ATTEMPT AT OPTIMIZATION OF THE BLADES' MILLING OPERATION OF THE GE90 TURBO JET-PROPELLED ENGINE'S TURBINE

Jan Wencelis, Marcin Recmanik

S u m m a r y

The article presents results of the research of the optimization of the blades' milling operation of the GE90 aviation engine's turbine. The problem is, first of all, the short tool life, resulting, among others, from the machining-resisting material of the blades (alloys on the basis of nickel and cobalt) and from low rigidity of the processed elements. An analysis has been carried out, whether it is justified to use the tool as far as the machining plates and the geometry of the face mill are concerned. The influence of the position of the face mill with respect to the machined element has been examined, taking into consideration the types of indentation of the tool into the material. On the basis of the research, a modification of the technological parameters of the machining has been proposed, as well as the optimal position of the tool, for prolonging its life, has been determined.

Keywords: milling of the blades, tool life, types of indentation

Próba optymalizacji operacji frezowania łopatek turbiny silnika turboodrzutowego GE90.

S t r e s zc z e n i e

Podstawowym problemem operacji frezowania łopatek turbiny lotniczego silnika GE90 jest mała trwałość narzędzia spowodowana obróbką z trudno skrawalnego materiału łopatek (stopy na osnowie niklu i kobaltu) oraz mała sztywność obrabianych elementów. Przeprowadzono analizę zasadności używanego narzędzia ze względu na rodzaj stosowanych płytek skrawających oraz geometrię głowicy frezowej. Określono wpływ położenia głowicy względem przedmiotu obrabianego, uwzględniając typy wcinania się narzędzia w materiał. Zaproponowano modyfikację parametrów technologicznych obróbki oraz wyznaczono optymalne położenie narzędzia dla wydłużenia jego okresu trwałości.

Słowa kluczowe: frezowanie łopatek, trwałość ostrza, typy wcinania.

1. Introduction

During the process of milling of the elements of the stator blades of the turbo jet-propelled engine GE90, the problem of the low durability of the machining plates has been discovered. Because of the low rigidity of the machined elements and the machining-resistant material of the blades, the

Address: Jan WENCELIS, D.Sc., Eng., The Institute of Machine Technology and Automation, Academy of Humanities and Technology, 43-309 Bielsko-Biała, 2 Willowa St., Marcin RECMANIK, M.Sc., Eng., Elektrometal S.A., 43-400 Cieszyn, 71 Stawowa St.

process of milling takes place in extreme conditions. The initial analysis of the machining enabled to determine the probable reasons of the low life of the tool:

- inappropriate tool (geometry of the face mill and the sort of the machining plates) for a very demanding machined material,
- unfavourable position of the face mill with respect to the machined object;
- not optimal technological parameters of the process.

All of the factors mentioned have a negative influence on the cutting edge's life and result in catastrophic wear of the plates.

The examined blades (2÷6 row of the stator blades) are a part of the turbine of low pressure LPT (Low Pressure Turbine). They work in the area of exhaust gases from the combustion chamber (Fig. 1), which results in very high demands as far as the used material is concerned (high temperature 1100-1300°C, harmful atmosphere).

The analyzed blades were made from the heat-resisting nickel and cobalt alloys and alloys on the nickel base (HRSA – Heat Resistant Super-Alloys). The most popular representatives of this group of alloys are "Rene 77" and "Rene 142" alloys, and the latter is known as the best alloy on the nickel basis used in the aircraft turbines.

It is easy to anticipate that the materials described above, being a masterpiece of the material engineering, pose a great challenge at the attempt of machining. Alloys on the nickel matrix still very recently used to be machined only by abrasive machining. Currently, the rough milling with the usage of the cutting edges from sintered carbides (of the H sort) is possible.

