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Optics and photonics — Quality evaluation of optical systems — Determination of distortion

Optique et photonique — Évaluation de la qualité des systèmes optiques — Détermination de la distorsion

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 9039 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 1, *Fundamental standards*.

This second edition cancels and replaces the first edition (ISO 9039:1994) which has been technically revised.

Introduction

Generally, the function of rotationally symmetric optical systems is to form an image that is geometrically similar to the object, except for some particular systems, such as fish-eye lenses and eyepieces, where this condition is deliberately not maintained. Ideally, this function is accomplished according to the geometry of perspective projection. Departures from the ideal image geometry are called distortion. The distortion is a position-dependent quantity which generally has a vectorial character. In a given image plane (which may also lie at infinity), this vector, representing the difference between theoretical and real image position, has a radial and a tangential component. In optical systems, the tangential component is basically conditioned by imperfect rotational symmetry. The systems manufactured in accordance with the present state of the art have a negligible tangential distortion. A tangential component of the distortion appears, however, as primary aberration in the case of electromagnetically focused electro-optical systems. This International Standard deals only with the radial distortion. For special systems, e.g. certain electro-optical systems, an expansion may become necessary to include vectorial representation.

Optics and photonics — Quality evaluation of optical systems — Determination of distortion

1 Scope

This International Standard specifies methods of determining distortion in optical systems for the purposes of quality evaluation. It applies to optical imaging systems in the optical spectral range from 100 nm to 15 000 nm which, by their design, aim at a rotationally symmetric image geometry. It is applicable to electro-optical imaging systems provided that adequate rotational symmetry of the image is guaranteed. It does not, therefore, apply to anamorphic and fibre optic systems.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
distortion
measure of the deviation of the extra-axial image points from the ideal image points in a given plane lying parallel to the reference plane of the system

NOTE If the image plane is at infinity, the image positions are given in terms of tangents of field angles.

2.2
reference plane
plane corresponding to a physical feature of the device under test which is used for alignment, e.g. a mounting flange or a fixture specially mounted for that purpose

2.3
absolute distortion
V_a
distance in the radial direction between the observed image point and the ideal image point, expressed in millimetres or micrometres

2.4
relative distortion
V_r
distance in the radial direction between the observed image point and the ideal image point, expressed as a percentage of the ideal image height h'_0

NOTE With the image at infinity, relative distortion is the difference between the tangents of the observed field angle and the ideal field angle, expressed as a percentage of the tangent of the ideal field angle ω'_0.

2.5
object height
h
distance between an object point and the axis of rotational symmetry of the test specimen, expressed in millimetres

2.6
image height
h'
distance between an image point and the axis of rotational symmetry of the test specimen, expressed in millimetres

2.7
object pupil field angle
ω_p
absolute value of the angle, expressed in radians or degrees, between the axis of rotational symmetry and the direction of travel of radiation from the object to the entrance pupil of the test specimen

2.8
image pupil field angle
ω'_p
absolute value of the angle, expressed in radians or degrees, between the axis of rotational symmetry and the direction of travel of radiation from the exit pupil of the test specimen to the image

2.9
object distance
a
distance between the object plane and the first principal point, expressed in millimetres

2.10
image distance
a'
distance between the image plane and the second principal point, expressed in millimetres

2.11
object plane
plane parallel to the reference plane containing an object point

2.12
image plane
plane parallel to the reference plane containing an image point

2.13
ideal image height
h'_0
image height without distortion, given by the geometry of perspective projection, expressed in millimetres

2.14
ideal image field angle
ω'_0
image field angle without distortion, given by the geometry of perspective projection, expressed in radians or degrees

2.15
angular magnification
Γ
limiting value of the equation

$$\Gamma = \lim_{\omega_p \to 0} \frac{\tan \omega'_p}{\tan \omega_p}$$

2.16
lateral magnification
m
limiting value of the equation

$$m = \lim_{h \to 0} \frac{h'}{h}$$

3 Classes of application

3.1 Infinite object distance, finite image distance

The reference quantity is the image distance a', obtained as the limiting value of the equation

$$a' = \lim_{\omega_p \to 0} \frac{h'}{\tan \omega_p}$$

The absolute distortion is

$$V_a = h' - a' \tan \omega_p$$

and the relative distortion is

$$V_r = 100 \frac{h' - a' \tan \omega_p'}{a' \tan \omega_p}$$

For telecentric imaging, the image distance a' is replaced by the distance of the telecentric stop from the first principal point.

If the image side focus lies in the image plane, then a' is the equivalent focal length. For photogrammetric lenses, the calibrated focal length is used instead of a' in the calculation of the absolute distortion V_a. The calibrated focal length is an adjusted value chosen to distribute the distortion within the image field in a specified manner.

3.2 Infinite object distance, infinite image distance

The reference quantity is the angular magnification Γ.

