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Part 3: Telescopes

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Partie 3: Télescopes

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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 documents 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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 4, *Telescopic systems*.

This second edition cancels and replaces the first edition (ISO 9336-3:1994), which has been technically revised.

The main changes compared to the previous edition are as follows:

— update of the document based on the latest technical developments;

— Annex A regarding tests on components and sub-assemblies using azimuth scanning systems removed, due to lack of practical relevance;

— two new Annexes added regarding test methods using detector arrays and deriving an objective image quality criterion from the MTF.

A list of all parts in the ISO 9336 series can be found on the ISO website.

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

Methods of assessing the imaging quality of telescopic systems can be found in ISO 14490-7. The methods described in this document are basically subjective, relying as they do on the judgement of the observer and the quality of his vision. The technique of measuring the “limit of resolution” is relatively easy and quick to perform and provides a single figure of merit for each orientation of the test pattern. However, being a subjective measurement, it can be open to significant variations in its results. Measuring the optical transfer function (OTF), or more usually just its modulus, the modulation transfer function (MTF), provides a completely objective means of evaluating imaging quality that can be compared directly with the theoretical assessment done by the optical system designer.

Integration of the system MTF over a certain domain of spatial frequencies and normalised to the diffraction limited MTF will provide a single figure of merit that is a reasonable representation of the system performance without relying on any subjective assessment. When the spatial frequency domain is selected in accordance with the properties of the detector system the method can be applied to telescopic systems operating with any detector type, thus not limiting the method to visual observation. This is of importance as in state-of-the-art telescopes the same optical path can be used for visual observation as well as for wavelengths outside the visual range (using appropriate detector systems).

As a special case, an “objective limit of resolution”, providing a single figure of merit, can be derived from a measurement of MTF by using the latter in combination with a “contrast sensitivity” curve for the eye and a measurement of MTF may also be used as the basis for several other image quality criteria (see Annex B).

Optics and photonics — Optical transfer function — Application —

Part 3:
Telescopes

1 Scope

This document specifies a method of testing telescopes in terms of imaging states aimed at making valid optical transfer function (OTF) measurements.

This document includes two annexes (Annex A and B) that provide information on the more recent techniques for measuring optical transfer function and methods of deriving image quality criteria from such measurements.

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*

ISO 9335, *Optics and photonics — Optical transfer function — Principles and procedures of measurement*

ISO 14132-1, *Optics and photonics — Vocabulary for telescopic systems — Part 1: General terms and alphabetical indexes of terms in ISO 14132*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9334 and ISO 14132-1 apply.

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

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

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

4 General description of test specimen types and the relevance of OTF tests

The specimens considered are telescopic observational instruments with direct view used for viewing remote objects and include many instruments such as telescopes, binoculars, telescopic sights or spotting scopes.

Ideally, instruments would be best with no astigmatism and no field curvature coupled with good chromatic correction but frequently compromises as mentioned above shall be tolerated.

Many optical systems include roof prisms to give a compact instrument. However, the image produced by such systems is basically made up of two superimposed images and the accuracy with which they match will depend on the accuracy with which the roof edge has been constructed. In such cases the orientation of the roof edge shall be noted (see 5.5).

In use, the eye is coherently coupled to the telescope, so it may be contended that the only valid test would be one that included the eye: reference is made to the case of cascaded optical systems in the introduction to ISO 9334. However, in observer tests using telescopes, improved performance has been obtained with instruments with better measured OTF performance in a variety of tests, including contrast sensitivity using sinusoidal grating targets, which confirms the value of OTF tests.

OTF tests also enable performance to be compared with that computed by the telescope designer and provide effective quality assurance tests of production specimens.

When considering the details of tests, some features of the eye need to be borne in mind, especially its ability to accommodate for varying object distances and to adjust the working aperture, varying the iris size, according to the ambient illumination. Thus firstly, unlike the photographic lens testing case, refocusing for off-axis tests is necessary. Secondly, the working aperture of the telescope, i.e. the exit pupil diameter, will need to match the receiving eye pupil, which generally has a range of 7 mm down to 2 mm diameter for different ambient illumination levels. The size of the evaluation pupil for the MTF measurement (receiving pupil in the test setup) is specified in the corresponding imaging state tables.

5 Test arrangement

5.1 General

MTF values can typically be obtained by

a) direct measurement of frequency response to targets of different spatial frequencies,

b) calculating from measurements of wavefront aberration in the exit pupil,

c) calculating from measurement of the intensity distribution generated through the system under test of a (quasi-ideal) point source.

