CONSIDERATIONS REGARDING THE POSSIBLE USE OF SOME OPTICAL ELEMENTS

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Considering the development of optomechanical instruments, that is, optical and precision instruments, one finds that the use of optical elements are noticeably divergent for surveying, astronomical, controlling and measuring instruments, and, finally, for military instruments. A comparison of the instruments belonging to the first large group to the military instruments reveals that the elements used in the latter are not too widely applied there. The difference between the two groups is due not so much to theoretical reasons as to their respective construction and arrangement. The design of military instruments, in particular, is subject to special requirements as regards accuracy under difficult climatic and atmospheric conditions, as well as possible chemical or mechanical influences. It is a fact that instruments belonging into the first group are subjected to milder conditions and with the exception of geodetic instruments, they are generally used indoor in air-conditioned rooms. In addition, the consideration of the use of optomechanical elements shows that some such elements which have a satisfactory record of long standing, are but occasionally used in optomechanical instruments. Let here be mentioned the well-proved, permanent design and construction of the penta-mirrors, compensators, various types of mounts, prism arrangements, etc. The penta-mirror, for example, having a fifty-years-old mount, still firmly holds its ground, so that actually there is no need of further developing this element. The designer of optomechanical instruments may safely rely upon these elements in his work, whereas the designer of military instruments has to summons all his knowledge and inventiveness for effectively counteracting the difficult conditions referred to above. As a result, many of these instruments are surprising and ingenious in their design. In the course of time, the designers of optomechanical instruments have come to realize the benefits to be gained by making use of the experiences arrived at in connection with military instruments. Since military instruments and their components are but rarely described in literature, it often happens that the designers of optomechanical instruments employ certain elements as independent constructions, unaware of their origin, while in other quarters the same arrangements are considered as all but obsolete.

This refers to astrological instruments as well, a group which, owing to its special function, is also somewhat isolated from other optomechanical equipment.

The present paper deals with certain arrangements which have long been widely used in military instruments, and which might be employed to great advantage in optomechanics, too. Let us first consider the device for adjusting interocular distances in binocular instruments.

Neither prism binoculars (rotatable about a common axis) nor microscopes will be treated in this paper, except for remarking that in the case of binocular microscopes interocular distance is adjusted by rotating the tube, which contains a Porro prism arrangement, together with the eyepiece, whereas in binocular telescopes it is more usual to rotate the eyepiece in relation to the fixed tube. In every case, however, that condition must be satisfied, that the axes of the parallel bundles emerging from the eyepiece shall remain parallel during adjustment, and shall coincide with the optical axis of the viewer's eye. In the case of binocular telescopes with large exit pupils this rule may be modified in such a way that adjustment is also considered satisfactory if the exit pupil of the binocular instrument entirely covers the pupil of the human eye. Obviously, the spatial position of a binocular instrument's optical axes is also influenced by the tolerance values, not as yet established on an international level, hence, a certain lack of uniformity among the various products should be taken into account. In addition to the precise mechanical control of the instruments, the angular error of the built-in prisms also plays a certain role, so that the required accuracy of the instrument is to be set in conformity with its purpose [1].

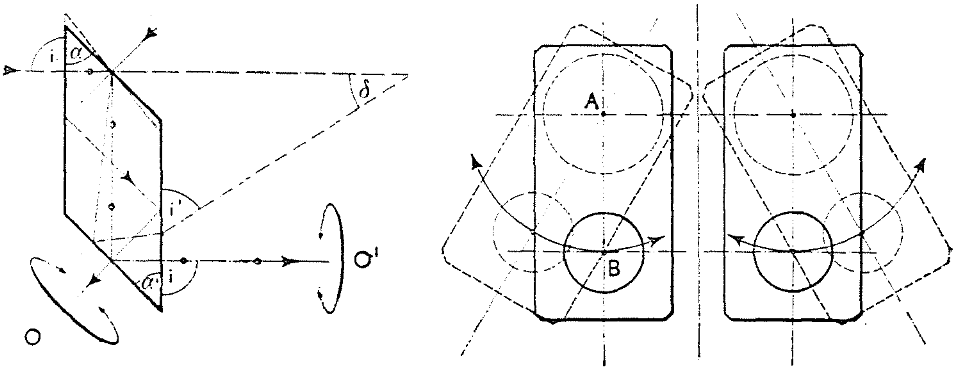


Fig. 1. Rotation of a rhombic prism about the axes normal to the planes of incidence

The most widely used means for adjusting the interocular distance are rhombic prisms rotated in relation to each other (Fig. 1). When such prisms are swung about the optical axis O or O′ which is normal to the plane of incidence, the position of the image is not changed. If the equation $a = a_1$ is observed for the prism, no deviation will occur. When the two receiving planes are not parallel to the plane of the drawing, they make an angle δ to each other. This holds true only for rays travelling in the plane of the drawing, that is, in the principal section of the prism, whereas the behaviour of the oblique spatial rays is more complicated and can be computed by analytical methods only. Obviously, even the prisms of the required angle must be mounted and controlled in a manner which ensures the mechanical axis of the mount coincide with the optical axis of the prism, and, ultimately, that there should be no undue slackness. When the interocular distance is within the range of 58 to 72 mm, the angular displacement of the individual prisms is not great. In instruments provided with telemeters another requirement has to be observed: the cross hairs must not be displaced during the adjustment of the eyepiece.

