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THE ESTIMATION OF POSSIBILITIES OF THE TURNING PRODUCTIVITY RISE WITH THE USE OF COATED CARBIDE CUTTING TOOLS AND TECHNOLOGICAL CUTTING FLUID

IVCHENKO Tatiana

The Department “Manufacturing Engineering”; SHEI “Donetsk National Technical University”; 58, Artyoma Street, 83001 Donetsk, UKRAINE
Corresponding author: IVCHENKO Tatiana, e-mail ivchenko.sovet@gmail.com

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Abstract. The method of optimization of the cutting regime at turning with the use of coated carbide cutting tools and technological cutting fluid on the criterion of maximum productivity is developed. Mathematical model of cutting process at turning taking into account limitations on the cutting temperature is developed. With the use of method of the linear programming analytical dependences of the optimum cutting regime on the turning parameters are defined. The factor of turning productivity rise, which takes into account the increase of coated carbide cutting tool life, cooling and oiling properties of technological cutting fluid is a creation. Based on that factor the estimation of possibilities of the turning productivity rise of the coated carbide cutting tools and technological cutting fluid application for various turning parameters is executed.

Keywords: turning, optimization, cutting temperature, coated tools, cutting fluid, productivity.

1. Introduction

Intensification of cutting process is the major problem of treatment of machine details. Now it is most effectively solved with use of coated carbide cutting tools (CCT) and technological cutting fluid (CF) [1].

For providing of maximal effect from their application, it is expedient to use various methods of optimization cutting parameters by criteria of the maximum productivity or the minimum cost price [2]. Now the linear programming method is most often applied to optimization of cutting speed and feed taking into account operating limitations by criterion of the maximum productivity.

Intensification of cutting process results in substantial growth of cutting temperature and necessity of account of limitations temperature during optimization. The presented in the article [3] researches allow calculating of thermal streams and cutting temperatures at turning with the use of CF and successfully solving the tasks of cutting parameters optimization taking into account temperature limitations for any terms of machining.

Problems of optimization are rather successfully solved for turning materials at application of CF [4, 5]. However, results of these probes cannot be to spread to a coated carbide cutting tools. The further development of optimization methods of turning conditions taking into account the increase of CCT life is of interest. It will allow essential increasing of cutting regimes and machining productivity.

The purpose of the represented work is to perfect the method of optimization and estimation of possibilities of the machining productivity rise taking into account an action CF for CCT.

2. Basic contents and results of probe

By optimization of cutting regimes, productivity is accepted as an objective function of the machining which maximum is reaching at a minimum of basic time

at rough turning limitations on possibilities of the cutting tool (1); on the maximum permissible cutting power N (2); on maximum permissible of cutting temperature Θ (3); on maximum permissible cutting tool strength (4); on maximum permissible ranges of a rotational speed n_{min} (6), n_{max} (7) and the feed S_{min} (8), S_{max} (9) operate, at finish turning on maximum permissible of machined surface roughness R_a (5), additionally operates in place of limitation on maximum permissible cutting tool strength.

As a result of linearization of objective function and limitations by taking the logarithm the mathematical model of the cutting process expressed by system of the linear inequalities is defined (*X1 = ln n*; *X2 = ln S*):

At rough turning at finish turning

$$\begin{cases} X1+y_V X2 \le b_1, \\ (n_P+1)X1+y_P X2 \le b_2, \\ z_t X1+y_t X2 \le b_3, \\ y_P X2 \le b_4, \\ X1 \ge b_6,\ \ X1 \le b_7, \\ X2 \ge b_8, X2 \le b_9, \\ (X1+X2) \to \max, \end{cases} \qquad \begin{cases} X1+y_V X2 \le b_1, \\ (n_P+1)X1+y_P X2 \le b_2, \\ z_t X1+y_t X2 \le b_3, \\ k_3 X1+k_2 X2 \le b_5, \\ X1 \ge b_6,\ \ X1 \le b_7, \\ X2 \ge b_8,\ \ X2 \le b_9, \\ (X1+X2) \to \max, \end{cases} \qquad (1)$$

$$b_1 = \ln\left(1000 C_V K_V K_T^m / \pi D T^m t^{x_v}\right);$$

$$b_2 = \ln\left(6 \cdot 10^3 \, {}^{(n_p+2)} N\eta / C_P K_P K_{MP} (\pi D)^{(n_p+1)} t^{x_p}\right);$$

$$b_3 = \ln\left(1000^{z_t} \Theta \ / N_\Theta K_\Theta K_O (\pi D)^{z_t}\right);$$

$$b_4 = \ln\left(34 n^{1.35} K_\varphi / C_P K_P K_{MP} t^{(x_p-0.77)}\right);$$

$$b_5 = \ln\left(R_a (\pi D/1000)^{k_3} / k_o K_R K_{MR}\right);$$

$b_6 = \ln n_{min}$; $b_7 = \ln n_{max}$; $b_8 = \ln S_{min}$; $b_9 = \ln S_{max}$.

