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Testing of Aspherics by Means of Rotational-Symmetric Synthetic Holograms**

In the last few years synthetic holograms have been used in interferometric tests aspherics. Provided that the surfaces to be tested have a rotational symmetry, also rotational symmetric synthetic holograms (RSH) can be used. Some basic test interferometers using RSH's, the calculating concept and a special 1:1 plotter are described. Aspherics having a deformation of about 2.5 mm were used as test samples.

1. Introduction

One of the most serious problems in optics is the generation of aspherical surfaces. Thus, it is not surprising that the testing of general aspherics is a serious problem too though the degree of difficulties involved in this problem is much lower.

From the viewpoint of testing procedure two types of aspherical lenses can be distinguished namely with and without stigmatic properties. The first type is simple to test considering the lens as a whole but taking the aspherical surface alone one is faced, in general, with a measuring problem of the second type.

Here, we are concerned with the second, more general, type of aspherical lenses or surfaces. In this case a master lens is required to perform interferometric tests with interference patterns, readable in the sense that the interference pattern shown the deviations of the lens under test more or less immediately.

How can the necessity of using a master aspheric be avoided? Since in interferometry only wavefronts are compared, therefore it suffices to generate a wavefront identical to the one which would be generated by a real master lens or master surface.

There are two principal possibilities. We can namely built an optical system generating the master wavefront, or use synthetic or computer-generated holograms as frozen master wavefronts. The second approach is especially appealing because of its flexibility. Therefore, in this paper we are concerned with synthetic holograms used in the interferometric tests of aspherical lenses or, more generally, in the testing of aspherical wavefronts.

In 1969, when the work in this field was started the testing of aspherical surfaces by means of synthetic holograms was given only in the paper by Pastor [1]. His work was based on the general principles, introduced by Lohmann and co-workers [2].

Most of the surfaces to be tested have a rotational symmetry. This results in a special type of a synthetic hologram, namely; it is advantageous in this case synthetic holograms having a rotational symmetry (RSH).

Interferometric test procedures employing such a symmetry are described in two patents by Schwider [3]. Several publications describing interferometric tests using synthetic holograms have appeared in the last few years. Most of them deal with carrier type holograms, as e.g. in the work by McGovern and Wyant [4]. Fercher and Kriese [5], Birch and Green [6]. Others authors use also RS-holograms, e.g. Mustafin and co-workers [7] and Ichioka and Lohmann [8].

2. General principles

The restriction to surfaces and lenses having a rotational symmetry yields some advantages concerning the computation, generation and use of synthetic holograms.

The RSH can be understood as an in-line hologram according to Gabor [9] or, more simply, as a deformed Fresnel Zone Plate (FZP). According to the spherical aberration caused by the aspherical lens the loci of the zones in the RSH are displaced as against those of an ideal FZP.

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Provided that the distance assumed between the surface to be tested and the RSH-plane is very small, an amplitude constancy in the plane of the RSH can be expected. Then the width of the zones in the RSH need not be controlled.

Let us consider some examples of possible interferometer arrangements for tests of general lens combinations or aspherics with the help of RSHs. Because of the ambiguity of the diffraction phenomenon the RSH offers at least two different applications.

Thus, the positive and negative diffraction orders can be used in interferometric set-ups. Fig. 1 shows a setup using the plus first order.

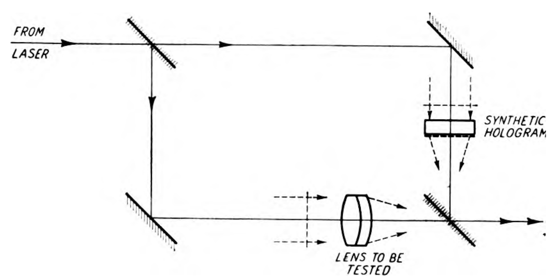

Fig. 1. Mach-Zehnder Interferometer using a synthetic hologram as reference parallel to the lens to be tested

The RSH is placed in one arm of a two-beam interferometer and the lens to be tested in the other. The RSH generates a wavefront identical with that of an ideal lens or master.

Fig. 2 shows the application of the RSH as a null lens. The minus first order of diffraction compensates the aspherical wavefront deformations caused by the lens under test. The resulting interference pattern indicates directly the deviations.

