Method for Increasing of Lens Gluing Technological Process Efficiency and a Reliable Evaluation of Output Controlled Parameters

R.V. Fiodortsev[1], E.A. Metelskaya[2], V.A. Marchik[2], A.V. Kuznetsov[1,2], A.E. Makarevich[2]

[1]*Belarusian National Technical University,*
Nezavisimosty Ave., 65, Minsk 220013, Belarus
[2]*JSC "Peleng",*
Makayonka str., 2, Minsk 220114, Belarus

Received 04.10.2021
Accepted for publication 08.02.2022

Abstract

The use of glued lens components in optical devices improves the image quality of telescopic and photographic lenses or inverting systems by eliminating a number of aberrations, and also reduces light losses in the optical system of the device. The traditional production process of lenses gluing involves the sequential execution of a set of technological operations and takes a significant period of time. The purpose of the research was to improve the accuracy and productivity of the technological process of lenses gluing by improving the optical system of the control and measuring device and automating the operation of lenses optical axes combining by introducing an electronic reference system and mechanisms for micro-movements of optical parts.

A technique is proposed for centering of two and three-component optical blocks by an autocollimation flare which provides a matching accuracy of less than 0.5 μm. The possibility of constructive modernization of the classic ST-41 autocollimation microscope with parallel separation of the displayed output information in the visual and television channels is shown. An automated system for controlling of the process of convergence of autocollimation points in the device is proposed. Using software methods an electronic grid template is formed on the monitor screen, onto which images of autocollimation points are projected. The decentering value $2\Delta e$ is determined and a corrective control voltage is applied to three stepper motors and pushers for transverse movement of the glued optical part.

Specialized software has been developed for automatically bringing the position of the autocollimating crosshair to the center of the measuring scale of the grid based on a combination of two methods of "least squares" and "successive approximation". Compliance with a number of technological transitions and the accompanying control of geometric parameters make it possible to achieve greater accuracy in determining the eccentricity of the crosshairs of the aligned optical axes of the glued lenses.

Keywords: decentering, lens, crosshair, optical axis.

DOI: 10.21122/2220-9506-2022-13-1-50-59

Адрес для переписки:
Фёдорцев Р.В.
Белорусский национальный технический университет,
пр-т Независимости, 65, г. Минск 220013, Беларусь
e-mail: feod@tut.by

Address for correspondence:
Fiodortsev R.V.
Belarusian National Technical University,
Nezavisimosty Ave., 65, Minsk 220013, Belarus
e-mail: feod@tut.by

Для цитирования:
R.V. Fiodortsev, E.A. Metelskaya, V.A. Marchik, A.V. Kuznetsov, A.E. Makarevich.
Method for Increasing of Lens Gluing Technological Process Efficiency and a Reliable Evaluation of Output Controlled Parameters.
Приборы и методы измерений.
2022. – Т. 13, № 1. – С. 50–59.
DOI: 10.21122/2220-9506-2022-13-1-50-59

For citation:
R.V. Fiodortsev, E.A. Metelskaya, V.A. Marchik, A.V. Kuznetsov, A.E. Makarevich.
Method for Increasing of Lens Gluing Technological Process Efficiency and a Reliable Evaluation of Output Controlled Parameters.
Devices and Methods of Measurements.
2022, vol. 13, no. 1, pp. 50–59.
DOI: 10.21122/2220-9506-2022-13-1-50-59

Devices and Methods of Measurements
2022, vol. 13, no. 1, pp. 50–59
R.V. Fiodortsev et al.

Метод повышения эффективности технологического процесса склейки линз и достоверная оценка выходных контролируемых параметров

Р.В. Фёдорцев[1], Е.А. Метельская[2], В.А. Марчик[2], А.В. Кузнецов[1,2], А.Е. Макаревич[2]

[1]Белорусский национальный технический университет
пр-т Независимости, 65, г. Минск 220013, Беларусь

[2]ОАО «Пеленг»,
ул. Макаёнка, 25, г. Минск 220114, Беларусь

Поступила 04.10.2021
Принята к печати 08.02.2022

Применение в оптических приборах склеенных линзовых компонентов позволяет повысить качество изображения телескопических и фотографических объективов или оборачивающих систем за счёт устранения ряда аберраций, а также обеспечивает уменьшение световых потерь в оптической системе прибора. Традиционный производственный процесс склеивания линз предусматривает последовательное выполнение комплекса технологических операций и занимает существенный промежуток времени. Цель исследований заключалась в повышении точности и производительности технологического процесса склейки линз за счёт совершенствования оптической системы контрольно-измерительного прибора и автоматизации операции совмещения оптических осей линз путём введения электронной системы отсчёта и механизмов для микроперемещений оптических деталей.

Предложена методика центрирования двух- и трёхкомпонентных оптических блоков по автоколлимационному блику, обеспечивающая точность совмещения менее 0,5 мкм. Показана возможность конструктивной модернизации классического автоколлимационного микроскопа СТ-41 с параллельным разделением отображаемой выходной информации в визуальном и телевизионном каналах. Предложена автоматизированная система управления процессом сведения автоколлимационных точек в приборе. Программными методами на экране монитора формируется шаблон электронной сетки, на которую проецируются изображения автоколлимационных точек, определяется величина децентричности $2\Delta e$ и подаётся корректирующее управляющее напряжение на три шаговых двигателя и толкатели для поперечной подвижки приклеиваемой оптической детали.

