INFLUENCE OF OBSERVATION PLANE POSITION ON ERROR OF THE FISEAU INTERFEROMETER

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In this paper we consider how the position of the plane of interference pattern observation influences the error of optical element testing in the Fiseau interferometer. Proposed is the technique to select the plane position for observation under the interference pattern.

The Fiseau interferometer[1] is most often used for quality control of optical surfaces. This scheme has the following advantages: simple production and adjustment, versatile optical scheme, and others. An interesting feature of interferometers of this type is also the stability of measurement results to residual aberrations of the measuring branch. This problem is considered in detail in Ref. 4, where it is shown that although Fiseau interferometer error is far less than the residual aberration of the illuminating branch, nevertheless it is not zero due to transformation of the residual aberration at the interferometer working arm. In addition to the geometry factors considered in Ref. 4, namely, the operating relative hole and the working arm length, we may expect that the position of interference pattern observation also affects the measuring quality.

Wave front deformation as it moves at a distance Δr_0 is described by the following relation[1]:

$$\Delta N_0 = \frac{\Delta r_0}{2}\left(\frac{\delta S'}{r_0}\right)^2 \sin^2 u', \qquad (1)$$

where $\delta S'$ is the longitudinal spherical aberration of the wave front with paraxial curvature radius Δr_0; u' is the angle between a ray coming from the considered point and the optical axis (Fig. 1).

Assuming that Δr_0 is the distance from the surface (reference or tested part); r_0 is the curvature radius of this surface; $\delta S'$ is the longitudinal residual spherical aberration, and applying Eq.(1) sequentially to the reference and working wave fronts, we can calculate how the interferometer error ΔW_{max} depends on the position of the observation plane. An example of such dependence is shown by curve *4* in Fig. 2*a*.

Sufficiently far from caustic, ΔW_{max} changes insignificantly (thousandth fractions of percent) with respect to ΔW_{max} in the plane of the reference surface, but it increases significantly as the caustic is approached. The relation (1) was obtained using several approximations,[1] therefore we attempted to obtain a more plausible result.

Spherical aberration of the third order makes the greatest contribution into the error of the Fiseau interferometer.[4] This circumstance causes us to restrict ourselves to consideration of only this aberration.

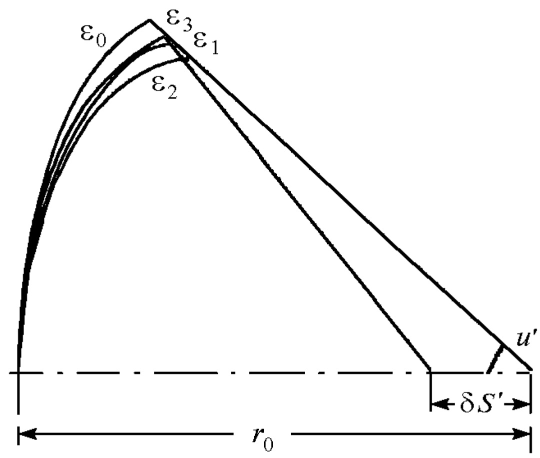

FIG. 1. Positions of wave fronts in the working part of the interferometer.

Figure 1 shows the relative positions of the reference wave ε_1 and the object wave front ε_2 with respect to the comparison sphere ε_0 when adding the spherical aberration to the illuminating beam; in cross section, the wave fronts have the following form: $W_1\,\rho^4$ and $W_2\,\rho^4$ (Ref. 3), where W_1 and W_2 are the coefficients of spherical aberration of the fronts ε_1 and ε_2, the difference between which is caused by transformation of residual aberration at a distance from the reference surface to the tested one. Usually the interferometer is adjusted to the minimum bend of interference bands, i.e. the center of a tested optical surface is at the plane of best adjustment. In this case, the object front is the front ε_3 having the following form:

$W_2\,\rho^4 - W_3\,\rho^2$,

where W_3 is the coefficient of defocusing caused by shift of the tested surface center with respect to the

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Gauss plane. Path difference ΔW between the reference front and the object one is distributed over the beam cross section as shown in Fig. 3, and maximum difference ΔW_{max} is just the aberration error of interference measurements for a fixed position of the observation plane.

