INFLUENCE OF FUNCTIONAL PROPERTIES OF TECHNOLOGICAL CUTTING FLUID ON A CHOICE OF OPTIMUM CUTTING REGIMES

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Abstract: The low workability of special brands corrosion-proof, heat resisting and high-resistance steels and alloys, widespread in details and nodes of modern machines, causes high labour input and the cost price of their manufacture. In this connection probes of possibilities of heightening of capacity and lowering of the cost price of handling of these materials at the expense of improvement of working conditions of the cutting instrument and, in particular, at the expense of application of various technological cutting fluid (TCF).
High temperatures in a workpiece range, arising because of low heat conduction of intractable materials, define necessity of probe of the temperature phenomena for a cutting zone. The further development of a technique of definition of temperatures is of interest for these aspects of materials in a cutting zone at use TCF and the account of their influence on a choice of optimum conditions of cutting.
Key words: cutting fluid, optimisation, high-resistance steels, optimum regimes.

1. INTRODUCTION

The low workability stainless, heat resisting and high-resistance steels and alloys, widespread in details and nodes of modern machines, causes high labour input and the low cost value of their manufacture. In this connection probes of possibilities of heightening of capacity and lowering of the cost value of machining of these materials are rather actual. One of paths of the decision of this problem is an application optimum regime of machining, for concrete conditions, and correctly picked up technological cutting fluid means (TCFM).
High temperatures in zone of machining define necessity to consider influence of temperature on regimes of machining by their optimizations. Correct application of technological cutting fluid means allows changing essentially character and magnitude of thermal flows and temperatures in a zone of machining.
One of modes of heightening of capacity of machining is simultaneous optimisation of cutting speed and of feed by criterion of the maximum capacity by means of a method of linear programming, (Starcov V.K., 1989). Available operations on optimisation of regimes of machining, as a rule, do not consider features of machining of the specified steels and alloys. There are no data on influence TCFM on regimes of machining, (Gurevitch V. A., 1986).
The purpose of represented operation – to fix influence of basic functional properties of TCFM on temperature of cutting and optimum on capacity cutting regimes at turning of workpieces from intractable materials, and also to evaluate their influence on heightening of capacity of their machining.

2. THE BASIC CONTENTS AND RESULTS OF PROBE

The temperature in a tool edge is shaped under the influence of the thermal streams q_1 and q_2 arising in a band of cutting owing to operation of deformation of metal q_∂, formation of a chip, a friction on contact platforms between a chip and a face of the tool $q_{TП}$ and a friction between a flank of the tool and the machined surface of a workpiece q_{T3} (Fig. 1).
Axis X in the examined system of coordinates oriented in the direction of front surface athwart to the main cutting edge; l is length of blivet in directions of tails of shaving; h is a wear on a back

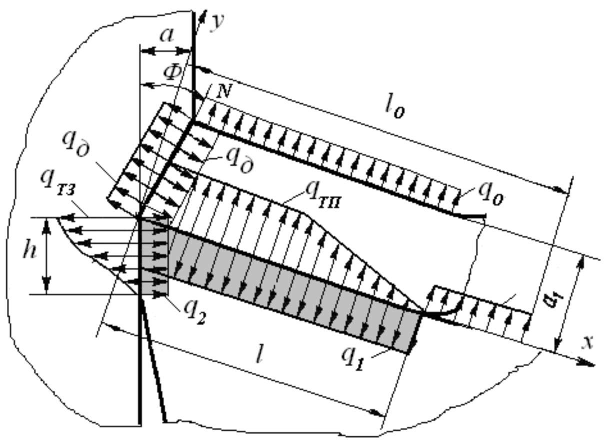

Fig. 1. Layout of warmth sources chart and distributing of thermal streams in the of cutting area with the use of CF

surface; a is a thickness of cut; a_1 is a thickness of shaving; Φ-- corner of change.

