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WORKABILITY OF THE SAPPHIRE CRYSTAL OF MEDICAL PURPOSE AND SCHEME OF FORMATION OF SPHERICAL SURFACE OF INCREASED PRECISION

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ТЕХНОЛОГІЧНІСТЬ КРИСТАЛІЧНОГО САПФІРУ МЕДИЧНОГО ПРИЗНАЧЕННЯ І СХЕМА ФОРМОУТВОРЕННЯ СФЕРИЧНОЇ ПОВЕРХНІ ПІДВИЩЕНОЇ ТОЧНОСТІ
Розглянуто проблеми взаємозв'язку ступеня впливу орієнтації кристала сапфіра з його оброблюваністю під час алмазного шліфування, також розроблена перспективна оригінальна схема формоутворення неповної сферичної поверхні, особливо, сапфірова голівка эндопротеза людського стегнового суглоба.

Рассмотрены проблемы взаимосвязи степени влияния ориентации кристалла сапфира с его обрабатываемостью во время алмазного шлифования, также разработана перспективная оригинальная схема формообразования неполной сферической поверхности, особенно, сапфировая головка эндопротеза человеческого бедренного сустава.

Problems connected with the definition of influence degree of orientation of sapphire crystal on its machinability during diamond grinding by disc face and elaboration of the perspective, original scheme of formation of the incomplete spherical surface, particularly, sapphire head of endoprosthesis of the human hip joint are considered.

The endo-prosthesis heads of human’s hip joint from the point of view of character and volume of load are exploited in extreme conditions. Therefore, in each specific case the selection of the necessary material with corresponding physical-mechanical characteristics and also increasing of precision and quality of the most significant part of endo-prosthesis – spherical surfaces is rather actual task the acuteness of which intensively grows in recent years. It is conditioned by the fact that if earlier the necessity of similar operations was caused by the age factor of the man or traumatologic fractures in recent two decades abruptly increased the number of patients at young age of 30-40 years of both men and women without any injuries and fractures. In opinions of physicians the principal reasons of it are non-active way of life of youth, composition of contemporary artificial food products and metabolic disease. All the above-mentioned reasons determine the number of used endo-prostheses in some tens of millions of pieces a year and the statistics shows that unfortunately this number increases every year.

The medical practice proves that the repeated prosthetics of the human hip joint is connected with big problems. In many cases the implementation of such operations becomes practically impossible. Therefore, the durability of the endo-prosthesis of the human hip joint to the end of the patient’s life especially at young age has especially significant meaning.

By these circumstances is explained the fact that in such leading countries of the world as the United States, Germany, England, Japan, France etc. are conducted wide scale scientific-research works on elaboration of optimal schemes of formation, characteristics of abrasive tool for finishing operations and the technological process as a whole for fabrication of the spherical heads of endo-prosthesis from various materials with the minimum fault of shape and with high indices of the surface quality [1].

For nowadays in the world practice these heads are manufactured from various alloys, composition materials and ceramics which mainly are isotropic materials. Therefore, the data of the above-mentioned works do not give the necessary information on machining of anisotropic materials, particularly artificial crystal of sapphire [1, 2].

The most biocompatible with the human organism, wear proof and durable material for fabrication of the above-mentioned article is the sapphire artificial mono-crystal.

In connection with this through the Ukrainian Science and Technology Center was organized the International Project the performers of which are Georgian Technical University (Tbilisi), Institute of Super Hard Materials of the National Academy of Sciences of Ukraine (Kiev), and Institute of Mono-Crystals of the National Academy of Sciences of Ukraine (Kharkov).

By the Project participants were solved the independent scientific tasks, particularly: by Georgian Technical University is investigated the influence of anisotropy of sapphire crystal on workability of the material at grinding; are elaborated the perspective, theoretical schemes of formation of incomplete spherical surface taking into account advantages of the LPG method as the effective one for grinding of hard and brittle, intractable and non-metallic materials; by the Institute of Super Hard Materials were investigated the links of the friction coefficient with crystallographic properties of sapphire and annealing modes; were investigated work abilities of materials possessing anisotropy properties, particularly of sapphire, by the traditional technology for evaluation of the influence of anisotropy on the formation precision of spherical surface; were elaborated recommendations applicable to the process of diamond finishing of the endo-prostheses heads of the hip joint from the artificial mono-crystal of sapphire. By Kharkov Institute of Mono-Crystals were determined the growing modes providing maximum purification of the sapphire material; is obtained sapphire in crystallographic direction having the minimum anisotropy.

