VERSITA
ADVANCES IN MANUFACTURING SCIENCE AND TECHNOLOGY Vol. 37, No. 4, 2013
DOI: 10.2478/amst-2013-0028

MODELING AND SIMULATION OF OSCILLATORY SHOT PEENING PROCESS

Bartłomiej Frydel, Stanisław Płonka, Piotr Zyzak

Summary

The paper discusses issue of selection of oscillatory shot peening parameters in terms of layout of microgrooves and surface coverage by the microgrooves. There are presented results of modeling and simulation of such method of burnishing, aimed at optimization of processing parameters. Computer program developed on the base of calculation algorithms for relevant parameters of the oscillatory shot peening should simulate conditions of real processing, creating possibilities to change of virtual machine tool parameters, comparing intentional effect of the processing with the one obtained in practice. Thanks to this, in a relatively short period of time it is possible to make selection of optimal parameters of the oscillatory shot peening with respect to surface covered by the Sr microgrooves in such type of microgrooves system.

Keywords: oscillatory shot peening, microgrooves, modeling and simulation

Modelowanie i symulacja procesu kulkowania oscylacyjnego

Streszczenie

W pracy przedstawiono zagadnienie doboru warunków procesu kulkowania oscylacyjnego z uwzględ-nieniem kryteriów układu mikrorowków oraz powierzchni pokrycia mikrorowkami. Przedstawiono wyniki modelowania i symulacji tego sposobu nagniatania, w celu optymalizacji parametrów obróbki. Na podstawie algorytmu obliczania odpowiednich korelacji parametrów kulkowania oscylacyjnego opracowano program, który odtwarza warunki rzeczywistej obróbki, poprzez zmiany wartości parametrów wirtualnej obrabiarki. Porównano zamierzony efekt obróbki z uzyskanym w praktyce. Umożliwia to w krótkim czasie dobór optymalnych warunków procesu nagniatania oscylacyjnego, przyjmując jako kryterium rozmiar powierzchni pokrytej mikrorowkami Sr, w tym układ mikrorowków.

Słowa kluczowe: kulkowanie oscylacyjne, mikrorowki, modelowanie i symulacja

1. Introduction

Burnishing operation belongs to one from methods of finishing treatment of metals. The treatment consists in making use of local plastic deformations generated in surface layer of a workpice in result of pre-determined contact interaction of a hard and smooth tool (generally having shape of a ball, disc or

Address: Bartłomiej FRYDEL, MSc Eng; Stanisław PŁONKA, D.Sc., Eng., Professor; Piotr ZYZAK, PhD Eng., University of Bielsko-Biała, Department of Manufacturing Technology and Automation, 43-309 Bielsko-Biała, Willowa 2, Poland, phone: (0-48, 33) 82 79 213, fax: (0-48, 33) 82 79 300, e-mail: splonka@ath.bielsko.pl,

roller) with machined surface [1]. Actually, one develops a series of kinematics solutions of machining systems and tools to the burnishing. Methods of the burnishing can be divided, when analyzing e.g. character of the forces acting during the burnishing, into two main groups, differing from each other with mechanics of the machining process: i.e. static and dynamic. [1-3].

To the first group belong such methods like, among others: roller finishing, normal shot peening, finishing with oscillating roller, and oscillatory shot peening [1-3].

The oscillatory shot peening consists in additional forcing of oscillation movement of the ball in direction of feed motion, what results in generation of sinusoidal traces (grooves) on machined surface [1-3].

The present study is continuation of the work included in the [4], while developed program, written in universal C# language enables, except microgrooves of the 1st, 2nd and 3rd type, additional modeling of quadrangle and hexagonal microgrooves.

2. Mechanism of the oscillatory shot peening process

In the process of the oscillatory shot peening, hard and smooth ball, oscillating in plane of the lengthwise feed under specified thrust, displaces together with feed of the burnishing, causing plastic formation of a continuous groove on machined surface [1-3, 5]. Kinematics of the oscillatory shot peening is presented in the Fig. 1. System of after-machining traces on the surface results from superimposition of three basic movements:

- oscillatory movement of the burnishing element (ball) in plane of the feed,
- rotational movement of the workpiece,
- feed movement of the burnishing element with respect to the workpiece.

