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RESEARCH OF THE THERMAL STATE OF THE CUTTING AREA AT THE FACE MILLING

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Abstract. It is executed the analysis of conformities to law of forming of the thermal streams and the cutting temperatures in the area of treatment depending on the parameters of milling process. The calculation method of cutting temperature at milling taking into account irregularity of process in the conditions of the unset heat exchange is developed. Character and degree of influence of cutting speed, feed and cutting depth on the cutting temperature at the face milling is set. It is executed experimental verification of theoretical researches. The results of experimental researches confirm the theoretical calculations of the cutting temperature at the face milling.

Keywords: thermal stream, cutting temperature, unset process, face milling.

1. Introduction

The thermal state of the cutting tool largely determines efficiency of his use. The modern tendencies of the cutting regimes intensification at exploitation of the cutting tool result in the substantial increase of his thermal loadings that determines actuality of tasks on their research.

Presently the methods of researches of the thermal state of the cutting tool well enough are set in the conditions of the set heat exchange [1]. However in a number of cases at the brief or irregular cutting ignoring non-stationary ness of process is impossible. In researches of the thermal state of cutting area at the milling, it is necessary to take into account basic features: irregularity of process in the conditions of the unset heat exchange and changeability of parameters of milling process. Questions, which related to the calculations the cutting temperatures for the fragmentary cutting, considered in [2, 3, 4], enable theoretical determination of cutting temperatures at milling, however, need expansion of researches in this direction. There is of both scientific and practical interest research of possibilities of theoretical description of the thermal state of the cutting tool and estimation of their temperature under various conditions exploitations.

The purpose of the presented work is creation of method of calculation of the cutting tool temperature in the conditions of the unset heat exchange and analysis of influence of treatment terms on his thermal state.

2. Basic contents and results of probe

The main sources of warmth in the cutting area at the face milling are (fig. 1):

- warmth of the deformation in the area of chip formation on the plane of change (source $J_{д}$ with the thermal stream $q_{д}$);
- warmth of the friction between chip and face of the tool (source J_1 with the thermal stream q_{1T});
- warmth of the friction between the flank of the tool and the machined surface of a work piece (source J_2 with the thermal stream q_{2T}).

Axis X in the examined system of coordinates oriented in the direction of front surface athwart to the main cutting edge; l is contact length in directions of tails of chip; h is a wear on a back surface; a is a thickness of cut; a_1 is a thickness of chip; Φ - corner of change.

The cutting temperature is shaped under the influence of the thermal streams at face of the tool q_1 and at the flank of the tool q_2 [1].

$$q_1 = \frac{K_1 K_3 \lambda_u - K_2 N_2 m(F_o) h + K_1 M_2 m(F_o) h}{K_3 K_4 \lambda_u + M_2 K_4 h - N_1 N_2 \left(m(F_o)\right)^2 lh/\lambda_u}; \quad (1)$$

$$q_2 = \frac{(K_1 - K_4 q_1)\lambda_u}{N_2 m(F_o) h}, \qquad (2)$$

$$K_1 = \frac{(1+c)\omega_\partial k b' q_\partial}{\lambda_\partial V} + \frac{K_{c1} q_{1T}}{\lambda_\partial}\sqrt{\frac{\omega_\partial kl}{V}}\ ;$$

$$K_2 = \frac{(1+c)\omega_\partial k b' q_\partial T_u}{\lambda_\partial V} + \frac{K_{c2} q_{2T}}{\lambda_\partial}\sqrt{\frac{\omega_\partial h}{V}}\ ;$$

$$K_3 = 1{,}82 K_{c2}\sqrt{\omega_\partial h/V}\Big/\lambda_\partial\ ;$$

$$K_4 = 1{,}3 K_{c1}\sqrt{\omega_\partial kl/V}\Big/\lambda_\partial + M_1 l/\lambda_u\ .$$

$m(F_o)$ is function of dimensionless time;
λ_∂, λ_u, ω_∂, ω_u are coefficients of heat conductivity and diffusivity of materials of detail and tool accordingly;
k is a chip contraction coefficient; V is cutting speed;
c is a coefficient, taking into account heating of layers of metal for one turn of detail; T_∂ is the 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 ship;
K_{c1} , K_{c2} are coefficients, taking into account the law of distributing of thermal stream closeness on a front and a back tool surface, (for the combined law $K_{c1} = 0{,}77$; for the asymmetrical normal law $K_{c2} = 0{,}55$);
M_1, M_2, N_1, N_2 - the dimensionless functions spotting a heating of platforms on the face of the tool and the flank of the tool:

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

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 $\beta = 90°$.

