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Calculation of the Planer Tool with a Glance of Physical Components of the Cutting Process Acting on Limited Contact Areas

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Annotation. The article covers the designing of the planer tool considering the physical components of the cutting force acting on limited areas of chip contact and tool durability.

Keywords: planer tool, 3D model, feeding, cutting modes, contact voltage plot, stress-strain state, force, cutting part.

Machining the surface of the pocket with end mill is problematic because of the low rigidity of a long end mill and the impossibility of machining the surface under the overhanging upper part of the blank (Fig. 1 and 2), therefore, it was proposed to machine the surface of the pocket with a planer tool of width $b_p = b_п$, where $b_п$ is the width of the narrow part of the pocket. $b_п$ = 8 mm (Fig. 2 a and 3).

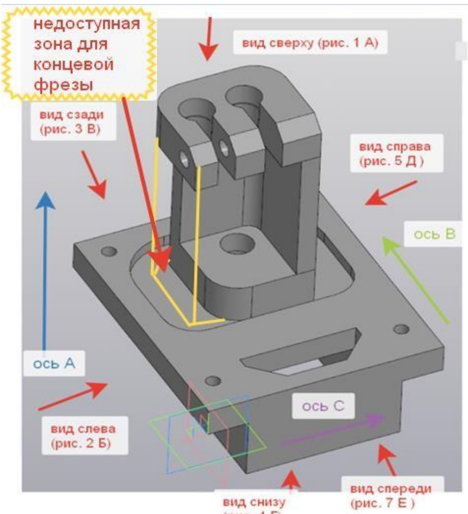

Fig. 1. 3D model of the blank indicating the inaccessible zone for the end mill during processing

The casting already has a pocket, but the stock needs to be removed to obtain a better surface finish.

Digging of the planer tool should be carried out gradually, as for the cut-off cutter: 0.1 mm per 1 mm of longitudinal feed, i.e. $s_{верт}$ = 0.1 mm/1 mm product feed, i.e. after 19 mm of longitudinal feed, digging will occur even to the full depth $t = t_{max}$ = 1.9 mm.

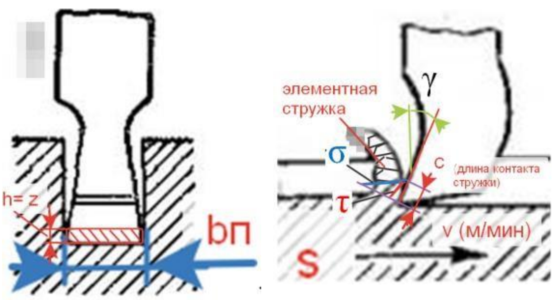

Fig. 2. Pocket planing scheme in front view (a) and side view (b).

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For planing slots and grooves, slotted cutters are used [1]. The cutting depth *t* of a cutting tool is the width of the cutting blade of the tool, i.e. $t = b_п$.

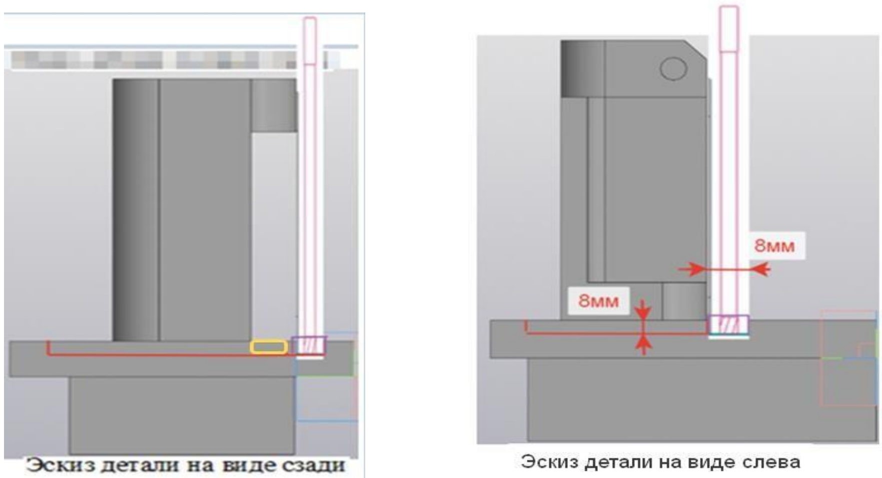

Fig. 3. View of the blank showing the inaccessible area for the end mill when machining a pocket (a) and the minimum slot width (b).

