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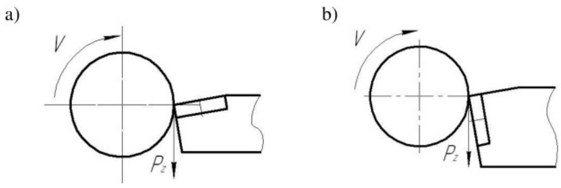
Mathematical model of cutting process of cutting tools with a side-mounted multifaceted, requiring no sharpening plates

The article presents the results of experimental research of the cutting process with cutoff tools with laterally mounted multifaceted unresharpenable plates (MUP), which allowed to confirm their efficiency and progressiveness. As a result of research and experimental data processing, for the first time, the mathematical models were obtained that adequately describe force parameters (Pz and Py) of cutting process by the proposedcutoff tools. The rational values of rake and relief angles are determined.

Keywords: assembled cutoff tool, multifaceted unresharpenable plate, mechanical mounting.

Trends in the development of modern tool production determine the widespread implementation into the machine-building industry of metal-cutting assembled tools with mechanical mounting of multifaceted unresharpenable plates (MUP). The conditions of operation of this type of tools significantly affect the way of mounting and fixing of the cutting plates. From the literature sources [1, 2] radial and tangential mounting of MUP are known (Fig. 1). In case of the radial mounting of MUP (along the front surface), the cutting force acts on a smaller overcutting of the plate, which limits the permissible feed of the instrument. With the tangential mounting of MUP (along the back surface), the force of cutting takes up larger overcutting of the plate and therefore a significant increase in feed is allowed.



a) radial b) tangential

Figure 1. Ways of MUP mounting

However, none of these mounting methods presupposes the use of MUP for assembled cutoff tools due to the large cutting area width.

The attempts to use MUP for cutoff tools at their lateral installation (along the lateral surface) are known and lateral fixing to cutter body (Fig. 2) [3]. The disadvantages of these designs are the complexity of the design of the plates, the low reliability of MUP fixing, the limitation of the depth of the grooves due to MUP basing simultaneously on the supporting and thrust surfaces - up to 6.5 mm, which limits the scope of the use of these cutting tools.

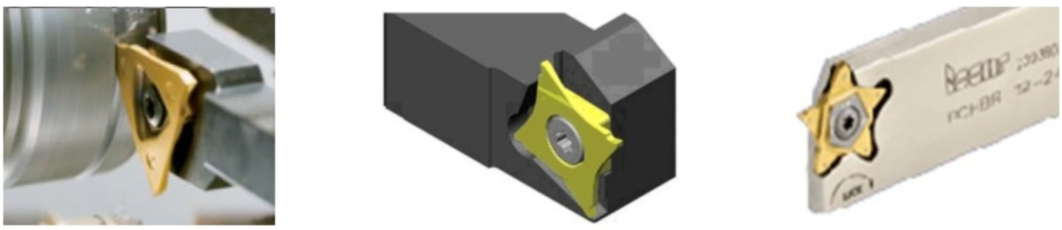


Figure 2. Groove cutters with lateral mounting of multifaceted plates

In order to eliminate the disadvantages listed above, the authors [4] for the first time proposed a new «lateral» scheme of installation of a multifaceted unresharpenable plate and on its basis a design of a cut-off tool with a laterally mounted MUP (Fig. 3, 4), consisting of a holder (1), hook (2), screw (3), and multi-faceted unresharpenable plate 4. In this design of the cutting tool, locating and fixing of MUP is carried out only on the thrust surfaces, which significantly increases the length of the cutting part and makes it possible to perform cutting of rods with a diameter of up to 24 mm.

