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# NUMERICAL ANALYSIS OF INFLUENCE OF SURFACE GEOMETRICAL STRUCTURE PREPARED UNDER BURNISHING ROLLING ONTO THE STATE OF STRAINS AND STRESS IN PRODUCT SURFACE LAYER

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**Abstract**

In the paper an application enabling computer simulations in Ansys computer program was created. The variables in the calculation are: deviation of the height of triangular asperity after turning equal 0.01÷0.04 mm and its space deviation equal 0.05÷0.2 mm. Selected results of calculations are presented for C45 steel and triangular asperities with the vertical angle of 90°. One parametrical function of regression was elaborated. Results are shown in the form of table, graphs and figures.

**Key words**: surface preparation, burnishing rolling, outline deviation, numerical analysis

## 1. INTRODUCTION

In technological processes, in which as finishing off processing steps out the burnishing rolling, the object's quality depends both from conditions of realization of burnishing rolling process and from the state of the object. Burnishing rolling is one of the methods of finishing metal treatment. It consist in making use of local strain, which is generated in object's surface layer, under specified (forces and kinematics) co-operation of hard and smooth tool sphere, roller, shaft - shaped or another) with treat surface [1]. Burnishing elements are presented in figure 1.

One of the factors, which influence on the object's quality after burnishing rolling is the roughness of the surface.

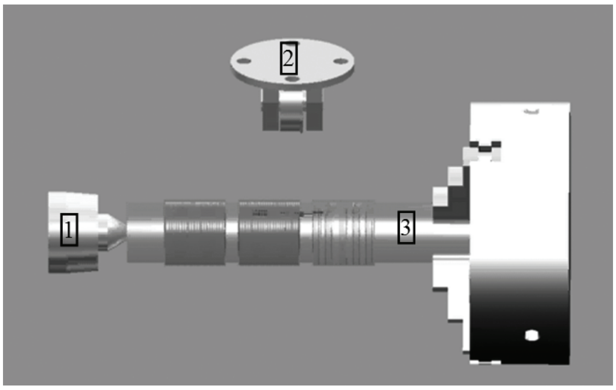


*Fig. 1. Burnishing elements: 1 – lathe chuck, 2 – burnishing roller, 3 – sample.*

Steering proprieties of surface layer shaped with burnishing rolling makes possible adaptation of the technological quality of article to diverse conditions of exploitation. It creates then possibility of wide


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utilization this method of processing in practice. From the qualitative analysis of changes of the outline of asperities after burnishing rolling with current and from the dependences quantitative on parameters of this outline, come the following steering possibilities:

a) distance of asperity's depressions - by the selection of the feed in previous treatment;
b) the height of asperity - by the selection of the previous treatments conditions, the outline of burnishing element and the depth of burnishing;
c) the shape of asperity's depressions:
   - the curve of the bottom of depressions - by the selection of tool's curve ray of the circuit surface in previous treatment,
   - the bearings of point $C_{k,l}$, by the selection of the previous treatment's conditions, the element's outline and the depth of burnishing;
d) the outline and profile of roughness of asperities bear part -by the selection of outline and roughness profile of the active surface of burnishing element [2, 3].

