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Development of technological process of metal machining from stamping on 5-axis CNC milling machine

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Abstract. The technological process of compressor working blade production from stamping with minimum allowance for machining of the working part, on 5-axis CNC machine aimed at reducing the units of machine equipment has been developed. The tooling for basing the working part of the blade on the principle of six-point basing adapted to the design of the machine tool is realised. The geometrical parameters of the obtained blade were analysed with its mathematical model by 3D scanning method.

1 Introduction

Blades of water engines used in civil engineering have a complex geometric shape, which causes not only labour-intensive technological process of production, but also high cost of blade manufacturing. When operating a turbine, blades are in an aggressive environment; in addition to prolonged mechanical load, the blades are also subjected to prolonged temperature load, corrosion, and erosion. To ensure the operation of blades in such conditions are used: high-alloy stainless steels [1].

The complexity of machining materials by cutting is primarily due to their mechanical properties, so to increase the productivity of machining, castings or forgings instead of bars are used as blanks for subsequent machining. The choice of such blanks increases the material use rate many times, reduces the machining time, and also reduces the consumption of cutting tools. But at the same time, due to the complex geometric shape of the workpiece, there is a need to use special tooling for basing and fixation of the workpiece in the manufacturing process, which in turn complicates the technological process [2-3].

Fig. 1. The results of scanning the stamping of the water mover blade MP-TR-210.17. The distinctive features of this stamping from the volume stampings are: minimum allowance for machining of the working part. $0.3^{+0.2}_{-0.05} mm$, machining allowance for the locking part $3 \pm 0.5 mm$, lack of technological bases, lack of material to machining the technological base surfaces for subsequent machining in a 5-axis machine (for one installation) [4-5].

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One of the main objectives in selecting bases is to minimise the tolerance margins for the dimensions of the main most important blade elements and their location. This reduction is inevitable due to the change of bases when the part is set for machining [6].

2 Methods and Materials

In this case, the workpiece setting base is the profile surface of the working part, which is defined with a smaller allowance or is made without allowance. The edge of the working part should serve as the guide base, and the end of the workpiece on the tail or head side should serve as the reference base. As a rule, the tract part of the workpiece is taken as the reference base. In this variant of the tooling, it was decided to prepare one of the basic technological surfaces by trimming the feather end on an erosion machine [7]. Thus, the blade-based scheme will be a restriction of 3 points on the feather sections on the back side, 2 points on the exit edge side, and the plane obtained after the electrical erosion operation Fig. 2.

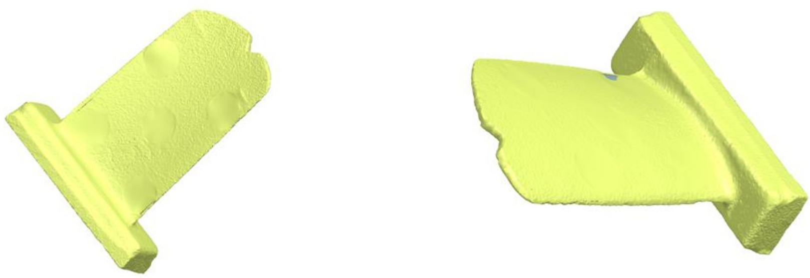

Fig. 1. Scanned model of a compressor blade stamping

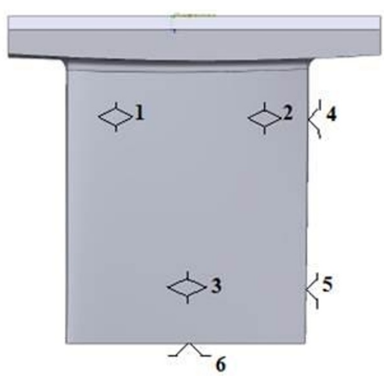

Fig. 2. Schematic of workpiece basing

Table 1. The technological process of blade manufacturing

no.	Type	Description	Machine
005	Electroerosive	End trimming with allowance (process base)	Sodick AQ535 CNC EDM machine
010	Milling	Tail machining	Hamuel Reichenbacher HSTM 500 5-axis CNC milling machining centre

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015	Milling	Feather machining with polishing allowance	Hamuel Reichenbacher HSTM 500 5-axis CNC milling machining centre
020	Electroerosive	Cutting the blade to size	Sodick AQ535 CNC EDM machine
025	Polishing	Polishing of the blade working part	not available

The kinematic diagram of the milling machine is shown in Fig. 3. 3. The workpiece can be installed in 2 horizontal driven counter spindles, which perform synchronised rotation around the axes A, U and are able to move together along the X axis. The main spindle with the tool is located on the bed which moves on guides along the Y and Z axes, tilting of the spindle is possible by means of a rotary head around the B axis, which provides continuous 5-axis machining [8-9].