Разработано специализированное программное обеспечение для автоматического сведения положения автоколлимационного перекрестия в центр измерительной шкалы сетки, основанное на сочетании двух методов – «наименьших квадратов» и «последовательного приближения». Соблюдение ряда технологических переходов и сопутствующий контроль геометрических параметров позволяют добиться большей точности при определении величины эксцентриситета перекрестия совмещаемых оптических осей склеиваемых линз.

Ключевые слова: децентрировка, линза, перекрестие, оптическая ось.

DOI: 10.21122/2220-9506-2022-13-1-50-59

Адрес для переписки:
Фёдорцев Р.В.
Белорусский национальный технический университет,
пр-т Независимости, 65, г. Минск 220013, Беларусь
e-mail: feod@tut.by

Address for correspondence:
Fiodortsev R.V.
Belarusian National Technical University,
Nezavisimosty Ave., 65, Minsk 220013, Belarus
e-mail: feod@tut.by

Для цитирования:
R.V. Fiodortsev, E.A. Metelskaya, V.A. Marchik, A.V. Kuznetsov, A.E. Makarevich.
Method for Increasing of Lens Gluing Technological Process Efficiency and a Reliable Evaluation of Output Controlled Parameters.
Приборы и методы измерений.
2022. – Т. 13, № 1. – С. 50–59.
DOI: 10.21122/2220-9506-2022-13-1-50-59

For citation:
R.V. Fiodortsev, E.A. Metelskaya, V.A. Marchik, A.V. Kuznetsov, A.E. Makarevich.
Method for Increasing of Lens Gluing Technological Process Efficiency and a Reliable Evaluation of Output Controlled Parameters.
Devices and Methods of Measurements.
2022, vol. 13, no. 1, pp. 50–59.
DOI: 10.21122/2220-9506-2022-13-1-50-59

Introduction

The use of glued lens components in optical devices can significantly improve the image quality of telescopic and photographic lenses or enveloping systems by eliminating chromatic and spherical aberrations, coma, and also reduces light losses in the optical system of the device by up to 10 % compared to by an independent mechanical method of each part fixing [1, 2].

The traditional production process of lenses from optical glass gluing provides for the sequential execution of a number of technological operations: the assembly of optical parts according to the shape accuracy of mating spherical surfaces within a given tolerance; cleaning the working surfaces of parts from various kinds of contaminants; applying a layer of glue on a concave surface, pressing and maintaining a uniform thickness within 0.005–0.02 mm; mutual centering of glued optical parts (combination of optical and geometric axes) by means of autocollimation instrumentation; if necessary, heating the parts in a thermal chamber to a temperature (70–130 °C) when gluing with a polymerizing optical adhesive; holding the set position and cooling the glued component to room temperature 20–45 °C (polymerization) for 1–4 days, depending on the brand of glue used (GOST 14887).

Thus the technological process of optical parts gluing is determined by a set of parameters: the brand and properties of the adhesive used (GOST 14887-80), the dimensions and material of the original elements, the error of the mating surfaces (no more than N = 3–5 interference Newton's rings of a common "pit"), surface cleanliness P, as well as technical requirements for the connection (thermal, mechanical and chemical resistance).

One of the options for reducing the time of this technological operation is the use of two-component adhesives with high adhesion based on epoxy resin or acrylate with fast polymerization under the influence of ultraviolet radiation (for example, FEK1-15, Vitralit 1505 and 1527 Panacol) for 0.2–1 minutes [3, 4]. The third alternative and effective way to connect optical parts is to use the optical contact method (Solaris Optics) or diffuse connection [5]. However there are physical limitations of application, in particular, the difference in the thermal expansion coefficients of the mating optical materials which reduces the resistance of the connection with significant temperature drops, etc.

The purpose of the research was to increase the accuracy and productivity of the technological process of lenses gluing by improving the optical system of the control and measuring device and automating the operation of combining of lenses optical axes by introducing an electronic reference system and mechanisms for micro-movements of optical parts.

Geometric parameters that determine the centering accuracy

In the design drawings of an optical part or a glued block, the centering error is specified (Figures 1 and 2):

– positional tolerance of the center of curvature (C_B, C_M, C_H);

– the difference in thickness over the diameter of the lens (Δ) or a flat surface;

– face runout of a flat surface.

The method of lens centering by autocollimation flare is applicable for optical parts with a diameter of 3 to 150 mm.

According to the design requirements and functional purpose of the optical part, the total outer diameter of the base lens is assigned a tolerance in the range $f6$–$e9$, for the glued one – $d10$–$c11$. It is allowed to make a glued lens with a reduced nominal diameter compared to the base lens by 0.2–0.4 mm per diameter. The tolerance for decentering of the base lens is assigned more stringent than the tolerance for the glued lens. This moment is significant when the refractive index of the material of the glued lens actually coincides with the refractive index of the adhesive. As a result, the thickness of the glue can have a certain effect on the construction of the path of rays and introduce aberrations into the optical system.

