TECHNOLOGICAL SUPPORT OF PERFORMANCE CHARACTERISTICS OF MACHINE COMPONENTS

ТЕХНОЛОГИЧЕСКОЕ ОБЕСПЕЧЕНИЕ ЭКСПЛУАТАЦИОННЫХ СВОЙСТВ ДЕТАЛЕЙ МАШИН

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The relationship between the layer quality parameters of the machined surface and the technological conditions of cutting has been presented, as well as the calculative estimation of the performance characteristics of machine components: fatigue life, wear life, and compression joints' strength.

KEYWORDS: CUTTING CONDITIONS, PROPERTIES OF MATERIALS OF MACHINE COMPONENTS, QUALITY OF THE SURFACE LAYER, PERFORMANCE CHARACTERISTICS.

1. Introduction.

Managing the surface layer quality in order to provide the performance characteristics for machine components makes feasible calculating correlations between the parameters which characterize the surface layer quality and the cutting conditions. In this regard, the functional relation has been defined between the cutting conditions, the tool geometry and the surface layer quality parameters as well as the cutting accuracy based on the properties of the machined and the tool materials and the stiffness of the machine-attachment-tool-work piece technological system:

$$(t, S, v, r, \varphi) = f\begin{pmatrix} \sigma_{\text{ост}}, h_{\text{н}}, Rz, T_{\text{р}}, \sigma_{\text{т}}, E_{\text{д}}, \tau_{\text{р}}, \mu, \beta_{\text{д}}, \beta_{\text{и}}, \lambda_{\text{ст}}, a, \lambda_{\text{д}}, \lambda_{\text{р}}, \\ c\rho, \theta_{\text{пл}}, \gamma,\ \alpha,\ \varphi_1,\ \rho_1, j_{\text{сист.}}, B_1, H_1, L_{\text{р}}, H, \alpha_1, \alpha_{\text{р}} \end{pmatrix},$$

where $T_{\text{р}}$ is the size tolerance provided when cutting; $\beta_{\text{д}}$ and $\beta_{\text{и}}$ are the coefficients of the linear expansion of the machined and the tool materials; $E_{\text{д}}$ and $\tau_{\text{р}}$ are the elasticity modulus and the flow shear strength of the machined material, respectively; $\lambda_{\text{д}}$ and $\lambda_{\text{р}}$ are the heat conductivity coefficients of the machined and the tool materials; $\theta_{\text{пл}}$ is the melting point of the machined material; α and γ are the face and the end tool edge angles; φ and φ_1 are the main and the auxiliary cutting edge angles in the plane; ρ_1 is the rounded cutting edge radius; B_1 and H_1 are the width and the height of the tool holder cross section; $L_{\text{р}}$ is the length of the cutter part projecting from the tool head; H is the size of the work piece; $\lambda_{\text{ст}}$ is the heat conductivity of the cutter holder material; α_1 and $\alpha_{\text{р}}$ are the conductivity coefficients of the machined material and cutter holder material; $j_{\text{сист}}$ is the stiffness of the machine-attachment-tool-work piece system; $c\rho$ is the volumetric specific heat of the machined material; S is the feed (the tool displacement rate); t and v are the cutting depth and rate; r is the tip radius in the plane; $\sigma_{\text{ост}}$ is the value of residual stresses on the set level from the work piece surface; $h_{\text{н}}$ is the degree of cold working of the surface layer material; Rz is the peak-to-valley deviation on the work piece surface; δ is the wear flat height on the tool point back face; a is the thermal diffusivity of the machined material; σ_{T} is the tensile yield strength of the work piece material.

Thus, the cutting conditions and the tool geometry are the function of the characteristics of the work piece surface layer, cutting accuracy, properties of the machined and the tool materials, work piece and the cutter dimensions, rigidity of the technological system.

2. Findings of the study.

To manage forming the work piece surface layer the calculative dependencies were obtained to define residual stresses in the surface layer $\sigma_{\text{ост}}$, those of degree N and depth $h_{\text{н}}$ of cold working, and parameters of surface roughness Rz etc. Some examples are given below.

For instance, axial residual stresses $\sigma_{\text{о.ост}}$ in the surface layer caused by the thermal effect, at $r > r_{\text{он}}$ and $\sigma_{\text{о.о max}} < 2\sigma_{\text{т}}$ are determined by the following formula:

$$\sigma_{\text{о.ост}} = -\sigma_{\text{т}} + \\ + \left\{ \left(\frac{r_{\text{н}} - r + a_1}{a_1} \right)^{X_2} + \frac{2}{a_1^{X_2} (r_{\text{н}}^2 - r_{\text{в}}^2)} \left\{ \begin{aligned} & \frac{r_{\text{н}} + a_1}{1 + X_2} \left[a_1^{1+X_2} - (r_{\text{н}} - r_{\text{в}} + a_1)^{1+X_2} \right] - \\ & - \frac{1}{2 + X_2} \left[a_1^{2+X_2} - (r_{\text{н}} - r_{\text{в}} + a_1)^{2+X_2} \right] \end{aligned} \right\} \right\} \frac{\beta_{\text{д}} A_1 E_{\text{д}}}{1 - \mu},$$

where r is the work piece radius from the center in which the values of the residual stresses are determined; $r_{\text{н}}$ and $r_{\text{в}}$ are the outer and the inner radii of the work piece; μ is the Poisson's ratio of the work piece material; A_1 and X_2 are the values defined by the technological cutting conditions [1].