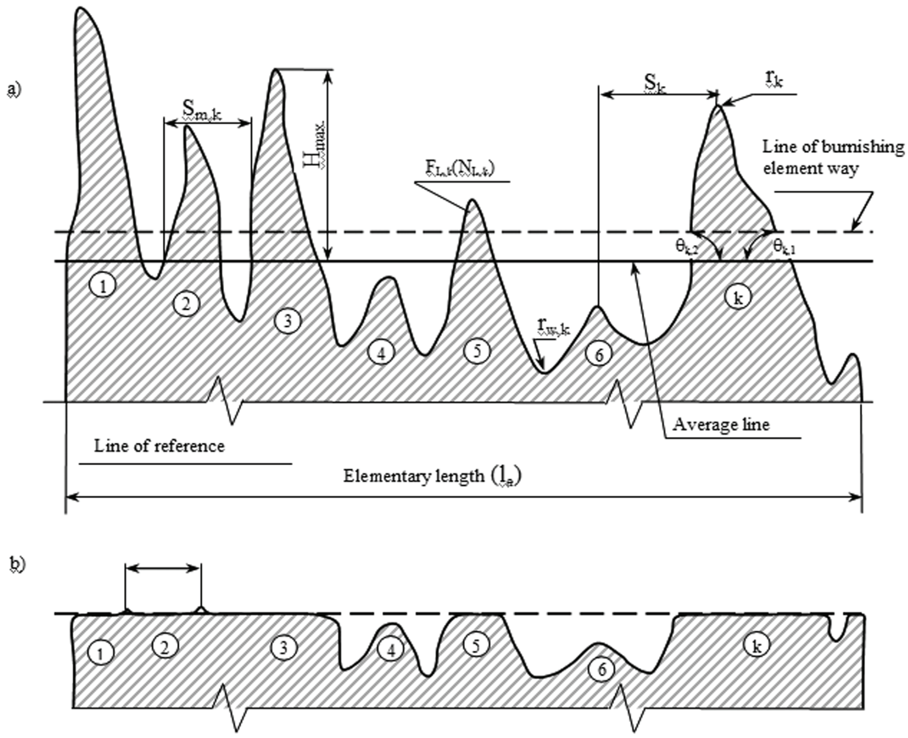


*Fig. 2. Stochastic roughness profile after turning (a) and after burnishing (b) [3].*

The possibility of steering of asperity's outline passed higher was experimentally confirmed.

The technological quality of the burnishing product, in fact, depends upon the quality of a semi-finished product after turning processing. On the surface layer after burnishing rolling ($SL2$) deciding influence has surface layer after previous treatment ($SL1$). The stochastic outline of surface in previous treatment decides that after burnishing rolling it is also stochastic. The regular outline of surface in previous treatment decides that after burnishing it is also regular. The stochastic roughness profile after previous treatment in figure 2a is presented and after burnishing rolling in figure 2b.

The best results of burnishing rolling are received when the surface after previous treatment possesses determined, periodical profile of roughness about triangular outline. Regular roughness profiles after turning and after burnishing in figure 3 are presented.

Numerical analysis of state of strains and stress in surface layer of rough surface after burnishing rolling is presented in this work. It is supposed that surface after previous treatment possesses determined, periodical profile of roughness about triangular outline [4]. The real surface's profile shaped in technological processes shows deviations of asperity's height. Therefore it is important to qualify the dependence between height's deviation of asperity prepared for burnishing rolling and state of strains and stress in shaped burnished surface layer. For this purpose, an application enabling computer simulations was created in Ansys computer program. The variables in the calculation are: deviation of the height of triangular asperity after turning $\Delta h_t$ = 0.01÷0.04 mm, its space deviation $\Delta s$ = 0.05÷0.2 mm. Exemplary calculations were presented for C45 steel and triangular asperities with the vertical angle of $\theta = 90°$. One parametrical functions of regression were elaborated. Results are shown in table, graphs and figures.

## 2. COMPUTER SIMULATION

A numerical analysis covered regular irregularities which differ in the deviation of height and space, for apex angle $\theta = 90°$. Definitions of height deviations and the space of irregularities after rolling and after burnishing are presented in figure 4.