The amount of decentering, determined based on the error of alignment of auto-collimation points (O_1, O_2, etc.) (Figure 3) and is calculated by the formula:

$$\Delta e_i = C_{devi} \cdot R_i / [(n_i - 1) \cdot f_i'],$$

where C_{devi} is the displacement of the nodal point from the optical axis, determined by the flare; R_i is the radius of the controlled surface; n_i is the refractive index of the material of the optical part; f_i' is the focal length of the controlled lens.

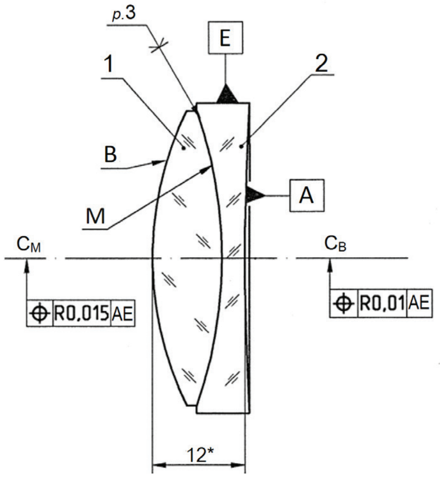


Figure 1 – Glued block of two lenses: 1 – positive meniscus; 2 – negative meniscus; A – basic supporting surface; B, M – working spherical surfaces; E – landing cylindrical surface; C_B, C_M – centers of curvature

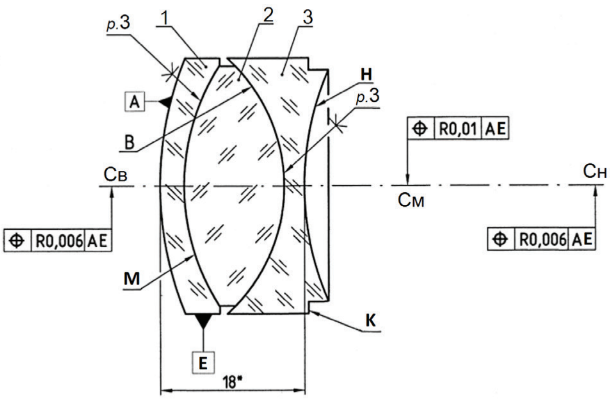


Figure 2 – Glued block of three lenses: 1 – convex-concave lens; 2 – positive meniscus; 3 – negative meniscus; A – basic supporting surface; M, B, H – working spherical surfaces; E – landing cylindrical surface; K – annular support end; C_M, C_B, C_H – centers of curvature

In accordance with ISO 10110-1, there is also a second method for estimating the amount of decentering through the angle of inclination of a separate spherical surface (γ) formed between the normal ($O_3'O_2'$) with the center of curvature O_2' and the reference axis (O_3O_2) [6, 7].

The criterion for assessing the complexity of the mechanical method of lens centering is the ratio of the clamping angle φ and decentering tolerance Δ*e* (Table 1) [8, 9].

Figure 4 shows the sequence of transitions during centering: scheme on the left (*a*) installation of lens 3 along the main base spherical surface A on the support ring 1 and fixation along the auxiliary base cylindrical surface D in the angle 2 at an angle φ – control of decentering parameter Δ*e*; scheme on the right (*b*) installation of lens unit 3 on a flat support surface G with control of the difference in inclination angles Δγ.

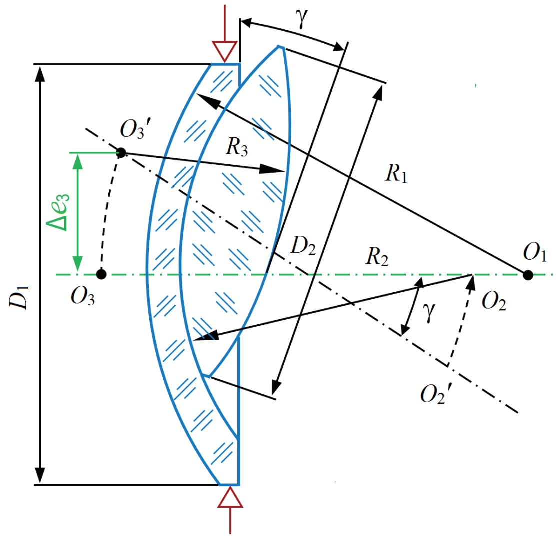


Figure 3 – The main parameters for determining the decentering

Table 1

Permissible decentering values for lenses of various optical instruments

Centering accuracy (complexity category)	Numerical tolerance value Δ*e*	Clamping angle φ, deg.	Scope in optical devices
High (I)	0.002… 0.005 mm	<12	microscopes, photographic and projection, interferometers
Medium (II)	0.005… 0.01 mm	12–18	telescopic systems and wrapping systems
Reduced (III)	0.01… 0.02 mm	18–23	geodetic and goniometric (goniometers, levels, theodolites)
Low (IV)	0.02 and more, mm	>23	spectral, polarization, refractometric