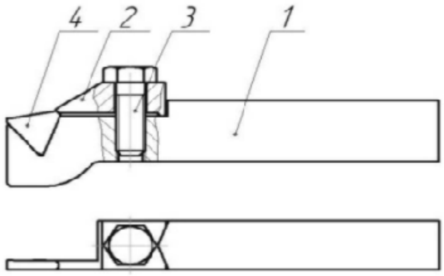


Figure 3. Design of assembled cutoff tool with lateral mounting of MUP

Figure 4. General view of cutoff tool with lateral mounting of MUP

However, the force parameters (Pz and Py) of the cutting process with the proposed cutting tools remain unexplored till now, and as a result, the rational geometrical parameters of the proposed tools (the value of rake γ and relief α angles), which is proposed to be performed in this paper.

Research results

Experimental investigations of the cutting process by cutoff tools with laterally mounted MUP were performed in laboratory conditions on a screw-cutting lathe of 1K62 model (Fig. 5).

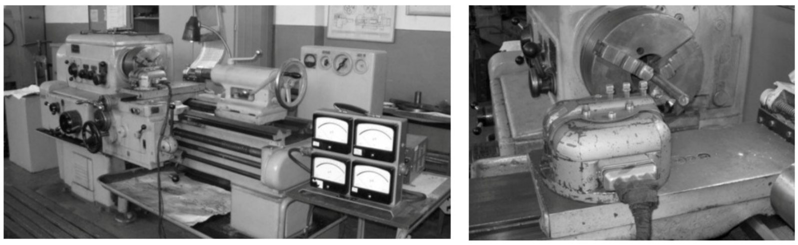


Figure 5. General view of experimental study of force parameters of cutting process with cutoff tool

The cutting forces were determined with the help of an electric universal dynamometer UDM-600 with a set of amplifying and indicating equipment. Measurements of the components of the cutting forces were carried out experimentally on two axes of coordinates: Pz — vertically; Py — perpendicularly to the axis of the workpiece. In experimental studies, cylindrical workpieces were used. The outer diameter of the workpieces was D = 20 mm. The material of processed workpieces was Steel 45.

In the first series of experiments, three experiments were carried out to measure the cutting forces at different values of cutting speed of $\upsilon 1 = 20$ m/min, $\upsilon 2 = 31.4$ m/min, $\upsilon 3 = 40$ m/min, but with a fixed value of rake angle $\gamma = -5^\circ$ and feed $s1 = 0.07$ mm/rev. The value of the components of the cutting forces in each experiment was entered in Table 1.

In the 2nd series of experiments, 3 experiments were carried out to measure the cutting forces at different values of cutting speed $\upsilon 1 = 20$ m/min, $\upsilon 2 = 31.4$ m/min, $\upsilon 3 = 40$ m/min, but with a fixed value of rake angle $\gamma = -5^\circ$ and feed $s4 = 0.12$ mm/rev.

In the 3rd series of experiments, 3 experiments were carried out to measure the cutting forces at different values of cutting speed $\upsilon 1 = 20$ m/min, $\upsilon 2 = 31.4$ m/min, $\upsilon 3 = 40$ m/min, but with a fixed value of rake angle $\gamma = -6^\circ$ and feed $s2 = 0.074$ mm/rev.

In the 4th series of experiments, 3 experiments were carried out to measure the cutting forces at different values of cutting speed $\upsilon 1 = 20$ m/min, $\upsilon 2 = 31,4$ m/min, $\upsilon 3 = 40$ m/min, but with a fixed value of rake angle $\gamma = -6^\circ$ and feed $s3 = 0.097$ mm/rev.

In the 5th series of experiments, 3 experiments were carried out to measure the cutting forces at different values of cutting speed $\upsilon 1 = 20$ m/min, $\upsilon 2 = 31,4$ m/min, $\upsilon 3 = 40$ m/min, but with a fixed value of rake angle $\gamma = -8^\circ$ and feed $s2 = 0,074$ mm/rev.

In the 6th series of experiments, 3 experiments were carried out to measure the cutting forces at different values of cutting speed $\upsilon 1 = 20$ m/min, $\upsilon 2 = 31.4$ m/min, $\upsilon 3 = 40$ m/min, but with a fixed value of rake angle $\gamma = -8°$ and feed $s3 = 0.097$ mm/rev.

