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Optics and optical instruments — General optical test methods — Measurement of relative irradiance in the image field

Optique et instruments d'optique — Méthodes générales d'essai optique — Méthode de mesurage de l'éclairement énergétique relatif dans le champ image

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Contents

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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 13653 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 1, *Fundamental standards*.

Introduction

In every image projected by an optical or electro-optical system, the irradiance varies from the centre to the edge independently of the object structures. It generally decreases, i.e. even an object surface of uniform radiance will be imaged with an irradiance which decreases from the image centre to the edge. In special cases, it can, however, increase. In optical systems which are rotationally symmetric, the variation will not always be rotationally symmetric, for example if limiting apertures are not rotationally symmetric.

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Optics and optical instruments — General optical tests — Measurement of relative irradiance in the image field

1 Scope

This International Standard is applicable to optical imaging systems in the optical spectral region from λ = 100 nm to λ = 1 µm. Theoretical reflections and the comparison with the calculation apply only to optical systems. These need not, however, be rotationally symmetric; anamorphic systems, for example, are included.

Telescopic systems are also included. The title of this International Standard refers to the relative irradiance in the image field, but this standard is also applicable to determination of the relative radiant power.

NOTE — For telescopic systems it will be suitable to state only the radiant power; for most imaging systems, the conversion from radiant power to irradiance will be easy.

As far as measurements are concerned, this International Standard can also be applied to electro-optical systems.

The two methods described differ particularly in the influence of veiling glare.

2 Quantities, symbols and units

Table 1 - Quantities, symbols and units

Quantity	Symbol	Unit
Relative irradiance	$E_{\text{rel}}\ (\omega_p)$	
Function for natural fall-off in brightness	$F_{\text{nat}}\ (\omega_p)$	
Function for relative pupil surface	$F_p\ (\omega_p)$	
Function for vignetting	$F_{\text{vig}}\ (\omega_p)$	
Function for relative transmission	$F_T\ (\omega_p)$	
Influence function of distortion	$F_{\text{ver}}\ (\omega_p)$	
Relative distortion	V_r	%
Image coordinates	u' v'	mm mm
Object height (one dimensional)	h	mm
Image height (one dimensional)	h'	mm
Pupil field angle, object-space	ω_p	rad, degree
Pupil field angle, image-space	$\omega'_{p'}$	rad, degree
Azimuth of object to be measured	Φ	rad, degree
Wall thickness of the analysing aperture	t	mm
Diameter of the analysing aperture	d	mm

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 relative irradiance

quotient of radiant power and surface area.

NOTES

1 When a surface element of the object is imaged, the irradiance in the image is a function
- of the object-space pupil field angle ω_p;
- of the radiant power which originates from the object element and passes through the lens (and possibly - also through the electro-optical imaging element);
- of the size of the image surface element which is struck by the radiant power.

2 Radiant power and surface area are functions of the object-space pupil field angle ω_p or of the image position (u', v').

3 The relative irradiance is related to the axial surface element.

3.2 object-space pupil field angle, ω_p

angle formed by the optical axis and the line joining the centre of the entrance pupil and the object point.

3.3 image-space pupil field angle, ω'_p

angle formed by the optical axis and the line joining the centre of the exit pupil and the image point.

4 Designation

Two measurement procedures are specified, the first of which has two variants. They will be distinguished by symbols.

Table 2 — Symbols for the measurement procedures

Symbol	Measurement procedure
A1	measurement of the relative irradiance at finite image distance
A2	measurement of the relative irradiance at infinite image distance
B	measurement of the relative radiant power

Example: designation of a measurement of relative irradiance according to measurement procedure A1:

Measurement of relative irradiance ISO 13653 - A1

5 Description of measurement procedures

5.1 Factors influencing the relative irradiance

5.1.1 General

The angular dependence of the relative irradiance is due to several factors which are independent of one another. In the various measurement and calculation procedures, they will be allowed for in different ways. It is therefore important to know the individual influence factors. The provisions of 5.1.2 to 5.1.7 are based on the assumption that the object surface is radiant Lambertian and the optical system has a flat entrance pupil.

5.1.2 Natural fall-off in brightness, $F_{\mathrm{nat}} = \cos^4 \omega_{\mathrm{p}}$ ($\cos^4$ law)

This $\cos^4$ law shall always apply if the pupil boundary is flat and perpendicular to the axis, the aperture of the test specimen small and the detector area a plane perpendicular to the axis.