Cases b) and c) obtain two-dimensional MTFs from which one-dimensional MTFs may be deduced.

5.2 Arrangement of optical bench

For case 5.1 a) direct measurement of the frequency response to targets of different spatial frequencies, a typical test setup is shown schematically in Figure 1. The separation between the test pattern unit and the collimator is adjusted to give an infinite conjugate for the test. The separation between the image analyser collimator ("decollimator") and the image analyser needs to be adjustable by a suitable micrometer, operating on the image analyser focus slideway, to position the image analyser at the image of the test pattern.

When the object generator assembly (test pattern unit and collimator) and the image analyser assembly (image analyser collimator and image analyser) are aligned, without the optical system to be tested, the micrometer setting for optimum response of the test system will be the datum. When the optical system to be tested is positioned for an on-axis test, refocusing of the image analyser is needed and any change from the datum setting gives a measure of the on-axis dioptre setting of the system being tested. In off-axis tests, a different setting from that for on-axis tests will be found and the new change from the datum will give the dioptre setting for the particular field point and azimuth of the test; the difference from that of the on-axis test gives a measure of the field curvature.

In off-axis tests with an arrangement where the test specimen is retained in a fixed position, the object generator assembly will be rotated about a point on the reference axis, at or near the entrance pupil of the specimen, through an angle ω_p. The image analyser assembly will be rotated about a point on the reference axis, at or near the exit pupil of the specimen, through an angle ω'_p.

Descriptions of optical bench arrangements for testing a variety of different types of telescopic system can be found in References [1] and [2].

5.3 Collimators

The object collimator shall be a well-corrected achromat with a focal length at least twice that of the objective of the specimen and a working aperture diameter at least 10 mm greater than the objective of the specimen. Reflective (off-axis) or catadioptric collimators may be preferred, especially for tests at different wavelengths, thus providing a constant apparent test object distance without the requirement for refocusing when changing the wavelength.

For the image analyser collimator, a convenient focal length would be 100 mm as this would ensure that the movement of the image analyser along its focus slideway would be within the range of a readily available (e.g. 25 mm) micrometer movement if the field curvature reached 2 m^{-1}. However, there may be circumstances where the resolution of the image analyser may require a longer focal length to be used. Alternatively, an image analyser collimator with fixed focal length in combination with well corrected microscope objectives of different lateral magnifications can be used.

5.4 Spectral response

Unless otherwise specified, the spectral response of the test system shall match that of an observer using the specimen in its normal viewing role or that of the detector if the specimen is intended for non-visual use (e.g. infrared systems). This may be achieved by using a specially designed filter combination to give the desired match in conjunction with the source emission and the detector spectral sensitivity (see notes to Table 2).

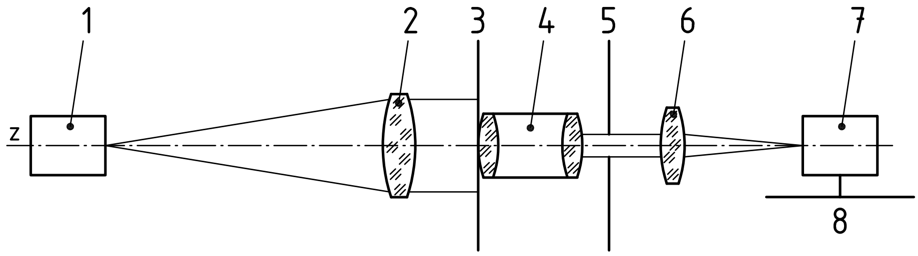
Ideally, measurements shall be carried out with narrow bandwidth (quasi-monochromatic) radiation, preferably at the dominant wavelength of the eye or the detector spectral response. If more than one wavelength or a wavelength range is of interest, it is advisable to perform quasi-monochromatic tests in succession to ensure the separation of chromatic and resolution deficiencies.

The most effective position for filters is after the image analysing element as the effect of stray radiation is reduced. However, in good laboratory conditions, it is quite practicable to position the filter within the test pattern unit.