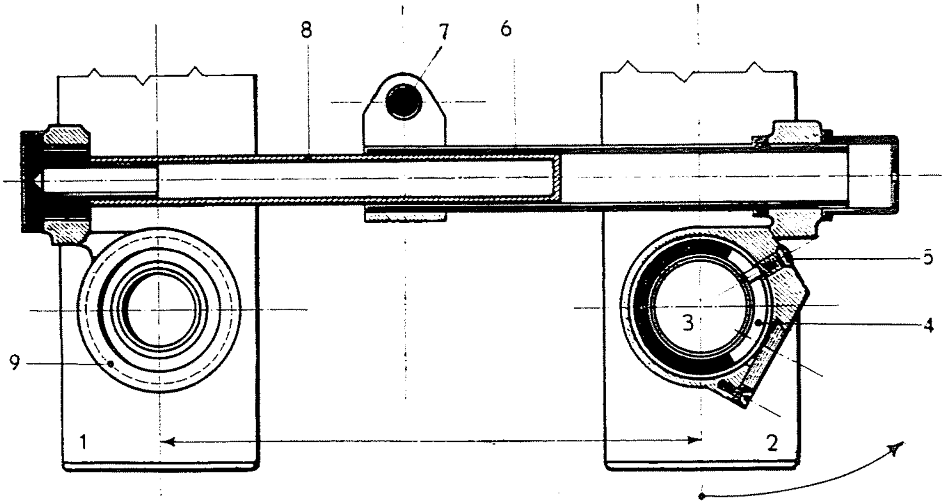


Fig. 2. Lever-controlled device for interocular distance adjustment

Fig. 2 represents a commonly used construction in which pin *8* fixed to ring *9* mounted on the eyepiece tube of telescope *1* is displaced in a guiding sleeve *6* during adjustment. Acting as a single arm lever, it turns ring *4*, loosely fitted on the eyepiece tube of telescope *2* which in turn makes the pin-ended screw *5* extending into the mount of the cross hairs and rotate them in relation to the telescope. As a result, the cross hairs remain in the adjusted position. Screw *7* serves for fixing the telescope after adjustment.

The control illustrated in Fig. 3 is similar to the one above described, in which the eyepieces, together with the tube, are swung about the axis outside the plane of the drawing; in the arrangement of Fig. 3 rhombic prisms are used for adjusting the eyepieces in relation to the fixed telescope tube. The objective image lying in the plane of the telemeter may be situated in the vicinity of the prism's plane of incidence or of emergence, requiring short or long focal distances, respectively, for the eyepieces. The prism mounts are rotated either by means of meshing racks fixed on the disc-shaped part, or on an endless loop-shaped steel band. The position of the cross hairs is secured by the gear mechanism shown in Fig. 2, with the extreme positions represented in Fig. 4. In this

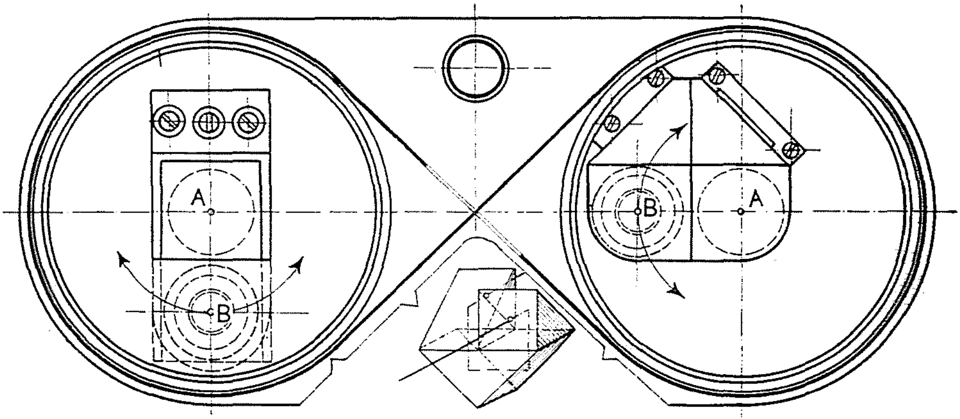


Fig. 3. Lever-controlled prism device for interocular distance adjustment. The left-hand eyepiece is adjusted by a rhombic prism, that of the right *e.g.* by a Porro system. *A* denotes the optical axis of the objective, *B* that of the eyepiece

