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Precision Machining of Mechanical Seals on the Machine "Rastr 220"

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Abstract

Here we present the "raster" method of final abrasive treatment of surfaces. Here we describe the theoretical foundations and patterns of "raster" processing method. We also describe the kinematics of lapping and polishing machine "Rastr 220". For pieces of brittle composite material based on graphite, we have designed and manufactured a universal multipiece arrangement. The number of simultaneously machined pieces and their location in the device shall provide an even lapping wear. For this purpose, the axis of rotation of the tool shall be offset about its axis of symmetry to 5-15 mm. The device of larger diameter at the lapping should provide for periodic lapping bleed of the pieces by a certain amount. However, from the viewpoint of surface grit, a high lapping bleed of the pieces is not desired. In the process of lapping, the device shall be fully loaded with pieces. In case of impossibility to meet these requirements, it is necessary to periodically change the position of pieces in it. The device allows to compensate for different height of processable workpieces, to provide for their self-aligning on the tool surface, and to place the pieces evenly over the surface of lapping. The experimental testing of the treatment process on the machines with "raster" kinematics of the tool working movement was carried out. The comprehensive studies of precision treatment process for high-precision pieces made of composite materials based on siliconized graphite of grade (GAKK 55/40) were conducted. The requirements for working planes of the pieces are the following: Ra not more than 0.1 µm, flatness deviation not more than 0.6 µm. An estimation method for surface indulation was offered, and common technological advice on the implementation of "raster" lapping process for siliconized graphite pieces on the machine "Rastr 220" was developed.

Keywords: "Raster" processing method, precision of geometric shape, surface grit, siliconized graphite, "Rastr 220"

1. Introduction

Reliability and durability of mechanisms and machines containing nodes with different mechanical seals is largely dependent on the quality of surface finishing for high-precision workpiece surfaces. One of the final methods of precise flat surfaces treatment is the abrasive lapping. Sometimes only this technique is possible, especially in the lapping of pieces made of solid composite materials, such as ceramics, cemented carbide, glass, ruby, siliconized graphite and others. (Nikiforova-Denisova, 1989; Babaev et al. 1976; T. Ekobori, 1994).

In the production environment with the small output or rebuilding of pieces such as mechanical seals, the finishing shall be made by repeated manual lapping. This technology is very time-consuming and requires professional skills. Therefore, to date, the mechanization of lapping operations is urgent. The feature of the abrasive lapping process is that the abrasive grains (or rather, a mixture of grains with paste components or lubricating and cooling fluid) under the influence of lapping perform the removal of the material. The lapping not only informs grains about the necessary movements and efforts, but also provides for the required accuracy of the surface treatment. (Kachalov, 1968; Kumanin, 1962; Vinokurov et al., 1962). This finishing operation allows to obtain a surface with the grit of R_a=0.004-0.16 µm and deviation from the desired geometric shape up to 0.1-0.3 µm**.** (Reznikov, 1977; Shalnov, 1972).

The small velocity shall be recognized as a characteristic feature of the lapping process. Therefore the process of circle or bar lapping can be referred to microgrinding (Chestnov, 1996), which increasingly develops with mastering the production of high quality micropowders, abrasives and ligaments. In case of lapping of plastics, i.e. most metals and alloys, the removal is performed by the abrasive grains fixed on the lap and scratching the machined surface. Alternatively, in case of lapping of brittle materials, the loose grains rolling on the workpiece' surface and puncturing the material particles are more effective and productive (Kosmachev et al. 1985).

One of the ways of abrasive treatment efficiency improvement is a complication of relative motion trajectory of the tool and workpiece. It was found that the complex working motion contributes to the improvement of treatment quality and performance, as it creates favorable conditions for the better use of cutting power and uniform wear of the tool (Z.I. Kremen et al., 1967).

