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KINEMATIC SUPPORT OF A REGULAR MICRO-RELIEF OF A SPHERICAL OF A WORKPIECE BY AN EMBRACING MILLING

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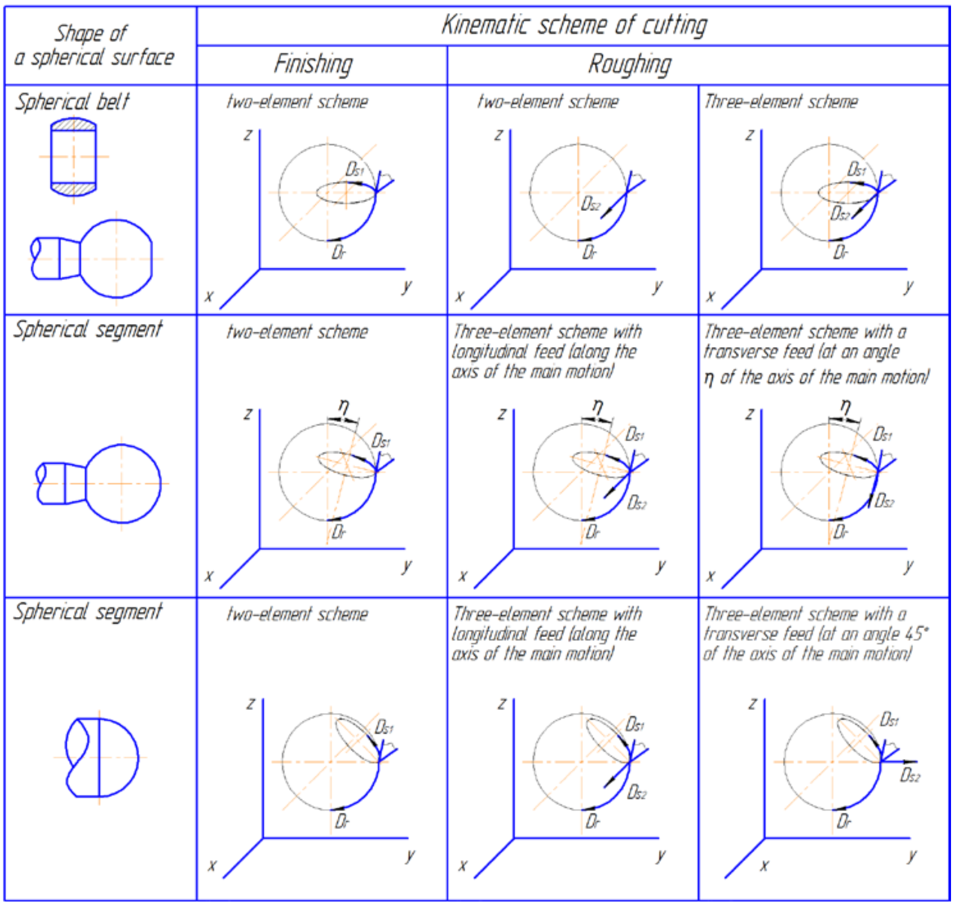
The possibilities of modification of spherical surfaces by cutting and ion-plasma processing with the purpose of improving the quality of machine parts are considered. An analysis of the kinematic features of the treatment of spherical surfaces by a rotating tool at a high cutting speed and the formation of a cutting surface is given. The results of experimental studies of the physical characteristics of the shear layer, microrelief, and microhardness of the resulting surface of the component are presented, including after coating with TiN by an ion-plasma method on a vacuum installation, confirming a decrease in the height of irregularities to Ra 0,6 ÷ 1,2 μm and increasing microhardness in 1,5 ÷ 3 times in comparison with the traditional methods of obtaining spherical surfaces.

Introduction. To the details contacting in the friction nodes on spherical surfaces, there are raised requirements for their wear and corrosion resistance [1]. In works [2,3, etc.], it is proposed to apply on their surface plastic deformation (rolling) and cutting (blade and abrasive treatment) of regular microrelief to improve the operational properties of such parts. In this work, a method of machining by cutting is used for these purposes. It is realized on universal and special machines equipped with a high-speed drive (rotation frequency of 10,000 min^{-1} and more) [4], as well as ion-plasma treatment in vacuum [5].

Kinematic and geometric characteristics of combined treatment. The method is implemented according to one of the kinematic cutting schemes presented in Table 1.

