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**A. Malyarenko**, Professor, PhD, DSc. Eng[1,a],
**A. Sorokina**, Associate Professor, PhD[2,b]
[1,2]Belarusian National Technical University,
Belarus, 220013, Minsk, Nezavisimosty Ave, 65
[a,b]*amalyar@tut.by*

# INNOVATIVE TRENDS OF HIGH-PRECISION PARTS PROCESSING TECHNOLOGY IMPROVEMENT

*The directions of development of high-precision parts production technology have been considered. The results of the theoretical and experimental studies in the field of precision and qualitative parameters of processed surfaces management are reflected. Recommendations on the improvement of the technological process, equipment, tools and devices are given.*
***Keywords:*** *high-precision surfaces, operational development, management, lapping tools, equipment.*

## Introduction

The modern engineering moves to the reduction of weight and overall characteristics of product parts and growth of accuracy of their actuator surfaces. Any product, meeting these requirements, may include, for example, ball bearing suspension vehicles, gas shut-off ball valves and hydraulic equipment, implants, bearing rotor gyro navigation systems, a number of laser optical products and aerospace engineering products, as well as special-purpose devices.

The value of the permissible error of the surface shape of the parts of this class is less than the tolerance value 01workmanship, and it is tenths and hundredths of a light wave; macro and micro calculating errors are comparable, and the roughness value is 2 nm.

The range of the parts is large, and their seriality varies widely. Considering complexity and ambiguity of high-precision surfaces processing, the development of technological processes of the parts processing was under the authority of industry scientific and research technological institutes where highly skilled researchers, technologists and workers worked.

It took several months to perfect the technology for each part [1,2]. Because of multiple factors and uncertainty of forming process of high-precision surfaces the search for the suitable processing regimes depended on the skills and craftsmanship of the worker. Thus, in each case the worker identified intuitively the influence of the factors affecting these processes, with the help of multi-variance of possible solutions and poor stability of processing [3].

The technological process of manufacturing parts with precision surfaces includes the following set of operations: rough (preliminary) grinding blanks for the removal of the defective layer formed by blanking operations; blocking of work pieces for the device; diamond fine grinding of contacting surfaces in one or more transitions; contacting surfaces polishing; protective cover of the treated side parts; reblocking; repetition of all the above mentioned operations for the second side; flushing; centering; enlightenment and packaging. Control over the form precision and condition of the part surface is performed after each operation.

The most responsible and time-consuming operation is the polishing process, which is, in fact, operational development, which occupies 40% of the time on processing all the details. During this operation the basic quality indicators of the processed products are achieved. At present the lack of research in this area is a constraint for all-around automation of processing of optical parts.

Analyzing trends in precision surfaces finishing we can assume that the further development of the production of precision surfaces will not move towards creation of new, radically different processing methods, but towards automating and improving the organizational structure of production.

At present, there is no competing method in efficiency and precisionto the method of complete machining of surfaces. Therefore, the improvement of the process at this stage is on the way of intensification of production modes [4].

**Optimizing the design of process equipment**

It is very important to fix billet parts on the machine tool in manufacturing the process equipment. The block can be fixed with the electromagnetic field, if it is made of magnetic material, or by vacuum-pumping. It is possible to fix billet parts mechanically on thread, in the collet chuck, in the jaw chuck with a mechanical or pneumatic drive of chucks. Fixation the platen units with collet, bayonet and jaw chucks in vacuum and magnetic devices can be used in automated machinery [5].

The speed of a nog plate is one of the most important factors under grinding conditions. It is well-researched that of relative motion speed of the tool and a billetaffects the process of forming underdiamond fine grinding. The runout rate during the grinding and polishing of glass is in direct proportion to the average speed of the relative motion. The value and the rule of cutting speed instabilityat any point of the contacting surfaces of the tool and the unit depend on the values of the velocity components and toolpath contour on the part. According to kinematics there are no such conditions under which steady operation of globular laps is possible [2,3].

