IEC 63145-20-20

Edition 1.0 2019-09

INTERNATIONAL STANDARD

Eyewear display –
Part 20-20: Fundamental measurement methods – Image quality

IEC 63145-20-20:2019-09(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 17.180.99; 31.120

ISBN 978-2-8322-7352-4

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EYEWEAR DISPLAY –

Part 20-20: Fundamental measurement methods – Image quality

FOREWORD

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International Standard IEC 63145-20-20 has been prepared by IEC technical committee TC 110: Electronic displays.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
110/1110/FDIS	110/1139/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 63145 series, published under the general title *Eyewear display*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

EYEWEAR DISPLAY –

Part 20-20: Fundamental measurement methods – Image quality

1 Scope

This part of IEC 63145 specifies the standard measurement conditions and measurement methods for determining the image quality of eyewear displays. This document is applicable to non-see-through type (virtual reality "VR" goggle) and see-through type (augmented reality "AR" glasses) eyewear displays using virtual image optics.

Contact-lens type displays and retina direct projection displays are out of the scope of this document.

NOTE See IEC TR 63145-1-1 [1][1] for eyewear displays, ISO 9241-302:2008, 3.5.45, for see-through types.

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.

IEC 63145-20-10:–[2], *Eyewear display – Part 20-10: Fundamental measuring methods – Optical properties*

ISO 9241-302:2008, *Ergonomics of human-system interaction – Part 302: Terminology for electronic visual displays*

3 Terms, definitions, abbreviated terms and letter symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 63145-20-10 and ISO 9241-302 apply.

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

NOTE 1 Terms related to eyewear displays will be defined in specific projects.

NOTE 2 Some terms relating to eyewear displays are given in IEC TR 63145-1-1 [1].

1 Numbers in square brackets refer to the Bibliography.

2 Under preparation. Stage at the time of publication: IEC FDIS 63145-20-10:2019.

3.2 Abbreviated terms

AR augmented reality
CCD charge-coupled device detector
CPD cycles per degree
DUT device under test
FOV field of view
LMD light measuring device
VR virtual reality

3.3 Letter symbols (quantity symbols/unit symbols)

The letter symbols for eyewear displays are shown in Table 1

Table 1 – Letter symbols (symbols for quantities, and units)

Quantities	Symbols and units	
Measuring point (i = 0: centre)	$\mathrm{P_i}$	
Luminance at $\mathrm{P_i}$	L_{vi}	(cd/m^2)
Distortion at the corner	δ_{vh}	(%)
Colour registration error for primary colour	$\varepsilon_{\mathrm{vh,\ colour}}$	(degree)
Michelson contrast	C_{m}	
Maximum luminance	L_{vM}	(cd/m^2)
Minimum luminance	L_{vm}	(cd/m^2)
Spatial frequency (CPD)	f_{CPD}	(1/degree)
Focal distance at $\mathrm{P_i}$	γ_{i}	(m)
Dioptre at $\mathrm{P_i}$	D_{i}	(1/m)

4 Standard measurement conditions

4.1 Standard environmental conditions

Unless otherwise specified, all tests and measurements for eyewear displays shall be carried out after sufficient warm-up time for the illumination sources and DUT (see 4.3), under the following standard environmental conditions:

- temperature 22 °C to 28 °C,
- relative humidity 25 % to 85 %, and
- atmospheric pressure 86 kPa to 106 kPa.

When different environmental conditions are used, they shall be reported in detail in the specification.

4.2 Power supply

In order to stabilize the performances of the DUT, the power supply for driving the DUT shall be adjusted according to the specification of the DUT.

NOTE When the DUT is driven by a battery, it is less susceptible to power supply fluctuations.

4.3 Warm-up time

The optical performances of DUTs are affected by the transient temperature behaviour of the device. It takes a certain time for the luminance output of the DUT to reach the steady state. If the luminance output is not within a ±3 % variation, it shall be reported. All measuring conditions shall be kept constant during the measurements.

NOTE If the measuring result does not become a steady state, it might be influenced by the output fluctuation of the DUT and/or the fluctuation of the LMD such as noise.

4.4 Dark room conditions

The luminance contribution from the background of the test room reflected off the measurement space shall be less than 1/20 of the minimum luminance output from the DUT. If this condition is not satisfied, then background luminance can be subtracted and it shall be reported.

5 Measurement systems

5.1 Standard coordinate system

To indicate the size and position of a virtual image, a spherical coordinate system of elevation (latitude) and azimuth (longitude) shall be used in the measurements; the polar axis is vertically oriented as shown in Figure 1. The angles measured in the vertical half plane of data are elevation angles, denoted as α, and the horizontal angles to the half plane are azimuth angles, denoted as Ψ. The origin direction ($\alpha = 0$, $\Psi = 0$) of the spherical coordinate system shall be coincident with the optical axis of the DUT.

To indicate the positional relationship among the eye-box, reference point on the DUT, eye point and eye relief of the DUT, entrance pupil of the LMD and so on, a three-dimensional Cartesian coordinate system (x, y, z) shall be used, as shown in Figure 2. Unless specified otherwise, the eye point of the DUT is placed in the centre of the entrance pupil of the eye, which is in the centre of the iris. The eye point defines the origin of the coordinate system. The manufacturer or supplier of the DUT shall specify the distance between a reference point on the DUT and the eye point. The eye relief is defined as the distance from the cornea of the eye to the closest optical element of the DUT.

The origins of both the spherical coordinate system and the Cartesian coordinate system shall be located at the eye point.

NOTE In the case of a binocular eyewear display, the left eye can be used as the origin of the Cartesian coordinate system.

