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Some designing possibilities of rays or image stabilization with lenses included to the image inverting system of the terrestrial telescope*

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In this paper two different types of stabilization: *line of sight stabilization* and *rays direction stabilization* are discussed. Three possibilities of designing both the types of stabilizations, based on pivoting of lenses belonging to image inverting system of a terrestrial telescope are shown. Some proposals for placing the field of tolerance of stabilizer pivoting centres are also presented.

Any vibration of a physical body in a properly short period of time may be considered as a sum of two small movements: linear displacement and rotation.

When a terrestrial telescope vibrates, its linear displacements have rather negligible influence on the image visibility, provided that the exit pupil of the telescope does not escape from the pupil of the observer's eye.

The image displacement is substantially influenced by even quite small rotation of the telescope, because such a rotation a is multiplied by the magnification G of the instrument; it results from the formula

$$\delta = a(G-1). \tag{1}$$

The quicker rotation, the worse visibility of the object. This visibility may be significantly improved by application of a properly working stabilizer. Every stabilizer may work in two ways giving different results. The first result may be called *rays direction stabilization* and the other one – *image stabilization* or – which means almost the same – *line of sight stabilization.* The last two terms are commonly used also for the case of *rays direction stabilization*, which is obviously incorrect. We can speak about *line of sight stabilization* only when a graticule has been incorporated into the telescope and thus there exists the line of sight.

In any case, the stabilizer work should cause an opposite deflection of rays leaving the telescope in relation to the deflection caused by a sudden instrument rotation, but the value of such a deflection depends on the type of stabilization.

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If the vibrating terrestrial telescope of higher magnification is to be used for observations only and an observer is to keep the instrument in hands, without any stand, then its most proper design requires that the rays leaving the telescope do not change their direction while the instrument vibrations. This may happen only in the case when deflection of rays leaving the telescope due to the operation of stabilizer is equal and opposite in sign to the deflection caused by this rotation. It means that

$$\delta_r = -\delta = -a(G-1). \tag{2}$$

This type of compensation should be termed instead of *image stabilizing* or *line of sight stabilizing, rays direction stabilizing.*

If the vibrating telescope is to be used as a sight or a photo-telescope, the most important task of its stabilizer is to minimize image displacements in relation to the graticule plane or to the film tape plane. Such a type of compensation produces the *line of sight stabilization* or *image stabilization.* This means that rays leaving the eyepiece of the telescope should appear as if being rigidly connected to the body of the eyepiece. If the rays leaving the eyepiece are parallel to its axis, they remain parallel to the same axis, being inclined, independently of the small angle a of the telescope inclination. This means that

$$\delta_l = -a' = -aG \tag{3}$$

where δ_l is angle of rays deflection stabilizing the sight or image lines.

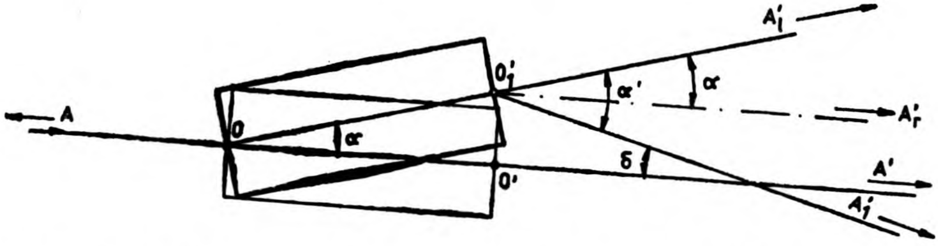

Fig. 1. The effect of terrestrial telescope rotation. A – object position, A' – primary image position, A_1' – image position for an uncompensated telescope and rotated by a small angle a, A_r' – image position for rays direction stabilization, A' – image position for line of sight stabilization

Figure 1 represents the rays from an object A coming to the telescope, and leaving it before and after its small rotation by the angle a. Rays A_r' and A_l' show the cases of *rays direction stabilization* and *line of sight stabilization,* respectively. It is obvious that

$$|\delta_r| < |\delta_l|. \tag{4}$$

That means that the deflections caused by stabilizing device must be larger for the case of *line of sight stabilization* than for the *rays direction stabilizing.*

