https://doi.org/10.31649/mccs2022.09

УДК 620.92:621.311.29

Anatoly Usov
Maksym Kunitsyn
Yuriy Zaychyk

MANAGEMENT OF THE QUALITY CHARACTERISTICS OF THE WORKING SURFACES OF COMPLEX PROFILE PRODUCTS DURING MECHANICAL PROCESSING

Odessa Polytechnic National University

The paper considers the temperature field model, which is formed in the surface layer of complex profile products during their processing in finishing operations. These operations are associated with defects in the surface layer of products, such as burns, cracks, and tensile stresses. Which significantly affects the reliability and durability of these parts during their operation. These defects, being local stress concentrators in operational conditions, lead to premature failure of products, even though the load on them forms stresses, the value of which does not exceed the limit values. The model is built based on the solution of the product's initial boundary value problem of thermal conductivity. Functional relationships of technological parameters with the grinding temperature obtained based on the model reflect the state of the treated surfaces for products with complex profiles and allow using appropriate techniques to eliminate burns on the treated surfaces. The study of the conditions for improving the quality of the treated surfaces by eliminating defects such as cracks and burns was carried out mainly at the level of identifying the connections of the temperature fields that are formed with technological parameters, physical and mechanical properties of the polished materials and the geometry of the products. It was established that when grinding complex profile products from a larger radius in the direction to a smaller one, the temperature increased in proportion to the angle of inclination of the treated surface. The adequacy of the built model was checked on the example of grinding conical products made of steel with known physical and mechanical characteristics, the choice of tool, and the designation of processing modes. Analysis of the simulation results shows that the temperature of the machined surface increases as the machining tool approaches a smaller diameter along the conical surface. This area of conical products' machined surface is most prone to defect formation during finishing operations. Therefore, when assigning treatment modes for such surfaces, they should be assigned with the condition that when the processing tool approaches the part of the conical surface with a smaller diameter, the temperature formed on it should not exceed the permissible values that ensure the required quality. Analysis of the results of numerical calculations of temperature fields showed sufficient accuracy according to the boundary conditions of the simulation.

Keywords: complex profiled products, temperature field model, defects, surface layer quality, finishing operations, adequacy.

Introduction

It is known that hereditary technological defects such as burns and micro-cracks are formed in the surface layer during the processing complex profiled products [1]. These defects, being local stress concentrators in operational conditions, lead to premature failure of products, even though the load on them forms stresses, the value of which does not exceed the limit values [2]. When forming the required geometric dimensions of complex profiled products in the processed stochastically located micro inhomogeneities and micro defects are formed on the surfaces [3]. Therefore, when studying the limit state of these products, the surface layer is weakened by micro defects. Building on this basis a justified theory of their bearing capacity, in addition to the deterministic one, a probabilistic statistical approach is also necessary. Finally, the active layer of such products is considered an environment weakened by random defects, the parameters of which are random variables with known distribution laws.

Formulation of the problem

The statistical approach in assessing the load-bearing capacity of products has certain advantages. First, it makes it possible to consider the impact on the strength of all defects and inhomogeneities at once, regardless of their physical nature, size, shape, and location [4]. However, on the other hand, this approach does not allow us to assess the role of the defect in the elementary act of destruction, the reduction of the strength of the surface layer containing the specified defects, and their appearance from the technology of product processing to the final state of the working surface [5]. Their geometry plays a specific role in forming defects in the surface layer of processed products [6]. It especially applies to the finishing methods of processing complex profiled products. The most common final processing method is grinding, which ensures high accuracy and productivity of manufacturing parts [7]. However, the application of grinding is associated with defects such as burns, cracks, and tensile stresses in the surface layers of parts, which significantly affects the reliability and durability of these parts during their operation. Existing functional connections of technological parameters with the grinding temperature [8] make it possible to eliminate burns on the processed surfaces of products that do not contain design and technological inhomogeneities and the material which does not contain significant deviations, using appropriate methods. The study of the conditions for improving the quality of the treated surfaces by eliminating defects such as cracks was mainly conducted at the level of identifying qualitative relationships between technological parameters and the physical and mechanical properties of polished materials [9].