Taking into account operation of a flow of warmth q_o mean temperatures on face and flank of a tool can be defined as follows, (Reznikov A.N., Reznikov L.A., 1990):

$$\Theta_1 = \frac{M_1 l}{\lambda_{\hat{e}}}(q_1 + q_o) + \frac{N_2 h}{\lambda_{\hat{e}}} q_2 - \frac{M_o l_o}{\lambda_{\hat{e}}} q_o$$
$$\Theta_2 = \frac{M_2 h}{\lambda_{\hat{e}}} q_2 + \frac{N_1 l}{\lambda_{\hat{e}}}(q_1 + q_o) - \frac{N_o l_o}{\lambda_{\hat{e}}} q_o \quad (1)$$

where q_1 and the q_2-thermal streams arising in a band of cutting owing of formation of a chip, friction on contact platforms between a chip and a face of the tool $l\times b$ (b – width of shear) and friction between a flank of the tool and the machined surface of a workpiece $h\times b$; λ_θ – heat transfer coefficient of tool; M_1, M_2, N_1, N_2 - the dimensionless functions spotting a heating of platforms on a face of the tool and a face of the tool; M_o, N_o – the dimensionless functions spotting cooling of a platform on a face of the tool under the influence of CF.

Dimensionless functions, determining heating of blivets:

$$M_{1,2} = (4{,}88+2{,}64\eta_{1,2}^{0{,}5}\lg \eta_{1,2})\beta^{-0{,}85}$$
$$N_{1,2} = (0{,}04+0{,}02\,\eta_{1,2}^{0{,}6}\lg \eta_{1,2})B_{1,2}(h/l)$$

where η - dimensionless width of cut: $\eta_1 = b/l$, $\eta_2 = b/h$ ($\eta_{1,2}>1$); $\beta = 90° - \gamma - \alpha$ - sharpening corner; $b = t/sin\varphi$ - width of cut; t - cutting depth, φ - a main corner in a plan; $B_{1,2}(h/l)$ - special functions: $B_1(h/l) = 2{,}85 - 0{,}9(h/l)$, $B_2(l/h) = 2(l/h)^{0{,}54}$ if $\beta = 90°$.

Dimensionless functions spotting cooling of a platform on a face of the tool under the influence of CF.

$$M_o = 4{,}88\beta^{-0{,}85},\ N_o = 0{,}04B_1$$

At application TCFM, gived in the form of a cutting fluid (CF) by free watering from a face of the tool, on a platforms $l_o\times l_o$ organises a flow of warmth with an equal distribution of tightness of a heat evolution q_o. According to a Newton's –Rihman's laws featuring process of convective heat exchange, the stream of warmth arising at activity CF:

$$q_o = \alpha_o \Theta_{med} \quad (2)$$

where α - convective heat exchange coefficient on a surface of contact of the tool with CF; Θ_{med} – medial temperature on this surface.

For calculation of coefficient of a convective heat exchange at delivery CF in a cutting band by the free watering, uses the equation, (Reznikov A.N., Reznikov L.A., 1990):

$$\alpha = C\,\lambda_o w^m \big/ l_o^{(1-m)} v^{(m-n)} \omega_o^n \quad (3)$$

where λ_o, ω_o - thermal conductivitie and thermal diffusivity of means; C, m, n, x, y, z - coefficient and the indexes of degrees depending on a mode of feeding of means in zone of machining; l_o - the characteristic size: $l_o = BH/2(B+H)$; B - width of tool shank, H- head of tool shank; w – mean velocity of flow; v - coefficient of kinematic viscosity of means.

