УДК 621.7.01:539.431

C. S. Barandich, S. P. Vysloukh, O. V. Voloshko
The National Technical University of Ukraine “Kyiv Politechnic Institute”, Kyiv, Ukraine

THE LIMIT OF ENDURANCE, AS THE MAIN INDICATOR OF OPERATIONAL PROPERTIES DETAILS OF DEVICES

Наведено аналіз наукових досліджень у галузі технологічного забезпечення заданих значень границі витривалості матеріалу деталей. Встановлена безпосередня кореляція між режимами механічної обробки, якістю поверхневого шару і границею витривалості. Показана актуальність створення науково обґрунтованої методики призначення оптимальних режимів механічної обробки з метою забезпечення необхідних значень границі витривалості матеріалу деталей. Створено нову математичну модель границі витривалості, що залежить від режимів обробки та характеристик оброблюваного матеріалу.

Ключові слова: механічна обробка, втомна міцність, границя витривалості, режими обробки.

This article presents an analysis of scientific research in the field of engineering support given values of detail’s endurance limit. Direct correlation between the modes of mechanical cutting, the quality of the surface layer and the endurance limit details were established. The urgency of creating science-based methods use the best mode of machining to ensure the required values of the detail’s endurance limit is shown. It has been developed a mathematical model of endurance limit, which depends on the mode processing and the characteristics of the material.

Key words: machining, fatigue strength, limit of endurance, the modes of machining.

Introduction. Details of devices are responsible components in control systems, the reliability of the work of device as a whole depends from their quality. Condition of the surface layer of a significant impact on the durability, reliability and performance of the device, as in alternating loads destruction detail starts from the surface [1-2]. Thus, an important performance properties of parts is fatigue resistance – the ability to resist the destruction of parts over a period of time when exposed to variable loads. This property is characterized by the limit of endurance.

Formation of the detail’s surface layer of mainly occurs through machining, which causes plastic deformation, heating and structural changes in the surface layer of the processed material. Thus, the detail’s surface layer is formed with specific details for the sign and magnitude of residual stresses, depth and degree of consolidation, and surface roughness.

Due to this promising approach, in which on the stage of technological preparation of production cutting conditions are determined that yield values of roughness, depth and degree of consolidation, residual stresses which are necessary to ensure the specified value limit of endurance detail’s material.

Review of previous researching. The issue of technological conditions influence for parameters on the quality of the surface layer and operating properties of machined details devoted to the work of many scientists, including A. G. Suslov, V. F. Bez'yazychnyy, T. D. Kozhina, A. M. Sulima, E. V. Ryzhov, V. P. Fedorov, S. S. Filin, M.A. Yelyzavetin, A. A. Matalin, M. Y. Evstyhnyeyev, S. A. Uryadov, etc. One of the main performance properties of details, which ensures their reliability and durability is the endurance limit was established.

The presence on the detail's surface operating under cyclic and alternating loads, certain defects and irregularities contribute to stress concentration that may exceed the strength limits of the material [3]. In this case, the surface defects and risks are causing a violation of the integrity of the surface layer, it loosening, the formation of fatigue cracks. In addition, numerous researching have established that endurance limit depends on the extent and depth of hardening, as well as sign and the depth of the residual stress of the surface layer. Thus, the presence on a surface layer of compressive residual stress endurance limit is increased, while the residual tensile stress – is reduced.

Research of Professor Matalina A. A. found that residual stresses, hardening and surface roughness change limit endurance ratio $1{,}5 \times 1{,}25 \times 1{,}03$.

According to research Sulima A. M. [2] the relative importance of each parameter from the quality of the surface layer in reducing limit endurance samples after grinding are: surface roughness by 50 %; strengthen the surface layer of 40-45 %, residual stresses technological 5-10 %.

This suggests doing conclusion that one opinion is absent about the degree of influence of a parameter on the endurance limit of the material details.