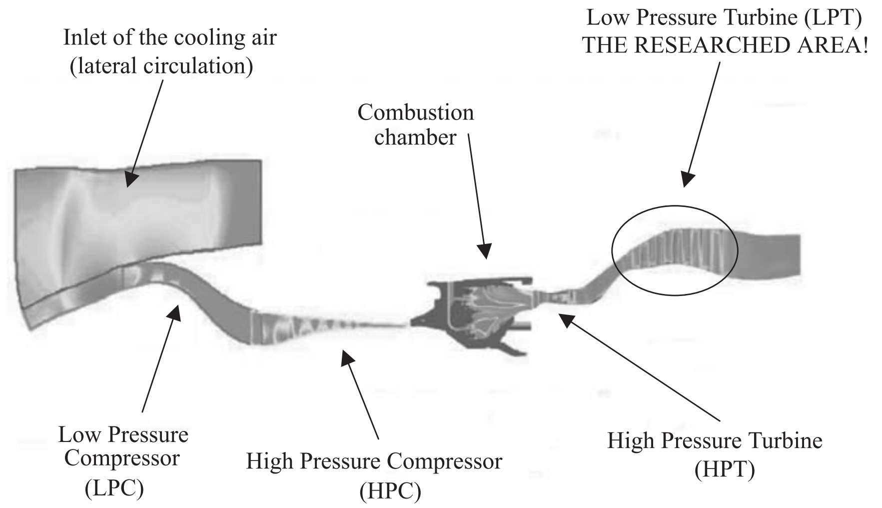


Fig. 1. Position of the researched blades on the chart of the gases stream flow through the GE90 engine [1]

The, so called, “locking pieces” of the blades, which need to resist great mechanical loads (Fig. 2) are processed by milling. Cutting edges from boron nitride or ceramic edges can be used for the finishing machining. Due to the high temperature of the machining and the content of iron in the above mentioned alloys, the tools with diamond edges are not recommended. Moreover, the heat-resistant alloys are characterized by high pressure per unit area on a small surface near the machining edge, as well as the creation of the segment or cog chip. All these factors often lead to the devastating wear of the cutting edge.

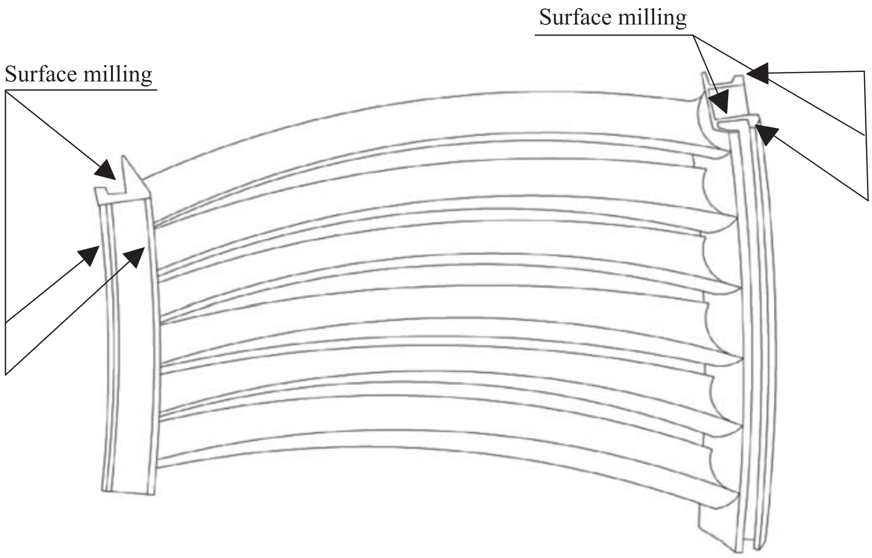


Fig. 2. Row 6 stator blade (STG6) with the marked milling areas

2. Life and wear of the tool

The tools life examination was conducted for the complete rough milling machining done in the machining station SAIMP MECTRA 6. The test concerned the following tools:

