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Some problems in the production of optical instruments during mounting and adjustment phases

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Some characteristic problems occurring in the final stage of optical instruments production – adjustment and testing– – have been treated with the special emphasis on monocular and binocular instruments. Problems concerning mounting and adjustment of fixed mirrors and prism systems in the convergent beam of monocular instruments have been discussed as well as all solutions related to fulfilling technical requirements for binocular optical instruments and hand binoculars in particular.

Key words: **optical system, optical instrument, binoculars (monocular instrument), binoculars (binocular instrument), mounting, adjustment, optical measurements.**

Nomenclature

AKD – autocollimator
Ob – objective
Ok – eyepiece
P – prism
O – mirror
Os – rotating system
M – point (center of the mirror)
e – angle of incidence to the mirror
e* – angle of refraction from the mirror
DC – dioptric cylinder for centring
SL – light spot from the left monocular
SD – light spot from the right monocular
C – center of the circle circumscribed by the light spot
u – angle of the monocular rotation about the rotating axle
r – radius of tolerancy of misalignement in binocular optical axes
G – magnification of the binocular
DG – difference in magnification of the right and left monocular of the binocular
udG – angle of divergence of output beams
u ok – apparent angle of the field of view behind the eyepiece
i – image tilt angle
a – image point exceed on the diaphragm of the field of view
Dp – field of view diaphragm diameter
fok – objective focal distance
P1 and **P2** – prisms of the PORO I rotating system
tok – tolerance of the eyepiece clearance in the eyepiece thread
U – tolerance of misalignements of output beams
w – inclination of the P1 prism cross-section to the eyepiece axis
Z1 – distance of the P1 prism edge from the front eyepiece focus
g ok – angular eyepiece increase
a2 – angle due to the P2 prism irregularity
Z2 – distance of the P2 prism edge from the front eyepiece focus
n – prism glass refraction index
pi – prism pyramidality

Introduction

ERRORS in the production of optical instruments have to be thoroughly studied. Fundamental errors occur in production of their elements [1], subassemblies and assemblies [2]. Each particular case needs a complete investigation of prevailing mistakes in technology procedures and their effects on the characteristics of the instrument in question. Subsequently, a so-called theory of instrument errors is necessary to be formulated but, unfortunately, adequate investigations of up-to-dated optical instruments, being so complicated that cannot be studied applying general theory, are conducted for each particular case separately.

Technical and economic costs of these researches are very high but after introducing their results into production, mounting and adjustment become less complicated as a rule and instrument quality and reliability increase.

In modern optical industry there are always new, complex problems to be solved in mounting, adjustment [3,4] and control [5]. Only when the effects of prevailing fundamental errors on desired characteristics are clearly understood, a scientifically-based methodology of mounting, adjustment, control and testing can be conceived and applied. Without knowing the theoretical basis underlying the instrument itself [6,7,8] it is difficult to develop its contruction, production technology and operational reliability.

Modern optical instruments are characterized by high requirements concerning manufacturing accuracy and, in particular, mutual orientation of details and assemblies related to schemes. Other characteristics of optical instruments include

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presence of specific optical elements, complexity of construction schemes containing complex optical, mechanical, electronic and other elements, frequent upgrade of construction, vast nomenclature, enormous diversity of types and dimensions and serial production. High requirements are set, for example, for precision in manufacturing and mounting different types of directioning devices, measuring and installation mechanisms for instruments while extre-mely high requirements relate to the manufacturing of optical elements and their assemblies. Highly precise, expensive and fragile optical elements, sensitive to strain and careless handling, require ultimate care during mounting as well as exceptional cleanliness and microclimate in rooms where final mounting and cleaning of instruments take place.

Modern complex optical instruments, containing often several hundreds of optical components and elements and thousands of mechanical, electronic and radio-electronic elements, require from workers-fitters universal knowledge, high qualification and complete dedication to their work.

Frequent changes of constructions due to every-day modernization of products impose constant upgrading of fitting units, replacement of technical equipment and reeducation of personnel.

Even a simple unexaustive list of characteristics of optical instruments production leads to the conclusion that their mounting is a complex task, speaking both in technical and organizational terms. It is therefore necessary to reduce the number of difficulties in their manufacturing process during mounting in particular, by the introduction of measures increasing processing aptitude of optical and kinematic schemes and instrument design, developing high-productibility technology, adopting automation of mounting and adjustment working processes, effective methodology of their realization and science-based organization of work. Experience implies that only deep understanding of characteristics of each optical instrument in particular enables enhancing the quality of their mounting, adjustment and testing.