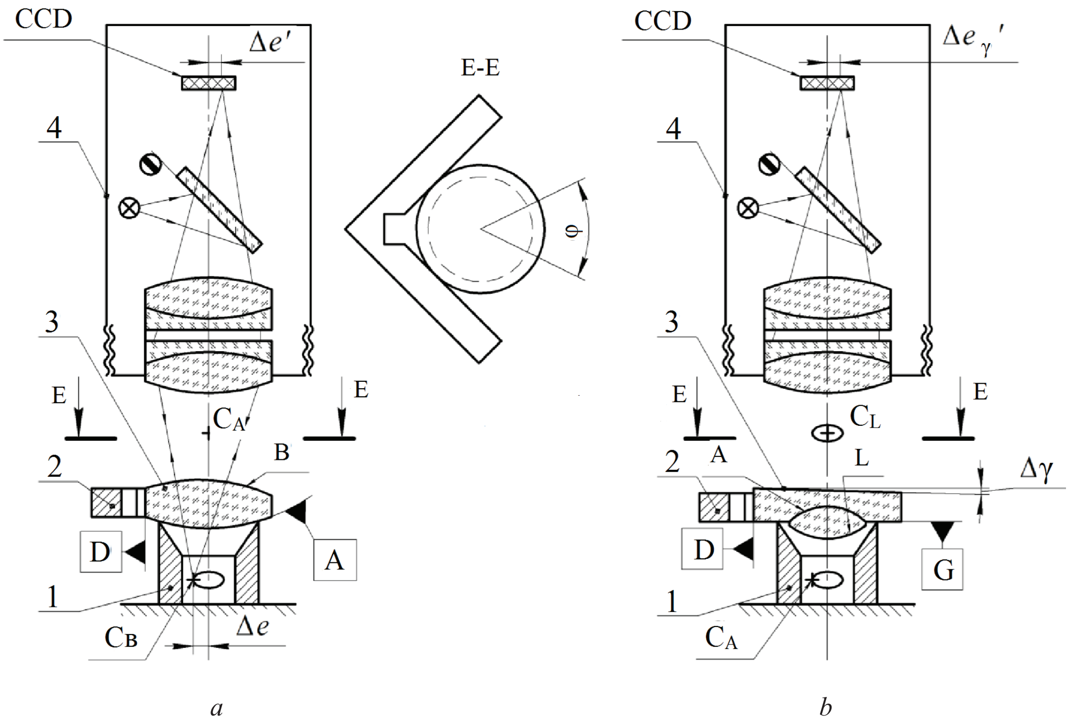


Figure 4 – Schemes for decentering control on an optical device: a single lens in a square (*a*) and a glued block of two lenses (*b*): 1 – support ring; 2 – square; 3 – lens or lens gluing; 4 – autocollimation microscope; Δ*e* – decentering on the optical part; Δ*e′* – the amount of decentering on the CCD site; Δγ – the difference in inclination angles; φ – clamping angle; A, D, G – basic surfaces; B, L – working spherical surfaces

Method and technological features of gluing lens blocks

Under production conditions, a control series of experiments was carried out to connect and control the decentering of glued components from two and three lenses (Figures 1 and 2, respectively) with the technical parameters indicated in Table 2.

Table 2

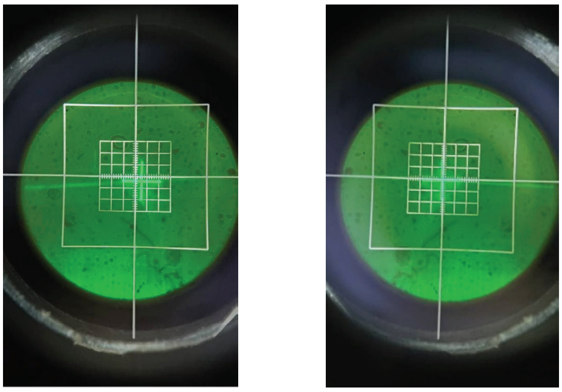
Structural and optical parameters of lenses (mm) for a glued block

Detail	f'	n	R_1	R_2	D_1	D_2
Bonded block of two lenses						
lens 1	38.86	1.65844	43.25	–57.81	38	38
lens 2	–65.5	1.80518	–57.81	682.3	38	40
Bonded block of three lenses						
lens 1	–118.2	1.75513	42.27	27.88	32	30.2
lens 2	24.6	1.53996	27.88	–21.58	30	30
lens 3	–17.1	1.78472	–21.58	36.39	32	29

The technological operation of gluing the lenses is performed in a horizontal position for the convenience of fixing and centering the assembly in the ring fixture. As a base part, as a rule, a negative lens 2 (Figure 1) or 1 (Figure 2) is chosen, since its concave surface M is better suited for the subsequent application of a drop of glue. In addition, for ease of fastening, the base part must have a large thickness along the edge (surface E). A drop of glue, such as Norland 61, is applied to the center of the spherical surface. Next, an attachable positive lens is installed on top, the glue is evenly squeezed out from the center to the edge and preliminarily illuminated with a UV lamp for 1–2 minutes. There is a partial harde-ning of the glue, but with the possibility of a slight transverse movement of the lenses between themselves. Next, the autocollimation points O_1 and O_3' ($\Delta e_3 \rightarrow 0$) are aligned (Figure 3) by visual control on the ST-41 device. The beating diameter of the autocollimation point is equal to the fourfold decentering $D_i = 4\ C_{devi}$. The division value of the rectangular scale of the grid is 3 µm, so the measurement accuracy of the device is 1.5 µm. Figure 5 shows two positions of the light-emitting diode (LED) mark