Research Professor Sulima A. M. the following dependence that characterizes the dependence of the surface layer on the limit of endurance:

$$\sigma_{-1} = A_0 + A_1 Ra + A_2 h_H + A_3 u_H\,, \tag{1}$$

where σ_{-1} – limit of endurance; h_H, u_H – depth and degree of consolidation; A_0, A_1, A_2, A_3 – coefficients, which depends from material and terms of machining.

Effect of tensile residual stresses in the surface layer of the limit of endurance is defined as:

$$\sigma_{-1} = \sigma_{-1init.} - C\sigma_{res.\max}\,, \tag{2}$$

where $\sigma_{-1init.}$ – limit of endurance for polished sample (without residual stresses); $\sigma_{res.\max}$ – value of maximum residual stresses; C – coefficient, which depends from type of machining.

According to research by Zybel and Geyer endurance limit of the detail's material after machining, follows the dependence of this type:

$$\sigma_{-1} = (C_1 - n\ln Rz)\sigma_{-1init.} \tag{3}$$

where Rz – height inequalities surface finish; C_1, n – values, which depends from material and kind of heat treatment.

Prof. Bez'yazychniy V. F. proposed the following relationship between the endurance limit of the material components and quality parameters of the surface layer:

For turning

$$\sigma_{-1} = m(\sigma_B / \sigma_{BE})^K Rz^{-0.05} \cdot h_H^{-0.147} \cdot \sigma_{res.}^{-0{,}09}\,, \tag{4}$$

for milling

$$\sigma_{-1} = n(\sigma_B / \sigma_{BE})^L Rz^{-0.067} \cdot h_H^{-0.139} \cdot \sigma_{res.}^{-0{,}063}\,, \tag{5}$$

where m, n, K, L – values, which depends from material's properties; σ_B / σ_{BE} – concern of strength limit of processed material to the strength electrical steel's limit, taken as a reference.

Uryadov S. A. [4] got next formulas to determine the endurance limit of detail's material depending on the quality parameters for the surface layer of materials classification groups:

heat-resistant nickel alloys

$$\sigma_{-1} = 1151 Ra^{-0.2153} \cdot \sigma_{res.\max}^{-0,095} \cdot h_H^{-0.164}, \quad (6)$$

titanium alloys

$$\sigma_{-1} = 1465 Ra^{-0.4042} \cdot \sigma_{res.\max}^{-0,095} \cdot h_H^{-0.164}, \quad (7)$$

constructional steel

$$\sigma_{-1} = 653 Ra^{-0.0881} \cdot \sigma_{res.\max}^{-0,095} \cdot h_H^{-0.164}. \quad (8)$$

The dependence between the endurance limit of the processed material $\sigma_{-1\,fin.}$ and the pendulum mode and deep polishing by Urjadov S. A. determined through the process of cutting energy criterion A that characterizes the work spent on the removal allowance

$$\sigma_{-1\,fin.} = f(A), \quad (9)$$

where $A = \frac{a_1 \cdot b_1 \cdot c \cdot \rho \cdot \Theta}{P_Z}$; a_1, b_1 – thickness and width of the cut layer; $c\rho$ – specific volumetric heat capacity of the processed material; Θ – cutting temperature; P_Z – cutting force.

Relative change in the elastic modulus of the detail's material regarding the beginning processed material $E_{fin.}/E_{init.}$ is taken as the criterion of damaged material. To determine the limit of material's endurance after processing, the following ratio:

$$\frac{\sigma_{-1}}{\sigma_{-1init.}} = f\left(\frac{E_{fin.}}{E_{init.}}\right) \quad (10)$$

where σ_{-1} and $\sigma_{-1init.}$ – endurance limit of detail's material after processing and in the initial state; $E_{fin.}$ and $E_{init.}$ – modulus of material's elasticity of the surface layer after processing details and in the initial state.

After a number of assumptions and transformation dependence between the elastic modulus of the material details after processing and energy criteria A were got:

$$E_{fin.} = C \cdot A^K, \quad (11)$$

where C, K – coefficients, which depends from type of material and processing method.

