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Justification of the dependencies for calculating gripping forces of multifaceted unresharpenable plates in the holder of a cutoff tool at their lateral installation

In the article mathematical dependencies to determine the gripping force of the cutting plate in the socket of assembled cutoff tools with the lateral installation of multifaceted unresharpenable plates (MUP) are proposed for the first time, which makes it impossible to move the plate in any direction while the cutting forces acting on it. Moreover, the expressions are obtained to determine the minimum height of the intersection of the cutoff tool socket head, which is important at the stage of creating a methodology for designing this type of tool.

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

Introduction

In modern machining of metals by cutting the most progressive are assembled tools with mechanical mounting of multifaceted unresharpenable plates. One of the main advantages of this type of tools is that when one cutting edge is worn, a cutting plate rotates around its own axis to enable the operation of another, which significantly reduces the time of tool adjustment, since in this case there is no need to remove it from the tool holder, which is very relevant for modern machine tools with numerical control and automated lines. Application in industry of assembled metal cutting tools with mechanical mounting of plates allows increasing productivity of processing, since the cutting speed of these tools is 1,5 – 2 times higher than that of brazed ones [1–5]. Therefore, the widespread use of assembled metal cutting tools is important for modern machine building.

However, for modern cutoff tools with mechanical mounting, predominately, single- or double-blade cutting plates of a specific non-technological complex shape are used. Cutoff tools equipped with multifaceted plates of three-, four- or five-faced shape [6–8] are used mainly for cutting rods with a diameter of up to 12 mm due to lateral installation of cutting plates on the tool case (Fig. 1), which significantly restricts the overhang of a cutting part and, as a result, the scope of their application.

In order to eliminate the disadvantages of listed above, the authors [9–14] for the first time proposed a new design of assembled cutoff tool with lateral installation of multifaceted unresharpenable plates (Fig. 2), consisting of a holder 1, hook 2, screw 3, and multifaceted unresharpenable plate 4. In this design of the cutting tool, locating and fixing of MUP is carried out only on the thrust surfaces, which makes it possible to perform cutting of rods with a diameter of up to 30 mm.

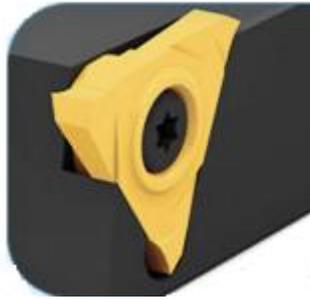


Figure 1. Groove cutters with lateral mounting of multifaceted plates

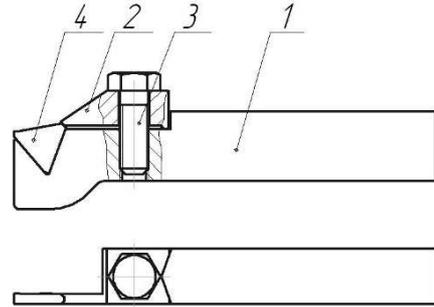


Figure 2. Design of assembled cutoff tool with lateral installation of multifaceted plates

Relevance. The main factors influencing the reliability of assembled metal cutting tools are the installation scheme, mounting and fixing of multifaceted unresharpenable plates. The provision of the necessary gripping force is a crucial task, which depends on the performance of the cutting tool under the action of the resulting cutting force.

Given kind of plate installation is proposed for the first time, in order to ensure the efficiency of this tool, it is necessary to obtain mathematical dependencies that will enable to determine the required strength of attaching the plate in the socket, which makes it impossible to move the plate in any direction while cutting forces acting on it, and to determine minimum height of the intersection of the cutter head socket.

Research results

The clamping of a plate should exclude the movement of MUP under the action of the forces that occur during cutting. Primarily, their action is determined by the physical and chemical properties of the material being processed (hardness, chemical composition), on the basis of which the cutting modes are specified, and by the heterogeneity of the distribution in it of the constituent elements, as well as the structural and geometric parameters of the cutting part and the conditions of the plate installation.