The blade blanks are usually mounted on the counter spindle using a self-centring vice. Typical vises are shown in Fig. 4-5.

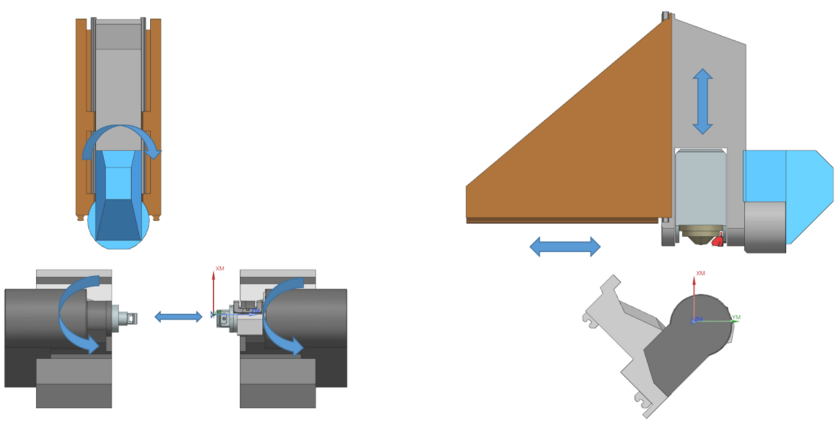


Fig. 3. Kinematic diagram of the Hamuel Reichenbacher HSTM 500 machining centre

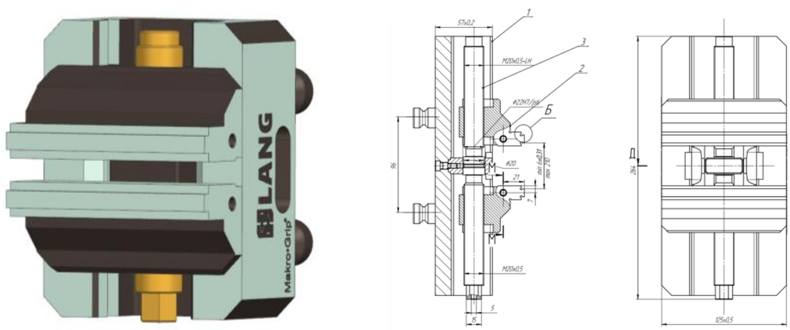


Fig. 4-5. Schematic of a typical Lang self-centring vise for the Hamuel Reichenbacher HSTM 500.

Based on the data on machine kinematics and machine tooling, special vise jaws have been developed. The profile of the jaws is shaped to confine the blade in 6 degrees of freedom. This leaves free access of the tool for milling the tail part of the blade. In Fig. 6. A 3D model of the jaws is shown. Instead of the standard modification of the jaws of the so-called crocodiles - Jaws 2 - special Profilo jaws are installed on the screw. A pyramid-shaped profile has been milled on these jaws to ensure tool access to all machining surfaces of the blade. On the ends perpendicular to the axis of the screw 3 are made holes for pins and 2 threaded holes, which allows to make this design of the vise modular [10-12]. The jaws themselves are also made with pin holes and bolt holes. Each jaw has its own profile:

Back profile - the sections correspond to parts of the blade profile at points 1-3, this solution allows, in contrast to repeating the complete blade profile, to minimise the effect of workpiece shape error on the setting. The two side planes are made in such a way as to limit the 2 degrees of freedom of the blade at points 4-5. Plane 6 is adjacent to the plane of the workpiece previously received at operation 005, thereby eliminating axial movement of the blade. Also, a threaded hole is made in the wall parallel to the exit edge to limit movement of the blade along the Y axis [13-15].

Trough profile - the sections correspond to the trough profiles at points 1-3. Taking into account the fact that the vise is capable of clamping the blade only in one direction, and the profile of the working part of the blade has its own curvature, it is necessary to ensure that the workpiece is clamped along the trough profile at each of the 3 points of the profile by applying a force in the direction of the normal to the base point. For this purpose, one of the jaws has a hole with a counterbore for a spherical pusher and a thread for a fixing screw. This solution made it possible to eliminate vibrations arising in the process of machining the tail part in the area of the blade exit edge [16].