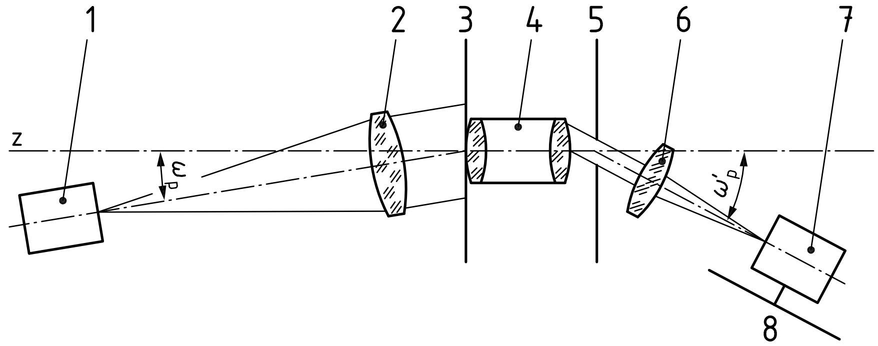
5.5 Spatial frequency range

To a large extent, the test specimen will be the controlling influence on spatial frequency ranges as derived in object space. In image space, the range might be limited by the resolution of the eye or the detector. The lower and upper bound of the spatial frequency range shall be defined in the imaging state table.

The corresponding frequency range in object space will be given by M times the lower and upper bounds, where M is the magnification of the telescope.



a) On-axis



b) Off-axis

Key

1	test target unit	6	image analyser collimator (decollimator)
2	object collimator	7	image analyser
3	fixture for test specimen	8	image analyser focus slideway
4	test specimen	ω_p, ω'_p	object and image pupil field angles
5	diaphragm (with role of exit pupil);	z	reference axis

Figure 1 — Schematic setup — Object at infinity, image nominally at infinity

The spatial frequency in object space may be obtained either:

a) by calculation, using the linear spatial frequency of the test pattern in conjunction with the focal length of the collimator; or

b) by measurement of the angular subtense of a number of cycles of the collimated test pattern, followed by the appropriate calculation to give the spatial frequency.

5.6 Azimuths

It is permissible to measure one-dimensional MTFs. These shall be taken at the azimuths with highest and lowest MTF values. For off-axis image points, this will generally be in the radial and tangential directions. In case of rotational asymmetry (e.g. for on-axis points) this fact shall be noted and measurement results given for the directions of highest and lowest MTF values.

A special case is that of systems containing roof prisms where one of the measurements shall be made with the direction of variation of intensity of the test pattern normal to the roof edge.

5.7 Preparing the test specimen

The exposed optical surfaces shall be clean and the specimen shall have attained the stable temperature of the test laboratory.

Unless otherwise specified, focusing eyepieces shall be set for an infinite conjugate (0,0 m^{-1}). It is permissible to refocus for best MTF (e.g. when measurements at different off-axis positions or at different wavelengths are taken). In cases 5.1 a) and c), refocusing shall preferably be accomplished on the analyser side (Key 8 of Figure 1). For case 5.1 b), refocusing with the eyepiece (or on the objective side of the specimen) is permissible. In any case, the amount of refocusing required shall be noted in the test report.

For tests assessing performance with a reduced exit pupil, uncertainties can arise due to the difficulty of correctly positioning a stop at the exit pupil especially when making off-axis measurements. This is due to a combination of vignetting, pupil distortion and pupil wander along the reference axis relative to the on-axis pupil position. Consequently, it is preferable to position a stop of the corresponding diameter at the entrance pupil. The size of the stop is given by the product of the desired exit pupil and the magnification of the specimen.

5.8 Auxiliary equipment

In addition to fixtures for holding test specimens, some means for aligning the test beam with the input axis of the specimen can be needed particularly for instruments having large offsets between input and output axes. Mechanical means should be used for this if practical; otherwise, adjustable periscopic beam deviators using a framework and plane mirrors may be employed. The combined effect of all auxiliary equipment on the wavefront aberration shall be significantly lower than the accuracy of measurement.

6 Normalization of OTF values

The normalization arrangement with equipment which permits the response at zero cycles to be set to 1,0 will generally be satisfactory but further checks can be used if needed.

7 Test condition

The testing shall be carried out in accordance with the general principles and procedures given in ISO 9335.

8 Specification of the imaging state

8.1 Test specimen

Table 1 specifies an imaging state for the test specimen.

Table 1 — Imaging state of test specimens

Parameter	Value/Setting	Notes	Clause
configuration	in line in line with offset angled periscopic	Some configurations require auxiliary equipment.	5.8
magnification and objective diameter	example: 6 × 42 8 × 40 10 × 30	these examples give exit pupils of 7 mm 5 mm 3 mm	—