The cutting plate during the cutting process is exposed to active forces: the resulting cutting force P_p and the force of gripping F_{gr} . the cutting plate, which are balanced by the reactions R_1 and R_2 of supporting surfaces of the plate socket (Fig. 3, Fig. 4). Since the forces acting on the plate form, a balanced plane system, the algebraic sums of the projections of these forces on the coordinate axis are equal to zero. The plate is under the action of a system of arbitrarily located forces, for the equilibrium of which the fulfillment of the three following conditions is required [15–18]:

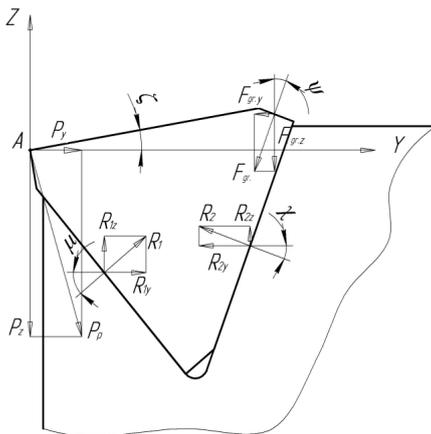


Figure 3. Scheme of active forces acting on the cutting plate

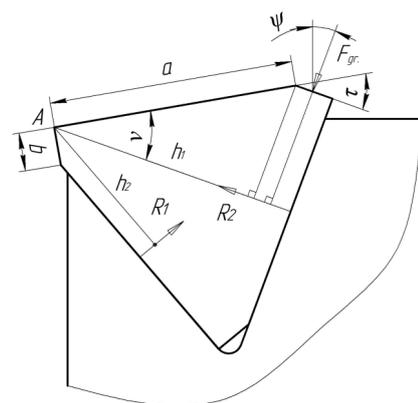


Figure 4. Scheme to determine the moments

$$\sum F_{iz} = 0; -P_z - F_{gr} \cdot \cos \psi + R_2 \cdot \sin \chi + R_1 \cdot \sin \mu = 0; \tag{1}$$

$$\sum F_{iy} = 0; P_y - F_{gr.} \cdot \sin \psi - R_2 \cdot \cos \chi + R_1 \cdot \cos \mu = 0; \quad (2)$$

$$\sum (F) = 0; -F_{gr.} \cdot h_1 + R_1 \cdot h_2 = 0. \quad (3)$$

From the equation (1) we derive the gripping force $F_{gr.}$:

$$F_{gr.} = \frac{R_1 \cdot \sin \mu + R_2 \cdot \sin \chi - P_z}{\cos \psi}. \quad (4)$$

From the equation (2) we determine the reaction R_2 :

$$R_2 = \frac{R_1 \cdot \cos \mu + P_y - F_{gr.} \cdot \sin \psi}{\cos \chi}. \quad (5)$$

From the equation (3) we determine the reaction R_1 :

$$R_1 = \frac{F_{gr.} \cdot h_1}{h_2}. \quad (6)$$

We apply the equation (6) to the equation (5)

$$R_2 = \frac{\frac{F_{gr.} \cdot h_1}{h_2} \cos \mu + P_y - F_{gr.} \cdot \sin \psi}{\cos \chi} = \frac{h_1 \cdot F_{gr.} \cdot \cos \mu + h_2 \cdot P_y - h_2 \cdot F_{gr.} \cdot \sin \psi}{h_2 \cdot \cos \chi}. \quad (7)$$

The obtained equations (6) and (7) we apply to the equation (4) to determine the gripping force of a cutting plate:

