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Possibilities of oil pockets creation by the burnishing technique

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ABSTRACT

This paper presents method of oil pockets creation by the burnishing (embossing) technique. Steel and ceramic forming elements were used to modify sliding surfaces. This technique allows to obtain dimples in a wide dimensional range and regular arrangement. Dimples array on machined surface depends on the forming element shape and many machining factors. Examples of textured cylinder liners surface topographies are shown. The computer software for visualization of oil pockets array on machined surface is presented in this paper.

1. Introduction

Surface texturing is an option of surface engineering resulting in improvement of tribological properties of sliding surfaces. The oil pocket (dimple) can serve as a micro-hydrodynamic bearing, a micro-reservoir for lubricant or a micro-trap for wear debris in either lubricated or dry sliding [1,2]. Lubricating oil contained in dimples makes easier the so-called dry starting, causing rapid oil supply into the contact zone, separating contacting surfaces and highly decreasing wear during running-in of assembly: journal-sleeve. It was found that the area density of oil pockets (pit-area ratio) is very important factor for the sliding pair: bronze–steel [3].

The oil consumption is one of the most important factors characterizing work of engine, especially assembly: piston–piston ring-cylinder. The small oil consumption is important from economical and ecological regards. The oil combustion in cylinder chamber is the main factor affecting the oil consumption, which caused increase in emission. In order to limit this phenomenon, it is necessary to introduce technical changes which allow to maintain oil consumption on the small level for long service life.

Cylinder liner surface topographies are commonly analyzed because of their large effect on the frictional losses, wear and operating parameters of internal combustion engines [4–6]. They also affect oil consumption and emissions of internal combustion engines [7,8]. Nowadays cylinder structure is frequently achieved by plateau honing. Plateau honed cylinder surface consists of smooth wear-resistant and load-bearing plateaux with intersecting deep valleys working as oil reservoirs and debris trap. Plateau-honed cylinder surface ensures simultaneously good sliding properties of a smooth surface and a great ability of maintaining oil on a porous surface. In order to minimize oil consumption, the core roughness depth and the so-called oil capacity should be minimized. However decrease in the oil capacity may cause higher inclination of cylinder surface to seizure (scuffing). The upper part of cylinder (near the top dead center of the

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first piston ring) is the region of the highest possibility of seizure and then engine failure. In order to prevent this danger it is necessary to accumulate more oil in this area. It can be done by laser texturing (see Fig. 1).

Introduction of laser texturing caused small engine oil consumption and hence lower pollutants emission comparing to conventional honed structures [9–11]. The laser textured cylinder surfaces showed less wear than the surface manufactured by conventional honing [9], and the presence of dimples on cylinder liner surfaces caused smaller coefficient of friction [12,13].

Laser texturing technique is most popular because of the following advantages: high speed of machining, precision of position and sizes of oil pockets. High cost of instrumentation and surface layer changes near oil pockets are the disadvantages of laser texturing. Creation of oil pockets by mechanical burnishing (embossing) can be an alternative to laser texturing of cylinder liner. Dimple sizes after this treatment are in the range 0.003–0.2 mm. The shape of hole depends on the shape of the burnishing element. The method of treatment using the burnished head is much cheaper than laser texturing, thermal changes are absent, tooling is comparatively simple and easy to use in various types of machine tools, which extends the possibilities of its application for various products, not only cylinder liners.

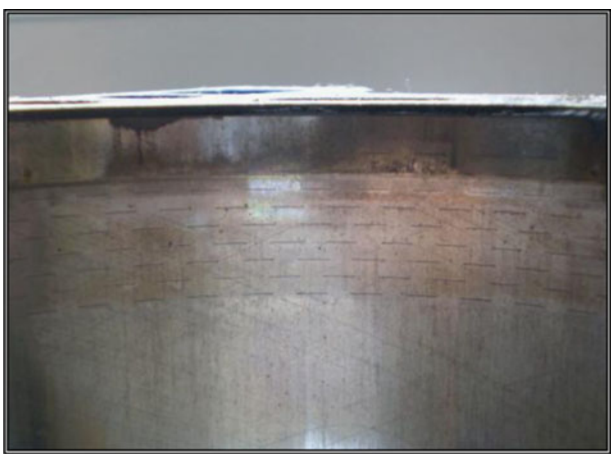

Fig. 1 – Cylinder liner with oil pockets in its upper part.

