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USING OF THE SCIENCE INTENSIVE TECHNOLOGIES IN THE BLADED WHEELS PRODUCTION

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Abstract: The problem of the structural optimization is considered in connection with design of the bladed wheals production technologies. Some data are generated required to build of the alternate technologies ways. Recommendations are proposed to work out the effective ways for producing of the bladed wheals with different sizes and forms. Some examples of the practical application are presented. Considered processing operations of a blade channel are useful on the assumption of ease input of a tool in a blade channel space. This condition is usually satisfied for most of the operations in the manufacturing of open blisks of turboshaft engine compressors. Bladed disks of a turbo pump are usually closed from the periphery by a shroud ring, and blade channel has a shape that excludes the use of milling and operations, based on beam processing methods. In the manufacturing of many blades of this group there is used transitional electric discharge machining to form blade channels. This technology allows us to solve the problem of forming blade channin els, however, as shown in the Table 1, it has two disadvantages: low productivity and the presence of the defect layer that must be removed in subsequent operations. The analysis shows that the removal of the defect layer with a simultaneous decrease of the roughness parameter is expedient to use with applying electrochemical polishing operations. The value of the allowance is 10-20% more than the maximum thickness of the defect layer and, depending on the parameters of the previous operation mode, is 15-60 microns. The problem of increasing the efficiency of production technologies for bladed disks is formulated and the way to solve it is discussed. Examples are given and the analysis of the effective use of new technologies in bladed disk production is performed.

Key words: structural technological optimization, blisk, working turbine wheals.

1. INTRODUCTION

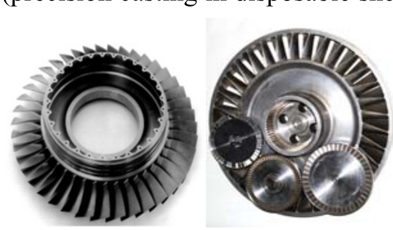
Bladed wheels are referred to the most difficult manufacturable products in mechanical engineering production [1, 2]. Fans of modern compressors generation gas-turbine engines are performed as blisks and blings made of titanium alloys, which allows significantly reduce compressor mass. [3] Rotors and turbine nozzle blocks of gas-turbine sets are also single wheels. These parts work under extreme conditions (high loads and temperature), so for their manufacturing there are used heat-resistant materials with low cutting ability [4] (Fig. 1).

2. EXPERIMENTAL RESULTS

Taking into account the structural complexity and high cost of these parts, we can conclude that an increase in the quality level of their manufacturing technology is an important task for mechanical engineering production. In some cases, the solving of this task by means of traditional machining methods is impossible or ineffective. The above relates, first of all, to the blades.

Development of efficient techniques for manufacturing of working disks and nozzle units becomes complicated due to a variety of dimension types and versions of these parts (Fig. 1, b). In addition, the relatively low quantity production of their manufacture (usually individual or small-scale production) impedes the use of modern high-efficiency equipment and appropriate technology. It is worth to notice that in some cases the access to the blade channel is complicated structurally because of the presence of a shroud ring at the periphery of the blades or a small radius of curvature of suction and pressure sides of a blade bottom and blade top.

Billets of bladed wheels are obtained in stampings, billets, obtained by the method of powder metallurgy, castings (precision casting in disposable shell molds),



a) b)

Fig.1. Compressor blisk of a gas-turbine engine *(a)* and working disks of a turbopump *(b)*

workpieces, obtained by the method of laser sintering providing the composition isotropy and properties of a material. When manufacturing single wheels of a gas-turbine engine compressor there are used stamped blanks, bladed disks of turbines are produced from castings, billets from powder produced by hot isostatic pressing [5], working disks of turbopumps are produced from blanks. A promising direction of blank production of small blisks is considered a technology of laser sintering, providing high accuracy and the quality of complicated spatial workpieces. Major role in the achievement of specified performance of this technology is a software product, so it is advantageous to use it in a multiproduct small-scale production.

The most crucial and time consuming stage of manufacturing technology of turbine fans is processing the shape of blades during which engineers set several technological goals:

1.Preliminary formation of the blade profile from billets 01 or 02 by the removal of most of material from the blade channel leaving allowance for final processing. In this stage it is better to use high-performance methods and technologies

2.Formation of top and bottom sides of a blade and transition radii to the hub and shroud ring while maintaining specified tolerances;

3. Finishing process with the formation of the specified properties for surface layer of a wheel space and edges of blades

4. Strengthening of edges, transition radii.

Blades of blisks from blanks (03), (0,4) are not usually treated in stages 1 and 2.