However, the lack of research on the peculiarities of the process of genesis of grinding defects and their impact on the decrease in performance depending on the structural, technological, and structural inhomogeneities of the material of the products do not allow us to unambiguously use the existing recommendations for the elimination of these defects.

The purpose of these studies is to build a model of thermomechanical processes that accompany the finishing of complex profiled products under which defects are formed in the surface layer, which leads to the loss of the load-bearing capacity of these products during their operation.

Research Methodology. Consider the following initial boundary value problem of thermal conductivity for a product in the form of, for example, a truncated circular cone (Fig. 1).

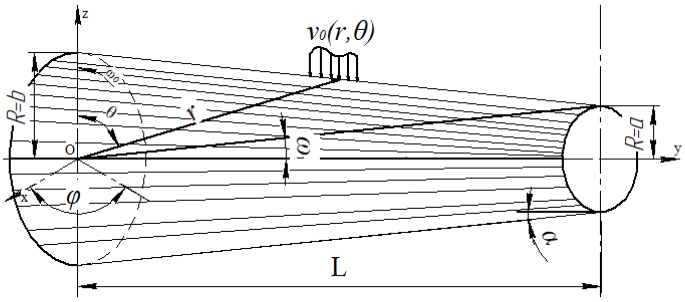

Fig. 1 Calculation scheme for modeling the temperature field formed in conical products during finishing operations

$$\Delta v(r,\theta,\varphi,t)=\frac{1}{a^*}\frac{\partial v(r,\theta,\varphi,t)}{\partial t}, a<r<b,\ \omega_0<\theta<\omega_1, t>0,$$
$$v(r,\theta,\varphi,t)=f(r,\theta,\varphi), v(a,\theta,\varphi,t)=v(b,\theta,\varphi,t)=0, |\varphi|<\pi,$$
$$a)\ v\left(r,\omega_j,\varphi,t\right)=g^j(r,\varphi,t),$$
$$b) v^{\cdot}\left(r,\omega_j,\varphi,t\right)+h_j v\left(r,\omega_j,\varphi,r\right)=g^j(r,\varphi,t), \tag{1}$$
$$c)\ v^{\cdot}\left(r,\omega_j,\varphi,t\right)=g^j(r,\varphi,t);\ j=0,1,$$

where Δ is the Laplace operator in the spherical coordinate system, the constants a^* and h are the thermophysical constants of the product material, the boundary conditions on the conical surfaces $r=a$ and $r=b$ can be of three types, and also heterogeneous. The specified conditions are chosen for the sake of shortening the records. As above, the derivative concerning the variable θ is marked with a dot and the derivative concerning the variable r with a dash. From the given functions, we will require that integral transformation and inversion formulas are valid for them [10].

Consistently applying the integral Laplace transform over time to (1):

$$v_p(r,\theta,\varphi)=\int_0^\infty v(r,\theta,\varphi,t)\,e^{-pt}dt, \tag{2}$$

and the Fourier transform by the angle φ:

$$v_{pn}(r,\theta) = \frac{1}{2\pi}\int_{-\pi}^{\pi} v_p(r,\theta,\varphi)e^{-in\varphi}d\varphi, n = 0, \pm 1, \pm 2, \dots, \tag{3}$$

instead of (1) we obtain:

$$\begin{gathered} \left[r^2 v_{pn}(r,\theta)\right]' - \nabla_n v_{pn}(r,\theta) - s^2 r^2 v_{pn}(r,\theta) = f_n(r,\theta), \\ v_{pn}(a,\theta) = 0, v_{pn}(b,\theta) = 0,\ \omega_0 < \theta < \ \omega_1, a < r < b, \\ a)\ v_{pn}(r,\omega_j) = g_{pn}^j(r), \\ b)\ v_{pn}^{\cdot}(r,\omega_j) + h v_{pn}(r,\omega_j) = g_{pn}^j(r), \\ c)\ v_{pn}^{\cdot}(r,\omega_j) = \ g_{pn}^j(r), j = 0,1. \end{gathered} \tag{4}$$

The following notations are introduced here:

$$-\nabla_n f(r,\theta) = \frac{[sin\theta f^{\cdot}(r,\theta)]}{sin\theta} - \frac{n^2 f(r,\theta)}{sin^2\theta}, s^2 = \frac{p}{k}, k = 0,1,2$$

Let us apply the integral transformation to the boundary value problem (4), denoting the corresponding transform of the desired function in the form:

$$v_{pnk}(r) = \int_{\omega_0}^{\omega_1} sin\theta\varphi_1(\theta,v_k)v_{pn}\,(r,\theta)d\theta, k = 0,1,2, \dots, \tag{5}$$

and similarly transformants of given functions.