Mounting and adjustment of monoculars

In terms of application, optical monoculars are divided into visual monoculars and riflescopes. The former are used for viewing distant objects where eye-sight cannot discern enough details. They include, for example, monoculars for viewing targets during firing, reading from scales of optical, electro-measuring instruments, viewing aircraft, cosmic and astronomic objects. The main requirement for this class of monoculars is to give high-quality magnified images of distant objects.

Riflescopes have a cross hair (cross-shaped or in other forms) enabling aiming at long distances, giving directions in space, their use as target angle indices, their application in projectors, etc. Focusing riflescopes enable aiming at points at different distances. However, keeping the aiming line direction (trajectory of the cross centre image in the object area) steady is not of the same significance as in autcollimators for centring and the aiming line is not required to be strictly straight as in levelling instruments.

Regarding their design, binoculars can be with lenses or mirrors [2,6,9], direct or with irregular axis if a beam pace includes mirror or prism systems shortening the length of an instrument and rotates the image.

Image quality in all binoculars depends first and foremost on the objective and the accuracy of its arrangement-mounting. The angle tolerance of decentricity in particular cases is 10 to 12 seconds and in common cases it is from one to two minutes. The length tolerance of decentricity is up to tenths of milimeters [10]. These tolerancies, relatively simply derived in direct binoculars with a straight line for an optical axis, impose special requests during the mounting of mirror or prism telescopes with an irregular-line axis.

Mounting and adjustment of fixed mirror and prism systems in a convergent light beam

Prisms and mirrors in a convergent beam pace should be arranged precisely into a previously calculated position [9] because their shifting and rotating provoque mutual decentricity of elements between which prisms and mirrors are fitted. The reflexive prisms in the convergent beam should be arranged so that their input and output refractive sides are perpendicular to the optical axis with the accuracy of several minutes. If it is not the case, in slopingly built-up prisms astigmatism appears in point images, even on the axis. Verifying the fullfilment of this requirement is not complicated. For example, in order to verify the arrangement of the Schmidt revolving prism (Fig.1a), it is possible to use two autocollimators of low magnification.

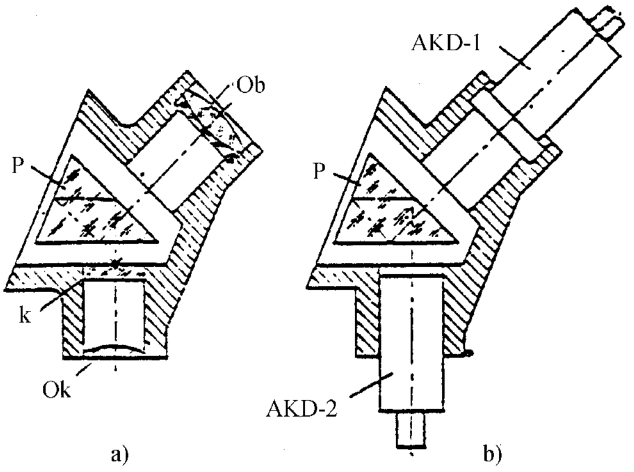


Figure 1. Control of prism arrangement using autocollimators

The first binocular, **AKD**-1 (Fig.1b) is fitted into the objective **Ob** holder, i.e. into the optical system part facing the prism **P**, and the other binocular **AKD**-2 is fitted into the eyepiece **Ok** holder instead of the optical system part behind the prism. The finder axes of each binocular should be parallel to the optical axes of the system parts they are replacing. In this case the finder axis of the first autocollimator should be perpendicular to the objective holder and the optical axis of the other autocollimator should be parallel to the eyepiece holder.The prism **P** should be adjusted and fixed so that its input and output sides are perpendicular to the corresponding autocollimators (**AKD**-1 and **AKD**-2), the autocollimation images of both binoculars taking the central position. After fitting the objective **Ob** and the eyepiece **Ok** in their positions, the input and output sides of the prism will be perpendicular to the optical axis, within the accuracy limits of the applied control method.

When applying this control method, there are no gradual prism shiftings, less damaging though, which are, nevertheless, as undesirable as prism rotating.

In spite of this disadvantage, there is no other way of adjustment in which dioptric cylinders for centring are used.

Its characteristics will be discussed using the example of the control of the eyepiece assembly of the observing periscope (Fig.2a) in which the mirror **O** is placed in the convergent beam between the second lens of the rotating system **Os** and the eyepiece **Ok** with the crosshair **K**. The eyepiece beam is placed on the vertical conical axle for rotating the periscope with the level for reading horizontal angles and its upper cross section "a" holds mounted tubes containing the rest of optical parts: the first lens of the rotating system, collector, objective, mobile prism in the head with vertical angles indexing circle and protective glass. The height of the periscope can be changed by removing one of intermediary tubes without optical parts which is placed in the parallel beam pace between the lenses of the rotating system.