$$\begin{aligned} F_{gr.} &= \frac{\frac{\sin \chi (h_1 \cdot F_{gr.} \cdot \cos \mu + h_2 \cdot P_y - h_2 \cdot F_{gr.} \cdot \sin \psi)}{h_2 \cdot \cos \chi} + \frac{F_{gr.} \cdot h_1}{h_2} \cdot \sin \mu - P_z}{\cos \psi}; \\ F_{gr.} &= \frac{\frac{tg \chi (h_1 \cdot F_{gr.} \cdot \cos \mu + h_2 \cdot P_y - h_2 \cdot F_{gr.} \cdot \sin \psi)}{h_2} + \frac{F_{gr.} \cdot h_1}{h_2} \cdot \sin \mu - P_z}{\cos \psi}; \\ F_{gr.} \cdot \cos \psi &= tg \chi \frac{h_1 \cdot F_{gr.}}{h_2} \cdot \cos \mu + P_y \cdot tg \chi - tg \chi \frac{h_2 \cdot F_{gr.}}{h_2} \sin \psi + \frac{F_{gr.} \cdot h_1}{h_2} \cdot \sin \mu - P_z; \\ F_{gr.} \cdot \cos \psi &= tg \chi \frac{h_1 \cdot F_{gr.}}{h_2} \cdot \cos \mu - tg \chi \frac{h_2 \cdot F_{gr.}}{h_2} \sin \psi - \frac{F_{gr.} \cdot h_1}{h_2} \cdot \sin \mu = P_y \cdot tg \chi - P_z; \\ F_{gr.} &= \frac{h_2 \cdot \cos \psi - tg \chi \cdot h_1 \cdot \cos \mu - tg \chi \cdot \sin \psi - h_1 \cdot \sin \mu}{h_2} = P_y \cdot tg \chi - P_z; \\ F_{gr.} &= \frac{h_2 \cdot (P_y \cdot tg \chi - P_z)}{h_2 \cdot \cos \psi - tg \chi \cdot h_1 \cdot \cos \mu - tg \chi \cdot \sin \psi - h_1 \cdot \sin \mu}. \end{aligned} \quad (8)$$

We determine the arms of forces according to Figure 4:

$$h_1 = a \cdot \cos \nu + \frac{b}{2};$$

$$h_2 = b \cdot \cos \tau + \frac{a}{2}.$$

We apply the determined values of the arms of forces to the equation and obtain the mathematical dependency that allows determining the necessary gripping force of a plate at the given type of its installation (8):

$$F_{gr.} = \frac{(b \cdot \cos \tau + \frac{a}{2}) \cdot (P_y \cdot tg \chi - P_z)}{(b \cdot \cos \tau + \frac{a}{2}) \cdot \cos \psi - tg \chi \cdot \cos \mu (a \cdot \cos \nu + \frac{b}{2}) - tg \chi \cdot \sin \psi - \sin \mu \cdot (a \cdot \cos \nu + \frac{b}{2})}.$$

However, the disadvantage of this plate mounting scheme (Fig. 4) is the action of the plate gripping force F_{gr} upon the front wall of the tool socket [19–22]. In order to eliminate this drawback, the following scheme of three-faceted plate (Fig. 5) was proposed. According to this scheme, the front socket wall is made at an angle $\mu = 40^\circ$, and the back one – at an angle $\chi = 20^\circ$, which, under the chosen scheme of hook installation removes the action of the gripping force F_{gr} on the front socket wall. Thus, the components of the cutting forces P_z , P_y and the resulting cutting force P_p are fully compensated by the reactions of the supports of the front R_1 , R_{1z} , R_{1y} and back R_2 , R_{2z} , R_{2y} socket walls [23–25].

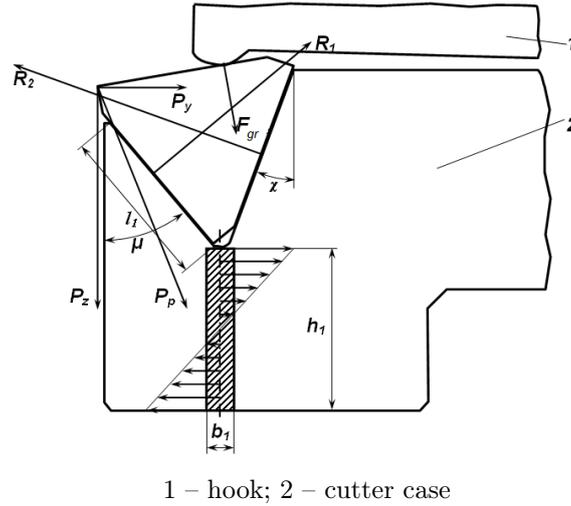


Figure 5. Scheme for calculating stresses and the minimum intersection of the cutter head