The relative distortion, V_r, is given by

$$V_r = 100 \frac{\dfrac{\tan \omega_p'}{\tan \omega_p} - \Gamma}{\Gamma}$$

3.3 Finite object distance, finite image distance

The reference quantity is the lateral magnification m.

The absolute distortion, V_a, is given by

$$V_a = h' - hm$$

and the relative distortion, V_r, is given by

$$V_r = 100 \frac{\frac{h'}{h} - m}{m}$$

3.4 Finite object distance, infinite image distance

The reference quantity is the object distance a, obtained as the limiting value of the equation

$$a = \lim_{h \to 0} \frac{h}{\tan \omega'_p}$$

The relative distortion, V_r, is given by

$$V_r = 100 \frac{a \tan \omega'_p - h}{h}$$

For telecentric imaging, the distance of the telecentric stop from the second principal point replaces a.

4 Test methods

4.1 General

In order to determine the distortion, conjugate value pairs of object- and image-side coordinates must be measured. For the object side, the values concerned are the object pupil field angle ω_p or the object height h, and for the image side the image pupil field angle ω'_p or the image height h'. The terms object-side and image-side must be understood with reference to practical application.

When making measurements, the direction of radiation should be from the object side to the image side. When making measurements, the direction of radiation (from the object side or the image side) changes the sign of the distortion values. If the opposite direction is to be applied for the convenience of measurement, this should be taken into account.

Illuminated reticles, an array of illuminated slits with known separations or a single illuminated slit whose displacement is measurable, serve the purpose of representing object positions of finite distance or, in the case of opposite direction of radiation, image positions of finite distance. Collimators are employed to represent objects at infinite distance whereas telescope lenses are used to render images at infinite distance measurable (or vice versa for the opposite direction of radiation).

For the measurement of the object or image pupil field angles, the collimator or telescope, and the optical system to be tested (with its image or object plane) are displaced relative to each other in a way that the angles can be measured. The axis of rotation should pass through the middle of the entrance or exit pupil of the system to be tested in order to cover the full aperture of this system, also in the case of larger field angles.

For the measurement of finite image or object heights, detection devices whose displacement is measurable or scales placed in the measuring plane are employed.

The distortion is calculated from the measured values in accordance with the formulae given in Clause 3.

NOTE In the case of the opposite direction of radiation, care should be taken not to confuse image- and object-side quantities, as otherwise the distortion would be reversed in sign.

4.2 Apparatus

4.2.1 General requirements

The measurement set-ups shall be so designed that the reference plane of the optical system to be tested and the object or image plane can be aligned parallel to each other. In the case of infinite object or image distance, for the field angle $\omega_p = 0$ or $\omega'_p = 0$, the reference plane of the system to be tested shall be adjustable perpendicular to the direction of radiation. It is appropriate to use an autocollimator for the alignment instead of the collimator or telescope.

The instruments used for measuring the object and image pupil field angles and object and image height shall have accuracies such that the influence on the calculated distortion values is 5 times to 10 times lower than the tolerance. For optical systems with very low permissible distortion, it may be not possible to achieve these instrument accuracies. In this case, the actual accuracy should be specified in the test report.

The general stability and precision of the measurement set-up, in particular of the swivel bearings, shall be included in the error assessment.

The spectral characteristic of the measurement set-up shall be adapted to the intended application of the optical system to be tested.

The coherency characteristics of the object illumination shall match those actually used for the optical system to be tested.

The mounting of appropriate diaphragms shall guarantee the limitations of the rays which correspond to the practical application of the optical system to be tested. Special attention is necessary in the case of magnifiers and eyepieces.

The illuminating optics shall be mounted in such a way that the principal rays correspond to practical applications.

If necessary, the illumination aperture shall be adapted to the intended application of the optical system to be tested.

Auxiliary optics used shall be sufficiently well corrected that they do not affect the measured values. Their pupils shall be large enough such that the pupils of the optical system to be tested are not vignetted.

It shall be ensured that, during the measurement, the image plane corresponds as closely as possible to that of practical application. The application of given focusing criteria may be necessary for this purpose.

If high demands are made on the accuracy of measurement, the application of criteria specified for the establishment of the image position may be necessary.

4.2.2 Infinite object distance, finite image distance

4.2.2.1 General

The measurement set-up shall allow the measurement of conjugate value pairs of the object pupil field angle ω_p and the image height h'.

4.2.2.2 Camera set-up

The object is represented by a mark in the focal plane of a collimator, preferably by an incoherently illuminated narrow slit. A device whose displacement can be measured is mounted in the image plane of the optical system to be tested in order to detect the image. It shall be possible to rotate the collimator and the optical system to be tested, with the detection device mounted in its image plane, relative to each other in such a way that the angle of rotation can be measured. It is of no importance which part is rotated and which part is stationary. The axis of rotation is perpendicular to the plane formed by the image height axis and the optical axis of the collimator and passes approximately through the middle of the entrance pupil of the optical system to be tested.