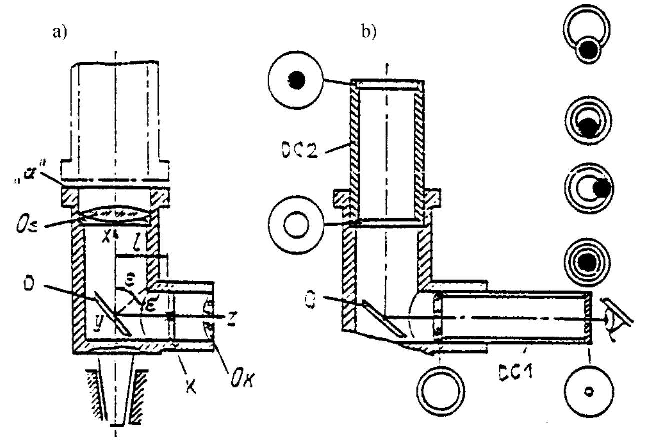


Figure 2. Control of plane mirror mounting using dioptric tubes for centring

The periscope is used for surveillance and visual ground searching as well as for angle measuring-therefore, the image quality should be high and the crosshair must not have the parallax. Furthermore, in periscopes for horizontal and vertical angle measuring there should not be lateral tilting of the finder axis or prism tilting.

The eyepiece assembly is an important part of the periscope and it has to fulfill the following requirements:

1. the optical system containing the rotating lens **Os**, the mirror **O** and the eyepiece **Ok** should be centric;
2. the crosshair **K** should be in the focal point of the objective **Ob**;
3. the finder axis, passing through the crosshair image in the mirror **O** at the reverse beam pace and through the back nodal point of the lens **Os**, should be parallel to the axis of periscope rotation;
4. the upper supporting surface of the "a" assembly should be perpendicular to the vertical rotation axis.

Tolerances in fulfilling these requirements can be deduced from the given boundary conditions and the accuracy of measuring angles by the periscope as well as from construction data.

Suppose the angle tolerances are given in minutes and the linear value tolerances in tenths of milimetres. Some requirements can be fulfilled only during mechanical working of the eyepiece assembly; for example, the last, fourth, requirement is provided by reducing the supporting surface "a" with the eyepiece assembly to the position parallel with the axis of the conical holder (sleeve).

Suppose then that the centring of the lens system, made of rotational portable objective **Os** and the eyepiece **Ok**, is done by adjusting the mirror **O**. It is necessary to provide not only the lens system centring but the finder axis perpendicularity to the support surface "a" as well. If both requirements are realized simultaneously by the adjustment of the mirror **O**, then it can be achieved only with the accuracy by which the center of the crosshair is centric with the eyepiece **Ok** optical axis.

If all the given requirements concerning eyepiece assembly working and crosshair centricity are fulfilled, then the mirror **O** is only needed to be placed in the correct position (Fig.2a), i.e. in the position where its reflection plane:

- overlaps with the point **M** where the optical axis of the rotational-portable objective **Os** system intersects the eyepiece **Ok** optical axis;
- is perpendicular to the plane which intersects the optical axes of both eyepieces,
- forms equal angles (90"–**e**) and (90"+**e***) with their optical axes where **–e** nd **e*** are the angles of incidence and refraction of the axial beam.

The first condition is provided by moving the mirror along its normal; the second one – by tilting the mirror about the axis overlapping the reflection mirror plane in the drawing plane (Fig.2a), and the third one – by rotating the mirror about the axis perpendicular to the drawing plane and lying in the reflexion plane.

Dioptric cylinders for centring (Fig.2b) are used for mounting into the correct position.

One of them, **DC**-1, is fitted on the rotating lens mount thus moving it away from the eyepiece assembly during the mirror adjustment. Two transparent plates made of organic glass are fixed on both sides of the cylinder. One plate, placed at the farthermost point, has a circular black spot on it, while the second one contains a black circle of a slightly bigger diameter. The centres of the spot and the circle should overlap with the geometrical axis of the cylindric tube.

The second dioptric cylinder, **DC**-2, 200 to 250 mm long, is placed on the lens holder. In the middle of its end,a transparent plate with a bigger circle than the previous one is fixed and behind it there is a metal diaphragm with the circular hole of 1 mm in diam

Some problems during mounting and adjustment of binoculars

Binocular instruments have a lot of advantages when compared to monoculars. They enable binocular vision which is more suitable and more natural for the observer because it is less tiring, it enables stereoscopic vision and more efficient work. Some disadvantages, such as strabism and dioptric difference between eyes, which spoil the fundamental relation between the accomodation of eyes and the convergence of their axes, can be eliminated. In binocular instruments there is a possibility to compensate for these disadvantages by introducing special dioptric eyepiece mounting.