Not absolute values of the speed of rotation of the spindle and crank, but their ratio affect significantly on changing the shape of the surface. To determine the length and location of the cumulative motionpath of the unit conjugate points and the tool just to forecast the shape of fading surface. During the traditional manufacturing process of optical parts a workercan change the parameters of the toolpath contour adjusting the hatch length and the tool overhang. So a worker can modify the nature and the speed of the stock removal. That means the technological equipment should provide the equality of the cumulative motions for steady operation of the glass and the tool degradation, and also the possibility to adjust the length of cumulative motions paths to reallocate the switching values of the glass and the tool overhang [6,7].

The rotation frequency of modern machine tools skirt is measured in hundreds and thousands of revolutions per minute. However, an increase of the skirt speed doesn't lead to a proportional increase of processing intensity. The dependence of the processing intensity on the relative velocity and the physical aspects of this phenomenon are not sufficiently studied that doesn't allow to givescience-based guidelines for choosing the speed range of the tool and the part [8].

**The peculiarities of the forming process control**

The control of the pressure variation is the greatest complication when controlling forming. The pressure variation during finishing affects crucially a lot of running abilities of the items and particularly the radiation resistance. It demands a special approach to the problem of processing the surfaces of lasers. But this characteristic for the majority of products is not limited and it proves the effort to find a possibility to intensify the process at the expense of the pressure boost at the final stage of processing procedure.

Heretofore the problem of the pressure variation appropriateness has not been sold yet when processing to form spherical surfaces with a glance to the level of running-in and the tool overrunning the edge of one item as well as a group of items glued in a nest. Lever control, pneumatic actuators, and mechanisms for ancillary horizontal transfer of the affecting lap columnare used to provide permanency of the specific operating pressure.

The problem of an item surface shape control during processing arose simultaneously with optical details appearance. But it has not been solved completely yet despite great progress, made by national and foreign researchers in the field of optical engineering [2,3,8].

They consider Preston's hypothesis as one of the first postulates about the control of the forming process; there he supposed the quantity of the material, dispersed in unit time, was in proportion to the product of the normal pressure and the relative motion speed of the surfaces. Subsequently other researchers proved that hypothesis. The instantaneous velocity vector of abrasive particles is equal in absolute value in the points of contact with the tool, as the values of the instant local force impact are. Simultaneously it is possible to detect the magnitude of the bearing face deterioration in the post space of time. The slip (cutting) speeds of processing in different points of bearing faces subject to the relative position of the tool and the item are constantly changing. The pressure distribution in these points is unequal either and its value depends on the running-in extent of the bearing twain, the relative position, the tool and the item shapes, the presence of liquid in the contact zone, etc.

There are widely used methods of the tool mechanical trajectory control with zone by zone processing. This method gives a possibility to maintain a special regime of processing for every separate zone of the processed surface, for example, hold-down pressure and cutting speed according to the specified rules. The research in the given direction is being done in the CIS and abroad.

The other method of forming process control is changing the number of a tool and an item revolutions according to the specified rule and their relative position in processing.

The accepted physical model of abrasive dispersion process is described satisfactorily by kinematic equations which allow detecting the lengths of sliding distances *L* in each zone of the item and the tool surfaces [5]. The overall length of the sliding distance during the kinematic cycle of the process *T* in the zone area *S*, located random on the analyzed surface, is defined by the equation

$$L = \left[\iint_S \left(\int_T V_p \cdot dt\right) ds\right] \Big/ \iint_S ds, \qquad (1)$$

where Vp is a speed of grinding, polishing or lapping.

While using the developed mathematical model for analysis of the existing diamond fine grinding processing procedure, the calculation of the overall length of the sliding distance distribution along the item and the tool zones of sphere has been performed and the general tendency of the sliding distance distribution for routine processing procedures has been detected; the tendency can be satisfactorily described by the equation

$$\frac{L_i}{L\max_i} = \sqrt{1 - \left(\frac{\gamma_i}{\alpha \cdot \gamma \max_i}\right)^2}, \qquad (2)$$

where $L_1$ is the length of the sliding distance in the zone of sphere with angular coordinate $\gamma_i (0 \le \gamma_i \le \gamma_{\max i})$; $L_{\max i}$ is the longest of the sliding distances; $\gamma_{\max}$ is a half of the apex angle of the tool or the item spherical calotte; $\alpha = 2/\sqrt{3}$ is a constant coefficient.