The presence of dimples created by burnishing technique on cylinder surface resulted in decreasing the coefficient of friction comparing to plateau honed cylinder liner surface. The beneficial oil pockets effect is mainly evident in full fluid lubrication condition, when the friction force decreased about two times. This effect was bigger for higher sliding speeds and smaller loads. The positive effect of additional cylinder liner surface texturing on frictional resistance under worse lubrication conditions was smaller. The dimple presence caused smaller friction force of the analyzed assembly up to 15% for the highest speed and applied load [14]. One can find the positive effects of burnishing texturing on tribological behavior (wear resistance, seizure resistance) of other sliding parts in [3,15,16].

2. Construction and principle of operation of head for cylinder liner burnishing

Tests with simplified tooling were the basis for elaboration of assumption for the presented method of cylindrical surfaces (cylinder liners or engine blocks) texturing. Roller, with bearing balls of 1 mm diameter located on cylindrical surface, was the forming element. This roller was fixed on self-aligning arm mounted in frame with elastic pressure. Whole tooling was mounted in turning tool. Initial tests of determination of tool clamp force in relation to oil pockets diameter

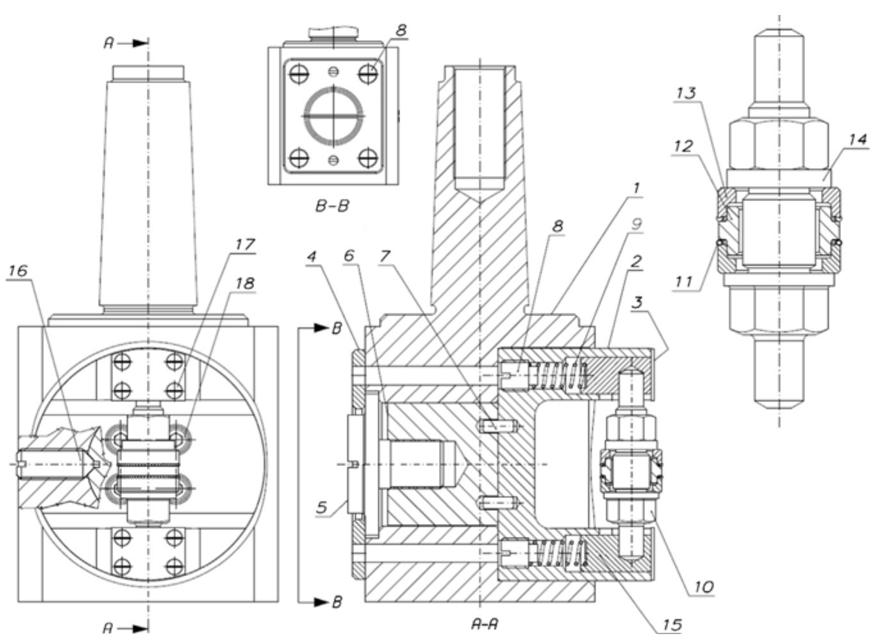

Fig. 2 – Scheme of head for oil pockets creation: 1—frame, 2—bracket, 3—pin packing plate, 4—support plate, 5—special screw, 6—shaft, 7—fixing pins, 8—control screw, 9—compression spring, 10—forming roller, 11—forming balls, 12—collar, 13—liner, 14—ring, 15—pin, 16—blocking screw, 17—fixing screw, and 18—screw.

showed non-uniform roller work, for small interference. In addition this tooling did not assure fixing repeatability and roller position much changed with pressure change. It was found that parallel shift of forming tool to machined surface and its elastic pressure were needed in order to make creation of oil pockets possible. Finally the head, fitted for operation in the vertical milling machine with elastic pressure adjustment and change in diameter of machined product in a specified range, was performed.

Fig. 2 presents scheme of the head and their fundamental components. The head consists of the frame (1) with integrated element for clamping in machine tool. The shaft (6), coupled by the special screw (5) and the support plate (4), is located in the frame. The shaft is blocked using the screw (16). This shaft is connected with the bracket (2), in which the forming roller (10) is located using pins (15). These pins are mounted in bracket seats by control screws (8) and compression springs (9). Exerting specified pressure on pins and by the forming roller on tested workpiece is the task of springs. Steel or ceramic balls (11), located in two rows are the working elements of the forming roller. These balls abut against the collar (12); they are pressed down by the ring (13), which protects them against falling out from seats during machining and guarantees precision of their position fixing in the roller. The pin packing plate (3) is fixed to frame by screws (17), it has two holes making control of compression spring force possible. The bracket, fixed on two pins (7) is mounted to shaft using screws (18). For the presented head the motion was announced to Patent Office for protection of invention P.394998.