Cutting depth. For all types of planing and chiselling, the depth of cut is assigned in the same way as for turning.

Feeding. For rough planing feed *s*, mm/mov.stroke, the maximum of the allowable values is chosen [2] in accordance with the depth of cut, the cross section of the holder, the strength of the plate; when finishing, planing, cutting and bite grooves [2].

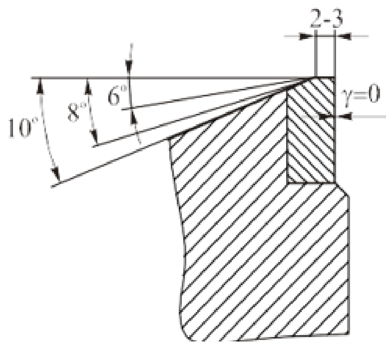

Fig. 4. Geometric parameters of a conventional planer tool in the main cutting plane.

Cutting speed. When planing planes with through cutters, cutting and bite grooves, the cutting speed is calculated according to the corresponding formulas for turning with the introduction of an additional correction factor K_{yv}, which considers the shock load [2]. In our case, there will be no shock load, because the cutter will smoothly cut into the surface of the pre-cast pocket, but due to the cutting, the forces will be increased during this period.

Cutting data for planing

Table 1.

Nature of processing	Area of cultivated surface, m^2	Number of passes *i*	Depth of cut *t*, mm	Feeding *s*, mm/mov. stroke	Cutting speed *v*, m/min
Semi-finish Rz = 40 - 10мкм	—	1	To 2	10-20	14-18

Notes: 1. The straight section of the blade is controlled by the curved ruler. 2. The surface to be treated is moistened with kerosene.

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Calculate the force $\boldsymbol{P_z}$ when planing with a cutter: $P_z = 10C_p t^x s^y v^n K_p$ (H).

$Kp = K_{Mp} \cdot K_{\varphi p} \cdot K_{\gamma p} \cdot K_{\lambda p} \cdot K_{rp}$

For gray cast iron SCh20 (GOST 1412 -85):

The coefficient and exponents in the formulas for the components of the cutting force during turning and planing

Table 2

Material to be processed	Cutter	Type of processing	Coefficient and exponents in formulas for components											
			Tangential Pz				Radial Py				Axial Px			
			Cp	x	y	n	Cp	x	y	n	Cp	x	y	n
Malleable iron, *HB* 150	Hard alloy	External longitudinal and transverse turning and boring	81	1.0	0.75	0	43	0.9	0.75	0	38	1.0	0.4	0
		Cutting and bite	139	1.0	1.0	0	—	—	—	—	—	—	—	—

When ensuring the cutting speed during planing due to the table feed, it is necessary to clarify the maximum allowable feed rate with the provision of the necessary feed force.

When planing, we accept that in the formula for calculating the cutting force, the feed s = 1 mm/rev corresponds to the depth of cut during planing (the thickness of the allowance removed in one pass z = 1 mm). $P_z = 10 \cdot Cp \cdot t^x \cdot s^y \cdot v^n \cdot K_p$

In the technical passport of the machine (machining center IS-800) we find the maximum allowable feed force of the table Ps = 12500 N, therefore, planing with the assigned mode (the width of the planer cutter is 8 mm, the depth of the allowance to be removed in one pass $h = z$ = 1 mm) is possible . The feed rate (cutting speed during planing) to create a force on the machine table Ps = 12500 N is assigned $s_{мин}$ = 1000 mm/min, or v = 1 m/min.

The IS-800 multi-purpose machine with a combined numerical control system, automatic tool and blank changer is designed for processing small-sized body parts of a particularly complex configuration.

Another important feature of multi-operational machines is the presence of a rotary table or dividing device with periodic or continuous (according to the program) division. This is a prerequisite for processing the blank from several sides without resetting. MS of new designs are equipped with additional tables and devices for automatic change of blanks.

Calculation of the physical components of the cutting force acting on limited areas of chip contact

Plots of contact stresses are built according to the physical components of the cutting force. For finite element analysis using the ANSYS program, it is necessary to set the load on each limited area of the contact surface of the chip with the front surface of the tool in the direction of the technological axes OZ, OX and OY.