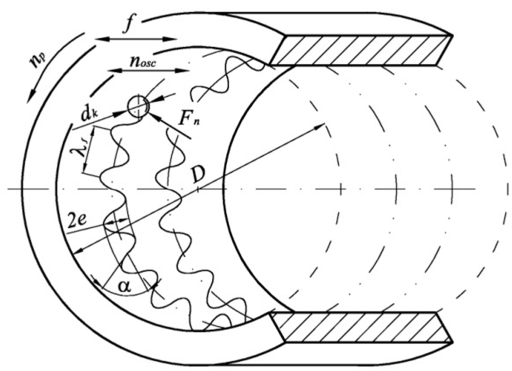

Fig. 1. Kinematics of the oscillatory shot peening of the holes [4, 6]

By changing values of individual movements, especially feed and rotational one, it is possible to generate various systems of the microgrooves on machined surface, and also totally new micro-geometry of surface irregularities in case of superimposition of after-machining traces. Basic types of the after-machining traces are shown in the Fig. 2 [1, 3, 4, 6,].

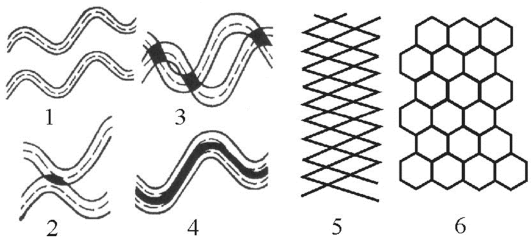

Fig. 2. Types of the after-machining traces on machined surface. 1st type – not intersecting; 2nd type – being in contact; 3rd type – intersection; 4th type – superimposed; 5th type – quadrilateral; 6th type – hexagonal [1, 3, 7]

Number of the microgrooves and their systems on machined surface can be changed during the oscillatory burnishing by change of the following kinetic parameters of the machining:

- oscillation frequency of the burnishing element n_{osc} (number of dual travels per second),
- number of rotations of the workpiece *n*,
- feed of the burnishing *f*,
- oscillation amplitude of the burnishing element e.

Mutual position of the microgrooves in circumferential direction of the workpiece is determined by the number i of the oscillations per single rotation of the workpiece.

$$i = \frac{n_{osc}}{n} \qquad (1)$$

This number shows how many times the wavelength λ of a microgroove is measured on circumference of the workpiece. Fractional part of the quotient $\{ i \}$ shows value of displacement of the microgrooves on machined surface with respect to each other, at each next rotation of the workpiece.

The wavelength λ of the microgrooves is described by the following dependency:

$$\lambda = \pi \cdot \frac{D}{i} \tag{2}$$

where: D – diameter of the workpiece.

To perform correct operation of the oscillatory shot peening it is necessary to select rotational speed of the workpiece *n*, feed of the burnishing element *f*, oscillation frequency of the burnishing element n_{osc}, oscillation amplitude *e* and width of microgroove ρ, which mutual correlation decides on type of the microgroove system, relative coverage of the surface S_r and other characteristic features of the microgrooves [1, 4].

Condition of generation of the 1st type microgrooves (not intersecting traces) is the following dependency:

$$f > 2 \cdot \rho + 2 \cdot e \cdot \sin\left(\pi \cdot \{i\}\right) \tag{3}$$

where: ρ – half-width of the microgroove, i – ratio of oscillation frequency of the burnishing element to number of rotations of the workpiece, $\{i\}$ – fractional part of the number i.

Condition of generation of the 2nd type system of the microgrooves (traces being in contact) is the following dependency:

$$2 \cdot \rho - 2 \cdot e \cdot \sin(\pi \cdot \{i\}) < f < 2 \cdot \rho + 2 \cdot e \cdot \sin(\pi \cdot \{i\}) \tag{4}$$

from the (4) comes that:

$$f > 2 \cdot e \cdot \sin(\pi \cdot \{i\}) \tag{5}$$

Whereas, condition of generation of the 3rd type microgrooves system (intersecting traces) is:

$$0 < f < 2 \cdot e \cdot \sin(\pi \cdot \{i\}) \tag{6}$$

$$f > 2 \cdot \rho - 2 \cdot e \cdot \sin(\pi \cdot \{i\}) \tag{7}$$

Surface with totally new micro-geometry of irregularities is generated when the following condition is fulfilled:

$$f < 2 \cdot \rho \cdot \left(1 - \{i\}\right) \tag{8}$$

Conditions of generation of different types of microgroove system are as follows [1-3]:

• radius of the burnishing element is considerably smaller than radius of the workpiece,

• oscillations amplitude of the burnishing element is equal to value of circular cam of the device,

• run of embossed microgrooves, creating regular system has shape of sinusoid having equation:

$$Y_n = e \cdot \sin \cdot \left(\frac{2 \cdot \pi \cdot t}{T_{osc}} + 2 \cdot \pi \cdot n \cdot \{i\} \right) + f \cdot n \tag{9}$$

where: $T_{sc}-$ oscillations period of the burnishing element.