In this connection the "raster" method of abrasive treatment which if widely used in lapping of precision surfaces and honing of internal precision holes, which was developed in Perm National Research Polytechnic University (PNIPU), is of great interest. (Nekrasov, 2000; Khanov, 2010).

The purpose of this work is to study the technological capabilities of finishing abrasive treatment of pieces surfaces made of siliconized graphite GAKK 55/40. The experimental study of composite rings lapping on the machine with "raster" tool path has the ultimate aim of establishing a rational treatment conditions ensuring minimum treatment time, necessary grit and flatness of the lapped surface. Based on the task set, the plan of experimental and design works consisted of the design and manufacturing of experimental tooling for rings lapping.

2. Techniques

The complex studies of precision treatment process for high-precision composite parts based on siliconized graphite of grade (GAKK 55/40) were conducted. Requirements for working planes of the pieces are the following: *Ra* not more than 0.1 μm, flatness deviation not more than 0.6 μm. (Konstantinova, 2010; Mayer, 1978).

The "raster" toolpath is formed in the result of orthogonal combination of two sine waves with different frequencies and ω_1, ω_2 amplitudes A, B. Parametric equations of the trajectory determine the Cartesian coordinates x, y in functions of time t:

$$x = \mathrm{A} \sin \omega_1 t, \quad y = \mathrm{B} \sin(\omega_2 t + \phi_0)$$

Where ϕ_0 - is zero phase shifting;

Moving point traces out a complex resulting trajectory, distributed over the area of the rectangle $x = \pm \mathrm{A}, \quad y = \pm \mathrm{B}$ (Figure 1). The simplest of such trajectories are known as Lissajous figures. The feature of Rastr lapping and polishing is the forward movement of the (tool) lapping on nonrecurring path in the form of a complex shape grid (Nekrasov, 1971).

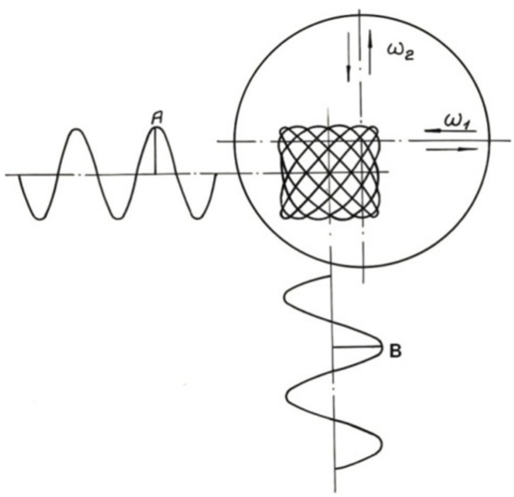

Figure 1. Raster trajectory of the lapping (tool) working motion

In this case, the velocity of all the points of the lapping working surface is identical. This enables the improvement of treatment quality; in addition, for large components it allows to reduce the lapping diameter thrice and the weight of the machine 5-10 times. The lapping dimensions and at the same time that of the largest workpieces is 220-350 mm (Nekrasov et. al., 2006).

The lapping and polishing machine Rastr 220 was used as the equipment. The general view of the lapping and polishing machine is presented on Figure 2. The machine was designed for finishing various machine parts with precision flat surfaces. Rastr 220 is a desktop machine that consists of three main components: drive unit, screwdown structure, and control panel with frequency converter. The drive unit 1 comprises an electric motor and the transmission, lowering the speed of rotation and includes a mechanism that converts the rotation into an oscillating motion of the lapping and the device for the control of its trajectory. The screwdown structure 3 serves to clamp the workpieces to the lapping 2 with adjustable force and the possibility of announcing to the pieces the additional movement relative to the lapping by means of abrasive forces of friction. The machine is equipped with a control unit 4, which houses wiring, which allows to work in semi-automatic mode, and a frequency converter 5, allowing to variate the lapping vibration frequency in the range of 50-360 1/min, and programs the time for acceleration, deceleration, and the law of variation frequency variation.