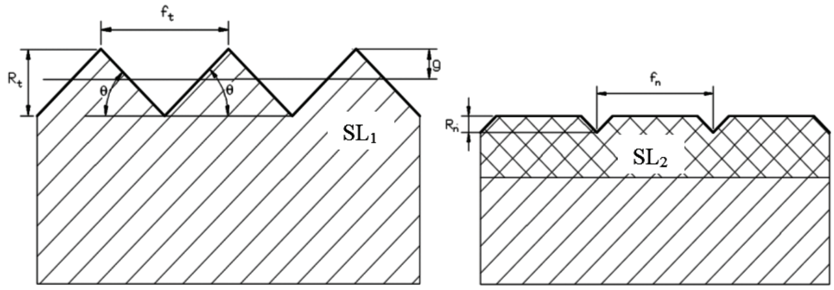


***Fig. 3.*** *Regular roughness profile after turning (a) and after burnishing (b).*

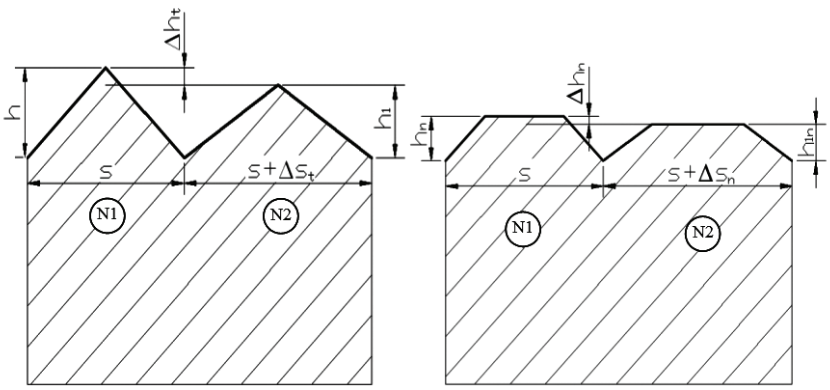


***Fig. 4.*** *Definitions of height deviations and the space of irregularities after rolling and after burnishing.*

In the analyses conducted, flat models were used, with the assumption that the burnishing tool is ideally rigid. C45 steel was the material used for the purpose of the analyses. An important issue is to obtain, after burnishing, a surface with a very good surface finish. An application in APDL language was developed, which was used for computer simulations in ANSYS programme. It is possible to divide the object into finite elements with free or regular shapes. It is also possible to give various initial and boundary conditions. There is also a possibility to concentrate the grid of finite elements in the area where strong non-linearity occurs [5]. An analysis of the influence of the deviations of irregularities after rolling on the deviation of the height of asperities was conducted in two steps. The first step concerns the interaction of the tool, while the second one concerns the shift of the punch.

In figure 5a maximum intensity of stresses with the interaction of tool and 5b after shift of the punch are presented. Results for $\Delta h_t$ = 0.01 mm and $\Delta s_t$ = 0.05 mm are presented.

In figure 6a maximum intensity of strains with the interaction of tool and 6b after shift of the punch are presented. Results for $\Delta h_t$ = 0.01 mm and $\Delta s_t$ = 0.05 mm are presented.

## 3. THEORETICAL ANALYSIS

The process of pressure rolling burnishing was considered as a geometrical and physical boundary and initial value problem, with unknown boundary conditions in the contact area. An updated Lagrange's description was used for the description of non-linear phenomena on a typical incremental step. The increments of strains and stresses were described respectively with an increment of a non-linear strain tensor of Green – Lagrange and an increment of the second symmetric stress tensor of Pioli – Kirchhoff. For the purpose of a variational formulation of the incremental equation of the object's movement for the case of stress rolling burnishing, a functional was introduced, in which there occurs only one independent field, namely the field of an increment of displacements. Moreover, it was accepted that compatibility equations are satisfied and the initial and boundary conditions are fulfilled. Such assumptions lead to the so-called compatible model for the problems of non-linear dynamics, which is expressed in the increments of displacements [6].

While writing particular equations of motion for all the finite elements separated from the tool and the object, after their expansion and totalising, after all the finite elements of the object, an equation of motion of the object's deformation in the burnishing process is obtained. While not resigning from the general nature of the discussion, it was accepted that the burnishing process of the rotating section is described. A general equation of the object's motion has then the following form:

$$[{}^t_t\mathbf{M}]\{{}^\tau_t\Delta\ddot{\mathbf{r}}\}+[{}^t_t\mathbf{C}_T(\cdot)]\{{}^\tau_t\Delta\dot{\mathbf{r}}\}+\left([{}^t_t\mathbf{K}_T(\cdot)]+[{}^\tau_t\Delta\mathbf{K}_T(\cdot)]\right)\{{}^\tau_t\Delta\mathbf{r}\}=$$
$$\{{}^\tau_t\Delta\mathbf{R}_T(\cdot)\}+\{{}^\tau_t\Delta\mathbf{F}(\cdot)\}+\{{}^t_t\mathbf{F}_T(\cdot)\} \qquad (1)$$

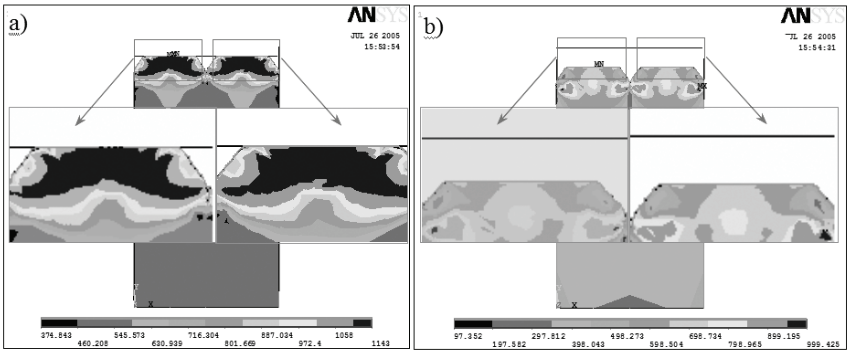

*Fig. 5. Maximum stress intensity: interaction of tool (a) and after shift of the punch (b).*