5.1.3 Relative pupil surface, F_{p} (ω_{p})

Due to pupil aberrations, the surface of the entrance pupil as an image formed by the aperture stop is a function of the pupil field angle if lens elements are arranged between the object and the aperture stop. The relative surface shall be related to the pupil surface for $\omega_{\mathrm{p}} = 0$.

5.1.4 Vignetting, F_{vig} (ω_{p})

With increasing pupil field angle, rims in front of and behind the aperture stop and other stops can limit (vignette) the aperture.

5.1.5 Influence of the transmission, $F_{\mathrm{T}}(\omega_{\mathrm{p}})$

Any change of the incident angle on the surfaces of the optical components (lenses, prisms) can result in a change of the reflectivity. The net transmission can change because the paths in glass are a function of the pupil field angle.

5.1.6 Change in size of the image surface element due to distortion

At the image scale $\beta' = 0$

$$F_{\mathrm{ver}}(\omega_p) = \frac{1}{\left(1+\frac{V_r}{100}\right)\cdot\left(1+\frac{V_r}{100}+\frac{\sin\omega_p\cdot\cos\omega_p}{100}\cdot\frac{dV_r}{d\omega_p}\right)}$$

At a finite image scale:

$$F_{\mathrm{ver}}(h) = \frac{1}{\left(1+\frac{V_r}{100}\right)\cdot\left(1+\frac{V_r}{100}+\frac{h}{100}\cdot\frac{dV_r}{dh}\right)}$$

5.1.7 Resulting relative irradiance

For the resulting relative irradiance in the image field as a function of the pupil field angle, the following relationship is valid:

$$E_{\mathrm{rel}}(\omega_p) = \cos^4\omega_p \cdot F_p(\omega_p) \cdot F_{\mathrm{vig}}(\omega_p) \cdot F_T(\omega_p) \cdot F_{\mathrm{ver}}(\omega_p)$$

The first four factors are related to a change in radiant power, whereas the last value characterizes the variation in size of the image surface element.

When making irradiance measurements, the radiant power shall pass through the optical system in the same direction that is experienced in normal operation because the influence of distortion and veiling glare will change when the direction of beam travel is reversed.

5.2 Classification of the measurement procedures

Two different measurement procedures are generally acceptable: irradiance measurement and radiant power measurement.

In the case of imaging systems, the procedure for irradiance measurements will directly take all five factors in the equation in 5.1.7 into account, and shall, therefore, be given preference.

The procedure of radiant power measurement will neglect the effect of distortion on the size of the image surface element. If the value is known, it can be taken into account by calculation. In a great number of cases, the factor is, however, to be neglected because the distortion is small (< 2 %). Even for medium levels of distortion it can, however, assume distinct values.

The result of the measurement shall be multiplied by the factor $\cos^3\omega_p$ so that the relative irradiance is obtained from the relative radiant power.

As compared with the method of irradiance measurement, this procedure offers the advantage that the result is generally influenced to a lesser extent by veiling glare.

According to this International Standard, telescopic systems shall be measured solely by the method of radiant power measurement.

5.3 Brief description of the irradiance measurement

The relative irradiance shall be determined as a function of the image height. This measurement presupposes that there is a uniformly radiating surface in the object space, which behaves as a Lambertian emitter and as a uniform radiance. It need not, however, be situated in the object surface but can also be arranged directly in front of the entrance pupil.

A small reference surface with photoelectric detector shall be displaced by a measurable amount in the image plane; the irradiance shall be measured in arbitrary units as a function of the image height h', and the measured value shall be related to the axial value (procedure A1, see figure 1).

In systems with an infinitely great image distance (e.g. projection lenses), the diaphragm can be arranged at the focus of an auxiliary optical system (telescope optics) which is turned to a measurable degree about the exit pupil of the object (procedure A2, see figure 2). The irradiance rated by the radiation detector shall be determined according to the $\cos^4$ law.

5.4 Brief description of the radiant power measurement

To measure the relative radiant power, the test specimen shall be irradiated with a collimated bundle of rays. The axes of collimator and test specimen can be swung in relation to one another.

