Technical Report

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Ophthalmic optics — Spectacle lenses — Aspects of three-dimensional properties and reference markings

Optique ophtalmique — Verres de lunettes — Aspects des propriétés tridimensionnelles et marquages de référence

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This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 7, *Ophthalmic optics and instruments*.

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Introduction

In current standards, spectacle lenses are mostly treated as two-dimensional objects.

However, knowing their three-dimensional geometrical properties is helpful to fully understand their optical effects. Therefore, these are already taken into account in the industry in some instances, e.g. to increase the performance of products and the accuracy of measurements.

The aim of this document is to deliver background information on this topic, to provide helpful terminology including parameters, and to present some ways of dealing with their impacts. It is intended as a source of information to the manufacturers of spectacle lenses, measurement systems, and mounting equipment as well as to the optometric and dispensing professions.

Ophthalmic optics — Spectacle lenses — Aspects of three-dimensional properties and reference markings

1 Scope

This document is applicable to the three-dimensional aspects of spectacle lenses and their mounting in frames. It gives possible details of how these aspects can be taken into account, particularly for lenses with their permanent reference engravings (markings) on their back surface.

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 13666, *Ophthalmic optics — Spectacle lenses — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13666 apply.

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

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

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

4 Technical background

4.1 General

Changes in the method of manufacture of spectacle lenses and in the styling of some spectacle frames have generated problems of positioning lenses correctly in the frame that did not occur in the 20th century. Conversely, free form manufacture allows the benefits of individualized computer enhancement and more sophisticated lens designs but requires an improved, and available, ability to position lenses.

Many aspects related to the use of free form technology are explained in ISO/TR 18476[1], which also covers optical effects relevant to the topics discussed in this document.

4.2 Spectacle lenses

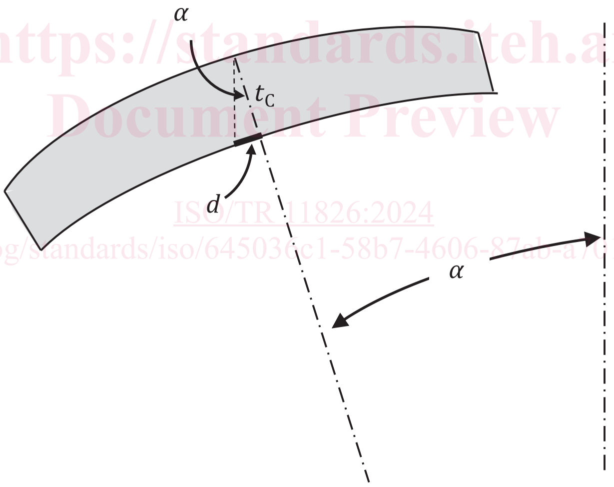
The reference points and design reference points are specified in ISO 13666 to be on the front surface of the lens. This is logical, in that the marking device on focimeters dots the front surface of the lens, in particular the optical centre for single-vision lenses. This dot is used for positioning the uncut lens correctly for edging it to shape for mounting in the frame. Although errors in prism imbalance (relative prism error) are generated if lenses are not correctly centred in the frame in front of the eyes, there is no or little effect on the binocular field of view for single-vision lenses or for the far and near fields of view with multifocal lenses. Position-specific single-vision lenses and power-variation lenses have, however, to be positioned so that their optical properties including, where applicable, the (intermediate) corridor and near portion are aligned with the eyes. The conventional construction of progressive-power and degressive-power lenses was to use a blank with the power-variation surface moulded (or sagged for glass blanks) on the front surface of the blank, then surfacing the prescription onto the back surface. The two permanent alignment reference markings were positioned on the complicated surface, and thus automatically on the front, and were used to generate the reference point for mounting the lenses.

The ability to combine the prescription and complicated surface of power-variation lenses on the back surface and generate this using free form technology – see ISO/TR 18476[1] – means that the permanent alignment reference markings are now usually positioned on the back surface of the lens. These markings are, however, viewed through the front surface when positioning the uncut lens for mounting in the frame. Prism incorporated in the lens, whether prism thinning or prism required by the lens order, displaces the apparent position of these markings and hence the midpoint between them, while the convex front surface will magnify their separation. Position-specific single-vision lenses also have complicated back surfaces generated with free form technology, and are likely therefore also to be marked on the back surface.

In many respects, it is more logical to have the reference points on the back surface of the lens, since it is rays leaving the back surface that enter the eye, but this change requires an enormous change to the methods of working in the lens mounting industry, including non-permanent lens inking and edging block positioning presently on the front. Moreover, nose pads and spectacle sides are likely to be in the way when measuring the positioning of mounted lenses. Changing to using the back surface for reference points for lenses is therefore a “non-starter”.

4.3 Spectacle frames

Until the early 2000's, spectacle frames had fronts which were relatively flat so that the two lenses lay in the same plane, or nearly so. Since then, a minority of frames have been designed with a significant face form or wrap angle (see ISO 8624[2]). This can have an effect on the decentration needed – the geometrical relationship between various distances is given in the notes to entry for the term “centration point” in ISO 13666.



