EFFICIENT DIRECTIONS OF DEVELOPMENT OF METHODS OF MECHANICAL PROCESSING OF MATERIALS

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Abstract: *The analytical dependencies for determining the main parameters of machining are given: the processing capacity, the nominal cutting stress (energy intensity of the treatment), the cutting temperature, the thickness of the heated layer of the processed material during blade machining and grinding. Theoretically, it is shown that the energy consumption of the processing is less than that when grinding, and the most efficient processing scheme, taking into account the processing precision limitation determined by the amount of elastic movement in the technological system, is the grinding scheme without transverse feed with a given initial interference in the process system.*

Keywords: machining, grinding process, processing capacity, conditional cutting stress, cutting temperature, elastic displacement value.

1. INTRODUCTION

The creation of modern competitive machine-building products requires a wide application of new science-intensive technologies of mechanical and physicotechnical processing of materials that ensure a multiple increase in labor productivity, quality, precision and cost-effectiveness in the manufacture of parts and machines [1, 2]. Processing of metals by cutting has received wide practical application due to low energy intensity of the process and high quality and productivity indicators in comparison with physical and technical methods of processing. Particularly effective was the use of metal machining in connection with the creation of high-speed machine tools with CNC machining center type and prefabricated carbide and ceramic blade tools with wear-resistant coatings [3]. However, in order to effectively implement the cutting process in each particular case, it is necessary to use the optimal processing conditions that ensure a reduction in the strength and thermal tension of the process. This requires the creation of theoretical fundamentals of mechanical processing that allow us to analytically solve optimization problems to substantiate the most promising methods and processing conditions without involving empirical approaches that require the implementation of labor-intensive and long-term experimental studies.

2. ANALYTICAL RESEARCH

To assess the main most effective areas for the development of machining, an analysis of the analytical dependence should be carried out to determine the processing capacity:

$$Q = S \cdot V = \frac{P_z}{\sigma} \cdot V , \tag{1}$$

where S is the cross-sectional area of the cut, m^2; V - cutting speed, m/s; P_z - tangential component of the cutting force, N; σ - conditional cutting voltage, N/m^2.

Increase the productivity of processing Q by increasing the parameters S and V or increasing, P_z, V and decreasing σ. The increase in the tangential component of the cutting force P_z is the implementation of power cutting, and the increase in the cutting speed V is the realization of high-speed (high-speed and ultra-high-speed) cutting. Reduction of the conditional cutting voltage σ - the control of the process of chip formation during cutting and, first of all, the contact processes occurring on the working surfaces of the tool.

The conditional stress of cutting σ is described by an analytical dependence:

$$\sigma = 2 \cdot \sigma_{ct} \cdot tg(\psi - \gamma), \tag{2}$$

where σ_{ct} is the compressive strength of the material being processed, H/m*2*; ψ - conditional friction angle on the front surface of the tool ($tg\psi = f$ - coefficient of friction); γ - the front corner of the tool.

Reduce the conditional cutting voltage σ by decreasing the angle $\psi - \gamma$, i.e. Reduction of the conventional friction angle ψ (friction coefficient *f*) and an increase in the front angle of the tool γ. Under certain conditions, $\psi - \gamma \to 0$, which can significantly reduce the nominal cutting stress σ and increase the cross-sectional area of the shear S and the processing capacity Q. However, the increase in S when cutting by cutting tools is limited by the strength of its cutting part. Therefore, an increase in the cutting speed V, according to the relationship (1), should be considered as the more preferable way of increasing the processing capacity Q.

As is known, as the cutting speed V increases, the friction coefficient f on the front surface of the tool decreases, which contributes to the reduction of the nominal cutting voltage and the increase σ in the processing capacity Q. The average temperature of the formed chips θ is determined by the approximate dependence:

$$\theta = \frac{\sigma}{c \cdot \rho \cdot \left(1 + \frac{h}{a}\right)}, \tag{3}$$

where c – is the specific heat of the processed material, J/kg ·K; ρ - density of the processed material, kg/m^3; a – is the thickness of the cut, m; h - thickness of the heated layer of the treated surface, m;

$$\frac{h}{a} = \sqrt{\frac{\lambda}{c \cdot \rho \cdot a \cdot V \cdot tg\beta}}, \tag{4}$$

λ - coefficient of thermal conductivity of the processed material, W/m·K; β - the conventional angle of shear of the processed material.