That dependence has been chosen as the model distribution of sliding distances [6]. The model distribution of relative sliding distances can be shown in diagram form as a part of ellipse where $L_i / L_{max}$in the central zone (if $\gamma_i$ =0) is 1 and in the peripheral zone (if $\gamma_i = \gamma_{\max i}$) is 0,5.

Despite the similarity in the kinematics of forming the fitting-in and setup processes vary first of all in the fact that during fitting-in the speed of stock removal from the item is exceeds considerably tool deterioration and the processing is carried out according to form-copying method when the form of the tool is transferred to the item. The specified curvature retention of the lap operating surface is of primary importance. When developing the speed the alterations of the forms of the tool and the item are corresponding. Besides that the processing during developing is done with loose abrasive existing as aqueous suspension between the surfaces of the tool and the item. In connection with the above-mentioned the methods and criteria, used to define the processing regimes during lapping, can be used only as preliminary tentative calculations which allow to narrow the diapasons of measuring the parameters of lapping to search the optimal combination.

Series of experimental and theoretical surveys have been carried out to set the criteria to optimize lapping of optical surfaces which allow setting the processing regimes without preliminary processing. When carrying out experiments they have been learning the influence on the processing accuracy of set (driver rocking amplitude, driver bias about the bottom spindle rotation axis, the bottom spindle hoisting height) and kinematic (the upper unit rotating frequency and the bottom unit oscillation frequency) processing parameters. During each experiment, to detect the influence of the cutting regime parameters upon the processing accuracy, only one parameter varied with recording the values of the others. The alteration limits of the parameters and their values were set in concordance with the calculations of the preferable values of processing parameters.

The computational investigation of the influence of the processing regimes upon the distribution of sliding distances along the zones of sphere on the item was conducted simultaneously with the full-scale experiment. It is necessary to pay attention to the fact that for diamond fine grinding wedetected the distribution of sliding distances along the tool surface rather than an item. That is the difference of approaches to modeling of lapping processes and adjustment on the level of analysis of kinematics. The parameters values, used in the computational investigation, have agreed with the processing regimes values during the full-scale experiment.

To detect the most favorable combination of the processing parameters it is recommended, at first, to limit the alternation diapasons for providing profitable tool operation. The comparison of the experimental and calculated values shows that the given criterion is achieved if the distribution of relative sliding distances $L^{И}_i/L^{И}_{max}$ corresponds to the criterion

$$\sqrt{1-\left(\frac{\gamma_i}{1{,}06\cdot\gamma_{\max i}}\right)^2} \le \frac{L_i}{L_{\max i}} \le \sqrt{1-\left(\frac{\gamma_i}{1{,}25\cdot\gamma_{\max i}}\right)^2}, \qquad (3)$$

where $\gamma_{\max i}$ is a half of the apex angle of the tool surface spherical calotte; $\gamma_i$ is the angular coordinate of I- zone of sphere $(0 \le \gamma_i \le \gamma_{\max i})$.

After limitation of the possible alternation diapason the search of the optimal combination of the lapping parameters should be conducted providing preferable conditions for stock removal from the item. To meet this condition the following criteria of lapping are specified [9]:

decreasing of the overall sliding distance along zone of sphere of the item when withdrawing off the central zone (the criterion of lack of growth) id est $L_{i-1}^{d} > L_{i}^{d}$;

minimal increasing of the overall sliding distance along the item zones (the criterion of smoothness)

$$\sum \left(L_{i-1}^{d} > L_{i}^{d}\right)^{2} \to min \quad (4)$$

where $L_{i}^{d}$, $L_{i-1}^{d}$ are the sliding distances in simultaneouslyandi-1 zones.