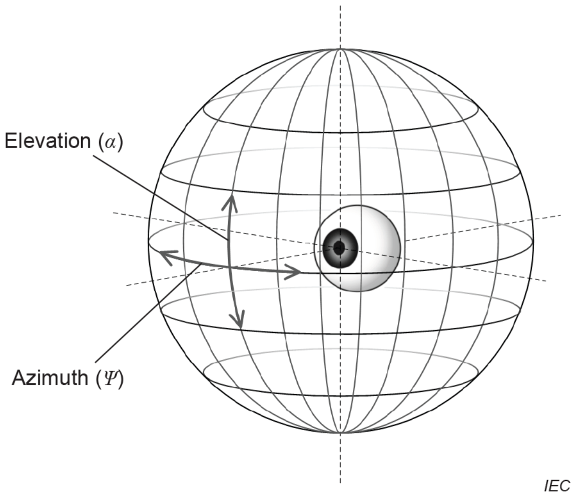
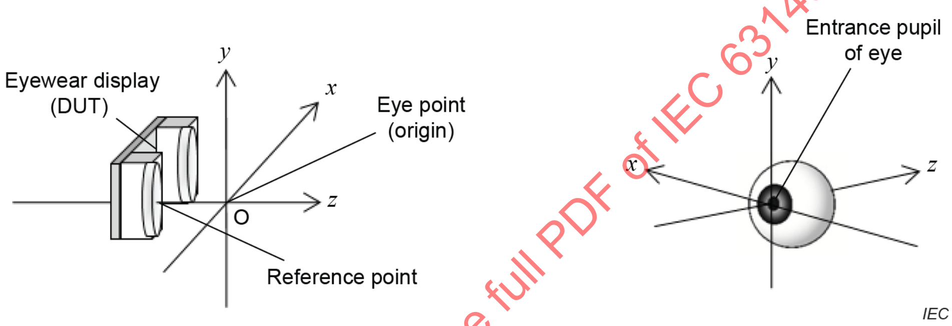


Figure 1 – Spherical coordinate system



NOTE This figure is an example of the eye pupil adjusting to the eye point, which is the origin position.

Figure 2 – Three-dimensional Cartesian coordinate system

5.2 Measurement equipment

5.2.1 Light measuring device (LMD)

5.2.1.1 General

The configurations and operating conditions of the equipment should comply with the structures specified in each item. To ensure accurate measurements, the following requirements shall be applied. Otherwise, the differences shall be noted in the report. ISO/CIE 19476 [4] describes the LMD evaluation procedures.

The optics of an LMD (a spot LMD or a 2D imaging LMD) shall be equivalent to the human eye, as shown in Figure 3. The LMD shall be equipped with an optical finder or a digital viewfinder. The position of the entrance pupil (aperture) of the LMD shall be provided by the manufacturer or the supplier. The entrance pupil size of the LMD should be set between 2 mm and 5 mm, and shall be smaller than the light ray of the DUT. The LMD to measure the optical characteristics such as luminance and colour shall be calibrated with the appropriate photometric or spectrometric standards. The LMD should be carefully checked before measurements, considering the following points:

- sensitivity of the measured quantity to the measuring light;
- errors caused by the veiling glare and lens flare (i.e., stray light in the optical system);
- timing of data-acquisition, low-pass filtering and aliasing-effects;
- linearity of detection and data conversion;
- measurement field size.

NOTE See IEC TR 63145-1-1:2018, 6.2 [1].

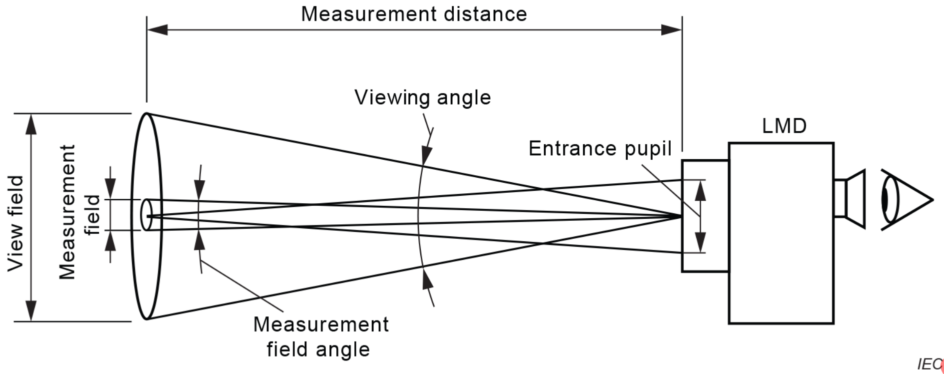


Figure 3 – Example of LMD structure

5.2.1.2 Spectrometer-type LMD

When a spectrometer-type LMD such as a spectroradiometer is used, the wavelength range shall be at least 380 nm to 780 nm, the spectral bandwidth shall be 5 nm or smaller, and the wavelength accuracy shall be 0,3 nm or smaller.

5.2.1.3 Filter-type LMD for measuring luminance

When a filter-type LMD such as a luminance meter is used, to ensure the luminance accuracy for the intended DUT light sources, its spectral responsivity should comply with the spectral luminous efficiency for CIE photopic vision or it should be compared with a calibrated spectrometer. The spectral mismatch correction factor can be applied, if necessary.

NOTE CIE-f_1' indicates the spectral mismatch function between the spectral responsivity of the filter-type LMD and the CIE photopic luminous efficiency function. Details of the spectral mismatch correction factor are given in ISO19476 [4].