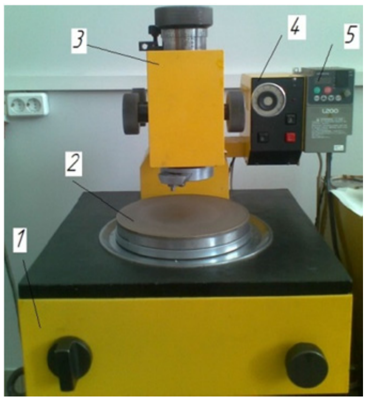

Figure 2. Lapping and grinding machine, Rastr 220

1 – drive unit, 2 – lap, 3 – screwdown structure,4 – remote control, 5 – frequency converter.

The kinematic scheme of the machine is shown in Figure 3. Drive unit. The electric motor 7 is tied by V-belt 5 with the intermediate shaft 21, which, through the belt transmission 2 is connected to two eccentric shafts l. The flywheels-balances 4 are mounted on the shafts, and their centers of gravity are directed to the sides opposing to eccentricities of shaft necks 1. By mutually perpendicular rods 3, the shafts 1 are connected to the face plate, on which the lap 19 is fixed.

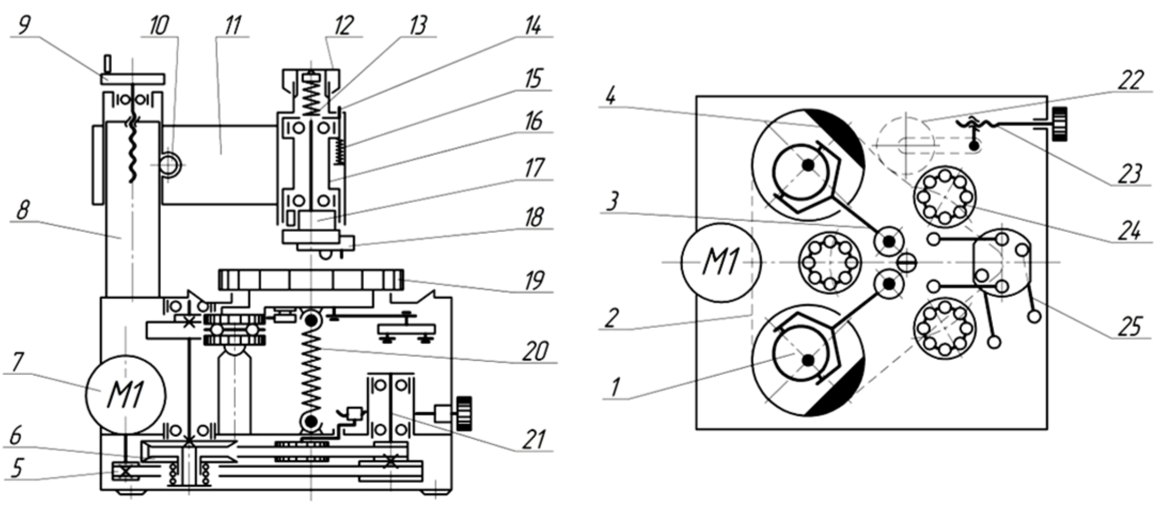

Figure 3. Kinematic scheme of the machine, Rastr 220

The face plate is located on three self-aligning ball bushings 24 and is pressed to them uniformly by the strain of central spring 20. By pantograph 25, the face plate is prevented from rotating, while maintaining freedom of movement in any direction of the horizontal plane. Such structure of the bearing and face plate in conjunction with the pivot suspension of the drive rods provides soft and quiet lapping motion and eliminates the influence of manufacturing errors on the accuracy of the machine. The speed variator 6 is mounted on one of the eccentric shafts 1, and on the other shaft - the unregulated pulley of the same diameter. The variator control is performed by a screw 23 connected via an angle lever with a pressure roller 22. During its displacement the roller alters the belt sag 2 and the radius of its contact with the variator 6, and the working tension of the belt is supported by an axial spring of the variator. In this way, the value of mutual oscillation frequency mismatch of the drive rods is adjusted infinitely, and such value determines the form of the lapping trajectory (Muratov et al, 2014).