When considering the loading of a replaceable polyhedral plate (LPP) in the main cutting plane, one usually operates with the OZ axis and an additional axis passing in the main cutting plane parallel to the main plane. In this case, it is often assumed that the component cutting force ***Pxy***, calculated by the formula:

$$P_{xy} = \sqrt{P_x^2 + P_y^2}$$

It passes in this main cutting plane *N-N* or in the cutting plane $NP\ xy$ - $NP\ xy$, approximately coinciding with *N-N*.

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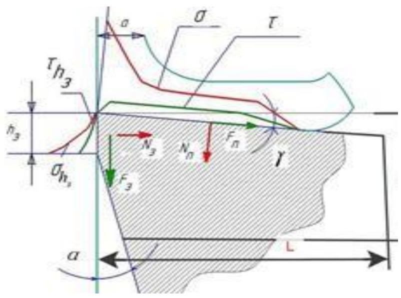

Fig. 5. Forces and distribution of contact stresses on the front surface of the tool and the chamfer of the back surface.

With such a small assumption, in order to calculate a simplified cutting wedge in the section $NP\ xy$ - $NP\ xy$ using the ANSYS program, it is necessary to set the load on each limited area of the contact surface of the chip with the front surface of the tool in the direction of the technological axes OZ and OY'. The stress-strain state (SSS) of a simplified cutting wedge in the section $NP\ xy$ - $NP\ xy$ is comparable to the stress-strain state of a cutter with rectangular free cutting [3]. Dimensions h and L (Fig. 5) are set when limiting the SSS calculation area to reduce the likelihood of an ANSYS program failure when using a computer with insufficient power. When planing SCH20 cast iron, when applying an external load in the ANSYS program, we divide the front surface of the cutting tool model into small sections with a length $L_{\text{п}i}$ = 0.05-0.2 mm and a width b equal to the width of the chip contact with the front surface (Fig. 6). On each i-th section, according to the diagrams of contact stresses, we determine the physical forces Ni and Fi , which we apply to the corresponding i-th section.

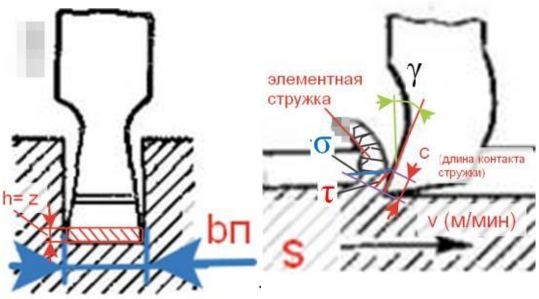

Fig. 6. Removable allowance z (a) and distribution of normal σ and tangential τ contact stresses on the front surface of the cutter (b).

$Ni = \sigma_{i\text{ср}} \times L_{\text{п}i} \times b$ (H); $Fi = \tau_{i\text{ср}} \times L_{\text{п}i} \times b$ (H),

where: $\sigma_{i\text{ср}}$ is average contact normal stress on the section $L_{\text{п}i}$; $\tau_{i\text{ср}}$ is the average contact shear stress in the section $L_{\text{п}i}$

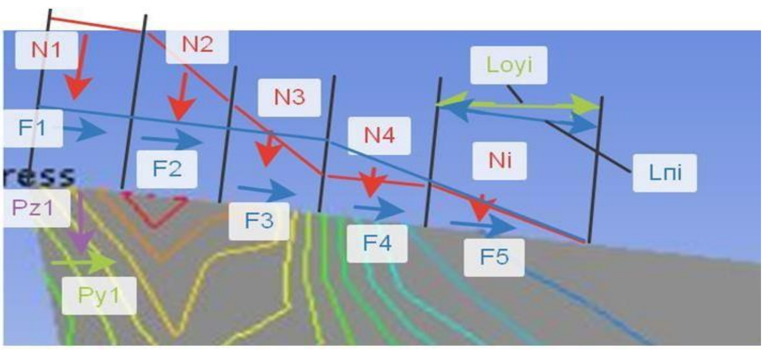

Fig. 7. Forces determined from the diagrams of contact stresses σ and τ, in different areas of chip contact with the front surface of the cutting tool.