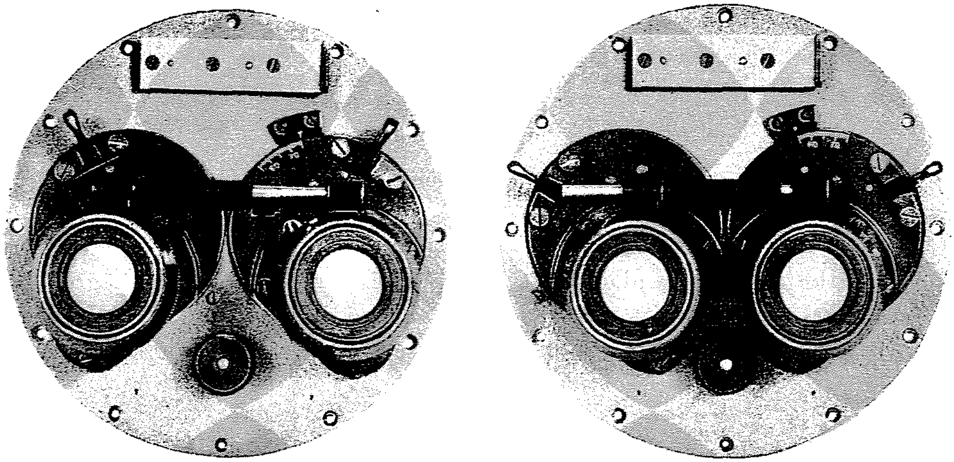
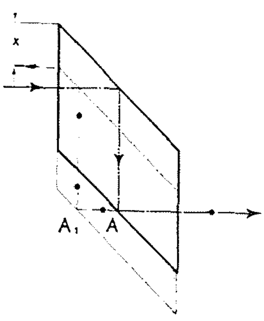


Fig. 4. The control mechanism of Fig. 3, with the eyepieces in extreme position

case the axes of the eyepieces describe an arc, since the prisms swing about an axis normal to their planes of incidence. The rhombic prism displaced in the direction of the optical axis located in the main section (Fig. 5) does not lead to vertical errors, for the axis of the bundle emerging from the prism maintains its direction even if displaced. The displacement, however, conveys point *A* of the optical axis, which is symmetrical to the plane of incidence, to *A'*, whereby the bundle ceases to be symmetrical. Thus, a certain portion of the marginal bundles may be eliminated, a phenomenon likely to occur with prisms having optimal dimensions. If, however, a rectangular 45° prism is shifted parallel to the plane of the hypotenuse, the image will be displaced.



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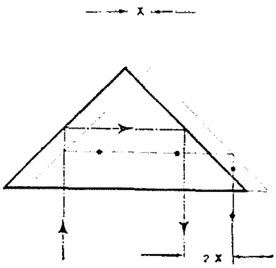

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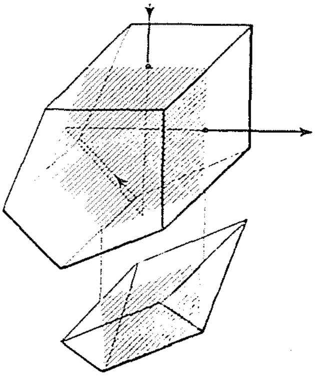

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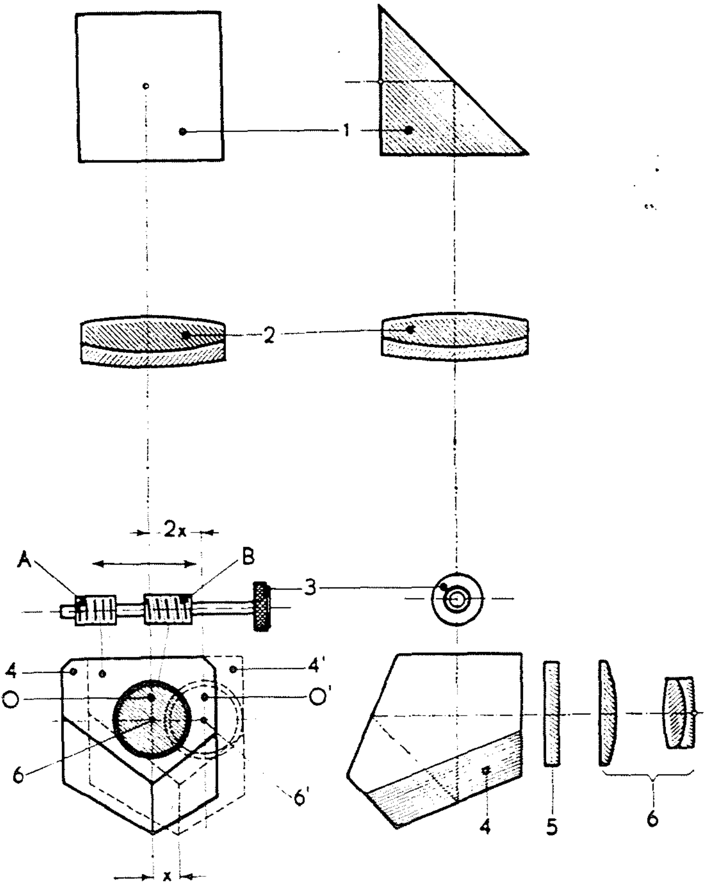
Fig. 5. When the rhombic prism is shifted in the direction of the main section, no vertica error, but possibly vignetting occurs

Fig. 6. Travelling of the optical axis with the displacement of the 45° rectangular prism

Fig. 7. Design of the penta roof edge prism

The principle of this latter arrangement has long been known, and has been applied for adjusting Porro telescopes. In order to eliminate the vertical error (Fig. 6), the prism in its mount is shifted by amount x, whereupon the axis of the emerging bundle suffers a displacement of $2x$ in relation to the original ray.