The screwdown structure 11 is mounted on the column 8 and is fixed with the clamp 10. Lifting and lowering of the screwdown structure is made by the flywheel 9 using helical gear. The spring 13 is applied as the load-bearing element. The clamping pressure of the processed parts to the lapping is set by a flywheel 12 and is controlled by the indicator 14. The spring 15 serves for compensating the weight of moving parts. The central shaft 17 with freewheel unit is mounted on bearings in a movable sleeve 16 which is secured against rotation. The screwdown structure has the ability to communicate to the workpieces an extra slow circular movement through abrasive friction forces in the direction permitted by the freewheel that promotes for the uniform distribution of the treatment process along the lapping surface. The radius and speed of the additional movement is adjusted by radial displacement of sliding member 18 relative to the axis of rotation of the shaft 17.

The special devices (cassettes) are designed and used for proper orientation and uniform placement of workpieces on lapping, for creation of a uniform contact pressure during lapping. The structure of the tool shall be selected depending on the shape and dimensions of parts, the requirements imposed on them, as well as depending on the number of simultaneously processed workpieces. The task of equipment designing is complicated by requirements specified for the accuracy of the relative location of the piece working surfaces.

These requirements affect the design of devices and the locating method.

The testing of lapping process was conducted on the typical sizes of rings of siliconized graphite GAKK 55/40, TU 48-20-114-81 is shown on figures 4- 5.

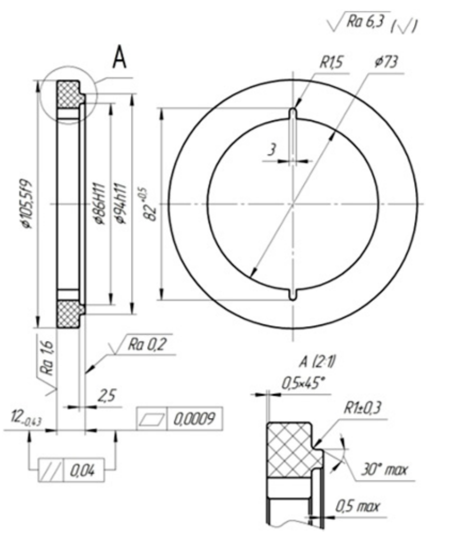

Figure 4. Non-rotating bearing

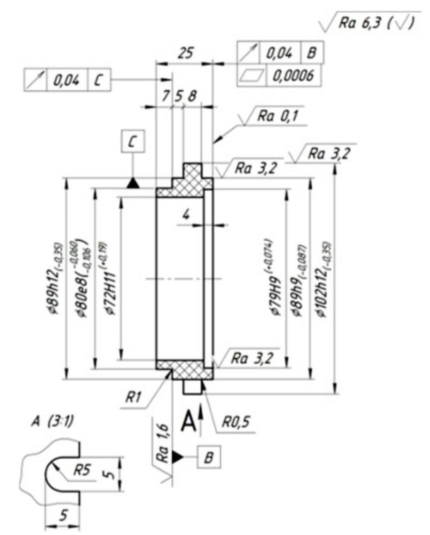

Figure 5. Rotating bearing

The main part of the experiments was carried out on the lappings (tools) of pearlitic cast iron (HB 160 ... .180) with the use of abrasive and diamond pastes and micropowders. On the final transitions the lapping plain circles of 6A2T shape, GOST 17007-80, having 200 mm in diameter made of synthetic diamond and cubic boron nitride (CBN) on metallic bond with the following characteristics were also tested: ACM 20/14 M2-01 4, KM 40/28 M5-22 50 and KM 28/20 M5-22 2 (PAO Catalogue "Poltavskiy Almazniy Instrument" (Poltava Diamond Tool), 2014).

