

Recommendations for

Measurement of the optical transfer function of optical devices

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- British Electrical and Allied Manufacturers' Association
- British Industrial Measuring and Control Apparatus Manufacturers' Association
- British Steel Industry
- British Mechanical Engineering Confederation
- British Nautical Instrument Trade Association
- British Railways Board
- Council of British Manufacturers of Petroleum Equipment
- Department of the Environment
- Electrical Research Association
- Electricity Council, the Central Electricity Generating Board and the Area Boards in England and Wales
- Electronic Engineering Association
- Engineering Equipment Users' Association*
- Gauge and Tool Makers' Association
- HEVAC Association
- Institute of Measurement and Control*
- Institution of Chemical Engineers
- Institution of Electrical Engineers
- Institution of Heating and Ventilating Engineers
- Institution of Mechanical Engineers
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- Meteorological Office
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- Ministry of Defence, Army Department*
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- National Coal Board
- National Physical Laboratory*
- Oil Companies' Materials Association
- Scientific Instrument Manufacturers' Association*
- Sira Institute*
- Water-tube Boilermakers' Association

The Government departments and scientific and industrial organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of these recommendations:

- British Photographic Manufacturers' Association Ltd.
- Department of Trade and Industry
- Federation of Manufacturing Opticians
- Flat Glass Manufacturers' Association
- Illuminating Engineering Society
- Institute of Physics and the Physical Society
- Ministry of Aviation Supply
- Royal Microscopical Society
- Individual manufacturers

These Recommendations, having been approved by the Instrument Industry Standards Committee, were published under the authority of the Executive Board on 10 November 1971

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Foreword

These recommendations make reference to the following British Standard:

BS 906, *Engineers' parallels (steel)*.

These recommendations have been prepared under the authority of the Instrument Industry Standards Committee at the request of both the manufacturers and the users of optical devices and assemblies.

Their principal aim is to establish an objective procedure for use when measuring the performance of optical devices. The measure of performance adopted in these recommendations is the optical transfer function (OTF). Techniques for the accurate measurement of this function have been established in recent years and it now not only forms the basis of reliable test methods but also serves as a means of expressing performance in design specifications.

At this time no other national or international specifications exist which use the OTF as an objective measure of the performance of optical devices.

It is realized that the complete assessment of optical systems may demand further tests, including interferometric examination, veiling glare and distortion measurement, each of which will make possible examination of other aspects of performance, and which may be the subject of subsequent British Standards.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 16, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope

These recommendations adopt OTF measurement as an acceptable test method for ascertaining and expressing the performance of optical devices and systems, including image-forming systems or assemblies and lenses but do not normally relate to the separate parts of a multi-component system. In addition, the recommendations are specifically limited to tests on lens or mirror image-forming systems, or combinations of both.

Although a variety of techniques have been used for measuring the OTF, these recommendations only consider methods employing localized apertures, such as slits or edges, or an extended periodic screen such as a grating, as these methods are suitable for precise instrumentation.

Methods of specifying conditions of test and of expressing the results are recommended. Guidance for the operation of OTF measuring equipment is also given, so that accurate results may be achieved.

NOTE The title of the British Standard referred to in these recommendations is given on page ii.

2 Definitions

For the purposes of these recommendations the following definitions apply:

2.1

line spread function

the distribution of intensity across the image of an infinitely narrow self-luminous line object as formed by an optical system or device

2.2

sine-wave grating

a device which has a transmittance that varies sinusoidally in the direction perpendicular to the length of the grating lines

2.3

object modulation

the modulation of the sinusoidal intensity distribution produced by uniform illumination of a sine-wave grating, defined by the equation:

$$\text{modulation} = \frac{\text{intensity maximum} - \text{intensity minimum}}{\text{intensity maximum} + \text{intensity minimum}}$$

an equivalent definition relates modulation to the ratio of the amplitude of variation in the sinusoidal intensity distribution to the mean intensity level. In Figure 1 modulation = β/α

2.4

spatial frequency (R)

the reciprocal of the distance between successive maxima of the grating distribution. The unit of spatial frequency is cycles per millimetre (c/mm)

there are certain circumstances, e.g. when testing an afocal system, when the sine-wave grating is imaged at infinity. In such cases a more appropriate unit of spatial frequency is cycles per milliradian (c/mrad)

2.5

image modulation

the image formed by an optical system or device of a sinusoidally varying object intensity distribution is also a sinusoidally varying intensity distribution. Its modulation is defined as for object modulation

2.6

modulation transfer factor

the ratio of image modulation to object modulation at a particular spatial frequency

2.7

modulation transfer function (MTF)

the variation of the modulation transfer factor with spatial frequency. This function is normalized to unity at zero spatial frequency

2.8

phase transfer value (PTV)

the image formed by an optical system of a sine-wave grating may be laterally displaced from a prescribed image position (Figure 1), for instance that predicted by Gaussian optical considerations. This displacement, as measured in units of the image spatial frequency, is the phase transfer value and is quoted in radians, where 2π rad is equivalent to one period of the sinusoidal image distribution

2.9

phase transfer function (PTF)

the variation of the phase transfer value with spatial frequency

from the definition above, this function is zero at zero spatial frequency. It may be made equal to zero at any other spatial frequency, this operation being equivalent to a redefined image position laterally displaced relative to the previous position