As a result, the boundary value problem (4) will take the form:

$$\begin{gathered} L_s v_{pnk} \equiv \left[r^2 v_{pnk}(r)\right]' - v_k(v_k+1)v_{pnk}(r) - r^2 s^2 v_{pnk}(r) = f_{pnk}(r) - S_k(r,\omega), \\ a < r < b, v_{pnk}(a) = v_{pnk}(b) = 0, \\ S_k(r,\omega) = \left[\varphi_1(\theta,v_k)sin\theta v_{pn}^{\cdot}(r,\theta)\right]_{\omega_0}^{\omega_1} - \left[\varphi_1^{\cdot}(\theta,v_k)sin\theta v_{pn}^{\cdot}(r,\theta)\right]_{\omega_0}^{\omega_1}. \end{gathered} \tag{6}$$

At the same time, the expression for $S_k(r,\omega)$ is decoded depending on the type of boundary conditions a), b) and c) in (4). This depends on which equation v_k should be found from, and the type of function $\varphi_1(\theta,v_k)$. So, in the case of boundary condition a), instead of $\varphi_1(\theta,v_k)$ in (4), the function $\varphi_a(\theta,v_k)$ defined by formula (7) should be used:

$$\varphi_a(\theta,V_k) = P_{V_k}^m(cos\theta)Q_{V_k}^m(cos\omega_1) - P_{V_k}^m(cos\omega_1)Q_{V_k}^m(cos\theta), \tag{7}$$

where $P_{V_k}^m(cos\,\theta)$, $Q_{V_k}^m(cos\,\theta)$ are linearly independent solutions of the differential equation of the Sturm-Liouville boundary value problem [10], and the numbers V_k are found from the equation:

$$\varphi''(\theta,V_k) + ctg\theta\cdot\varphi'(\theta,V_k) + [V_k(V_k+1) - m^2\,cosec^2\,\theta]\varphi(\theta,V_k) = 0. \tag{8}$$

and the expression $S_k(r,\omega)$ from (6) turns into the following:

$$S_k^a(r,\omega) = \sum_{j=0}^{1} sin\sigma_j\varphi_a^{\cdot}(\omega_j,v_k)g_{pn}^j\,(r).$$

In the case of boundary conditions b) and c), instead of the functions $\varphi_1(\theta,v_k)$ in (5), the functions $\varphi_b(\theta,v_k)$ and $\varphi_c(\theta,v_k)$, which are determined respectively by the formulas:

$$\varphi_b(\theta,V_k) = P_{V_k}^m(cos\theta)l_1^h Q_{V_k}^m - Q_{V_k}^m(cos\theta)l_1^h Q_{V_1}^m \tag{9}$$

This eigenfunction of the Sturm-Liouville boundary value problem [10]:

$$\ddot{T}(\theta) + ctg\theta\cdot\dot{T}(\theta) - \left[\lambda + \frac{1}{4} + \frac{m^2}{sin^2\theta}\right]T(\theta) = 0, \omega_0 < \theta < \omega_1,$$

will satisfy the boundary conditions:

$$\dot{\varphi}_b(\omega_j,V_k) + h_j\varphi_b(\omega_j,V_k) = 0, j = 0,1.$$

When $h_j = 0$, $j = 0,1$ we obtain the eigenfunction $\varphi_c(\theta,V_k)$ of the boundary value problem in the following form:

$$\varphi_c(\theta,V_k) = P_{V_k}^m(cos\theta)\frac{dQ_{V_k}^m(cos\omega_1)}{d\omega_1} - Q_{V_k}^m(cos\theta)\frac{dP_{V_k}^m(cos\omega_1)}{d\omega_1}. \tag{10}$$