where *T* - tool life; *t* – depth of cut; *D* – diameter of machining; C_v,K_v and x_v,y_v,*m* – factors and the indexes characterizing degree of influence of depth, feed and tool life for cutting speed; K_T – factor, which takes into account the increase of coated carbide cutting tool life; *n* – synchronous speed; C_p, K_p, x_p,y_p,n_p - factors and the indexes characterizing degree of influence of depth, feed and cutting speed for cutting force P_z; K_{MP} - factor, which takes into account the oiling properties of *CF* for cutting force; η - efficiency of transmission of machine tool; k_o, K_R, k_2,k_3 - factors and the indexes characterizing degree of influence of feed and cutting speed; K_{MR} - factor, which takes into account the oiling properties of *CF* for treated surface roughness; C_Θ, K_Θ and z_t, y_t – factors and the indexes characterizing degree of influence of cutting speed and feed for cutting temperature; K_O - factor of temperature lowering, which takes into account the cooling properties of *CF*.

The example of definition of optimum of cutting regimes at rough and finish turning of steel 45 is reduced on a figure 1.

Polygon *ABCD* on reduced fig. 1 represents the area of possible decisions at turning without CCT and CF. The objective function accepts the maximum value to a point *C*, for which the sum of distances to shafts (*X1+X2*) is maximum to what the extremely possible position of the line 10 characterizing objective function testifies. The point *C* is a cross point of limitations on possibilities of the cutting tool (1) and cutting tool strength (4) at rough turning and on a roughness of machined surface (5) at finish turning. Coordinates of a point *C* ($X1_o$, $X2_o$) are required the best values of parameters.

The use of CCT increases tool life and changes limitations on possibilities of the cutting tool (1_{CCT}). However, the presence of temperature limitation do not allows realizing the possible of the cutting regimes increase. The point C_1 is a cross point of limitations on maximum permissible temperature of cutting (3) cutting tool strength (4) at rough turning and on a roughness of machined surface (5) at finish turning. Coordinates of a point C_1 ($X1_{o1}$, $X2_{o1}$) are required the best values of parameters.

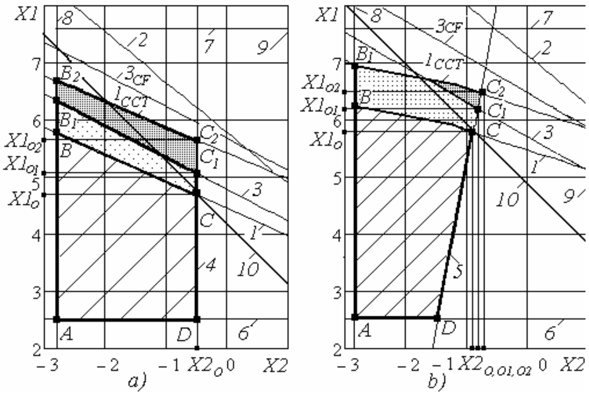

Fig. 1. Graphs of determination of the optimum regimes at rough turning (*t*=3*mm*; *T*=30*min*; *c*=5*mm*) – *a)* and finish turning (*t*=1*mm*; *T*=60*min*; R_a=3,2*mkm*) – *b)* with use of CCT and CF

The use of CF deletes temperature limitation and increases the cutting regimes. The point C_2 is a cross point of limitations on possibilities of the cutting tool (1_{CCT}) and cutting tool strength (4) at rough turning and on a roughness of machined surface (5) at finish turning. Coordinates of a point C_2 ($X1_{o2}$, $X2_{o2}$) are required the best values of parameters.