With an increase in the cutting speed V, the conventional shear angle of the material β being processed increases, and the ratio *h/a* decreases. Consequently, the amount of heat leaving the workpiece decreases and the amount of heat that flows into the resulting chips increases. The average chip temperature θ (equal approximately to the surface temperature of the workpiece) with increasing cutting speed *V* increases, asymptotically approaching the value $\sigma / c \cdot \rho$ (Fig. 1) because of the addition (1+*h/a*)$\rightarrow$1. This is the essence of the physical effect of high-speed and ultra-high-speed cutting performed with cutting speeds in excess of 100 m/s, since in this case the temperature of the surface layer of the workpiece remains virtually constant with increasing of cutting speed *V*.

It should be noted that traditional methods of processing with blade tools realize cutting speeds, as a rule, not more than 2 m/s. As the experience of the leading foreign machine-tool companies shows, the transition to the high-speed cutting area allows to increase the processing capacity by more than 10 times while improving the quality and accuracy of the machined surfaces, which is a cardinal solution to the problem of machining materials. For the practical implementation of these processing processes, it is necessary to create domestic machines that operate at cutting speeds of the order of 10,000 m/min. This will be an important step in raising production, improving the competitiveness of machine-building products and increasing labor productivity.

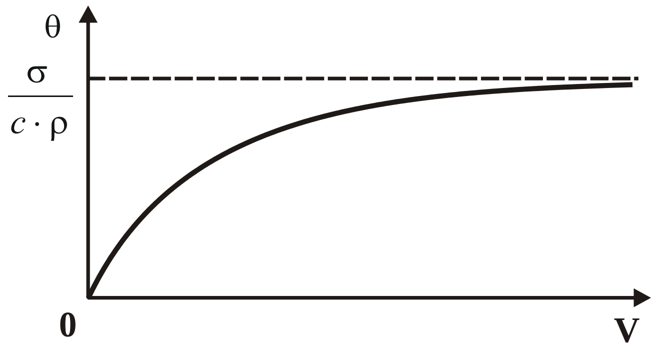

Fig. 1. *Dependence of surface layer temperature machined part from θ the cutting speed V.*

The revealed regularities are valid at cutting of metal materials. When cutting nonmetallic materials, almost all the heat goes to the heating of the cutting tool. In this case, the increase in cutting speed is limited and is determined by the level of the process strength and the heat removal conditions from the cutting zone, i. e. Thermal conductivity of instrumental material.

When grinding materials, in connection with the negative front corners of the cutting grains of the circle, the dependence (2) takes the form:

$$\sigma = 2 \cdot \sigma_{ct} \cdot tg(\psi + \gamma). \qquad (5)$$

Under the condition $(\psi + \gamma) \rightarrow 90^0$, we have $tg(\psi + \gamma) \rightarrow \infty$ (Fig. 2). To reduce the conventional cutting stress σ, it is necessary to reduce the angles ψ and γ, using effective technological media (reducing the coefficient of friction), providing high sharpness of the cutting grains, etc.

Comparing the dependences (2) and (5), it can be seen that under the blade treatment the conditional cutting stress σ is less than in grinding. When grinding, the total instantaneous cross-sectional area of the cut is less than all the simultaneously operating grains $S = Q / V_c$ and, accordingly, the processing capacity *Q*. Therefore, to increase *Q*, one can increase the speed of the circle V_c.

In general, when grinding materials, the productivity of processing *Q* is determined by the dependence:

$$Q = \frac{P_y \cdot V_c \cdot K_{gr}^2}{2 \cdot \sigma_{ct}}, \tag{6}$$

where P_y – is the radial component of the cutting force, H; $K_{gr} = P_z / P_y$ - coefficient of grinding.