Table 1. – Kinematic schemes of combined machining by cutting the spherical surfaces of parts



The spherical surfaces of non-complete shapes are machined - bounded by a plane from one or both sides. The kinematic cutting scheme can be two- (two rotational motions) and three- (two rotational and translational motions) element, the operations of forming the sphere on three transitions. At the first transition, the rotating tool is inserted into the rotating workpiece (roughing), and the direction of the translational movement of the infeed (feed) Ds_2 occurs along the axis of the main rotational movement of the tool *Dr*. The axis of the rotational motion of the feed of the workpiece Ds_1 is directed at an angle η to the axis of the main rotary motion, that is, the form of axial processing is simultaneously realized – the countersinking, since the tool has three or more blades, and the type of milling. At the second transition, the surfaces are groomed (semi-finished processing) and a two-element kinematic cutting scheme is realized with the main rotational motion of the tool *Dr* and the rotational movement of the workpiece feed Ds_1. On the third transition, when the tool blades reach the required sphere size, smoothing (finishing) of the surface of the sphere is realized. On these transitions, along with the counter motion of *Dr* and Ds_1, it is possible to realize their associated rotation, which will contribute to better surface smoothing.

With a two-element kinematic scheme, the cutting path is a cycloid turned on the circle of the sphere (Figure 1), and for a three-element cutting scheme, the trajectory of cutting is a cycloid turned on a circle of a sphere in a spiral (Figure 2). Due to the low velocities of the feed motions Ds_1 and Ds_2, the shape of one turn of the cycloid can be regarded as a circle.

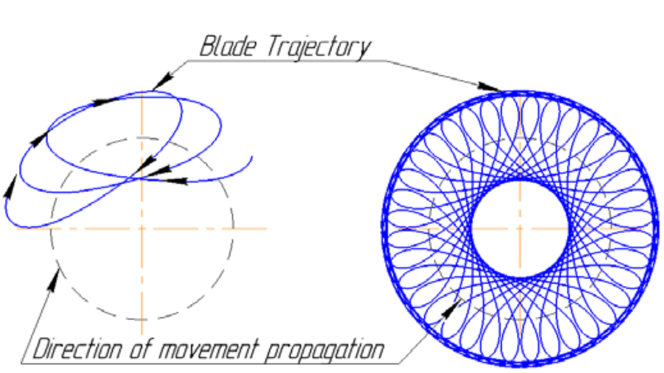


Fig. 1. Trajectory with a two-element cutting scheme

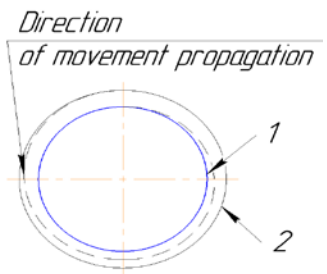


Fig. 2. Trajectory with a three-element cutting scheme: 1 – is the surface of the resulting spherical surface, 2 – workpiece surface

Figure 3 shows the development of the spherical surface of the part on a plane with the circumference of the circle πDs. The projection of the development of the circumference of the tool with the length πDt of the plane perpendicular to its axis for the transition of grooming. The directions of the vectors of the rotation speeds of the tool $\overline{V}_r$ and sphere $\overline{V}_{s1}$ are shown for the case of their opposite direction. If you change the direction of one of the rotations, a cut will be carried out. The linear velocity of rotation of the sphere in its various diametric cross sections varies from the maximum values at the largest diameter to zero at the poles of the sphere.

The cutting trajectories considered, the section of the cut layer and the kinematic angles of the blade determine the formation of the microrelief of the processed surface of the sphere. Figure 6 shows that the surface of the sphere is formed in the form of a "net" due to the intersection of the trajectories of the movements of the workpiece and the tool, and the direction of formation of uniform unevenness in the surface is determined by the angle of inclination of the axis of rotation of the workpiece relative to the axis of rotation of the tool and the value of the rotation speeds. The angle of inclination of lines with the same value of irregularities is in the range $65 \div 75^0$ at an angle of $\eta = 15 \div 25^0$. It is known [6, 7] that the use of steep-milling cutters (milling cutter) with an angle of inclination of the cutting edges of the blades within these limits, and also rotational tools providing a cutting angle of the trajectory of cutting $50 \div 70^0$, contributes to a decrease in the roughness of the treated surface.

This conclusion is confirmed by the investigation of the spherical surface of a sample with an atomic-force microscope of model NT-206 (Figure 4).

