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Optics and photonics — Optical transfer function — Principles and procedures of measurement

Optique et photonique — Fonction de transfert optique — Principes et procédures de mesure

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 1, *Fundamental standards*.

This third edition cancels and replaces the second edition (ISO 9335:2012), which has been technically revised.

The main changes are as follows:

— text was added concerned with distortion effects in 4.4.6;

— a note was added concerned with the notation tangential/sagittal in 7.2.

— the document has been revised to be in agreement with the terms and definitions of ISO/IEC Guide 98-3 (GUM) and ISO/IEC Guide 99 (VIM) regarding the expression of measurement uncertainties.”

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The optical transfer function is an important aid to objective evaluation of the image-forming capability of optical, electro-optical and photographic systems.

In order that optical transfer function measurements achieved using different measuring principles or obtained from measuring instruments in different laboratories can be compared, it is necessary to ensure equivalence of measurement parameters such as focus setting and spatial frequency range. For this reason, an agreed terminology has been defined in order for the measurement parameters used in this document to be understood by all users. This document gives guidance for the construction and operation of equipment for optical transfer function measurement.

The specifications in this document form the basic requirements of measurement instrumentation and procedures for guaranteeing a defined uncertainty of measurement of the optical transfer function.

Optics and photonics — Optical transfer function — Principles and procedures of measurement

1 Scope

This document gives general guidance for the construction and use of equipment for measurement of the optical transfer function (OTF) of imaging systems.

This document specifies important factors that can influence the measurement of the OTF and gives general rules for equipment performance requirements and environmental controls. It specifies important precautions that should be taken to ensure accurate measurements and correction factors to be applied to the collected data.

The OTF measuring equipment described in this document is restricted to that which analyses the radiation distribution in the image plane of the optical imaging system under test. Interferometer-based instruments are outside the scope of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9334, *Optics and photonics — Optical transfer function — Definitions and mathematical relationships*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9334 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp/ui

— IEC Electropedia: available at https://www.electropedia.org/

4 Measuring equipment and environment

4.1 General aspects

4.1.1 Measuring conditions

Any measured OTF depends on the imaging state (I-state) of the imaging system. Thus, before making measurements, those parameters which form the I-state of the system shall be identified and the degree to which the I-state depends on those parameters determined. The complete set of parameters that form the I-state shall be set to fixed values. The fixed values represent a particular I-state and are called the measuring conditions.

4.1.2 Uncertainty of measurement

The measuring equipment and the environment in which it is used, shall allow the prescribed measuring conditions to be set and maintained to a precision which is consistent with the required uncertainty of measurement (see ISO 11421, which describes the various parameters which have an impact on the uncertainty of measurement). The uncertainty of an OTF measurement may be considered as the combination of measurement uncertainties arising from the many separate parameters in the I-state. When a required uncertainty of OTF measurement is stated, it shall be apportioned among the known contributing parameters such that a tolerance can be set for each parameter of the I-state. Thus, an overall requirement to an uncertainty of measurement of 0,05 of the modulation transfer function (MTF) may require, among other factors, a temperature stability of the measuring equipment of ±1 °C and focal plane setting to ±5 µm. The discussion of instrumental and environmental settings in the following subclauses relates to tolerances apportioned from the required OTF measurement uncertainty in this manner.

4.2 Environment

4.2.1 General

The ambient conditions of the OTF equipment shall be kept sufficiently free from influences that can lead to climatic, mechanical or electromagnetic disturbances. The measuring equipment and the atmosphere in the measuring room shall be kept free from dust, moisture and smoke. All optical surfaces shall be protected from the incidence of scratches and finger prints.

Environmental influences like temperature and vibrations cause alignment and positioning errors in the system and thus their impact on the measurement uncertainty is specimen specific. Generally, the impact of a source of measurement uncertainty on the overall measurement uncertainty may be experimentally determined by varying the parameter within its defined tolerance and observing the associated rate of change in the measured OTF.

4.2.2 Temperature and humidity control

The temperature shall be kept constant within a stated tolerance and at a suitable value. Humidity shall also be kept within acceptable limits. Both temperature and humidity shall be recorded. Air turbulence and stratification may affect the measurement and shall be minimized through the use of shielding.

4.2.3 Vibration

Vibration shall be kept to a minimum and the use of basement space is recommended if vibration, caused for example by machinery, cannot otherwise be avoided. The degree of vibration isolation for a given measurement uncertainty depends on the characteristics of the vibration, the measuring method, and the spatial frequency range. If the method consists of measuring the line spread function, a suitable tolerance may be that the movement of the image and the analyser caused by vibrations should not exceed, for example, 1/20 of the width at half the maximum intensity of the test slit image.

