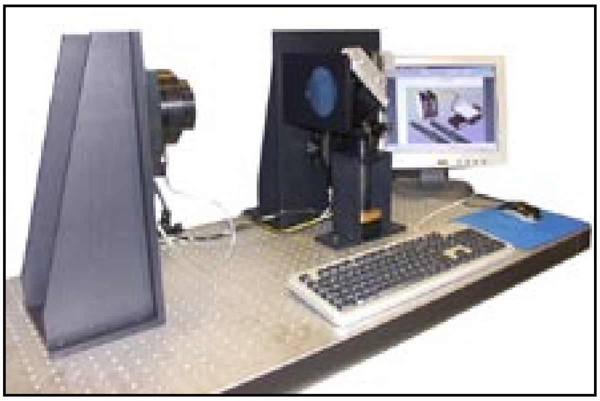
Wavefront Distortion Measurements - MTF vs Interferometry

PRECISION-OPTICAL ENGINEERING

IF007

Application Note

Introduction



The change in shape of a wavefront passing through or being reflected from an optical system, compared to the incident wavefront is an indication of the quality of the optical components. A quality indicator is the Modulation Transfer Function (MTF) of the image. There are two common methods of measuring MTF in optical components in systems: Fourier transform of measured linespread function and interferometric measurements. This technical datasheet compares and contrasts these two techniques.

Modulation Transfer Function

MTF measures how effectively contrast in an object is transferred into the image by the optical component or subsystem under test. It provides a quantitative measure of image quality. Consider an object consisting of a series of black and white lines of equal thickness. The greater the difference in intensity between the light and dark lines, the better the contrast:

$$\% \text{ contrast object, } M_t = \frac{(T_{max}-T_{min})}{(T_{max}+T_{min})}$$

where Tmax = object maximum intensity and Tmin = object minimum intensity
The image produced by the optical component will also exhibit contrast which can be expressed in a similar way:

$$\% \text{ contrast image, } M_i = \frac{(I_{max}-I_{min})}{(I_{max}+I_{min})}$$

where Imax = image maximum intensity and Imin = image minimum intensity

The MTF at this particular line thickness is given by M_i/M_t However, by changing the thickness of the lines, the frequency or number of line pairs per mm can be varied so the MTF can be measured at different spatial frequencies.
Equipment is available to measure the MTF in optical systems. In practice bar charts are not used, but the image of a slit illuminated by a light source is collected after interaction with the optical component and the shape is measured and then subjected to a spatial Fourier Transform to give MTF as a function of cycles/mm. Most systems measure MTF over a range of wavelengths.

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Interferometric measurements

Some of the practical considerations in making interferometric measurements of optical systems are discussed in other datasheets in this series (IF003, "Fringe Measurement Techniques", IF005 "Fizeau and Twyman Green Interferometers" and IF006 "Good Practice in Interferometry). Interferometric measurements are made at a single wavelength.

MTF vs Interferometry

Interferometry gives instantaneous test results in real time. The key benefit of this is that adjustments can be made to the optical system and the effect on the fringe pattern can be seen dynamically. When using the MTF approach, alterations to the optical system are made, the MTF measurement are then made an the effect on the MTF curve interpreted. Polychromatic system MTF measurements cannot be made from a single wavelength interferometric measurement, although the MTF at that wavelength can be calculated for qualification purposes. System MTF at a single wavelength can be used for qualification purposes provided there are no gross uncertainties in the dispersion of the optical materials used. The Fourier approach to MTF can be carried out quite quickly, provided high accuracy is not required. P-OE has recently supplied IR MTF equipment designed for rapid turn around in a production environment. This features a hot wire source, lens, mirror, relay lens and IR camera, mounted on an optical bench with suitable mounting for the lens under test. For high accuracy, especially in the IR, cooled detectors and slow scanning systems (which give long integration times) are required. While this produces good results, it is not necessarily a useful diagnostic tool. If a lens fails, the fault is as likely to be due to bad positioning as to a badly manufactured component. Interferometry, however, offers real-time diagnostic capabilities. Where lenses are being tested in high volumes, a fully motorised MTF bench may be more suitable than interferometry. In these cases, though, staring array cameras must be used instead of scanning detectors with a consequent increase in noise, reduction in sensitivity and hence reduction in measurement accuracy.

Practical example

In the recent design of zoom optical telescopes, the development phase was taking a long time due to the evaluation of full MTF curves. By going to interferometric measurements, the design evolved more rapidly. It was rapidly determined that small scale astigmatism resulted from misalignment of the front objective lens; coma resulted from misalignment of the negative zoom group, and large scale astigmatism came from eyepiece misalignment. All of these were instantly correctable using the interferometer, but not using the MTF equipment. It was therefore much more time-efficient to pass the telescope initially by interferometry and then carry out a single final acceptance test on the MTF bench.

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