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Development of Combined Cutting Process using Water-Cooled Cutting Tool

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***Abstract*: Technological aspects of the process of turning shafts with heating of their surfaces to temperatures below recrystallization point and simultaneous improvement of the heat sink from the cutting zone, as well as increasing stability of the cutting edge of a tool. A constructive diagram of the tool device has been developed, which allows for high-performance machining with a given quality of the surfaces of parts from hard materials on lathe equipment.**

Keywords: Cutting, Wear, Tool, Scheme, Method, Workpiece, Cutter, Detail, Material, Heating, Op-Eration, Heat.

I. INTRODUCTION

At the present stage of scientific and technological progress strength, viscosity and other characteristics of structural materials increase so quickly that the tool materials available for production, in a number of cases do not allow high performance processing of billets. In addition, cutting often has to be carried out in extreme conditions — crust, high-strength surfacing, large cut sections, which exacerbates technological difficulties. In connection with these features of modern production in metalworking along with other methods of intensification of technological operations. A direction is developing to increase the efficiency of cutting processes by temporarily reducing the strength of the material that is processed and changes in the mechanisms of contact processes occurring on working surfaces. This effect on the processed material and contact phenomena is achieved by combining the mechanical energy of the cutting process with one or more other types of energy - thermal, electrical, chemical, ultrasonic, electromagnetic, etc. — to facilitate the cutting process and increase tool life.

II. THEORETICAL AND METHODOLOGICAL APPROACHES

Heated cutting is a combined process in which mechanical energy and low temperature gas burner energy are shared to enhance cutting efficiency in the manufacture of machine parts from modern hard-to-work with materials.

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Processing by preheating a workpiece, in which the torch (arc) of the heating flame mainly heats and only partially melts the allowance on the surface, is implemented using various schemes and has a relatively small distribution in industry. In addition, there is limited information about the combination of processes and phenomena occurring in the cutting area, as well as the parameters of the cutting mode, heating and control during processing. In this regard, it remains very important to find and implement more promising and efficient combined processing methods, especially in modern conditions of development of small enterprises and repair works. Which are aimed at increasing productivity, quality of manufacturing and repair of parts.

The proposed method and efficiency of application of flame mechanical processing (PMO) largely depends on geometrical parameters and design of cutting tools. The importance of the cutting tool in the process of PMO is explained by two reasons. Firstly, during flame machining, the cutting tool is subjected to power and heat loads, often far exceeding similar loads in conventional cutting. Secondly, a number of technical conditions, which are the limiting restrictions when optimizing the PMO modes, depend on the parameters of the cutting tool. Consider the features of loading of the cutting tool during PMO and requirements for its design.

With PMO, the productivity of the processing increases by increasing the cross section of the cut. An increase in the cutting elements during conventional cutting causes, an increase in the main component of the cutting force P_z. The heating of the processed material by a flame arc reduces the value of P_z, but nevertheless, the force turns out to be quite large, and often even greater than when cutting without heating, since the regime with PMO increases [3, 7].

An increase in the size of the cut and significant shrinkage of chips, which usually accompanies the cutting process with flame heating, and also increase the contact area along the front surface of the tool, which should be taken into account when choosing the size of the cutting. When choosing the method of attachment of cutting plates, the dynamic nature of the application of force to the tool during PMO, since this process is often used for roughing castings and forgings with uneven allowance.

The heat loads on the tool during the transition from conventional cutting to PMO also increase. First, the amount of heat coming into the cutting wedge from the cutting zone increases, secondly, the tool is additionally heated by heat emitted by the flame arc. To estimate the amount of heat coming from the cutting zone, use the formula [5]:

$$Q_p = \delta_p (W\eta + N_Э), \qquad (1)$$

where $W\eta$ and $N_Э$ — effective heating and cutting power, Watt. Using the latter formula, it is possible to show that the value Q_p^+ during the heat cutting significantly exceeds the value of Q_P in the normal method of processing ($T_n = 0$; $W = 0$), despite the fact that the heat fraction δ_p^+ is less than δ_p.

Thermal tension of the working surfaces of the tool also increases due to the heat that enters in the form of radiation from a flame arc. Let's try to evaluate that energy. Let's imagine the arc torch as a concentrated heat source that gives watts of energy to the environment $W(1-\eta)\eta_и$. The product $W(1-\eta)$ is the energy loss of the arc, and $\eta_и$ is the coefficient characterizing how much of these losses is spent on thermal radiation into the environment. Suppose that heat $W(1-\eta)\eta_и$ spreads equally in all directions. Then the density (Wt/cm^2) of the heat flux at a distance l_1 from the arc has the same value on the entire surface, the center of which is located in the heat source and the radius is equal to the size l_1

$$q_{из} = \frac{100W(1-\eta)\eta_и}{4\pi l_1^2}. \quad (2)$$

The amount of heat entering a cutting tool per unit time, the surface of which is bxl (b – is the width of the cutter, mm; l is its deviation from the tool holder, mm^2) is heated by arc radiation, calculated by the formula:

$$Q_{из} \approx \frac{W(1-\eta)\eta_и}{4\pi}\frac{bl}{l_1^2}. \quad (3)$$

The experimental determination of temperature fields in the cutter confirms [5] that the tool undergoes higher heat loads during PMO than with conventional cutting. This sets out a number of requirements that should be taken into account in the design and manufacture of tools for flame mechanical cutting:

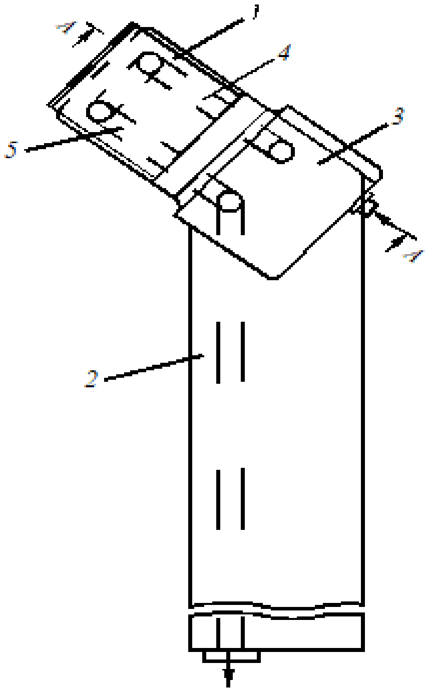
1) design should be prefabricated, containing interchangeable cutting plates or blocks that are easily replaced when the tool blades are damaged or worn; at the same time, the prefabricated structure should be sufficiently rigid and with anti-vibration;
2) cutting tool should have as much strength and thermal conductivity as possible, to resist shock load well;
3) fastening of cutting plates and blocks should be carried out in such a way that the front surface of the tool is free of chips to avoid stacking;
4) the most active heat removal from the cutting wedge should be provided.

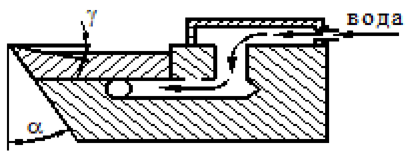
Special requirements are imposed on the design types of cutters and plates. The first requirement is tool assembly. In practice it is implemented in constructions of three types:

1) cutters with replaceable plates, fastening of which in the holder is carried out mechanically;
2) cutters with replaceable blocks, in which the inserts are clamped and the blocks are fixed in the tool holder;
3) cutters with replaceable blocks in which the plates are fixed with soldering and blocks in the holder are fixed mechanically.

III. RESULTS OF THE STUDY

The analysis showed that the third type of construction is most widely used in production, in which the cutting plate is soldered to a replaceable block. In this regard, we have developed a cooled cutter (Fig. 1) [1].





1 — plate T5K10;
2 — cutter (body);
3 — housing for cooling;
4 — channels for water supply
5 — channel for water drainage

Geometric parameters:
$\alpha = 6\text{-}8°$; $\varphi = 45°$; $\gamma = 10°$
$f = 0{,}5$ mm; $\gamma_f = -5°$; $r = 1$ mm

Figure 1. Water-cooled cutter

Plate *1* soldered to the block, inside the holder body there are channels to supply coolant directly to one of the plate surfaces. For the same purpose, a casing *3* is soldered to the holder body, where coolant is supplied.

As a cutting part of the tool in transition to PMO should be used wear-resistant hard alloys such as T15K6, T5K10, BK8, etc.

Geometrical parameters of the tool used in PMO are generally different from those recommended in normal cutting. The front angle γ of T5K10 alloy cutters for PMO has slightly lower values than for unheated cutting. This is necessary to strengthen the cutting wedge and facilitate heat removal through the tool. Chamfers on the front surface with a length f = 0.4 ... 1 mm with an angle on γ_f close to zero or even with a negative value that serve the same purpose. As we known, the double front cutters are more stable than the flat front tool, in particular vibrations occur less frequently during cutting and chip removal is facilitated.

The main rear angle α, like angle α_1 of the tool for the PMO, should have a slightly lower value than conventional incisors. This is necessary to increase the strength and heat resistance of the cutting wedge.

The value of the main angle in terms φ, as shown by the PMO experience, affects not only the cutting forces, but also the heating efficiency of the processed material, because at this feed the angle φ determines the thickness of a cut. It is easier to remove the metal layer when the angle is the smaller in plan ($a = s \sin\varphi$). However, the simultaneous increase in the cutting width causes an increase in the degree of irregularity in the metal heating on active part of the cutting edge. The increase φ reduces the strength of the tip of the cutter and heat dissipation through it. These different aspects of the main angle influence on the PMO process result in the use of a tool with a principal angle in plan φ = 45…60°. Auxiliary angle in plan φ_1 = 15…20°.