In the image space, the passing radiant power shall be measured relative to the axial value as a function of the object-space pupil field angle ω_p using an integrating sphere and a photoelectric detector (procedure B, see figure 3).

6 Measurement of relative irradiance

6.1 Description of the measuring set-up

6.1.1 Source of radiation

To represent a Lambertian radiation characteristic, it will be advantageous to insert a diffusing screen into the aperture of an integrating sphere according to figure 1. In the spectral region in which the specimen is used, the inside surface of the integrating sphere shall be non-selective, and the diffusing screen shall ensure uniform radiance over that part of its surface which is made use of.

The source of radiation shall emit radiation into the test specimen at least from the useful range of the pupil field angle. Within this range, the constancy of the radiance shall be better than 2 %.

6.1.2 Test specimen holder

The test specimen shall be held so that the front edge of its mount abuts almost directly on the diffusing screen or extends so far to the aperture of the integrating sphere that irradiation from the entire useful range of the pupil field angle is ensured.

The test specimen holder may be of the rigid type. To measure in different azimuths, test specimens whose mechanical design is not rotationally symmetric shall, however, be rotatable about their own axes.

6.1.3 Measuring system

6.1.3.1 General

The measuring system shall consist of the diaphragm, a filter frame and a radiation detector. It shall be possible to axially displace the measuring system so that it can be adjusted to the respective image plane. To adjust the image point, the system shall be displaceable in the image plane by a measurable amount. An auxiliary device is necessary for focussing.

To measure test specimens with an infinitely great image distance, the measuring system shall be arranged in the axial image point of an auxiliary optical system (telescope lens). It shall be possible to horizontally swing the auxiliary optical system, together with the measuring system, to a measurable degree about the exit pupil of the test specimen.

6.1.3.2 Analysing aperture

The analysing aperture has an opening whose size should not exceed 2 % of the maximum image height h'. If this value is exceeded, this is to be stated. The material thickness at its edge and the cone angle at which the opening is chamfered shall be selected so that diaphragm vignetting is less than 1 % even at the greatest image-space pupil field angle $\omega'_{p'}$ occurring.

The following formula shall apply to circular diaphragms:

$$t \cdot \tan \omega'_{p'} < 0{,}01\, d$$

where

t is the wall thickness of the diaphragm;

d is the diameter of the diaphragm.

6.1.3.3 Filter

The filter serves to adapt the spectral selectivity. If necessary, the angular dependence of the spectral transmission shall be taken into account.

6.1.3.4 Radiation detector

The responsivity of the radiation detector shall be linear and constant in space. Linearity and spatial constancy errors of up to 1 % are permissible; in the case of errors exceeding this value, corrections shall be applied. The size of the radiation detector shall be sufficient for receiving the entire radiation transmitted by the diaphragm. If necessary, a field lens may be inserted.

The aperture of the radiation detector, i.e. its maximum possible acceptance angle, shall be greater than the aperture of the test specimen plus the image-space pupil field angle ω'_{p}, unless the radiation detector is also horizontally swung about the diaphragm.

6.1.3.5 Auxiliary devices for focussing

It shall be possible to adjust the diaphragm to the desired image plane. For this purpose, auxiliary devices are necessary.

Adjustment can be made mechanically, for example, by means of suitable scales on the measuring arrangements or by adjusting the distance between test specimen and diaphragm using distance gauges. For optical adjustment, the source of radiation shall be replaced by an axial mark at object-to-lens distance, for example, a collimator. In the image space, the radiation detector can be replaced by a magnifier lens or a microscope which can be focussed onto the diaphragm edge.

6.2 Measurement

6.2.1 Adjustment of the measuring set-up

The test specimen shall be placed in the holder and turned so that the reference mark points to the specified azimuth direction. Auxiliary devices shall be used to axially align and focus the diaphragm.

6.2.2 Spectral region

The spectral region shall be adapted to the specific application by a suitable combination of source of radiation, detector and filter.

6.2.3 Determination of measurement value

As a function of the displacement of the diaphragm in the image plane to the desired image height, first the radiant power passing through the diaphragm shall be measured in relative units and related to the value measured when the diaphragm is in its axial position. The measurement shall be carried out with the test specimen rotated through 360°. For test specimens whose design is intended to achieve symmetry, the measurement value shall be averaged with reference to the most favourable point of symmetry.