Technical requirements compensate for the errors of instruments due to glass work and mounting of elements. The basic requirements for binocular instruments with stereoscopic vision can be formulated as follows:

1. Instruments should be suitable for being used by the observers with the eyebase from 52 to 74 mm.
2. Instruments should have the possibility for the dioptric correction of observer's both eyes within the limits not less than +/–5 diopters as well as the possibility for the correction of dioptric difference between the eyes within the range not less than 3 diopters.
3. At any distance between the centers of exit-pupils as well as at any dioptric arrangement of eyepieces in instruments, the relation between the distance to the object image and the angle between the axes of output beams should be preserved. For telescopic binoculars, the axes of ray beams from both eyepieces coming from the same point, should be parallel within the following tolerances:

- in the horizontal plane at the axes convergence up to 60 minutes (100 minutes*);
- in the horizontal plane at the axes divergence up to 20 minutes (40 minutes*);
- in the vertical plane up to 15 minutes (30 minutes*).

4. The magnifications of both optical systems should be equal. The difference between their magnifications should not exceed 2 per cent if the field of view of the eyepiece is not greater than 50 per cent and 1.5 per cent if the field of view of the eyepiece is greater than 50 per cent.
5. The image in the optical system shold not be tilted. The algebraic difference of the angles of image rotating about the optical axis in the two systems of binoculars should not exced 30 minutes in absolute value. There are other less significant requirements not simple to be met, i.e. when both eyepieces are set to zero diopter and the binocular is placed on the horizontal surface, the eye-holes should not differ in height for more than 2 mm.

Methods for fulfulling these requirements are various and complex

In order to enable the use of binoculars for the observers with different distances between the pupils – different eye base – it is possible to increase the holes of the system exit-pupils. For example, if the diameters of the exit-pupils in a monocular are 9 mm, and the average distance between the tube axes is 63 mm, then, at the aperture of observer's pupil of 2 mm, light beams will not intersect in the case of any distance between eyes ranging form 56 to 74 mm. It practically means that any observer can use such a binocular instrument.

The calculation and construction of such systems is complex and not cost-effective. Therefore, the distance between the eyepiece optical axes is set to be changeable in most binocular instruments, i.e. rotating axles are used in assembling lightscopes. By rotating the monoculars about the rotating axle axis **O** for a particular angle the distance "d" between the eyepieces is changed and matched with observer's eye base (Fig.3).

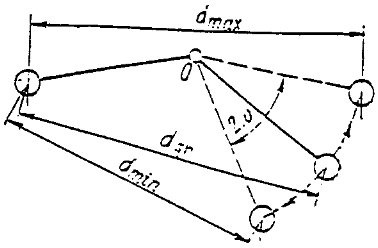


Figure 3. Changing of the distance between the exit–pupils in the handscopes in relation to observer's eyebase

In more massively–constructed instruments (stereo distance finders, periscopic instruments, etc.) both systems of the binoculars are fitted into the same housing, and romb prisms, moved by geared sectors into the opposite direction, are used to change direction, thus enabling the eye base to suit the observer.

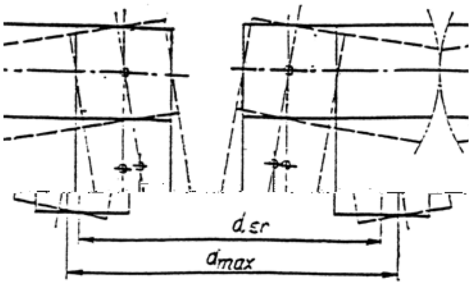
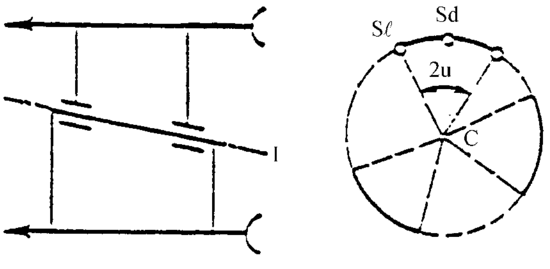


Figure 4. Changing of the distance between the exit-pupils in complex constructions of binocular instruments

In binoculars with adjustable distance between eyepieces mutual parallelism of output light beams should be preserved for any eye base, namely, for the adequate distance of eyepiece optical axes (Fig.5a). When monoculars are assembled by rotating axles, the axle axis I - I is taken as a base of an instrument (Fig.5a). The optical axes of both monoculars should be mutually parallel with the accuracy from 0.02 to 0.04 mm, depending on the eyepiece focal distances. However, it is not enough to meet only this requirement: it is also required that the optical axis of the rotating monocular should be parallel to the axle axis. The accuracy with which the second requirement should be fulfilled depends on the



a) b)

Figure 5. Effect of misalignement of the binocular optical axes with respect to the rotating axle on the deviation of the output beam axes

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*) data given in [11]

mutual rotation of the monocular u around the axle and on the mutual position of the optical axes for the average distance between the eyepieces.