In order to increase the strength of the near-surface part and reduce the roughness of a machined surface, the radius of curvature between the edges during PMO is larger than usual to r = 3.

Internal cooling can be carried out by means of a single-phase or two-phase coolant circulating in the channels or cavities of the cutter blocks and holders. Water is used as a single-phase coolant. The channel diameter or coolant flow can be calculated based on a thermal analysis of the convective heat transfer process. The tool is supplied in a unit time heat $\left(Q_p^+ + Q_{из}\right)$. Part of this heat, for example ξ_1, $\left(Q_p^+ + Q_{из}\right)$, must be taken through a channel with a diameter $d_к$ and an active length $l_к$, in which the flow G (cm^3/s) circulates in water. The average temperature on the surface of the walls of the channel is θ_0, and the coefficient of heat transfer α, Wt / (cm^2 · °C). Then the diameter of the channel

$$d_к = \frac{100\xi_1\left(Q_p^+ + Q_{из}\right)}{\pi\alpha\theta_0 l_к}. \quad (4)$$

The coefficient of heat transfer α during fluid movement in smooth channels can be calculated [5] according to the criterion equation:

$$\mathrm{Nu} = 0{,}021\mathrm{Re}^{0,8}\,\mathrm{Pr}_ж^{0,43}\left(\frac{\mathrm{Pr}_ж}{\mathrm{Pr}_c}\right)^{0,25}, \quad (5)$$

where $\mathrm{Pr}_ж$ and Pr_c are Prandtl criteria calculated for the temperature of the liquid at the entrance and for the temperature of walls of the channel, and Nu and Re are the Nusselt and Reynolds criteria. For water in a fairly wide range of temperatures and pressures $\mathrm{Pr}_ж^{0,68}\,\mathrm{Pr}_c^{-0,25} \approx 3{,}8$.

$$\mathrm{Nu} = \frac{\alpha d_к}{10\lambda_н} \text{ and}$$

$$\mathrm{Re} = \frac{\omega d_к}{10\nu_в} = \frac{400G}{\pi d_к^2}\frac{d_к}{10\nu_в} = \frac{40}{\pi}\frac{П}{d_к\nu_в},$$

where G - water flow, cm^3/s; ν_b - kinematic viscosity of water at the inlet to the channel, cm^2/s; λ_b - the coefficient of temperature conductivity, Wt/(cm^2 · °C). Instead of the formula (2.22) at $\lambda_b \cong 0.0042$ and $\nu_b \approx 0.01$ we get Wt/(cm^2 · °C),

$$\alpha \approx \frac{G^{0,8}}{d_к^{1,8}}. \quad (6)$$

Further, considering the cutter as a flat wedge with a taper angle β and $\approx 90°$, on the edge of which there is a heat source with a density $q_л = \frac{10\left(Q_p^+ + Q_{из}\right)}{b}$ of Wt/cm, where b is the width of the cutter, mm, in accordance with the thermophysics formulas [2, 6]:

$$\theta_0 = \frac{10\left(Q_p^+ + Q_{из}\right)}{\pi\lambda_p b}\left(-\mathrm{Ei}\left[-\frac{R_0^2}{4\omega_p\tau}\right]\right), \quad (7)$$

where Ei is an integral-demonstration function for which there are special tables; R_0 is the distance from the edge of the cutter to the channel axis, mm (the channel is assumed to be parallel to the edge).

For small values of the argument (namely, they, as a rule, correspond to our tasks), the last expression can be represented as:

$$\theta_0 \approx \frac{10\left(Q_p^+ + Q_{из}\right)}{\pi\lambda_p b}\ln\frac{225\omega_p V}{R_0^2}.$$

Substituting the valuesα and θ_0 in the formula (3), we get, cm^3/s

$$G = d_к\left(\frac{l_к}{10\zeta_1\lambda_p b}\ln\frac{225\omega_p V}{R_0^2}\right)^{-1,25}. \quad (8)$$

The expression (8) allows you to calculate the cooling water flow or, at a given G - diameter of heat-removing channels

IV. CONCLUSION

Performed calculations allowed to establish d_{eq} = 8.2 mm, G = 4.8 cm^3/s ≈0.3 l/min at l_k = 0.86, λ_p = 0.385,ω_p = 0.145, l_1 = 12 mm, ζ_1 = 0.5, τ= 720 s.

This cooling causes a decrease in the temperature in the cutting area by an average of 200° C and, as a consequence, an increase in the durability of the cutter compared to the treatment without cooling in 1.5-2 times [4].

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