On the base of the (1) and (2), the wavelength is determined by the dependency:

$$\lambda = \frac{\pi \cdot D \cdot n}{n_{osc}} \tag{10}$$

where: $D-$ diameter of hole of the workpiece,

Surface area S of the microgroove produced during one period T_{osc} of oscillatory movement of the ball is determined with use of the following equation:

$$S = \frac{2 \cdot \pi \cdot \rho}{3 \cdot i} (2 \cdot D + \sqrt{D^2 + 4 \cdot e^2 \cdot i^2}) \tag{11}$$

Marking by L, the length measured along generator of the surface from the oscillatory shot peening, it is possible to evaluate surface of the workpiece S_r covered by the microgrooves over the entire L :

$$S_r = \frac{i \cdot L \cdot S}{f} \tag{12}$$

From many mathematical models used to calculation of the S_r, the Feldman model, based on the following assumptions, gained the widest application [1]:

- burrs with height h_n located at the edge of the of the microgroove are not taken into considerations, while the depth h of channels is assumed as constant for a given process of the oscillatory shot peening,
- shape and dimensional deformations of the microgrooves, connected with elastic strain of machined material h_{spr} are assumed as insignificantly small,
- half-width of the microgroove (Fig. 3), is calculated from the formula [1]:

$$\rho = \sqrt{d_k \cdot h} \tag{13}$$

where: d_k – diameter of the burnishing ball, h – depth of imprint of the ball (microgroove).

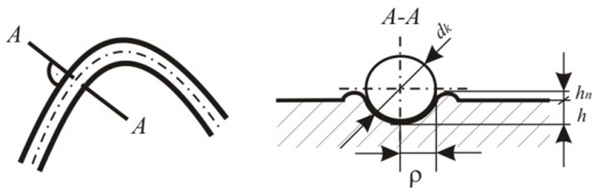

Fig. 3. Section through the imprint of the burnishing element (ball)

For the microgrooves of the 1st type, the surface is expressed as:

$$S_r = \frac{i \cdot S}{\pi \cdot D \cdot f} \cdot 100\% \tag{14}$$

The dependencies (13) and (14) are true only in case of microgrooves of the 1st type, i.e. not intersecting each other microgrooves. In case of the traces being in contact or intersecting each other, from the calculated surface S one should subtract the surface of contacts, or surface of intersections (S_1 and S_2 respectively).

For the microgrooves of the 2nd type, the coverage surface S_r:

$$S_r = \frac{i \cdot (S - S_1)}{\pi \cdot D \cdot f} \cdot 100\% \tag{15}$$

where surface of the contacts:

$$S_1 = \frac{16 \cdot \pi \cdot D \cdot e \cdot G^3}{3 \cdot i} \cdot 100\% \tag{16}$$

value G in the dependency (16) is calculated from the formula:

$$G = \sqrt{\{i\} - \{i\}^2 + \frac{2 \cdot \rho - f}{8 \cdot e}} \tag{17}$$

While, for the system of microgrooves of the 3rd type, the coverage area S_r :

$$S_r = \frac{i \cdot (S - S_2)}{\pi \cdot D \cdot f} \cdot 100\% \tag{18}$$

where:

$$S_2 = \frac{4 \cdot \rho^2 \cdot i \cdot (\frac{D^2}{e^2} + e^2 - f^2)}{D \cdot \sqrt{e^2 - f^2}} \tag{19}$$

For kinetic model of microgroove's generation it is possible to specify equations for calculation of the microgroove's surface in form of [6]:

- for system of microgrooves of the 1st type:

$$S = v_k \cdot \frac{60}{n_{osc}} \cdot \rho \tag{20}$$

where: v_k − peripheral speed of the ball,

hence:

$$S_r = \frac{v_k \cdot 60 \cdot \rho}{n \cdot \pi \cdot D \cdot f} \cdot 100\% \tag{21}$$

- for system of the microgrooves of the 2nd type:

$$S = \frac{\lambda \cdot \rho}{\cos\alpha} - \rho \cdot \frac{2 \cdot e - f}{\sin\alpha} \tag{22}$$