Let us derive the equation of vertical (main) Pz and radial Py of the cutting forces components for each fixed value of rake angle γ according to the experimental data presented in Table 1. In this case, the components of the cutting forces are functions of the arguments: the feed S (mm/rev) and the cutting speed V (m/min). Since the measurement of the components of the cutting forces was performed for two values of the feed S (mm/rev), the response surface can be restored as lined one.

Table 1

Results of experimental data of the research of cutting process with cutoff tools with lateral mounting of MUP

Series No.	Experiment No.	Cutting modes				Cutting force components	
		γ, degrees	S, mm/rev	n, rev/min	υ, m/min	Pz, N	Py, N
1	1	– 5	0.07	315	20	1600	650
	2	– 5	0.07	500	31.4	2000	780
	3	– 5	0.07	630	40	2225	920
2	4	– 5	0.12	315	20	1600	650
	5	– 5	0.12	500	31.4	1900	780
	6	– 5	0.12	630	40	2250	940
3	7	– 6	0.074	315	20	1500	600
	8	– 6	0.074	500	31.4	1800	720
	9	– 6	0.074	630	40	2225	920
4	10	– 6	0.097	315	20	1815	650
	11	– 6	0.097	500	31.4	1900	780
	12	– 6	0.097	630	40	2100	820
5	13	– 8	0.074	315	20	2225	920
	14	– 8	0.074	500	31.4	2400	940
	15	– 8	0.074	630	40	2600	1100
6	16	– 8	0.097	315	20	2720	1180
	17	– 8	0.097	500	31.4	2720	1180
	18	– 8	0.097	630	40	3100	1310
7	19	– 10	0.07	315	20	2400	940
	20	– 10	0.07	500	31.4	2700	1080
	21	– 10	0.07	630	40	3100	1310
8	22	– 10	0.12	315	20	3250	1380
	23	– 10	0.12	500	31.4	3330	1395
	24	– 10	0.12	630	40	3540	1415

As it is know, the line surface has the following equation:

$$P(S;V) = f(0;V) \cdot (1 - w) + f(1;V) \cdot w, \tag{1}$$

where w is normalized value ($0 \leq w \leq 1$), which corresponds to the variable S, being connected with the former by the following formula:

$$w = \frac{S - S_1}{S_k - S_1}, \tag{2}$$

where S_1 is the first and S_k - the last experimental value of the feed S.

The formula (2) transforms the segment $[S_1; S_k]$ to unit segment $[0; 1]$.

The functional dependences $f(0;V)$ and $f(1;V)$ at fixed feed values S are obtained by the least square method (LSM) by setting unknown values of the coefficients a and b in the formulas:

$$f(0;V) = a_0 V^{b_0}; \quad f(1;V) = a_1 V^{b_1}. \tag{3}$$

For the realization of LSM we apply CAS Maple 15, namely the Nonlinear Fit command from the Statistics package, which performs nonlinear approximation of experimental data [5]. Applying it to experimental dependencies (*Vi; Pi*) for all cases of fixed values of rake angle γ and feed S, we obtain the analytic dependencies of the form (3), which are given in Table 2.

Table 2

Analytical dependences $\mathbf{f\,(0;V)}$ and $\mathbf{f\,(1;V)}$, reestablished by means of experimental data

γ, degrees	P_z		P_y	
	$f\,(0;;V)$	$f\,(1;;V)$	$f\,(0;;V)$	$f\,(1;;V)$
–5	$386.094 \cdot V^{0.476}$	$358.601 \cdot V^{0.493}$	$141.908 \cdot V^{0.503}$	$127.914 \cdot V^{0.536}$
–6	$260.391 \cdot V^{0.575}$	$985.635 \cdot V^{0.195}$	$87.988 \cdot V^{0.628}$	$299.075 \cdot V^{0.248}$
–8	$1139.795 \cdot V^{0.221}$	$1579.327 \cdot V^{0.174}$	$429.294 \cdot V^{0.246}$	$768.142 \cdot V^{0.138}$
–10	$788.178 \cdot V^{0.367}$	$2273.029 \cdot V^{0.117}$	$217.021 \cdot V^{0.480}$	$1242.151 \cdot V^{0.035}$

According to the formula (2) let us calculate the values of the expressions $\boldsymbol{w}$ and $\boldsymbol{(1\text{-}w)}$ for each fixed value of the rake angle γ. The results of calculations are presented in Table 3.