Optimum cutting regimes - feed S_o and cutting speed V_o can be define analytically:

At rough turning

$$S_{i1} = \left(34 c^{1,35} t^{(0,77-x_P)} K_\varphi / C_P K_P K_{MP}\right)^{1/y_p} . \qquad (2)$$

$$V_{i1} = \begin{cases} \left(\Theta / C_\Theta K_\Theta K_O t^{x_t} S_{o1}^{y_t}\right)^{1/z_t} , & if\ \Theta < \Theta_{01}; \\ C_V K_V K_T^m / T^m t^{x_V} \ S_{o1}^{y_v}, & if\ \Theta \ge \Theta_{01}. \end{cases} \qquad (3)$$

At finish turning

$$S_{o2} = \begin{cases} \left(\dfrac{\Theta (k_o K_R K_{MR})^{z_t/k_3}}{C_\Theta K_\Theta K_O R_a^{z_t/k_3} t^{x_t}}\right)^{\frac{k_3}{y_t k_3 - z_t k_1}} , if\ \Theta < \Theta_0; \\ \left(\dfrac{R_a T^{m k_3} t^{k_3 x_v}}{k_o K_R K_{MR} \left(C_V K_V K_T^m\right)^{k_3}}\right)^{\frac{1}{k_1 - y_v k}} , if\ \Theta \ge \Theta_0; \end{cases} \qquad (4)$$

$$V_{o2} = \begin{cases} \left(R_a / k_o K_R K_{MR} S_{o2}^{k_1}\right)^{1/k_3}, & if\ \Theta < \Theta_o; \\ C_V K_V K_T^m / T^m t^{x_V}\ S_{o2}^{y_v}, & if\ \Theta \ge \Theta_0. \end{cases} \qquad (5)$$

where Θ_{o1}, Θ_{o2} – boundary value of cutting temperatures for which it is necessary to consider temperature limitation:

$$\Theta_{o1} = C_\Theta K_\Theta t^{x_t} \left(\frac{C_V K_V K_T^m}{T^m t^{x_v}} \right)^{z_t} \times$$

$$\times \left[\frac{R_a T^{mk_3}}{k_o K_R (C_V K_V K_T^m)^{k_3}} \right]^{\frac{y_t - y_v z_t}{k_1 - y_v k_3}};$$

$$\Theta_{o2} = C_\Theta K_\Theta t^{x_t} \left(\frac{C_V K_V K_T^m}{T^m t^{x_v}} \right)^{z_t} \times$$

$$\times \left[\frac{340 c^{1,35} t^{(0,77 - x_P)} K_\varphi}{C_P K_P} \right]^{\frac{y_t - y_v z_t}{y_p}}.$$

The results of analysis of cooling and oiling properties for different CF are presented on table 1, 2, 3 [3].

Table 1
Factors of temperature lowering K_O for different CF

Machining material	Factors of temperature lowering K_O for different CF:		
	Acvol-2	Ukrinol-1	MR-1y
Constructional steel	0,85	0,82	0,78
Stainless steel	0,80	0,76	0,73

Table 2
Factors K_{MP} of cutting force lowering at rough turning for different *CF*

Machining material	Factors of t cutting force lowering K_{MP} for different CF:		
	Acvol-2	Ukrinol-1	MR-1y
Constructional steel	1	0,95	0,85
Stainless steel	1	0,9	0,8

Table 3
Factors K_{MR} of machined surface roughness lowering at finish turning for different *CF*

Machining material	Factors of machined surface roughness lowering K_{MR} for different CF:		
	Acvol-2	Ukrinol-1	MR-1y
Constructional steel	1	0,97	0,9
Stainless steel	1	0,95	0,85

The analysis for followings most widespread CF: Akvol-2 (CF, which owns the most expressed cooling properties); Ukrinol-1 (CF, which owns the most expressed cooling properties and partly oiling properties); MR-1y (CF, which owns the most expressed oiling properties and partly cooling properties)is carried out. MR-1y has the minimal factors of temperature lowering K_O, factors cutting force at rough turning K_{MP} and machined surface roughness at finish turning K_{MR}.

The use of CF ensures possibility of optimum feeds S_{oCF} and cutting speed V_{oCF} rise in comparison with optimum cutting regimes S_o and V_o at machining without CF.

