EFFECT OF RESIDUAF INSTRUMENTAL ABERRATIONS ON QUALITY CONTROL OF OPTICAL COMPONENTS

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In the fabrication of optical antennas for problems in atmospheric optics a great deal of attention is paid to the quality of the optical components. In this paper control and measuring instruments (shadow and interferometer), in which residual aberrations do not affect quality control, are analyzed. These instruments are used for checking the surfaces of optical antennas with a large aperture ratio.

In many problems involving optical sounding of the atmosphere it is necessary to employ high-quality optical antennas because the quality of the optics determines the error in measuring the parameters. This pertains to instruments operating in the regime of both integrated measurements, for example, under conditions of weak illumination of a photodetector, and differential measurements in which the structure of the focal spot is analyzed.[1] The error due to residual aberrations of the optical system in measuring the corresponding parameters of the atmosphere is of a random character and cannot be eliminated by precalibration.[1] The easiest way out of this situation is fabrication of high-quality optics.

An integral part of the technological process of fabrication of optical components is careful checking of the quality of fabrication. In designing a control scheme, namely, control and measuring instruments, special attention must be devoted to the effect of residual aberrations of the checking instrument on the results of measurements. This situation pertains to all optical measurements, and especially the checking of components for problems in atmospheric optics.

The problem is that lidar antennas are quite large (150–600 mm) and are employed only under stationary conditions, so that the designers are faced with the problem of reducing the mass-size characteristics of the antennas. This problem is solved by employing in lidars optical components with high aperture ratios ranging from 1:1 to 1:4. In the process of checking the optics it is necessary to work wavefronts with large aperture angles. It is obvious that the effect of residual aberrations of the control and measuring instrument is especially large in this case.[2]

In this paper we present the results of an analysis of well-known optical schemes for checking concave spheres.

SHADOW INSTRUMENT

The Foucault scheme for studying concave mirrors is presented in Fig. 1. A point source of light *1* illuminates the component being checked – the sphere *2*, which forms an image 3 of the source. A spatial filter *4* is placed near the image *3*. When the filter 4 is inserted into the pencil of rays near the focal point 3 the filter introduces changes in the spatial frequency spectrum of the wavefront, formed by the component *2*, such that the aberrations of the wavefront are visualized in the form of a half-tone relief – the shadow pattern *3*. A screen with a sharpened edge – a Foucault knife – is usually employed as a spatial filter. In this case the photometric profile of the shadow pattern, passing through the optical axis in a direction perpendicular to the knife edge, equals within a constant factor the transverse aberration of the wavefront (the so-called Filbert method[3]). D.D. Maksutov showed[4] that in order to increase the illumination of the shadow pattern a line source oriented parallel to the knife edge can be used instead of a point source.

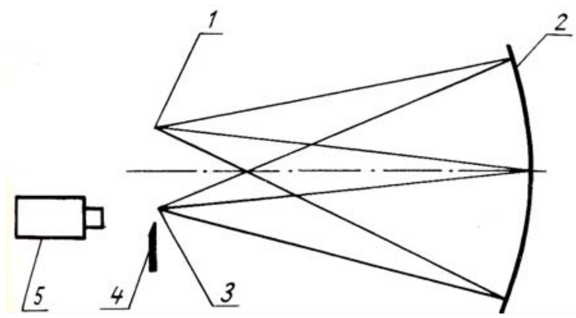

FIG. 1. Foucault scheme for studying concave spheres;: 1) point source of light; 2) sphere being checked; 3) image of the light source; 4) spatial filter (Foucault knife); 5) TV camera.

In the Foucault-Filbert shadow instrument the light source and its image are separated in order to separate the analyzed beam from the illuminating beam. This separation is the source of residual aberrations in the shadow instrument. Several variants of the decoupling unit are distinguished (Fig. 2).

