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CALCULATED DETERMINATION OF THE PARAMETERS OF THE SURFACE LAYER

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ABSTRACT

While producing important parts it is necessary to follow the quality parameters of the surface layer, in particular surface roughness, hardening depth, residual stress. It's much easier to solve this problem if you have the generalized theoretical dependencies which determine interrelationship of the criteria of surface layer quality and the cutting process parameters. This gives the opportunity to set cutting conditions coming from the reguired roughness value, hardening depth, residual stress level.

KEY WORDS
Quality, stress, hardening, roughness, cutting condition.

The authors developed the method of calculated determination of residual stresses in the surface layer of the worked part applied to the blade tool treatment (turning, boring, planing) and also to grinding. Residual stresses caused by the structural and phase transformations were not taken into account which can be right while treating heat resistant steels and alloys, because their influence on the final residual stresses aren't important in this case. Thus, the main task is to calculate the temperature residual stresses and residual stresses caused by the force action on the surface layer. Since residual stresses are elastic and for the addition of the latter the method of laying on is applied. Summarized residual stresses were determined by algebraic summation of temperature and force residual stresses. To determine residual stresses from every factor individually it was necessary to ascertain regularities of temperature distribution in the surface layer of the worked part; it was also necessary to determine the cutting forces acting on the worked surface. Temperature residual stresses were determined by algebraic summation of stresses which appear in the surface layer in the condition of heating and cooling; they can appear only if stresses exceed yield limit in the condition of heating. Stresses formed during cooling can be elastic as well as elastoplastic. Method of body break up is used to determine stresses. As an example some formulas are given to determine temperature residual stresses while working flat surfaces by blade tools not taking into account strengthening of the worked material:

$$\sigma_{rez.\,т} = -\sigma_т + \frac{\beta_\partial A_1 E_\partial}{1-\mu}\left\{\left(\frac{H-y+a_1}{a_1}\right)^{x_2} - \frac{a_1^{1+x_2}-(H+a_1)^{1+x_2}}{a_1^{x_2}(1+x_2)H}\right\} \text{ at } y \ge y_{он};\ \sigma_{0_{max}} < 2\sigma_т \quad (1)$$

$$\sigma_{rez.\,т} = \frac{\beta_\partial A_1 E_\partial}{1-\mu}\left\{\frac{\frac{E_\partial}{a_1^{x_2}(1+x_2)}\left[(H+a_1-y)^{1+x_2}-(H+a_1)^{1+x_2}\right]+(1-\mu)\sigma_т(H-y_{он})}{E_\partial y_{он}} + \right.$$

$$\left. + \frac{a_1^{1+x_2}-(H+a_1)^{1+x_2}}{a_1^{x_2}(1+x_2)H}\right\} \text{ at } y < y_{он};\ \sigma_{0_{max}} = 2\sigma_т \quad (2)$$

$$\sigma_{rez.\,т} = \sigma_т \text{ at } y > y_{oo};\ \sigma_{0_{max}} = 2\sigma_т \quad (3)$$

$$\sigma_{rez.\,т} = -\sigma_т + \frac{\beta_\partial A_1 E_\partial}{1-\mu}\left\{\left(\frac{H-y+a_1}{a_1}\right)^{x_2} + \right.$$

$$\left. + \frac{\frac{E_\partial}{a_1^{x_2}(1+x_2)}\left[(H+a_1-y_{oo})^{1+x_2}-(H+a_1)^{1+x_2}\right]+2(1-\mu)\sigma_т(H-y_{oo})}{E_\partial y_{oo}}\right\} \text{ at } \begin{cases} y_{oo} > y \ge y_{он}; \\ \sigma_{0_{max}} = 2\sigma_т \end{cases} \quad (4)$$

$$\sigma_{rez.т} = \frac{\beta_\partial A_1 E_\partial}{1-\mu}\left\{\frac{\frac{E_\partial}{a_1^{x_2}(1+x_2)}\left[(H+a_1-y_{00})^{1+x_2}-(H+a_1)^{1+x_2}\right]+2(1-\mu)\sigma_т(H-y_{00})}{E_\partial y_{00}}-\right.$$

$$\left.-\frac{\frac{E_\partial}{a_1^{x_2}(1+x_2)}\left[(H+a_1-y_{он})^{1+x_2}-(H+a_1)^{1+x_2}\right]+\sigma_т(1-\mu)(H-y_{00})}{E_\partial y_{0н}}\right\} \text{at} \begin{cases} y<y_{он}; \\ \sigma_{0_{max}}=2\sigma_т \end{cases}, (5)$$