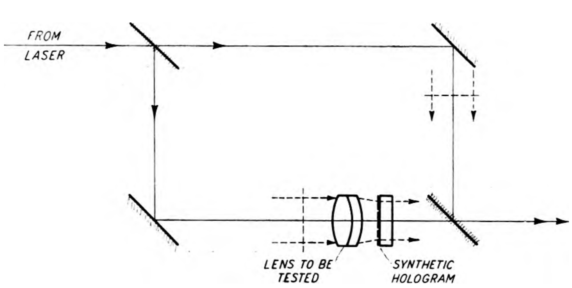

Fig. 2. Mach-Zehnder Interferometer with a series arrangement of the lens to be tested and a RSH. In this case the wavefront deformations caused by the lens are compensated by the RSH

In addition, arrangements in reflected light, as demonstrated in Fig. 3, are also possible. Here, one has to cope with deformations from a best-fit reference wave four times stronger than in transmitted light. In general, additional optics must be used which should be tested beforhand in their turn. In reflected light the probe wavefront is not influenced by inhomogeneities in the bulk of the lens. These few examples may suffice to demonstrate the possible uses of RSHs in interferometry.

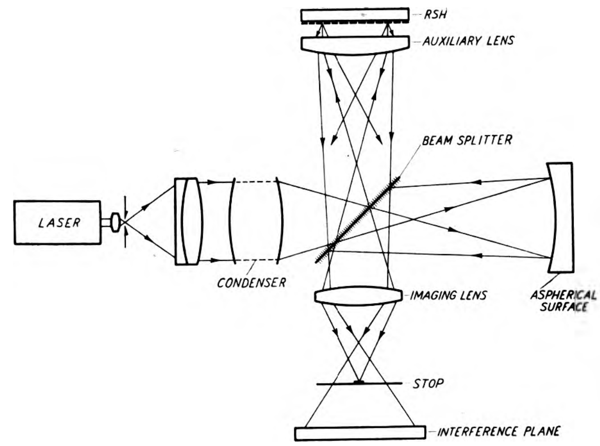

Fig. 3. Twyman-Green Interferometer for tests in reflected light. The RSH is, in general, combined with a auxiliary lens generating the main amount of wavefront curvature

A principal problem, however, is connected with the in-line character of the RSH. During reconstruction parasitic images of the desired wavefront may occur. In general, it is sufficient to block the zero order light so as to obtain a field of view free from severe disturbances. Below, the single steps of the procedure-computation, fabrication and interferometric use — will be dealt with.

3. Computational concepts

Like every synthetic hologram, the RSH can be interpreted as the superposition of two hypothetical waves; the object wave generated by the master piece assumed and an appropriate reference wave. Plane or spherical reference waves are especially suitable, due to their testability. Like all other holograms the RSH carries the information in the form of fringe displacements and variations of transparency. As we have mentioned above, a very small distance between the lens to be tested and the RSH-plane is chosen in order to assume the amplitude constancy similar to a kinoform [11]. Thus, only the loci of the hypothetical interference pattern must be determined.

The intensity distribution of the hypothetical interference pattern is of the form:

$$I = 1+\cos 2\pi f(h).$$

In some cases it is more useful to compute $f(h)$ via the optical path difference, in other cases via the directions of object and reference waves in the RSH-plane.

In the first case the maxima determined by:

$$f(h) = [W^{(h)}_{\mathrm{obj.}} - W^{(h)}_{\mathrm{ref.}}]/\lambda = m; \ |m| = 0,(1), M.$$

The path lengths $W_{\mathrm{obj.}}$, $W_{\mathrm{ref.}}$ of the object and reference waves are computed by ray tracing between the entrace and the RSH-plane, as shown in Fig. 4a.

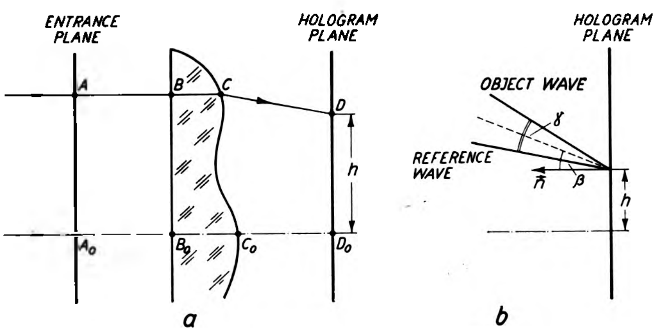

Fig. 4. Computational concepts
a) path length calculation; b) calculation of the spatial frequency at the RSH-plane

The second procedure corresponds to the angular spectrum aspect of the RSH. The object and reference rays impinge on the RSH-plane at different angles. The spatial frequency ν at point h (see Fig. 4b) is:

$$\nu = [2\sin\gamma/_2\cos\beta]/\lambda,$$

where γ is the angle between object and reference wave, β the angle between the bisector of the object and reference waves and the RSH-plane.