In the lapping on these circles the mixture of kerosene (70%) oil, I20 (25%), and oleic acid (5%) by volume was used as the cooling mixture. Before lapping the mixture is applied to the plate in the amount of 0.8 - 1 cm3. During experiments of rings lapping a wide range of abrasive materials differing by type and grit of the abrasive was tested (Reznikov, 1977).

The following abrasive types were tested: White electrocorundum 24A; Green silicon carbide 63C-64C; Cubic boron nitride (CBN) - LM; Synthetic diamond ASM-ASN. During the experiments the abrasive grit was changing in the range of 40/28; 14/10; 7/5; 5/3 (Catalogue "Center Abrazivnogo Instrumenta" (Abrasive tool center), 2014).

The surface undulation was estimated by *Ra* µm - the surface average grit (Tebenkin et al 2007). The measurements were carried out on II type profile recorder, degree of accuracy 2, GOST 19300-86, model 170623, manufacturer "Calibr", OJSC. Before the measurements, the instrument was checked according to grit standards. In order to obtain reliable results in each series of experiments the grit was measured on different areas of the treated surface. The average value of *Ra* was determined by 8 - 12 measurements.

3. Results and Discussion

The multipiece arrangement for simultaneous treatment of three parts was designed and manufactured for lapping of rings made of siliconized graphite. The multipiece arrangement (Figure 6) consists of interchangeable inserts 2.3, caps 4 and carrier 1 with three spherical stops 5 or 6. The processed pieces with the appropriate inserts and covers are installed on the working surface of the lapping tool. The carrier 1 is superimposed so that the stops 5 and 6 were docked with conical holes of the relevant covers and inserts. The operating pressure of the workpieces processed for lapping is created by the screwdown structure of the machine by joining spherical stop and a drive lug mounted on the prism of the device with a central hole and groove of the carrier 1.

This design of the tool allows to compensate for different height of the workpieces processed and to their self-installing on the lapping surface, and that ensures an even distribution of pressure on each ring. Furthermore, the possibility of the radial displacement of stops 5 and 6 in the grooves of the carrier 1 allows to place pieces over the lapping surface evenly. This ensures the even lapping wear, improves and stabilizes the flatness of the lapped surfaces.

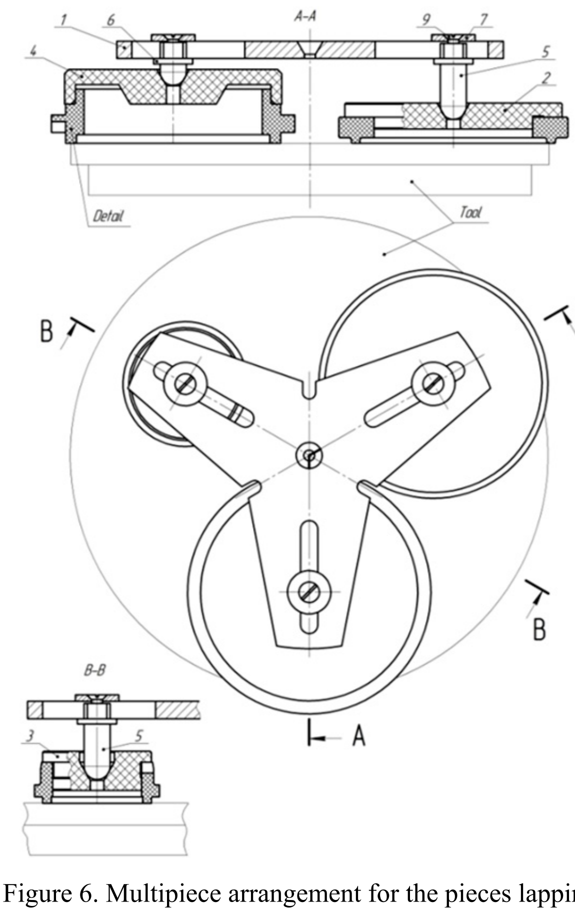

Figure 6. Multipiece arrangement for the pieces lapping

The device allows you to make lapping of pieces both similar and different in design and size. The design of the cases and inserts for medium and large rings allows to dock with the screwdown structure of the machine, which enables the individual fine-tuning of these pieces.