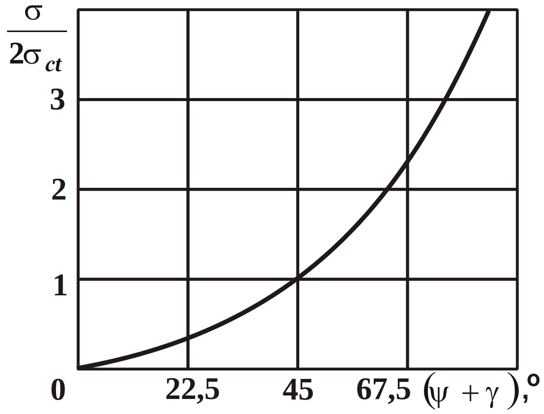

Fig. 2. *Dependency ratio* $\sigma / 2\sigma_{ct}$ *from the corner* $(\psi + \gamma)$.

Proceeding from the dependence (6), it is possible to increase the productivity of the processing *Q*, first of all, by increasing the grinding factor K_{gr} due to the increase in the cutting ability of the wheel (K_{gr} varies within *f* ... 1, where *f* is the coefficient of friction of the grain of the wheel with the material being processed). Parameters P_y and V_c have the same effect on the processing performance of *Q*, i. e. Effectively use both power (deep) and high-speed (ultra-high-speed) grinding. The effect is enhanced in case of combining deep and high-speed grinding. It should be noted that at present the leading foreign machine-tool companies have mastered the production of grinding machines operating at cutting speeds of 300 m/s.

Machining processes are extremely complex and little studied. Unfortunately, even now there is no clear scientific understanding of the mechanics of the behavior of the technological system during processing. This limits the ability to design new machines and create highly efficient processing methods. To develop new solutions, it is necessary to move from traditional empirical to scientific analytical approaches, using the enormous achievements of science in the field of mechanics of deformed systems. For example, by calculating the amount of elastic displacement *y* and the productivity of processing *Q* with round external grinding, it was possible to obtain an interesting and important solution:

$$Q = Q_{nom} - (Q_{nom} - Q_0) \cdot e^{(-\overline{\beta} \cdot \tau)}; \tag{7}$$

$$y = y_s - (y_s - y_0) \cdot e^{(-\overline{\beta} \cdot \tau)}, \tag{8}$$

where Q_{nom} - nominal processing capacity, m^3/s; $Q_0 = \frac{y_0 \cdot V_c \cdot K_{gr} \cdot c}{\sigma}$ - processing capacity when the initial tension in the process system is reached y_0, m^3/s; V_c - speed of the wheel, m/s; c - rigidity of the technological system, N/m; $\overline{\beta} = \frac{V_c \cdot K_{gr} \cdot c}{\pi \cdot D_{det} \cdot l_{det} \cdot \sigma}$; $y_s = \frac{\sigma \cdot Q_{nom}}{V_c \cdot K_{gr} \cdot c}$ - steady-state value of elastic displacement in the technological system, m; D_{det}, l_{det} - diameter and length of the workpiece, m; τ - processing time, s.

The nature of the change Q and y over time processing is shown in Fig. 3a, b. For $Q_{nom} < Q_0$ and $y_s < y_0$, the conditions $Q > Q_{nom}$ and $y > y_s$ (curve 1) are satisfied. For $Q_{nom} > Q_0$ and $y_s > y_0$, the conditions $Q < Q_{nom}$ and $y < y_s$ (curve 3) are satisfied. For $Q_{nom} = Q_0$ and $y_s = y_0$, the conditions $Q = Q_{nom}$ and $y = y_s$ (curve 2) are satisfied.