The equations of interaction of these forces are as follows:

$$P_z = R_1 \cdot \sin \mu + R_2 \cdot \sin \chi; \quad (9)$$

$$P_y = -R_1 \cdot \cos \mu + R_2 \cdot \cos \chi. \quad (10)$$

From the equation (10) we determine the support reaction R_2 of the back socket wall:

$$R_2 = \frac{P_y + R_1 \cos \mu}{\cos \chi}.$$

Applying it to the equation (9), after performing transformations we obtain:

$$\begin{aligned} P_z &= R_1 \cdot \sin \mu + \frac{P_y + R_1 \cos \mu}{\cos \chi} \sin \chi = \\ P_z \cos \chi &= R_1 \sin \mu \cos \chi + P_y \sin \chi + R_1 \cos \mu \sin \chi = \\ P_z \cos \chi - P_y \sin \chi &= R_1 \sin \mu \cos \chi + R_1 \cos \mu \sin \chi = \\ P_z \cos \chi - P_y \sin \chi &= R_1 (\sin \mu \cos \chi + \cos \mu \sin \chi) = \\ P_z \cos \chi - P_y \sin \chi &= R_1 \sin (\mu + \chi). \end{aligned} \quad (11)$$

From the equation (11) we determine the support reaction R_1 of the front socket wall:

$$R_1 = \frac{P_z \cos \chi - P_y \sin \chi}{\sin (\mu + \chi)}.$$

The most dangerous is the bending stress σ_{bs} in the minimum intersection of the cutter head on the bottom of the socket, from the action of the reaction force R_2 on its front wall, which we consider to be applied in the middle of this wall, having a length $l_1 = 14$ mm:

$$\sigma_{bs} = \frac{R_2 \sin \mu \cdot \frac{1}{2} l_1 \sin \mu}{W_x}, \quad (12)$$

where W_x – the moment of resistance to the bend of the minimum intersection on the head of the cutter, which has a height h_1 and a thickness $b_1 = 2.5$ mm:

$$W_x = \frac{b_1 h_1^2}{6}. \quad (13)$$

After applying the equation (13) to the equation (12), we obtain the following:

$$\sigma_{bs} = \frac{6R_2 \sin \mu \cdot \frac{1}{2} l_1 \sin \mu}{b_1 h_1^2} = \frac{3 \cdot R_2 \cdot l_1 \sin^2 \mu}{b_1 h_1^2}. \quad (14)$$

From the equation (14) we obtain the minimum height of the intersection h_1 :

$$h_1 = \sqrt{\frac{3 \cdot R_1 \cdot l_1 \sin^2 \mu}{b_1 [\sigma_{bs}]}}$$

where $[\sigma_{bs}]$ – maximum allowable bending stresses, MPa.

Conclusions

As a result of the performed researches, mathematical dependencies to determine the gripping force of the cutting plate in the socket of assembled cutoff tools with the lateral installation of multifaceted unresharpenable plates, are proposed for the first time which makes it impossible to move the plate in any direction while the cutting forces acting on it. Moreover, the expressions are obtained to determine the minimum height of the intersection of the cutoff tool socket head, which is important at the stage of creating a methodology for designing this type of tool.