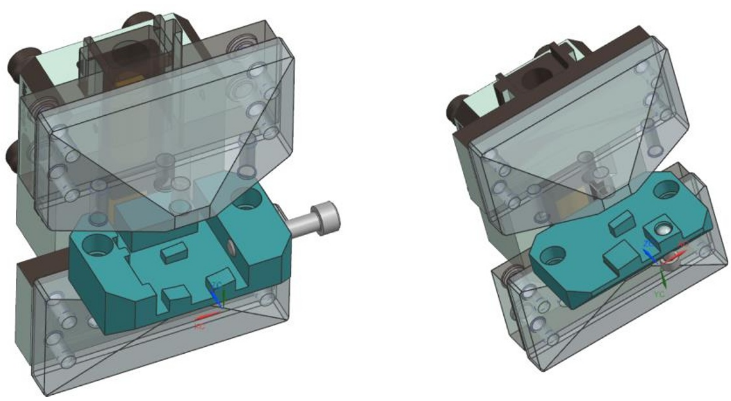


Fig. 6. a, b Model of the jaws of the profile vice, c - model of the vise with the blade assembly.

Trajectories of the control programme for machining of the lock part are shown in Fig. 8. To control the linear dimensions of the locking part and the subsequent correction of dimensions in the machine, standard measuring tools were used - micrometer - Micrometer MK 75-1 GOST 6507-90 [17]. Also a set of templates (pass/no pass) for controlling the size of the fullness of the cone (see Fig. 8-9) was made on an electric discharge machine.

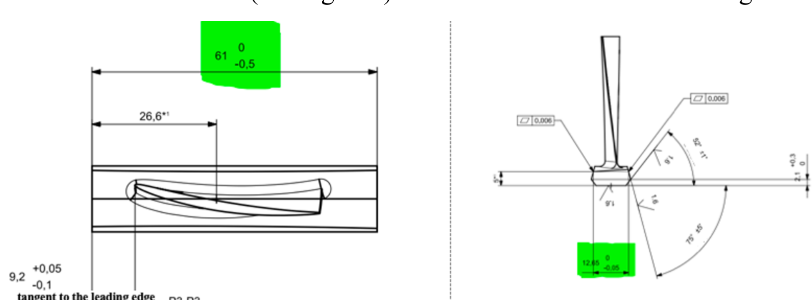
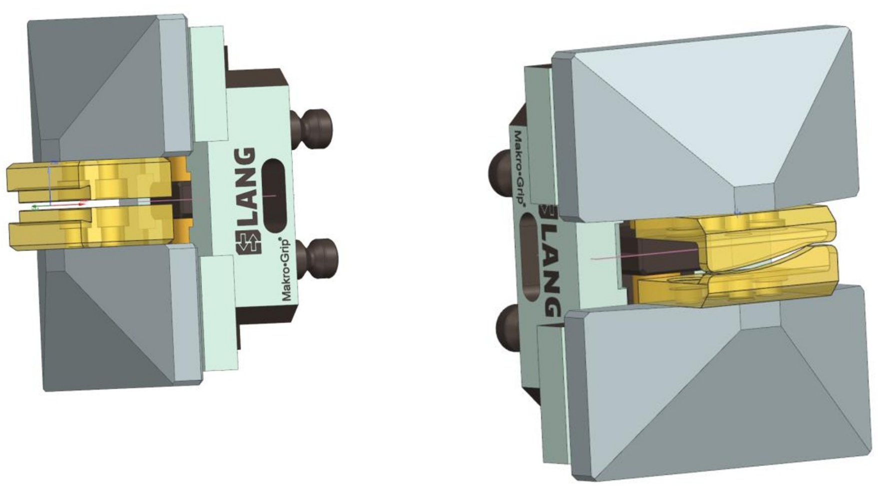


Fig. 7. Controlled dimensions at operation 010

Fig. 8. Measurement tools

During the machining of the blade working part and the tract part, the blade will be based on the previously machined shank [18]. For this purpose, a set of dovetail jaws for basing the blade on the shank, a set of jaws made according to the profile of the working part of the blade to clamp the blade on the side of the working part and minimise vibrations arising during the machining of the feather of Fig. 10 [19-20] were manufactured.

At this operation, the tract and working parts of the blade were milled with an allowance of +0.1 mm for further polishing operation. The milling trajectories of the working and tract parts are shown in Fig. 11. The blade after milling is shown in Fig. 12 [21].



a) b)

Fig. 9. 3D jaw models for operation 015

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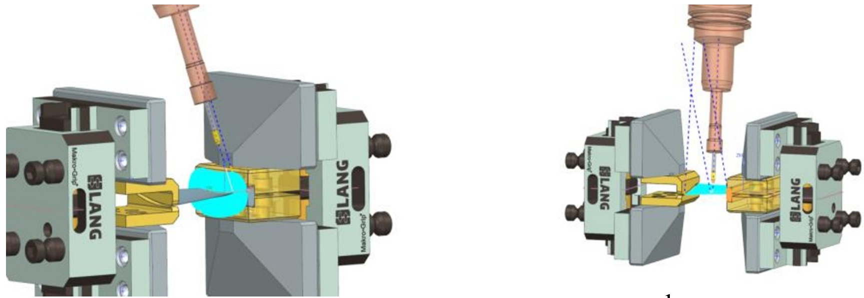

a b

Fig. 11. a. Tool trajectories for milling the blade tract. b. Tool trajectories for milling the working part of the blade.

