INTERNATIONAL STANDARD

ISO 9336-3

First edition
1994-10-15

Optics and optical instruments — Optical transfer function — Application —

Part 3:
Telescopes

Optique et instruments d'optique — Fonction de transfert optique — Application —
Partie 3: Télescopes

INTERNATIONAL ISO

Reference number
ISO 9336-3:1994(E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9336-3 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 1, *Fundamental standards.*

ISO 9336 consists of the following parts, under the general title *Optics and optical instruments — Optical transfer function — Application*:

— *Part 1: Interchangeable lenses for 35 mm still cameras*

— *Part 2: Lenses for office copiers*

— *Part 3: Telescopes*

Annexes A and B of this part of ISO 9336 are for information only.

International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

Optics and optical instruments — Optical transfer function — Application —

Part 3: Telescopes

1 Scope

This part of ISO 9336 specifies a method of testing telescopes in terms of imaging states aimed at making valid optical transfer function measurements.

Information is also given on the testing of some of their components and sub-assemblies.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 9336. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 9336 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 9334:—[1], *Optics and optical instruments — Optical transfer function — Definitions and mathematical relationships.*

ISO 9335:—[1], *Optics and optical instruments — Optical transfer function — Principles and procedures of measurement.*

CIE Publication No. 18.2 (1983), *The basis of physical photometry.*

1) To be published.

3 Definitions

For the purposes of this part of ISO 9336, the definitions given in ISO 9334 apply.

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

The specimens considered are direct view telescopes which generally give the observer an enlarged presentation of a distant scene and include many instruments such as theodolite telescopes, hand-held binoculars and vehicle-mounted observation instruments.

Some, such as theodolite telescopes, have small fields of view, say $\pm 1°$ in object space, present a flat field with little or no astigmatism and have magnifications of about $\times 20$. On the other hand, binoculars and other similar instruments have larger fields of view, say up to $\pm 3{,}5°$ in object space with a magnification of $\times 10$. Such instruments can have significant curvature of field coupled with astigmatism depending on the aims of the optical designer. For example, curvature of field can be minimized in one section but considerable astigmatism can be left or alternatively the astigmatism can be reduced to a negligibly low level with field curvature of 1 or 2 dioptres at the edge of the field.

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

Many optical systems now include roof prisms to give a compact instrument in which case the orientation of the roof edge shall be noted.

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 3 mm diameter, in OTF tests relevant to the use of the telescope at different ambient illumination levels.

5 Test setup

5.1 Arrangement of optical bench

The 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 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 curvature of field.

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. 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'.

5.2 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 last 10 mm greater than the objective of the specimen.

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 curvature of field reached, say, 2 dioptres.