After these preliminaries we shall now treat an angle telescope provided with a penta roof prism, in which the adjustment of the interocular distance is effected by displacing one of the prisms in the direction normal to the optical axis. The roof surface of the penta prism may be replaced by a rectangular 45° prism, the main section of which is normal to the main section of the prism (Fig. 7). Hence, a displacement in a direction normal to the main section will give rise to the phenomena illustrated in Fig. 6. The reflecting surfaces of the roof edge give an angle of 90°, and the axis of the incident bundle passes through the edge formed by the roof faces, thus, the axis of the bundle and the roof edge have to fall in the same plane. The angle made by the roof faces must be precisely 90°, as first a portion of the bundle is reflected by the first mirrored face, while another portion is reflected by the second mirrored face, so that the angle made with the incident rays must not be modified after being reflected twice, not even if the order is reversed. In the binocular telescope diagrammed in Fig. 8, the image made with the objective (*2*) and reversed in the horizontal plane through 90° by the rectangular 45° head prism (*1*) is erected in the image plane by the penta roof prism (*4*). The axis (*0*) of the objective is precisely adjusted to the roof edge, at the internationally accepted 65 mm interocular distance, with the telescope adjusted to infinity. When, during the adjustment



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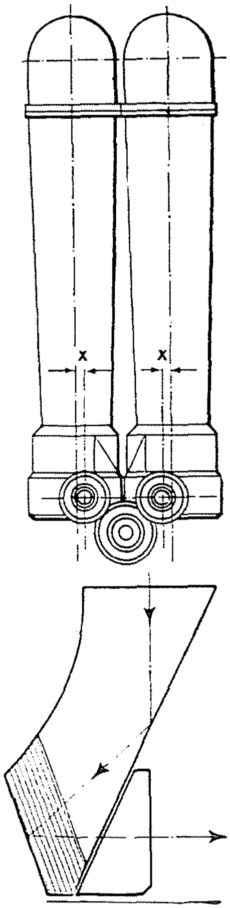

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Fig. 8. Path of rays and image erection in penta roof prism binocular telescopes. Adjustment of interocular distance by means of displacing eyepiece and prism with a differential screw

Fig. 9. Angle telescope with eccentrically disposed roof prism

of the interocular distance, the prism is displaced in the direction of the arrow (*6'*), that is, normal to the main section, then the axis emerging from the prism (Fig. 2) is displacing twice the amount of the prism itself, so that an inconvenient double image is produced. To remove this, the eyepiece is displaced — in our example by means of a differential screw (*A* and *B*) — at twice the velocity as the prism is (System Goerz).

The same principle has since long been applied by Messrs Zeiss, although not for the adjustment of the interocular distance. In the 12 by 50 binocular telescope derived from 1911 (Fig. 9) it was impossible, for constructional reasons, to adjust the axes of the eyepieces to the smallest accepted interocular distance, thus, they were approximated by $2x$ each, calculated from the vertical optical axis of the telescope. Hence, the axes of the eyepieces no longer coincided with the axis of the instrument. Image erection was effected by means of the roof prism system represented at the lower part of the figure. The front view (Fig. 10) shows that the axis a of the eyepiece is at a distance $2x$ from the optical axis c of the instrument. In order to eliminate this inconvenience, the roof edge of the prism d is situated at point b, which is in the midpoint of the distances a and c.

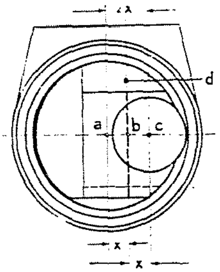

Fig. 10. Effect of the roof prism on the angle telescope of Fig. 9

Fig. 11 represents the perspective view of a gear mechanism of the Zeiss system, used for the alignment of the adjustable eyepieces. When lever *1* is shifted, the left-hand eyepiece, disposed eccentrically in relation to the right-hand fixed eyepiece, is displaced in alignment. Fig. 12 shows a rear view of the two extreme positions of the eyepiece. Upon the shifting of lever *1* disc *4* swings along with mount *5* and eyepiece *3*, the mount being eccentrically disposed in the disc. In the meantime rack *6* fixed on disc *5* revolves on the fixed rack *8*. The motion resulting therefrom, and from the rotation of the eccentric disc, shifts the eyepiece in alignment. Ring *9* bearing a slot serves against over-rotation in the two extreme positions of the eyepiece.