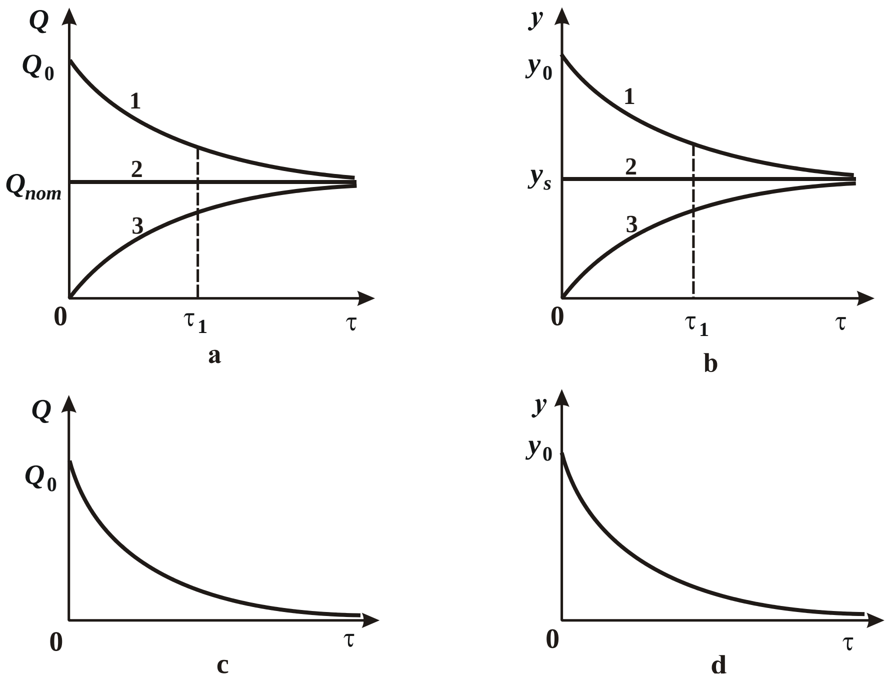

Fig. 3. *Dependence of processing performance (a, c) and the elastic displacement (b, d) of the processing time.*

The average processing capacity over time τ_1 for the three curves presented in Fig. 3a, will be different. So, if a family of curves is drawn $Q-\tau$ through a fixed point with coordinates Q, τ_1 then the greatest average processing capacity will be provided under the condition $y_s < y_0$, and the smallest - under the condition $y_0 = 0$ (Fig. 3b). Obviously, the greater the initial interference in the process system y_0, the greater the average processing capacity.

From the transformed dependence $y = y_s \cdot \left[1-e^{(-\beta\cdot\tau)}\right] + y_0 \cdot e^{(-\bar{\beta}\cdot\tau)}$ (8): it follows that the maximum value y_0 (for given values of y and $\tau=\tau_1$) is achieved under the condition $y_s = 0$. Consequently, the most efficient processing scheme, taking into account the limitation in the processing accuracy (determined by the amount of elastic motion y) is the grinding scheme without transverse feed $(Q_{nom}=0)$ with initial interference y_0 in the process system. Current values Q and y in this case are determined by the dependencies (Fig. 3c, d):

$$Q = Q_0 \cdot e^{-\frac{V_c \cdot K_{gr} \cdot c \cdot \tau}{\pi \cdot D_{det} \cdot l_{det} \cdot \sigma}}; \tag{9}$$

$$y = y_0 \cdot e^{-\frac{V_c \cdot K_{gr} \cdot c \cdot \tau}{\pi \cdot D_{det} \cdot l_{det} \cdot \sigma}}. \tag{10}$$

The higher the value V_c, K_{gr}, c and the smaller y_0, D_{det}, l_{det}, σ, the faster the specified accuracy of processing is achieved. Obviously, the largest value y_0 can be equal to the value of the allowance being removed Π. To fulfill this condition, starting from the dependence (9), it is necessary that the maximum possible processing capacity, due to the cutting properties of the grinding wheel, be equal to or commensurate with the value under the condition [4].

Dependencies (9) and (10) describe the "ideal" cutting scheme from the point of view of ensuring accuracy and processing capacity, i.e. The cutting scheme, which in the future can become the main in the machining of materials. From the data given, it follows that by creating a preliminary tightness in the technological system y_0, it is possible to realize the condition $Q > Q_{nom}$.

It should be noted that machining according to a rigid scheme (curve 2 in Fig. 3b) leads to an increase in the amount of elastic displacement (a decrease in the accuracy of processing). Consequently, the methods of processing blades and abrasive tools that are applied in practice in a rigid scheme from the point of view of ensuring the accuracy of processing are inefficient. It is necessary to use a scheme without feed with an initial radial movement, reducing the allowances for processing and limited to finishing operations with the use of abrasive and blade tools. In fact, the hard cutting schemes used in practice are a necessary measure in connection with the need to remove relatively large allowances.

3. CONCLUSION

The analytical dependencies for determining the processing capacity, the nominal cutting stress (energy intensity of the treatment), the cutting temperature, the thickness of the heated layer of the processed material during blade machining and grinding which are the main parameters of machining are given. Energy consumption of the machining processing is theoretically shown and analyzed taking into account the processing precision limitation determined by the amount of elastic movement in the technological system.

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