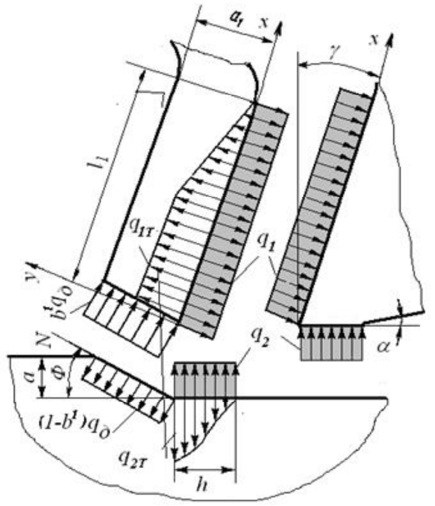

Fig. 1. Layout of warmth sources chart and distributing of thermal streams in the cutting area at the face milling

The function of dimensionless time $m(F_o)$ can be certain as follows:

$$m(F_o) = T(F_o)/T(\infty), \qquad (3)$$

$T(F_o)$, $T(\infty)$- dimensionless a temperature of characteristic point of blade is his tops accordingly during the unset and permanent heat exchange:

$$m(F_o) = \frac{1}{T(\infty)}\int_0^1 d\psi_u \int_{-\alpha}^{\alpha} \frac{\left(1 - erf\left[\sqrt{\psi_u^2 + \zeta_u^u}\Big/2\sqrt{F_o}\right]\right)}{\sqrt{\psi_u^2 + \zeta_u^2}} d\zeta_u,$$

(4)

$\psi_u = x_u/l$, $\zeta_u = z_u/l$ are dimensionless co-ordinates; $\alpha = 0{,}5b/l$ is a dimensionless width of cut b.

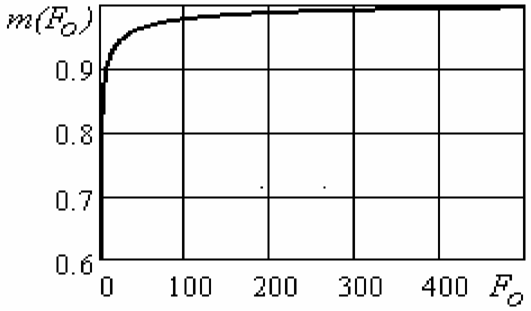

Fig. 2. Graphs of change of function of dimensionless time $m(F_o)$depending on criterion Fourier

The graphs of change of function of dimensionless time $m(F_o)$ depending on criterion Fourier ($F_o = \omega\tau/l^2$, τ -real time) is resulted on fig. 2. In initial moment function of dimensionless time $m(0) = 0$; farther it quickly grows and approached to 1; value of function of dimensionless time $m(F_o) = 1$ characterizes a permanent heat exchange. For practical calculations with an error which does not exceed 1% it can be accepted $m(200) \approx 1$, with an error 0,5% - $m(500) \approx 1$.

Conformities to law of change of the thermal streams closeness on front and back tool surfaces in time at the unset heat exchange are presented on a fig. 3 (F_o is dimensionless time, τ - the real time of cutting). Calculations are executed for terms: the processed material is steel 45; instrumental material is T15K6; wear on the back surface $h = 0{,}1$mm.

The relative closeness of thermal streams are considered $q_{relative1}(F_o) = q_1(F_o)/q_1(200)$; $q_{relative\ 2}(F_o) = q_2(F_o)/q_2(200)$ on condition that a process is set at $F_o = 200$.

In initial moment of time thermal streams on the front and back tool surfaces are very great, the relative closeness of thermal streams $q_{relative\ 1}$ and $q_{relative\ 2}$ at the unset heat exchange in twice exceed the closeness of thermal streams at the set heat exchange, and then stabilized ($q_{relative\ 1} = q_{relative\ 2} = 1$).

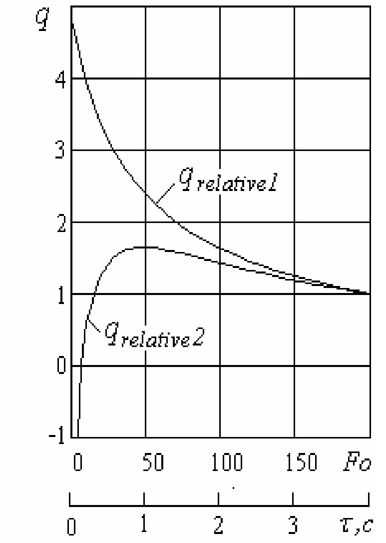

Fig. 3. Graphs of change of the relative closeness of thermal streams on front and back tool surfaces in time at the unset heat

The cutting temperature in the conditions of the unset heat exchange *Θ* can be certain as a middle temperature on the front and back tool surfaces taking into account the function of dimensionless time *m(F_o)* [1]:

$$\Theta = \frac{\left[q_1 l\left(M_1 l + N_1 h\right) + q_2 h\left(M_2 h + N_1 l\right)\right] m(Fo)}{(l+h)\lambda_u}, \quad (5)$$

The irregular process of cutting at milling is characterized by the presence of workings strokes by duration t_p, which alternate with idling duration t_x and in a sum determine duration of cycle $t_o = t_p + t_x$.