5.2.1.4 Filter-type LMD for measuring colour

When a filter-type LMD such as a colorimeter is used to ensure the colour accuracy for the intended DUT light sources, its spectral responsivity should comply with the CIE colour-matching functions for the CIE 1931 standard colorimetric observer (see ISO 11664-1 [3]) or it should be compared with a calibrated spectrometer. The colour correction factors can be applied, if necessary. The filter-type LMD shall not be used for absolute colour quantities, but for relative colour quantities such as colour uniformity.

5.2.1.5 2D imaging LMD

The 2D imaging LMD (using a two-dimensional sensor such as a CCD) is a kind of a filter-type LMD. The performances of the 2D imaging LMD shall comply with 5.2.1.3 and 5.2.1.4. The valid measurement field angle of the 2D imaging LMD shall be confirmed and the peripheral image of the 2D imaging LMD shall confirm the absence of vignetting. The number of pixels of the 2D imaging LMD should not be less than four times the sub-pixels number within the measurement field.

NOTE 1 The measurement field of some 2D imaging LMDs is affected by the smaller entrance aperture.

NOTE 2 The 2D imaging LMD using a colour filter array might cause moiré.

5.2.2 Stage conditions

5.2.2.1 General

The stage shall be used to realize the coordinate system specified in 5.1. The stage should be constructed with the equivalent of a biaxial goniometer and an orthogonal three-axis translation stage.

5.2.2.2 Goniometer

A biaxial goniometer shall be assembled to be capable of measuring the azimuth (horizontal) and elevation (vertical) angles in the spherical coordinate system as shown in Figure 1. Examples of a five-axis stage are shown in Figure 4. The angular accuracy should be no less than 0,1°. The goniometer can be pivoted at the centre of the entrance pupil of the LMD or 10 mm behind the entrance pupil.

5.2.2.3 Translation stage

An orthogonal three-axis translation stage is assembled with an adequate range to cover the measuring distance such as the eye-box volume, and, if necessary, to cover the interpupillary distance for binocular DUTs, as in the examples shown in Figure 4. The translation accuracy should be no less than 0,05 mm.

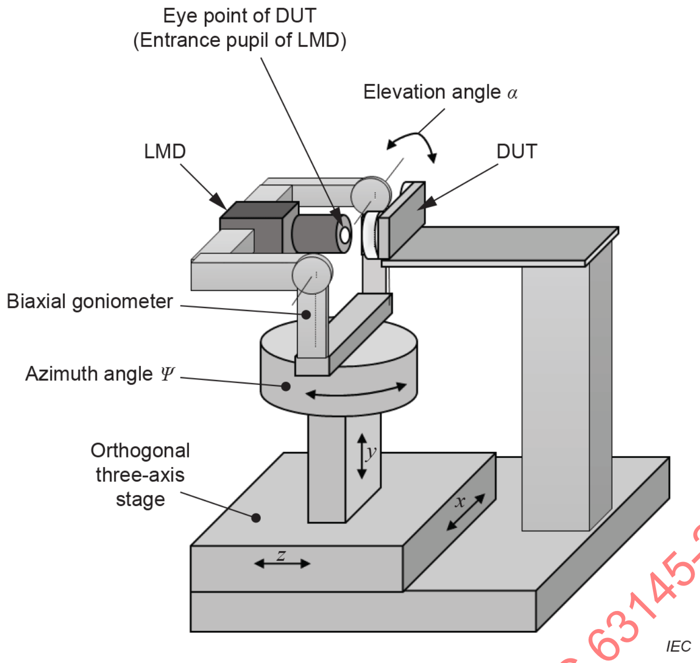
5.2.3 Setup conditions

The DUT shall be mounted on a stable platform to ensure image stability. The LMD position relative to the DUT shall be moved, and it can use a five-axis system (a biaxial goniometer and orthogonal three-axis translation stage). Examples of a measuring setup are shown in Figure 4. The eye point of the DUT shall match the origin of the biaxial goniometer. The optical axis of the DUT which is decided by the manufacturer or a supplier shall be adjusted to the optical axis of the LMD and shall be aligned with the z-axis of the orthogonal three-axis translation stage. The aspect of the virtual image of the DUT shall be adjusted to the x- and y-axes of the orthogonal three-axis translation stage.

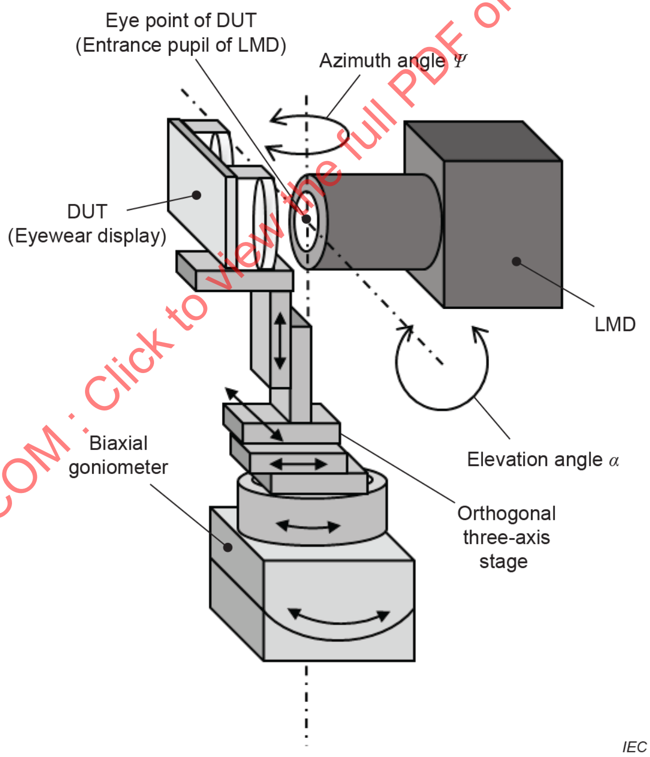
To measure the conditions viewed from the front side, when the DUT does not suppose a change of gaze angle (eye rotation), the origin of a biaxial goniometer shall be assumed as the entrance pupil of the eye (eye point), not the rotation centre of the eyeball (eye movement). When the origin of the biaxial goniometer does not match the eye point of the DUT, the coordinate correction shall be required and shall be reported. When the DUT supposes a change of the gaze angle, the detailed information such as the position of the rotation centre shall be specified by the manufacturer or the supplier and shall be reported.