In view of the above mentioned formulas endurance limit of the detail's material after processing can be defined by the formula

$$\sigma_{-1} = \frac{C \cdot A^K}{E_{init.}} \cdot \sigma_{-1init.}. \quad (12)$$

After substituting in the formula value of the energy criterion A for cases pendulum and deep polishing received:

for pendulum polishing

$$\sigma_{-1} = C \frac{\sigma_{-1init.}}{E_{init.}} \cdot \left[0.0885 \sqrt{\frac{v_d l}{a_d}} \left(1 + \sqrt{\frac{(\lambda c\rho)_c}{(\lambda c\rho)_d}} + \frac{0,565 \cdot t \cdot v_d}{lB} \cdot \sqrt{\frac{v_d l}{a_d}} \right) \right]^K, \quad (13)$$

for deep polishing

$$\sigma_{-1} = C\frac{\sigma_{-1init.}}{E_{init.}} \cdot \left[\frac{0.833 \cdot a_d \cdot l}{\lambda} + 2.16 \cdot 10^{\frac{0.09 a_d^2}{v_d \cdot l}} \cdot \left(\frac{v_d \cdot l}{2a_d} \right)^{0.428} \right]^K, \quad (14)$$

where v_d – speed of detail's movement; l – length of the contact area of the polishing wheel whit detail; a_d – temperature conductivity of the detail's material; $(\lambda c\rho)_c$ and $(\lambda c\rho)_d$ – product of thermal conductivity and specific heat capacity of the bulk material abrasive wheels and detail; t – allowance for processing; B – width of processed detail.

Mathematical Model. The proposed mathematical model endurance limit detail's material obtained by improving the dependences obtained in [4], taking into account the real characteristics of the material. In general terms, it can be represented as follows:

$$\sigma_{-1} = 653 Ra^{-0.0881} \cdot \sigma_{зал.\max}^{-0,095} \cdot h_H^{-0.164} \cdot K_m, \quad (15)$$

where K_m – coefficient, which takes into account the real value of the chemical composition and physical properties of the material.

According to research results by A. M. Suslov [5-6], based on similarity theory, S. S. Silin, dependence between indicators of quality of the surface layer (roughness, residual stresses, the depth of hardening) and polishing modes are as follows:

$$Ra = 180\xi^{\left(N\frac{B}{S_l}-1\right)} \times$$
$$\times \left\{ t - \frac{P_y}{j_{ts}} - \frac{\frac{P_y}{S_l}\left[E_2\left(1-\mu_1^2\right)+E_1\left(1-\mu_2^2\right)\right]}{\pi E_1 E_2} \times \ln \frac{2\pi E_1 E_2 (D+d)}{\frac{P_y}{S_l}\left[E_2\left(1-\mu_1^2\right)+E_1\left(1-\mu_2^2\right)\right]} + \frac{l^2\left(1 \pm \frac{v_d}{v_c}\right)^2}{4D} \right\} +$$
$$+ \frac{\left(1-\frac{\tau_s}{\sqrt{\tau_s^2+\sigma_l^2}}\right)\left[2s+2\left(1-\frac{\tau_s}{\sqrt{\tau_s^2+\sigma_l^2}}\right)\right]}{32}; \quad (16)$$

where ξ – coefficient, which depends on the concentration of abrasive grains; N – quantity of passes; B – width of polishing wheel; S_l – longitudinal feed; t – polishing deep; P_y – normal component of the cutting force; j_{ts} – stiffness of the technological system; E_1, μ_1 i E_2, μ_2 – elastic modulus and Poisson's ratio of binder and blank circle; D and d – diameter of polishing wheels and detail according to; v_d – speed of detail; v_c – speed of circle; l – middle step between grains tool; τ_s – strength of the material being worked on shift; σ_l – liquid limit processed material.

$$\sigma_{res.\max} = f(\sigma_h + \sigma_c); \quad (17)$$

where σ_h i σ_c – residual stresses in the surface layer during heating and cooling.

$$h_H = \frac{1}{0.855\sqrt{Б}} \left| \ln \frac{\sigma_l (1-\mu)}{\beta_d \theta_{\max} E_d} \right|^{\frac{2}{3}}. \quad (18)$$

where $Б$ –criterion of the cutting process that characterizes the degree of influence of operating conditions of treatment compared with the influence of thermal and physical properties of the processed material; E_d and μ – elastic modulus and Poisson's ratio of the detail’s material; β_d – coefficient of temperature linear expansion of processed material; θ_{max} – maximum temperature in the surface layer.