It satisfies the boundary condition $\dot{\varphi}_c(\omega_j,V_k) = 0$, $j = 0,1$, and the numbers V_k should be found from the equation:

$$\Delta_k^m \equiv \Omega_{V_{k,0}}^m(\omega_0,\omega_1) = 0, \qquad k = 0,1,2, \dots \tag{11}$$

Integral transformations based on the Sturm-Liouville problem are defined by the following expressions [10, 11]:

$$g_k^m = \int_{\omega_0}^{\omega_1} \sin\theta \cdot \varphi_e(\theta, V_k) g(\theta) d\omega,\ e = a, b, c,$$

$$g(\omega) = -\frac{g_k^m \varphi_e(\theta, V_k)}{\sigma_{mk}^e(\omega_0, \omega_1)},\ \omega_0 \le \theta \le \omega_1.$$

The asymptotic formula for finding V_k has the form:

$$V_k = \gamma k - \frac{3}{2}, \qquad \gamma = \pi(\omega_1 - \omega_0)^{-1}.$$

The formula for $S_k(r, \omega)$ should be replaced by the following expressions:

$$\begin{Vmatrix} S_k^b(r,\omega) \\ S_k^c(r,\omega) \end{Vmatrix} = -\sum_{j=0}^{1} \begin{Vmatrix} \varphi_b(\omega_j v_k) \\ \varphi_c(\omega_j v_k) \end{Vmatrix} g_{pn}^j(r) sin\omega_j$$

Thus, in all three cases of boundary conditions $S_k(r, \omega)$ in (6) is a known function and the solution of the initial boundary value problem (1) is reduced to the solution of the one-dimensional self-adjoint boundary value problem (6). To solve Green's function $G_n(r, \rho)$ of the boundary value problem (6) should be constructed. It can be done using the technique outlined in [10, 11], taking into account that the whole system of solutions $y_0(r)$ and $y_1(r)$ of the differential equation (6) are modified Bessel functions:

$$y_0(r) = r^{-1/2} I_{v+1/2}(rs), y_1(r) = r^{-1/2} K_{v+1/2}(rs), \tag{12}$$

where Vronsky determinant $W(y_0, y_1) = -r^2$ according to the formula [12].

After performing the operations provided by the mentioned method, we will find:

$$G_N(r,\rho) = \frac{\sqrt{ab}}{\Delta_N(a,b)} \begin{cases} \psi_0(\rho)\psi_1(r), r \le \rho; \\ \psi_0(r)\psi_1(\rho), r \ge \rho, \end{cases} \tag{13}$$

where

$$\Delta_S(a,b) = I_{v+1/2}(as)K_{v+1/2}(bs) - I_{v+1/2}(bs)K_{v+1/2}(as),$$

$$\sqrt{br\psi_0}(r) = K_{v+1/2}(bs)I_{v+1/2}(rs) - I_{v+1/2}(bs)K_{v+1/2}(rs),$$

$$\sqrt{br\psi_1}(r) = I_{v+1/2}(as)K_{v+1/2}(rs) - K_{v+1/2}(as)I_{v+1/2}(rs)$$

Here v should be replaced by v_k. Using the constructed Green's function (13), we can find the transformant, and it will have different names depending on the boundary condition in (4):

$$\begin{Vmatrix} v_{pnk}^a(r) \\ v_{pnk}^{b,c}(r) \end{Vmatrix} = \int_a^b G_N(r,\rho) \left[f_{pnk}(\rho) - \sum_{j=0}^{1} sin\omega_j \begin{Vmatrix} \varphi_a(\omega_j, v_k) \\ \varphi_a(\omega_j, v_k) \end{Vmatrix} g_{pn}^j(\rho) \right] d\rho.$$

After inverting the found transformants, we will find the solution of boundary value problems (4) using formula (14):

$$v_{pn}^e(r,\theta) = -\sum_{k=0}^{\infty} \frac{v_{pnk}^c(r)\varphi_c(\theta, v_k)}{\sigma_{mk}^c(\omega_0, \omega_1)}, \qquad e = a, b, c. \tag{14}$$

In order to obtain the solution of the original initial-boundary value problems (1), the found Fourier transforms (3) and Laplace transforms (2) should be converted according to the known transformation formulas, taking into account that $m = |n|$.