Fig. 12. a. Result of milling the blade on the back side, b. Result of milling the blade on the trough side.

After the milling operation of the working part of the blade, a polishing operation follows to ensure the required roughness (Ra.0.4). It is important to maintain the previously formed blade profile, for this purpose the polisher must control the blade profiles with a PMKL (Blade Mechanical Control Instrument) [22-25].

The principle of operation of the fixture is as follows:

- the blade is installed in the fixture by the tail part.
- the fixture has special grooves corresponding to the cross-section to be controlled. For each section, a set of prisms was made, repeating the profile of the section from the back and trough sides.
- section control is performed by visual inspection of the fit of the profile of the prisms to the profile of the blades. The amount of deviations is also controlled by means of sets of feeler gauges. The fixture and installation procedure is shown in Fig. 13 a, b [25-27].

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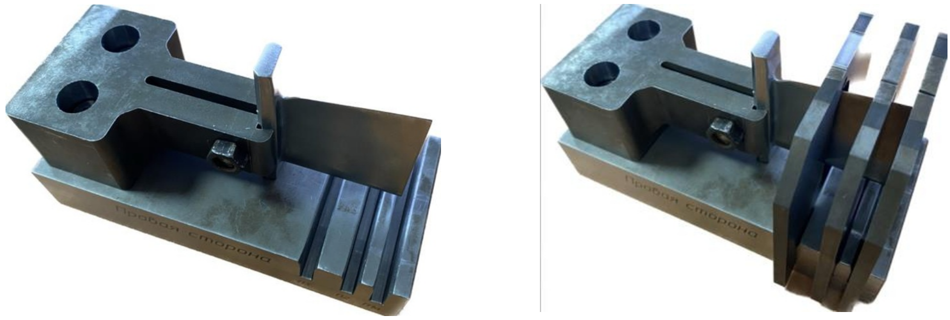

Fig. 13. a. Installation of the blade in the PMKL, b. Checking the blade cross-sections with the help of PMKL prisms.

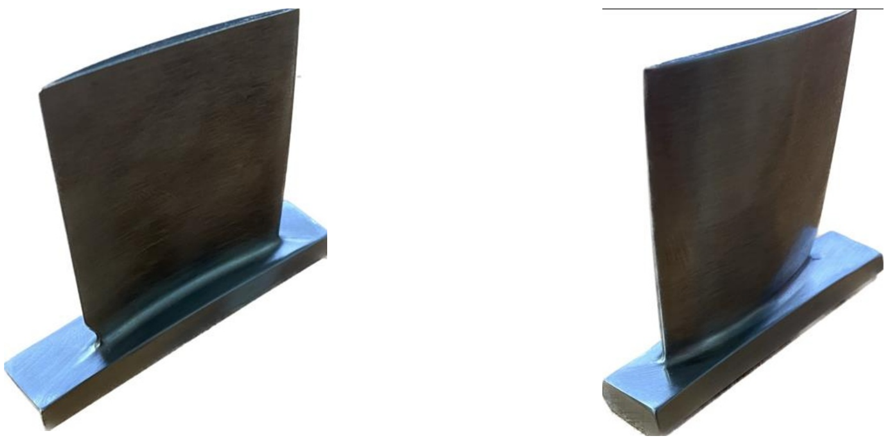

Fig. 13. a. Installation of the blade in the PMKL, b. Checking the blade cross-sections with the help of PMKL prisms.

3 Results

Control of geometric parameters of the finished product is carried out by means of optical geometry control (3D scanner).
- Equipment: Optical 3D scanner ATOS Q
- Accuracy of measured data up to 0.006mm.

The equipment allows you to control the external geometry of the product.

Output data - point cloud file in STL format.

The inspection software is Geomagic Control X.

Fig. 15 a, b, c. shows the results of geometry control of the finished compressor blade realised using the above-described technology [27-31].

Fig. 15a. Inspection of blade geometry and deflection in the longitudinal section.

outcome data
actual values
deviations
name
result name
allowance
reference value
actual value

Fig. 15b. Checking the linear dimensions according to the drawing.

4 Conclusion

The advantages of the technology are as follows:
- Use of 3 units of machine tools
- 2 operations with change of base surfaces
- High speed of part production
- Repeatability
- High accuracy of the final product

Disadvantages of the technology:
- Obtaining the final dimensions of the working part at the polishing operation
- High tool consumption during machining of the workpiece
- High auxiliary time T_{aux} on operations 015
- High auxiliary time T_{aux} on operations 025.

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