where H - thickness of the disc blade; $\sigma_{0_{max}}$ - stress on the surface while cooling; y- depth of the considered layer from the surface; $y_{он}, y_{00}$ – limits of division of elastic and plastic deformations while heating and cooling; $\sigma_т$ and E_∂ - yield limit and elastic modulus of the worked material; β_∂ and μ - coefficient of temperature linear expansion and Poisson's ratio of the worked material; A_1 and x_2 - quantities determining temperature value in the surface layer of the worked part; a_1 - thickness of shear. Residual stresses caused by the force affect on the surface layer were determined in accordance with the Henky theorem as the stress difference arising during loading σ_{fict} and unloading σ_{real}. Fictitious stresses were determined according to the formulas:

$$\left.\begin{aligned} \sigma_x &= -\frac{\tau_p}{2\pi}\left\{\psi_1\left[B;\frac{y}{h};\frac{h}{a_1}\right]-\frac{b}{b_1\cos\alpha}\xi_1\left[\frac{y}{h};B;\frac{\Delta}{\Delta_1};\gamma\right]\right\}\frac{1}{1-\mu^2} \\ \sigma_y &= -\frac{\tau_p}{2\pi}\left\{\psi_2\left[B;\frac{y}{h};\frac{h}{a_1}\right]-\frac{b}{b_1\cos\alpha}\xi_2\left[\frac{y}{h};B;\frac{\Delta}{\Delta_1};\gamma\right]\right\}\frac{1}{1-\mu^2} \\ \tau_{xy} &= \frac{\tau_p}{2\pi}\left\{\psi_3\left[B;\frac{y}{h};\frac{h}{a_1}\right]-\frac{b}{b_1\cos\alpha}\xi_3\left[\frac{y}{h};B;\frac{\Delta}{\Delta_1};\gamma\right]\right\}\frac{1}{1-\mu^2} \end{aligned}\right\}, (6)$$

where τ_p – resistance of the worked material to the plastic shift; b_1 – shear width; b - perimeter of working parts of the cutting edges; Δ – length of the contact area of the back cutter surface and the working surface; Δ_1 – projection of the shear surface on the horizontal plane; h - depth of the advancing plastic deformations in the surface layer; B - criterion characterizing angle of chip oversize; α and γ - back and front angles of the cutting tool. True stresses are also determined with the formulas (6) under the condition that y corresponds to the depth of the plastic deformations. Plastic condition was determined by the Huber-Mizes theory. While analyzing roughness of the worked surface we took into account that in common case not only geometry of shear section and tool but volume and speed of plastic deformation of the metal caused by the complex of temperature-force phenomena arising in the cutting area influence the formation of unevenness of the worked surface. According to this:

$$R_Z = \left\{ \begin{array}{l} \dfrac{a_1^{0,125} b_1^{0,7} c\rho\, \theta\, \rho_1^{0,1} a^{0,43} \left[2{,}85 \sin^{0,115} \alpha\, V^{0,57} a_1^{0,345} \lambda b^{0,3} + 0{,}6625 \lambda_p \beta \varepsilon\, a^{0,57} \rho_1^{0,075} \right]}{V \lambda \sin^{0,165} \alpha} \times \\ \times \dfrac{-0{,}5 \tau_p \rho_1 b \left[\arccos\left(1 - a_2 B^{-b_2 (1-\sin\gamma)^{-x_2}}\right) + \dfrac{a_2 B^{1-b_2(1-\sin\gamma)^{-x_2}}}{\sin\alpha (\cos\gamma + B \sin\gamma)} + \dfrac{\delta}{\rho_1} \right] \cos\alpha}{t \tau_p \left[1 + \dfrac{1}{B} + \operatorname{tg}(\operatorname{arctg} B - \gamma) \right]} \end{array} \right\}^2 \frac{1}{8r}, \quad (7)$$

where $c\rho$ – specific heat of the worked material; θ – temperature in the cutting area; ρ_1 – radius of rounding of the cutting edge; t - cutting depth; δ – wear area length along the back surface of the cutter; a - coefficient of the temperature conductivity of the worked material; V- cutting speed; λ and λ_p - coefficients of thermal conductivity of the worked and instrumental materials; β and ε - angle of taper and angle at the vertex of the cutter in the plan; r - radius at the vertex of the cutter in the plan; a_2, b_2, x_2 - quantities depending on the treatment conditions (angle of chip oversize). Hardening depth of the worked surface h_c was assumed to be equal the depth of plastic deformations. There was the condition that plastic deformations in the surface layer are caused by the mutual affect of force and temperature factors. In this case the depth of plastic deformations is determined from the condition of equality to the yield limit of the algebraic sum of stresses in the surface layer caused by force and temperature affect, namely