NOTE 1 The cornea position is about 3 mm in front of the iris position. Some optical designs are used based on the cornea position.

NOTE 2 The rotation centre of the eyeball is located about 10 mm behind the iris.



a) LMD mounted on a biaxial goniometer and orthogonal three-axis translation stage



b) DUT mounted on a biaxial goniometer and an orthogonal three-axis translation stage

NOTE 1 When the LMD is installed on the biaxial goniometer, the elevation stage is set on the azimuth stage.

NOTE 2 Some eyewear displays change their virtual image depending on their orientation.

Figure 4 – Examples of measurement setup

5.3 Test patterns

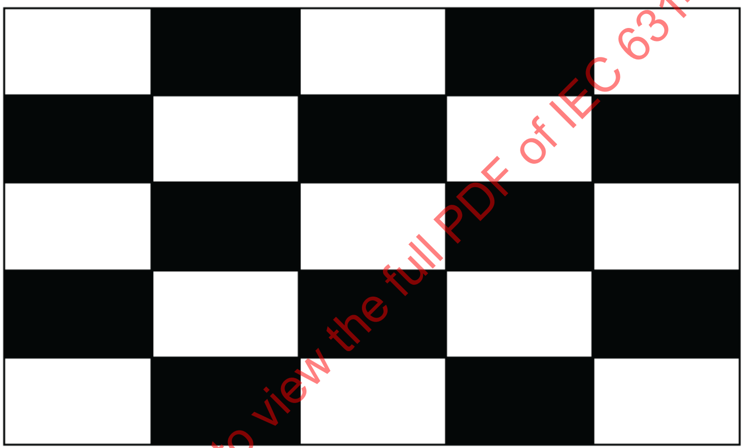
5.3.1 General

The following test patterns shall be specified by the manufacturer or the supplier, and the applied test pattern shall be noted in the report. When other test patterns are applied, they shall be noted in the report.

NOTE Unlike a conventional display, the boundary of the display area is not clear, and the choice of test pattern might affect the measurement results.

5.3.2 Checkerboard pattern

The checkerboard pattern as shown in Figure 5 should be used to measure the applicable properties, and can be used for alignment of the DUT and LMD optics. The checkerboard pattern with crosses whose example is specified in ISO 9241-305 [2], should also be used for alignment of the DUT and LMD optics. Both patterns of white and black at the centre can be used. Usually, a white and black checkerboard pattern is used, but a checkerboard pattern of another colour (red, green, blue and so on) and black can be used if necessary.



NOTE The 5 x 5 checkerboard pattern is helpful in navigating across the virtual image and focusing the LMD.

Figure 5 – Example of 5 x 5 checkerboard pattern

5.3.3 Solid colour patterns

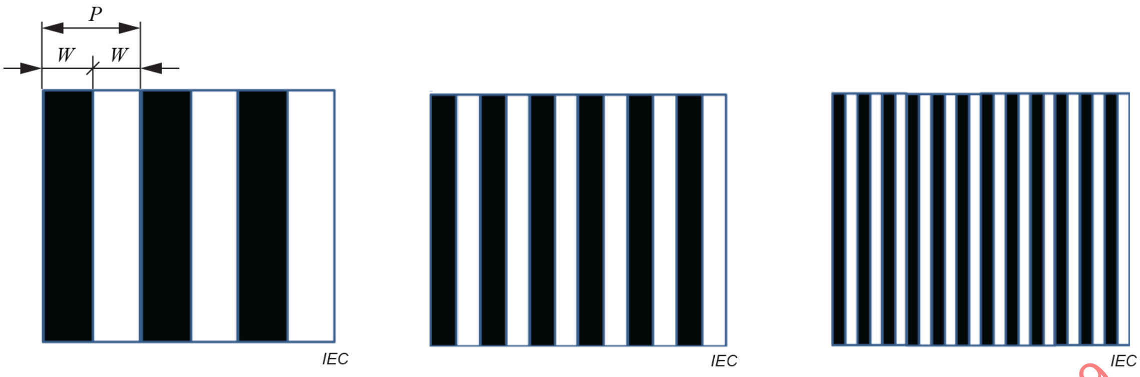
The solid colour patterns can be used to measure the optical qualities. The colours should be defined in terms of the display primaries as white, black, red, green and blue. The pattern (full screen) is filled with a single colour.

5.3.4 Test patterns for Michelson contrast

As shown in Figure 6, black and white line-pair patterns with the same vertical or horizontal width but with different periodicities should be used to measure the Michelson contrast of eyewear displays. The inverse of the pitch of the line-pairs is the spatial frequency (f_{CPD} = $1/P$). The CPD is the line-pair cycles per degree, which is the view through the DUT. The spatial frequency should be specified by the manufacturer or the supplier. The highest resolution should be started with the one-by-one line-pair.

NOTE 1 The spatial frequency can be calculated from the pitch of the line-pair.