Let a binocular consisting of monoculars coupled by a rotating axle be placed into a parallel light beam between the optical bench collimator and the **measuring collimator** [12]. The screen, placed in the rear focal plane (Fig.5b), will show two light spots, one coming from the left monocular **SL**, and the other from the right one **SD**. If the right monocular could rotate completely (360°) then its spot would trace on the screen a full circle given by the dotted line in Fig.5b. The centre **C** of this circle represents the point through which the axle axis passes through the screen. The main beam, passing through that centre, is parallel to the axle axis. If the light spot originating from the right monocular does not overlap the center **C** and does not make a circle around it, then it means that the optical axis of the right monocular is not parallel to the axle axis.

In binoculars, the monocular angle of rotation about the axle is limited **(u)** - this is the reason for the light spot not to trace the full circle but an arc. Depending on the direction of the misalignement of the axes in the monoculars, that arc can be found on any part of the circle. Evidently the most suitable positions for an arc are the vertical parts of the circle. If the eyepiece distance has its average value and the left side light spot is in the center of the arc traced by the right side, then the tolerance of the misalignement of the rotational monocular with respect ot the axle axis can be deduced from the condition:

$$r = < 0{,}002 / \sin \mathbf{u} \text{ (rad)}$$

It has been accepted here that the misalignement of the mentioned axes causes an additional misalignement of light beams which is not greater than 0.002 radians, i.e. 7 minutes.

It can be seen that the smaller monocular rotation angle about the axle is, the rougher tolerance r is displayed. If, for example, the monocular angle of rotation about the axle is *u*=+/–30° then the tolerance r is less than 0.004 rad. And for *u*=+/–10°, the tolerance r is less than 0.012 rad.

Magnifications of the monoculars in the binoculars should be equal. Fig.6 shows a binocular with different magnifications in the monocualrs **dG**.

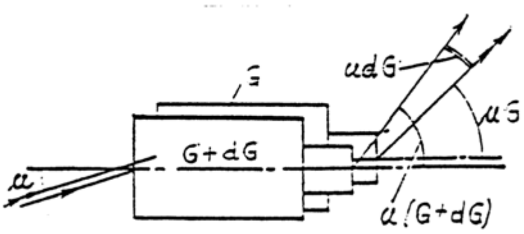

Figure 6. Effect of the difference in the monocular magnification of the binocular on the misalignement of the output light beam axes

If the optical axes of both monoculars are strictly parallel, then the divergence of rays for peripheral points of a field of view, for the angle **udG**, can be explained only by a difference in the magnifications of the right and the left monoculars. That divergence should not exceed 0.002 radians, i.e. it should fulfill the condition **udG**=0.002 rad. Thus the tolerant magnification difference in relative measure is

$\mathbf{dG/G} = < 0.002/\mathbf{u\,G} = 0.002/\mathbf{u}$ ok

where **u** ok stands for the angle of the field of view behind the eyepiece (apparent field of view of the eyepiece).

Thus the tolerance of monocular magnifications depends only on the eyepiece field of view and the larger the field is the more strict this tolerance should be. In common binoculars the field of view of the eyepiece is from 25° to 30° and the tolerance of the magnification difference in monoculars **dG/g**, is not greater than 0.004 to 0.003 radians, or from 0.4 to 0.3 per cent.

The magnification difference depends on real values of the focal distances of objectives and eyepieces. In mass production, the deviations of the obtained values from the theoretical ones are tolerated for +/–1 per cent in objectives and for +/–2 to 3 per cent in eyepieces. The consequence is that the greatest difference of monocular magnifications can exceed 6 per cent which is 20 times greater that the permissible tolerance. Therefore, the 0.3 to 0.4 per cent tolerance can be achieved only by completing objectives and eyepieces in respect with focal distances which is a common practice in production.