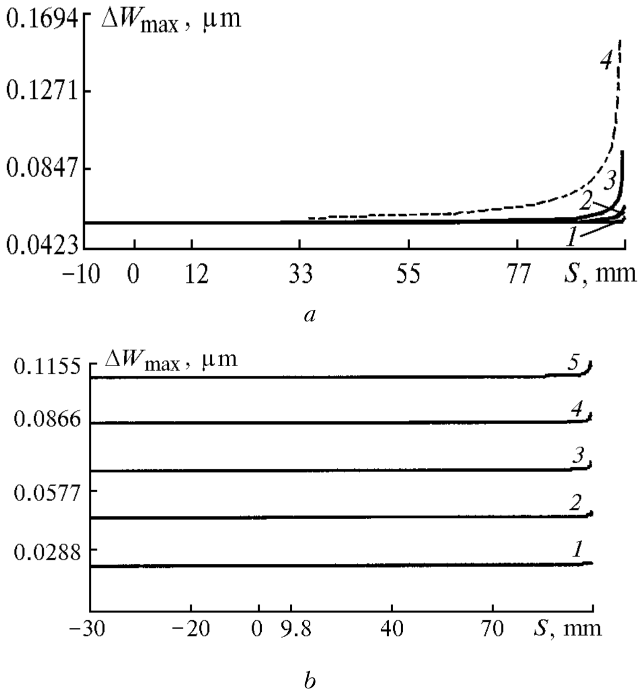

FIG. 2. Error of interference measurements ΔW_{max} vs the position of the plane of interference pattern observation S at R_{ref} = 100 mm and (a) for different diameter of input pupil of the reference surface D_p, mm: 100 *(1),* 60 *(2),* 20 *(3), and* 100 *(4) (using the relation (1)); (b) for D_p =* 100 mm *and different value of the residual aberration W_{ra}:* 0.4λ *(1),* 0.8λ *(2),* 1.2λ *(3),* 1.6λ *(4), and* 2λ *(5).*

To calculate the transformation ΔW_{max} with changed position of the observation plane, it is necessary to estimate deformation of the wave fronts ε_1 and ε_3 in their motion along the optical axis. Let us use the direct modeling of wave fronts ε_1 and ε_3 at a distance S from the reference surface plane by interpolating them by the array of points with coordinates obtained from the condition of eikonal equality in wave front propagation in a homogeneous medium. Then let us find ΔW_{max} calculating, by simple iterations, the distance between points, at which the ray passing through the center of comparison sphere, intersects the fronts ε_1 and ε_3 at the position S. The given accuracy (of the order of 10^{-10}) of these numerical methods allows sufficiently accurate estimation of the interferometer error ΔW_{max} caused by spherical aberration of the third order.

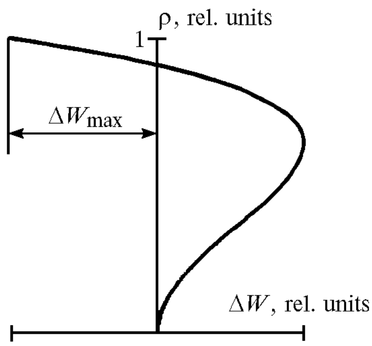

FIG. 3. ΔW dependence on ρ (height of the point where ray intersects the plane of reference input pupil) provided that a tested part is at the plane of best adjustment.

The calculation results for different values ΔW_{ra} of residual spherical aberration and parameters of the working branch of the interferometer are presented in the Fig. 2 and in the Table I. Here, D_p is the diameter of the reference input pupil; R_{ref} is the curvature radius of the reference surface; S is the position of the observation plane with respect to the reference surface.

TABLE I. ΔW_{max}, in μm, *for D_p =* 100 mm, *W_{ra} =* 2λ.

Relative hole	S					
	$-10R_{ref}$	$-R_{ref}$	0	$0.5R_{ref}$	$1.5R_{ref}$	$10R_{ref}$
1/1	0.1080812	0.1080815	0.1080818	0.1081143	0.1080813	0.1080809
1/10	0.1080812	0.1080816	0.1080818	0.1085204	0.1080814	0.1080812

It is seen from the table that ΔW_{max} remains stable within a wide range of S. Error difference far from caustic at large values of residual aberration is $5\cdot10^{-4}$ μm. This value is small enough to be neglected even in high-precision interferometer. In the immediate vicinity of caustic (see Fig. 2), ΔW_{max} increases due to increasing of mutual curvature of the fronts ε_1 and ε_3.

Thus, the performed calculation has shown that the Fiseau interferometer has such advantages as stability to defocusing of the observation system and constant error when changing the observation plane position within wide range. The results obtained using Eq. (1) do not contradict this conclusion and are error estimation from above. Consequently, from the viewpoint of influence of residual aberrations on the quality of interference measurements, the observation plane position in the Fiseau interferometer can be chosen arbitrarily far from caustic.

Traditionally, interferometer developers follow the following way. The observation plane is placed in the plane of input pupil of a tested part, thus providing the possibility of refocusing (depending on the value of R) and zooming (to ensure scale) in the observation part.[7] However, in this case it is too problematic to correct for the distortion scale errors of the interference pattern, since due to refocusing and zooming the observation part scheme changes, therefore the distortion value also changes.

Additionally, in testing high-aperture optical parts, the situation often occurs, when interferogram aperture is determined by the pupil diameter of the reference surface, and then diffraction phenomena on reference edge swallow up a part of information about a tested part, now not at an edge but within light diameter.

Therefore, more promising is the scheme when the observation plane is placed at the plane of input pupil of the reference surface. In this case, there is no need in refocusing of the observation system, because the observation plane is fixed. Distortion errors in this case can be taken into account readily enough, for example, by numerical calibration of the interference field.

The results presented above give the reasons to apply this observation scheme.

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