Now:

$$f(h) = \int_0^h \nu(h')dh' = m; \ |m| = 0,(1),M$$

has to be computed, under the assumption that $m = 0$ for $h = 0$. Because of the rotational symmetry, only the meridional section has to be dealt with.

4. Plotting procedure

The RSH consists of alternating transparent and opaque annuli. These annuli with their radii h_m have to be plotted one after the other. When the aspherical wavefront deformations are considerable, more than 1000 such ringzones are necessary. To avoid distortion the RSHs are produced on a 1:1 scale.

To do so we built a laboratory plotter. Fig. 5 shows a schema of the plotter. A small light spot imaged through a microscope onto a photographic plate is moved to the required positions one after the other. The photographic plate rests on a rotating table. Both the translational and rotational tables are equipped with air bearings. The translation operates at two speeds; a fast screwdrive and a slow piezodrive. The incorporation of the piezodriver guarantees the stickslip-free approach to the required position. The translation is controlled by a laser interferometer with $\lambda/4$-increment. The change from fast to slow translation is effected by means of a difference counter, operating in a count-down mode. The various positions are read from papertape. A small magnet fixed to the rim of the rotational table generates a sharp pulse when passing a magnetic recorder head. This pulse cycles the plotter. After reaching the required position the control unit is in the "ready for exposure" mode and the next pulse from the magnetic head serves as "open" command for the shutter. The following pulse gives the "close" command and initiates the next cycles. The plotter allows for the generation of RSHs with a diameter up to 100 mm and spatial frequencies up to 200/mm. The accuracy of the RSH depends mainly on the laser interferometer used, and could be further improved by using a commercial set-up.

5. Interferometric applications of RSHs

To prove the feasibility of the concept we have chosen an arrangement according to Fig. 6, where the RSH compensates the wavefront deformations. At present we use amplitude holograms printed on LO2 plates. Unfortunately, the glass base of these plates causes rather big wavefront deformations. The elimination of these distortions is achieved by storing the distorted wavefront in an additional hologram CH. To do so, the aspherical lens is removed