Image tilt / mutual image inclination should not occur in binoculars since it causes the misalignement of light beam axes coming from the farthermost lateral points of the field of view. If, for example, there is an image tilt only in the right part of the system for an angle i, then at the end of the field of view, behind the eyepiece, the output light beams will be misaligned for the angle **a/fok** (Fig.7) where **a** is the exceed of image points within the limits of the field of view diaphragm with the diameter **Dp**, where **a**=0.5**Di**; **fok** – the focal distance of the eyepiece. With the previously defined tolerance – less than 0.002 radians – of the misalignement of the beam axes the tilt tolerance is

$$\mathbf{i} = < 0.002/ \sin \mathbf{u} \text{ ok (rad)}$$

The image tilt tolerance also depends on the eyepiece field of view and it is more strict for wide-angle eyepieces.

The image tilt occurs as a consequence of an incorrect arrangement of the prisms in the rotation system, i.e. of the rotation of their main sections from their nominal mutual position. If, for example, in one monocular the main sections of the prisms PORO – I are not mutually perpendicular then the image tilt will be as twice as bigger. In common binoculurs the eyepiece field of view is from 25° to 30° and thus the image tilt is tolerated up to 0.004 and 0.003 radians, or 15 and 12 minutes respectively. Therefore, during the binocular adjustment, in each of its halves, the prisms should be mutually perpendicular with an error less than 8 to 6 minutes.

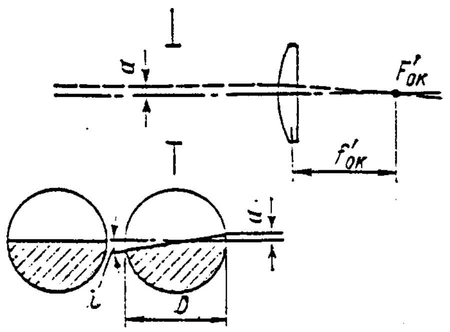

Figure 7. Effect of the image tilt in binoculars on the misalignement of output light beams

One of basic requirements a binocular should meet is **the strict mutual parallelism of monocular optical axes**. Using a prismatic binocualr as an example, we will discuss the causes of optical axes misalignement and the method of their elimination during mounting. Fig.8 shows a half of a binocular. The main construction base is **Kb-Kb**, i.e. the rotation axle axis.

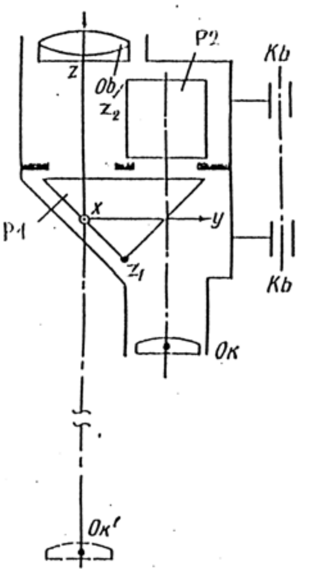

Figure 8. Diagrammatic drawing of a prismatic binocular and the image tilt as a consequence of an irregular arrangement of the PORO prisms

Parallely with it, there is the monocular axis which passes through the equivalent main points of the objective **Ob** and the eyepiece **Ok**, namely, the eyepiece image behind the prisms **P1** and **P2** system, obtained at the inverse beam pace. Let the working angle of monocular rotation about the axle not be greater than **u**=+/–45°. Following the formula

$$r =< 0.002/ \sin \mathbf{u},$$

the tolerance of the optical axis misalignement with respect to the axle axis will be 0.003 rad. For the eyepiece focal distance of 20 mm, this tolerance corresponds to the cross shifting of the eyepiece or objective main point for 0.06 mm.

Let us discuss the effect of **shiftings and errors** in manufacturing basic elements and assemblies influencing the direction of the optical axis of the monoculars in the prismatic binocular. We will further define **the limiting tolerance values** of these shiftings and errors supposing that each of them, taken separately, causes the mutual misalignement of the optical axes for 0.002 rad or the misalignement of each monocular with respect to the axle axis for 0.003 rad:

1. Error in enlarging the objective fitting in the binocular body-decentricity of the objective in its fitting 0.06 mm (we define and accept it!)
2. Error in enlarging the eyepiece holder-decentricity of the eyepiece in its holder 0.06 mm (we accept it). The clearances in the eyepiece screw thread of the mechanism for dioptric adjustment directly produce the misalignement of monocular optical axes, therefore the clearance tolerance should be determined by the formula **fok K** where we assume 20x0.0002<0.04 mm.
3. Shifting of the edge of the first prism **P1** (Fig.8) along the *y*-axis instead milling the prism mount on the holder and rounding the prism contour for less than 0.03 mm, because the prism edge shifting produces two times higher increase of the output beam shifting.
4. Shifting of the prism **P2** edge about the *x*-axis should be less than 0.03 mm for the same reasons.
5. Inclination of the main cross-sections of the prism **P1** about the *y*-axis for the angle **w** caused by the prism mount irregularity should be less than 0.003/2 w, i.e. 0.03/**Z1** mm where
   - **Z1** is the distance from the equivalent edge of the prism **P1** to the front eyepiece focus, and
   - **w** is the angular increase of the eyepiece for the point of the prism **P1** edge cross-section.