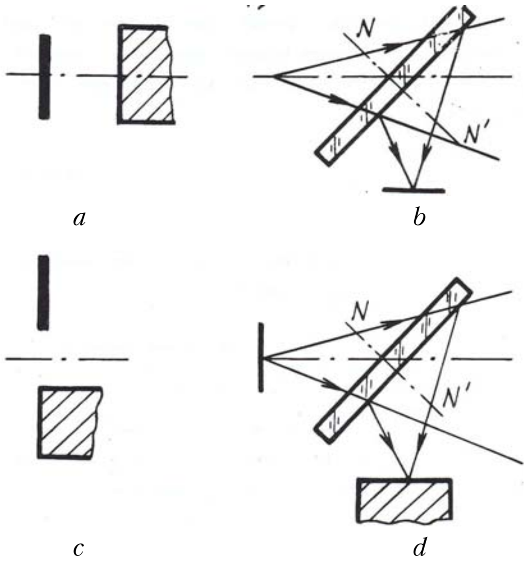

FIG. 2. Variants of the decoupling unit. Off-axis schemes: a) photometric measurements are performed in the meridional section; c) photometric measurements are performed in the sagittal section; scheme with beam-splitting plate: b) photometric measurements are performed in the meridional section; d) photometric measurements are performed in the sagittal section.

It is obvious that off-axis schemes introduce into the wavefront being checked an aberration due to the fact that the illuminating beam, is incident off-axis on the spherical mirror[2], while schemes with a beam-splitting plate introduce an aberration due to the passage of the beam through a tilted plane-parallel plate[2]. Numerical analysis of the residual aberrations of these schemes can be easily performed by calculating the wave aberrations for a point source. Thus Table 1 gives the results of calculations using the STRAHLE program on an ES-1055 computer for a concave spherical mirror with the parameters $D/f' = 1/1$, where D is the diameter of the sphere being checked and f' is the focal length.

Analysis of Table 1 shows that the most useful scheme is the one with a beam splitting mirror. For the same residual aberrartion the scheme in Fig. 2c is structurally more advantageous, since it makes it possible to separate the slit and the knife by a significant distance. It should be noted that a small aberration in some section does not exclude a poor shadow pattern as a whole, when the component being checked has a large aperture ratio the knife will be observed to "rotate", the shadow pattern will be smeared at the edge of the component, etc. The section perpendicular to the surface of the knife and passing through the center of the component will nonetheless give the correct pattern. Filbert's method is therefore more efficient.

TABLE 1.

The dependence of residual wave aberration of the shadow instrument on its optical arrangement

off-axis variant	maximum wave aberration in the sagittal section (μm)	maximum wave aberration in the meridional section (μm)	
		in right half-plate	in left half-plate
0.5	$-0.1\cdot10^{-9}$	$-0.2\cdot10^{-3}$	$-0.19\cdot10^{-3}$
1.0	$-0.3\cdot10^{-8}$	$-0.8\cdot10^{-3}$	$-0.76\cdot10^{-3}$
2.5	$-0.1\cdot10^{-6}$	$-5.24\cdot10^{-2}$	$-4.6\cdot10^{-2}$
5.0	$-0.2\cdot10^{-5}$	-0.022	-0.017
10	$-0.3\cdot10^{-4}$	-0.099	-0.059
half-transmit. plate d=2.5 mm L=30 mm	-0.095	1.917	-2.192

UNEQUAL PATH INTERFEROMETER

Figure 3 shows a diagram of an unequal path Interferometer employed for checking concave spheres.

The laser *1* and the microobjective *2* form a point source of light In such a manner that the mirror *4* being checked and the reference mirror *5* are illuminated from the center of curvature. The beam splitter in this scheme Is a cube *3* with whose help the wavefronts are separated and combined in order to form an interference pattern. The equation of the interference pattern has the form[5]

$$I_{(x,y)} = a^2_{s(x,y)} + a^2_{w(x,y)} - 2a_s^{(x,y)}\, a_w^{(x,y)} \cos(\varphi_s^{(x,y)} - \varphi_w^{(x,y)}), \tag{1}$$

where I is the intensity of the light in the plane of the interference pattern; a_s and a_w are the amplitudes of the standard and working wavefronts, φ_s and φ_w are their phases.