Diverse combinations of values of fixing and kinematic parameters allow receiving various trajectories of relative movement of the tool and the item points. The alternation of those trajectories causes the alternation of the form of the processed surface when lapping. To alternate the form of the processed surfaces, when lapping optical details, workers use, as a rule, one or two of the above-mentioned parameters. The choice of the alternating parameter and the adjusting diapason depend on the design of the applied equipment, workers'qualification and intuition, and, as a rule, are not formalized. The offered criteria allow choosing the optimal combinations of the setup and kinematics parameters of forming, taking into consideration the applied process equipment of any design, and create conditions for transfer from the anthropological principle in design of multilimbed machine tools for polishing and lapping of optical surfaces which imitate workers' hands motions to functional principle of design process equipment of simplified kinematics [10].

**Ways to improve constructions of process equipment**

The design feature of the newly created equipment is the creation of mechanisms automatic changing adjustment of the tool point path relatively to the processed surface and the landed force value, the stabilization of the pressure distribution in the contact area, and equipping machine tool with program control systems.

Spherical grinding machines with a diamond annular cutting tool became widespread for pre-shaping. The basic principle of these machines operation is a diagram of "hard axis". In this case, the item and the tool rotate around a fixed symmetry axis, whichintersect at a certain fixed angle. This scheme is based on the principle of the spherical grinding machines like "Almaz" (Diamond), АШС (Spherical grinding machine), Ш-150К (Grinding machine-150K), etc. [1, 5].

What concerns lapping equipment it is determined that the previously created machine tool holding meets neither constructive nor intellectual aspects of modern requirements, facing the optical industry. Today samples of the equipment which have the required range of opportunities haven`t been created, moreover, there is no solution to a number of technological problems prior to the development of such machines.

Linkages (hinged four, two-crank lever-hinge mechanism, rocker mechanism, a combination of slider-crank, rocker mechanism and hinged four and others) have been widely used in the design of optical machines due to their simplicity and manufacturability. The disadvantages of these mechanisms include long kinematic chain and the presence of the reverse movement of units at the extreme points, which prevents the increased productivity of the process by increasing the frequency of oscillation output link. However, they do the relatively easy resizing of the links in the process, which makes it possible to control automatically the path of the tool.

Using the planetary and differential drive mechanisms eliminates the reverse output link of the machine. The adjustment of the planetary mechanism eccentricity in processing allows you to control automatically the toolpath [11]. However, such devices are cumbersome and difficult to manufacture.

Over the last decades the situation has changed dramatically with the production of precision parts in the Commonwealth of Independent States. Earlier the optical industry plants specialized mainly in serial and mass production. The current annual production of goods fell sharply in the constant expansion of the range of parts and their complexity. Nowadays businesses need equipment with the following features:

- the possibility to readjust a machine quickly for processing details of different radius of curvature (from $\infty$ to 0);
- an effective control system for formation process with feedback;
- a high degree of mutual unification (up to 80 - 85%) of the equipment for preliminary spherical grinding, fine diamond grinding and polishing.

**Optimization of the processing tool constructions**

The improvement of the processing tool is moving towards creating of the constructions providing: first, increase in size resistance of the tool; guaranteed and sufficient supply of cutting lubricant and abrasive suspension to processed details; second, division of the full-sized tool into separate elements and creation of the most favorable processing conditions by adjustingpower and speed parameters on the elements according to their position on a detail surface; and third, stabilizing of pressure in processed zone.

They have developed special constructions of adjustable and elastic tab grinding/lapping. It allows obtaining the given shape of processed surface and constancy of working pressure in the tool contact zone with a product irrespective of distance between the contact point and the center of work force application.Much attention is given to processing carried out with the help of the tool-"mask" which active elements are distributed on the surface of working area in a certain order. In the process of the tool application for final processing of optical surfaces it has been found out that its dimensional resistance is unsatisfactory in several cases. Besides, low stability of grinding/lapping operation has been observed. Thus the tasks of control over the shape of a processed detail and the tool in the course of forming as well as design of tool possessing high size resistance are highlighted [12].