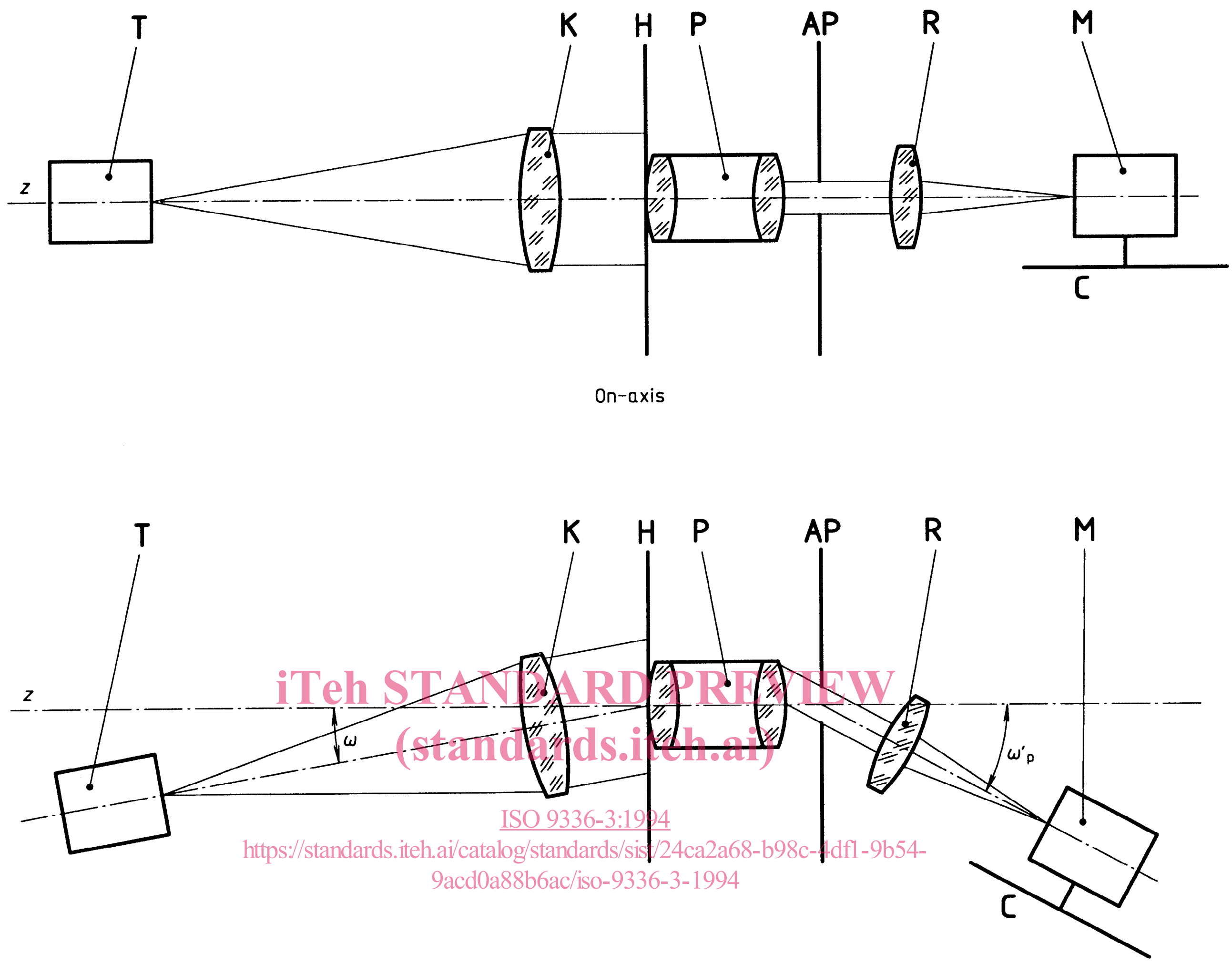
5.3 Spectral response

The spectral response of the test system must match that of an observer using the specimen in its normal viewing role. 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).

The most effective position for the filter 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.

5.4 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 is limited by the resolution of the eye, and for most applications a range of 0 to 2 mrad^{-1} is adequate. The corresponding frequency range in object space will be given by 0 to $2M$ mrad^{-1} where M is the magnification of the telescope.



T	Test target unit
K	Object collimator
P	Test specimen
H	Fixture for test specimen
AP	Exit pupil
ω_p, ω'_p	Object and image pupil field angles
M	Image analyser
R	Image analyser collimator (decollimator)
C	Image analyser focus slideway
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.

5.5 Azimuths

Tests at two orthogonal azimuths are generally sufficient, i.e. in the radial and tangential sections.

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.

5.6 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 to −1,0 dioptres, a value frequently used for fixed focus instruments. The complete series of specified tests is carried out at this setting.

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.

5.7 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. Mirrors for this purpose should be flat to $-\lambda/10$. The combined mirror system shall be such that the wavefront degradation does not significantly affect 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 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.

8.2 Measuring equipment

Table 2 specifies an imaging state for the measuring equipment.

8.3 Measurement

Table 3 specifies an imaging state for the measurement.

9 Presentation

Table 4 specifies an imaging state for presentation.

10 Accuracy of equipment

The uncertainty of measurement shall be assessed either by using recognized or known test telescopes, or by estimation of all systematic and random sources of error.

One method is to replace the test specimen and image analyser collimator with a collimator, which is similar to the object collimator, to form an image of the test target without the test specimen. Then, using a narrow bandwidth filter, 546 nm, and assuming that the collimators have diffraction limited performance the correct response should be obtained through a range of spatial frequencies.

Alternatively, special instruments of stable construction can be used. To facilitate the alignment of the test setup, for all field points considered, a graticule with circles is incorporated so that each field point is identified as the centre of a circle (see reference [3] in annex B).