$$\sigma_y + \sigma_н = -\sigma_т, \quad (8)$$

where $$\sigma_{rez\ т} = \frac{\beta_\partial A_1 E_\partial}{1-\mu} \left\{ \left(\frac{H - y + a_1}{a_1} \right)^{x_2} + \frac{a_1^{1+x_2} - (H + a_1)^{1+x_2}}{(1 + x_2) a_1^{x_2} H} \right\} \quad (9)$$

$$\sigma_т = -\frac{\tau_p}{2\pi} \left\{ \frac{1 + B + B \operatorname{tg}(\operatorname{arctg} B - \gamma)}{\left[B \cos\left(\frac{\pi}{2} - 2 \operatorname{arctg} B \right) + \sin\left(\frac{\pi}{2} - 2 \operatorname{arctg} B \right) \right] \cos\left(\frac{\pi}{2} - 2 \operatorname{arctg} B \right)} \times \right.$$

$$\times \left[2 \arccos \frac{B + B \frac{y}{a_1}}{\sqrt{1 + \left(B + B \frac{y}{a_1} \right)^2}} - \sin\left(\frac{\pi}{2} - 2 \operatorname{arctg} B \right) + \right.$$

$$+\frac{2\left(B+B\frac{y}{a_1}\right)\left[2\sin^2\left(\frac{\pi}{2}-2\operatorname{arctg}B\right)-1\right]+\sin 2\left(\frac{\pi}{2}-2\operatorname{arctg}B\right)\left[\left(B+B\frac{y}{a_1}\right)^2-1\right]}{1+\left(B+B\frac{y}{a_1}\right)^2}\Bigg]\Bigg]\Bigg\}-$$

$$-\frac{\tau_p b}{2\pi b_1\cos\alpha}\left[\frac{2}{\sin 2\left(\frac{\pi}{2}-2\operatorname{arctg}B+\gamma\right)}\arccos\frac{1}{\sqrt{1+\left(\frac{\Delta/\Delta_1\,B}{y/a_1}\right)^2}}+1-\right.$$

$$\left.-\frac{\pi}{2}\frac{2-\frac{\pi}{2}\sqrt{1+\left(\frac{\Delta/\Delta_1\,B}{y/a_1}\right)^2}}{\sqrt{1+\left(\frac{\Delta/\Delta_1\,B}{y/a_1}\right)^2}}+\frac{2}{\operatorname{tg}2\left(\frac{\pi}{2}-2\operatorname{arctg}B+\gamma\right)}\frac{\frac{\pi}{2}\sqrt{1+\left(\frac{\Delta/\Delta_1\,B}{y/a_1}\right)^2}}{1+\left(\frac{\Delta/\Delta_1\,B}{y/a_1}\right)^2}\right] \quad (10)$$

Thus depth of the hardening layer is functionally determined:

$$h_c = f(\sigma_т, E_д, \tau_p, \mu, \beta_д, \lambda, \lambda_p, c\rho, V, s, t, r, \alpha, \gamma, \varphi, \varphi_1, \rho_1), \quad (11)$$

where φ and φ_1 - chief and auxiliary angles in the plan. It is stated that in treatment of structural and heat-resistant steel and alloys the hardening degree with enough accuracy for practical purposes can be determined by the formula:

$$N = \frac{h_c}{1{,}25\left(\frac{\sigma_B}{\sigma_{BЭ}}\right)^{0{,}8}}, \% \quad (12)$$

where σ_B – strength limit of the worked material; $\sigma_{BЭ}$ – strength limit of electromechanical steel. The results of research make it possible to solve the problems of determining the parameters of the surface layer of the worked part, also to choose technological conditions of treatment providing parameters of the surface layer given by technical conditions.

While setting the working conditions the features of the concrete part are not taken into account therefore usually the hardest conditions of metal working are chosen during calculations. Besides in the system with "hard" working regimes the influence of changing outer affects and the parameters of the system "machine tool - device - instrument - billet" are not taken into consideration although they influence greatly the quality of the surface layer and accuracy of working.

To provide the required surface layer quality and accuracy of working taking into account joint affects of force and temperature factors a new system of automatic control of the working process which has no analogs in the country and abroad is being suggested.

The suggested system includes machine tool with numerical program control and with the temperature meter and the meter of tangential component of cutting force. It also includes electronic computer with electronic measuring device providing exchange of information between machine tool with numerical program control and controlled electronic computer.