In the first stage different types of abrasive materials provided by experimental technique were tested. In comparative tests, the micropowders of single gritness of 14/10 microns were used. The lapping was performed in the multipiece arrangement and three workpieces were processed simultaneously. The tests were conducted on the basic modes, at a pressure of 30 kPa (0.3 kg / cm2). The time for lapping of three workpieces is 2 minutes. Each test was repeated 6 - 9 times. The results of experiments are presented in Table 1.

The comparative experiments have shown that conventional abrasives, such as white electrocorundum (24A) and green silicon carbide (63C and 64C) are not suitable for lapping of rings of material GAKK 55/40 because of very small takeoff performance and high surface indulation. This is because GAKK 55/40 for over 40% consists of solid phase of silicon carbide, the hardness of which is comparable with the hardness of 63C or 64C, and exceeds the hardness of white corundum 24A. Therefore, in the process of lapping the graphite alone is removed, exposing and slightly blunting the silicon carbide grains in the material of workpieces. Satisfactory and almost the same results of takeoff performance Q average µm/ min, and of the average great *Ra avg.* of the treated surface were obtained in the process of lapping of the same pieces with the synthetic diamond powders and ACM 14/10 and (CBN) cubic boron nitride LM 14/10(Table 1).

Table 1. Results of comparative experiments of the abrasive types

Abrasive type	Ring sample no.4, no.5		Ring sample no.3	
	Qavg, µm/ min	*Ra avg*, µm	*Qavg,* µm/ min	*Ra avg*, µm
White electrocorundum EBM 14/10	2	1.22	1.7	0.3
Green silicone carbide (GSC) 14/10	3.4	1.34	3	0.21
Synthetic diamond, ASM 14/10	15	0.22	17	0.15
Cubic boron nitride (CNB), LM 14/10	14.8	0.27	14	0.14

Therefore, all further experiments were carried out using standard pastes of ASM (synthetic diamond) and CBN of LM (cubic boron nitride) grade.

From the basic modes of siliconized graphite lapping the value of the contact pressure of the parts for the lapping and treatment time was experimentally determined. Experiments were carried out at the final lapping of pieces of "ring" and "bush" types. The contact pressure varied in the range of 30 - 80 kPa (0,3 - 0,8 kg / cm2). The lapping was performed using diamond (ASM) and boron nitride (LM) pastes with the gritness of 40/28 microns. The time for treatment of one load - 2 minutes. The results are presented in Table 2.

Table 2. The effect of the contact pressure value on the performance and surface undulation

P kPa	Paste ASM 40/28		Paste LM 40/28	
(kg/cm^2)	*Qavg,* µm/min	*Ra avg,* µm	*Qavg,* µm/min	*Ra avg,* µm
30 (0,3)	12	0.7	25	0.76
50 (0,5)	15.3	0.65	28.6	0.8
80 (0,8)	16.9	0.7	32	0.8

With the increase in the contact pressure about 3 times the takeoff efficiency increases by only 25 - 30% (Table 2). The surface undulation by *Ra* parameter remains practically unchanged. However, at a pressure of 50 kPa (0.5 kg / cm2) it is visually observed the heterogeneity of the treated surface, and at a pressure of 80 kPa (0.8 kg / cm2) the surface becomes blotchy and contains metallic "flashes". This is due to deterioration of access of abrasive mix into the working area, which leads to the periodic local contact of lapping with the treated surface. Furthermore, the excessive increase in pressure causes deformation of the workpiece and impairs the flatness of the treated surface. Therefore, it has been experimentally determined the optimum pressure, and all further experiments were carried out at a pressure not exceeding 30 kPa (0.3 kg / cm2).