$$A_1 = C_0 \theta_A (БB)^{X_1} \left(\frac{\rho_1}{a_1} \right)^{X_3 - d} \sin\alpha^{0,05-0,042X_4} \sin\gamma^{-0,021X_4},$$

where $Б = \frac{\nu a_1}{a}$ is the cutting process dimensionless group characterizing the impact of cutting conditions on the temperature in the surface layer comparing to the impact of heat-transfer properties of the machined material [2]; $B = \frac{1}{\mathrm{tg}\beta_1}$ is the dimensionless group characterizing the plastic yield degree of the removed stock material and the material of the work piece surface layer; β_1 is the relative shear plane inclination; C_0, X_1, X_3, X_4 and d are the values depending on the cutting conditions [1].

The depth of cold working in the surface layer is determined based on the condition of equality:

$$\sigma_y + \sigma_{\text{н}} = -\sigma_{\text{т}},$$

where σ_y is the stress conditioned by the force impact on the surface layer; $\sigma_{\text{н}}$ are the stresses caused by the heat impact on the surface layer.

$$\sigma_y = \left[\frac{\tau_p}{2\pi} \cdot \psi\left(B; \frac{y}{h}; \frac{h}{a_1} \right) - \frac{\tau_p b}{2\pi b_1 \cos\alpha} E\left(\frac{y}{h}; B; \frac{\Delta}{\Delta_1}; \gamma \right) \right] \cdot \frac{1}{1-\mu^2};$$

$$\sigma_{\text{н}} = \frac{\beta_{\text{д}} A_1 E_{\text{д}}}{a_1^{X_2}(1-\mu)} \left\{ -(r_{\text{н}} - r + a_1)^{X_2} + \frac{1}{0,5(r_{\text{он}}^2 - r_{\text{в}}^2) E_{\text{д}}} \times \right.$$

$$\times \left[E_{\text{д}} (r_{\text{н}} - r_{\text{он}} + a_1)^{1+X_2} \left(\frac{r_{\text{н}} - r_{\text{он}} + a_1}{2 + X_2} - \frac{r_{\text{н}} + a_1}{1 + X_2} \right) + (r_{\text{н}} - r_{\text{в}} + a_1)^{1+X_2} \times \right.$$

$$\left. \left. \times \left(\frac{r_{\text{н}} + a_1}{1 + X_2} - \frac{r_{\text{н}} - r_{\text{в}} + a_1}{2 + X_2} \right) E_{\text{д}} \right] - \frac{0,5 a_1^{X_2} \sigma_{\text{т}}}{\beta_{\text{д}} A_1} (r_{\text{н}}^2 - r_{\text{он}}^2) \right\},$$

where τ_p is the flow shear strength of the machined material; h, Δ, Δ_1 are the dimensions of the area of the plastic material in the surface layer; y is the depth of the layer under consideration from the surface; $r_{\text{он}}$ is the radius corresponding to the boundary of elastic and plastic flow in the surface layer under heating, $r_{\text{он}} = r_{\text{н}} - r = y$.

The degree of the cold working on the work piece surface is defined by the formula:

$$N = \frac{h_{\text{н}}}{1,25(\sigma_{\text{в}}/\sigma_{\text{вэ}})^{0,8}},$$

where $\sigma_{\text{в}}$ is the yield value of the machined material; $\sigma_{\text{вэ}}$ is the yield value of the electrical steel taken as a standard.

If the cutting rate changes in dependence of the speed of the maximal build-up forming $\nu_{\text{нар}}$ to the optimal $\nu_{\text{о}}$, then at $r\left[1-\sqrt{1-(S/2r)^2}\right] \le t \le r(1-\cos\varphi)$ the peak-to-valley ratio is as follows, mm:

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

Using the above dependencies to determine the surface layer quality parameters the dependences were obtained to define the indices of performance characteristics of machine components. So, the endurance limit of the work piece material machined with the edge tool is determined as follows:

– when turning

$$\sigma_{-1} = m \cdot (\sigma_{\text{в}}/\sigma_{\text{вэ}})^K \cdot Rz^{-0,05} \cdot h_{\text{н}}^{0,147} \cdot \sigma_{\text{ост}}^{-0,09};$$

– when milling

$$\sigma_{-1} = n \cdot (\sigma_{\text{в}}/\sigma_{\text{вэ}})^L \cdot Rz^{-0,067} \cdot h_{\text{н}}^{0,139} \cdot \sigma_{\text{ост}}^{-0,063},$$

where m, n, K, L are the values depending on the cutting type [1]; $\sigma_{\text{в}}$ and $\sigma_{\text{вэ}}$ is the ration between the yield value of the machined material and the yield value of the electrical steel taken as a standard.