Because the temperature of surfaces of the tool exceeds 100°C, at definition of coefficient of a convective heat exchange it is necessary to consider change of a modular state of a fluid. Convective heat exchange coefficient in a boilling fluid $\alpha_к$:

$$\alpha_{\hat{e}} = 3{,}33\cdot 10^6 (\Theta_S - 100)^{-1{,}43} \text{ at } \Theta_S \geq 120\,°\text{C} \quad (4)$$

The motion of a fluid concerning the tool makes changes to boil process. Therefore we use the given coefficient of a convective heat exchange $\alpha_{пр}$, considering joint influence of boil and convective heat exchange:

$$\alpha_o = \alpha\left[\frac{(4\alpha + \alpha_{\hat{e}})}{(5\alpha - \alpha_{\hat{e}})}\right] \text{ at } 0{,}5\alpha \leq \alpha_{\hat{e}} \leq 2\alpha \quad (5)$$

where $\alpha_к$ and α_o - independently calculated coefficients of a convective heat exchange at boil and at convective heat exchange accordingly.

For definition of density of a thermal emission q_o it is necessary to use value of medial temperature Θ_{med} of surfaces of contact of the tool with CF. For its definition it is accepted: $\Theta_{med} = m_o\Theta_1$; $m_o = \rho^{-0{,}86}$, $\rho = 2l_o/(b+l)$ – the dimensionless parametre comparing the sizes of a band of cooling with the sizes of a contact platforms of a chip with an edge of the tool: Θ_1 – medial temperature on a face of the tool. Then the thermal emission density is equal:

$$q_o = \alpha_o m_o \Theta_1 \quad (6)$$

Closenesses of thermal streams on front q_1 and back q_2 surfaces of blade of instrument at the set heat exchange with application CF can be expected:

$$q_1 = \frac{K_1K_3\lambda_u - K_2N_2hp_1 + K_1(M_2 - p_2N_2)h}{K_3K_5\lambda_u + (M_2 - p_2N_2)K_5h - N_1N_2lh/\lambda_u}$$
$$q_2 = \frac{(K_1 - K_5q_{11})\lambda_u}{N_2hp_1}, \quad (7)$$

where $K_1 = \dfrac{(1+c)\omega_\partial kb' q_\partial}{\lambda_\partial V} + \dfrac{K_{c1}q_{1T}}{\lambda_\partial}\sqrt{\dfrac{\omega_\partial kl}{V}}$

$$K_2 = \frac{(1+c)\omega_ä k b' q_ä T_u}{\lambda_ä V} + \frac{K_{c2} q_{2T}}{\lambda_ä}\sqrt{\frac{\omega_ä h}{V}}$$

$$K_3 = \frac{1{,}82 K_{c2}}{\lambda_ä}\sqrt{\frac{\omega_ä h}{V}}$$

$$K_5 = \frac{1{,}3 K_{c1}}{\lambda_ä}\sqrt{\frac{\omega_ä k l}{V}} + \frac{M_1 l p_1}{\lambda_u}$$

$$p_1 = \frac{\lambda_u}{\lambda_u + \alpha_o m_o (l_o M_o - l M_1)}$$

$$p_2 = \frac{\alpha_o m (l_o N_o - l N_1)}{\lambda_u + \alpha_o m_o (l_o M_o - l M_1)}$$

$$I_1 = (1+c)\omega_ä k b' / \lambda_ä V$$

$$I_2 = 0.75 K_{c2}\sqrt{\omega_ä h} / \lambda_ä \sqrt{V}$$

$\lambda_д$, λ_u, $\omega_д$, ω_u is coefficients of heat conductivity and diffusivity of materials of detail and instrument accordingly; k is a coefficient of усадки of shaving; V is cutting speed; c is a coefficient, taking into account heating of layers of metal of shaving for one turn of detail; $T_д$ is a dimensionless function of distributing of temperatures in a detail, caused by the warmth of deformation; b' is a coefficient of relative amount of warmth, get-away in shaving.K_{c1} it is a coefficient, taking into account the law of distributing of closeness of thermal stream on a front surface (for the combined law K_{c1} = 0,77); K_{c2} is a coefficient, taking into account the law of distributing of closeness of thermal stream on a back surface (for the asymmetrical normal law K_{c2} = 0,55).

Graphs of dependence of thermal streams closeness on front q_1 and back q_2 surfaces of blade from a wear on the back surface h at treatment without CF and with the use of CF are presented on fig. 2.