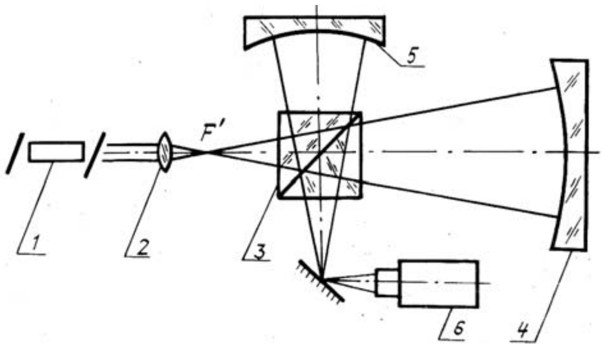

FIG. 3. Optical layout of an unequal path interferometer: 1) laser; 2) microobjective; 3) beamsplitting cube; 4) mirror being checked; 5) reference mirror; 6) TV camera.

The presence of a plane-parallel plate-cube in the homocentric pencil of rays introduces into the wavefronts in the reference and working arms a spherical aberration whose magnitude grows rapidly as the aperture of the mirror being checked increases. When the residual aberration is the same in both arms its magnitude is of no significance, since the difference of the phases of the interfering beams appears in Eq. (1).

The same situation is observed in an equal arm interferometer. When the arm lengths are substantially different the situation changes. Table 2 gives the results of the calculation of the magnitude of the wave aberration in the working arm $W(R_{w,m})$ as a function of its length and the difference of the wave aberrations ΔW in the working and standard arms. The dimensions of the optical elements of the interferometer are given below:

the edge length c of a K8-glass cube is 30 mm;

the distance d from the point F to the cube is 35.2 mm;

the radius of curvature R_s of the reference surface is 80 mm;

the aperture A of the component being checked is 1.

TABLE 2

The effect of the length of the working arm on the difference of the wave aberrations

$R_{w.m.}$ mm	-60	-80	-1500	-3000	-10000
$W(R_{w.m})$ µm	-7.459	-7.508	-7.650	-7.654	-7.657
$\Delta W=W(R_{w.m})-W(80)$	0.079	0	-0.142	-0.146	-0.149

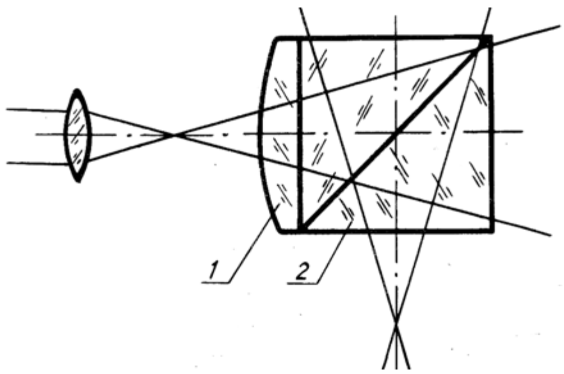

FIG. 4. Optical diagram of the beam splitter in the interferometer: 1) compensator (planoconvex lens); 2) beamsplitting cube.

The significant magnitude of the residual aberration, which can be referred to the component, makes this scheme unsuitable for checking mirrors with large apertures. To eliminate this drawback the optical scheme must be modified so that spherical beams propagate in the arms of the interferometer. This effect can be achieved by introducing into the optical system a compensator whose spherical aberration is equal in magnitude bit opposite in sign to that of the cube. It Is proposed that a planoconvex lens 1, glued to the beamsplitting cube *2* (Fig. 4), be used as a compensator. The structural parameters of the compensator with a 30 mm thick cube, fabricated from K8 glass, are: $R_1 = 295.8$, $R_2 = 0$, and $d = 7$.

Table 3 gives the results of the calculation of the magnitude of the wave aberration in the working arm $W(R_{w,m})$ as a function of its length and the difference in the wave aberrations ΔW of the working and reference arms.

$R_{w.m.}$ mm	-60	-80	-1500	-10000
$W(R_{w.m})$ µm	-2.870	-2.872	-2.873	-2.879
$\Delta W=W(R_{w.m})-W(80)$	0.002	0	-0.001	-0.007

The values obtained for AW make it possible to check large-aperture spheres with much greater reliability. It should be noted that the scheme shown in Fig. 4 is much simpler than those employing special microobjectives in order to compensate for the spherical aberrations of the cube[6] or a cube with spherical faces[6].

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