- for system of microgrooves of the 3rd type:

$$S = \frac{\lambda \cdot \rho}{\cos\alpha} - \frac{2 \cdot \rho^2}{\sin\gamma \cdot \cos\alpha} \tag{23}$$

Size of the mesh’s angle can be calculated with some approximation from the dependency:

$$tg\alpha = \frac{2 \cdot e \cdot n_{osc}}{n \cdot D} \tag{24}$$

3. Application to simulation of the oscillatory shot peening process

To select optimal parameters of the oscillatory shot peening one developed application program written in C# language. Choice of this programming language was dictated by its advantages such as: object oriented programming, string–orientated langue, memory garbage collection, reloading of operators and hardware interchangeability. The disadvantages of this technology are generally a moderate capacity, lacking direct access to the hardware and need of installed .NET Framework environment. It has been confirmed, however, that this language is the best suited to implementation of design application. To create the solution one selected the Visual C# 2008 Express Edition packet, being a free system to construct application in C# language [8, 9]. To calculate conditions of the generation and parameters of the microgrooves, in the calculation application one made use of the equations (1)÷(24).

Functionality of the developed application is characterized by:

- simple input method of preset calculation parameters,
- possibility of selection of a suitable correlations, enabling obtainment with high accuracy of assumed degree of surface coverage by the microgrooves,
- visualization of the calculations,
- smoothness and speed of processing, with required accuracy of the calculations,
- text and graphic presentation of obtained results,
- print-out of results and diagrams,
- writing to file of obtained results and diagrams,

• presence of the module with theoretical knowledge from area of oscillatory shot peening and „help" file,

• compatibility with various versions of Windows operating system.

Selection algorithm of optimal parameters of the oscillatory shot peening is shown in the Fig. 4.

The calculation application developed on the basis of the algorithm presented above comprises transparent panel to data input, display of the data obtained in process of selection of optimal parameters for the oscillatory shot peening, and presentation of obtained degree of surface coverage by the microgrooves.

On the base of presented algorithm, after input of predetermined initial data and performed calculations, the program searches for the optimal solution. In result of the calculations, the program finds suitable correlation of the feed rate, rotations of the workpiece and frequency of the oscillations, resulting in final

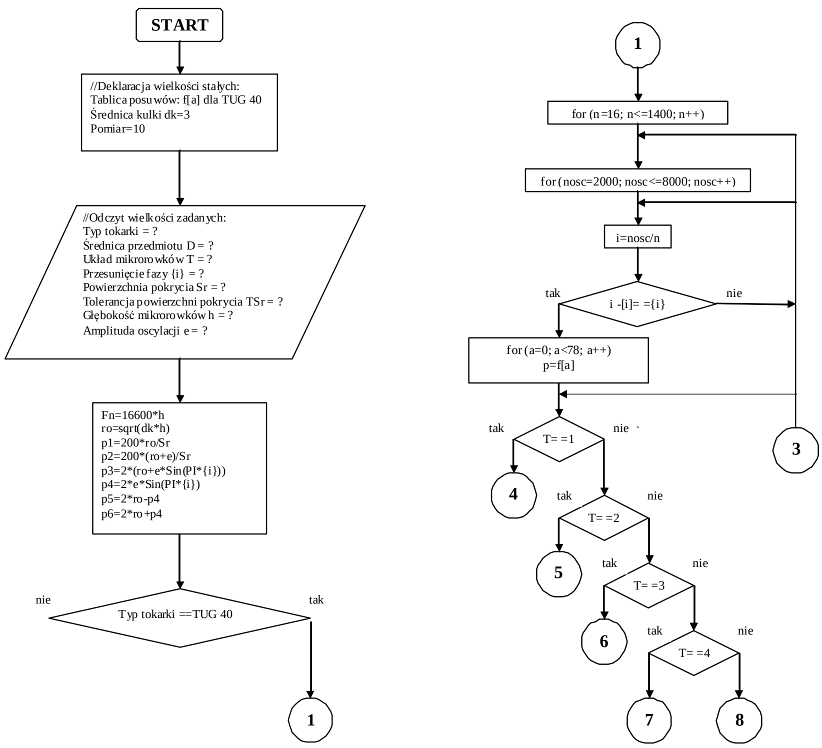

Fig. 4. Algorithm of calculation of suitable correlations of parameters of the oscillatory shot peening [9]