Devices and Methods of Measurements
2022, vol. 13, no. 1, pp. 50–59
R.V. Fiodortsev et al.

relative to the crosshair of the autocollimator, the initial one – before the alignment process (*a*) decentering $\Delta e = 2$ μm, and the final one – after alignment (*b*) the alignment accuracy $\Delta e \approx 0.5$ μm.



a *b*

Figure 5 – The position of the laser mark relative to the crosshairs of the autocollimator: initial (*a*) and final (*b*)

When gluing a block of three components (Figure 2), at the second stage, a change in technological bases occurs. The surface H of the negative meniscus 3 is used as the base support surface. Glue is applied to the inner spherical surface B, and the ready-made gluing of lenses 1 and 2 is installed on top. Next, the value of the angle γ for the base surface A is recalculated depending on *R* relative to the support surface H and auxiliary base surface E.

In both cases, after alignment, the final fixation of the lens block is carried out in 3–4 iterations with a UV lamp for 10 min with an interval of 10 min.

After hardening of the glued joint, the total error *N* of Newton's interference rings on the outer working spherical surfaces of the parts (A and B for two-component gluing or A and H for three-component gluing) may increase due to the drying of the glue and deformation of the edge zones.

Control and measuring equipment

The classic autocollimation microscope ST-41 was built according to the optical scheme of A.A. Zabelin (Figure 6) and allows you to combine the point image of your source with the autocollimation point of a spherical surface, which gives an image of the source placed in it reflected from the surface in the same plane where it is located [10]. The degree of non-coincidence is equal to twice the amount of decentering, and the rotation of the lens allows you to double its value. If a concave surface is controlled, then the autocollimation point coincides with the center of its curvature, for a convex one, it is necessary to calculate its distance from the surface.

The basic optical system of the ST-41 device uses two interchangeable lenses 1 and 2 with focal length $f' = 201.76$ mm and $f' = 400.1$ mm. The illumination source is a low-power incandescent lamp RN8-20. The autocollimating crosshair is formed on an inclined grid 3, which introduces astigmatism. As a result, in the field of view of the symmetrical eyepiece 7 and 8, the image of the crosshair at the edges looks fuzzy.

In order to improve the image quality of the reference elements and the accuracy of decentering measurement, the optical system of the ST-41-01 device was improved (Figure 7). To ensure the versatility of measurements of glued lenses with different focal lengths, a movable 4-component short-focus lens 1 ($f' = 40.56$ mm) is installed with the possibility of linear movement along the optical *Z* axis and fixation in specified positions graduated scale ($E = 8.42$–53.08 mm). Grid 7 with a crosshair is installed perpendicular to the optical axis, which ensures its uniform illumination over the entire field of view from a three-component 4-lens condenser 8 and a high-power white light LED (type XREWHT-LI-0000-00001) or LUXEON (LXML-PM01-0100). The convergence of the visual and lighting channels is carried out by means of a cube-prism 2.

In order to reduce the decentering measurement error, the new version of the optical system of the device also provides for the separation of the output observation channel into a visual channel through a symmetrical eyepiece 6 and a television channel (image plane on the CCD array area) using a beam-splitting cube prism 4.

An improved version of the design of the ST-41-01 control and measuring device is shown in Figure 8.

A vertical stand 2 and an object table 5 are rigidly fixed on the adjusted horizontal base 1. An angle 6 is installed on the round table 5, which holds the frame with the base optical part or the optical part itself separately. In the process of alignment of autocollimation points, the table has the possibility of circular movement due to the support screws 7, which provide the possibility of exposing the base surface to a horizontal position. Focusing of the autocollimating microscope 4 is carried out due to the smooth vertical and rectilinear movement of the arm 3 along the trapezoidal thread of the stand 2. The arm has a unit with screws for micro-movements 8, which allows the optical axis of the microscope to be aligned with the axis of rotation of the stage with the support ring. As a source for illumination of the crosshairs in an autocollimation microscope, an emitter 9 is used – an LED with the possibility of longitudinal and transverse movement within ±0.5 mm. Observation of the autocol-limation image of the crosshairs on the microscope grid can be carried out by the operator's eye through the eyepiece 10 or broadcast by a high-resolution black-and-white television camera 11 (VBC-751) to a personal computer monitor.