References

- 1 Arslan, H., Er, A.O., Orhan, S. & Aslan, E. (2016). Tool Condition Monitoring in Turning Using Statistical Parameters of Vibration Signal. *International Journal of Acoustics and Vibration*, 21(4), 371–378. Retrieved from <https://doi.org/10.20855/ijav.2016.21.4432>.
- 2 Barry, J. & Byrne, G. (2001). Cutting tool wear in the machining of hardened steels Part II: cubic boron nitride cutting tool wear. *Wear*, 247(2), 152–160. Retrieved from [https://doi.org/10.1016/s0043-1648\(00\)00528-7](https://doi.org/10.1016/s0043-1648(00)00528-7).
- 3 Boim, N.G. & Sokolov, I.N. (1984). The use of super-hard material and ceramic cutting tools in machine-tool construction. *Soviet Engineering Research*, 4(7), 55–56.
- 4 Chen, W.Y. (2000). Cutting forces and surface finish when machining medium hardness steel using CBN tools. *International Journal of Machine Tools & Manufacture*, 40(3), 455–466. Retrieved from [https://doi.org/10.1016/s0890-6955\(99\)00011-5](https://doi.org/10.1016/s0890-6955(99)00011-5).
- 5 Chou, Y.K. & Evans, C.J. (1997). Tool wear mechanism in continuous cutting of hardened tool steels. *Wear*, 212(1), 59–65. Retrieved from [https://doi.org/10.1016/s0043-1648\(97\)00139-7](https://doi.org/10.1016/s0043-1648(97)00139-7).
- 6 Chou, Y.K. & Song, H. (2004). Tool nose radius effects on finish hard turning. *Journal of Materials Processing Technology*, 148(2), 259–268. Retrieved from <https://doi.org/10.1016/j.jmatprotec.2003.10.029>.
- 7 Dasgupta, S. & Mukherjee, S. (2016). Effects of machining parameters on tool life and its optimization in turning mild steel with brazed carbide cutting tool. *International Conference on Advances in Materials and Manufacturing Applications (IConAMMA)*. Retrieved from <https://doi.org/10.1088/1757-899X/149/1/012005>.
- 8 Gao, D., Liao, Z.R., Lv, Z.K. & Lu, Y. (2015). Multi-scale statistical signal processing of cutting force in cutting tool condition monitoring. *International Journal of Advanced Manufacturing Technology*, 80(9–12), 1843–1853. Retrieved from <https://doi.org/10.1007/s00170-015-7116-0>.
- 9 Grzesik, W., Wanat, T. & Sme. (2005). Hard turning of quenched alloy steel parts using conventional and wiper ceramic inserts. *Transactions of the North American Manufacturing Research Institution of SME, Vol 33*, 9–16.
- 10 Huddle, D. (2002). A new direction for turning — Plunge turning can be a cost-effective grinding alternative. *Manufacturing Engineering*, 128(4), 76–83.
- 11 Jiang, X.C., Li, B., Mao, X.Y., Hao, C.H. & Liu, H.Q. (2018). Tool condition monitoring based on dynamic sensitivity of a tool-workpiece system. *International Journal of Advanced Manufacturing Technology*, 98(5–8), 1441–1460. Retrieved from <https://doi.org/10.1007/s00170-018-2252-y>.
- 12 Klimenko, S.A., Mukovoz, Y.A., Lyashko, V.A., Vashchenko, A.N. & Ogorodnik, V.V. (1992). On the wear mechanism of cubic boron-nitride base cutting tools. *Wear*, 157(1), 1–7. Retrieved from [https://doi.org/10.1016/0043-1648\(92\)90183-9](https://doi.org/10.1016/0043-1648(92)90183-9).
- 13 Klimenko, S.A., Mukovoz, Y.A. & Polonsky, L.G. (1996). Cutting tools of superhard materials. *Advanced Ceramic Tools for Machining Application - Ii*, 114, 1–66. Retrieved from <https://doi.org/10.4028/www.scientific.net/KEM.114.1>.