The aim of the presented work is a definition of the influence degree of orientation of the sapphire crystal on its workability by the method of low temperature precision grinding (LPG) elaborated at the Department Mechanical Engineering of the Georgian Technical University and development of perspective, original scheme of formation of incomplete spherical surface, particularly sapphire head of endo-prosthesis of the human hip joint taking into account the advantages of LPG method [2, 3, 4].

The basing of conducted investigations on workability of the sapphire crystal by LPG method served its successful production probation on the scale of super hard, brittle, intractable non-metallic materials, particularly mono-crystals.

In Fig. 1a is shown the LPG scheme - machined parts set on a cassette in separators or other methods of fixture, for example, gluing carry out rotational movement with angular speed of ω_2 and grinding ring with the speed of ω_1 in the same direction. In the cutting area is implemented a hold-down by force P of machined surfaces of parts from the work surfaces of the grinding ring.

The cutting speed is determined within the contact area as a medium meaning of the speed relatively the travel of the tool work surface on the machined surface of the part where F_g is the area of the machined surface of the part – contact area.

$$V_{cut} = \frac{1}{F_g} \int_F V dF,$$

The investigations of the orientation influence of the sapphire crystal on the workability of a material were conducted on the sapphire samples with orientation (0001), (1010) and (1012). The sizes of samples are 10x10x6 mm and Φ 10x6 mm.

The experimental investigations were conducted on a laboratory device equipped with a special precision head for LPG (Fig. 1.b). Diamond rings with granularity of 14/10 and 28/20 on ceramic, metallic and organic bunches of shape 6A2 were used.

The output parameters of the LPG process were: productivity of machining, linear minute takeoff of the material –q, mkm/min, the height of irregularities of the surface roughness –R_z, mkm relative support length of the profile at the level of 03 – t_{P03},%, sub-relief violated layer – H, mkm.

The LPG process factors are: cutting speed – V, m/s, pressure in the cutting area P kPa and characteristics of the diamond tool: granularity – d_3, mkm, bunch, concentration – К,%.

The experiments were conducted in following conditions: cutting speed range – V=1...12 m/s, pressure in the cutting area – P=100...1500 kPa. The cooling liquid – filtered running water.

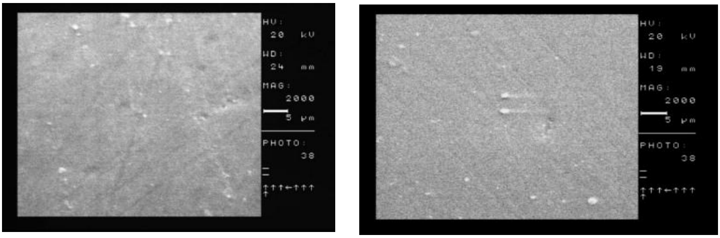
By the analysis of the data of all-side experimental investigations conducted by us one can make the following conclusion:

The influence character of factors of the LPG process on the output parameters for selected orientations of the sapphire crystal of ((0001), (1010), (1012)) is constant.

From the characteristics of the diamond tool on the productivity by prevailing way influence granularity and bunch of the diamond tool. The concentration influence is insignificant. With increasing of the granule size within d_3=14/10…28/20 the productivity grows 1,5 ...2.5 times.

In other equal conditions of machining on orientation (0001) is achieved higher quality of the surface than on the rest two ones. The difference is in 1...1,5 class of roughness.

From the LPG factors on the surface quality in prevailing way influence the granularity and the material of tool bunch. With increasing grain in the investigated range the height of irregularities Rz grows within 1...1.5 of class and the depth of the violated layer of H – 1,5...2 times.



a b

Figure 2 – Micro-photos of surfaces of experimental samples
of sapphire machined by the LPG method.
a- Orientation 1010, b- 1012. Diamond ring –ACM 14/10, bunch organic special 50 % Cutting modes: V=1m/s, P=750 kPa.

By the quality of machined surface the best results are given by the diamond rings on organic bunches BC-11 and organic bunches BC-11 and organic special elaborated by us is in the process of patenting. In comparison with diamond rings on metallic and ceramic bunches parameter R_z in order below ~0,25 mkm, parameter t_{P03} is 1,5 times higher than ~ 35...45% and parameter H is 3...5 times less than ~ 2...5 mkm.