Binocular telescopes are usually provided with exchangeable colour filters. The simplest way of changing the filters is by pushing them onto the eyecup of the eyepiece, but it is generally preferred to use built-in filter changing devices of the revolving disc, drum or sliding type. All these solutions require a certain amount of space, so that when there is little available space, one has to resort to other solutions. By chance we became acquainted with a binocular telescope provided with an unusually ingenious device for chang-

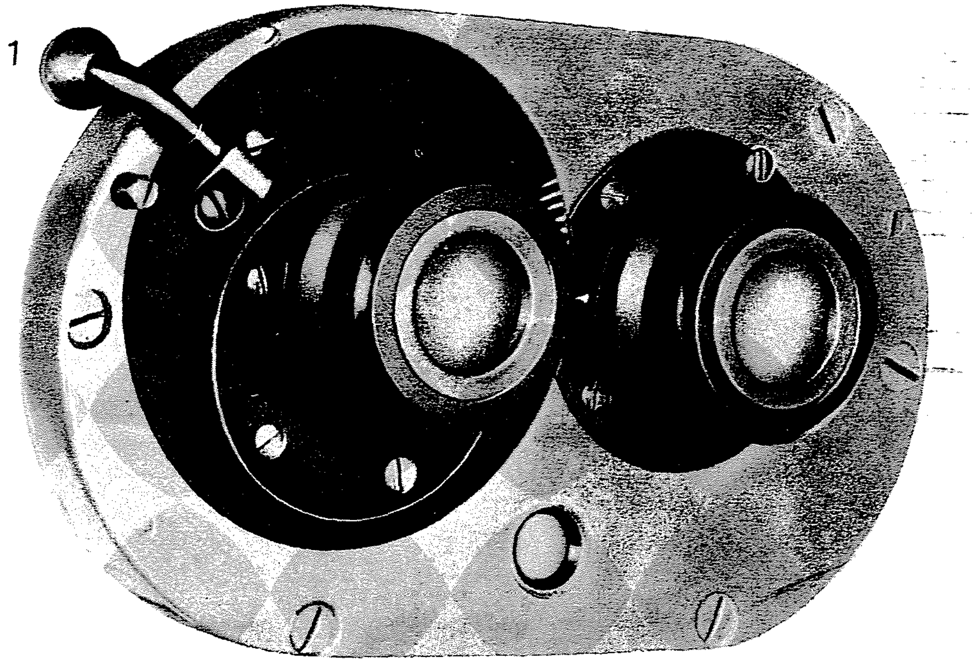

Fig. 11. Adjustment of interocular distance, with rack-and-pinion control and eccentrically disposed eyepieces

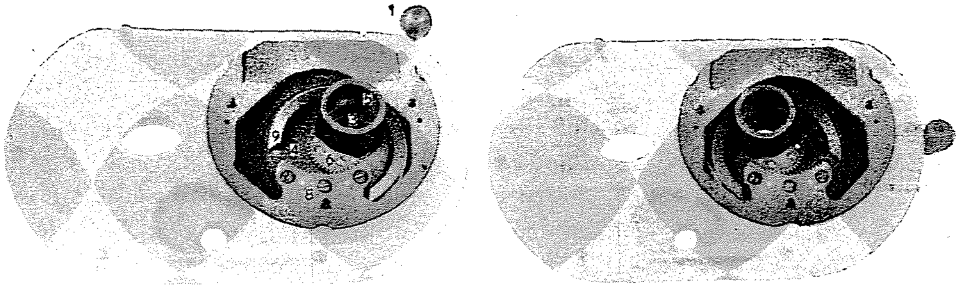

Fig. 12. Rear view of the eyepiece control of Fig. 11, with the eyepieces in extreme position