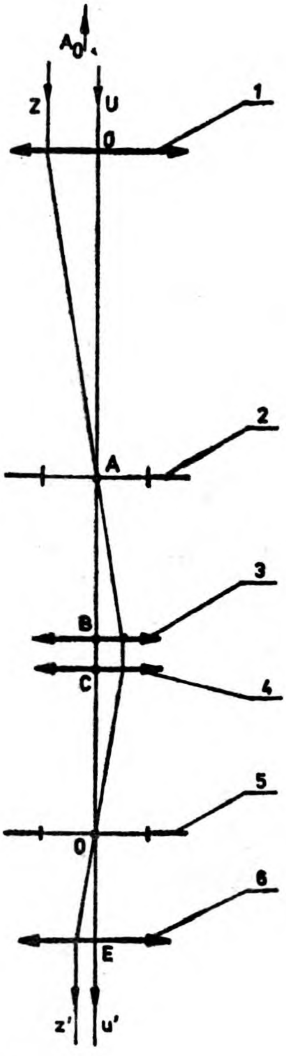

Fig. 2

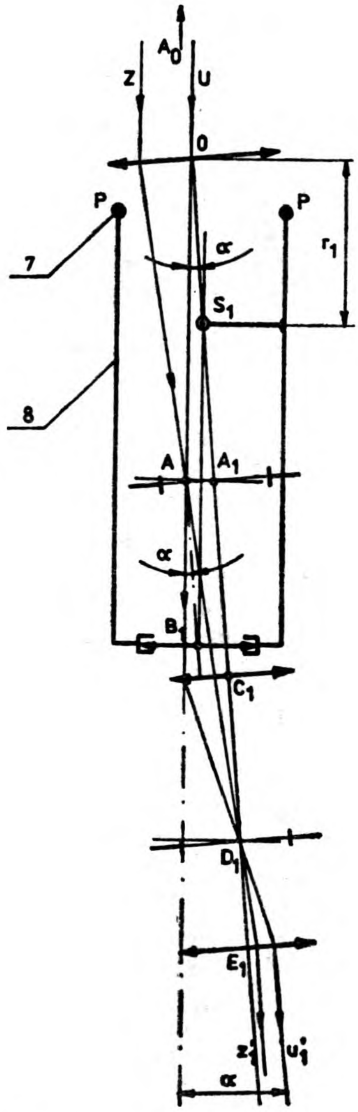

Fig. 3

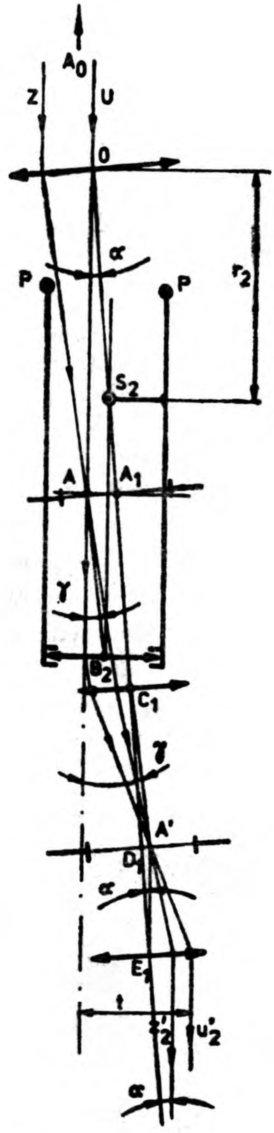

Fig. 4

Fig. 2. Schematic diagram of a terrestrial telescope. A_0 – object position, 1 – objective, 2, 5 – diaphragms, 3, 4 – image inverting system, 6 – eyepiece

Fig. 3. Image stabilization by pivoting the first lens of inverting system. O – centre of the telescope rotation, S_1 – pivoting centre, 7 – balance weight, 8 – pivoted assembling, a – small rotation angle

Fig. 4. Rays direction stabilization by pivoting the first lens of image inverting system. S_2 – pivoting centre

Up to now various types of stabilizing devices have been patented and described in literature [1–10]. Most of them are based either on liquid or glass-made optical wedges put in front of the objective or on precisely pivoted mirrors and prism-systems built in the stabilized instrument.

There is another, quite interesting possibility of producing both the types of stabilization, based on a traditional type of lens image inverting system, commonly used in the terrestrial telescope.

Figure 2 shows a schematic diagram of a terrestrial telescope with objective 1, two-component lens inverting system 3 and 4, field diaphragm 5 and eyepiece 6. Objective-entering rays Z, U and eyepiece-leaving rays $-z'$, u'.

Let us imagine that the first component B of the inverting system is frictionless pivoted in some point S_1 situated on the optical axis of the instrument and that this point overlaps the gravity centre of the pivoted assembling. If there occurs any sudden rotation of the telescope by a small angle a, the pivoted assembling does not follow this rotation; its position in such a situation has been shown in Fig. 3. When the pivoting centre is placed after the objective at the distance r_1, equal to the focal length of the suspended lens, the rays leaving the eyepiece parallelly to the axis of the telescope remain parallel to the same but inclined axis. This means that the pivoted assembling plays a role of image stabilizer and that the image is motionless with respect to the field diaphragm of the telescope eyepiece.