In the course of processing the essential role is given to liquid surroundings in the processed zone. Its composition, physical and chemical characteristics influence the process productivity and the tool operation stability. Polishing of optical detail surfaces takes place in the obligatory liquid suspension of special abrasive powder, and grinding takes place in cutting lubricant. Thus, in addition to chemical impact on glass and wedging effect in micro cracks, this presence of liquid with certain speed values of relative motion and landed force can lead to "emersion" of polisher. As a result, the intensity of stock removal is declining, and in certain cases it can stop abrasive dispersion process. Observed "suction” of the polisher to glass and its "emersion" at the initial stage of the process is testified the above phenomena being possible.

During processing the temperature of abrasive suspension, motion speed and landed force influence the amount of the liquid interlayer between the tool and the part surfaces. It is followed by forcedcutting lubricantleak, which is accompanied by a considerable increase in hydrodynamic pressure. This pressure value can be decreased, for example, with the help of plotting grooves on the cutting surface of the tool, or with the help of application of porous couplants, etc. The conducted researches have established that the hydrodynamic phenomena in contact zone of lapping and processed surface in the course of finishing have essential impact on accuracy and forming productivity. Lapping performance is influenced not only by ratio of the tool working section areas, but also dimensions, configuration and quantity of intervals between these sections which are the channels for polishing suspension, and it is possible to select a tool with the optimum shape of channels for each mode of finishing [12].

The angle of channel curvature has essential effect on a hydraulic gap value between the tool and the part. This angle enlargement leads to hydraulic power growing; as it is required to strip the liquid out of the processed zone. Therefore, the amount of liquid in inter-object space also expands. It leads to growingof the elevating force affecting the tool, expanding the distance between adjoining surfaces of lapping and the part, it also leads to changing of inertial and tractive characteristics of gear tool detail, and as a result to declining in production. The use of grooves bent in the direction following the tool rotation allows receiving a smaller gap value between the tool and the detail, than when using direct channels even with double value of summary flow section. In case of tool rotation in the direction opposite to channel curvature, gaps prove to be the biggest and at high speed they even exceed liquid layers between detail and entire tool.

The technique of polisher working surface design has been developed [4]. It enables to configure inter tabliquid channels in order to lower hydrodynamic lifting force whenever there occurs an increase in high-speed parameters of processing and achieve it in an optimum way. Efficiency of this technique went through the experimental checks. As a result of the conducted researches it was established that the optimum choice of channel geometry forcutting lubricantallows increasing productivity by at least 20% while saving fixed processing accuracy. Thus, productivity increase without essential accuracy deterioration if one toughens processing modes is achievable through increase in kinematic parameters of polishing with simultaneous corrections in the configuration of working section of lapping.

The process of abrasive dispersion is accompanied by certain quantity of energy emission in the area of cutting. Intensification of modes leads to grow warmth emission. In order to stabilize processing and to manage effectively the process of optical detail finishing one needs to keep the form and original properties of the tool bottom layers. Due to the temperature in the area of cutting applied colophony-foam pitch polishers get soft and acquire half–finished form. At the same time workers adjust the processing by plotting a grid of scratches on pitch working surface of the polisher in the central or edge areas depending on the sizes received and the form of a processed detail surface. In automatic cycle similar additional operations are completely unacceptable. Film polishing bottom layers based on foam polyurethane, which are widely spread today, have acquired a good reputation in production.

In the course of processing, due to a very narrow range of tolerance on the size (radius) of processed surface (0,01... 0,1 microns), the tool with diamond as well as with polyurethane bottom layer is sensitive to temperature fluctuations in the technological environment. It has been established that temperature of polishing suspension has essential impact on the accuracy of form of the processed surface and productivity of polishing process. Besides, an opportunity has been found to manage effectively the forming process when polishing optical details by means of changing the temperature of polishing suspension.