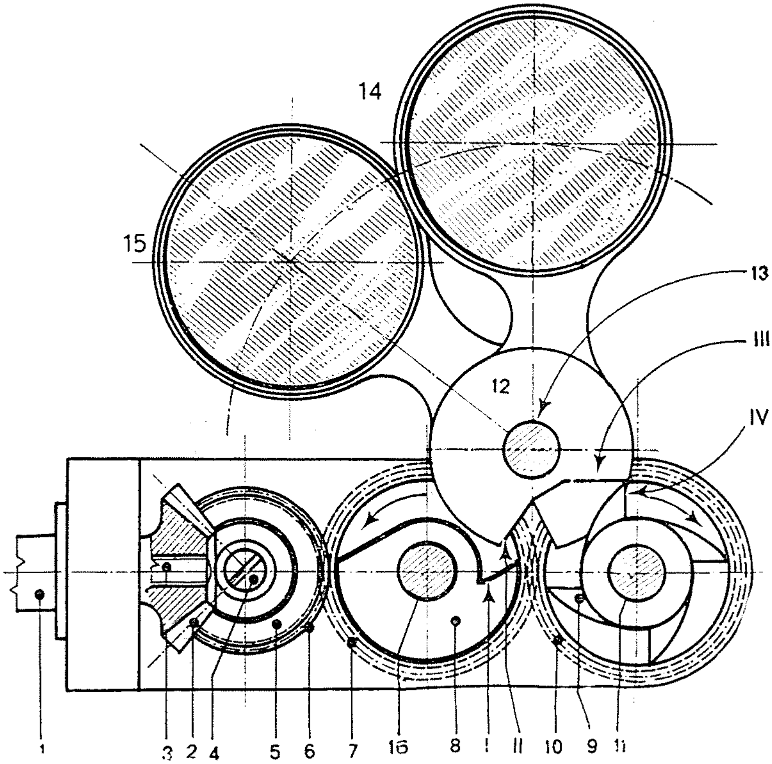

Fig. 13. Top view of a swinging colour filter changing device

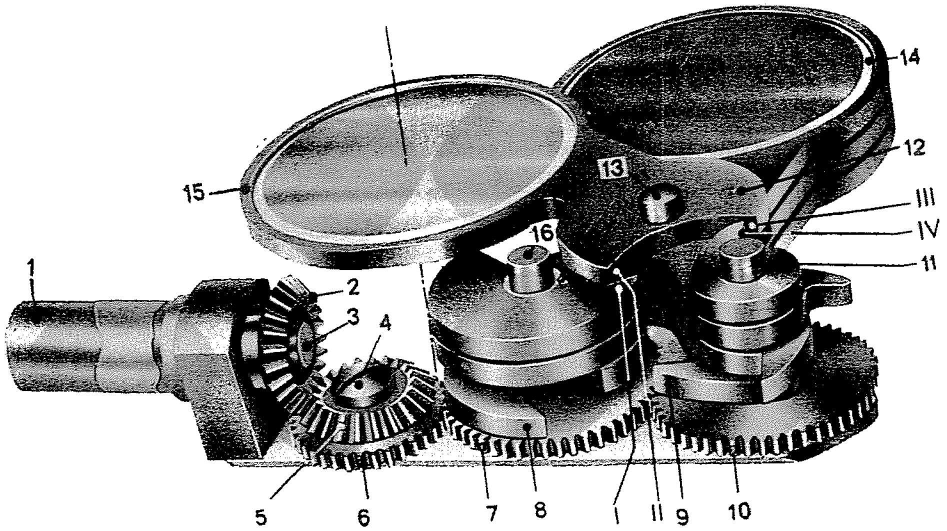

Fig. 14. Perspective view of a swinging colour filter changing device

ing the colour filters (Figs. 13 and 14). The origin of the instrument could not be ascertained as it was found in a badly damaged condition.

The four filter arms, situated one below the other, are free to rotate about pivot *13* through a certain angle. In the position represented filter *15* is in the optical axis of the telescope. The bevel gear mounted on pivot *3* driven by axle pin *1* rotates spur gear *6* about pivot *4* by means of bevel gear *5*. Spur gear *6* takes along gear *7* as well as spur gear *10* which has a similar diameter. The series of superposed cam-discs *8*, mutually displaced through a certain angle, swing about pivot *16* along with gear *7*. The clawed discs *9*, also situated one below the other and mutually displaced, similarly swing about pivot *11* along with spur gear *10*. One of the clawed discs turns the filter arm into the optical axis, while the other secures the arm in its final position. When the filter enters the optical axis, cam-disc *8* and claw *9*, respectively, support filter arm *15* swinging about pivot *13*. When the filter arm is placed into position by one of the cams *8*, the edge of the claw *9* revolves on the plane surface III of arm *12*. Upon further rotation, the top cam will only just touch face II of arm *12* by top cam I. Simultaneously, the top one among the cams *9* is just about to leave the face III of arm 12 with its claw *4*. In this position filter *12* is still fixed. During rotation, however, the cams and claws swing on in such a manner that only one filter at a time is swung into the optical path. When rotation is continuous, the filters alternately enter or leave the optical axis.

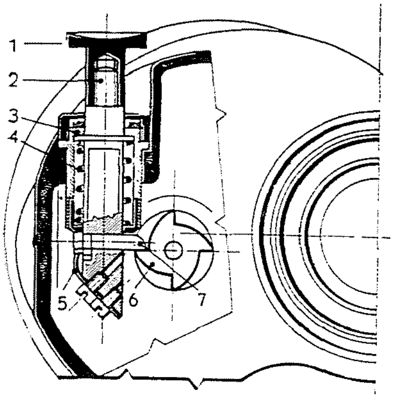

Fig. 15. Push-button colour filter changing device for prism binoculars

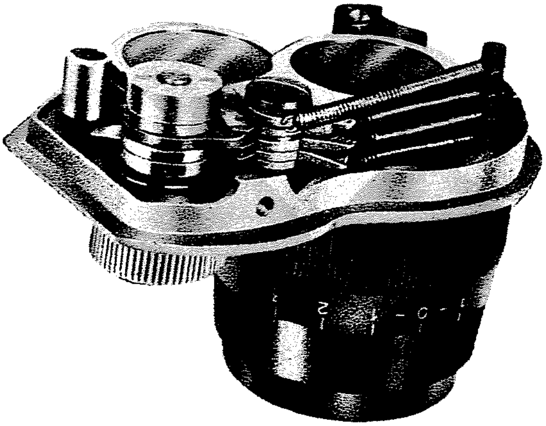

Fig. 16. Swinging colour filter changing device for prism binoculars

This equipment may be well-adapted for using in prism binoculars. The colour filters conventionally used for small prism binoculars are slid onto the eyepieces, a procedure which is very inconvenient when rapid changes are required, and may result in the loss of the filters. When more extensive observation is involved, together with the necessity of various colour filters, it is advisable to incorporate a mechanism of this type into the instrument (see Fig. 15).