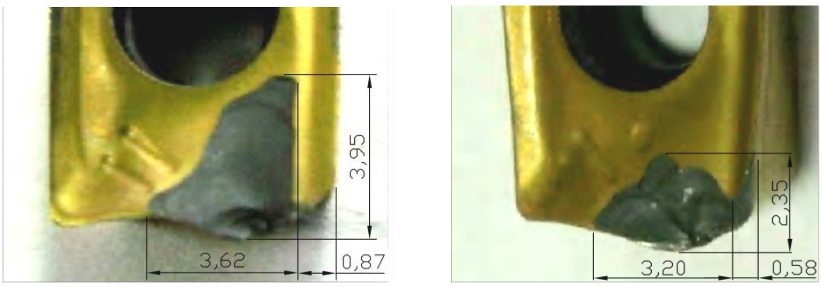
- ϕ 50 SANDVIK face mill, no R390-050C5-36H;
- SANDVIK conic face mill, no 250-R-113200;
- ϕ8 to ϕ12 slotting mill.

The number of the processed blades at one clamping has been assumed as a unit serving the determination of the tools life. This means that if a tool is capable of machining of one blade from both sides it gets two units. The decision of changing of the tool is done by the operator on the basis of observation of the milling process (noise, vibrations) and of the machined surface. The final criterion is the measure of the blade pack at the control stations in order to determine the correctness of the obtained dimensions.

The determined life of the R390-050C5-36H face mill ranges from 2÷6 clampings, i.e. one to three blades at one set of plates. This situation is unacceptable, as far as the costs of producing a blade pack are concerned. The tool for the row 4 blades (STG4 – 2÷4 clampings) has been characterized by the shortest life and it is for this set of blades that we present the following optimization of milling.

Moreover, the form of the wear of the machining plates has not been determined by any wearing criteria known from literature. The plates are damaged due to chipping of the edge and of a large fragment of the tool flank or tool rake (Fig. 3). Further processing with such a tool is impossible and dangerous. Damages of the element involving separating of a piece of corner and pressing it into the machined material by the next cutting edge are likely to happen.

a)



b)

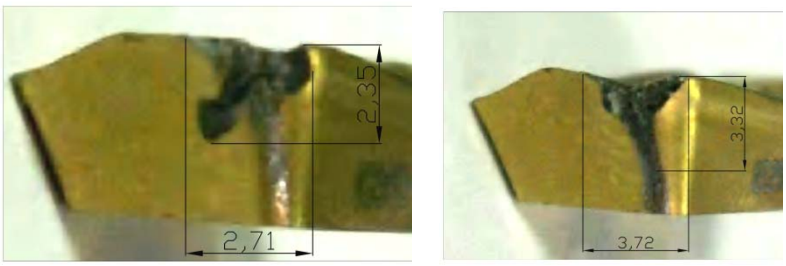


Fig. 3. Damages of the machining plates (R390-11 T3 16M-PM 1025) before optimization: a) tool rake, b) tool flank

3. Analysis of the justification of the usage of the applied tool

Due to the disastrous wear of the machining plates it has been decided, first of all, to determine the suitability of the R390-050C5-36H face mill for the given usage. The tool has been examined as far as the used milling plates (kind and sort of the carbide), tool dimensions and types of the edge's indentation into the material are concerned.

The applied plates no R390-11 T3 16M-PM 1025 are the, so called, rectangular plates of the K = 90° tool cutting edge angle and made of the GC1025 sintered carbide. The main application of these kinds of plates are the, so called, surfaces with rim. However, the producer [2] claims that they are also suitable for processing of the delicate constructions of thin walls. It is due to the fact that the majority of the generated machining forces are radially directed. It means a low axial load of the processed element and thus the risk of damaging of the machined walls is decreased. The surfaces researched in the paper are a few millimeters wide and are indeed elements of thin walls, so from this perspective the choice of the plates seems to be justified. Due to the disastrous wear, however, the application of the "H" model (Heavy), having strengthened geometry or of a plate from a different kind of carbide should be considered. Other proposed kinds for milling of the HRSA materials are:

- H10F – plates from an uncoated carbide of a very high hitting resistance;
- GC2030 – plates from carbides coated with the PVD method for medium precise and rough milling.