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The ANSYS program defines forces along the OZ, OY, and OX (or OY') axes. Therefore, the calculated physical components in each section are converted into technological ones according to the appropriate formulas. When considering forces in the main secant plane, it is necessary to add the OXY axis, which will be denoted as OY for simplicity of notation, i.e. $Py = Pxy$. Two technological components will act from the physical force Ni: $Pz\ Ni$ and $Py\ Ni$; two technological components will also act from the physical force Fi: $Py\ Fi$ and $Pz\ Fi$ i. We calculate them according to the formulas: $Pz\ Ni = Ni \times \cos\gamma$; $Py\ Ni = Ni \times \sin\gamma$; $Py\ Fi = Fi \times \cos\gamma$; $Pz\ Fi = Fi \times \sin\gamma$.

The resulting Pzi и Pyi of these technological components are applied on the front surface of the cutting tool to the considered section i of the length $L\text{п}i$:

$Pzi = Pz\ Ni + Pz\ Fi$; $Pyi = Py\ Fi - Py\ Ni$.

Calculate $Py\ Fi$ and $Pz\ Fi$ according formulas:

$Pz\ Ni = Ni \times \cos\gamma$; $Py\ Ni = Ni \times \sin\gamma$; $Py\ Fi = Fi \times \cos\gamma$; $Pz\ Fi = Fi \times \sin\gamma$.

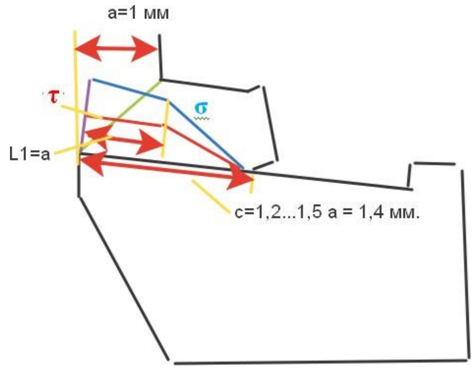

Fig. 8. Plots of contact stresses during turning of SCH20 cast iron.

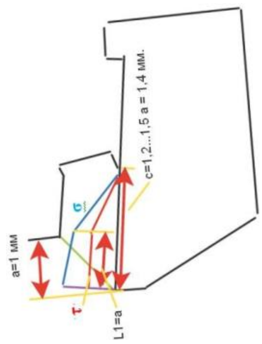

Fig. 9. Plots of contact stresses when planing cast iron SCH20.

To reduce the complexity of preparing for loading the model with external loads, it was proposed to rotate the model before loading so that the front surface was horizontal, i.e. as if the front angle γ is equal to zero (γ*=10º).

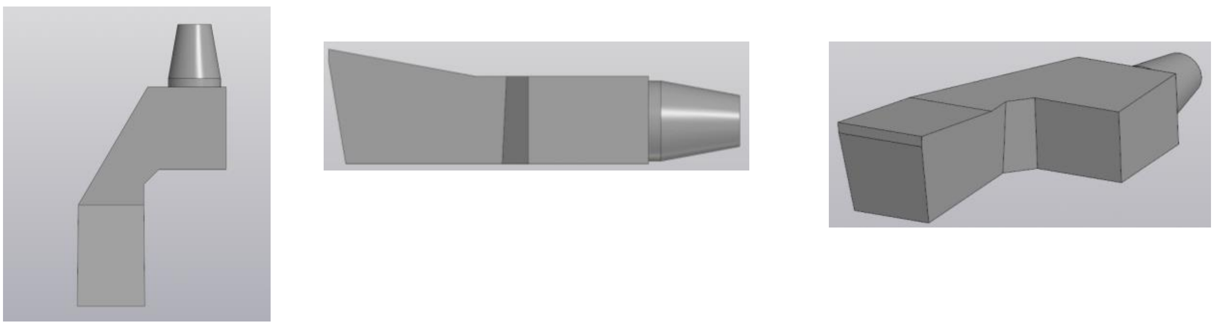

Fig. 10. 3D model of an insert with a cutting part in the form of a rectangular plate with a width.