In order to create oil pockets on working surface of the cylinder liner it should be mounted in special holder on table of machine tool, for example vertical milling machine, and in spindle seat the forming head should be mounted.

Before machining in dependence on oil pockets sizes it is necessary to control forming roller pressure to workpiece using control screws. One should determine position of the roller in relation to the frame depending on the machined liner diameter. The head prepared to work is inserted in the cylinder liner, the machining parameters are adjusted in dependence on the dimples layout and machine tool drive is actuated.

The dimples lay-out on cylinder surface mainly depends on the forming roller construction (Fig. 3) and feed of the head.

3. The analysis of textured surfaces

Fig. 4 presents isometric views of four textured cylinder liner surfaces. Before burnishing, liners were plateau honed. Surface topographies were measured using Talysurf CCI Lite white light interferometer. Height resolution was 0.01 nm; the measuring areas were 3.3 mm × 3.3 mm; sampling interval in two orthogonal directions was 3.2 μm. Fig. 5 shows cross-sections of surface topographies presented in Fig. 4. Definitions of surface topography parameters are given in Ref. [17].

Sizes of dimples depend on the diameter of bearing balls used as tool (1 mm) and interference of this tool within the workpiece. The burnishing process was performed in order to obtain dimple depth up to 10 μm. Many studies suggested the use of a reasonably small oil pocket depth, because deep textures may have a considerable negative effect on lubrication film formation. The presence of deep oil pockets may greatly increase the risk of surface failures due to contact fatigue [18]. Dimples depths of surfaces A and B were similar between 6 μm and 8 μm; the range of dimple diameter was 0.2–0.25 mm. Sizes of dimples from surface C were smaller: the depth was between 5 and 6 μm; the diameter was in the range 0.15–0.2 mm. However oil pockets on surface D were characterized by the highest dimensions: the depth was in the range 10–13 μm; the diameter was between 0.27 mm and 0.33 mm. The pit-area ratio of four textured surfaces was 11–14%. Roughness heights in areas free of dimples of surfaces A, B and C were similar, of surface D bigger. The high dimple sizes are reflected by large amplitude parameters characterizing the valley surface part and oil capacity. For example the values of the reduced valley depth (connected with oil capacity) of surfaces A and B were similar (4.8–5.3 μm), of surface C smaller (2.8 μm), but of surface D higher (6.2 μm). Due to the smallest diameters of oil pockets surface C was characterized by the smallest value of the fastest decay autocorrelation length Sal: 0.06 mm (for the other surfaces about 0.09 mm) and texture parameter Str: 0.47 (for other

Fig. 3 – View of forming elements prepared to mount in head.

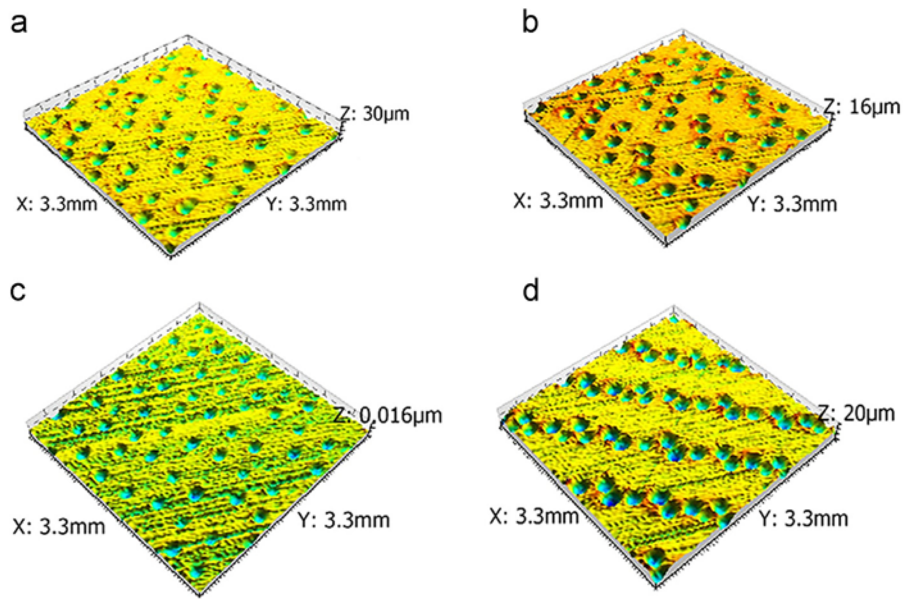

Fig. 4 – Isometric views of cylinders A (a), B (b), C (c) and D (d).