   If **Z1**=80 mm, then **b1**<0.0004 rad, i.e. less than 1.5 minutes.
6. Inclination of the main cross-section of the other prism **P2** about the *x*-axis for the angle **a2** produced by this prism mount irregularity should be **a2**<0.03/**Z2** mm, where
   - **Z2** is the distance from the equivalent prism **P2** edge to the eyepiece focus.
7. Error of the prism **P1** right angle <0.03/(**nZ1**), where **Z1** is as in point 5, and **n** is the prism refraction index.
8. Error of the prism **P2** right angle <0.03/(**nZ2**), where **Z2** is as in point 6.
9. Pyramidality of the prism **P1** due to the inclination of its main cross-section for the angle b(pi)=n(pi), (see point 5), (pi)<0.03/(**nZ1**).
10. Pyramidality of the prism **P2** having similar effects as the inclination of its main cross-section (see point 6) for the angle (pi)2<0.03/(**nZ2**) mm.

It is clearly seen here that there are more than 10 first-order errors affecting the direction of the optical axis of each monocular. Maximum tolerances of these values, strict enough, cannot be achieved without adjustment. In practice, a total error, due to the previously given errors, is dozens of times greater than the permitted value which is, in our case, 0.003 rad, i.e. 10 minutes behind the eyepiece or 0.06 mm in linear measure. In order to compensate for such an error two compensators should be provided – one for preliminary, coarse adjustment of the parallelism of monocular optical axes in the binocular and the other for final, fine and accurate adjustment.

Moving any movable element in the system (moving objectives, prisms or eyepieces) – which produces the monocular optical axis deviation – can be utilized to compensate for all the cited errors during the adjustment of the mutual parallelism of the binocular optical axes.

For the final adjustment of the binocular axis parallelism, *CARL ZEISS*– Jena applies transversal shifting of the objective for 0.5 mm using a double-excenter. In some models of its binoculars, the excenters on the eyepieces are applied which, evidently, is not cost-effective due to reduced reliability in service. For coarse adjustment of binoculars there is only one possibility – to tilt main cross-sections of the prisms using lateral supports fitted on adequate places of prism mounts.

For coarse and final adjustments of the binocular axis parallelism, U.S. firm *BUSHNELL* applies shifting of prisms in their mounts along their main cross-sections using brass fixing elements which are twisted into the bodies. The objectives are without any regulation. More simple and less expensive binocular constructions are thus obtained, but the prisms are constantly under mechanical stress in the contact points with the fixing elements and the crushing of angles occurs frequently.

Some English firms for adjustment use the tilting of prisms by the help of fixing elements about the axes parallel to their main cross-sections.

The adjustment of parallelism in some French firms is also done by longitudinally shifting prisms which are afterwards fixed by special cement into their mounts. The mounts under the prisms are milled and then free to move during adjustment. The objectives cannot be moved for the sake of adjustment. All this make the construction more simple and less expensive, cementing provides for reliability and original adjustment but the overhaul of such binoculars is significantly more difficult.

A general disadvantage of all these adjustment methods is that objective shifting and prism tilting can cause mutual decentricity of lens systems and, consequently, deteriorate the image quality. In modern binoculars for the coarse adjustment of mutual parallelism of monocular optical axes, the tilting of main cross-sections of the mount is done by lateral supports put under the prisms, and both prisms on their mount, which is separated from the body, are fixed by moving the complete mount. The final adjustment is done by moving the objective in its fitting by the help of a double excenter. During the adjustment, the mutual second-order decentricity of the objective and the eyepiece can occur, but it has a slight effect on the image quality. In wide-angle systems this decentring is not permitted, so, instead of autonomous correction, joint correction of the objective and the eyepiece is applied.

A typical technological procedure of binocular mounting and adjustment includes the following basic operations:

1. Mounting of objective, eyepieces and axle assemblies;
2. Completion of the objective and the eyepiece regarding the measured focal distances in order to provide monocular magnification within the tolerance limits;
3. Mounting of prisms inside the bodies, elimination of the image tilt and fixation of prisms in their mounts;
4. Preliminary mounting of the binocular, elimination of axis misalignement by putting lateral supports under the prisms (or in some other way);
5. Cleaning of optical parts, final mounting of the binocular, axis adjustment using excenters, setting of zero diopters;
6. Hermetic sealing, completion;
7. Control and testing.

