а* – фрезерование и сверление базовых поверхностей; *б* – черновое фрезерование технологических поверхностей; *в* – фрезерование основных поверхностей

Conclusion. The preliminary consolidated technical and economic analysis shows that the developed new group technological process of machining typical UAD parts used at JSC ”ISS” provides the opportunity to reduce labor input, the number of machine tools used (from 7 to 4 machines) and interoperational transitions.

The total laboriousness of manufacturing the USP element (according to the enterprise's data) is 130 hours, according to the proposed new technological process, labor intensity is reduced by 63 %. The technical and economic effect is determined by preferential differences in terms of manufacturability – GOST 14.201–83.

The use of methods for constructing group technological processes makes it possible to expand the possibilities for automating the technological preparation of production, simplifies the procedure for developing control programs for machining blanks on multipurpose machines with numerical program control, and reduces the complexity of preparing technological documentation by digitizing it.

References

1. King J. R., Nakornchai V. A. Machine-component group formation in group technology: review and extension. *International Journal of Production Research*, 1982, No. 2 (20). P. 117–133.
2. King J. R. Machine-component grouping in production flow analysis: an approach using a rank order clustering algorithm. *International Journal of Production Research*. 1980, No. 2 (18), P. 213–232.
3. Markov A. M., Markova M. I., Pletneva E. M. [The algorithm design group of the technological process of machining parts]. *Obrabotka metallov.* 2012, No. 4(57), P. 5–9 (In Russ.).
4. Kutin A. A., Turkin M. V. [High-performance engineering technologies based on GPS of new generation]. *Vestnik MGTU “Stankin”*. 2010, No. 4 (12), P. 41–46 (In Russ.).
5. Tappin N. [Flexible manufacturing cell for Superjumbo wing rib manufacture]. *Aircraft Engineering and Aerospace Technology*. 2006, Vol. 75, P. 6.
6. M. V. Gandhi, B. S. Thompson. Automated design of modular fixtures for flexible. *Manufacturing Systems*. 1986, Vol. 5, P. 4.
7. Ogorek M. Workholding in the flexible system. *Manufacturing Engineering*. 1985, Vol. 95, No. 1, P. 28–31.
8. Makharinsky E. I., Machalinski J. E., Belyakov N. V. [Theory of basing in the problem of designing technological processes of machining and machine tools]. *Vestnik machinostroeniya*. 2008, No. 9, P. 34–45 (In Russ.).
9. Makharinsky E. I., Machalinski J. E., Belyakov N. V. [On the theory of basing in machining]. *STIN*. 2005, No. 4, P. 29–32 (In Russ.).
10. *Instrument ”Favorit” – Prizmy USP 12* [Tool Favorit – Prism, UAD 12] (In Russ.). Available at: http://favorit-instrument.ru/catalog/usp-8-usp-12-universalno-sborochnye-prisposobleniya/prizmy-usp-12/ (accessed 12.09.2017).
11. *Metallorezhushchie instrumenty firmy Iscar* [ISCAR metal-cutting tools] (In Russ.). Available at: http://www.iscar.ru/index.aspx/countryid/33 (accessed 12.09.2017).
12. *Osnastka firmy Shunk* [Snap firms Shunk] (In Russ.). Available at: https://schunk.com/ru_ru/domashnjaja-stranica/ (accessed 12.09.2017).
13. Indakaw N. S., Bencharov A. S., Gordeev Y. I. [The study of the process of turning a multi-faceted rotary cutters]. *Materialy XIX Mezhdunar. nauch. konf. “Reshetnevskie chteniya”* [Materials XIX Intern. Scientific. Conf “Reshetnev reading”]. Krasnoyarsk, 2015, P. 464–466 (In Russ.).
14. Kozlova N. I., Gordeev I. Y., Anistratenko N. E. [The possibilities of using of group technologies for manufacturing the parts of universal-assembled devices]. *Materialy XXI Mezhdunar. nauch. konf. “Reshetnevskie chteniya”* [Materials XXI Intern. Scientific. Conf “Reshetnev reading”]. Krasnoyarsk, 2017, P. 507–508.
15. Indakov N. S., Gordeev Y. I., Binchurov A. S. Method of Rotational Turning With Multifaceted Cutters. *IOP Conference Series: Materials Science and Engineering. – IOP Publishing.* 2016, Vol. 124, No. 1, P. 012150.
16. Gordeev Y. I., Apkarian A. K., Bencharov A. S., Yasinsky V. B., Vadimov V. N. [Design and study of nano-structured tungsten carbide composites with high level of strength and operational characteristics due to modification of nanoparticles and thermomechanical treatment]. *Vestnik SibGAU*. 2014, No. 4 (56), P. 209–218 (In Russ.).
17. Gordeev Y. I., Abkaryan A. K., Binchurov A. S., Yasinski V. B. Design and Investigation of Hard Metal Composites Modified by Nanoparticles. *Advanced Materials Research*. 2014, Vol. 1040, P. 13–18.
18. Gordeev Y. I., Abkaryan A. K., Binchurov A. S., Lepeshev A. A., Yasinski V. B. Influence of Additives of Nanoparticles on Structure Formation of Fine-Grained Hardmetals. *Key Engineering Materials*. 2007, Vol. 743, P. 3–8 (In Russ.).