4.2.4 Electromagnetic disturbances

For some systems, it can be necessary to monitor power supply vibrations and keep these to a tolerable minimum. The influence of external electromagnetic fields and the level of ambient light shall be reduced until they do not affect the measured OTF significantly.

4.3 Measuring equipment

4.3.1 Optical mounts

The basis of any measuring equipment shall be a sturdy optical bench or plate, to which mountings for the test target unit, test specimen, image analyser and other auxiliary units can be attached and brought into position, with respect to each other, to the required uncertainty.

Depending on the imaging systems to be tested, different requirements can arise regarding the linearity of adjustments and/or the parallelism of equipment slideways. Deviations from ideal linearity and parallelism requirements shall not cause a greater change of the measured MTF than 1/3 of the permitted or specified measurement uncertainty.

4.3.2 Defocusing tolerance

For photographic lenses, the defocusing effects caused by bench misalignment result in errors in the measured MTF which increase with rising spatial frequency or with decreasing *f*-number and reduced wavefront aberration. Table 1 gives the defocusing tolerances in µm of a diffraction-limited lens with circular pupil and incoherent illumination that leads to a ±0,05 MTF change. The wavelength of the light is assumed to be 500 nm.

Table 1 — Defocusing tolerances in µm

***f*-number**	**Spatial frequency**/mm^{-1}					
	1	5	10	20	50	100
1	45	9	4,5	2,3	1,0	0,5
1,4	62	12,5	6,3	3,2	1,4	0,8
2	89	18	9	4,7	2,0	1,1
4	180	36,5	18,8	9,8	4,6	3
8	360	74	39	21,5	12	12,2
16	720	157	86	54	49	46,8
NOTE For a change of 0,10 in MTF, defocusing tolerances are twice those shown in this table.						

4.3.3 Provision of measuring scales

The measuring equipment shall provide adequate means for determining the positions of test target, system or device under test (test specimen), image analyser and auxiliary systems. These include scales, spindles and dial gauges. Furthermore, means shall be provided to monitor, set or determine all other parameters that form the I-state of the specimen.

4.4 System components

4.4.1 General

The following subclauses give details concerning the measuring arrangement and its basic elements including the test target unit, test specimen, image analyser and auxiliary imaging systems.

4.4.2 Optical benches

4.4.2.1 General

Several arrangements of the measuring equipment are possible, but those in 4.4.2.2 to 4.4.2.5 are recommended.

4.4.2.2 Object and image at finite distances

For tests in which object and image are at finite distances from the test specimen, the configurations shown in Figure 1 or Figure 2 shall be used. In these arrangements, two of the three basic units (test specimen, test target unit and image analyser) are moved along slideways parallel to one another and perpendicular to the reference axis. Usually, the test specimen is fixed and the other two units moved as shown in Figure 1 and Figure 2.

When electro-optical components such as image intensifiers are to be tested, auxiliary imaging systems are used to produce an image of the test pattern at the input of the test specimen. The image at the output of the test specimen is then relayed to the image analyser. The corresponding arrangement is shown in Figure 2.

4.4.2.3 Nominal infinite object distance

For tests in which the object distance is infinite (i.e. the test target is at the principal focus of a collimator), arrangements similar to that shown in Figure 3 shall be used. When off-axis measurements are to be made, the collimator may be rotated by an angle ω about an axis passing through the entrance pupil of the test specimen and perpendicular to the reference axis (see Figure 3).

Alternatively, the collimator may be fixed and the test specimen and image analyser rotated together about the entrance pupil. In this case, the mounting fixture for the test specimen and the image analyser slideway are both rigidly fixed to a rotating baseplate (this arrangement is consequently often referred to as the "rotary table" type).

4.4.2.4 Nominal infinite image distance

The same arrangement as described in 4.4.2.3 (see Figure 3) shall be used, with the image analyser and test target unit interchanged.

4.4.2.5 Object and image at nominal infinite distances

For systems which are tested with both the object and image at infinite distances, arrangements similar to those shown in Figure 4 shall be used. When off-axis measurements are to be made, the object side collimator with the test target unit should be rotated by an angle ω about an axis passing through the entrance pupil and perpendicular to the reference axis of the test specimen. The image side decollimator, together with the image analyser, shall be rotated by an angle ω' about an axis passing through the exit pupil and perpendicular to the reference axis and shall be refocused according to the test criteria.