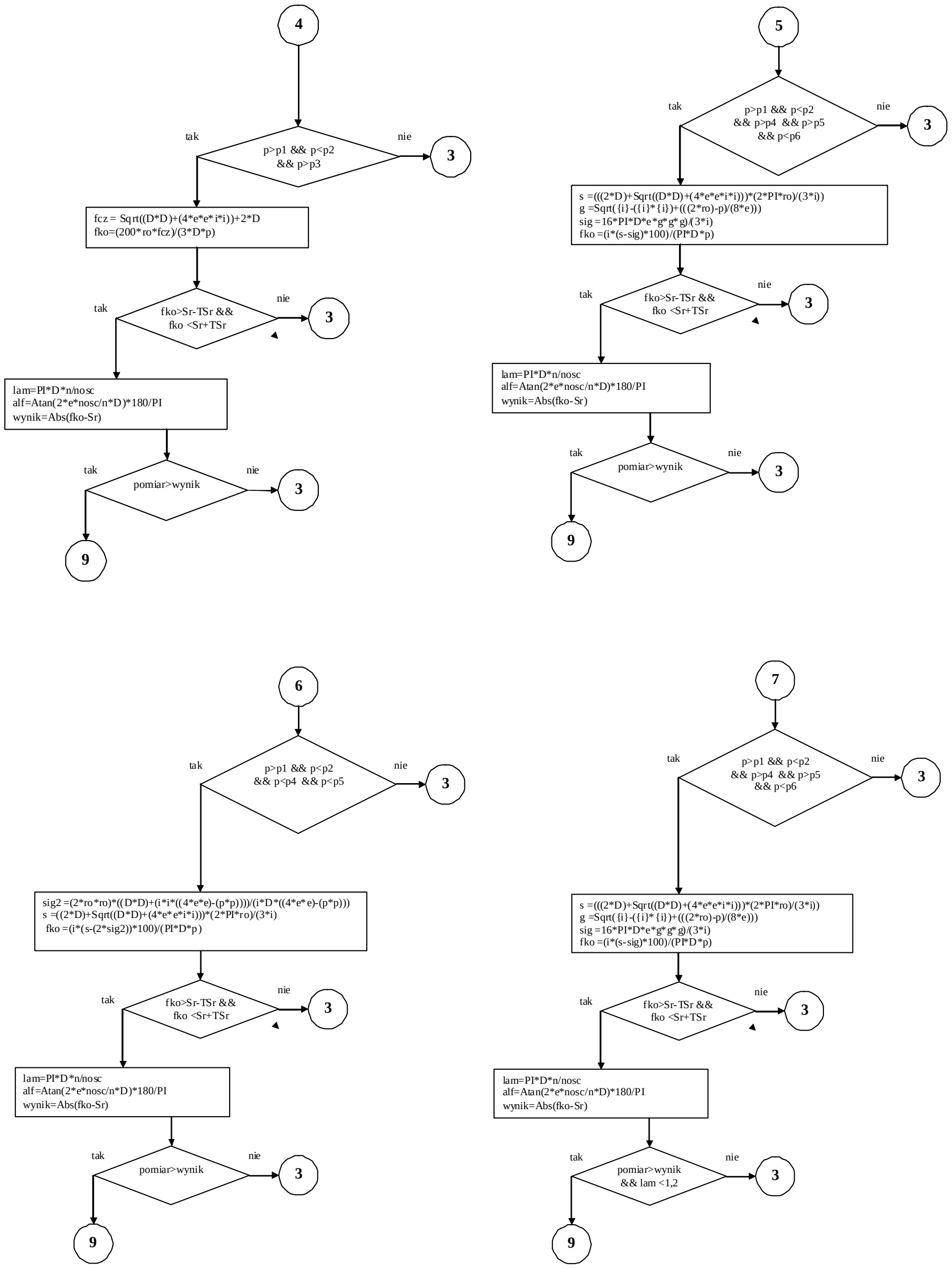

Fig. 4. (contd) Algorithm of calculation of suitable correlations of parameters of the oscillatory shot peening [9]