Table 3

Expressions of normalized variable $\boldsymbol{w}$ and $\mathbf{(1}$–$\boldsymbol{w}\mathbf{)}$, found from experimental data

γ, degrees	$\boldsymbol{w}$	$\mathbf{(1-}\boldsymbol{w}\mathbf{)}$
–5	$20.000S - 1.400$	$2.400{-}20.000S$
–6	$43.478S - 3.217$	$4.217{-}43.478S$
–8	$43.478S - 3.217$	$4.217{-}43.478S$
–10	$20.000S - 1.400$	$2.400{-}20.000S$

Substituting found expressions from Tables 2 and 3 in the formula (1), we obtain the approximating equations for the vertical (main) P_z (Table 4) and the radial P_y components of the cutting forces (Table 5).

Table 4

Approximation equation of the vertical (main) component of the cutting force $\mathbf{P_z}$

γ, degrees	Equation	Maximum relative error, %
–5	$\left(386.094 \cdot V^{0.476}\right)(2.400 - 20.000S) +$ $+\left(358.601 \cdot V^{0,493}\right)(20.000S - 1.400)$	3.4
–6	$\left(260.391 \cdot V^{0.575}\right)(4,217 - 43.478S) +$ $+\left(985.635 \cdot V^{0.195}\right)(43.478S - 3.217)$	6.5
–8	$\left(1139.795 \cdot V^{0.221}\right)(4.217 - 43.478S) +$ $+\left(1579.327 \cdot V^{0.174}\right)(43.478S - 3.217)$	5.8
–10	$\left(788.178 \cdot V^{0.367}\right)(2.400 - 20.000S) +$ $+\left(2273.029 \cdot V^{0.117}\right)(20.000S - 1.400)$	3.3

Table 5

Approximation equation of the radial component of the cutting force $\mathbf{P_y}$

γ, degrees	Equation	Maximum relative error, %
–5	$\left(141.908 \cdot V^{0.503}\right)(2.400 - 20.000S) +$ $+\left(127.914 \cdot V^{0.536}\right)(20.000S - 1.400)$	3.9
–6	$\left(87.988 \cdot V^{0.628}\right)(4.217 - 43.478S) +$ $+\left(299.075 \cdot V^{0.248}\right)(43.478S - 3.217)$	8.2
–8	$\left(429.294 \cdot V^{0.246}\right)(4.217 - 43.478S) +$ $+\left(768.142 \cdot V^{0.138}\right)(43.478S - 3.217)$	6.5
–10	$\left(217.021 \cdot V^{0.480}\right)(2.400 - 20.000S) +$ $+\left(1242.151 \cdot V^{0.035}\right)(20.000S - 1.400)$	5.3

Graphs of line surfaces $P_z\,(S;;V)$ i $P_y\,(S;;V)$are given in Figures 6, 7.