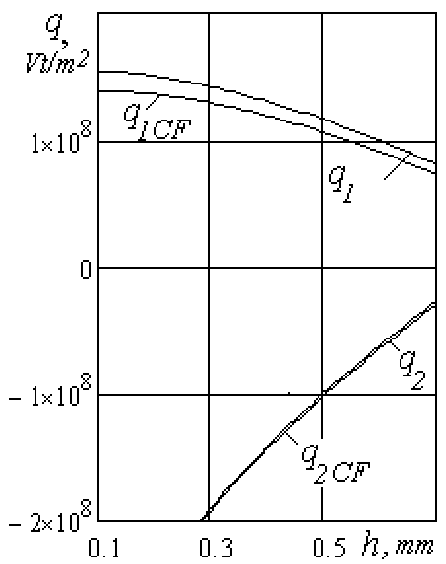

Fig. 2. Graphs of dependence of thermal streams closeness on front q_1 and back q_2 surfaces of blade from a wear on the back surface h at treatment without CF and with the use of CF

Taking into account the action of warmth flow with the use of CF middle temperatures on front Θ_1 and back Θ_2 surfaces of blade can be certain as follows:

$$\Theta_1 = p_1\left(\frac{M_1 l}{\lambda_u} q_1 + \frac{N_2 h}{\lambda_u} q_2\right)$$
$$\Theta_2 = \frac{(M_2 - p_2 N_2) h}{\lambda_u} q_2 + \frac{(N_1 - p_2 M_1) l}{\lambda_u} q_1 \qquad (8)$$

In default of CA (a_0 = 0) temperatures on front Θ_1 and back Θ_2 surfaces of blade can be certain on the same formulas taking to account that $p_1 = 1$, $p_2 = 0$.

The cutting temperature represents medial temperature on face and flank of the tool:

$$\Theta = (\Theta_1 l + \Theta_2 h)/(l + h) \qquad (9)$$

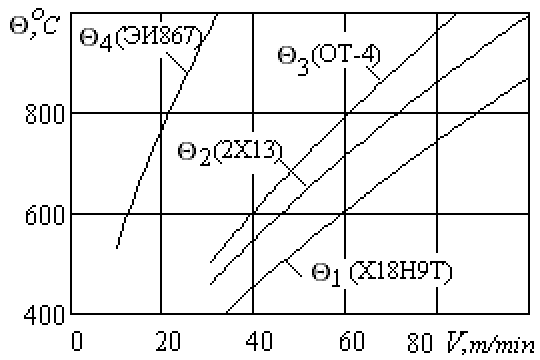

Fig. 3. Graphs of dependence of cutting temperature from cutting speed for the different processed materials

Graphs of dependence of cutting temperature from cutting speed for the different processed materials at treatment without CF are presented on figure 3.

As a result of examination of dependences of temperature of cutting Θ from velocity of cutting V and feed S with use plural regression analysis at machining of steel X18H9T with various CF became erected following sedate association (with a margin error, not exceeding 5 %):

At machining without CF:

$$\Theta_{theor} = 53{,}5 V^{0.71} S^{0.51}$$

At machining with use as CF of emulsion IY-2:

$$\Theta_{CF\,1} = 38{,}2 V^{0.72} S^{0.53}$$

At machining with use as CF of emulsion NGL-205:

$$\Theta_{CF\,2} = 34{,}6 V^{0.72} S^{0.53}$$

At machining with use as CF of emulsion SDM,u :

$$\Theta_{CF\,3} = 31 V^{0.72} S^{0.53}$$

Agency of cutting speed V on cutting temperature Θ at machining of stainless steel X18H9T by carbide-tipped cutting tool BK8 with use various CF is presented on fig. 1 (tool wear admissible on a flank is accepted h = 0,2мм). The calculated value given heat transfer coefficient $\alpha_p = 4\cdot 10^4$ $vt/m^{2}\cdot{}^{o}C$

Inspection of adequacy of the received dependences is executed by comparison of theoretical dependences with results of the experiments presented in, (Gurevitch V. A., 1986).