NOTE 2 The resolution range required depends on applications, and some applications do not need the one-by-one resolution.



a) **Low resolution** b) **Middle resolution** c) **High resolution**

P: Pitch of the line-pair

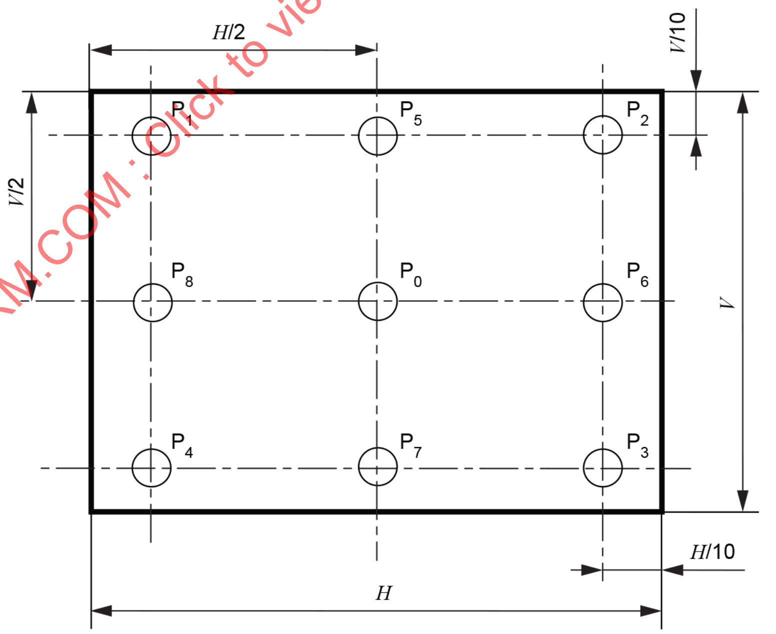
W: Line width

Figure 6 – Example of Michelson contrast test pattern

5.4 Measurement points

The centre-point (one point) or the multi-point (five points or nine points) measurements shall be applied, which are provided by the manufacturer or the supplier. The measuring point(s) of one-point, five-point and nine-point measurements are: P_0, P_0 to P_4, and P_0 to P_8, respectively, as shown in Figure 7. When using other measuring points, the manufacturer or the supplier should point out these positions. The applied measuring points are defined in each measuring item. If other measuring points are applied, this shall be defined in the relevant specification.

NOTE The centre-point measurement is carried out to measure the typical characteristics of the DUT. The five-point and nine-point measurements are carried out to measure the deviations, averages and uniformities.



H: Horizontal size of virtual image
V: Vertical size of virtual image

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Figure 7 – Measuring points for the centre- and multi-point measurement

6 Measurement methods for image quality

6.1 General

In order to evaluate the image quality of eyewear displays, the distortion, colour registration error, Michelson contrast and focal distance (dioptre) shall be measured. The distortion represents the geometric deformation of the virtual image. The colour registration error represents the chromatic displacement between the primary colours. The Michelson contrast represents the resolution of the virtual image. The dioptre is equal to the reciprocal of the focal distance.

NOTE The term “monocular virtual image distance” is sometimes used as “focal distance”.

6.2 Preparation

The eyewear display to be measured (DUT) should be placed in the measurement arrangement specified in 5.2.3 using the checkerboard pattern specified in 5.3.2. The eye point of the DUT shall be specified by the manufacturer or supplier (see IEC 63145-20-10:–, Annex A). The eye point and the entrance pupil of the LMD shall match the origin position (x = 0, y = 0, z = 0, α = 0, Ψ = 0).

The DUT-adjustable conditions which are related to the optical properties shall be specified by the manufacturer or supplier, and reported. Some DUTs use image processing, and if a setting for the image processing is also adjustable, the default setting specified by the manufacturer or the supplier shall be applied and reported.

The focus of the LMD should be adjusted through the finder to become the clear virtual image. A raster pattern with a high resolution which can be displayed by the DUT and which is provided by the manufacturer or the supplier can be applied for the adjustment of the virtual image focus.

The optical quantities of the LMD, such as luminance and spectral radiance, shall be calibrated against the regular standards under the same conditions (for example aperture size, measurement field angle and focus position in some structures).

The devices reach the steady state specified in 4.3. The optical quantities shall be measured at the steady state using the methods specified in IEC 63145-20-10.

NOTE Some eyewear displays have eye-tracking capabilities for optimizing the image. The direction of the gaze of the LMD might be different from the direction of the gaze as detected by the DUT for a true eye.

6.3 Distortion

6.3.1 General

The standard measurement conditions shall be applied. The full screen distortion shall be calculated under the measurement results of the FOV using the white solid (full screen) pattern. For the positional distortion, the rectangular test pattern with the black background shall be specified by the manufacturer or the supplier. When the FOV is not rectangular, the other distortion methods which are specified by manufacturer or supplier shall be applied. The distortion shall be evaluated by comparing the measured FOV or the measured rectangle with the ideal FOV or the ideal rectangle.

NOTE 1 For example, the white solid rectangular test pattern is 50 % of the width and height of the full screen.

The angle from the centre to the edge shall be measured to determine the FOV or the rectangle using the luminance measuring methods described in 6.3.2. The eight angles (two horizontal edges, two vertical edges and four corners) shall be measured. If the display is the binocular type, both oculars shall be measured.

NOTE 2 The luminance measurement is generally based on the prerequisite that in the measurement field the light emission is uniform. However, in this procedure, around the edge or corner the light emission is not uniform, and some spot luminance meters do not support this measurement.

NOTE 3 Sometimes, only the position of the edge or corner of the virtual image is measured by a camera, but in such a case the quantitative threshold of the FOV is ambiguous. See IEC TR 63145-1-1:2018, 6.4 [1].