In this construction, the return of the filters is effected by the action of springs. Instead of using a revolving knob, adjustment is done by means of a push button. When pressing the button in alignment, pin *7* mounted on the end of rod *2* disposed in sleeve *3* imparts a jerk-like turn to wheel *6*. The wheel is secured in any desired position by laminated spring 5, and a coiled spring *4* pushes the button back into starting position. Fig. 16 illustrates another construction, also for prism binoculars. In this case adjustment is carried out from the outside, by means of a revolving knob.

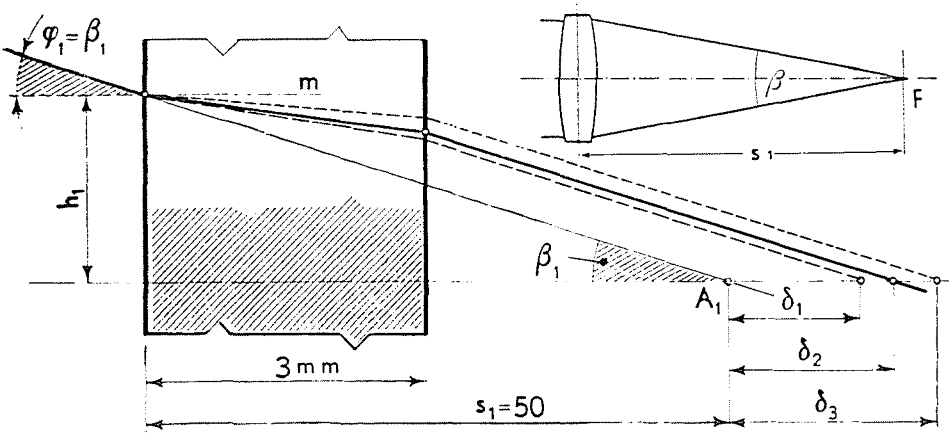

Fig. 17. The path of rays in an optical plate

In the case of a telescope adjusted to infinity, filters disposed in front of or behind the eyepiece have no optical effect, apart from astigmatism, provided that the filters are strictly plano-parallel. When the filters are placed so as to intersect a diverging or converging bundle, the image will be shifted backwards from the plane of the field of view — depending on the thickness and the refractory index of the glass — for the filter will add to the length of the path of rays. Therefore, after the removal of the filters, a neutral optical plate has to be inserted into the path of rays, so as to maintain the image section of distance at the same value as did the filters. The role played by the thickness and the refractory index stresses the importance of considering these factors in the choice of filters, with reference to the following numerical examples (Fig. 17).

Lens *1* forms the image of an object at infinity in the focal plane *F*. Let $s = 100$ mm and $\beta = +45°$. When filter plates of 3 mm thickness, made from glasses having different refractory indices, are inserted before the image plane at $s_1 = 50$ mm, the image plane F will be displaced by value

$$\delta = \frac{n-1}{n} d$$

The data of the three types of glasses used in the example are

FK3	BK7	SF6
$n_D = 1{,}464\,50$	$n_D = 1{,}516\,33$	$n_D = 1{,}805\,18$

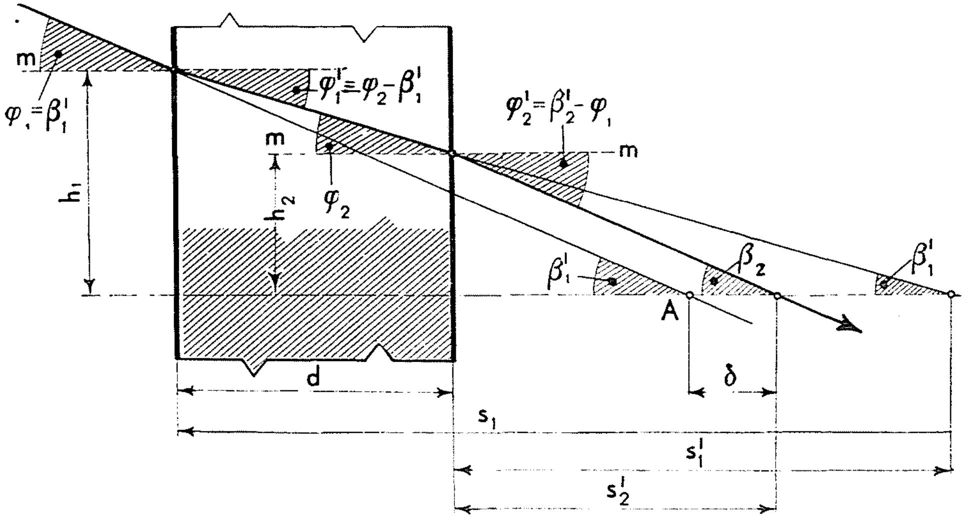

Fig. 18. The effect of the filter's thickness depending on the refractive index

The amount of displacement is

$$\delta_1 = 0{,}951\,5$$
$$\delta_2 = 1{,}021\,5$$
$$\delta_3 = 1{,}338\,1$$

respectively. If it is desirable to produce the same amount of displacement for each filter, for instance δ_2, the thickness of the other two optical plates has to be varied. When