To be able to conduct the full analysis of the justification of the usage of the applied tool it is necessary to provide the information about its geometry. Tool rake angles are significant at determining the type of indentation. Thus, apart from the position of the tool in relation to the machined element, also the geometry suitable for the given operation influences the optimal type of indentation. Literature presents the dependences between the size of the processed surface and the geometry of the face mill, which enable the determination of the type of indentation. The parameters below are necessary for the determination of the type of indentation:

- inlet angle ε, and thus indirectly: the diameter of the face mill d and the distance from the indentation edge A;
- axial tool rake angle γ_p;
- radial tool rake angle γ_f;
- tool cutting edge angle K.

Thanks to introduction of such prepared data to the proper dependences, it is possible to determine the point of the first contact (Fig. 4) and the type of the face mill indentation, and thus possibly to start acting specifically to find solution for the unfavorable area of the tool's work. Literature presents three basic types of the face mill indentation:

- VST – unacceptable type of indentation;
- VFT – not recommended type of indentation;
- VUT – optimal type of indentation.

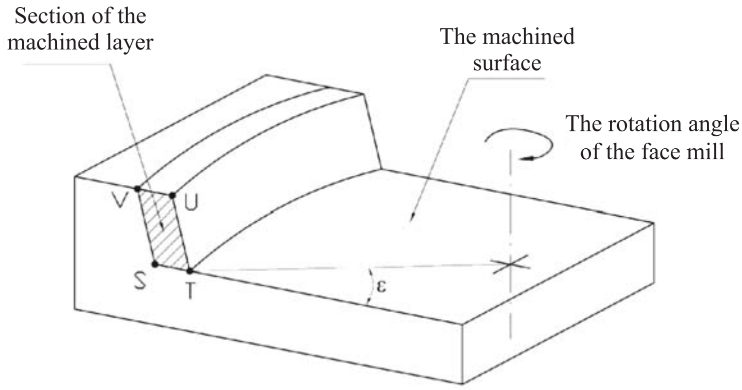


Fig. 4. Geometry of the layer machined by the face mill

In these types of indentation the first contact point of the tool with the processed material may have the position in the points VUTS or in the positions between.

Thus, there appeared the necessity to measure the interesting angles, which was done using the measuring device ECO 210 MicroSet from the DMG company. The results of the measuring are shown in Fig. 5.

A computer program for simulation of the indentation of the face mill in the surface, limited by practically any outline, has been written in order to simplify the process of determining the type indentation of the face mill. The application has been created in Delphi (Delphi 7.0) system. The program uses the included in literature [3] formula that identify the contact point and indentation type for face milling on the basis of the face mill's geometry, shape of the processed surface, position of the face mill in relation to the processed surface. The examined outline should be prepared earlier, e.g. in any version of AutoCAD, and saved in DXF format. The outline should be closed.

Having the full geometry of the face mill, a simulation of the justification of the usage of a given tool has been carried out (Fig. 6). The simulation was done, as follows:

- a surface has been selected for the simulation (row IV, operation 03);
- not changing the position of the face mill, the indentation type for a currently working tool has been determined (type: VST contact point: S);

• an attempt at modification of the face mill's geometry has been done in order to obtain the optimal contact point.