For the face milling duration of cycle t_o, duration of working stroke t_p, duration of idling t_x determined by such method:

$$t_o = \frac{60}{n}, \quad t_p = \frac{60 \arcsin(B/D)}{\pi n}, \quad t_x = \frac{30\left(2\pi - \arcsin(B/D)\right)}{\pi n},$$

n is the frequency of rotation; B is the milling width, D is the diameter of the milling cutter.

In the period of working stroke there is heating of tool, which is described the analytical dependences resulted before (5). In the period of idling in absence of heating there is cooling of cuttings edges due to taking of heat from the area of cutting deepen blades. A cooling process in this case is described as follows:

$$\Theta_o(F_o) = \Theta(\infty)\exp\left[-0.04 F_0\right]. \quad (6)$$

Cyclic process of change of the cutting temperature at the fragmentary cutting has analytical description:

$$\Theta_o(\tau) = \begin{cases} \Theta(\tau - i\tau_o + x_i), \\ if\ t_o(i-1) \le \tau \le \left(t_p + t_o i\right), i = 1,2..n_o; \\ \Theta(\tau_p + x_i)\exp\left[-0{,}04\left(\tau - \tau_p\right)\right], \\ if\ \left(t_p + t_o(i-1)\right) \le \tau \le t_o i, \end{cases} \quad (7)$$

$\Theta(\tau - i\tau_o + x_i)$ – is the cutting temperature at heating in the period of working stroke; $\Theta(\tau_p + x_i)\exp[-0{,}04(\tau - \tau_p)]$ is the middle temperature at cooling in the period of idling; n_o is a number of cycles; x_i is a period of time which corrects beginning of counting out of the temperature of heating in every next loop recognition cooling in previous.

For every cycle x_i settles accounts numeral methods as a root of equalization:

$$\Theta(x_i) = \Theta(\tau_p + x_{i-1})\exp\left[-0{,}04(\tau_h)\right]. \quad (8)$$

Graphs of change at time cutting temperatures at milling in the conditions of the unset heat exchange are presented in fig. 4.

Graphs are built for face milling cutters with diameter D = 125мм, milling width B = 85, number of teeth of milling cutter z = 8, that provide duration of working stroke t_p = 0,06c, single t_x = 0,19c, duration of cycle t_o = 0,25c.

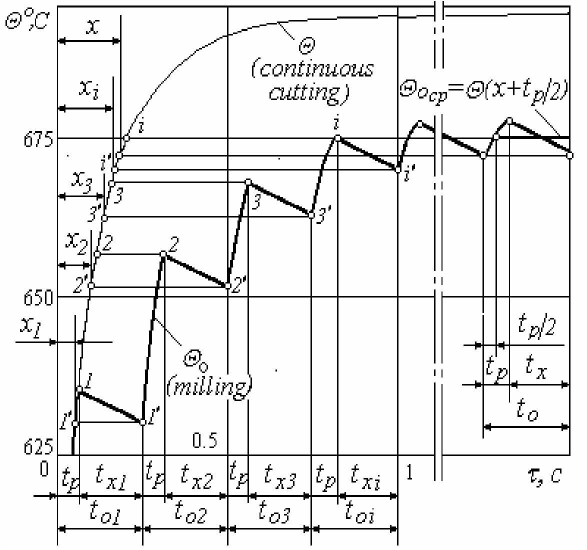

Fig. 4. Graphs of change at time cutting temperatures at milling in the conditions of the unset heat exchange

In initial moment $\tau = 0$ and $F_o = 0$ during the unset heat exchange the function of dimensionless time equals a zero. In the first loop t_{o1} there is sharp growth of function of dimensionless time during the first working stroke t_p due to heating to value x_1 = 0,053c. In the next loop t_{o2} heating in the period the point 1, and then during idling *of* t_x there is its decline due to cooling to the point 1'.