By the study of morphology of the machined surface is proved the cutting possibility of the sapphire material by plastic deformation of the removed layer at low cutting speeds V=1…3 m/s with the least depth of the violated sub-relief layer (Fig.2).

This result deserves special attention as the machining of the vitreous materials, particularly, crystals of sapphire by means of plastic deformation of removed layer the pledge of obtaining of the machined surface practically without inherited defects – without sub-relief layer. H value appeared to be the least namely on these samples of sapphire.

Elaboration of the new or updating of existing technological process of machining of sapphire head sets an actual task of creation of new highly effective schemes of formation. The optimization criteria of technological operations such as productivity, indices of the surface quality and precision of machining determine the place of new schemes-methods of formation in the technological process taking into account their advantages.

The applied nowadays methods for abrasive machining of incomplete spherical surface of articles of wide purpose as separate operations of technological process of machining of incomplete sphere can be divided into two groups: grinding by abrasive-diamond rings and finishing by free abrasive.

The method of LPG relates to the first group methods, however, the method of diamond abrasive machining of flat surfaces unlike the existing methods unites in itself positive sides of methods of the above-mentioned groups; namely, LPG is characterized by the high productivity at the same high precision of machining and quality of surface.

For elaboration of the theoretical scheme of diamond machining of sapphire spheres taking into account kinematics and other positive features of LPG were considered and analyzed the well-known formation schemes of incomplete spherical surface.

The most close by kinematics method of LPG is the method for grinding of the incomplete sphere by the flank of grinding ring with double rotation of part with angle speeds of ω_2 and ω_3 (Fig. 3) which is taken for the base of elaboration of the original version of theoretical scheme of diamond machining of sapphire spheres taking into account kinematics and other positive features of the LPG method [4, 5].

We elaborated some versions of theoretical schemes of formation of the incomplete spherical surface. One version of the original kinematics scheme of formation of the incomplete spherical surface of sapphire head (Fig. 4) by the flank grinding ring is shown in Fig. 5 The cutting tool is the special, combined flank grinding ring with two concentric diamond layers with cutting surfaces in a form of internal in point A and external in point B cut off cones.

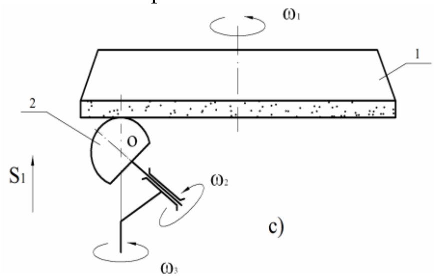


Fig. 3 Formation scheme of the incomplete spherical surface by the flank diamond ring with double rotation of the part.
1 – diamond grinding ring; 2 – machined part – incomplete sphere.

The grinding ring performs a rotational movement with the angular speed of ω_1. The machined part – sphere performs a double rotational movement with angular speeds of ω_2 around its own axis 4 and ω_3 around axis 3 which is the axis of the part spindle. The direction of angular speeds ω_1, ω_2 and ω_3 is similar. The machined part 2 is pressed to the cutting surface of grinding ring in two point's A and B by spring loaded force P. At that the cutting surfaces of grinding ring in axis section (flat of the drawing) form β angle.

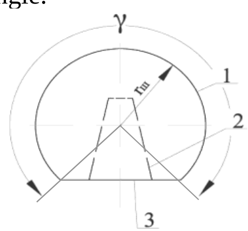
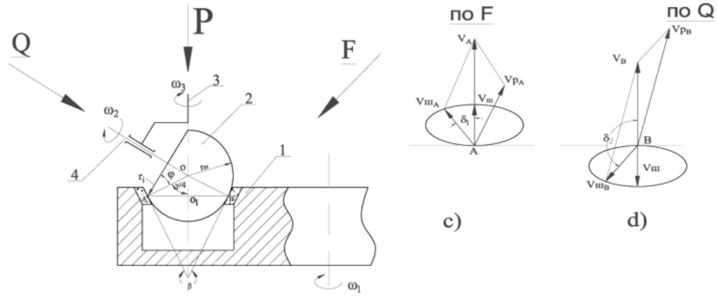


Figure 4 – Sapphire spherical head:
r_{III} – radius of sphere, γ – angle of segment of the spherical surface.