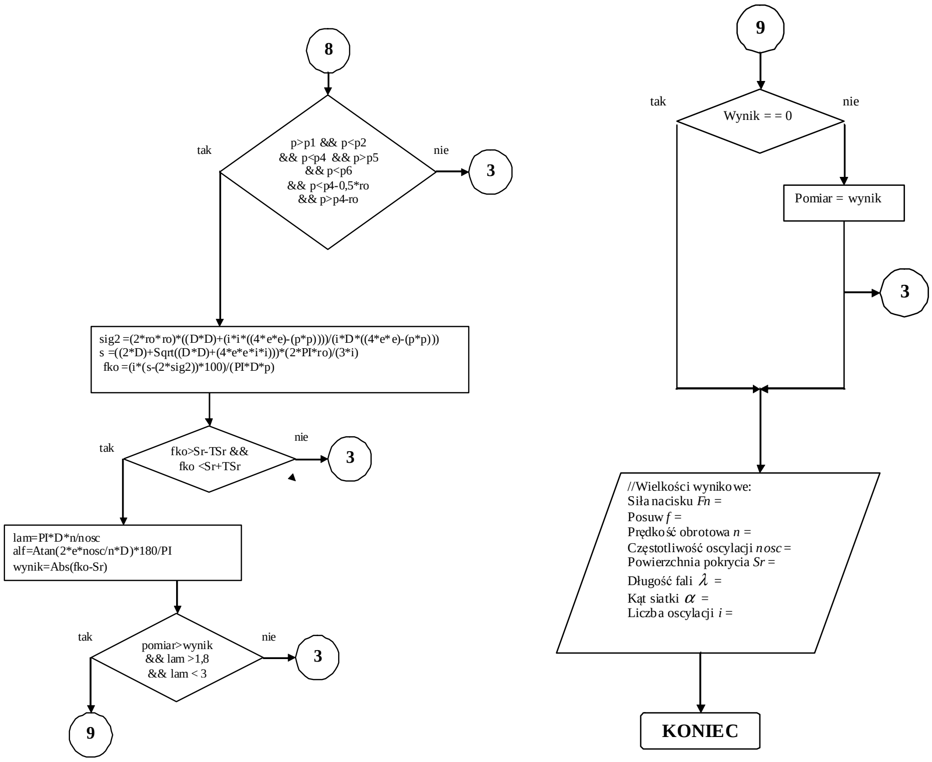

Fig. 4. (contd) Algorithm of calculation of suitable correlations of parameters of the oscillatory shot peening [9]

degree of surface coverage included within allowable interval. On the RH side in the window of the calculation application are displayed results, to which the user can attach diagram of the microgrooves. Necessary condition to display the diagram is presence of calculation results. In case when the program can not find any results for the input data and preset coverage area, on the screen is displayed suitable information. In the Fig. 5 and 6 are presented windows of the program comprising exemplary input parameters, results of the calculations, and diagrams with five types of the microgrooves.

A system of the microgrooves of the 2nd type (being in contact) was taken as a starting point to generation of the mesh with system of quadrilateral and hexagonal microgrooves. It has been noticed, that for some values of the wavelength of the microgroove (smaller than 1.2 mm), it is possible to obtain very small fillets of the runs. Therefore, it is possible to obtain a system of quadrilateral microgrooves.

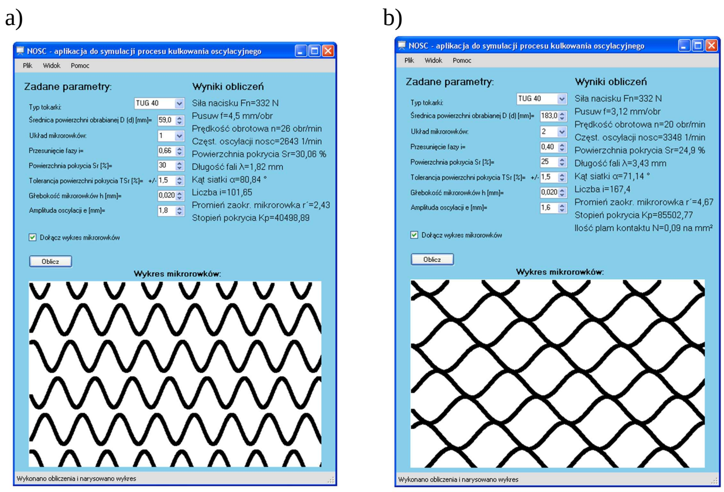

Fig. 5. Results of the calculations and diagram of the microgrooves:
a) 1st type, b) 2nd type

