MTF measurement via diffraction shearing with optically superimposed gratings

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The use of double grating diffraction shearing for measurement of MTF is demonstrated. By superimposing two gratings optically we avoid the problem of grating contact and subsequent degradation. This simple and economical method is especially advantageous for optical systems with large pupil for which a rotating plate interferometer becomes prohibitively expensive.

Hariharan, *et al.*[1] devised a double grating shearing interferometer (Fig. 1) with variable lateral shear and the ability to tilt the sheared wave to facilitate measurement of small departures from the Gaussian sphere. Wyant[2] pointed out that a system of this type can be used to measure OTF. Unlike those demonstrated previously,[3–10] this system can use a white light source because the signal at any interferometer orientation corresponds not to shear S but to S/λ, which in turn is proportional to spatial frequency. Thus, light of all wavelengths contributes to the OTF signal.

Our initial interest in diffraction shearing was to avoid the expense of a large thick shearing plate necessary for testing optics of diameters greater than 2 cm by means of a rotating parallel plate interferometer.[9–11] However, in attempting to use the quasi-contacting double grating system (Fig. 1) to measure MTF we found that gratings were often destroyed due to too close contact. This problem became especially severe for f-numbers less than 20, where depth of focus is small, and gratings must therefore be maintained extremely close together. To avoid the problem of grating contact we superimposed the gratings optically instead of physically and eliminated unwanted diffraction orders as shown in Fig. 2.

If the lens under test is illuminated with a collimated beam (Fig. 1), lens L, in addition to being diffraction limited when used on axis at unit magnification, must be considerably faster than the lens under test. Figure 3 shows an arrangement to minimize this latter requirement (e.g., if the lens in Fig. 3 consists of a pair of identical lenses, each need be only twice as fast as the lens under test). This requirement of fast transfer lenses is not, however, fundamental to the present technique, as the high numerical aperture of a fast lens under test can readily be transformed to a lower numerical aperture. For example, if instead of the arrangement shown in Fig. 1, we illuminate the test lens with light from a point source, the transmitted beam can be focused onto the first grating by a second lens with an arbitrarily small numerical aperture.

In this preliminary work lens L consisted of two identical Mamiya $f/3.8$ camera lenses, used back-to-back. Figure 4 shows a typical MTF measurement, including grating angle markers every 2°. The reduced data are presented in Fig. 5, where the MTF is compared with the theoretical diffraction-limited values and also with the best data we obtained using the quasi-contacting grating system. In both cases the lens under test was a 200-mm focal length Tropel collimating lens with an aperture of $f/20$, and the collimating lens was a 200-mm focal length Spectra-Physics collimating lens.

The choice of grating frequency is dictated by the f-number of the optics under test and the relay lens L. The grating frequency must be high enough so that there is no overlap between the zero and first diffraction orders, yet not so high that the relay lens vignettes the diffracted light. In the present work the bleached gratings were holographically made with 100 lines/mm.

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Received 24 October 1979.
0003-6935/79/081247-02$00.50/0.

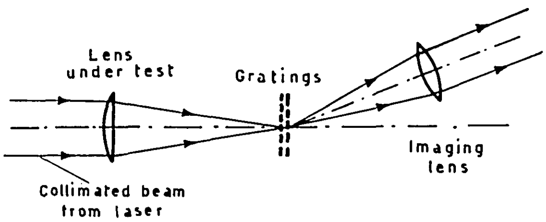

Fig. 1. Schematic diagram of the optical system of the double grating interferometer.

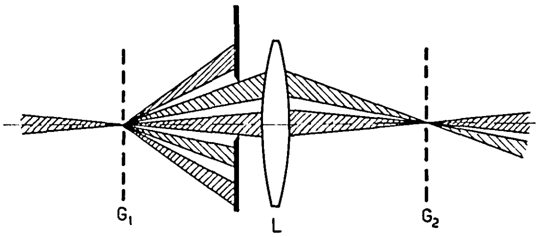

Fig. 2. Optically superimposed double grating interferometer.

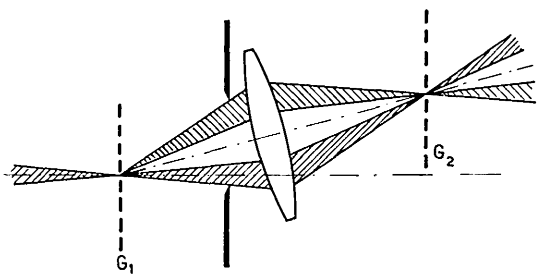

Fig. 3. Optically superimposed double grating interferometer, modified for relaxed f-number requirement on lens.

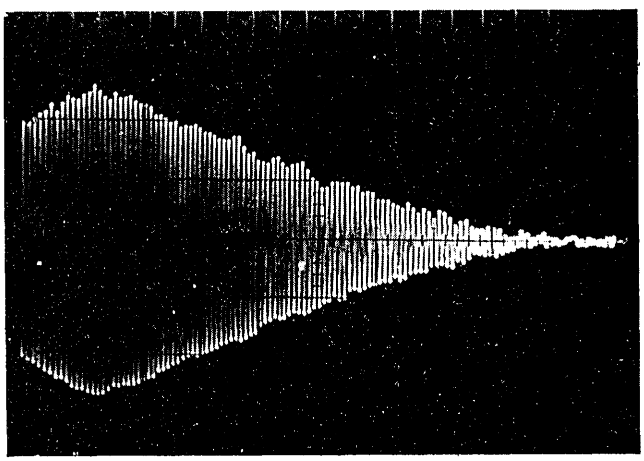

Fig. 4. MTF data for $f/20$ optical system. Markers indicate grating angle every 2°.

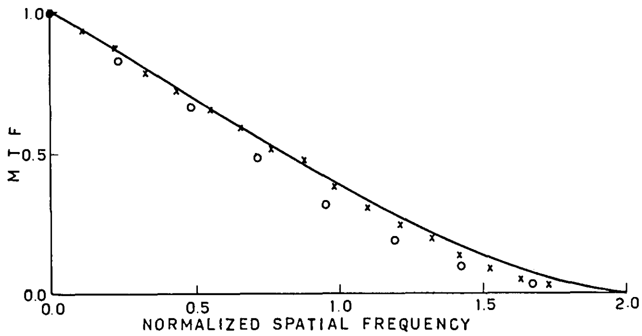

Fig. 5. MTF vs normalized spatial frequency for $f/20$ system: — = theory (diffraction limited MTF); × = optically superimposed gratings; O = quasi-contacting gratings.

Wyant has pointed out that, if desired, one can readily adjust the phase of the oscillating signal in Fig. 4 to give a maximum (and thus a data point) at zero shear by translating one grating in its plane.

In summary, diffraction shearing by means of optically superimposed gratings appears to be an economical and accurate MTF measurement method. Compared to the rotating parallel plate system, diffraction shearing appears more economical for testing large apertures. For small apertures, however, we appreciated the simplicity of the rotating parallel plate system, which made possible verification of our MTF measurements.

We gratefully acknowledge useful discussions with J. C. Wyant concerning this work. This work was partially supported by the Consiglio Nazionale delle Ricerche. Also, one of us (SFJ) acknowledges partial financial support of Minna-James-Heinemann-Stiftung, for work done while on leave from the Optical Sciences Center of the University of Arizona.

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