When the 2D imaging LMD with the biaxial goniometer is used, the luminance values and the angles of each edge and corner should be calculated under the 2D data.

NOTE 4 Using a 2D imaging LMD, the distance between the centre and edge (corner) can convert to the angle. If the measurement field of the 2D imaging LMD is large, the goniometer movement can be reduced.

6.3.2 Procedure

6.3.2.1 Full screen distortion

The angle from the centre to the edge shall be measured to determine the FOV as follows. The white solid (full screen) test pattern shall be displayed on the virtual image.

a) Move the direction of the LMD to the point P_1 using the biaxial goniometer.

b) Measure the luminance at P_1 (L_{v1}) according to IEC 63145-20-10.

c) Move the direction of the LMD from point P_1 toward the nearest corner of the virtual image using the biaxial goniometer and checking the measuring area through the finder of the LMD, until the measured luminance becomes 1/4 L_{v1}.

d) Record the coordinate angles at 1/4 L_{v1} for the corner.

e) Repeat the steps from a) for the other remaining corners (P_2 to P_4).

f) Move the direction of the LMD to point P_5 using the biaxial goniometer.

g) Measure the luminance at P_5 (L_{v5}) according to IEC 63145-20-10.

h) Move the direction of the LMD from point P_5 toward the edge of the virtual image using the biaxial goniometer and checking the measuring area through the finder of the LMD, until the measured luminance becomes 1/2 L_{v5}.

i) Record the coordinate angles at 1/2 L_{v5} for the edge.

j) Repeat the steps from f) for the other remaining edges (P_6 to P_8).

k) Repeat for the other ocular, if applicable.

6.3.2.2 Positional distortion

The angle from the centre to the edge shall be measured to determine the rectangle as follows. The white solid rectangular test pattern which is specified by the manufacturer or the supplier shall be displayed on the virtual image. The criteria limits of the corner and the edge shall be specified by the manufacturer or the supplier.

NOTE For example, the corner criteria limit is 1/4 L_{v0}, and the edge is 1/2 L_{v0}.

a) Move the direction of the LMD to the point P_0 using the biaxial goniometer.

b) Measure the luminance at P_0 (L_{v0}) according to IEC 63145-20-10.

c) Move the direction of the LMD from the point P_0 toward the top left corner of the virtual image using the biaxial goniometer and checking the measuring area through the finder of the LMD, until the measured luminance becomes the criteria limit of the corner.

d) Record the coordinate angles at the criteria limit luminance for the corner.

e) Repeat the steps from c) for the other remaining three corners.

f) Move the direction of the LMD to point P_0 using the biaxial goniometer.

g) Measure the luminance at P_0 (L_{v0}) according to IEC 63145-20-10.

h) Move the direction of the LMD from point P_0 toward the left edge of the virtual image using the biaxial goniometer and checking the measuring area through the finder of the LMD, until the measured luminance becomes the criteria limit of the edge.

i) Record the coordinate angles at the criteria limit luminance for the edge.

j) Repeat the steps from h) for the other remaining three edges.

k) Repeat for the other ocular, if applicable.

6.3.3 Calculation

The distortion shall be calculated as follows.

a) Calculate the ideal angles of the FOV or the rectangle using the following formulae. The angular values for the four corner locations, assuming that the image centre is at the origin and the width and height of the image correspond to the measured average values, are:

$$\psi_{a,L} = \frac{\psi_{TL} + 2 \cdot \psi_{L} + \psi_{BL}}{4} \tag{1}$$

where

$\Psi_{a,\,L}$ is the ideal left azimuth angle of the horizontal FOV or rectangle;

Ψ_{TL} is the azimuth angle of the top left corner;

Ψ_{L} is the azimuth angle of the left edge;

Ψ_{BL} is the azimuth angle of the bottom left corner.

$$\psi_{a,R} = \frac{\psi_{TR} + 2 \cdot \psi_{R} + \psi_{BR}}{4} \tag{2}$$

where

$\Psi_{a,\,R}$ is the ideal right azimuth angle of the horizontal FOV or rectangle;

Ψ_{TR} is the azimuth angle of the top right corner;

Ψ_{R} is the azimuth angle of the right edge;

Ψ_{BR} is the azimuth angle of the bottom right corner.

$$\alpha_{a,T} = \frac{\alpha_{TL} + 2 \cdot \alpha_{T} + \alpha_{TR}}{4} \tag{3}$$

where

$\alpha_{a,\,T}$ is the ideal top elevation angle of the vertical FOV or rectangle;

α_{TL} is the elevation angle of the top left corner;

α_{T} is the elevation angle of the top edge;

α_{TR} is the azimuth angle of the top right corner.

$$\alpha_{a,B} = \frac{\alpha_{BL} + 2 \cdot \alpha_{B} + \alpha_{BR}}{4} \tag{4}$$

where

$\alpha_{a,\,B}$ is the ideal bottom elevation angle of the vertical FOV or rectangle;

α_{BL} is the elevation angle of the bottom left corner;

α_{B} is the elevation angle of the bottom edge;

α_{BR} is the azimuth angle of the bottom right corner.

b) Calculate the semi-diagonal angle (A_{vh}) of each corner using Formula (5). The ideal semi-diagonal angles shall be calculated using the ideal angles as indicated in Formulae (1) to (4). The measured semi-diagonal angles shall be calculated using the measured corner angles.

$$A_{vh} = \tan^{-1}\left(\sqrt{\tan^2 \alpha_v + \tan^2 \psi_h}\right) \quad (5)$$

where

A_{vh} is the semi-diagonal angle of the corner;

α_v is the elevation angle of the corner;

Ψ_h is the azimuth angle of the corner.

c) Calculate the distortions as percentages: the ratio between the measured (derotated) and ideal semi-diagonal angles at the four corner locations is:

$$\delta_{vh} = \frac{A_{m,vh} - A_{i,vh}}{A_{i,vh}} \times 100 \quad (6)$$

where

δ_{vh} is the distortion of each corner (%);

$A_{m,vh}$ is the measured semi-diagonal angle of each corner;

$A_{i,vh}$ is the ideal semi-diagonal angle of each corner.