Quantitatively the rise of machining productivity can be justified based on factor $K = S_{oCF} V_{oCF} / S_o V_o$. Ground fixed analytical dependences of optimum feeds S_o and cutting speed V_o on machining conditions, the factor of machining productivity rise at the expense of use CF for rough turning K_1 and finish turning K_2 is defined:

$$K_1 = \begin{cases} K_O^{-n_1} K_{MP}^{n_2} K_T^m, & if\ K_O \ge K_{O1}; \\ \left(\frac{C_V K_V K_T^m}{T^m t^{x_v}} \right) \left(\frac{C_\Theta K_\Theta}{\Theta\ t^{-x_t}} \right)^{n_1} \left(\frac{C_P K_P t^{(x_p - 0,77)}}{34 c^{1,25} K_\varphi^{0.8}} \right)^{n_3}, & \end{cases}$$

(6)

$$n_1 = \frac{1}{z_t};\ n_2 = \frac{y_t - z_t}{y_p z_t};\ n_3 = \frac{y_v z_t - y_t}{y_p z_t};$$

$$K_2 = \begin{cases} K_O^{n_4} K_{MR}^{n_5} K_T^m, & if\ K_O \ge K_{O2}; \\ \left(\frac{C_V K_V K_T^m}{T^m t^{x_v}} \right)^{n_6} \left(\frac{C_\Theta K_\Theta}{\Theta\ t^{-x_t}} \right)^{n_7} \left(\frac{R_a}{k_0 K_R} \right)^{n_8}, & \end{cases} \qquad (7)$$

$$n_4 = \frac{k_1 - k_3}{y_t k_3 - z_t k_1};\ n_5 = \frac{y_t - z_t}{y_p z_t};\ n_6 = \frac{k_1 - k_3}{k_1 - y_v k_3};$$

$$n_7 = \frac{k_3 - k_1}{y_t k_3 - z_t k_1};\ n_8 = \frac{(y_v z_t - y_t)(k_1 - k_3)}{(y_t k_3 - z_t k_1)(k_1 - y_v k_3)}.$$

where $K_{O1} = \Theta / \Theta_{o1}$, $K_{O2} = \Theta / \Theta_{o2}$ - the factor considering cooling action of CF, which defines a limiting value for which it is necessary to consider temperature limitation.

Graphs of dependence of factors K_{O1} and K_{O2} on cut-

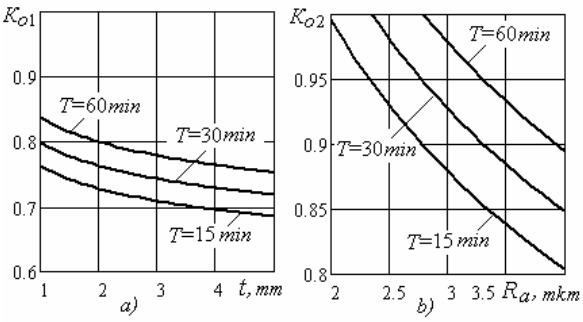

Fig. 2. Graphs of dependence of factor K_{O1} and K_{O2} on cutting feed *t* at rough turning – *a)* and on machined surface roughness R_a at finish turning – *b*)

ting feed *t* and machined surface roughness R_a (in the conditions of the machining, specified earlier) for different values tool life *T* are reduced on figure 2.

The factors considering cooling action of CF, which defines a limiting value, for which it is necessary to consider temperature limitation, are higher than cutting depths at rough turning (fig. 2*a*) and machined surface roughness at finish turning (fig. 2b) are higher.

Graphs of dependence of factors K_{O1} and K_{O2} on cutting feed *t* and machined surface roughness R_a (in the conditions of the machining, specified earlier) for different values tool life *T* are reduced on fig. 2.

The factors considering cooling action of CF, which defines a limiting value, for which it is necessary to consider temperature limitation, are higher than cutting depths at rough turning (fig. 2*a*) and machined surface roughness at finish turning (fig. 2b) are higher.

With the use of the known normative information [6] the factors of machining productivity rise for different steels: steel 45, steel 30ХГС, stainless steel X18H9T can be presented:

$$K_{1st45}=\begin{cases}K_O^{-2{,}6}K_{MP}^{-0{,}17}K_T^{0{,}2}, & K_O\ge K_{O1st45};\\ 2{,}6K_T^{0{,}23}\big/T^{0{,}2}t^{0{,}28}; & \end{cases}$$

$$K_{2st45}=\begin{cases}K_O^{-3{,}0}K_{MR}^{-0{,}06}K_T^{0{,}2}, & K_O\ge K_{O2st45};\\ 1{,}24K_T^{0{,}23}R_a^{0{,}9}\big/T^{0{,}2}t^{0{,}15}; & \end{cases}$$