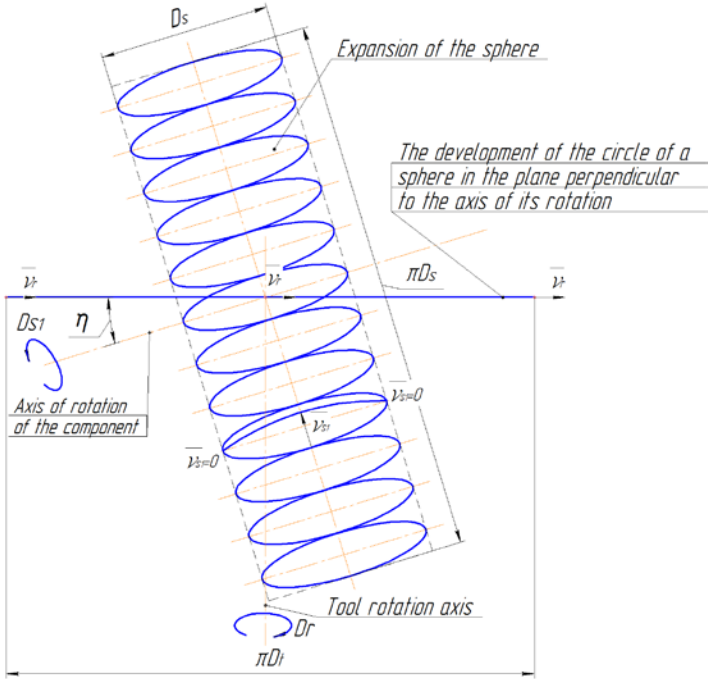
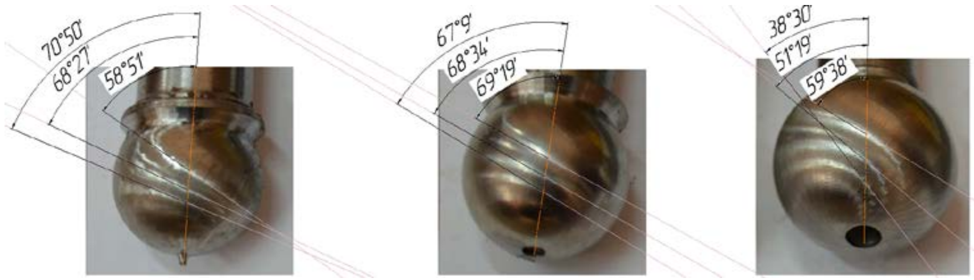


Fig. 3. Scanning the surface of the sphere and the tool circle to the plane



a) *b*) *c*)

Fig. 3. Roughness of a spherical surface of a detail and angles of an inclination of lines of an equal roughness: *a* – Ra 1,3 µm at the tool rotation speed n_1 = 3150 min^{-1}; rotational speed of the workpiece n_2 = 20min^{-1} and diameter of the sphere 25 mm; *b* – Ra 0,6 µm at the tool rotation speed n_1 = 3150 min^{-1}; the rotation speed of the workpiece is n_2 = 20 min^{-1} and the diameter of the sphere is 30 mm; *c* – Ra 0,7 micron at the tool rotation speed n_1 = 6300 min^{-1}; rotation speed of the workpiece n_2 = 180 min^{-1} and diameter of the sphere 35 mm;

a) b) c) d)

Fig. 4. Samples for study on an atomic force microscope: *a* – machining with tool rotation speed n_1 = 3150 min^{-1}; rotational speed of the workpiece n_2 = 20 min^{-1}, *b* – machining with tool rotation speed n_1 = 6300 min^{-1}; rotational speed of the workpiece n_2 = 180 min^{-1}, *c* – machining with tool rotation speed n_1 = 12000 min^{-1}; rotational speed of the workpiece n_2 = 20 min^{-1}, *d* – machining with the lathe on the lathe with a speed of n = 1200 min^{-1} and feed rate S_0 = 0,2 mm / rev.

(the top row is the surface view near the axis of rotation (poles of the sphere), the bottom row is the surface view at the maximum distance from the axis of rotation (pole of the sphere)).

Figure 5 clearly shows unevenness and risk along the cutting path, which provides a low surface roughness between the risks-trajectories (Ra 0,021 ÷ 0,64).