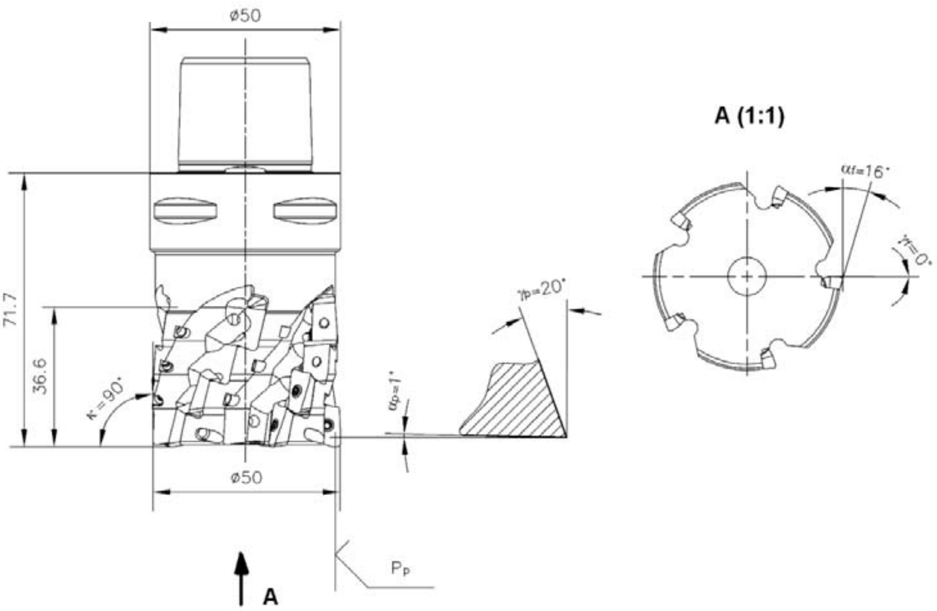


Fig. 5. R390-050C5-36H face mill with the determined geometry [4]

Already the first simulations prove that we are dealing with the worst type of indentation VST and in this type work starts in the most damage-exposed place S. Simulation has been done within certain distances on the whole length of the processed surface and it has been noticed that the unacceptable indentation type VST has appeared continuously during the work of the face mill.

In the next step the mill's geometry has been modified and the results were as follows:

• no change of the radial tool rake angle γ_f (positive-negative) has any influence on the indentation type of the face mill;

• the change of the tool cutting edge angle K between 45°-90° does not change the type of indentation;

• attempt at diminishing/enlarging the tool's diameter does not give any result;

• the only possibility is the modification of the axial tool rake angle γ_p, where a small negative angle value is sufficient to obtain the optimal indentation type VUT.

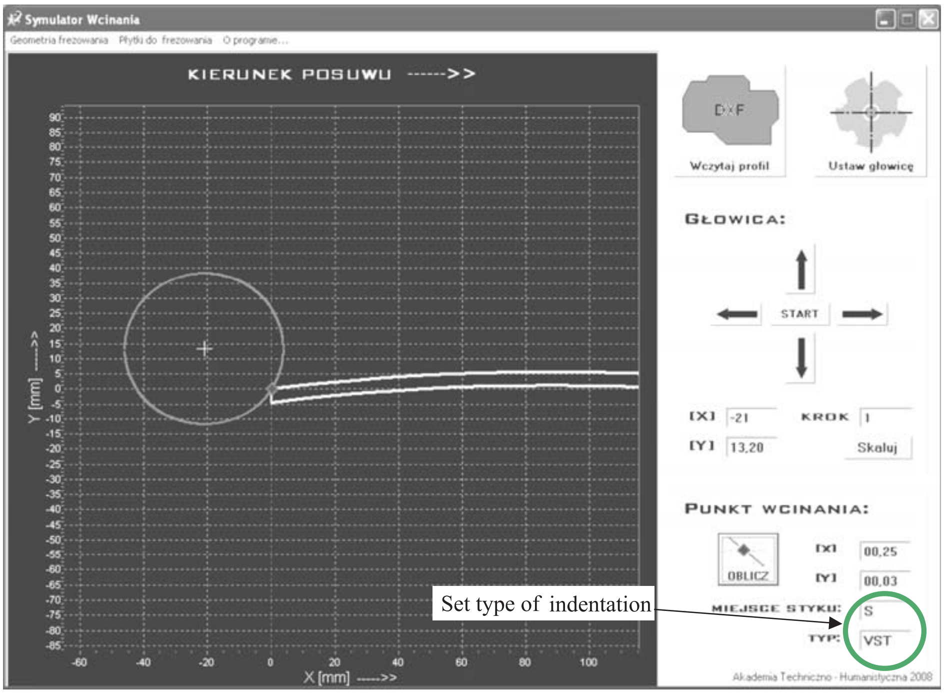


Fig. 6. Results of simulation for row 4 (STG4) and operation 03

Not many face mills available on the market enables using the negative tool rake angles. Such solutions can be found in the series of AUTO mill from Sanvic company, that are intended for the machining of the cast-iron blocks of combustion engines. However, these tools are very complex in construction and very expensive. An alternative might be the face mill for hard machining, marked as T-Max 45. The machining plates are not fixed directly in the face mill but in special holders, enabling the positive and negative regulation of the tool rake angles.