- 14 Kramer, B.M. & Suh, N.P. (1980). Tool wear by solution — a quantitative understanding. *Journal of Engineering for Industry-Transactions of the Asme*, 102(4), 303–309. Retrieved from <https://doi.org/10.1115/1.3183869>.
- 15 Kumar, A.S., Durai, A.R. & Sornakumar, T. (2003). Machinability of hardened steel using alumina based ceramic cutting tools. *International Journal of Refractory Metals & Hard Materials*, 21(3–4), 109–117. Retrieved from [https://doi.org/10.1016/s0263-4368\(03\)00004-0](https://doi.org/10.1016/s0263-4368(03)00004-0).
- 16 Letot, C., Serra, R., Dossevi, M. & Dehombreux, P. (2016). Cutting tools reliability and residual life prediction from degradation indicators in turning process. *International Journal of Advanced Manufacturing Technology*, 86(1–4), 495–506. Retrieved from <https://doi.org/10.1007/s00170-015-8158-z>.
- 17 LoCasto, S., LoValvo, E., Lucchini, E., Maschio, S., Piacentini, M. & Ruisi, V.F. (1996). Machining of steel with advanced ceramic cutting-tools. *Advanced Ceramic Tools for Machining Application - Ii*, 114, 105–133. Retrieved from <https://doi.org/10.4028/www.scientific.net/KEM.114.105>.
- 18 Matsumoto, Y., Barash, M.M. & Liu, C.R. (1987). Cutting mechanism during machining of hardened steel. *Materials Science and Technology*, 3(4), 299–305. Retrieved from <https://doi.org/10.1179/mst.1987.3.4.299>.
- 19 Nastasenko, V.O., Babii, M.V. & Protsenko, V.O. (2018). Mathematical model of cutting process of cutting tools with a side-mounted multifaceted, requiring no sharpening plates. *Bulletin of the Karaganda University. Mathematics series*, 92(4), 132–138. Retrieved from <https://doi.org/10.31489/2018m4/132-138>.
- 20 Ozel, T., Hsu, T.K. & Zeren, E. (2005). Effects of cutting edge geometry, workpiece hardness, feed rate and cutting speed on surface roughness and forces in finish turning of hardened AISI H13 steel. *International Journal of Advanced Manufacturing Technology*, 25(3–4), 262–269. Retrieved from <https://doi.org/10.1007/s00170-003-1878-5>.
- 21 Ozel, T., Karpas, Y., Figueira, L. & Davim, J.P. (2007). Modelling of surface finish and tool flank wear in turning of AISI D2 steel with ceramic wiper inserts. *Journal of Materials Processing Technology*, 189(1–3), 192–198. Retrieved from <https://doi.org/10.1016/j.jmatprotec.2007.01.021>.
- 22 Schaal, N., Kuster, F. & Wegener, K. (2015). Springback in metal cutting with high cutting speeds. *15th Cirp Conference on Modelling of Machining Operations (15th Cmm0)*, 31, 24–28. Retrieved from <https://doi.org/10.1016/j.procir.2015.03.065>.
- 23 Shintani, K., Ueki, M. & Fujimura, Y. (1989). Optimum cutting tool geometry when interrupted cutting carburized steel by cbn tool. *International Journal of Machine Tools & Manufacture*, 29(3), 415–423. Retrieved from [https://doi.org/10.1016/0890-6955\(89\)90010-2](https://doi.org/10.1016/0890-6955(89)90010-2).
- 24 Thangarasu, S.K., Shankar, S., Thomas, A.T. & Sridhar, G. (2017). Prediction of Cutting Force in Turning Process-an Experimental Approach. *International Conference on Advances in Materials and Manufacturing Applications (IConAMMA)*. Retrieved from <https://doi.org/10.1088/1757-899x/310/1/012119>.
- 25 Zak, K. (2017). Cutting mechanics and surface finish for turning with differently shaped cbn tools. *Archive of Mechanical Engineering*, 64(3), 347–357. Retrieved from <https://doi.org/10.1515/meceng-2017-0021>.

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Кескідегі кескіш ұстағышындағы бүйірлік орнатуда көпқырлы қайта жоңылмайтын пластиналарды бекіту күшін есептеуге арналған тәуелділіктерді негіздеу

Мақалада алғаш рет кесу күшінің әсерінен болатын пластинаның кез келген бағыттағы қозғалысын болдырмайтын, бүйірлік орнатуда көпқырлы қайта жоңылмайтын пластиналарды кескідегі кескіштер жиынтығының орнына кескіш пластинаны бекітуге қажетті күшті анықтау үшін математикалық тәуелділік ұсынылды. Сонымен бірге мұндай құрылғының жобалау әдістемесін құру кезінде маңызды болатын, кескіш басы орнының қимасының минималды түрде биіктігін анықтауға қажетті өрнек алынды.

Кілт сөздер: кескінің кескіш жиынтығы, көпқырлы қайта кескіш пластина, механикалық қондырғы.

М.В. Бабий, В.О. Настасенко, В.О. Проценко, Д.А. Зинченко

Обоснование зависимостей для расчета сил закрепления многогранных неперетачиваемых пластин в державке отрезного резца при их боковой установке

В статье впервые предложены математические зависимости для определения необходимой силы закрепления режущей пластины в гнезде сборных отрезных резцов с боковой установкой многогранных неперетачиваемых пластин, которая сделает невозможным движение пластины в любом направлении при воздействии на нее сил резания. Также получены выражения для определения минимальной высоты сечения гнезда головки резца, что является важным на этапе создания методики проектирования данного вида инструмента.

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