surfaces 0.8–0.85). The Str texture parameter is used to describe the level of isotropy of a rough surface; a ratio of 1 indicates a perfectly isotropic surface topography. All surface types are characterized by negative skewness Ssk (between −2.2 and −1.2) and high kurtosis Sku (between 5.5 and 7.7). The absolute values of Ssk and Sku parameters can be much higher after pile-ups (bulges, burrs) removal. Height of pile-up was up to 2 μm. The results of preliminary laboratory tests of textured cylinder liners were very promising [14].

4. Calculation of coordinates of oil pockets and visualization of their lay-out

The method of holes burnishing on machined surface using the roller transforms shapes of forming elements with their layout along the machining path. In order to determine oil pockets lay-out on machined surface two diameters should be taken into consideration: diameter created by forming elements endings on workpiece (*do*)—calculated from diameter of oil pocket (*ak*) and radius (*r*) of forming element (not shown in Fig. 6) and diameter, created by forming elements on roller circumference (*dr*). In order to obtain an example of layout formed by burnishing with roller, development of layout track and development of one-row roller were used (see Fig. 6).

On the basis of scheme of development of machining path one can obtain dependencies defining lay-out of dimples on machined surface, where

$$LR = \pi\, dr, \tag{1}$$

$$LK = \frac{\pi\, dr}{p}, \tag{2}$$

$$LS = \sqrt{(\pi\, do)^2 + f^2} \tag{3}$$

Making an assumption that the center of the first machining oil pocket is for the first path in the point 0.0, when the distance between adjacent imprints LK (dependent on roller construction and interference) is known, one can determine the number of dimples on one machining path (p_S) and residual length:

$$lr = LS - p_S LK \tag{4}$$

After considering Eqs. (2) and (3), the following formula for *lr* was obtained:

$$lr = \sqrt{(\pi\, do)^2 + f^2} - p_S \frac{\pi\, dr}{p}, \tag{5}$$

where $0 \le lr \le LK$.

Then the center of the first imprint for the second path of machining was calculated from the dependence:

$$lp = LK - lr. \tag{6}$$

Hence, after inserting (2) and (5) into dependency (6) and making simple transformations:

$$lp = \frac{\pi\, dr}{p}(1 + p_s) - \sqrt{(\pi\, do)^2 + f^2}. \tag{7}$$

On the basis of Fig. 6, coordinates of the first dimple of the second path are as follows:

$$x_1 = lp \cos\ \alpha + f, \tag{8}$$

$$y_1 = lp \sin\ \alpha, \tag{9}$$

where

$$\cos\ \alpha = \frac{f}{\sqrt{(\pi\, do)^2 + f^2}}, \tag{10}$$

$$\sin\ \alpha = \frac{\pi\, do}{\sqrt{(\pi\, do)^2 + f^2}} \tag{11}$$

After inserting expressions (10) and (11) into (8) and (9), respectively, one can obtain:

$$x_1 = lp\frac{f}{\sqrt{(\pi\, do)^2 + f^2}} + f, \qquad (12)$$

$$y_1 = lp\frac{\pi\, do}{\sqrt{(\pi\, do)^2 + f^2}} \qquad (13)$$

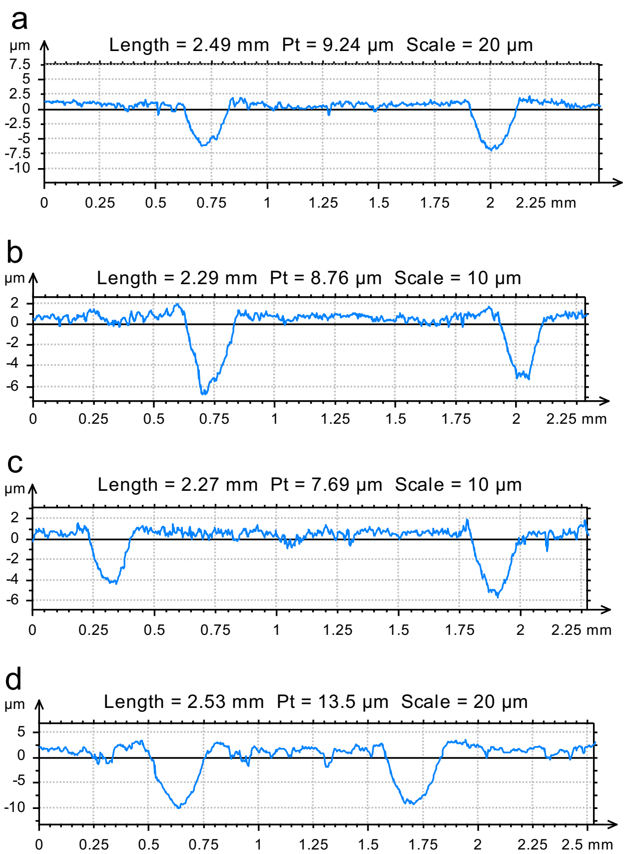

Fig.. 5 – Cross-sections of surfaces from cylinders A (a), B (b), C (c) and D (d).

Coordinates of successive oil pockets were calculated by addition to preceding coordinates of imprint, using dependencies:

$$\tilde{x} = LK\frac{f}{\sqrt{(\pi\, do)^2 + f^2}} \qquad (14)$$

$$\tilde{y} = LK\frac{\pi\, do}{\sqrt{(\pi\, do)^2 + f^2}} \qquad (15)$$

Such calculations can be done analogically for all coordinates: $x_i \leq L$, $y_i \leq \pi\, do$ of oil pockets at all machining paths.

In order to make computations easier and quicker the computer application was done using the selected dependencies (see Fig. 7).

It is possible to determine the total number of machining tracks on length L and coordinates for each center of hole x_i and y_i. One can calculate the following quantities: *apw*, *do*, *LK* and *LS* using the developed software; visualization of the results of machining can be obtained for the following input data: *R*, *dr*, *p*, *ak*, *f*, *d*, and *L*. In addition one can select visualization of oil pockets tracks, machining paths or two these variants simultaneously.

5. Conclusions

Original method of oil pockets creation by burnishing technique is presented. Roller, with bearing balls of 1 mm diameter located on cylindrical surface, was the forming element. Parallel shift and elastic pressure of forming tool to machined surface were necessary in order to make proper creation of oil pockets possible. Effects of interference, slip of forming elements and changes in diameters of workpiece on the holes lay-out were smaller than those of construction of the forming roller and feed.

The presented technique allows to obtain dimples of stable sizes in wide dimensional range and regular arrangement. The range of dimple depth was 5–13 µm, of dimple diameter 0.15–0.33 mm, pit-area ratio was 11–14%. Due to larger oil pocket sizes, amplitude parameters characterizing

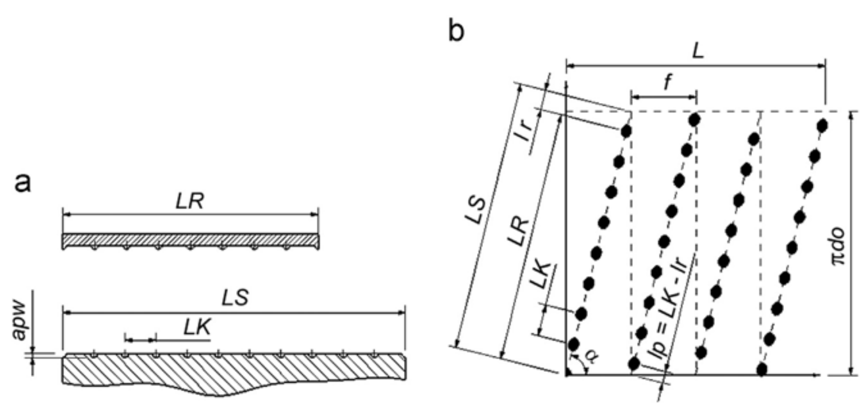

Fig. 6 – Scheme of development of (a) machining path and burnishing one-row roller and (b) machining track; *L*—length of machining, LR—length of roller development, LS—length of one path machining, LK—distance between oil pockets, *p*—the number of forming elements on roller circumference, apw—depth of oil pocket, lr—residual length, lp—initial length (LK–lr), and *α*—slope angle of machining path.