The differences of theoretical scheme from LPG are such as the shape of the tool work surface, additional motion of a machined part – rotation of a sphere around its own axis with the speed of ω_2 the contact form of the machined surface of the part with cutting surface of grinding ring.



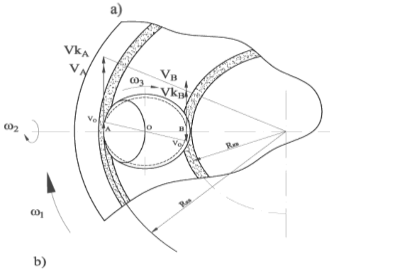


Figure 5 – Kinematics scheme of formation of the incomplete spherical surface by flank grinding on the basis of LPG method.
1–flank grinding ring; 2–machined part – incomplete sphere; 3–rotation axis of the part spindle; 4-rotation axis of the part.

For creation of equal conditions of machining in two points A and B is necessary to observe the equality of both speeds and forces of cutting.

The condition equality of machining on the cutting speed means the equality of maximum meanings of the cutting speeds and identity of their laws of change in cycle in two areas of cutting.

The cutting speeds during grinding of the incomplete sphere by the suggested scheme in points A and B are shown in Fig.5 в, c, and d.

The resulting cutting speeds v_{PA} are in point A,

$$\vec{v}_{PA} = \vec{v}_B - \vec{v}_{ШB} \quad (1)$$

$$v_{P_A} = \sqrt{v_A^2 + v^2_{ш_A} - 2 v_A \cdot v_{ш_A} \cdot \cos\delta_1} \quad (2)$$

Where $$v_A = v_{KA} - v_0 = R_{KA} \cdot \omega_1 - r_ш \sin\frac{\gamma}{4} \cdot \omega_3 \quad (3)$$

and $$v_{ШA} = r_{iA} \cdot \omega_2 \quad (4)$$

Identically to pointA in point B the resulting speed of cutting is equal to

$$\vec{v}_{PB} = \vec{v}_B - \vec{v}_{ШB} \quad (5)$$

$$v_{P_B} = \sqrt{v_B^2 + v^2_{ш_B} - 2 v_B \cdot v_{ш_B} \cdot \cos\delta_2} \quad (6)$$

Where $$v_B = v_{KB} - v_o = (R_{KA} - 2r_ш \cdot \sin\frac{\gamma}{4}) \cdot \omega_1 + r_ш \cdot \sin\frac{\gamma}{4} \cdot \omega_3 \quad (7)$$

and $$v_{ШB} = r_{iB} \cdot \omega_2 \quad (8)$$

The linear speed of the part from rotational motion with the angular speed of ω_2

$$v_{Шi} = r_i \cdot \omega_2 = \omega_2 \, r_Ш \cdot \cos\varphi =$$

$$\omega_2 \cdot r_ш \sqrt{\sin^2\frac{\gamma}{4} \cdot \cos^2\alpha + \frac{1}{4} \cdot \sin^2\frac{\gamma}{2}\left(1 + \sin\alpha\right)^2} \quad (9)$$

where φ is the inclination angle of axis 4 relatively to the forming work surface of the ring in axis section, α is the bending angle of axis 4 respectively to axis 3 with angular speed of ω_3 .

The current radius r_i of the part surface point during the turning of axis 4 around axis 3 to 180^0 changes within $0 \le r_i \le r_ш$ .Thus for the full description of spherical surface during one cycle one rotation of the part around axis 4 is enough at turning of axis 3 to half of rotation i.e. to 180^0. Thus in these conditions the machined spherical surface of the part during one cycle is described twice one time in each area of machining.

Coming out of the above-mentioned between angular speeds of ω_2 and ω_3 we have dependence

$$\omega_2 = 2\,\omega_3 \quad (10)$$

v_{P_A} of maximum reaches at $\alpha = \pi\, 3/2$, and thus $\delta_1 = \frac{\pi}{2}$.

$$v_{P_{Amax}} = v_A = R_{KA} \cdot \omega_1 - r_ш \cdot \sin\frac{\gamma}{4}\omega_3 \quad (11)$$

v_{P_B} of maximum reaches at $\alpha = \pi/2$ and thus $\delta_2 = \pi$.