Comparison of the various technology options, suitable for the tasks outlined above, is given in the Table 1. As the statement indicates, for each stage technological decision is multivariate, and there occurs the problem of choosing the best technology in a way that relates to the class of multi-criteria optimization [6].

3. THEORETICAL ANALYSIS

Using the coding system, mentioned in the table, we can make possible routes of processing blades in the form of the M set:

$$M = E_0 \cup E_1 \cup E_2 \cup E_3 \cup E_4 \qquad (1)$$

where $E_o = (e_{01}, e_{02}, e_{03}, e_{o4})$ – a set of blanks, e_{0i} – possible way of obtaining a blank; $E_1 = (e_{11}, e_{12}, e_{13}, e_{14}, e_{15}, e_{16})$ - a set of rough machining technologies, e_{1j} - manufacturing operation according to Table 1; $E_2 = (e_{21}, e_{22}, e_{23})$ – a set of finishing technologies with the corresponding elements; $E_3 = (e_{31}, e_{32}, e_{33}, e_{34}, e_{35})$ – a set of finishing technologies; $E_4 = (e_{41}, e_{42}, e_{43})$ – a set of hardening technologies.

A set of possible routes are graphically presented by a graph whose vertices represent the state of an object of production (the first peak is a blank), and arcs - manufacturing operations in accordance with the Table 1. Each path of the graph is an element of possible routes:

$$m_k = (e_{0i}, e_{1j}, e_{2l}, e_{3n}, e_{4u}) \qquad (2)$$

Expressions (1) and (2) describe the structure of the route, but it is impossible to choose the route based on them, the best in these circumstances. To perform this task, a set of routes are presented in the form of:

$$M= \{E, C, O\}, \qquad (3)$$

where E - a set of elements in the expression (1), C – a set of properties of these elements, O - a set of relations between properties. The basic properties of the elements are shown in the Table 1. The formulation of the relationship between the properties can significantly reduce the number of possible routes.

To do this, the relationship between the properties of the elements of the M set is formalized, using in the simplest case of one-sided or two-sided inequality. Such relationships serve as the conditions, matching rules, restrictions. Not presenting here a formal record, let’s describe some of the relationships between the elements of the M set in words:

- matching condition for stages (sequence of operations);
- the condition of tools accessibility in the work area;
- restriction on strength and stiffness of a tool;
- restriction on workpiece stiffness;
- restriction on blank dimensions.

General method for solution of structural optimization, in this case, involves the following procedures:

- finding a set of possible routes;
- compiling of a system for conditions and limitations with due account taken of the technical requirements and drawing for the specific product;
- reducing the number of possible alternative solutions;
- selection of an optimization criteria;
- formulation of preference rule;
- selection of an optimal (best) technological solution.

In mechanical engineering technology formulated optimization problem is usually solved by a scalar convolution of vector criterion. The main difficulty is the need for technical and economic evaluation for estimating the cost, requiring developed database.

Table 1. Comparative characteristics of alternative technologies for the implementation of the various stages of the wheelspace processing

1	2	3	4	5	6	7	8	9	10	11
Stage	Variant of technology	Code	v_0, mm^3/min	z, mm	Ra, µm	h_d, mm	T_o	C_o	Precision, mm	Restrictions on use
	Laser cutting	12	$(4\text{-}8)\cdot10^3$	1	3,2-6,3	0,3-0,4	5	4	±(0,1-0,2)	Restrictions on thickness and quality of a cut. Heat-affected zone
	Plasma cutting	13	$4\cdot10^4$	2	6,3-12,5	0,3-0,5	5	4	±(0,25-0,5)	Restrictions on thickness and quality of a cut. Heat-affected zone
	Water jet cutting	14	$(2\text{-}4)\cdot10^3$	0,5	2,5-4,5	0,025	4	4	±(0,1-0,2)	Restrictions on geometry of bladed disks, high cost
1	EDM	15	50-100	0,5-1	3,2-12,5	0,05-0,15	1	2	IT11/13	Low productivity
	ECM	16	500-2000	0,3-0,5	1,6-3,2	0-0,015	3	2	IT11/13	Restrictions on geometry of bladed disks.
	CNC machining	17	700	0,2-0,3	6,3-12,5	0,05	2	1	IT 12/13	Restrictions on machinability of the material
	EDM	21	10-50	0,05	3,2	0,01-0,05	2	3	0,05-0,1	Low productivity
	ECM	22	500-1000	0,05-0,1	1,6-3,2	-	5	3	0,1	Special equipment
2	CNC machining finishing	23	200	0,05-0,1	3,2-6,3	0,03	3	2	0,1	Low productivity, high cost.
	ECM (polishing)	31	50-500	-	0,4-0,8	-	5	4	0,08	Special equipment
	Mechanical polishing	32	50-100	-	0,8-1,6	-	1	2	0,1	High labour-output ratio, manual labour
3	Hydroabrasive stream	33	10-50	-	0,8-1,6	-	4	4	0,1	Not uniform material removal in channels of small curvature. Restrictions on geometry of bladed disks, special equipment
	Hydroabrasive extrusion	34	10-50	-	0,8-3,2	-	3	4	0,1	
	Vibroabrasive machining	35	5-50	-	0,2-0,8	-	2	4	0,1	Low productivity
	Shot blasting strengthening	41	-	-	0,8-1,6	-	2	5	-	Compressive stresses. Cheap equipment.