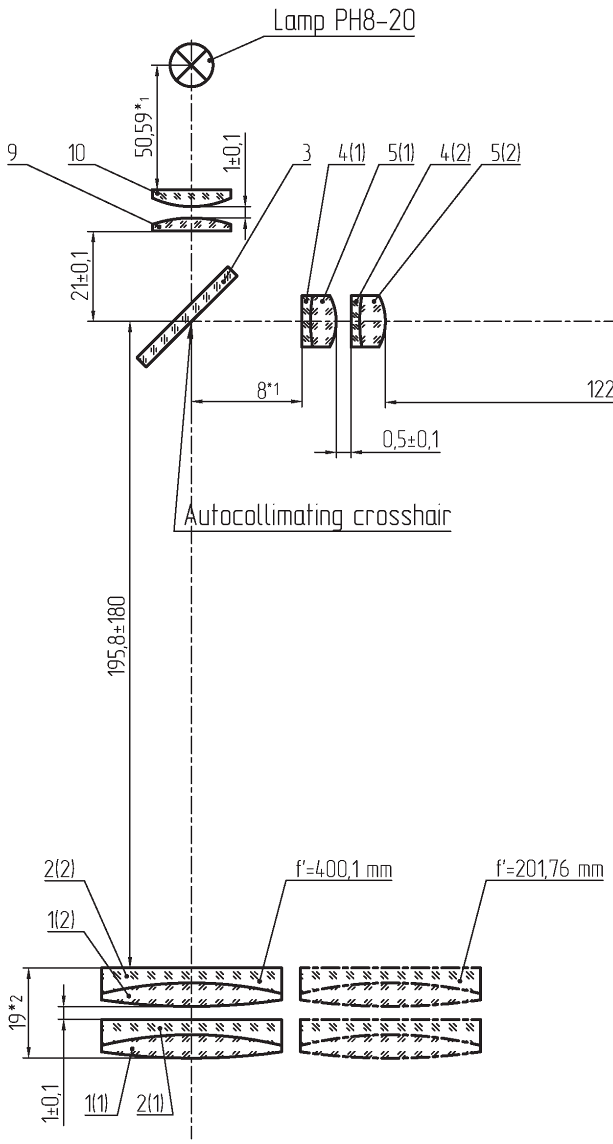


Figure 6 – Schematic optical diagram of the classic device ST-41: 1 and 2 – double lens block of the teleobjective; 3 – grid with crosshairs; 4 and 5 – double lens block of the microobjective; 6 – measuring grid; 7 and 8 – lens blocks of a symmetrical eyepiece; 9 and 10 – condenser lenses

The image receiver in the television camera is a CCD matrix model SONY ICX-409AL, Super-Had, 1/3 inch format with the number of active elements 752 (horizontal)×582 (vertical). The high resolution of the optical system is ensured by the small pixel size of the CCD 6.5×6.25 μm.

The next step in improving the accuracy of connecting optical components and eliminating the influence of the subjective human factor when measuring decentering was the creation of an automated control system for the process of bringing together autocollimation points in the ST-41-M2 device and the gluing process.