Research results

We will examine the adequacy of the built model to ensure the quality characteristics of the surface layer using the example of grinding conical products made of 12X2H4BA steel, the active layer of which is subject to heat treatment. Physical and mechanical characteristics of steel: $G = 6.13 \times 109\ N/m^2$ is the shear modulus; $\nu = 0.27$ is the Poisson's ratio; ⍰$_t = 11.6 \times 10^{-6}$ is the temperature coefficient of linear expansion; $a_c = 16 \times 10^{-5} W/m^2 \times degrees$ is the coefficient of thermal conductivity; ƛ $= 22.2\ W/m \times\ degrees$ is the thermal conductivity coefficient. The tool is a solid circle 24A25 CM18K5 ПП 250×75×20. Processing modes: $V_d = 16 m/min$ is the speed of the part; $P_z = 27H$; $V_{rot} = 30 m/s$ is the speed of the grinding wheel; $L_k = 2l = 1.58 \times 10^{-3} m$ is the length of the arc of contact of the tool with the processed surface; $t_{grind} = 0.01 mm$ is the grinding depth; $S_n = 31.6 \times 10^{-6} m^2$ is the contact area of the tool with the processed surface. The geometry of conical products: $r = a = 0.03$ m, $r = b = 0.06\ m$, $L = 0.09\ m$. The contact temperature was calculated according to formula (14). In Fig. 2 shows the temperature field formed when grinding the working surface of conical products. Analysis of the simulation results shows that the temperature of the processed surface increases as the processing tool approaches the conical surface to a smaller diameter. This result is explained by the fact that heat flows into the narrower part of the conical surface.

This area of conical products' machined surface is most prone to defect formation during finishing operations. Therefore, when assigning treatment modes for such surfaces, they should be assigned with the condition that when the processing tool approaches a narrower part of the surface, the temperature formed on it should not exceed the permissible values that ensure the required quality.

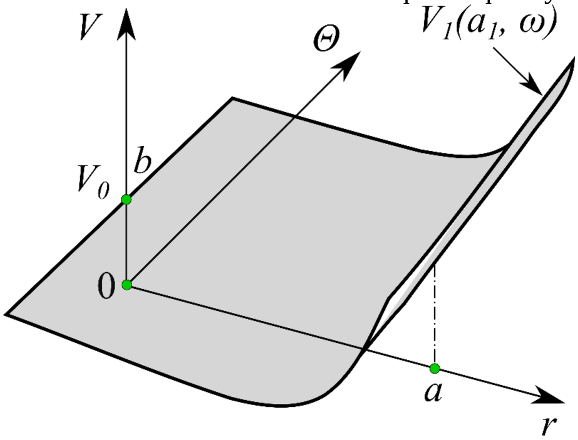

Fig. 2 Grinding temperature distribution on the surface of a conical product when the tool moves from a larger diameter to a smaller one

Conclusions

A model has been developed for determining the temperature field formed in the surface layer of complex profiled products during finishing operations, which allows, due to functional connections with technological parameters, to ensure the required temperature level on the processed surface in order to avoid the formation of defects such as burns and cracks on it. Analysis of the simulation results shows that the temperature on the processed surface increases as the processing tool approaches the narrowed surface to a smaller cross-sectional area. This area of the processed surface of complex profiled products is most prone to defect formation during finishing operations. Therefore, when assigning treatment modes for such surfaces, they should be assigned with the condition that when the processing tool approaches a narrower part of the surface, a temperature is formed, which should be within the permissible values that ensure the required quality.

REFERENCES

[1] Goodstein D. Thermal Physics / D. Goodstein, Cambridge University Press, 2015. 175 p.

[2] Kunitsyn M. V., Usov A. V. The Possibilities of Increasing the Reliability and Durability of a Cylindrical Group by Technological Methods. Odeskyi Politechnichnyi Universytet Pratsi. 2018. T. 1 (54). P. 26-35.

[3] Altenbach H., Altenbach J., Kissing W. Mechanics of Composite Structural Elements. Singapore : Springer, 2018.

[4] Cogswell F. N. Thermoplastic Aromatic Polymer Composites: A Study of the Structure, Processing and Properties of Carbon Fibre Reinforced Polyetheretherketone and Related Materials. Elsevier Science, 2013.