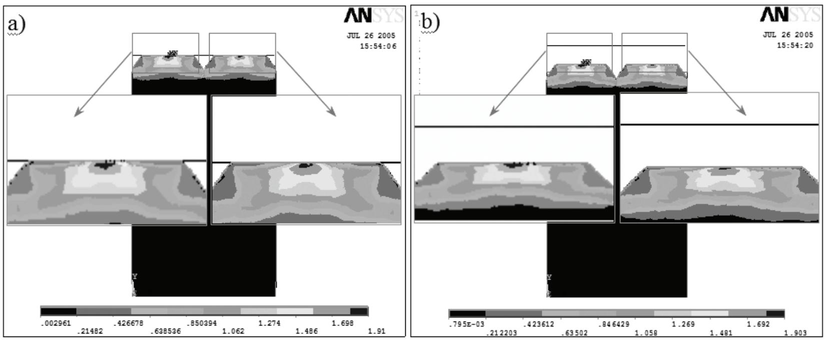

*Fig. 6. Maximum strain intensity: interaction of tool (a) and after shift of the punch (b).*

where: $[{}^{t}_{t}\mathbf{M}]$ - global matrix of the mass of the system in moment *t*, $[{}^{t}_{t}\mathbf{C}_{T}]$ - global matrix of the damping of the system in moment *t*, $[{}^{t}_{t}\mathbf{K}_{T}]$ - global matrix of the rigidity of the system in moment *t*, $[{}^{\tau}_{t}\Delta\mathbf{K}_{T}]$ - global matrix of an increment of the object's rigidity on a step, $\{{}^{t}_{t}\mathbf{F}_{T}\}$ - global vector of the object's internal loads in moment *t*, $\{{}^{\tau}_{t}\Delta\mathbf{F}\}$ - vector of an increment of the object's internal loads, $\{{}^{\tau}_{t}\Delta\mathbf{R}_{T}\}$ - global vector of an increment of the object's internal loads, $\{{}^{\tau}_{t}\Delta\mathbf{r}\}$ - vector of an increment of the displacements of the object's nodes, $\{{}^{\tau}_{t}\Delta\dot{\mathbf{r}}\}$ - vector of an increment of the velocity of the object's nodes, $\{{}^{\tau}_{t}\Delta\ddot{\mathbf{r}}\}$ - vector of an increment of the accelerations of the object's nodes.

The system of equations (1) includes *N* equations, where there are 4*N* unknowns, i.e. components of the following vectors: an increment of the nodes' displacements $\{{}^{\tau}_{t}\Delta\mathbf{r}\}$, an increment of the nodes' velocities $\{{}^{\tau}_{t}\Delta\dot{\mathbf{r}}\}$, an increment of the nodes' accelerations $\{{}^{\tau}_{t}\Delta\ddot{\mathbf{r}}\}$, an increment of the object's internal loads $\{{}^{\tau}_{t}\Delta\mathbf{F}\}$ and $N^2$ unknown elements of the matrix of the increment of the object's rigidity $[{}^{\tau}_{t}\Delta\mathbf{K}_{T}]$. It is further assumed that the elements of vector $\{{}^{\tau}_{t}\Delta\mathbf{F}\}$ and of matrix $[{}^{\tau}_{t}\Delta\mathbf{K}_{T}]$ are known from the previous iteration. Therefore, the system of equations includes 3*N* unknowns. An analytical solution of this equation is not possible due to an excessive amount of unknowns. Only an approximate solution is possible through a reduction of the number of variables occurring in it. From among the basic approaches applied for an approximate solution of these equations, a group of approximation methods is to be distinguished, known as the methods of a direct integration [6-9], for example Newmark or Wilson's methods.

## 4. RESULTS

Received results allowed make graphs of the dependence of height deviation after burnishing from percent of asperity burnishing. Exemplary results, for $\Delta h_t = 0.02$ mm and $\Delta s_t = 0$ mm and $\Delta s_t = 0.1$ mm and $\Delta h_t = 0$ mm are presented in figure 7. In table 1 values of burnishing depth, percent of asperity burnishing, space deviation and height deviation are presented.