Библиографические ссылки

1. King J. R., Nakornchai V. Machine-component group formation in group technology: review and extension // International Journal of Production Research. 1982. № 2 (20). С. 117–133.
2. King J. R. Machine-component grouping in production flow analysis: an approach using a rank order clustering algorithm // International Journal of Production Research. 1980. № 2 (18). С. 213–232.
3. Марков А. М., Маркова М. И., Плетнева Е. М. Алгоритм проектирования группового технологического процесса механической обработки деталей // Обработка металлов. 2012. № 4 (57). С. 5–9.
4. Кутин А. А., Туркин М. В. Высокоэффективные машиностроительные технологии на основе ГПС нового поколения // Вестник МГТУ «Станкин». 2010. № 4 (12). С. 41–46.
5. Tappin N. Flexible manufacturing cell for Superjumbo wing rib manufacture // Aircraft Engineering and Aerospace Technology. 2006. Vol. 75. P 6.
6. Gandhi M. V., Thompson B. S. Automated design of modular fixtures for flexible // Manufacturing Systems. 1986. Vol. 5. P. 4.
7. Ogorek M. Workholding in the flexible system // Manufacturing Engineering. 1985. Vol. 95. № 1. P. 28–31.
8. Махаринский Е. И., Махаринский Ю. Е., Беляков Н. В. Теория базирования в проблеме проектирования технологических процессов механической обработки и станочных приспособлений // Вестник машиностроения. 2008. № 9. С. 34–45.
9. Махаринский Е. И., Махаринский Ю. Е., Беляков Н. В. О теории базирования при механической обработке // СТИН. 2005. № 4. С. 29–32.

10. Инструмент «Фаворит» – Призмы УСП 12 [Электронный ресурс]. URL: http://favorit-instrument.ru/catalog/usp-8-usp-12-universalno-sborochnye-prisposobleniya/prizmy-usp-12/ (дата обращения: 12.09.2017).

11. Металлорежущие инструменты фирмы Iscar [Электронный ресурс]. URL: http://www.iscar.ru/index.aspx/countryid/33 (дата обращения: 12.09.2017).

12. Оснастка фирмы Shunk [Электронный ресурс]. URL: https://schunk.com/ru_ru/domashnjaja-stranica/ (дата обращения: 12.09.2017).

13. Исследование процесса ротационного точения многогранными резцами / Н. С. Индаков [и др.] // Решетневские чтения : материалы XIX Междунар. науч. конф. (10–14 нояб. 2015, г. Красноярск) : в 2 ч. / под общ. ред. Ю. Ю. Логинова ; Сиб. гос. аэрокосмич. ун-т. Красноярск, 2015. С. 464–466.

14. Возможности использования групповых технологий для изготовления деталей универсально-сборных приспособлений / Н. И. Козлова [и др.] // Решетневские чтения : материалы XXI Междунар. науч. конф. (08–11 нояб. 2017, г. Красноярск) : в 2 ч. / под общ. ред. Ю. Ю. Логинова ; Сиб. гос. аэрокосмич. ун-т. Красноярск, 2017. С. 507–508.

15. Indakov N. S., Gordeev Y. I., Binchurov A. S. Method of Rotational Turning With Multifaceted Cutters // IOP Conference, Series: Materials Science and Engineering. IOP Publishing. 2016. Т. 124, №. 1. С. 012–150.

16. Конструирование и исследование наноструктурированных твердосплавных композитов с повышенным уровнем прочностных и эксплуатационных характеристик за счет модифицирования наночастицами и термомеханической обработки / Ю. И. Гордеев [и др.] // Вестник СибГАУ. 2014. № 4 (56). С. 209–218.

17. Gordeev Y. I., Abkaryan A. K., Binchurov A. S. Design and Investigation of Hard Metal Composites Modified by Nanoparticles // Advanced Materials Research. 2014. Т. 1040. С. 13–18.

18. Influence of Additives of Nanoparticles on Structure Formation of Fine-Grained Hardmetals / Y. I. Gordeev [et al.] // Key Engineering Materials. 2007. Vol. 743. P. 3–8.