$$K_{1st30XGC}=\begin{cases}K_O^{-2{,}6}K_{MP}^{-0{,}17}K_T^{0{,}2}, K_O\ge K_{O1st30XGC};\\ 3{,}4K_T^{0{,}23}\big/T^{0{,}2}t^{0{,}28};\end{cases}$$

$$K_{2st30XGC}=\begin{cases}K_O^{-3{,}0}K_{MR}^{-0{,}06}K_T^{0{,}2}, K_O\ge K_{O2st30XGC};\\ 2{,}14K_T^{0{,}23}R_a^{0{,}9}\big/T^{0{,}2}t^{0{,}15};\end{cases}$$

$$K_{1stX18H9T}=\begin{cases}K_O^{-2}K_{MP}^{-0{,}5}K_T^{0{,}25}, & K_O\ge K_{O1stX18H9T};\\ 4{,}4K_T^{0{,}29}\big/T^{0{,}25}t^{0{,}2}; & \end{cases}$$

$$K_{2stX18H9T}=\begin{cases}K_O^{-2}K_{MR}^{-0{,}17}K_T^{0{,}25}, & K_O\ge K_{O2stX18H9T};\\ 3{,}25K_T^{0{,}29}R_a^{0{,}3}\big/T^{0{,}25}t^{0{,}3}. & \end{cases}$$

The results of estimation of possibilities of the turning productivity rise with the use of technological cutting fluid based on the presented method are reduced on figure 3-5.

Graphs of dependence of factors of machining productivity rise K_1 and K_2 on factor of temperature lowering K_O considering cooling action of CF at rough and finish turning of different steels are reduced on fig. 3.

The machining productivity with use of CF rises in connection with reduction of factor of cutting temperature lowering to the level defined by removal of temperature limitation and then productivity remains constant. The subsequent change of factor of cutting temperature lowering becomes inexpedient from the point of view of machining productivity rise.

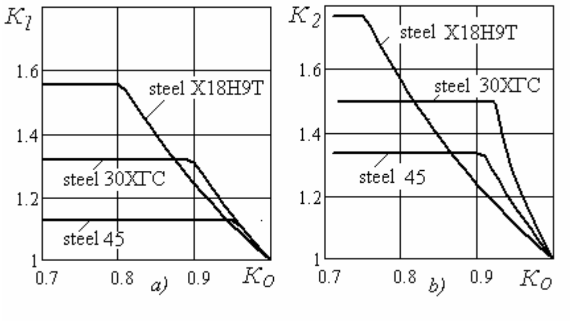

Fig. 3. Graphs of dependence of factors of machining productivity rise K_1 and K_2 on factor of temperature lowering K_O for different steels at rough turning – *a)* and finish turning – *b*)

The greatest increasing of the productivity can be reached for stainless steel X18H9T at finish turning.

Graphs of dependence of factor of machining productivity rise K_1 and K_2 on factor of temperature lowering K_O for different factors K_{MP} and K_{MR} which takes into account the oiling properties of *CF* for cutting force at rough turning and machined surface roughness at finish turning are reduced on figure 4.

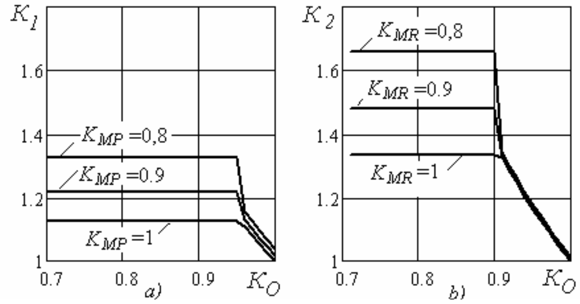

Fig. 4. Graphs of dependence of factors of machining productivity rise K_1 and K_2 on factor of temperature lowering K_O for different factors K_{MP} at rough turning – *a)* and factors K_{MR} at finish turning – *b*)

Machining productivity is higher than factors K_{MP} and K_{MR} are less that corresponds to higher oiling properties CF. The greatest increasing of the productivity can be reached at value factors K_{MP} which takes into account the oiling properties of *CF* for cutting force at rough turning (fig. 4*a*) and small value factors K_{MR} which takes into account the oiling properties of *CF* for machined surface roughness at finish turnings (fig. 4*b*).

Graphs of dependence of factor of machining productivity rise K_1 and K_2 on factor of temperature lowering K_O for different cutting depth at rough turning and machined surface roughness at finish turning are reduced on figure 5.