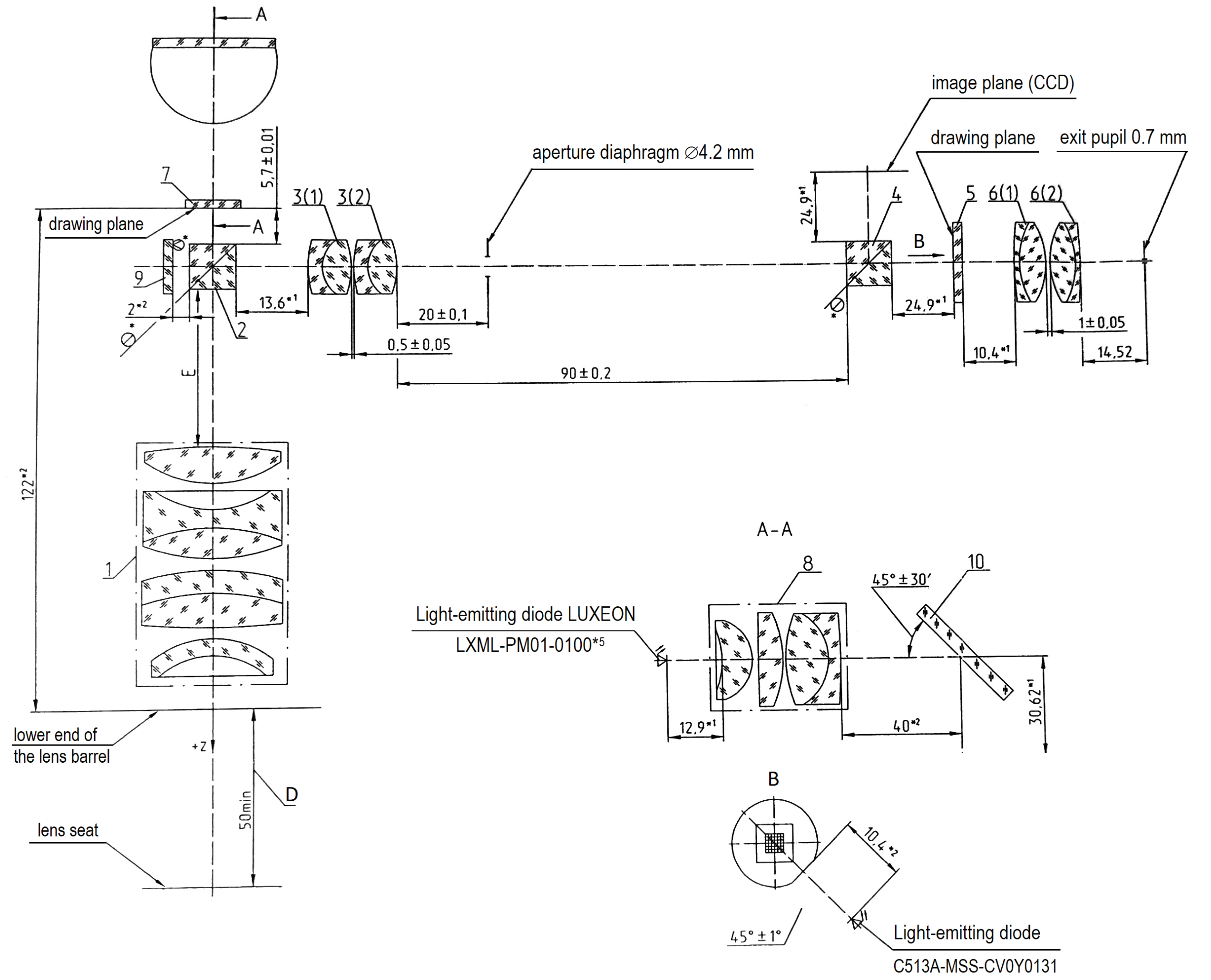


Figure 7 – Schematic optical diagram of a new version of the ST-41-01 device: 1 – 4-component telephoto lens; 2 and 4 – cube-prism beam splitters; 3 – double lens block of the microobjective; 5 – measuring grid; 6 – lens blocks of a symmetrical eyepiece; 7 – grid with a crosshair; 8 – condenser lenses; 9 and 10 – mirrors

Using software methods, an electronic grid template is created, which is also displayed on the monitor screen (Figure 8). The image of autocollimation points is projected onto the area of the CCD matrix. Both images are combined. Next, the coordinates of the points of the circle of maximum rotation of the crosshair along the X and Y axes are determined. Taking into account the decentering value $2\Delta e$, a corrective control voltage is applied to motorized linear translators (for example, 8MT167-25 Standa), which move the pushers holding the positive lens to be glued until the autocollimation image of the crosshair completely coincides with the center O on the electronic grid (Figure 9).

The mathematical apparatus for solving this problem is based on a combination of two methods of "least squares" and "successive approximation".

To achieve a given calculated decentering value, it is necessary to ensure the following ratio:

$$C = \frac{2\Delta e}{4\beta_{m.ob.3} \cdot \beta_{ob.1}},$$

where C is the decentering value for the controlled spherical surface, specified in the working drawing, mm (Figure 1); $\beta_{m.ob.3}$ 8× – magnification of the microlens 3 (Figure 7); $\beta_{ob.1}$ is variable magnification of lens 1 (Table 3).

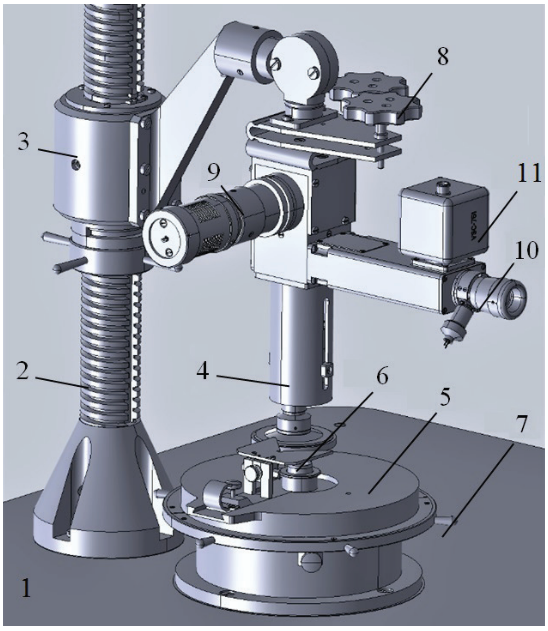


Figure 8 – Device for controlling the gluing of lenses model ST-41-01: 1 – base; 2 – rack; 3 – bracket; 4 – microscope; 5 – table; 6 – square; 7 – support screws; 8 – screws for micro-movements; 9 – light-emitting diode; 10 – eyepiece; 11 – television camera

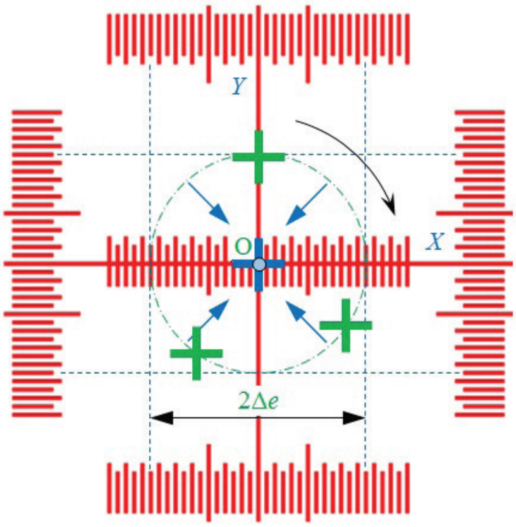


Figure 9 – Drawing of an electronic measuring grid

Specialized software has been developed for automatically bringing the position of the autocol-limation crosshair to the center of the measuring scale of the grid.

During the gluing process, the beating value of the autocollimating crosshair ($2\Delta e$) is preliminarily recorded in a video fragment with the FSP option to be adjusted. A previously generated video file can also be uploaded through the "Video options" menu (Figure 10). To determine the extreme points of the circle, the "screenshot" button SCR is provided. The color, as well as the number of vertical (V1, V2) and horizontal (H1, H2) strokes of the electronic grid is configured through the "Lines Operation" menu (Figure 11).