Collimators for the control of binoculars during mounting and adjustment can be designed in different ways. In this author's opinion, the most suitable collimator is the one described in [12]. This measuring collimator is very suitable to be worked with, since all of its basic parts are the same as in both monoculars. It is universal in a way, being applicable to binoculars with different objective bases, binoculars of all possible designs and in controling nearly all requirements in binocular control.

Conclusion

The paper gives a method for solving every-day complex problems in the process of mounting and adjustment of monocular and binocular optical instruments in their production.

Problem solving is given with more details for binocular instruments, notably binoculars. Productivity and the quality of final work largely depend on such solutions which require a lot of knowledge and intution, problems being various and complex. This experience will be no doubt useful for working on new, more complex instruments. The realization has brought into life an idea of designing a new, more suitable and more reliable universal collimator for measuring misalignement of output light beams in binoculars – a universal one because other requirements and characteristics, such as image tilt, crosshair tilt, differences in monocular magnification and field of view, can be measured as well.

The solutions to these problems of some well-known producers of optical instruments (*CARL ZEISS, BUSHNELL*, etc.) are briefly given and the most efficient procedures and solutions in our circumstances are proposed.

References

[1] …*Spravočnik tehnologa optika.* Pod red. S. M. Kuznecova, Leningrad, Mašinostroenie, 1983.

[2] PLOTNIKOV,V.S. i dr. *Rasčet i konstruirovanie optiko-mehaničeskih priborov.* Moskva, Mašinostroenie, 1983.

[3] DIMITRIJEVIĆ,D. *Opšte uputstvo za justažu.* Sarajevo, »Zrak«, 1970–1979.

[4] POGARE,J.V. *Justirovka optičeskih priborov.* Leningrad, Mašinostroenie, 1968.

[5] AFANASEV,V.A. *Optičeskie izmerenija.* Moskva, Visšaja škola, 1981.

[6] BEGUNOV,B.N. *Teorija optičeskih sistem.* Moskva, Mašinostroenie, 1981.

[7] …*Vičislitelnaja optika. Spravočnik.* Pod. red. M. M. Rusinova. Leningrad, Mašinostroenie, 1984.

[8] ANTONIJEVIĆ,D. Automatski proračun aberacija optičkih sistema. *Naučnotehnički pregled*, 1972, no.2, pp.25-45.

[9] JOVIĆ,B. *Tehnička optika.* TŠC KoV JNA, Zagreb, 1972.

[10] MALCEV,M.D. *Rasčet dopuskov na optičeskie detali.* Moskva, Mašinostroenie, 1974.

[11] OSTROVSKAJA,M.A. i dr. Dopustimie otklonenija ot paralelnosti optičeskih osej binoklej. *Optiko-mehaničeskaja promišlenost*, 1978, no.10.

[12] ANTONIJEVIĆ,D., KOČIĆ,S. Merenje vidnog polja teleskopskih sistema i neparalelnosti optičkih osa binokularnog dvogleda pomoću mernog kolimatora MK-1. *Naučnotehnički pregled*, 1994, vol.XLIV, no.8, pp.25-27.

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Rešavanje nekih problema montaže i justaže u proizvodnji optičkih uređaja

Rad prikazuje neke značajne probleme nastale u finalizaciji proizvodnje optičkih uređaja – montaži, justaži i ispitivanju, s posebnim osvrtom na monokularne i binokularne uređaje. Izložena su pitanja i problemi vezani za montažu i justažu nepokretnih ogledala i sistema prizmi u konvergentnom snopu zraka kod monokularnih uređaja, kao i sva rešenja vezana za ispunjenje tehničkih zahteva koji se postavljaju pred binokularne optičke uređaje s njihovim posebnim preciziranjem za ručne dvoglede.

Ključne reči: **optički sistem, optički uređaj, dogled (monokularni uređaj), dvogled (binokularni uređaj), montaža, justaža, optička merenja.**

Quelques problèmes dans la fabrication des instruments optiques pendant l’assemblage et l’ajustage

L'article traite quelques problèmes importants dans les phases finales de la fabrication des instruments optiques (l'assemblage et l'ajustage) aussi bien que pendant leur examination en mettant l'accent sur les instruments monoculaires et binoculaires. Les problèmes concernant l'assemblage et l'ajustage des miroirs fixes et des systèmes de prismes dans l'onde convergente chez les instruments monoculaires sont présentés de même que toutes les solutions relatives aux prescriptions techniques à lesquelles les instruments binoculaires doivent satisfaire, les jumelles en particulier.

Mots-clês: **système optique, instrument optique, jumelles (instrument monoculaire), jumelles (instrument binoculaire), assemblage, ajustage, mesure optique.**