In Figure 4 the same lens has been pivoted in some distance r_2, a little longer than r_1. Basing on Fig. 4 one can write

$$ar_2 = \gamma f_1', \gamma = a\left(1+\frac{f_{oc}'}{f_2'}\right), \beta = -f_2'/f_1'.$$

Hence

$$r_2 = f_1' - \frac{f_{oc}'}{\beta} \tag{5}$$

where f_1' and f_2' are focal distances of lenses creating the inverting system and f_{oc}' is the focal distance of eyepiece.

Equation (5) describes the case when the pivoted lens plays a role of a ray direction stabilizer, because the rays leaving the eyepiece parallelly to the axis of not inclined telescope do not change their previous direction with respect to the surroundings of the telescope, independently of the values of small angles a.

Figure 5 represents the image stabilizer, based on frictionless suspension of the second component of the same inverting system in some chosen distance r_3 after the telescope objective. From this figure we can write

$$\gamma_1 = a\left(1+\frac{f_{ob}'}{f_1'}\right), la = r_3 a + f_2'(\gamma_1 - a),$$

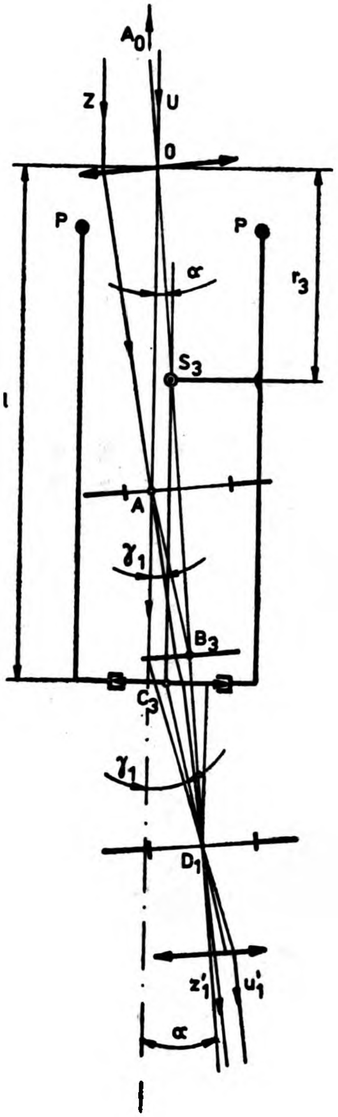

Fig. 6

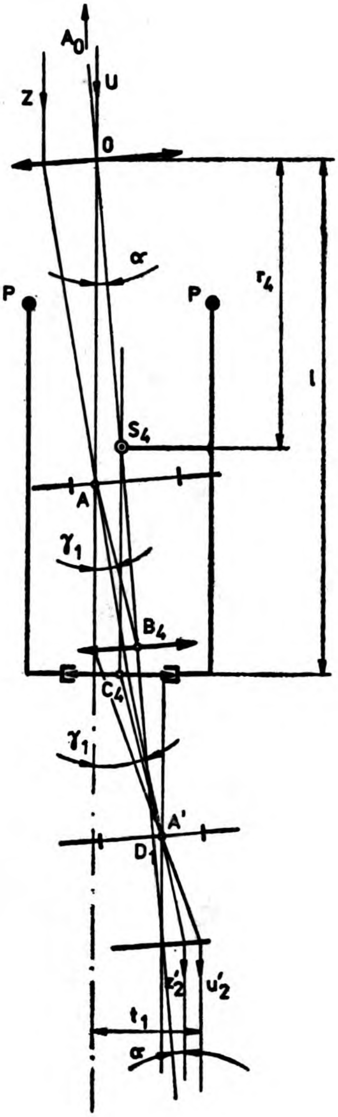

Fig. 5

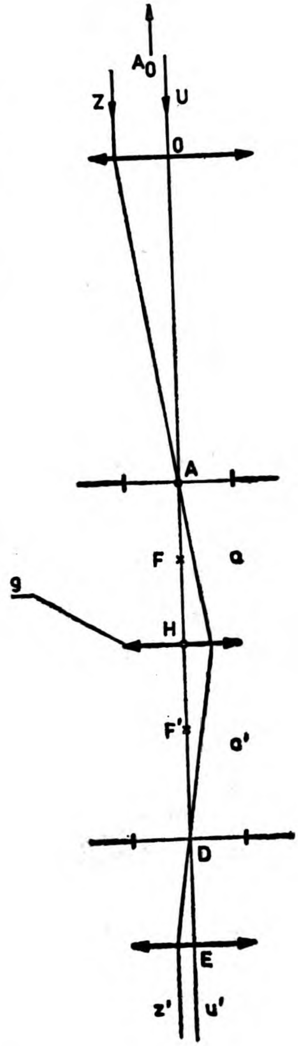

Fig. 7

Fig. 5. Image stabilization by pivoting the second lens of image inverting system. S_3 – pivoting centre

Fig. 6. Rays direction stabilization by pivoting the second lens of image inverting system S_4 – pivoting centre

Fig. 7. Simplified diagram of a terrestrial telescope: 9 – image inverting system

which yields $r_3 = l + f'_{ob}\beta$ (6)

where f'_{ob} is focal distance of the objective, and β is magnification of the inverting system.