4. Optimization of the position of the face mill in relation to the processed object

Due to the specific character of the hereby examined surfaces (very small width of the milled surfaces, small thickness of walls, small rigidity of the elements), the distribution of the machining forces and the way they load the processed elements should be noticed. Figure 7 presents two situations with different position of the tool. In case a), when the mill's axis is near the processed edge, the angle that is formed by the direction of the force F_C and tangent to the surface [α] is close to 90°.

In such a case the machined wall is loaded with a force of the direction similar to normal, so in the direction most susceptible to deflection. Cyclically deflecting wall causes vibrations, transmitted partially on the tool, loading it additionally.

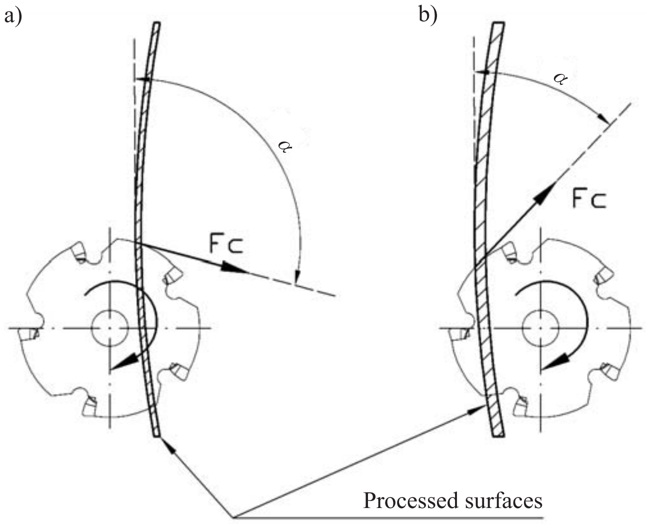


Fig. 7. Influence of the face mill's position on the direction of the circumferential machining force Fc

A better situation is shown in Fig. 7b, where the mill's axis is distant from the machined edge. Angle [α] is an acute angle of 30-45°. A force directed in such a way loads the wall in the direction of higher rigidity, which happens due to its construction. Such position of the tool will enable reducing vibrations and partially prolonging the tool's life.

After a series of simulation, it has been determined that at a given diameter of the face mill and constant geometry, it is impossible to change the indentation type VST to the less harmful VFT, or to the recommended VUT. It is due to a few factors:

- the position of the mill in some cases is limited due to the simultaneous face and lateral surface machining;
- uniform shape of the machined surface hinders finding a place of better geometry for the appearance of the optimal indentation type;
- the accepted geometry of the tool is not proper for the given surface.

However, a method has been found for changing the contact point in the area of the type of indentation VST from point S to point V (Fig. 8)

Point V is a bit more distant from cutting edge's corner (Fig. 4) and in spite of the fact that it lies on the cutting tool's edge, the plate in the area is more rigid and has better resistance to hitting.

Moreover, it can be observed from the research of the plates' durability that during the processing of the blades in which the first contact point V (STG5, STG6) appears, a better durability of the tools is obtained. The fact is used at creating a modified movement trajectory of the tool and, where possible, the position of the face mill guaranteeing the first contact point V has been proposed.

Fig. 8. Results of simulation of the blades STG4 and operation 07 [modified position of the mill]

In order to obtain a real confirmation of the results of simulation, we have decided to carry out an experiment through an attempt at implementation of the proposed movement trajectory of the tool (R390-050C5-36H), for one row of the blades.