Treatment time. In this case we consider the time for lapping of one workpiece, i.e. without changing the abrasive layer. The treatment time is often determined empirically as it depends on many factors: material of lapping and workpieces, abrasive material and consistency of the abrasive mixture, treatment conditions and so forth. It was experimentally established that at the lapping in multipiece arrangement of three or more pieces of siliconized graphite GAKK 55/40 it is not appropriate to set treatment time while processing one load for more than two minutes. This is due to the rapid accumulation of sludge in the form of graphite and microcutting products. For removal of large allowances it is appropriate to make treatment in multiple loads with periodic change of the abrasive layer.

Abrasive grit. At this stage of the experimental work a range of pastes with different abrasive grit in the range of 40/28 - 5/3 µm was tested. The tests were conducted on the basic modes, at the same contact pressure of 30 kPa (0.3 kg / cm2). The lapping was performed in the multipiece arrangement by three pieces. The results of experiments are shown in Table 3.

Table 3. The effect of the abrasive grit on the performance and grit of lapping process

Abrasive grit	Diamond ASM		CNB – LM; KM	
	Qavg, µm/ min	*Raavg,* µm	*Qavg,* µm/ min	*Raavg*, µm
40/28	15	0.54	25	0.60
14/10	14	0.22	14.8	0.27
10/7	7.5	0.14	8	0,16
7/5	6	0.084	________	_____
5/3	3	0.078	________	_____

With the increase of the abrasive grit, the takeoff efficiency and grit increase proportionally. Table 3 shows the average results of a large number of experiments conducted on different pieces (samples). This is because the parts of a composite material GAKK 55/40 have very inhomogeneous structure with many pores. To ensure the efficiency of the process and the desired quality of the treated surface it is advantageous to make lapping in two, three transitions with the decrease of abrasive grit.

In the lapping of pieces of composite materials based on siliconized graphite, the greatest difficulties are associated with determining the real grit of the treated surface after the final transitions. The difficulties are primarily due to the porosity of these materials. The pores introduce a large error in the assessment of the actual surface undulation especially after the finishing lapping with fine-grained abrasives.

For the objective assessment of the lapped surface a profilometer 107 622 was used, which allows to measure both the overall grit of the treated surface and to numerically evaluate the resulting grit, but excluding the porosity of the material. Measurement and evaluation were carried out in two stages. At the first stage the strip chart recording of the large area of the treated surface and automatic calculation of parameters of the overall grit was made. At the second stage the automatic calculation of grit parameters on the sections that do not contain deep pores, i.e, excluding the pores, was performed. This method of surface grit evaluation allows to determine the rational technology of finish lapping of the powder composite pieces.

The flatness of the lapped surface of the pieces was determined mainly by the errors of the form of a working lapping surface, which in turn depends on the degree of uneven wear. Therefore, to ensure the required flatness of the rings (0.0006 - 0.0009 mm) it is necessary to create conditions for uniform wear lapping. In the process of lapping in multipiece arrangement it is necessary to periodically change the position of pieces in the device in a radial direction relative to the center of the carrier so that the entire lapping surface was engaged in action.

In the process of lapping after polishing and their mutual flattening having a convex shape in the limits of 3 – 5 µm the unevenness of the lapped surface of pieces shall not be more than two interference fringes, that is not more than 0.5 µm. It was experimentally established that the uneven lapping wear in the shape of concave chamber of 0.015 – 0.020 mm increases the unevenness of the treated surface to four or more fringes, i.e. greater than 1 µm. If it is impossible to ensure the uniform load of the lapping surface, often - a central part, it is appropriate to decrease the lapping down to 0.05 - 0.1 mm.