Precision of the optical surfaces shapes processed by the tool with a polyurethane foam bottom layer, when the temperatureof polishing suspension can vary, is connected with the change of polishing tool shapeprecision (of curvature radius). The brand of glass and change of detail thickness don't influence the dependence of precious shape on polishing suspension temperature. Radius of processed surfaces curvature enlarges whenthe temperature grows [13]. Analysis of thermo elastic state of lapping proved that form of the tool case transverse section has its impact on a local error occurrence (a deviation from sphericity) of processed surface with any change of technological environment temperature. Thermal deformations of the tool case increasing from center to the periphery of thickness distort sphericity of the surface at the greatest degree. As for the tool with thickness decreasing from center to the periphery distortion of sphericity develops at the smallest degree. However a change of profile makes it possible to adjust the form received [14]. This observation can be used not only to control the process of receiving a spherical surface, but also for a surface asferization.

Comparative production tests displayed operation stability and 3-4 times increase in size resistance of polishing tool, which working part configuration was developed projected taking into account hydrodynamic effect influence in the course of finishing, in comparison with the tool designed without these phenomena, and more than 10 times in comparison with a continuous polisher [15].

**Conclusion**

The article has formulated the criteria for the optimization of the kinematical and adjustment parameters of the data processing modes for the particular operations. The selection of the operating modes on the basis of established criteria can improve the productivity in the operations in question by 25%.

The hydrodynamic phenomena can occur in the contact area of the lapping block and working surface during the finishing and can have a significant impact on the accuracy and efficiency of the process. It is possible to increase the productivity of finishing,and at the same time tokeep a predetermined precision of the shape of the item, due to growth the tool rotating frequency.Simultaneously it is necessary to adjust the working area lapping configuration, and the shape and the location of the channels for supplying polishing soliquid to suppress the polishing pad surfacing effect under the action of the hydrodynamic force. The optimization of the channel configurations leads to the increase in the productivity and processing accuracy compared with the conventional tool lapping for not less than 20%.

The temperature of the processing environment has a significant effect on the deviation of the curvature radius of the machined surface from the standard (overall form N error) and on the productivity of the finishing process. The overall form N error, when the temperature of the polishing soliquid changes, is related to the change in the curvature radius of the polishing tool.The radiusenlarges with the temperature rise of the processing environment. It is proved theoretically and confirmed by the practice of the optical engineering that the lapping cabinet construction with membranous polishing pad has impact on the working area deviation from spherical (a local form ΔN error) when the temperature of the processing medium changes.

The system approach takes into consideration the physical phenomena occurring in the contact zone "tool – part" and in the system "machine – device" at various production stages, the technology process optimization, the applied equipment design improvement.Based on this approach the processing technology formanufacturing the precision itemscontacting surfaceshas allowed increasing the processing productivity by 25...30%, reducing faulty production to 10...15%, cutting the required qualifications of workers from class 6 to class 3.

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**А. Маляренко, А. Сорокина**

**ИННОВАЦИОННЫЕ ТЕНДЕНЦИИ СОВЕРШЕНСТВОВАНИЯ ТЕХНОЛОГИЯ ОБРАБОТКИ ВЫСОКОТОЧНЫХ ДЕТАЛЕЙ**

*Были рассмотрены направления развития технологии производства высокоточных деталей. Отражены результаты теоретических и экспериментальных исследований в области управления точностью и качественными параметрами обрабатываемой поверхности. Приведены рекомендации по улучшению технологического процесса, оборудования, приборов и устройств.*

***Ключевые слова:*** *высокоточные поверхности, доводка, менеджмент, доводочные инструменты, оборудование.*

**А. Маляренко, А. Сорокіна**

**ІННОВАЦІЙНІ ТЕНДЕНЦІЇ ВДОСКОНАЛЕННЯ ТЕХНОЛОГІЯ ОБРОБКИ ВИСОКОТОЧНИХ ДЕТАЛЕЙ**

*Були розглянуті напрямки розвитку технології виробництва високоточних деталей. Відображені результати теоретичних і експериментальних досліджень в галузі управління точністю і якісними параметрами оброблюваної поверхні. Наведено рекомендації щодо поліпшення технологічного процесу, обладнання, приладів і пристроїв.*

***Ключові слова:*** *високоточні поверхні, доведення, менеджмент, довідні інструменти, обладнання.*