Machining productivity is higher than cutting depths at rough turning and machined surface roughness at finish turning are higher. The greatest increasing of the

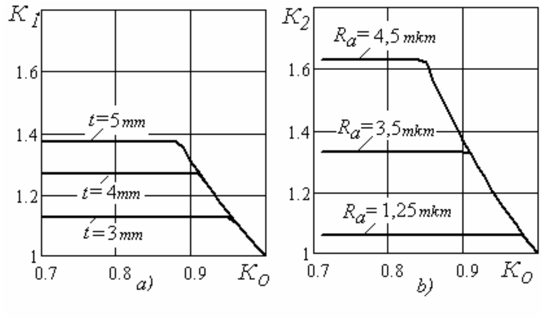

Fig. 5. Graphs of dependence of factors of machining productivity rise K_1 and K_2 on factor of temperature lowering K_O for different cutting depth t at rough turning – *a)* and roughness R_a at finish turning – *b*)

productivity can be reached at great values of cutting depth (fig. 5*a*) and great values of the machined surface roughness (fig. 5*b*).

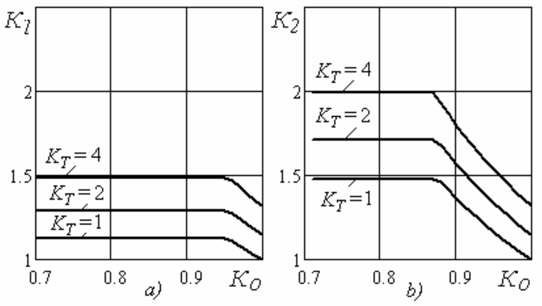

Fig. 6. Graphs of dependence of factors of machining productivity rise K_1 and K_2 on factor of temperature lowering K_O for different factors K_T, which takes into account the increase of coated carbide cutting tool life at rough – *a)* and finish – *b*) turning steel 45

The results of estimation of possibilities of the turning productivity rise with the use of coated carbide cutting tools based on the presented method for different steels are reduced on figure 6 and figure 7.

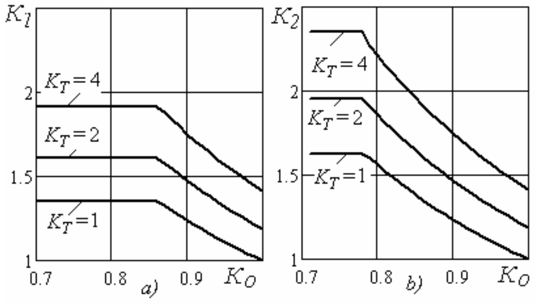

Fig. 7. Graphs of dependence of factors of machining productivity rise K_1 and K_2 on factor of temperature lowering K_O for different factors K_T, which takes into account the increase of coated carbide cutting tool life at rough – *a)* and finish – *b*) turning steel X18H9T

Machining productivity is higher than factors K_T, which takes into account the increase of coated carbide cutting tool life, are higher. The greatest increasing of the productivity can be reached at finish turning.

3. Conclusions

As a result of the carried out researches the method of optimization of the cutting regime at turning with the use of coated carbide cutting tools and technological cutting fluid on the criterion of maximum productivity is developed. The mathematical model of cutting process at turning taking into account limitations on the cutting temperature is developed. With the use of the method of the linear programming analytical dependences of the optimum cutting regime on the turning parameters are defined.

The factor of turning productivity rise, which takes into account the increase of coated carbide cutting tool life, cooling and oiling properties of technological cutting fluid is created. The influence of the factors of temperature lowering with account of cooling and oiling properties of technological cutting fluid and properties of coated carbide cutting tools for different steels on the factor of turning productivity rise is stated.

Estimation of possibilities of the turning productivity rise of the coated carbide cutting tools and technological cutting fluid application for various turning parameters is done.

Greater increase of the all steels productivity at finish turning than at rough turning (to 30%) can be reached. Greater increase of the productivity for stainless steel X18H9T at finish and rough turning than at turning for construction steel 45 (to 25%) can be reached.

The greatest increase of the productivity for stainless steel X18H9T (to 2.5 times) and construction steel 45 (to 2 times) can be reached at finish turning with application of the coated carbide cutting tools and technological cutting fluid.

The designed method can be used for estimation of possibilities of the productivity rise at various aspects of machining with application of technological cutting fluid and coated carbide-cutting tools.

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