$$d_1 = \frac{n \cdot \delta_2}{n-1} = 3$$

for the BK7 glass, then

$$d = 3{,}22$$
$$d_2 = 2{,}29$$

(Fig. 18). The following table indicates the course of the ray, calculated for modified thicknesses.

		FK3	BK7	SF6
s_1		50	50	50
$\varphi_1 = \beta' = \beta_2$	=	5°	5°	5°
$\mathrm{tg}\,\beta'$	=	0,0874 887	0,0874 887	0,0874 887
$h_1 = s_1 \cdot \mathrm{tg}\,\beta'$	=	4,3744 35	4,3744 35	0,3744 35
$\sin\varphi_1 = \sin\varphi_2'$		0,0871 557	0,0871 557	0,0871 557
$\sin\varphi_1' = \dfrac{\sin\varphi}{m} = \sin\varphi_2$	=	0,0595 122	0,0574 780	0,0482 809
$\varphi_1' =$	=	3°24'42,53"	3°17'42,24"	2°46'02,52"
$\mathrm{tg}\,\varphi_1' = \mathrm{tg}\,\beta_1'$	=	0,0596 179	0,0575 733	0,0483 372
$s_1' = \dfrac{h_1}{\mathrm{tg}\,\beta_1}$	=	73,3745 16	75,9802 72	90,4982 33
$-d$	=	−3,22	−3	−2,29
$s_2 = s_1' + [-d]$	=	70,1545 16	72,9802 72	88,2082 33
$h_2 = s_2 \cdot \mathrm{tg}\,\beta_1$	=	4,1824 653	4,2017 151	4,2294 233
$s_1' = \dfrac{h_2}{\mathrm{tg}\,\beta_2}$	=	47,805 8	48,025 8	48,735 8
Glass thickness		3,22	3,00	2,29
$s_2' + \delta$	=	51,0258	51,0258	51,0258
$s_1 + \delta = 50 + 1{,}0215$	=	51,0215		
$s_2' + \delta$	=	51,0258		
the difference		0,0043		

If the calculation is made with even greater accuracy for the modified glass thickness, the deviation will be eliminated.

When there is very little space available, the colour filter changing device is arranged between the eyepiece and the exit pupil near to the eyepiece lens, so as not to inconvenience the observer's eye and to leave sufficient space for approaching the exit pupil. The construction is similar to the revolver objective widely applied in microscopes (Fig. 19). Colour filters *4* and *7* are mounted in a spherical calotte shaped disc *2*, rotatable about screw *5* acting as a pivot. The disc swings about sleeve *10* fixed in head *3*, instead of swinging directly about the screw. The revolver arrangement is mounted on magnifying tube *8* machined in telescope *9*. A cover *1* is screwed on to cover the mechanism. A slot *11* is cut into an appropriate place of the cover to allow the rotation of the filter.

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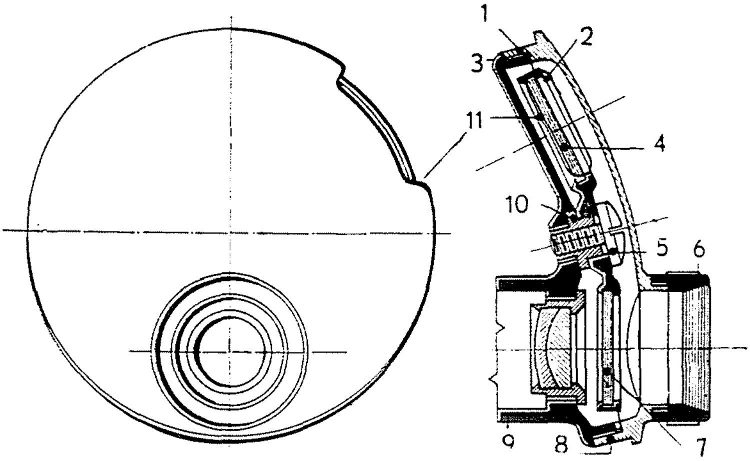

Fig. 19. Colour filter changing device disposed behind the eyepiece

Summary

The paper discloses a number of known adjusting devices well-adapted for using in optomechanical instruments. A few examples of interesting but unduly neglected control mechanisms are described, pointing out the possibility of their use in optical and precision instruments. Certain mechanical constructions are also mentioned, not well-known in general use but widely applied in military instruments.

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