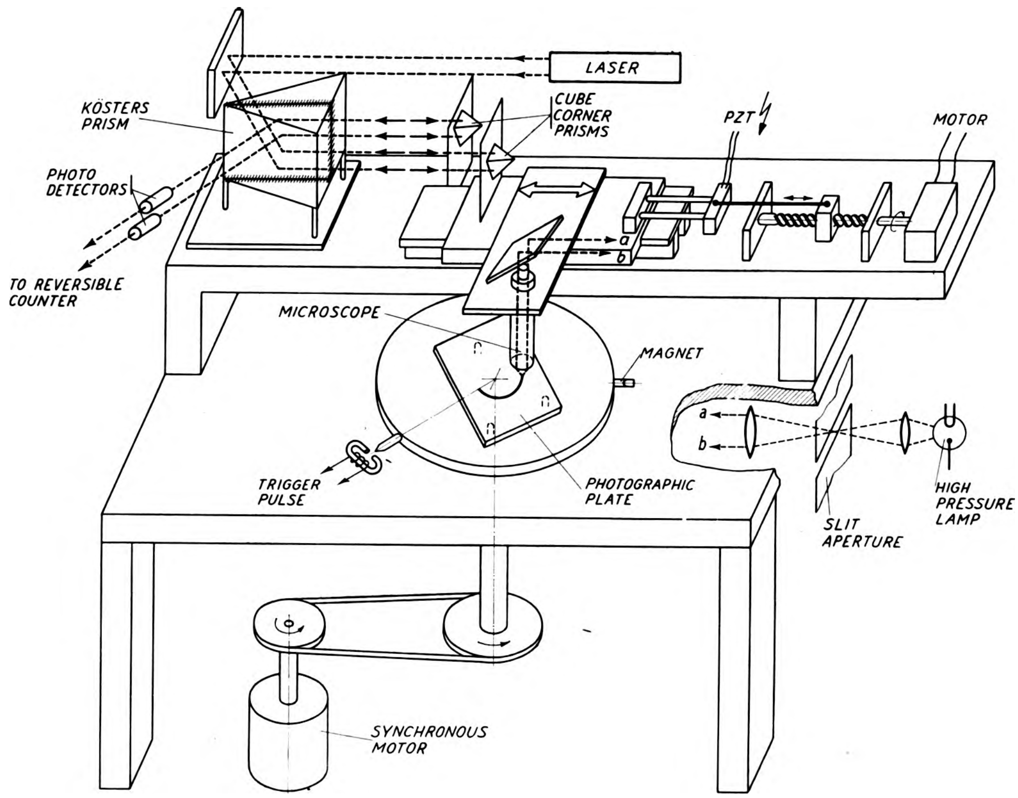

Fig. 5. Schema of the plotter for the generation of the RSHs. Only the basic functions are represented

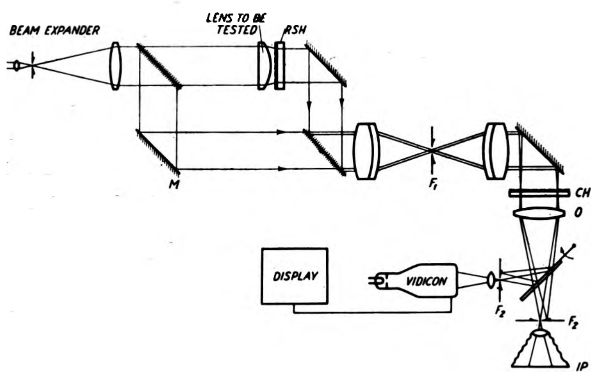

Fig. 6. Schema of the interferometric arrangement

The in-series-arrangement of Fig. 2 is used. The interferometer is combined with a double diffraction apparatus making possible compensation of interferometric distortions. In the compensating hologram CH wavefront deformations caused by the RSH-carrier are stored. Tilt of the reference mirror M furnishs the carrier frequency of the hologram CH. F_1, F_2 – filterplanes, IP – imageplane, O – objective

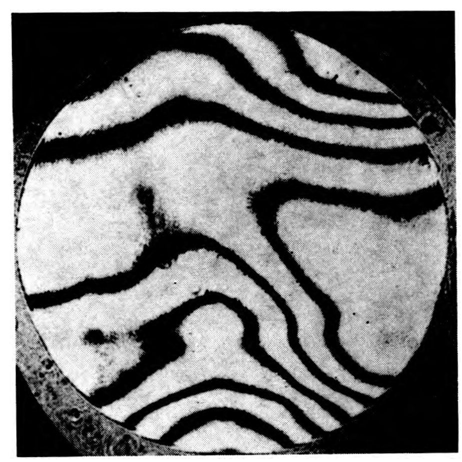

Fig. 7. RSH-substrate distortions of the interference pattern

from the interferometer and the undiffracted wave passing the RSH is superposed in the hologram CH together with a reference wave (see Fig. 6).

Fig. 7 gives an example for such distortions. After exposure, development, and repositioning of the hologram CH, a compensated interferogram can be attained (see Fig. 8). Now the aspherical lens can be introduced into the interferometer. In the set-up in Fig. 6, only the wavefront between the aspherical surface and the RSH is strongly aspherical. After being diffracted the object wave is approximately plane. Obviously, this wave carries also the distortions of the glass base.

Thus, when causing the wave from the object and the reconstructed wave of the reference beam to interfere, the distortions are eliminated and only the deviations of the aspheric from the master show up.

Let us now discuss the compensating procedure from a holographical point of view (see Fig. 9). The following denotations are used:

Fig. 8. Interferogram showing the compensation of the distortions shown in Fig. 7. The straight and equidistant fringes indicate the removal of all distortions