2.10

optical transfer function (OTF)

a complex function of which the modulus is the modulation transfer function and the argument is the phase transfer function

an alternative, and mathematically rigorous, definition is that the OTF is the Fourier transform of the line spread function. The modulus of this function is normalized to be unity at zero spatial frequency and the argument is zero at zero spatial frequency

2.11

radial¹⁾ and tangential azimuths (*see Figure 4*)

optical transfer function measurements are defined as applying to the radial azimuth when an extension of a slit or edge object (or of a line in a periodic grating test pattern [see 3.2 1]) would pass through the optical axis of the system under test

slits, edges or lines of a grating pattern in a direction at right angles to that defined above are referred to as being in the tangential azimuth. In the case where the test pattern consists of a grating masked by a narrow slit, the grating lines are taken for the purpose of these definitions as being always perpendicular to the masking slit

3 General requirements

3.1 Laboratory environment. In order to obtain reliable results it is advisable to contain the measuring equipment within a relatively vibration and dust free environment, with adequate temperature and humidity control. In addition the level and type of ambient light should be such as not to affect the accuracy of OTF measurement. Special consideration should be given to the effects of air turbulence where long optical paths are involved.

3.2 Equipment. The equipment for measuring the OTF of a lens consists of three main items.

1) *An object generator.* This contains a light source, filters [see 4.1.1 2]) to enable the spectral content of the light to be varied, and the object which is to be imaged by the system under test. The object may consist of a single narrow slit, an edge, an extended grating-like pattern of lines or a similar grating masked by a narrow slit. (The latter system is employed to vary the effective spatial frequency of the grating from zero to a maximum.) The range of spatial frequency may be covered in discrete steps between zero and the maximum spatial frequency, as when using a series of targets of extended grating-like patterns of lines, or may be made to vary continuously. Means should normally be available for rotating the object pattern to enable the OTF of the test system to be measured in radial, tangential and intermediate azimuths. The object generator may include a separate optical channel to act as a reference in the measurement of the phase transfer function.

2) *An image analyser.* This comprises the complementary scanning aperture which is located in the image plane conjugate to the object, a photoelectric detector, signal processing circuits and an output recorder or display.

¹⁾ Radial and tangential are the preferred terms; the terms “sagittal” and “meridional” have sometimes been used as alternatives.

When the object is a single narrow slit the complementary scanning aperture for direct measurement of the OTF may be either an extended grating or a masked grating with the masking slit perpendicular to the object slit. An alternative scanning aperture for this target and for the edge target is a narrow slit, parallel to the length of the slit and edge, which measures the line and edge spread functions respectively. (Mathematical analysis of these functions is then required to derive the OTF.) When the target is an extended grating the scanning aperture may be a narrow slit parallel to the grating lines and for a masked grating target the scanning aperture may be a narrow slit perpendicular to the masking slit. Means for adjusting the orientation of the scanning aperture about the optical axis of the image analyser should be available to ensure that the conditions of parallelism or perpendicularity mentioned in this paragraph are achieved.

3) *The optical bench*²⁾. The purpose of this is to support the optical system under test, the object generator, the image analyser and any ancillary equipment in the manner required for performing prescribed measurements. Where it is necessary to explore the whole image field, not just one diameter of that field, then the optical bench is to have provision for rotating the optical system under test about its optical axis.

The type of configuration used on the optical bench will depend upon the specified test conditions for the optical system under test. Three main possibilities exist:

- a) one finite and one infinite conjugate, on-axis and off-axis,
- b) two finite conjugates, on-axis and off-axis,
- c) two infinite conjugates, on-axis and off-axis.

Any particular optical bench facility will not necessarily permit all three test configurations. In particular, many existing facilities are designed for measurements at one finite and one infinite conjugate, using an auxiliary collimator.

Two typical bench types commonly used are the nodal slide type and the camera type. In both cases it is necessary to maintain the plane of the image analyser slit parallel to the image plane. Figure 2 and Figure 3 show the essential features of each type of bench.

4 Detailed equipment requirements

To ensure that accurate values of OTF are obtained the measurements described in these recommendations should be made under controlled conditions. In particular, wherever instrumental parameters may influence the results they should either be offset by the application of correction factors (see 8) or, if this is not practicable, they should be taken into account when estimating the accuracy of the measured OTF.

At present, it is not possible to make precise statements concerning accuracies required of component parts of the measuring equipment to give a stated precision of measurement of the OTF for all possible equipments or set-ups. In some of the following subclauses, indications of tolerances are provided which are considered obtainable from good practice.

The purpose of this clause is to indicate those instrumental parameters which require particular attention. Suggested procedures for checking whether some of these requirements are met are given in 8.

4.1 Object generator characteristics

4.1.1 Light source. The following factors should be taken into account.

- 1) *Stability.* The light source should be monitored for variations in intensity which could significantly affect measurements. Such variations are significant if they occur over periods of time comparable in length to that involved in plotting a single OTF curve.
- 2) *Spectral characteristic.* The spectral energy distribution of the light source(s) should be known for the spectral range over which the detector is sensitive.

²⁾ The term "optical bench" is the general term embracing all types of bench from the very simple to the most sophisticated arrangement.