Results of computer simulation allow to elaborate one parametrical function $\sigma_i = \mathrm{f}_1(\Delta h_t)$, for $\Delta s_t = 0$:

– for $a = 0.06$ mm:

$$\sigma_i = -101450\Delta h_t^2 + 666.7\Delta h_t + 764.56, \qquad R = 0.9977, \tag{2}$$

– for $a = 0.2137$ mm:

$$\sigma_i = -10025\Delta h_t^2 - 1538.2\Delta h_t + 997.41, \qquad R = 0.992, \tag{3}$$

– for $a = 0.3674$ mm:

$$\sigma_n = 3850\Delta h_t^2 - 2130.3\Delta h_t + 1009, \qquad R = 0.999, \tag{4}$$

– for $a = 0.5211$ mm:

$$\sigma_i = -11175\Delta h_t^2 - 1251.6\Delta h_t + 1006.8, \qquad R = 0.9944, \tag{5}$$

– for $a$ = 0.675 mm:

$$\sigma_i = 1222.5\Delta h_t^2 - 985.85\Delta h_t + 1008.5, \qquad R = 0.999, \tag{6}$$

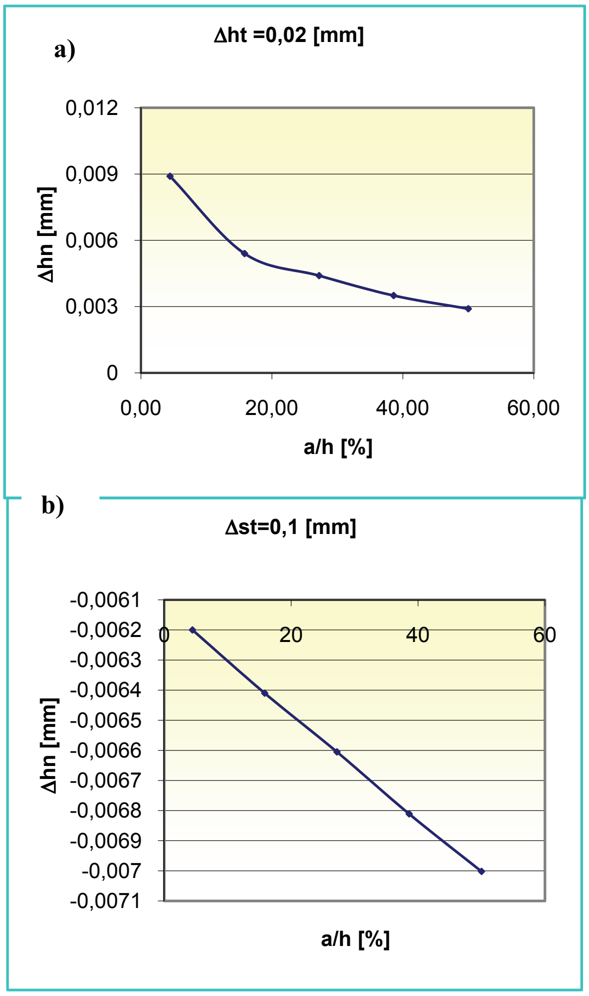


***Fig.** 7. Dependence of height deviation after burnishing from percent of asperity burnishing: $\Delta h_t = 0.02$ (a) and $\Delta s_t = 0.1$ (b).*

***Table 1.** Values of input factors.*

| No | Depth of burnishing | % of asperity burnishing | $\Delta s_t$, mm | $\Delta h_t$, mm |
|---|---|---|---|---|
| 1 | 0,06 | 4,44 | 0 | 0 |
| 2 | 0,2137 | 15,83 | 0,05 | 0,01 |
| 3 | 0,3674 | 27,215 | 0,1 | 0,02 |
| 4 | 0,5211 | 38,6 | 0,15 | 0,03 |
| 5 | 0,675 | 50 | 0,2 | 0,04 |

One receives also $\varepsilon_i = f_2(\Delta h_t)$, for $\Delta s_t = 0$:

– for $a$ = 0.06 mm:

$$\varepsilon_i = -37.5\Delta h_t^2 - 0.975\Delta h_t + 0.254, \qquad R = 0.9997, \tag{7}$$

– for $a$ = 0.2137 mm:

$$\varepsilon_i = 14.8\Delta h_t^2 - 1.429\Delta h_t + 0.9621, \qquad R = 0.9987, \tag{8}$$

– for $a$ = 0.3674 mm:

$$\varepsilon_i = 8.75\Delta h_t^2 - 2.446\Delta s_t + 1.135, \qquad R = 0.9568, \tag{9}$$