6.3.4 Report

The following items shall be reported:

- distortions at the four corners as percentage;
- type of distortion: “full screen” and/or “positional”;
- ideal semi-diagonal angle of the four corners $A_{i,TL}$, $A_{i,TR}$, $A_{i,BL}$ and $A_{i,BR}$;
- measured semi-diagonal angle of the four corners $A_{m,TL}$, $A_{m,TR}$, $A_{m,BL}$ and $A_{m,BR}$;
- four corners direction (Ψ_{TL}, α_{TL}), (Ψ_{BR}, α_{BR}), (Ψ_{TR}, α_{TR}) and (Ψ_{BL}, α_{BL});
- four edges direction (Ψ_L, α_L), (Ψ_R, α_R), (Ψ_T, α_T) and (Ψ_B, α_B);
- type of test pattern;
- criteria limits of luminance (if necessary);
- eye point, eye relief and position of z-axis;
- type of LMD and aperture size;
- accuracy of sample stage;
- correction methods for angle (optional).

6.4 Colour registration error

6.4.1 General

The colour registration error shall be evaluated by comparing the coloured FOV.

6.4.2 Procedure

The procedure shall be the same as that for the distortion measurement specified in 6.3.2. However, the red, green and blue solid colour patterns shall be used instead of white. Record the spherical coordinate angles of the corners and edges for the red, green and blue solid colour patterns, respectively. Other additional positions, such as the middle points between the centre point and corner points, should be measured, if necessary. When the other positions are measured, the colour edge angles should be measured using the coloured 5 x 5 checkerboard patterns.

NOTE Generally, the boundary of the display area is sufficient to measure the colour registration error, but sometimes the area around the centre of the display area has a larger error. In such a case, other additional positions can be applied.

6.4.3 Calculation

The colour registration error shall be calculated as follows.

a) Calculate the semi-diagonal angle (A_{vh}) of each colour corner using Formula (5).

b) Calculate the colour registration error of red and blue as angles: the ratio between the angles of the corner (edge) for the red (blue) colour test pattern and the angles of the corner (edge) for the green test pattern is:

$$\varepsilon_{vh,colour} = A_{vh,colour} - A_{vh,green} \tag{7}$$

where

$\varepsilon_{vh,\ colour}$ is the colour registration error of the corner (edge) for a primary colour (red or blue);

$A_{vh,colour}$ is the measured angle of the corner (edge) for the red or blue test pattern;

$A_{vh,\ green}$ is the measured angle of the corner (edge) for the green test pattern.

6.4.4 Report

The following items shall be reported:

- colour registration errors of the corners and edges (horizontal and vertical) for each colour;
- measured four corners direction (Ψ_{TL}, α_{TL}), (Ψ_{BR}, α_{BR}), (Ψ_{TR}, α_{TR}) and (Ψ_{BL}, α_{BL}) for each colour test pattern;
- measured four edges direction (Ψ_L, α_L), (Ψ_R, α_R), (Ψ_T, α_T) and (Ψ_B, α_B) for each colour test pattern;
- if necessary, the colour registration errors of the other positions for each colour;
- if necessary, the measured spherical coordinates of the other positions for each colour patterns and the specifications of the used test patterns;
- eye point, eye relief and position of z-axis;
- type of LMD and aperture size;
- accuracy of sample stage;
- correction methods for the angle (optional).

6.5 Michelson contrast

6.5.1 General

The standard measuring conditions shall be applied. The Michelson contrast test pattern shall be used, and at least three different pitches of line-pairs, which are specified by the manufacturer or the supplier, should be applied. The 2D imaging LMD shall be applied.

6.5.2 Procedure

The Michelson contrast of the nine points on the virtual image described in 5.4 shall be measured as follows. If necessary, more than nine measurement points should be specified by the manufacturer or the supplier.

a) Position the DUT according to 6.2.

b) Adjust the LMD to the specified distance and viewing direction, according to angles α and ψ.

c) Apply the Michelson vertical contrast test pattern.

d) Adjust the focus of the LMD.

e) Measure the DUT at point P_0 (centre) to obtain the image, the maximum luminance $L_{vM,0}$ and the minimum luminance $L_{vm,0}$ in the image.

f) Repeat from d) to maximize the difference between the maximum and minimum luminance.

g) Repeat from c) for other Michelson contrast test patterns.

h) Repeat from b) for the remaining points.

i) Repeat from b) using the horizontal test patterns instead of the vertical test patterns.

j) Repeat for the other ocular, if applicable.

NOTE 1 As described in ISO 9241-305:2008, 6.11.1[2], "Measuring focal distance", it is not easy to adjust the focus of the 2D imaging LMD, because if the 2D imaging LMD has a narrow aperture, it has a large depth of focus. Therefore, the focus range is obtained by using the Michelson contrast measurement.

NOTE 2 Since the line of the virtual image consists of multi-colour lines, the luminance value can be obtained from the zonal average of the measured luminance.