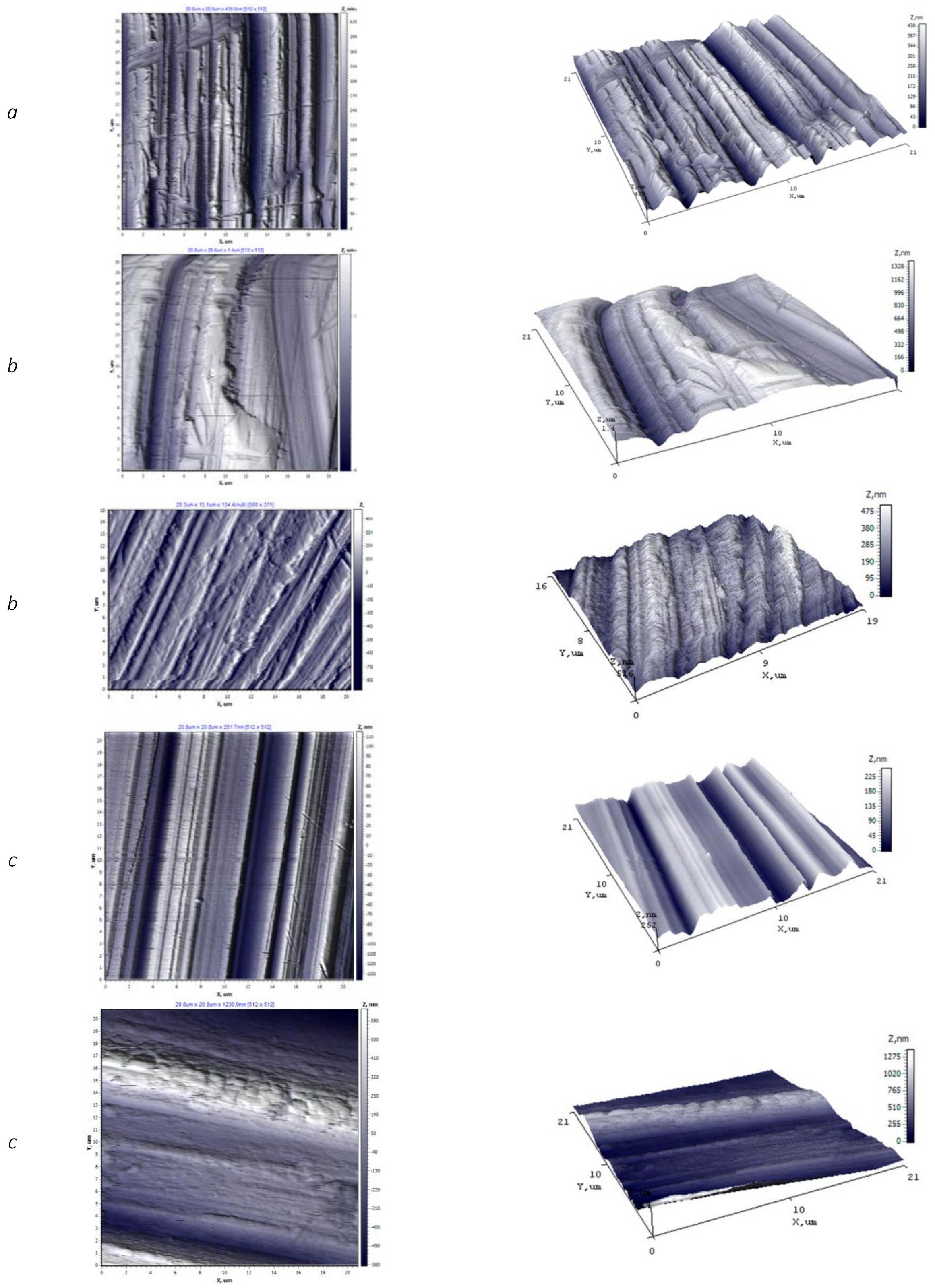


Fig. 5. Surface topography after treatment: *a, b* – a rotating tool; *c* – turning lathe

In this case, the microhardness of the surface is increased by a factor of 1,5 to 3 as compared with the base: an increase in the tool's rotation speed from 3000 to 6000 min^{-1} leads to an increase in the microhardness of the surface by 10-20% (Table 2).

Table 2 – The value of microhardness of sample surface

№ test unit	Processing type	Machining rate	Microhardness, HV 0,025
test unit 1	By rotating tool	n_1=3150 min^{-1}	625
test unit 2		n_2=20 min^{-1}	750
test unit 3	By rotating tool	n_1=6300min^{-1};	780
test unit 4		n_2=180 min^{-1}	850 (support plate's hardness 282 HV 10)
test unit 5	By rotating tool	n_1=12000min^{-1};	515
test unit 6		n_2=20 min^{-1}	525
test unit 7	By lathe tool	n=1200min^{-1};	565
test unit 8		So=0,2mm/rev.	390 (support plate's hardness 278 HV 10)

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