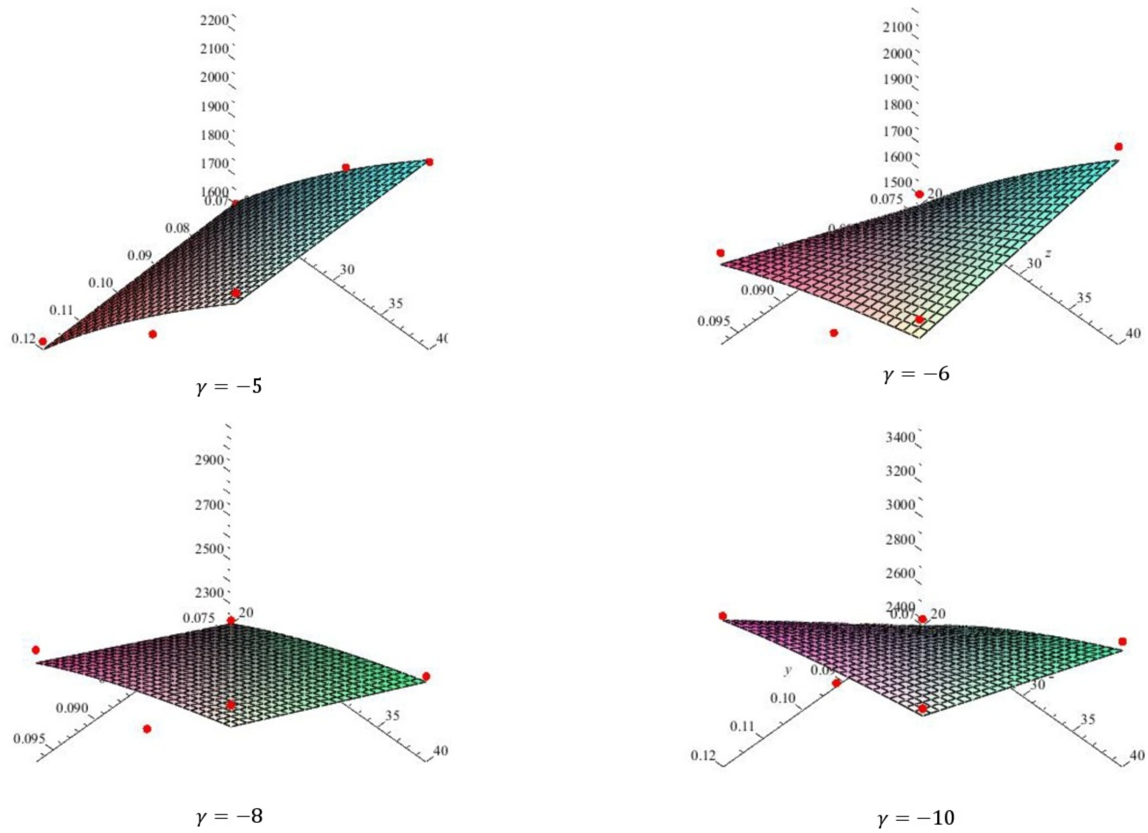


Figure 6. Graphs of line surfaces $P_z(S;V)$

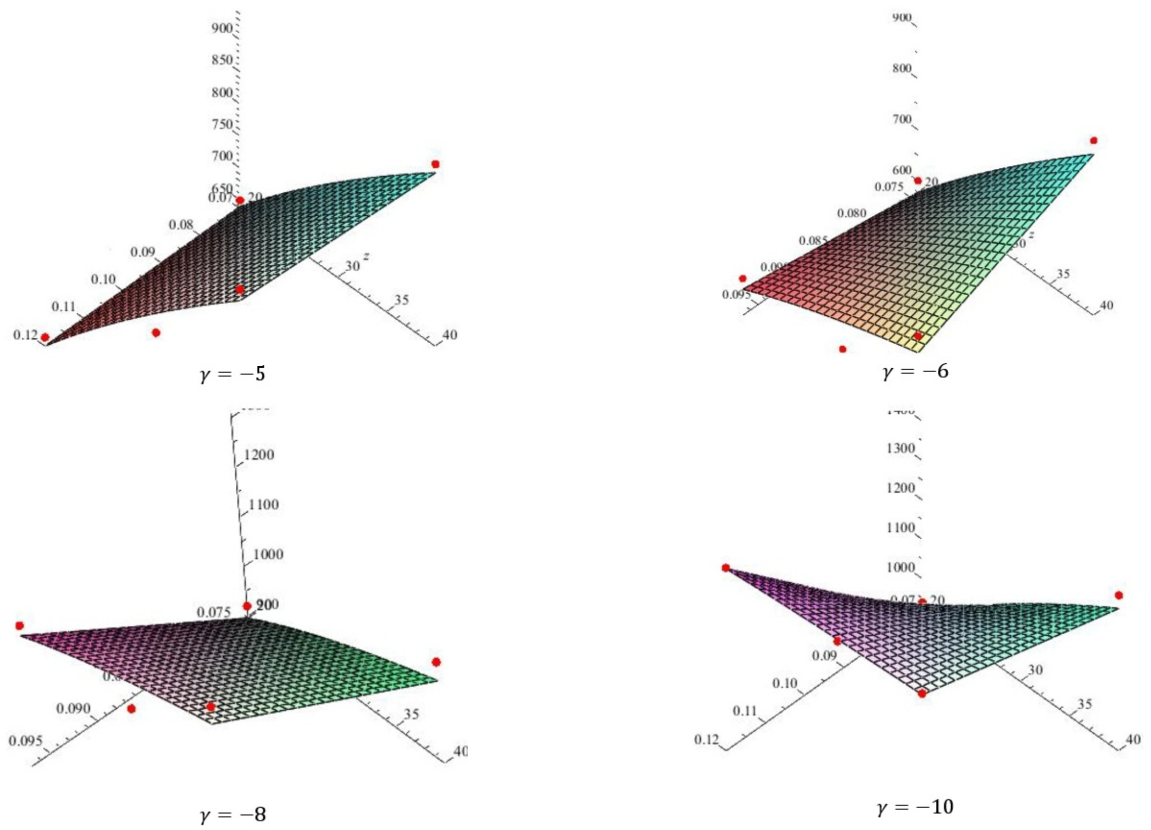


Figure 7. Graphs of line surfaces $P_y(S;V)$

Conclusions

Experimental studies of the cutting process with proposed cutting tools with laterally mounted MUP, carried out in laboratory conditions, allowed to confirm their performance. As a result of these studies and the processing of experimental data, mathematical models were first obtained that adequately describe the force parameters (Pz and Py) of the cutting process with the proposed cutting tools. It is found that it is inappropriate to perform negative rake angles $\gamma >$ -6o, since this results in a significant increase in the cutting forces and relief angles must not be $\alpha <$6o, as this leads to the rubbing on the back surface. There are no other principal differences in the cutting conditions by proposed cutting tools and MUP from those previously known, which allows to consider, with high level of reliability, that all the basic modes of their operation and performance indicators are identical.

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Бүйірлі орнатылған көпқырлы қайралмайтын пластиналарды кесілген кескіштермен кесу процесінің математикалық моделі