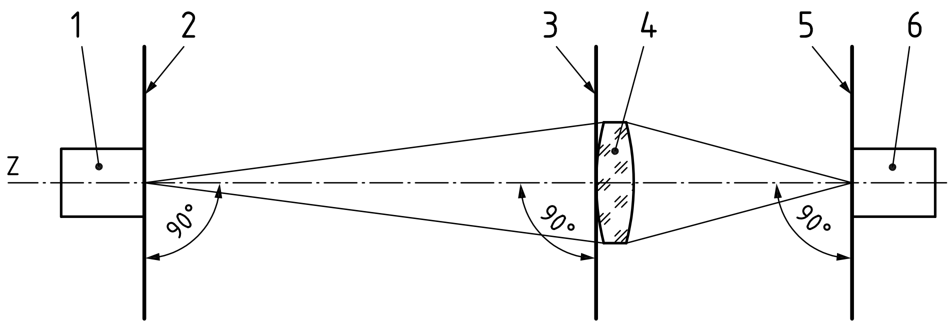
4.4.3 Test target unit

4.4.3.1 General

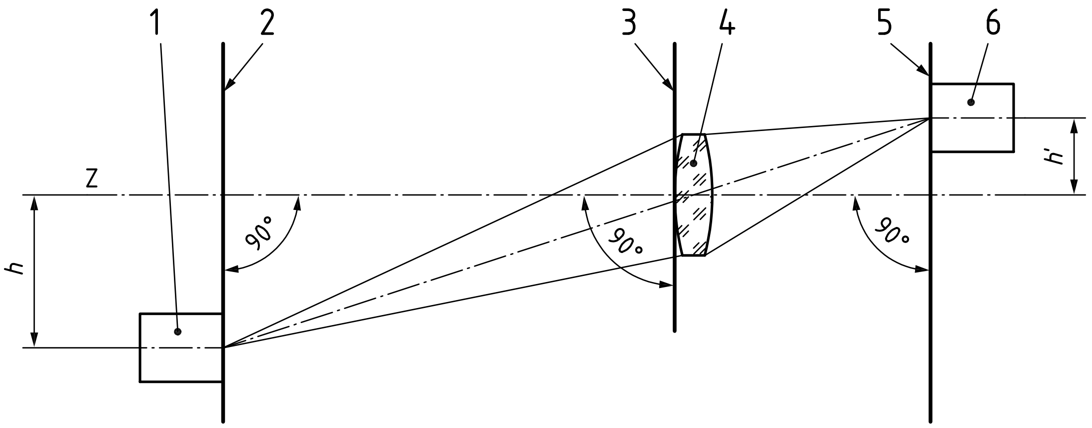
The test target unit shall consist of a source of radiation and a test target.

4.4.3.2 Test target

Depending on the characteristics of the test specimen, several different types of test target may be used. Circular apertures, slits, edges, gratings and self-luminous test targets such as incandescent wires are commonly used. The spatial frequency spectrum of the test target used for the OTF measurement shall be known with an uncertainty that is determined by the required measuring uncertainty. The actual frequency spectrum of the test target usually differs from its ideal (geometrically predicted) spectrum. If the actual spectrum cannot be measured, precautions shall be taken to ensure that the target is as close as necessary to the specified geometry.



a) On-axis

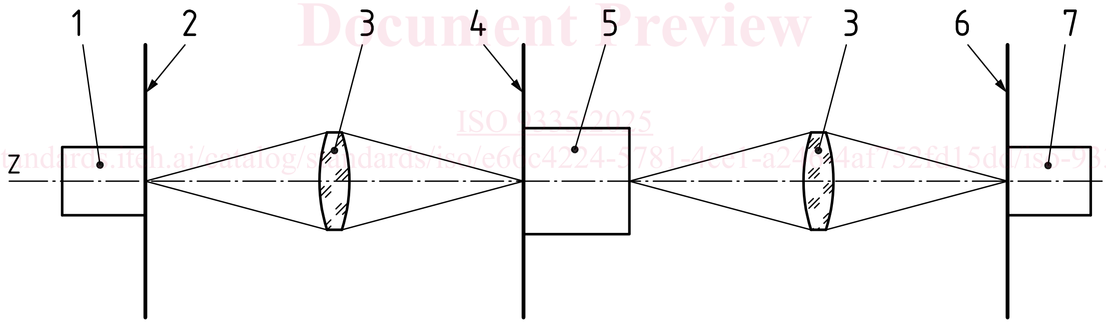


b) Off-axis

Key

1 test target unit (TTU)
2 TTU slideway
3 fixture for test specimen
4 test specimen
5 image analyser slideway
6 image analyser
Z reference axis
h, h′ object, image heights

Figure 1 — Schematic test setup: object and image at finite distances



a) On-axis