The results of comparison reduced on figure 4, testify that, with a margin error, not exceeding 10 %, theoretical dependence of temperature of cutting Θ_{theor} from cutting speed V at ming without CF proves to be true experimental Θ_{exp} both on level of temperatures, and on character of dependences.

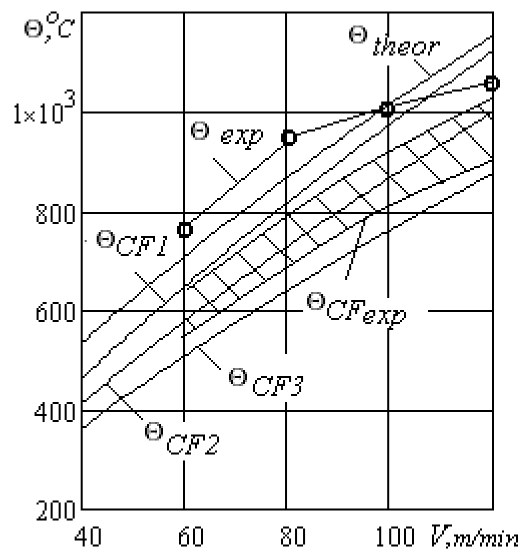

Fig. 4. Graphs of dependence of temperatures of cutting from cutting speed at machining of stainless steel X18H9T with various CF

Results of experimental researches of temperatures depending from cutting speed V for various CF are presented on fig. 4 by shaded zone also well enough coinciding with settlement dependences.

For the estimation of efficiency of action CF the coefficient of cutting temperature decline is entered:

$$K_o = \Theta_{CF} / \Theta_{teor} \qquad (10)$$

Graphs of dependences of coefficient of cuttings temperature decline K_o from speed V for different CF are presented on a fig. 5.

The decline of cutting temperature Θ_{CF1}.at treatment with the use as CF of emulsion on the basis of эмульсола IY-2 is arrived at mainly due to the cooling effect of CF. At the use of emulsion on the basis of эмульсола NGL-205, consisting of oily solution of sulphonate of sodium and passivatings additions of inhibitors to corrosion, to the cooling effect an effect is added oiling, that strengthens the decline of temperature Θ_{CF2}. The most effect of temperature decline $\Theta_{CF3}$is observed at the use of emulsion on the basis of emulsion SDM,u, being the waterless system containing butter, sulphonate of sodium, inhibitors of corrosion and two-bit (to 3 %) of molybdenum (as an antiwear additive), passing ultrasonic treatment disulfide. The presence of molybdenum disulfide promotes the oiling action of CF substantially, what provides the maximal decline of cutting temperature.

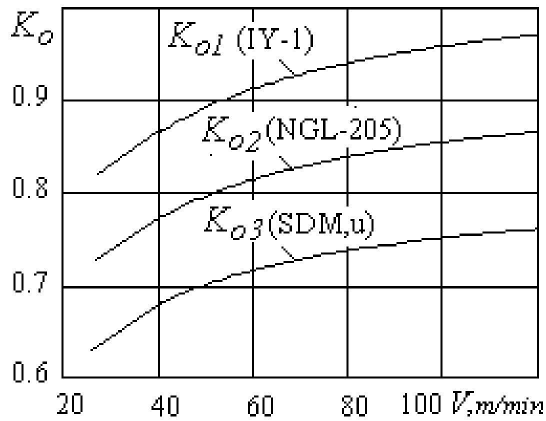

Fig. 5. Graphs of dependences of coefficient of cuttings temperature decline K_o from speed V at machining of steel X18H9T for different CF

The got coefficients are used for the account of action of different CF in temperature limitations during further optimization of the cutting modes.