If the same lens has been pivoted at some distance r_4 greater than r_3 then basing on Fig. 6 we can write

$$la = r_4 a + f'_2 \left(\gamma_1 - a - a\frac{f'_{oo}}{f'_2}\right)$$

or

$$r_4 = l + f'_{ob}\beta + f'_{oo}. \quad (7)$$

When such a condition is fulfilled the suspended assembling plays a role of rays direction stabilizer.

A more simplified schematic diagram of the same telescope is shown in Fig. 7. The inverting system is created by one lens, the object and image distances being a and a', respectively.

In Figure 8 the image inverting system has been pivoted in the distance r_5 behind the telescope objective. From this figure we can write

$$\gamma_1 = \frac{r_5}{a}a, \ \beta = a'/a, \ a(f'_{ob} + a + a') = \gamma_1(a + a'),$$

which results in

$$r_5 = a + \frac{f'_{ob}}{1-\beta}. \quad (8)$$

In this way another image stabilizing system for a telescope may be created.

Obviously, it is possible to design a ray direction stabilizer making the suspending distance r_6 a little longer than r_5.

From Figure 9 we can write

$$\gamma_2 = \frac{r_6}{a}a, \ \ a(f'_{ob} + f'_{oo} + a + a') = \gamma_2(a + a').$$

or $$r_6 = a + \frac{f'_{ob} + f'_{oo}}{1-\beta}. \quad (9)$$

Comparing the formulae defining the positions of pivoting centres for image stabilizing with these for rays direction stabilizing we may find that for each kind of design the distance between these pairs of the points are usually not greater than the focal distance of the telescope eyepiece.

In a really made instrument, for every dimension should be assured some field of tolerance. As far as optimization of the performance is concerned, it seems that the best possible solution of the problem, especially in the case of sight designing for every distance r, is when these fields of tolerance are between

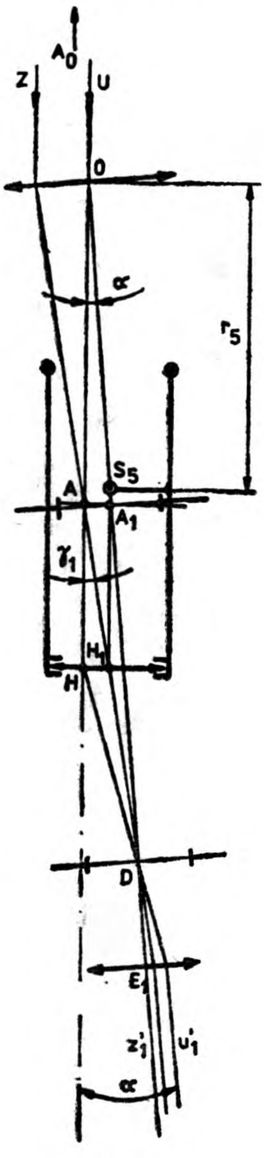

Fig. 8

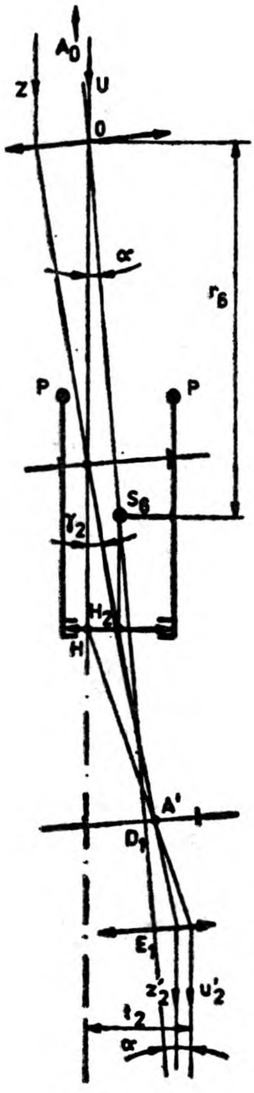

Fig. 9

Fig. 8. Image stabilization by pivoting the whole image lens inverting system. S_5 – pivoting centre

Fig. 9. Ray direction stabilization by pivoting the whole image lens inverting system. S_6 – pivoting centre

the points for image and for rays direction stabilization. Of course, in any case each pivoting centre should be as near as possible to its theoretical position. In this way such a really existing image stabilizer, having some inavoidable inexactness of performance, will slightly approach the ray direction stabilizer and vice versa.

References

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