Expected of working stroke t_p originates from a point 1' to the point 2 and then again there is cooling to the point 2'. Expected value x_2 = 0,098c. The next cycle

t_{o3} begins in a point 2', heating during the working stroke tp place is taken to the point 3, cooling is closed in a point 3'. Expected value x_3 = 0,136c. Then a process repeats oneself multiple, gradually heating and cooling are counterbalanced, a process is stabilized and can be considered permanent for such value x, which provides the identical increase of function of dimensionless time Θ_o during a working stroke and it diminishing during cooling during idling. The value x settles accounts a numeral method as a root of equalization:

$$\Theta(x) = \Theta(\tau_p + x)\exp[-0{,}04(\tau_h)]. \qquad (9)$$

Graphs of dependence of parameter x (root of equalization (9)) from duration of working stroke τ_p and correlation of duration single τ_x and workings strokes τ_p: $K = t_x / t_p$ is resulted on fig. 5. The values of parameter x diminish with growth of duration of working stroke and correlation of duration of single and workings motions.

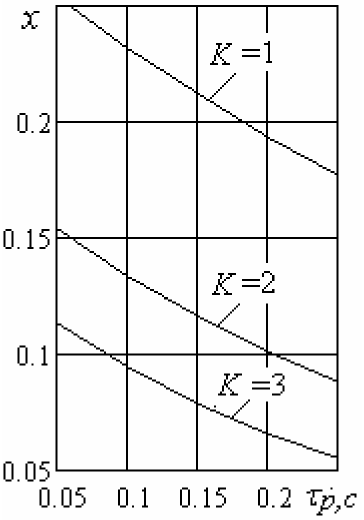

Fig. 5. Graphs of dependence of parameter x from duration of working stroke τ_p for different correlation of duration single τ_x and workings strokes τ_p

Maximal $\Theta_{o\ max}$, minimum $\Theta_{o\ min}$ and middle the temperatures of cycle of fragmentary process of milling during the cc cutting can be certain as follows:

$$\Theta_{o\,max} = \Theta(x + \tau_p);$$
$$\Theta_{o\,min} = \Theta(x); \qquad (10)$$
$$\Theta_{o\ midle} = \Theta(x + \tau_p/2).$$

For the considered terms of milling x = 0,185c, $\Theta_{o\ max}$ = 678°C, $\Theta_{o\ min}$ = 673°C, $\Theta_{o\ middle}$ = 676,4°C. The middle function of dimensionless time $m_{o\ middle}$ in the conditions of the permanent cutting during the butt-end milling can be certain:

$$m_{o\ midle} = m(x + \tau_p/2). \qquad (11)$$

The graphs of dependence of the middle function of dimensionless time $m_{o\ middle}$ in the conditions of the continuous cutting at the face milling from duration of working stroke τ_p for different correlations of durations of single and workings motions are resulted on fig. 6.

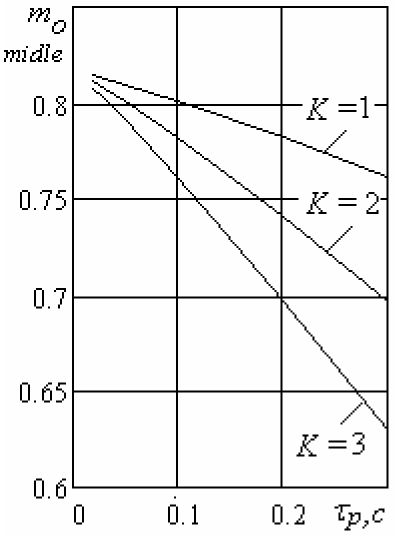

Fig. 6. Graphs of dependence of the middle function of dimensionless time $m_{o\ middle}$ in the conditions of the continuous cutting at milling from duration of working stroke τ_p

The middle function of dimensionless time $m_{o\ middle}$ characterizes the decline of the cutting temperatures during the fragmentary cutting as compared to continuous in the conditions of continuous heat exchange at the face milling. Determination of the middle function of dimensionless time $m_{o\ middle}$ for the set terms of treatment allows substantially simplifying the method of analytical calculation of cutting temperature at the face milling.

With the use of the developed method, researches of influenceof the cutting regimes on the cutting temperature are executed.

The graphs of of change at time of cutting temperature for different feeds (cutting speed V = 1,5m/c) and cutting speeds (feeds S = 0,1mm/teeth, cutting depth t = 1mm) during milling in the conditions of the unset heat exchange are resulted on fig. 7 and fig. 8.

In initial moment of time of cutting temperature sharply grow and stabilized gradually. Than higher feed and cutting speed, the more intensive growth of the temperature and higher its level is during the continuous cutting. At the change of feed duration of cycle at the face milling remains unchanging. The cutting temperature depends only on the levelof feed and increases in connection with its growth. Duration of cycle and duration of working stroke changes at a changeto cutting speed. With the increase of cutting speed duration of cycle and duration of working stroke, diminish. The cutting temperature increases in connection with growth of cutting speed, and additionally increases in connection with a change to duration of cycle.