As target function by optimisation of regimes of machining we accept productivity of the machining which maxima is reached at a minimum of computed machine time, or a maxima $n\ s \rightarrow max$. In the present work following basic restrictions of regimes of cutting at machining intractable materials [4] are considered:

1) by the cutting possibilities of the cutting tool caused by cutting speed, its corresponding tool life:

$$\pi Dn / 1000 \le C_V K_V / T^{m_v}\ t^{x_v} s^{y_v} \qquad (11)$$

where D – diameter of machining, C_V, K_V – coefficients and x_v, y_v, m_v – indexes which characterise degree of influence of depth of cut t, of feed s and tool life T for cutting speed V, difiniendums depending on conditions of service;

n – frequency of rotation;

2) on maximum permissible temperature of cutting:

$$\tilde{N}_t t^{x_t} s^{y_t} v^{z_t} \le \Theta_{äîï} \qquad (12)$$

where C_t - fixed coefficient, z_t, y_t, x_t – the apparent exponents characterising influence on temperature of cutting speed, of feed and depth of cutting.

3) on strength of a plate of a cutting tool:

$$34c^{1.35}t^{0.77}\, K_{\varphi} \geq C_P K_P s^{y_p} t^{x_p} \qquad (13)$$

where c – width of a plate; φ- the tool cutting edge angle; C_P, K_P – coefficient and x_p, y_p, – the indexes characterising degree of influence of depth and feeding on force of cutting P_z, defined depending on service conditions $K_\varphi = \left(\sin 60^\circ / \sin\varphi\right)^{0.8}$.

As a result of a linearization of target function and restrictions by a taking the logarithm, the mathematical model of process of the cutting, expressed by system of the linear inequalities ($X1 = \ln n$; $X2 = \ln s$) is defined and graphically presented on fig. 6.

$$\begin{cases} X1 + y_V X2 \leq b_1, \\ z_t X1 + y_t X2 \leq b_2, \\ y_P X2 \leq b_3, \\ (X1 + X2) \to \max, \end{cases} \qquad b_1 = \ln\left(\frac{1000 C_V K_V}{\pi D T^{m_v} t^{x_v}}\right)$$

$$b_2 = \ln\left(\frac{1000^{z_t}\,\Theta_{äï}}{\tilde{N}_t t^{x_t} (\pi D)^{z_t}}\right)$$

$$b_3 = \ln\left(\frac{34\tilde{n}^{1.35} K_\varphi}{C_P K_P s^{y_p} t^{(x_p - 0.77)}}\right)$$

Definition of optimum of regimes of cutting is executed for rough cut turning of the shaft (depth of cutting t = 2mm,) diameter D = 100mm, length L=200 mm from steel X18H9T. Machining is executed on the engine lathe by clamped-tip tools with throw-away from sintered hard alloy ВК8; accepted tool life T = 30мин, allowable wear on a flank h = 0,2мм. At machining with CF it is used emulsion SDM,u.

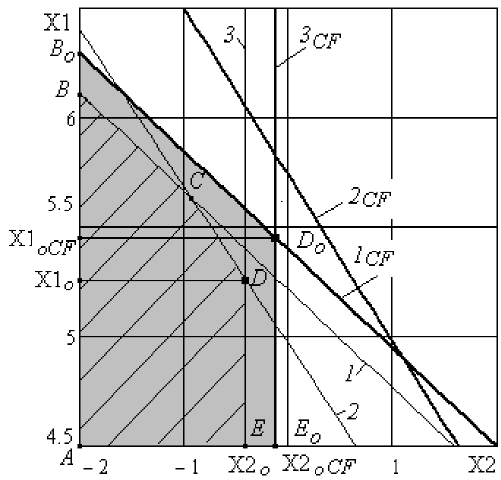

Fig. 6. The circuit of definition of optimum regimes of cutting at turning handling of steel X18H9T with application CF

For the set conditions of a machining the accepted following coefficients and the indexes characterizing degree of influence of depth, feeding and tool life for for cutting speed [2]: C_V =150; x_v = 0,15; y_v = 0,45; m = 0,25; K_V = 1,2; coefficients and the indexes characterizing degree of influence of depth, feeding and cutting speed on force of cutting [2]: C_P = 3400; x_p = 0,95; y_p = 0,75;
n_p =-0,15; K_P = 0,8.