– for $a$ = 0.5211 mm:

$$\varepsilon_i = -37.25\Delta h_t^2 + 1.067\Delta h_t + 1.126, \qquad R = 0.9984, \tag{10}$$

– for $a$ = 0.675 mm;

$$\varepsilon_i = -21\Delta h_t^2 - 1.22\Delta h_t + 1.968, \qquad R = 0.9945, \tag{11}$$

Results of computer simulation allow to elaborate one parametrical function $\sigma_i = f_1(\Delta s_t)$, for $\Delta h_t = 0$:

– for $a$ = 0.2137 mm:

$$\sigma_i = 468\Delta s_t^2 - 23.448\Delta s_t + 937.07, \qquad R = 0.9994, \tag{12}$$

– for $a$ =0.3674 mm:

$$\sigma_n = 22.8\Delta s_t^2 + 84.208\Delta s_t + 954.58, \qquad R = 0.9924, \tag{13}$$

– for $a$ = 0.5211 mm:

$$\sigma_i = 236.6\Delta s_t^2 + 42.39\Delta s_t + 973.31, \qquad R = 0.997, \tag{14}$$

– for $a$ = 0.675 mm:

$$\sigma_i = 1050\Delta s_t^2 - 9.7\Delta s_t + 999.77, \qquad R = 0.9983, \tag{15}$$

One receives also $\varepsilon_i = f_2(\Delta h_t)$, for $\Delta s_t = 0$:

– for $a$ = 0.2137 mm:

$$\varepsilon_i = 2.046\Delta s_t^2 - 0.451\Delta s_t + 0.9478, \qquad R = 0.692, \tag{16}$$

– for $a$ = 0.3674 mm:

$$\varepsilon_i = 3.105\Delta s_t^2 - 0.498\Delta s_t + 1.082, \qquad R = 0.928, \tag{17}$$

– for $a$ = 0.5211 mm:

$$\varepsilon_i = 2.28\Delta s_t^2 - 0.364\Delta s_t + 1.134, \qquad R = 0.934, \tag{18}$$

– for $a$ = 0.675 mm;

$$\varepsilon_i = -0.6\Delta s_t^2 + 1.122\Delta s_t + 1.76, \qquad R = 0.936, \tag{19}$$

## 5. CONCLUSIONS

Results of numerical analyses show that there is a possibility to execute properly analyses of surface layer deformation in treatment zone during burnishing rolling and forecasting technological quality of product with asperities outline deviation after turning [5].

The deviations of the height and space of the roughness after rolling have a significant impact on the stress and strains intensity after burnishing.

Numerical algorithms can be used for an assessment of the influence of the deviations of height and the space of asperities of the product burnished. They facilitate a better understanding of the phenomena which occur in the zones of contact and strains, and therefore can constitute the basis for the development of guidelines for the selection of the conditions of rolling and burnishing processes considering the required technological quality of the product.

The developed functions of the regression of the dependences of the intensity of stresses ($\sigma_i$), and the intensity of strains ($\varepsilon_i$) of the surface layer after burnishing from the deviations of the outline ($\Delta h_t$ and $\Delta s_t$) of asperities after rolling for the apex angles of asperities $\theta$ = 90°, make possible to determine the maximum permissible deviations of the height and space of asperities after rolling and of the permissible deviations of the intensity of stresses and the intensity of strains of the surface layer after burnishing.

## ACKNOWLEDGEMENTS

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## ANALIZA NUMERYCZNA WPŁYWU STRUKTURY GEOMETRYCZNEJ POWIERZCHNI PRZYGOTOWANEJ POD NAGNIATANIE NAPOROWO TOCZNE NA STANY ODKSZTAŁCEŃ I NAPRĘŻEŃ W WARSTWIE WIERZCHNIEJ PRODUKTU

Streszczenie

W pracy przedstawiono opracowaną w systemie komputerowym Ansys aplikację wykorzystywaną do symulacji procesu nagniatania naporowego tocznego. Zmiennymi w obliczeniach są odchyłka wysokości trójkątnych nierówności powierzchni po toczeniu w zakresie 0.01÷0.04 mm oraz odchyłka odstępu w zakresie 0.05÷0.2 mm. Przykładowe obliczenia przedstawiono dla stali 45 i trójkątnych nierówności o kącie wierzchołkowym 90°. Opracowano jednoparametryczne funkcje regresji odkształceń i naprężeń. Wyniki przedstawiono w postaci tabeli, wykresów i zdjęć.

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