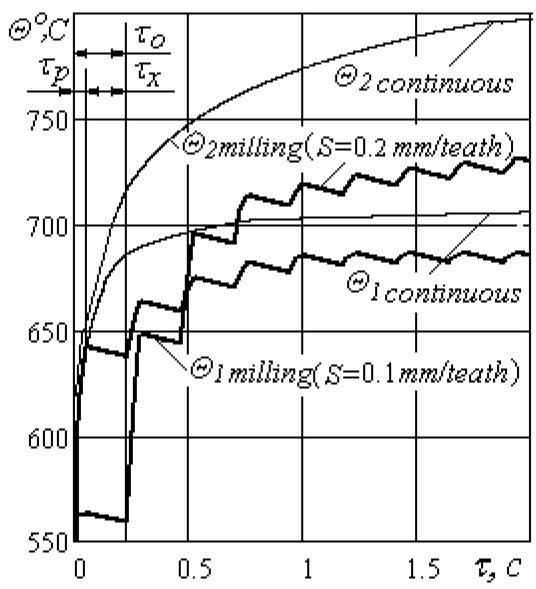

Fig. 7. Graphs of change at the time the cutting temperatures at the milling in the conditions of the unset heat exchange for different feeds

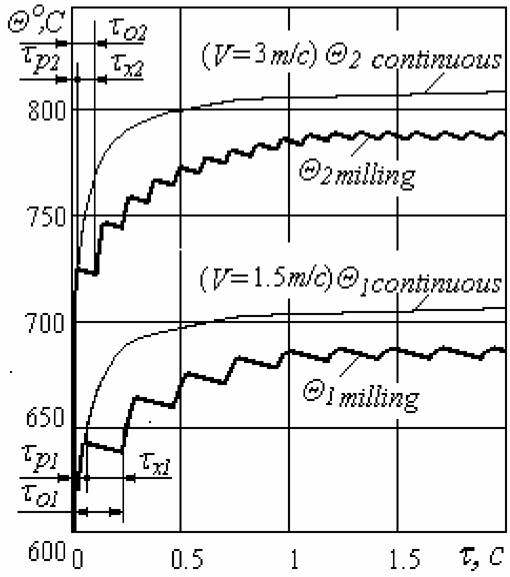

Fig. 8. Graphs of change at the time the cutting temperatures at the milling in the conditions of the unset heat exchange for different speeds

On the basis of the developed method with the use of plural regressive analysis analytical dependences of temperature of cutting Θ_{theor} on cutting speed V, feeds S and cutting depths t at face milling of construction steels are set (an error does not exceed 10%):

$$\Theta_{theor} = 424\ V^{0,19} S^{0,11} t^{0,1}. \qquad (12)$$

For verification of adequacy of the set analytical dependence $\Theta_{milling}$ its comparing is executed to the results of experimental researches of the cutting temperature $\Theta_{experim}$ at milling of steel of 30HGCA (feed S = 0,1mm/teeth, cutting depth t = 0,5mm) [5], the graphics of which are resulted on fig. 9.

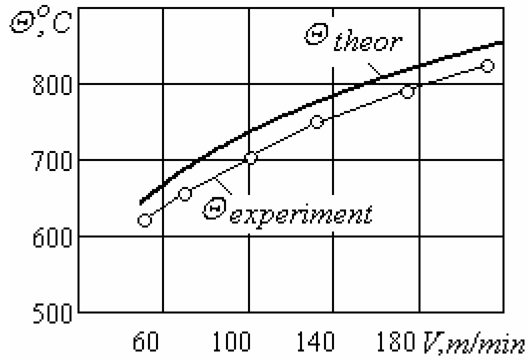

Fig. 9. Graphs of dependence of the cutting temperature from speed at the face milling

The high enough degree of coincidence of theoretical and experimental dependences (an error does not exceed 10%) testifies to adequacy of theoretical model and possibility of the use of the developed method for the calculations of cutting temperature during milling.

3. **Conclusions**

As result of the executed researches, the calculation method of cutting temperature at the face milling taking into account irregularity of process in the conditions of the unset heat exchange is developed. It is executed the analysis of conformities to law of forming of the thermal streams and the cutting temperatures in the area of treatment depending on the parameters of the face milling process. Character and degree of influence of the cutting speed, feed and cutting depth on the cutting temperature at the face milling is set. It is executed experimental verification of theoretical researches.

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