Following values of parametres b_i are defined: at machining without CF: b_1 = 5,214; b_2 = 3,527; b_3 =-0,092; b_4 =-2,996; b_5 = 1,03; b_6 = 2,536; b_7 = 7,601.
at machining with CF: b_1 = 5,397; b_2 = 4,073; b_3 = 1,765; b_4 =-2,996; b_5 = 1,03; b_6 = 2,536; b_7 = 7,601.
Polygon $ABCDE$ represents area of possible solutions at machining without CF, polygon $AB_oD_oE_o$ - at machining with CF. Target function accepts maximum value in point D for which the sum of distances to axes ($X1+X2$) is maximum. Coordinates of points D ($X1_{opm}$, $X2_{opm}$) and D_o ($X1_{opm}$, $X2_{opm}$) are required best values of parametres on which foundation optimum frequency of rotation and feed are defined. Point D is a crosspoint of limitations on maximum permissible temperature of cutting (2) and limitations on strength of a plate of a cutting tool (3). At the expense of use CF temperature limitation (2) does not operate, point D_o is a crosspoint of limitations by cutting possibilities of the tool (1) and limitations on strength of a plate of a cutting tool (3) owing to what optimum values of feedings, and cutting speed increase that reduces in heightening of capacity of machining.
For the set conditions following optimum regimes of cutting at turning of a steel X18H9T is are defined:
-at machining without CF: cutting speed V_o = 62 m/min, feeding S_o= 0,65mm/revolution;
- at machining with CF: cutting speed V_o = 73 m/min, feeding S_o = 0,8mm/ revolution.
Graphs of dependence of serve from the cutting depth and cutting speed from the tool life for the different processed materials are presented on figure 7.

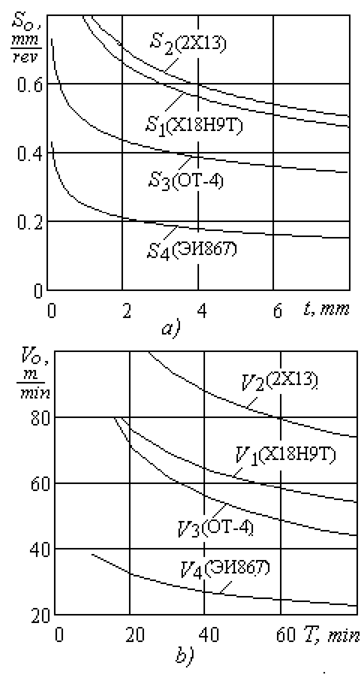

Fig. 7. Graphs of dependence of serve from the cutting depth – *a)* and cutting speed from the tool life – *b)* for the different processed materials

Graphs of dependence cutting speed from serve at treatment of steel X18H9T without CF and with the use of CF are presented on figure 8.