6.5.3 Calculation

Calculate the Michelson contrast using Formula (8).

$$C_{m,i} = \frac{L_{vM,i} - L_{vm,i}}{L_{vM,i} + L_{vm,i}} \tag{8}$$

where

$C_{m,i}$ is the Michelson contrast at P_i;

$L_{vM,i}$ is the maximum luminance in the image at P_i;

$L_{vm,i}$ is the minimum luminance in the image at P_i.

6.5.4 Report

The following items shall be reported:

- Michelson contrast of each test pattern on the nine points;
- spatial frequency of the test patterns (f_{CPD}) at each measuring point;
- eye point, eye relief and position of z-axis;
- type of LMD and aperture size;
- accuracy of sample stage;
- correction methods for angle (optional).

6.6 Focal distance (dioptre)

6.6.1 General

The standard measuring conditions shall be applied. The focal distance (dioptre) of the centre on the virtual image shall be measured using the following methods. The focal method can be applied for all kinds of DUTs. The parallax method can be used as specified by the manufacturer or the supplier. The parallax method shall not be applied to the DUT whose virtual image focus is designed at infinity.

6.6.2 Procedure

6.6.2.1 Focal method

The focal method shall be applied as follows. The Michelson contrast test pattern specified by the manufacturer or the supplier shall be used. A 2D imaging LMD shall be applied, and it should have a function for measuring the distance from the 2D imaging LMD to the virtual image. If the function is not equipped, the procedure for acquiring the measuring distance shall be executed.

a) Position the DUT according to 6.2.

b) Adjust the 2D imaging LMD to the specified distance and viewing direction, according to angles α and ψ.

c) Apply the Michelson contrast test pattern.

d) Adjust the focus of the 2D imaging LMD.

e) Measure the DUT at the P_0 point (centre) to obtain the image, the maximum luminance $L_{vM,0}$ and the minimum luminance $L_{vm,0}$ in the image.

f) Calculate the Michelson contrast according to 6.5.3.

g) Change the focus of the 2D imaging LMD, repeating e) and f), and record the focus range where the Michelson contrast keeps the same maximum value.

h) Repeat for the other ocular, if applicable.

NOTE As described in ISO 9241-305:2008, 6.11.1[2], "Measuring focal distance", it is not easy to adjust the focus of the 2D imaging LMD, because if the 2D imaging LMD has a narrow aperture, it has a large depth of focus. Therefore, the focus range is obtained by using the Michelson contrast measurement.

If the 2D imaging LMD does not have the function of measuring the distance, the following procedure shall be applied.

i) Prepare the normal display (i.e., an LCD monitor) on the stage (the resolution target can also be a paper resolution chart) and apply the Michelson contrast test pattern.

j) After f), without changing the focus, the 2D imaging LMD is set to measure the normal display.

k) Change the distance between the 2D imaging LMD and the normal display to find the distance where the Michelson contrast value becomes the highest value as follows. Note that the focus of the LMD is not changed.

l) Measure $L_{vM,0}$ and $L_{vm,0}$.

m) Calculate the Michelson contrast according to 6.5.3.

n) Change the distance and repeat l), then find the distance where the Michelson contrast is highest. Record the distance, which is the measuring focal distance that the focus of the 2D imaging LMD is in f).

6.6.2.2 Parallax method

The parallax method shall be applied as follows. A 2D imaging LMD shall be applied. The test pattern, the translation amount (Δx) and the translation direction shall be specified by the manufacturer or the supplier. The translation amount should be within the eye-box of the DUT.

a) Position the DUT according to 6.2; the optical axis of the 2D imaging LMD is centred at the DUT virtual image.

b) Move the 2D imaging LMD in the pupil by a small amount (Δx) using the translation stage.

c) Measure the angle θ to rotate the 2D imaging LMD using the goniometer, such that its optical axis is re-centred on the DUT virtual image.

d) Calculate the focal distance using the following formula.

$$\gamma_0 = \frac{\Delta x}{\tan\theta} \quad (9)$$

NOTE If the translation amount is smaller, the resolution of the goniometer is finer.

6.6.3 Calculation

The dioptre and its range are calculated as the reciprocal of the obtained focus range.

$$D_0 = \frac{1}{\gamma_0} \quad (10)$$

where

D_0 is the dioptre at P_0 (centre);

γ_0 is the focal distance (in metre) at P_0 (centre).

NOTE The sign (±) of the dioptre depends on the focus direction in the z-axis. The absolute value of the dioptre is usually used.

6.6.4 Report

The following items shall be reported:

- focal distance (with range);
- dioptre (with range);
- type of procedure (focal method or parallax method);
- Michelson contrast (for focal method);
- spatial frequency of the test patterns (f_{CPD}) (for focal method);
- test pattern (for parallax method);
- translation amount (Δx) (for parallax method);
- eye point, eye relief and position of z-axis;
- type of LMD and aperture size;
- accuracy of sample stage;
- correction methods for angle (optional).

6.7 FOV based on Michelson contrast

6.7.1 General

The standard measuring conditions shall be applied. The Michelson contrast test pattern shall be applied. The spatial frequency (line-pairs) of the test patterns and the criteria limit values of the Michelson contrast shall be specified by the manufacturer or the supplier. The 2D imaging LMD shall be applied. The spherical coordinates shall be applied.

6.7.2 Procedure

The angles from the centre to the edges and corners of the whole virtual image produced by the test pattern shall be measured to determine the FOV in the following manner.

a) Position the DUT according to 6.2.

b) Move the direction of the 2D imaging LMD to the point P_1 using the biaxial goniometer.

c) Display the specified test pattern on the DUT.

d) Measure the image and calculate the Michelson contrast according to 6.5.3.