Thus, in experimental studies of material finishing - siliconized graphite GAKK 55/40, the optimum regimes and processing conditions were defined. Recommended cutting modes: speed - 15 m / min, contact pressure - 20 - 40 kPa (0.2 - 0.4 kg / cm2), relative detuning of the drive rods oscillation frequencies - 8-10%. The maximum allowable time for lapping of one load is 2-3 minutes. Also it was experimentally established the unsuitability of conventional abrasives - white electrocorundum and green silicon carbide for lapping of siliconized graphite pieces. The lapping of pieces of such material shall be performed with the use of powders or pastes of synthetic diamond (ASM) or cubic boron nitride (CBN).

4. Conclusion

The process of "raster" lapping may be successfully used for finishing of rings' surfaces of siliconized graphite GAKK 55/40, as well as of the other grades of similar structure and composition. The lapping and polishing machine "Rastr 220" does not require the additional production spaces, it is easy in maintenance and adjustment, and can perform both group and routine treatment of pieces.

For lapping of pieces of siliconized graphite, it is advisable to use a multipiece arrangement. The devices must provide good self-aligning of pieces on the lapping surface.

The extensive experience in flat lapping accumulated by our team allowed us to formulate the following recommendations to be observed in the development of devices for lapping on the machines with "raster" tool kinematics:

1. The number of simultaneously machined pieces and their location in the device shall provide an even lapping wear. For this purpose, the axis of rotation of the tool shall be offset about its axis of symmetry to 5-15 mm. At the finishing, the device of larger diameter shall provide for periodic lapping bleed of the pieces by a certain amount. However, from the viewpoint of surface grit, a high lapping bleed of the pieces is not desired. In the process of lapping the device shall be fully loaded with pieces. In case of impossibility to meet these requirements the periodic change of the pieces position in it is necessary.

2. The height of the cassette with the pieces should be as small as possible. During lapping of pieces in very high cassettes, the flatness of the treated surface deteriorates due to the unstable position of the cassette.

3. To ensure parallelism of the treated and bearing surface of the workpiece the base cassette surfaces shall have sufficiently high flatness.

4. To compensate for the different height of the pieces, the cassette shall have elastic gaskets. Such gaskets ensure the uniform pressure of parts on the lap and the proper installation. In addition, the compensating pads protect bearing surfaces of pieces from damage (nicks, scratches, guide scratches).

5. The cassette housing must be sufficiently rigid because in case of small rigidity of the cassette the geometrical precision of the treated parts can be reduced.

6. In order to ensure high performance in serial production the device must be capable to simultaneously treat the largest possible number of pieces, easy and quick installation and removal thereof.

The flatness of the lapped three-piece surface shall be determined mainly by errors of the form of a working lapping surface, which in turn depends on the degree of uneven wear. Therefore, to ensure the required flatness of the rings (0.0006 - 0.0009 mm), it is necessary to create conditions for uniform wear lapping. In the process of lapping in the multipiece arrangement it is necessary to periodically change the position of pieces in the device in a radial direction relative to the center of the carrier that the entire lapping surface was engaged in action [4].

Also it was experimentally established the unsuitability of conventional abrasives - white electrocorundum and green silicon carbide for lapping of siliconized graphite pieces. The lapping of pieces of such material shall be performed with the use of powders or pastes of synthetic diamond (ASM) or cubic boron nitride (CBN).

To ensure the efficiency of the process and the desired quality of the treated surface, it is advantageous to make lapping in two, three transitions with a decrease in abrasive grit.

Recommended cutting modes: speed - 15 m / min, contact pressure of 20 - 40 kPa (0.2 - 0.4 kg / cm2), relative detuning of the oscillation frequencies of the drive rods 8-10%. The maximum allowable time for lapping of one load of parts is 2- 3 minutes.

In the finish lapping transitions, it is advisable to control both the overall roughness of the treated surface and the roughness excluding deep pores using computer profilometer 107622.

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