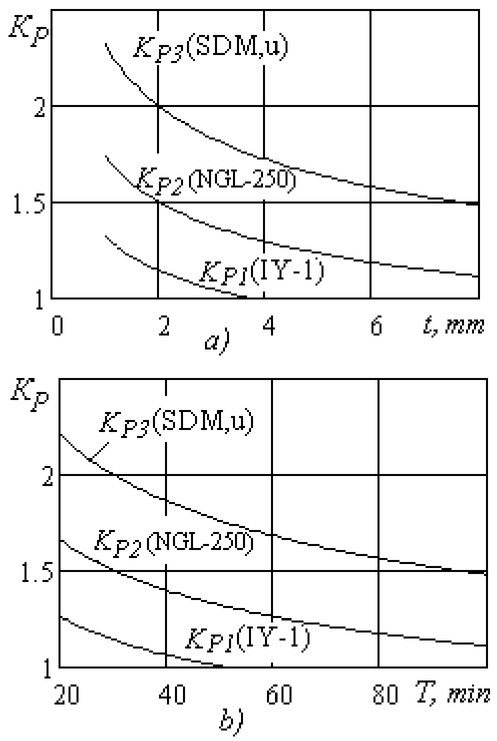

Fig. 8. Graphs of change of coefficient heightenings of capacity K_P at turning of steel X18H9T with application various CF depending on depth of cutting – *a)* and the tool life – *b)*

Optimum regimes of cutting - feeding and cutting speed can be defined analytically:

$$S_{\hat{i}} = \left(34c^{1,35} t^{(0,77-x_P)} K_\varphi / C_P K_P\right)^{\frac{1}{y_P}} \qquad (14)$$

$$V_{\hat{i}} = \left(\frac{\Theta}{C_t}\right)^{\frac{1}{z_t}} \left[\frac{C_P K_P}{34c^{1,35} t^{(0,77-x_P)} K_\varphi}\right]^{\frac{y_t}{y_P z_t}} \quad if \ t \le t_o \qquad (15)$$

$$V_{oCF} = \left(\frac{C_V K_V}{T^m t^{X_V}}\right) \cdot \left(\frac{C_P K_P}{34c^{1,35} t^{(0,77-x_P)} K_\varphi}\right)^{\frac{y_v}{y_P}} \quad if \ t \ge t_o$$

$$t_o = \left(\frac{C_V K_V}{T^m}\right)^{\frac{1}{x_V}} \cdot (S_o)^{\frac{y_t - y_v z_t}{z_t x_V}} \left(\frac{C_t}{\Theta}\right)^{\frac{1}{z_t x_V}}$$

The received analytical expressions allow calculating optimum regimes of cutting at machining of intractable materials for any conditions of machining. On their foundation the coefficient of heightening of capacity of machining of intractable materials can be defined at use CF:

$$K_{\ddot{I}} = \left(\frac{C_V K_V}{T^m t^{x_V}}\right) \left(\frac{C_t}{\Theta}\right)^{\frac{1}{z_t}} \left(\frac{C_P K_P t^{(x_p - 0,77)}}{34c^{1,35} K_\varphi}\right)^{\frac{y_v z_t - y_t}{y_p z_t}}$$

Graphs of change of coefficient heightenings of capacity K_{Π} at turning of steel X18H9T with application various CF depending on depth of cutting and the tool life, presented on figure 9, testify that with their increase capacity of machuning decreases.

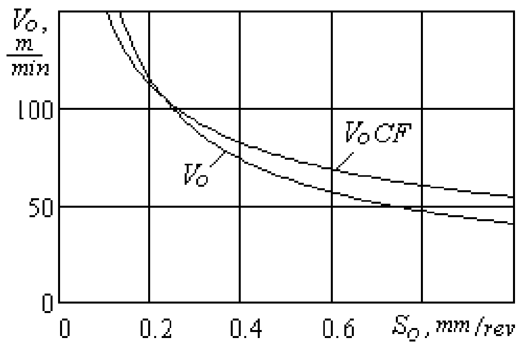

Fig. 9. Graphs of dependence cutting speed from serve at treatment without CF and with the use of CF

Ground introduced of coefficient heightenings of capacity of machining the estimation of efficiency of application various CF can be executed.

3. CONCLUSIONS

In operation the estimation of possibility of lowering of temperature in a cutting zone is executed at machining of intractable materials with application various CF. Influence CF on the optimum regimes of cutting ensuring the maximum capacity of machining is fixed**.** The received analytical expressions for calculation of optimum regimes of cutting ensure possibility of a quantitative estimation of heightening of capacity of machining of workpieces from intractable materials at use various CF. The designed technique can be used for optimization of regimes of cutting at various aspects of machining with application CF.

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