The wear rate of the machined surface is defined by the formula:

$$J_h = 0{,}0316 \cdot 3{,}7^{\nu+1} \alpha_2^{0{,}5} b \times$$

$$\times \frac{\left\{ \frac{1}{8r} \left[\begin{matrix} 0{,}6625 a_1^{0{,}125} c\rho\theta_0 \times \\ \times \dfrac{4{,}3 \sin^{0{,}115} \alpha \nu^{0{,}57} a_1^{0{,}345} \lambda \left(\dfrac{t}{m} \right)^{0{,}3} + \lambda_{\text{p}} \beta \varepsilon a^{0{,}57} \rho_1^{0{,}075}}{\begin{matrix} \tau_{\text{p}} a^{-0{,}43} \sin^{0{,}05} \alpha v_0 t^{0{,}25} c_0 m^{0{,}74-n_0} \times \\ \times b^{0{,}04} \rho_1^{n_0-0{,}1} (1 - 0{,}45 \sin\gamma) \end{matrix}} \end{matrix} \right]^{\frac{2}{1-n_0}} \right\}^{0{,}719-0{,}2(\nu+1)+5{,}2t_y}}{(\nu+1) \left(\dfrac{34{,}64\sigma_0}{kf_{\text{м}}} \right)^{t_y} \left(\dfrac{N}{A_c} \right)^{-0{,}323(\nu+1)+0{,}161-0{,}16t_y} \left(\dfrac{1-\mu^2}{E} \right)^{0{,}161+0{,}84t_y-0{,}323(\nu+1)}},$$

where Rz is the peak-to-valley ratio of the contact surface profile, mm; ν and b are the bearing surface approximation curve parameters; σ_0 is the acting stress in the contact area of mating surfaces, MPa; N is the load acting on the contact, H; A_c is the nominal area outlined by the dimensions of the adjoining solids, mm^2; μ is the Poisson's ratio of the work piece material; E is the elasticity modulus of the material which wears out faster, Pa; t_y is the friction fatigue curve parameter [3]; K is the coefficient characterizing the stress condition on the contact (for brittle materials $K = 5$, for high-plasticity materials $K = 3$); $f_{\text{м}}$ is the value of the molecule-based component of the friction ratio.

Thus, the surface wear rate is the function of its cutting conditions, as well as the properties of the work piece material.

When making pressure couplings the values of axial force P_{o} and torque $M_{\text{кр}}$, which provide the strength of such connections, are determined by the formulas:

- when manufacturing joinable parts made of the same material:

$$P_{\text{o}} = \pi \cdot l \cdot f_{\text{oc}} \cdot \frac{2(1+\mu) \cdot \sigma_{0{,}2}^2}{\alpha^2} \cdot \frac{\delta_{\text{н}} - 1{,}2(Rz_1 + Rz_2)}{\dfrac{C_1 W_1}{N_1^2} + \dfrac{C_2 W_2}{N_2^2}},$$

$$M_{\text{кр}} = \pi \cdot d \cdot l \cdot f_{\text{кр}} \cdot \frac{(1+\mu) \cdot \sigma_{0{,}2}^2}{\alpha^2} \cdot \frac{\delta_{\text{н}} - 1{,}2(Rz_1 + Rz_2)}{\dfrac{C_1 W_1}{N_1^2} + \dfrac{C_2 W_2}{N_2^2}},$$

where l is the length of the contact area of the mating parts; d is the nominal mating diameter; f_{oc} and $f_{\text{кр}}$ are the friction coefficients under the press fitting and press fitting with twisting; δ is the value of the nominal tension; Rz_1 and Rz_2 is the peak-to-valley ratio on the contacting surfaces; N_1 and N_2 are the cold working degrees on the surface of mating parts; $\sigma'_{0,2}$ and $\sigma''_{0,2}$ are the conventional yield stress for the materials of the mating parts; W_1 and W_2 are the values of the stored power in the surface layer of the materials of the first and the second mating parts; μ_1 and μ_2 are the Poisson's ratio of the mating part materials [3]; C_1 and C_2 are the factors depending on the part dimensions and the Poisson's ratios of the materials of the mating parts.

3. Conclusion.

Thus, the methods was presented to calculate the cutting mode, providing the predetermined performance characteristics of work pieces and allowing to control the cutting process thereby ensuring manufacture of reliable and durable products and making the manufacturing process be science-intensive and cost-effective.

4. References.

1. **Bezjazychnyi V.F.** The method of similarity in engineering technology. – M: Machinostroyeniye, 2012. – 320 p.
2. **Silin S.S.** The method of similarity when cutting materials. – M: Machinostroyeniye, 1979. – 152 p.
3. **Malinin N.N**. Applied theory of plasticity and creep – M: Machinostroyeniye, 1970. – 400 p.