Table 3

Correspondence of the division value of the electronic grid and the scale of the lens 1 at various magnifications β

Division value, µm	$E \pm 0.05$ mm	L, cm	β_{ob}, multiple
3.5	53.08	5.30	–0.893
5	42.22	6.16	–0.625
6	37.99	7.04	–0.521
8	32.71	9.11	–0.391
10	29.54	11.38	–0.313
12	27.43	13.77	–0.260
15	25.32	17.45	–0.208
20	23.20	23.73	–0.156
50	19.40	62.28	–0.063
15.4"	16.87	–	–
40	13.70	–55.09	0.078
30	12.64	–42.22	0.104
23	11.36	–33.26	0.136
15	8.42	–23.17	0.208

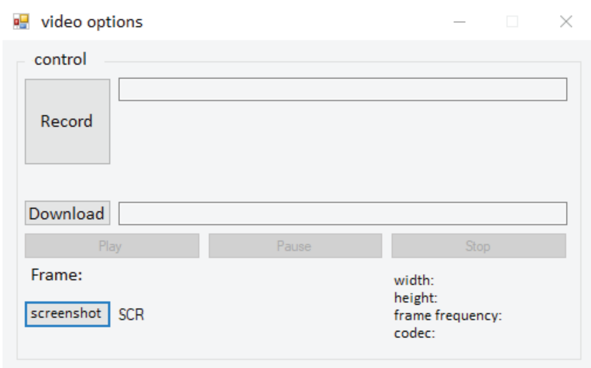


Figure 10 – The working window of the software "Video options"

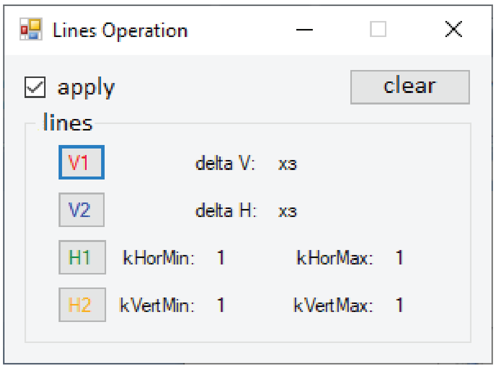


Figure 11 – The working window of the software “Lines Operation”

Conclusion

It has been established that, subject to a number of technological transitions and the accompanying control of geometric parameters, it is possible to achieve the eccentricity of the crosshairs of the combined optical axes of the glued lenses at the level of 5 µm (complexity category *I*).

The use of a movable lens with variable magnification expands the functionality of the ST-41-01 device when monitoring the decentering of parts with spherical surfaces in the range of diameters from 3 to 100 mm and curvature radii from 3 to 200 mm.

The introduction of an automated control system for the process of convergence of autocollimation points in the device model ST-41-M2 makes it possible to exclude the subjective influence of the operator when assessing the accuracy of measuring the decentering of glued optical parts and provides a shift value of 0.1 µm.

References

1. Ruggedization of Imaging Lenses. Edmund Optics, Inc. Whitepaper. Section 5.3 of the Imaging Resource Guide – 2017. Access mode: www.edmundoptics.com/know-ledge-center/application-notes/imaging/ruggedization-of-imaging-lenses/

2. Patrik Langehanenberg, Josef Heinisch, Christian Buß, Christian Wilde. High-Precision Mounted Lens Production. WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, *Optik&Photonik*, 2/2014, pp. 41–45.
DOI: 10.1002/opph.201400045

3. The Bonding of Optical Elements Techniques and Troubleshooting. Summers Optical. A Division of EMS Acquisition, Inc. PO Box 380 – 1560 Industry Road Hatfield, PA 19440.

4. Krithika S. Prabhu, Tony L. Schmitz, Peter G. Ifju, John G. Daly. A Survey of Technical Literature on Adhesive Applications for Optics. *New Developments in Optomechanics*, ed. by Alson E. Hatheway, Proc. SPIE 6665, 2007, 0277-786X/07/$18.
DOI: 10.1117/12.735948

5. Optical bonding techniques – Review. *Solaris Optics*, 20.07.2020. Available at: https://solarisoptics.eu/optical-bonding-techniques-review/

6. Jim H. Burge. Mounting of Optical Components. Mounting of lenses. *Optical Sciences and Astronomy*. The University of Arizona, Tucson, 2011, 46 p.

7. Frederic Lamontagne, Ulrike Fuchs, Martin Trabert, Anna Mohl. Aspheric lens mounting. *Optical Engineering*, 2018, vol. 57, no. 10, p. 101708.
DOI: 10.1117/1.OE.57.10.101708

8. Bui Dinh Bao, Beloyvan P.A., Latiev S.M., Tabachkov A.G. Centering of stacked lenses. *Modern problems of science and education*, 2015, no. 1 (part 1), 20 p. Access mode: science-education.ru/ru/article/view?id=17909

9. Bui Dinh Bao, Latiev S.M., Namesake R. Automation of lens centering when pasting into frames. *Scientific and technical bulletin of information technologies, mechanics and optics*, 2015, vol. 15, no. 6, pp. 1030–1035.
DOI: 10.17586/2226-1494-2015-15-6-1030-1035

10. Patent RU 2560920. Device for locating lenses in cylindrical frames when measuring decentering of their optical surfaces. Appl. 11/18/2013. Published 08/20/2015. Bull. No. 23.