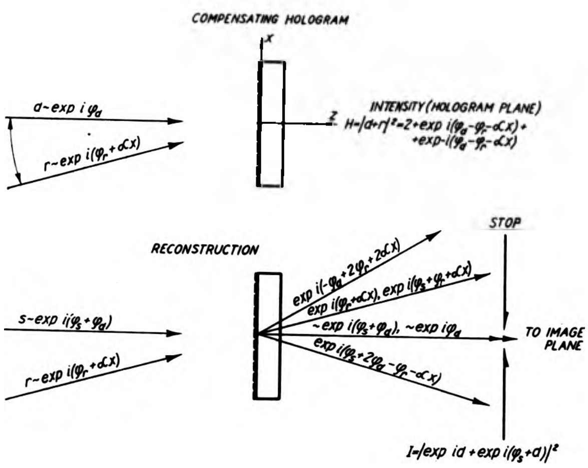

Fig. 9. Discussion of the compensating technique from a holographical point of view

φ_s – the deviations of the lens under test: φ_r – the deviations of the reference wave; φ_d – the distortions caused by the glass of the RSH and ax – a linear phase function according to the tilt of the reference beam

φ_s – the deviations of the lens under test, φ_r – the deviations of the reference wave, φ_d – the distortions caused by the glass base, and ax – a linear phase function according to the tilt of the reference beam.

Then the intensity distribution in the hologram plane during recording of CH is:

$$H = |\exp[i\varphi_d] + \exp[i(\varphi_r + ax)]|^2$$
$$= 2 + \exp i(\varphi_d - \varphi_r - ax) + \exp - i(\varphi_d - \varphi_r - ax).$$

During reconstruction the deviations of the aspheric have to be added to φ_d. From the superposition of the undiffracted object (considering the CH-plane only) and the diffracted reference wave one gets the following intensity distribution:

$$I = |\exp[i\varphi_d] + \exp[i(\varphi_s + \varphi_d)]|^2 = 2[1 + \cos\varphi_s].$$

In this way we have got rid the measuring result from all unwanted disturbances originating from the interferometer components and the RSH glass base. Figs 10, 11 show interference patterns of a good and an inferior aspherical lens.

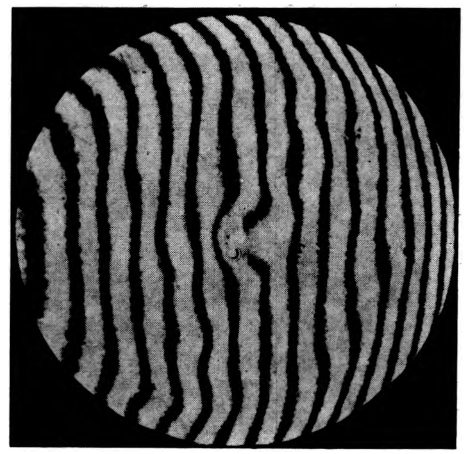

Fig. 10. Interferogram of a aspherical lens with a mean square deviation of $\lambda/7$

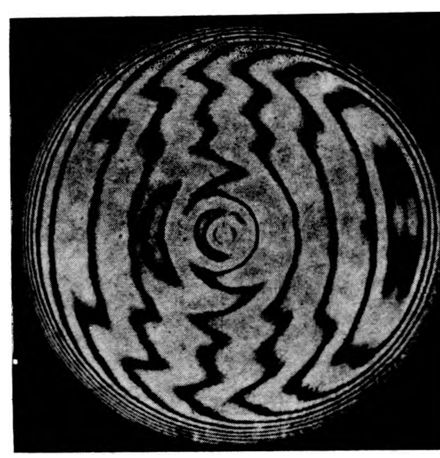

Fig. 11. Interferogram of an inferior aspheric

6. Conclusions

It was shown that aspherical rotational symmetric wavefronts can be tested by means of RSHs. After computation of the radii of the RSH on a computer the RSH is plotted on a special device. Up to 2000 rings per 30 mm radius could be made. The planer the photographic plates, the higher spatial frequencies in the RSH are possible. Spatial frequencies up to 200/mm appear to be manageable.

The disturbances due to the glass base of the RSH and the interferometer mirrors were eliminated by a further hologram.

Испытания асферических линз с помощью синтетических вращатетьно-симметрических линз

Показано, что асферические вращательно-симметрические фронты волны можно испытывать с помощью синтетических вращательно-симметрических голограмм (ВСЛ). После расчета лучей ВСЛ на ЭЦВМ вычертили ВСЛ на специальном приборе. Возможно получить до 2000 колец на луче в 30 мм. Чем более плоски фотопластинки, тем выше пространственная частота ВСЛ. Достижимая пространственная частота составляет 200/мм.

Возмущения, вызванные стеклянным основанием ВСЛ и зеркала интерферометра, были устранены в очередной голограмме.

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