[5] K. T. Kim, D. W. Kim, S. H. Kim et al. Synthesis and improved explosion behaviors of aluminum powders coated with nano-sized nickel film. Applied Surface Science. 2017. Vol. 415. P. 104-108.

[6] Kunitsyn M., Usov A. Development of Quality Criteria for the Surface Layer of Cylinders with Wear-Resistant Coatings. Advanced Manufacturing Processes. 2020. P. 137-147.

[7] Hao Nan Li, Tian Biao Yu, Li Da Zhu, Wan Shan Wang. Analytical modeling of ground surface topography in monocrystalline silicon grinding considering the ductile-regime effect. Archives of Civil and Mechanical Engineering. 2017. Vol. 17, no. 4. P. 880-893.

[8] Zhenyu Han, Hongyu Jin, Maoyue Li, Hongya Fu. An open modular architecture controller based online chatter suppression system for CNC milling. Mathematical problems in Engineering. 2015. Vol. 2015

[9] Oborsky G. A., Dashchenko A. F., Usov A. V., Dmytryshyn D. V. Modeling of systems: monograph. Odessa: Astroprint, 2013. 664 p.

[10] Hoch M. J. R. Statistical and Thermal Physics: An Introduction / M. J. R. Hoch, CRC Press, 2011. 452 p.

[11] Nouari M., Makich H. On the Physics of Machining Titanium Alloys: Interactions between Cutting Parameters, Microstructure and Tool Wear // Metals. 2014. № 3 (4). P. 335–358.

[12] Srivastava H. M. Some Families of Generating Functions Associated with Orthogonal Polynomials and Other Higher Transcendental Functions // Mathematics. 2022. № 20 (10). P. 3730.

СПИСОК ВИКОРИСТАНОЇ ЛІТЕРАТУРИ

[1] Goodstein D. Thermal Physics / D. Goodstein, Cambridge University Press, 2015. 175 с.

[2] Kunitsyn M. V., Usov A. V. The Possibilities of Increasing the Reliability and Durability of a Cylindrical Group by

Technological Methods. Odeskyi Politechnichnyi Universytet Pratsi. 2018. T. 1 (54). C. 26-35.
[3] Altenbach H., Altenbach J., Kissing W. Mechanics of Composite Structural Elements. Singapore : Springer, 2018.
[4] Cogswell F. N. Thermoplastic Aromatic Polymer Composites: A Study of the Structure, Processing and Properties of Carbon Fibre Reinforced Polyetheretherketone and Related Materials. Elsevier Science, 2013.
[5] K. T. Kim, D. W. Kim, S. H. Kim et al. Synthesis and improved explosion behaviors of aluminum powders coated with nano-sized nickel film. Applied Surface Science. 2017. Vol. 415. C. 104-108.
[6] Kunitsyn M., Usov A. Development of Quality Criteria for the Surface Layer of Cylinders with Wear-Resistant Coatings. Advanced Manufacturing Processes. 2020. C. 137-147.
[7] Hao Nan Li, Tian Biao Yu, Li Da Zhu, Wan Shan Wang. Analytical modeling of ground surface topography in monocrystalline silicon grinding considering the ductile-regime effect. Archives of Civil and Mechanical Engineering. 2017. Vol. 17, no. 4. C. 880-893.
[8] Zhenyu Han, Hongyu Jin, Maoyue Li, Hongya Fu. An open modular architecture controller based online chatter suppression system for CNC milling. Mathematical problems in Engineering. 2015. Vol. 2015
[9] Оборский Г. А., Дащенко А. Ф., Усов А. В., Дмитришин Д. В. Моделирование систем : монография. Одесса : Астропринт, 2013. 664 с.
[10] Hoch M. J. R. Statistical and Thermal Physics: An Introduction / M. J. R. Hoch, CRC Press, 2011. 452 с.
[11] Nouari M., Makich H. On the Physics of Machining Titanium Alloys: Interactions between Cutting Parameters, Microstructure and Tool Wear // Metals. 2014. № 3 (4). С. 335–358.
[12] Srivastava H. M. Some Families of Generating Functions Associated with Orthogonal Polynomials and Other Higher Transcendental Functions // Mathematics. 2022. № 20 (10). С. 3730.