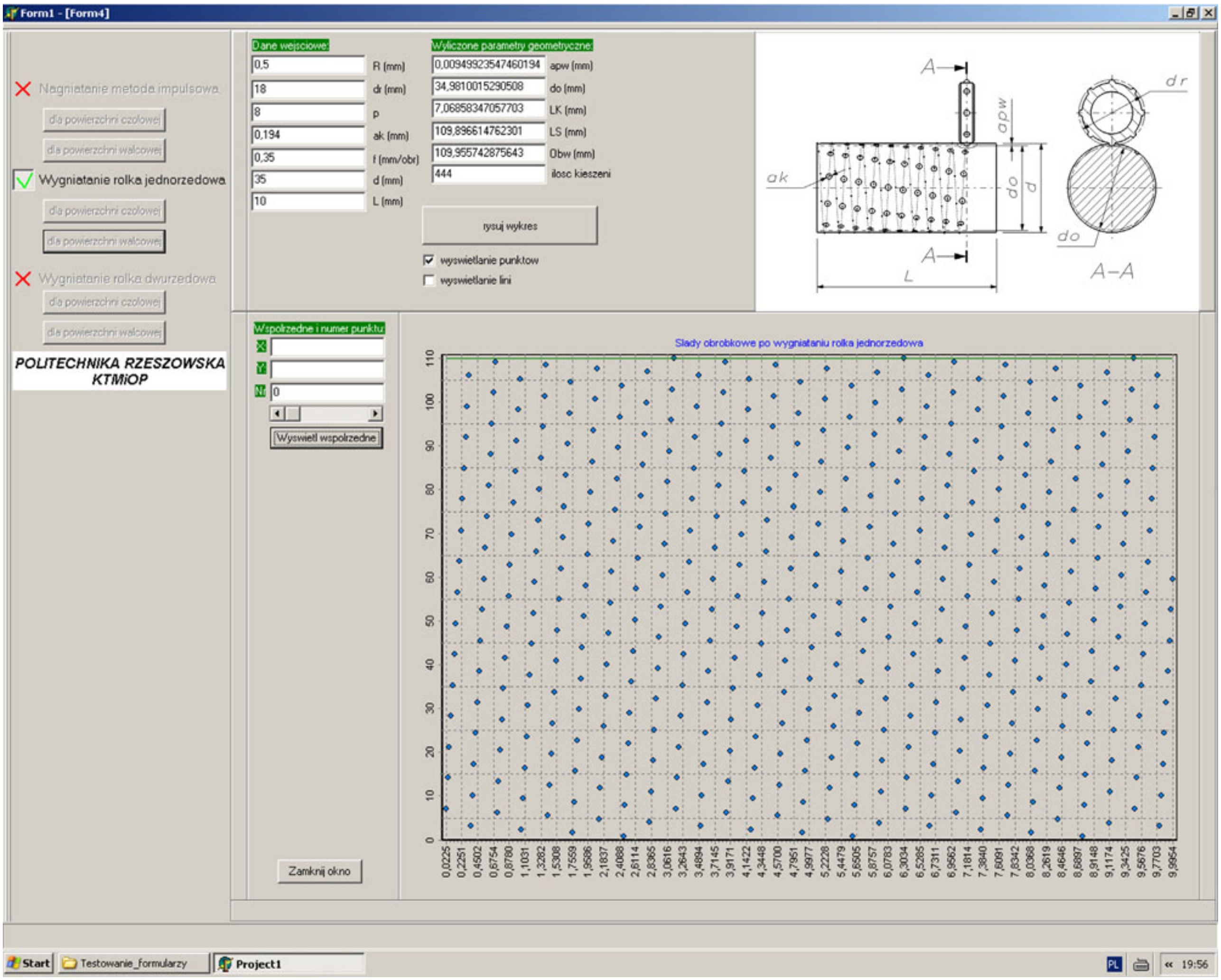

Fig. 7 – Example of window of application to surface texturing visualization.

valley surface part and oil capacity were higher. Height of pile-up was up to 2 μm.

The presented computer simulation allows to determine possible changes of the holes lay-out before machining and considerably simplifies calculation of coordinates of oil pockets positions on the surface.

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