$$v_{P_{Bmax}} = R_{KA} \cdot \omega_1 - 2r_ш \sin\frac{\gamma}{4}\omega_1 + r_ш \cdot \sin\frac{\gamma}{4} \cdot \omega_3 + r_ш \sin\frac{\gamma}{2}\omega_2 \quad (12)$$

In condition $v_{P_{Amax}} = v_{P_{Bmax}}$, by expressions (10), (11) and (12) is determined the correlation of angular speeds ω_3 и ω_1

$$\frac{\omega_3}{\omega_1} = \frac{1}{1 + 2\cos\frac{\gamma}{4}} \quad (13)$$

Thus by the suggested scheme of formation of incomplete spherical surface for achievement of the equality of machining conditions by the cutting speed one must observe the relations of angular speeds ω_1, ω_2 and ω_3, by expressions (10) and (13).

The equality of conditions in two areas by the force of pressing is achieved by the location of machined part respectively to the grinding ring. The spring loaded force P passes through the center O of sphere and coincides with the bisector of angle β and thus passes at equal distances from two A and B areas of machining. In each area are created equal forces on P/2, which in their turn are added up to two composing, normal P_N and tangential P_τ (they are not shown in the Figure).

At that $$P_N = \frac{P}{2} \cdot \cos\frac{\gamma}{4}, \quad P_\tau = \frac{P}{2} \cdot \sin\frac{\gamma}{4}.$$

The kinematics similarity of the new scheme of formation with the LPG method taking into account keeping of physics of the cutting process at LPG which determined its name "Low temperature" (low in comparison with usual grinding cutting speed – 1,6 m/s and as consequence low temperature in contact -100^{0}C) and also "Precision" (high precision of the work form of the tool surface is achieved during shaping and is maintained in work by the kinematics process by which is provided high precision of machining-flat parallelism on plate 10x10 mm 1mkm) allows the suggested scheme of formation as the initial from the first to call Low temperature precision grinding of incomplete sphere in abbreviation LPGIS which is in the process of patenting.

It is supposed that the LPGIS method in comparison with traditional methods of diamond grinding which are used nowadays in the technological process of machining of sapphire in other equal conditions will enable: considerably (not less than twice) increase the productivity of machining not worsening the quality indices of surface and precision of the article shape; considerably increase the quality of machined surface and precision of the article shape not increasing the productivity of machining by that considerably decrease the operational stock material, finally the time and cost price of machining on finishing operations (transitions).

Thus in our view the LPGIS method can be fully competitive on preliminary operations up to finishing machining in the technological process of machining of sapphire head.

One can imagine that LPGIS method will enable to increase considerably the surface quality and shape precision of the spherical head on the preliminary operations up to the finish machining in comparison with traditional methods of diamond machining.

The results of conducted investigations within the above-mentioned Project by our estimation represent a good data base for perspective elaborations. And namely, by the Project participants to the STCU was submitted the new Project under the title "Development of Methods for Strengthening of Sapphire Used in Medicine". Within this Project is planned conducting of works on the elaboration of complex method of strengthening of sapphire for fabrication of articles exploited at high mechanical loads in extreme conditions and also competitive technological processes of fabrication of sapphire standards by LPG method for definition of physical-mechanical properties of the new material and original technological process of fabrication of sapphire articles of medical purpose.

By the long-term program is foreseen the organization of Euro-Project with creation of the necessary equipment, tools, technological rig and the whole technological process of fabrication of the high-precision spherical surfaces from sapphire of increased stability or other appropriate by their properties materials.

Discussion of the results.

1. In other equal conditions of machining by the LPG method the most intractable is orientation (0001). For all the tested diamond rings the correlation of linear meanings of the material takeoff – q is within

$$q_{0001} / q_{1010} = 0,25…0,5,$$

at that, $$q_{1012} / q_{1010} = 0,75 …1.$$

2. In the investigated ranges of the cutting modes of V and P the machining productivity grows at V=…6 m/s and at V> 6 m/s – remains constant, also at P =100…1500 kPa– grows and at P>1500 kPa remains constant.

3. The maximum meaning of productivity is achieved by the tool on ceramic bunch – CK6 – 130 ...300 mkm/min for all the selected orientations of the sapphire crystal. At that the correlation increases

$$q_{0001} / q_{1010} = 0,4 … 0,5.$$

The tool on this bunch works in the mode of self-sharpening.

4. Scheme of machining of spherical surfaces and abrasive tool of special profile is suggested that in our opinion will grow the machining precision.

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