Usov Anatoliy V. – Dr. Sc. (Eng.), Professor, head of the Department of Higher Mathematics and System Modeling of the Odessa Polytechnic National University, e-mail: usov_a_v@op.edu.ua, ORCID: 0000-0002-3965-7611.

Kunitsyn Maksym V. – Cand. Sc. (Eng.), Associate Professor of the Department of Integrated Management Technologies of the Odessa Polytechnic National University, e-mail: m.v.kunitsyn@op.edu.ua ORCID: 0000-0003-1764-8922.

Zaychyk Yuriy I. – Ph. D. student of the Department of Higher Mathematics and Systems Modeling of the Odessa Polytechnic National University, e-mail: yuriy.zaichik@gmail.com ORCID: 0000-0002-8577-1095.

А. В. Усов
М. В. Куніцин
Ю. І. Зайчик

УПРАВЛІННЯ ЯКІСНИМИ ХАРАКТЕРИСТИКАМИ РОБОЧИХ ПОВЕРХОНЬ СКЛАДНО ПРОФІЛЬНИХ ВИРОБІВ ПРИ МЕХАНІЧНІЙ ОБРОБЦІ

Національний університет «Одеська політехніка»

У роботі розглядається модель температурного поля, яке формується в поверхневому шарі складно профільних виробів при обробці їх на фінішних операціях. Із застосуванням цих операцій пов'язана поява в поверхневому шарі виробів дефектів типу припіків, тріщин, розтягуючих напружень, що значно впливає на надійність і довговічність цих деталей, у процесі їх експлуатації. Ці дефекти, будучи локальними концентраторами напружень в експлуатаційних умовах призводять до передчасного виходу виробів із ладу, попри те, що навантаження на них формує напруження, величина яких не перевищує граничних значень. Модель будується на основі розв'язку початково-крайової задачі теплопровідності для виробу. Отримані на підставі моделі функціональні зв'язки технологічних параметрів із температурою шліфування відображають стан оброблених поверхонь для складно профільних виробів і дозволяють за допомогою відповідних прийомів усувати припіки на оброблюваних поверхнях. Дослідження умов підвищення якості оброблюваних поверхонь шляхом усунення дефектів типу тріщин і припіків проводилося в основному на рівні виявлення зв'язків температурних полів, що формуються, з технологічними параметрами, фізико-механічними властивостями шліфованих матеріалів і геометрією виробів. Встановлено, що при шліфуванні складно профільних виробів від більшого радіусу в напрямі до меншого, температура збільшувалася пропорційно куту нахилу оброблюваної поверхні. Адекватність побудованої моделі перевірялася на прикладі шліфування конічних виробів зі сталі, з відомими фізико-механічними характеристиками, вибором інструменту і призначенням режимів обробки. Аналіз результатів моделювання показує, що температура оброблюваної поверхні зростає по мірі наближення оброблюючого інструменту по конічній поверхні до меншого діаметру. Саме ця область оброблюваної поверхні конічних виробів найбільше схильна дефектоутворенню на фінішних операціях. Тому при призначенні режимів обробки таких поверхонь, їх слід призначати з умови, що при наближенні оброблюючого інструменту до частини конічної поверхні меншого діаметру температура, що формується на ній не повинна перевищувати допустимих значень, які забезпечують необхідну якість Аналіз результатів чисельних розрахунків температурних полів показали достатню точність за граничними умовами моделювання.

Ключові слова: складно профільні вироби, модель температурного поля .дефекти, якість поверхневого шару, фінішні операції, адекватність.

Усов Анатолій Васильович – д. т. н., професор, завідувач кафедри вищої математики та моделювання систем Національного університету «Одеська політехніка», e-mail: usov_a_v@op.edu.ua, ORCID: 0000-0002-3965-7611.

Куніцин Максим Володимирович – к. т. н., доцент кафедри інтегрованих технологій управління Національного університету «Одеська політехніка», e-mail: m.v.kunitsyn@op.edu.ua, ORCID: 0000-0003-1764-8922.

Зайчик Юрій Ігоревич – аспірант кафедри вищої математики та моделювання систем Національного університету «Одеська політехніка», e-mail: yuriy.zaichik@gmail.com, ORCID: 0000-0002-8577-1095.