v_0 – volume rate of allowance removal, z – allowance on a side for processing, h_d – thickness of the defect layer, T_0 – relative labor-output ratio, C_0 - relative cost. Columns 8 and 9 are filled on the basis of expert judgment on the 5th grade scale – the higher the score, the lower the rate.

Without such a database we should focus on the existing experience of application of modern technologies in different stages of production of bladed disks. Let's discuss some of the trends specific to the production, as reflected in the Table 1.

In the analysis of technologies based on the so-called beam processing methods (laser, plasma, water jet) we took into account the following.

Volume rate of material removal v_0 for such technologies is calculated by the formula:

$$v_0 = v_c b h, \quad (4)$$

where v_c - linear cutting speed, b - average width of a cut, h - depth of cutting.

Linear cutting speed is related to the depth of cut by hyperbolic dependence:

$$v_c = B/h, \quad (5)$$

where B is a value depending on properties of the material and the machining parameters.

Table 1 shows the data calculated for cutting stainless steel with a thickness of 20 mm. As far as for all beam processing methods there is the area of "quality cut" without jet marks on the walls of a cut, there are

compared roughness parameters typical for this area. Linear cutting speed was taken according to the recommendations given in [6, 7].
Parameters of the mode for the preliminary and final milling of blade airfoil are taken for corrosion-resistant steel. Characteristics of rough and finishing operations of EDM and ECM correspond to the data given in [7]. The characteristic of operations 3 and 4 of stages of processing blades was taken according to the background of the enterprise and the source [2] based on the total treatment area of 200 cm^2.
Application of technologies in the stage 2 based on beam processing methods allows to avoid the necessity of bulk metal dispersion from the blade channel, reduce the complexity of processing blisks, energy intensity and the time of technological cycle. According to a number of important technological parameters, waterjet cutting more preferable than plasma and laser cutting.
In addition, processing of workpieces using powerful localized sources of heat requires to enter into the process operations of heat treatment to relief stress and stabilize the shape of semi-finished product.
That is why a number of leading companies of propulsion engineering industry introduces water jet cutting operation in the second stage of manufacturing technology of open cylindrical bladed disks of compressor. In [7] there is given a technical and economic analysis of the replacement a rough milling processing by water jet cutting and demonstrated the effectiveness of such a technical solution for a particular bladed disk. It is not ruled out that the processing of small bladed disks with relatively small depth of a cut laser cutting operation with an effective cooling of the cutting area will be preferred. So, for small bladed disks, which geometry satisfies adopted restrictions, it is needed to justify the decision of choosing the operation of the second stage by means of a calculation. Electrochemical machining (ECM) has being used for manufacturing bladed disks of a turboshaft engine compressor since 1985. This operation is performed on special equipment and use both in the stage 2 and the stage 3. Calculations show that for a range of blisk sizes this operation successfully compete with the operations of milling and ГАО (in the stage 2) and only absence of technological equipment constrains the application of this operations for manufacturing blades of bladed disk of turboshaft engine.
Considered processing operations of a blade channel are useful on the assumption of ease input of a tool in a blade channel space. This condition is usually satisfied for most of the operations in the manufacturing of open blisks of turboshaft engine compressors. Bladed disks of a turbo pump are usually closed from the periphery by a shroud ring, and blade channel has a shape that excludes the use of milling and operations, based on beam processing methods. In the manufacturing of many blades of this group there is used transitional electric discharge machining to form blade channels. This technology allows us to solve the problem of forming blade channels, however, as shown in the Table 1, it has two disadvantages: low productivity and the presence of the defect layer that must be removed in subsequent operations. The analysis shows that the removal of the defect layer with a simultaneous decrease of the roughness parameter is expedient to use with applying electrochemical polishing operations. The value of the allowance is 10-20% more than the maximum thickness of the defect layer and, depending on the parameters of the previous operation mode, is 15-60 microns.

5. CONCLUSION

The problem of increasing the efficiency of production technologies for bladed disks is formulated and the way to solve it is discussed. Examples are given and the analysis of the effective use of new technologies in bladed disk production is performed.

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