The research has been done as follows:

- row 4 (STG4) of the stator blades has been chosen as an object of research, due to the lowest obtained durability if the machining plates (Fig. 9);

• a controlling program for a machine tool SAIMP MECTRA 6 has been prepared, for both of the mounting of the blade (front, back), taking into consideration new positions of the tool (Fig. 10);

• new machining plates has been installed on the face mill (5 pieces: R390-11 T3 16M-PM 1025);

• a machining with a face mill has been carried out, for the amount of blades equal the plates' life for row 4 (3 sides);

• after finishing of the machining the plates have been taken out and next observed and their damage documented (Fig. 11).

No	Material allowance, mm	Tolerance mm
1	0,6	± 0,2
2	0,6	± 0,2
3	0,6	± 0,2
4	0,6	± 0,2
5	0,6	± 0,2
6	0,6	± 0,2
7	0,6	± 0,2

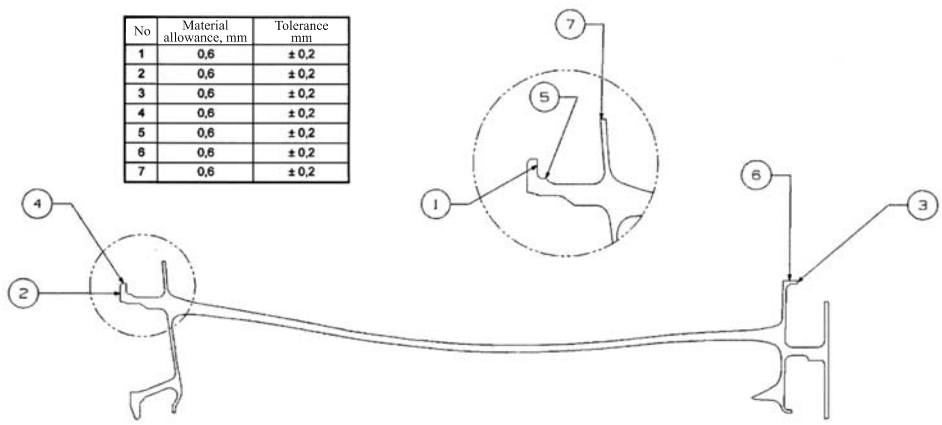


Fig. 9. Tolerance and allowance for STG4 blades

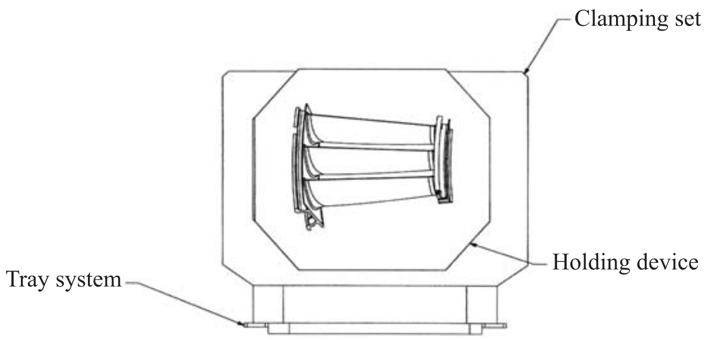
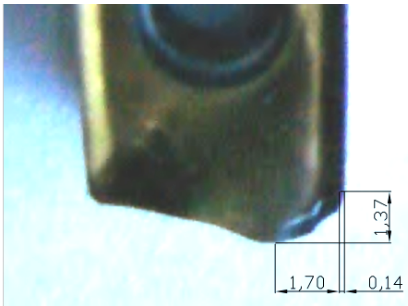


Fig. 10. Method of positioning the blade pack on the machine tool tray

The results of the experiments are promising. Still the wear of the plates does not meet the standard criteria of the tools wear (chipping of the corner of the cutting edge), but the size and character of the damage is visibly smaller.