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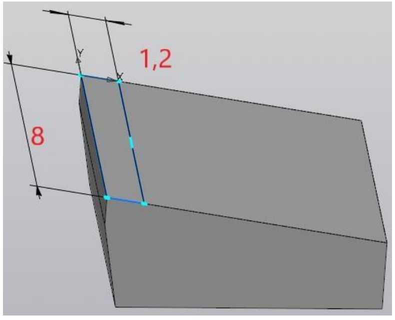
b=8 mm, $\gamma = +10°$, $\varphi = 90°$, $\varphi 1 = 0°$, $\alpha 1 = 3°$, $\alpha = 10°$)

Calculate the cutting part of the planer cutter. It can be made from quick-cutting steel, but it would be better to use a brazed carbide insert from VK8. We restrict ourselves to a small area of the cutting part to increase the accuracy of the SSS calculation and reduce the size of the finite elements.



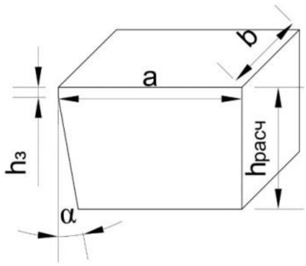


Fig.11. 3D model (rectangular plate, width *b*=8 mm, thickness *h*=6 mm, length *L*=18 mm, with $\gamma = +10°$ and α=10°, length of chip contact with the front surface *c* = 1.2 mm

To assess the strength of the tool, it is necessary to know the dimensions and nature of the load distribution in contact with the tool surface. On the front surface, there is a tangential $P_{z\ п}$ and a radial $P_{y\ п}$. On a cutter worn along the back surface, two additional forces appear on the back surface: tangent to the chamfer $F_h = P_{z\ h}$ and normal to the chamfer $N_h = P_{y\ h}$.

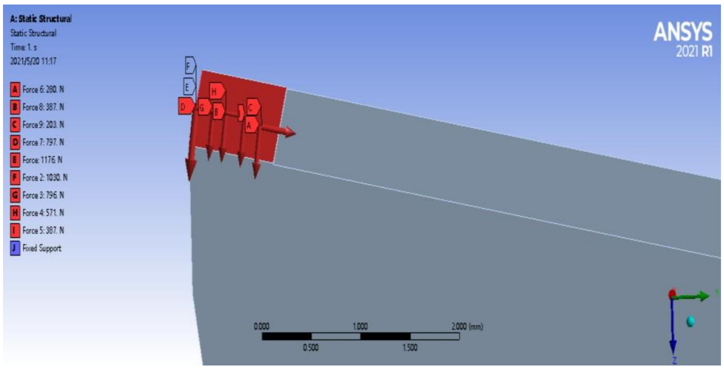
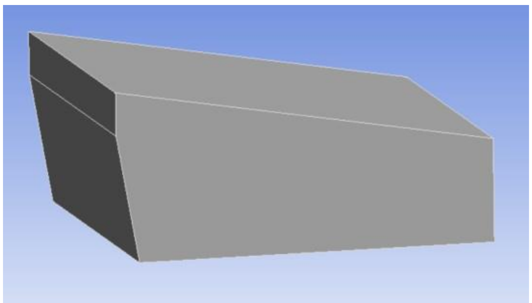


Fig. 11. Scheme of the application of forces on the front and rear surfaces of the cutter.



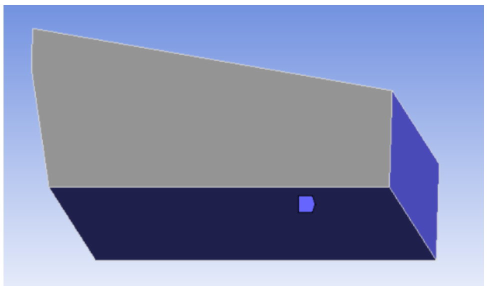


Fig. 12. Fastening the insert with a planer cutter with a soldered cutting plate, dimensions and view of the final elements of the cutting part.

The pocket is best machined in the first operation by planing with a table feed that ensures the cutting speed. The cutting force *Pz* must be 1.5 times less than the allowable table feed force.

The plotting of contact stress diagrams on the front surface is based on the determination of the physical components ***N*** and ***F*** of the cutting force, the length of contact between the chip and the tool, the

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stability of the diagram of shear contact stresses, and the change in the friction coefficient on the front surface.

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