Then the mathematical model of endurance limit of constructional steel after polishing will take the following form:

$$\sigma_{-1} = 653\left(180\xi^{\left(N\frac{B}{S_l}-1\right)}\times\left\{\begin{array}{l} t-\dfrac{P_y}{j_{ts}}-\dfrac{\dfrac{P_y}{S_l}\left[E_2\left(1-\mu_1^2\right)+E_1\left(1-\mu_2^2\right)\right]}{\pi E_1 E_2}\times \\ \times\ln\dfrac{2\pi E_1 E_2 (D+d)}{\dfrac{P_y}{S_l}\left[E_2\left(1-\mu_1^2\right)+E_1\left(1-\mu_2^2\right)\right]}+\dfrac{l^2\left(1\pm\dfrac{v_d}{v_c}\right)^2}{4D}\end{array}\right\}+\frac{\left(1-\dfrac{\tau_s}{\sqrt{\tau_s^2+\sigma_l^2}}\right)\left[2s+2\left(1-\dfrac{\tau_s}{\sqrt{\tau_s^2+\sigma_l^2}}\right)\right]}{32}\right)^{-0.0881}\times$$

$$\times\left(f(\sigma_h+\sigma_c)\right)^{-0,095}\times\left(\frac{1}{0.855\sqrt{\dfrac{v_c t}{a_d}}}\left|\ln\frac{\sigma_l(1-\mu)}{\beta_d\theta_{max}E_d}\right|^{\frac{2}{3}}\right)^{-0.164}\times K_m. \qquad (19)$$

Conclusions. Thus, in this article the relevance of the methodology appointment technological modes of machining to provide the necessary values of endurance limit device details. The influence of the main parameters of the surface layer of the devices on their performance properties, particularly, the endurance limit of the material components, making it possible to identify the most important characteristics of the surface layer of components: roughness, extent and depth of hardening, residual stresses were established. The dependencies that bind the endurance limit values with quality parameters of surfaces quality of details of devices and modes of processing, making it possible, on the basis of previous studies, a new mathematical model determining the limit of endurance as a dependencies between endurance limit and technological modes of polishing and develop a methodology destination technological regimes of polishing for providing the required parameters of values of the surface layer and endurance limit of device’s details.

1. Bezjazychnyj V. F. Tehnologicheskie metody obespechenija ekspluatacionnyh svojstv i povyshenija dolgovechnosti detalej / V. F. Bezjazychnyj, T. D. Kozhina, Ju.K. Charkovskij. – Jaroslavl': JaPI, 1987. – 87 s. 2. Sulima A. M. Poverhnostnyj sloj i jekspluatacionnye svojstva detalej mashin / A. M. Sulima, V. A. Shulov, Ju.D. Jagodkin. – M.: Mashinostroenie, 1988. – 240 s. 3. Urjadov S. A. Vlijanie tehnologij obrabotki na soprotivlenie ustalosti detalej mashin / S. A. Urjadov // Spravochnik. Inzhenernyj zhurnal. – 2009. – № 9. – s.8–11. 4. Urjadov S. A. Issledovanie vzaimosvjazi predela vynoslivosti materiala detali s tehnologicheskimi uslovijami obrabotki pri shlifovanii: dis. k.t.n.: spec.: 05.02.08. – tehnologija mashinostroenija / S. A. Urjadov. – Rybinsk, 2010. – 149 s. 5. Suslov A. G. Kachestvo poverhnostnogo sloja detalej mashin / A. G. Suslov. – M.: Mashinostroenie, 2000. – 320 s., il. 6. Suslov A. G. Inzhenerija poverhnosti detalej / koll. avt.; pod red. A. G. Suslova. – M.: Mashinostroenie, 2008. – 320 s., il.