A small part of the cutting edge's corner is susceptible to damage and the torn out pieces do not pose a huge threat for the machined detail. The edge is deformed but its integrity is untouched, which can be seen on the plates before optimization (Fig. 3.).

a)



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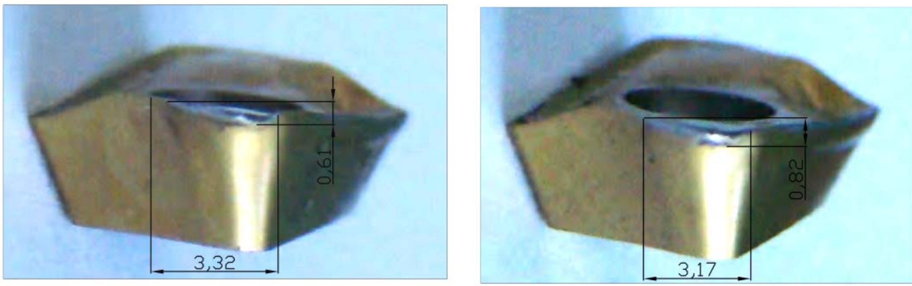

Fig. 11. Damage of the machining plates (R390-11 T3 16M-PM 1025) after optimization: a) tool rake, b) tool flank

5. Technological parameters of the process

The technological parameters used in the milling process are determined individually per each of the processed surfaces. It is due to the fact that for the bigger surfaces, bigger feeds can be applied because of their greater rigidity. The parameters read from the controlling programs are in the ranges below:

- speed of machining v_C = 40-55 m/min;
- feed for the cutting edge: f_Z = 0,04-0,09 mm/cutting edge;
- depth of cut: a_p = 0,3-0,7 mm.

Manufacturer of the tool recommends applying speed of machining v_C = 35-40 m/min (values for the type of carbide GC1025), for milling of the superalloys based on nickel. Literature [5-12] recommends not exceeding the value of 30 m/min for roughing. It may be concluded, that the applied speed of machining is also the reason for quicker wear of the tool. According to the possessed information, the optimal speed of machining is v_C = 30-35 m/min.

In case of the feed for the cutting edge, the recommended values are between f_Z = 0,06-0,15 mm/cutting edge (for the mill from 390 group and M-PM geometry). The applied feed is thus set with a carefulness resulting from the machining-resistant material. Keeping the feed in the range 0,04-0,09 mm/ cutting edge can be assumed as justified.

The applied depth of cut constitutes the whole allowance for roughing and it is collected during one cut. Applying two cuts would prolong the machining time significantly and would be unprofitable. Besides, the depth a_p = 0,3-0,7 mm at the size of the plate 11 seems to be reasonable.

6. Conclusions

Geometry of the applied tool is not proper for the machined material. The results of a computer simulation confirm the fears for the appearance of the worst type of indentation VST. Proposed solutions to the problem are, as follows:

a) applying a plate of a hardened geometry (HEAVY);

b) change of the type of sintered carbide into GC2030 or H10F;

c) change of the face mill into a tool that has adjustable tool rake angles or with a negative axial tool rake angle γ_p.

The position of the face mill is not optimal in all the cases. Such a position of the tool has been determined, that enables changing the first contact point with the material from *S* into the safer *V*. While creating the new trajectory of the face mill, also the rigidity of the machined elements and the possibility of shortening of the tool's track has been taken into consideration. After an experiment, further appearance of the wear in the form of chipping and cracks on the surface of the plate has been noticed. An analysis of the photos taken enables to find a significant improvement, in comparison with the plates examined before the optimization (Fig. 3).

Due to the short tool life, a reduction of the technological parameters of machining should be taken into consideration. The proposed changes (recommendations of the tools' manufacturer and literature [5]) are, as follows:

a) reducing the speed of machining from the current v_C = 40-55 m/min into the speed v_C = 30-35 m/min, which corresponds to the rotational speed of the spindle S = 190-225 rev/min;

b) reducing the scope of feed of the applied tool from F = 50-150 mm/min into F = 50-100 mm/min.

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