Table 1

Parameter	Value/Setting	Notes	References
Configuration	In line In line with offset Angled Periscopic	Some configurations require auxiliary equipment.	5.7
Magnification and objective diameter	Example: 7 × 50 8 × 40 10 × 30	These examples give exit pupils of 7 mm 5 mm 3 mm	
Exit pupil	7 mm 5 mm 3 mm 2 mm	To obtain reduced exit pupil diameters appropriate stops are used.	5.6
Field of view	e.g. ± 3°	In object space.	Clause 4
Eyepiece focus setting	– 0,5 dioptre for focusing eyepieces		5.6
Reference mark	Mounting characteristic	If the test specimen contains a roof prism the angle between the reference mark vector and the roof edge, as projected to the entrance pupil, shall be stated. It is preferable that this angle is 0°.	Clause 4

Table 2

Parameter	Value/Setting	Notes	References
Bench configuration	Object at infinity Image side decollimator forms an image in the plane of the image analyser	A focus adjustment is needed.	5.1 and 5.2 5.2
Spectral characteristics	The radiation source broad band filter and analyser combination should have overall spectral characteristics which match the V_λ curve of the eye	1. Spectral range: At least 400 nm to 670 nm . 2. Radiation source: Tungsten halogen lamp operated at a correlated colour temperature of (3 200 ± 200) K in combination with a broad band filter. 3. Analyser: Photomultiplier with S 20 photocathode.	5.3 V_λ = Spectral luminous efficiency for photopic vision (CIE No. 18.2)

Table 3

Parameter	Value/Setting	Notes	References
MTF	MTF is essential PTF if specified		
Focusing	On-axis maximum MTF at 2 $mrad^{-1}$ in image space Focus for both radial and tangential sections can be required Off-axis: refocusing for both radial and tangential sections will be needed	Datum focus for ∞ to be established. For some classes of specimens, either lower or higher spatial frequencies may be appropriate.	5.1
Exit pupil	Full aperture and 3 mm	Others if requested as defined in table 1.	
Pupil field angles (ω_p)	On-axis ± 0,5 semifield ± 0,7 semifield ± 0,85 semifield		
Reference angle (θ)	1) 0°, 90°, 180° and 270° 2) Angle of roof edge		
Azimuth	Radial and tangential		5.5
Dioptre setting	If specified	Generally applicable to fixed focus specimens. Calculated from the difference between the datum focus and the on-axis focus setting.	
Field curvature		Calculated from the difference between the on-axis focus setting and off-axis focus settings in both radial and tangential sections for selected field angles.	
Astigmatism		Calculated from the difference between radial and tangential focus settings at selected field angles.	
Reference plane	Datum focus setting at image analyser	Objet at ∞; no test specimen; image analyser focused for maximum MTF.	
Selected spatial frequencies in image space ($mrad^{-1}$)	0,25; 0,5; 0,75; 1,0; 1,25; 1,5; 1,75 and 2,0	The performance of the specimen may preclude spatial frequencies above 1 $mrad^{-1}$ or even 0,5 $mrad^{-1}$.	5.4

Table 4

Parameter	Value/Setting	Notes	References
Frequencies for numerical presentation	10 equidistant frequencies over the practical measurement range		

11 Quality assurance tests

11.1 General procedure

A shortened form of testing procedure can be all that is needed for many applications. A reduced spatial frequency range or tests at one or two spatial frequencies applied on-axis and perhaps at one off-axis field point may suffice.

11.2 Azimuth scanning MTF systems

The generally used MTF tests at radial and tangential azimuths may not be adequate if there are significant variations in performance at intermediate azimuths. Thus it can be advantageous to test at a single spatial frequency scanning through all azimuths. Figure 2 shows a schematic arrangement of such a test system in which the test pattern rotates about the optical axis in a plane normal to the axis and the analysing element is a pinhole. The measuring equipment parameters being as in table 2.

11.2.1 Focusing

When focusing, the following three modulation transfer factor criteria may be considered:

a) that giving the minimum variation of the indicated factor when scanning through all azimuths;

b) that bringing the minimum value of the indicated factor to its maximum value when scanning through all azimuths;

c) that giving the highest value of the mean of the indicated factor when scanning through all azimuths.

If a single value for the MTF response is required to characterize the specimen, it is preferable to take the minimum value obtained when using criterion b). If the mean value is quoted, the variation about the mean shall also be stated and consequently a more sophisticated test procedure is required.

Generally, criterion b) is the mandatory technique.

11.2.2 Spatial frequency

Due to the searching nature of the test, a spatial frequency which gives a modulation tansfer factor between 0,4 and 0,7 is appropriate.