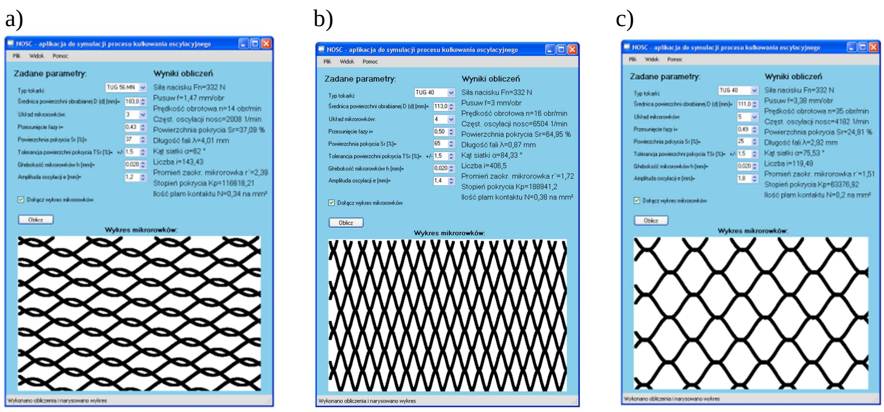

Fig. 6. Results of the calculations and diagram of microgrooves: a) 3 rd type,
b) rhomboidal, c) hexagonal

In case of the hexagonal microgrooves, one took advantage of conditions to generation of the intersecting microgrooves. Owing to fixed range of the intersection (from 0.5 to 1 radius of the microgroove), and limitation of usage for the wavelength from 1.8 to 3 mm, it is possible to obtain a run characterized by a big fillet, which in the contact point is compensated by successive runs intersecting this fillet. As result, in some approximation this sector is seen as a straight line. For the both systems of the microgrooves it is possible to obtain a solution laying in complete range of assumed diameters from ϕ50 to ϕ200 mm.

4. Summary

Developed application program enables modeling and simulation of the oscillatory shot peening process on two types of turning lathes: conventional one of TUG 40 type and TUG 56 MN type with the SINUMERIK 810D nc control system.

Modeling and simulation of the oscillatory shot peening process with use of developed application program enables very accurate, with respect to assumed, surface coverage by the microgrooves, both in case of the conventional turning lathe and nc controlled turning lathe.

Limitation of feed rates for the TUG 56 MN turning lathe to 2 mm/rotation has adverse effect on number of obtained associations of calculated results. Making analysis of the oscillatory shot peening process one confirmed, that it is very difficult to generate a system of quadrilateral and hexagonal microgrooves.

It was confirmed, that usage of the program presented in this paper enables selection of optimal parameters, with respect to surface coverage with the microgrooves and system of the microgrooves, of the oscillatory shot peening in relatively short time.

Bibliography

[1] W. PRZYBYLSKI: Technology of machining with burnishing. WNT, Warszawa 1987.
[2] Ju.G. SZNIEJDER: Ekspluatacyonnyje swojstwa dietalej s riegularnym mikrorielefom. *Maszynostrojenije*. Leningrad 1982.
[3] Ju.R. WITTENBERG i in.: Tiechnołogiczeskije mietody powyszenija kaczestwa powierchnosti dietalej Maszyn. Izdatielstwo Leningradskogo Uniwiersitieta. Leningrad 1978, s. 87-115.
[4] A. MOCZAŁA, S. PŁONKA: Optimization of oscillatory burnishing process with use of a microcomputer. *Mechanik*, **62** (1989)4,141-143.
[5] H. CZARNECKI: Effect of oscillatory burnishing on some properties of surface layer of the 55 steel 55. Doctor’s thesis. Politechnika Częstochowska, 1983.
[6] S. PŁONKA, L. OGIŃSKI: Fundamentals of experimental parametric optimization of manufacturing operations. Wydawnictwo Akademii Techniczno-Humanistycznej, Bielsko-Biała 2004.
[7] S. ŚWIRAD, K. DUDEK: Burnishing as decorative machining. [W:] Praca zbiorowa pod red. W. Przybylskiego: Współczesne problemy w technologii obróbki przez nagniatanie, tom 2. Wydawnictwo Politechniki Gdańskiej, Gdańsk 2008.
[8] B. FRYDEL, S. PŁONKA: Modeling and simulation of oscillatory shot peening process. Not published work. Akademia Techniczno-Humanistyczna, Bielsko-Biała 2010.
[9] W.M. LEE: C# 2008 programmer’s workshop. Helion, Gliwice 2010.

Received in July 2013