Common scheme of functioning of given system is made in the following way:

- with the help of a subsystem of calculating of working regimes according to given surface layer quality factors and the factors of working accuracy the initial technological conditions are determined: cutting conditions (feed, depth and speed of working) and geometrical parameters of the instrument;
- optimum energetic criterion and it's acceptable deviation is calculated; this criterion corresponds calculated working regimes;
- control program of the machine tool with numerical program control for the beginning of the part working is generated with the help of the subsystem of working program formation on the basis of the datas received earlier;
- the created control program is transmitted from electronic computer through the connection adapter into the machine tool and fulfilment of this program begins;
- with the help of the electronic-measuring device the electronic computer makes the continuos measuring of temperature in the cutting area and the constituent cutting fierce the values of which show the current values of the energetic criterion;
- in the case of coming the current criterion value behind the limits of the acceptable values the calculation of the required for it's correction values of cutting speed, feed and cutting depth is done. On the basis of new datas the control program of the further part working is formed. It's transmitted to the machine tool with numerical program control which allows to correct the working conditions to provide necessary values of the energetic criterion.

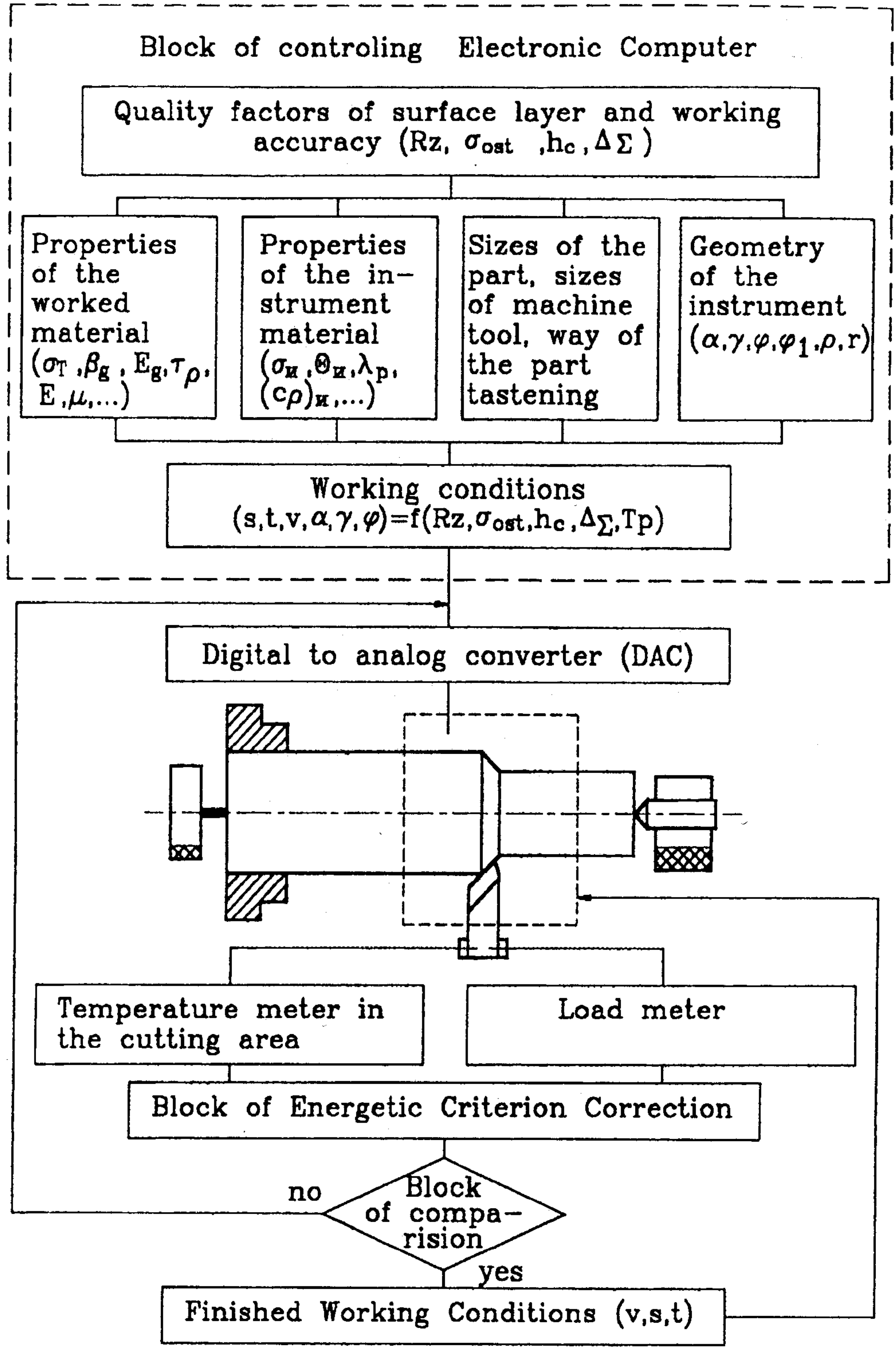

Fig.1 The principle scheme of the automated control system of the working process.