Мақалада бүйірлі орнатылған көпқырлы қайралмайтын пластиналарды кесілген кескіштермен кесу процесінің эксперименталды зерттеулер, олардың жұмыс жасау мүмкіндігі мен прогрессивтілігін растайтын нәтижелері берілген. Зерттеулерді жүргізу және эксперименталды нәтижелерді өңдеу нәтижесінде ұсынылып отырған кескіштермен кесу процесінің (Pz және Py) күш параметрлерін сипаттайтын алғашқы рет математикалық модельдері алынған. Алдыңғы және артқы бұрыштардың рационалды мәндері келтірілген.

Кілт сөздер: жиналған кесетін кескіш, көпқырлы қайралмайтын кесетін пластина, механикалық бекіткіш.

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Математическая модель процесса резания отрезными резцами с боковой установкой многогранных неперетачиваемых пластин

В статье представлены результаты экспериментальных исследований процесса резания отрезными резцами с боковой установкой многогранных неперетачиваемых пластин, позволившие подтвердить их работоспособность и прогрессивность. В результате выполнения исследований и обработки экспериментальных данных впервые получены математические модели, адекватно описывающие силовые параметры (Pz и Py) процесса резания предлагаемыми резцами. Определены рациональные значения переднего и заднего углов.

Ключевые слова: сборный отрезной резец, многогранная неперетачиваемая режущая пластина, механическое крепление.

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