Key

α as-worn face form angle

d displacement

t_c centre thickness

Figure 1 — Displacement caused by the face form angle and lens thickness

An additional point for lenses in frames with significant face form angle is the thickness of the lens. The front surface can lie in front of the plane of the lens shape or of the dummy/demonstration lens by an amount depending upon the centre thickness of the lens and the position of the peak of the bevel relative to the edge of the lens. This results in a nasal displacement between the centration point on the front surface and the intersection of the normal to the front surface at this point with the back surface. As shown in Figure 1, this displacement, d, can be calculated by Formula (1):

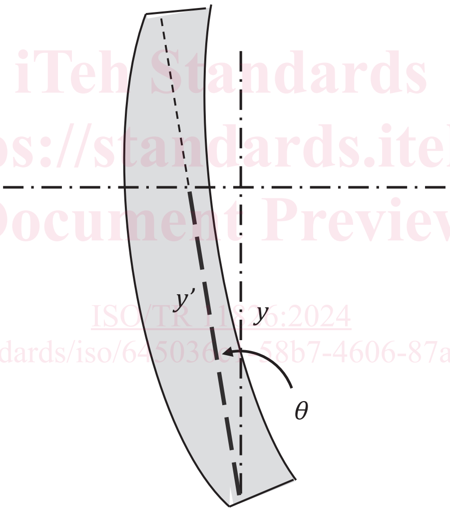
$$d = t_c \tan \alpha \tag{1}$$

e.g. 0,67 mm for a lens 2,5 mm thick or thicker than the dummy lens for a face form angle of 15°.

The as-worn pantoscopic angle can have a similar effect on vertical centration, but at least the errors are in the same direction in both lenses rather than additive with base in or base out for the face form angle. If the vertical component of the centration point position is measured in the plane of the lens shape, no errors are expected to occur, but if it is measured projected onto a vertical plane, e.g. by a digital dispensing system that does not take account of the as-worn pantoscopic angle, then errors could occur. If the height measured in the vertical plane is y and the as-worn pantoscopic angle is θ, then the height y' in the plane of the lens shape as shown in Figure 2 is given by Formula (2):

$$y' = y/\cos \theta \tag{2}$$

Taking an example of an as-worn pantoscopic angle of 10° and a centration point height of 20 mm from the tangent to the bottom rim, the required measurement in the plane of the lens shape is only about 0,31 mm larger than the apparent measurement in the vertical plane, but for a pantoscopic angle of 15°, it is 0,71 mm. At the centre of rotation of the eye, about 27 mm behind the lens, these distances correspond to just over 1,0 Δ and 2,5 Δ respectively. The wearer can compensate for such a small induced prismatic effect by an upwards or downwards gaze movement.



Key

y apparent height measured in a vertical plane

y' height measured in the plane of the lens shape

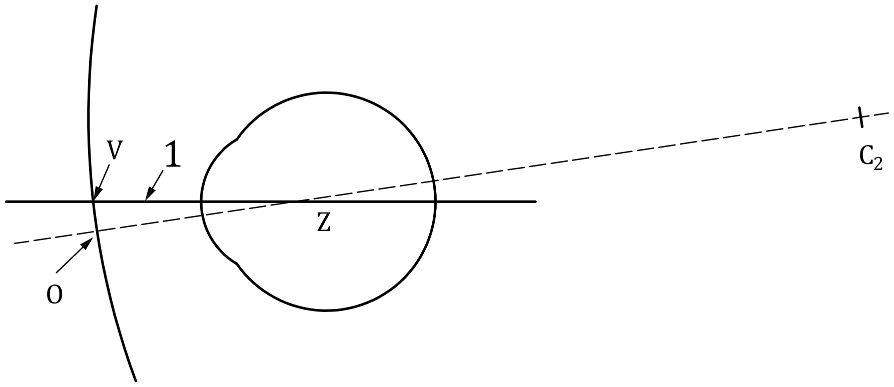
θ as-worn pantoscopic angle

Figure 2 — Potential error in fitting height with the as-worn pantoscopic angle

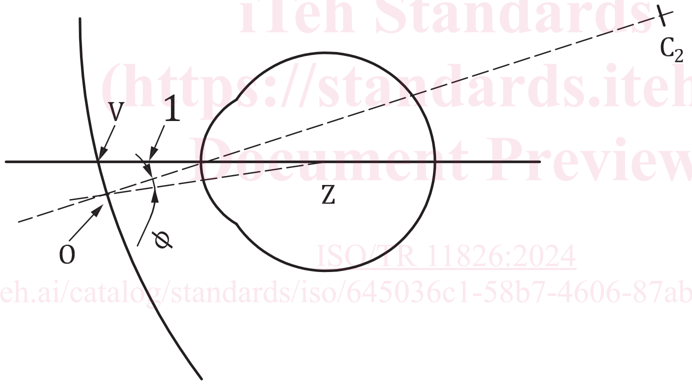
5 Influence of three-dimensional effects and necessity to deal with them

5.1 Optical effects

Optical aberrations in conventional spectacle dispensing can be minimised by decentring the optical centre of the lens horizontally and vertically in the spectacle frame so that the optical axis of the lens passes approximately through the eye's centre of rotation, the "centre of rotation condition". With a relatively flat fronted spectacle frame (see 4.3), matching the centration distance to the wearer's monocular centration values is sufficient to achieve the horizontal requirement. In the vertical direction, the optical centre is usually positioned below the pupil centre position, i.e. the visual point, V, when the wearer's eyes are looking in the primary direction, (Key 1 in Figure 3), i.e. the eyes are in their primary position. This is because, as pointed out by Jalie[3], most frames are designed to have the plane of the spectacle lens (‘plane of the lens shape’) approximately parallel to the plane joining the supra-orbital ridge to the chin, giving an as-worn pantoscopic angle of 5° to 15°. This centre of rotation condition is satisfied if the optical centre is displaced downwards by 1 mm for each positive 2° of as-worn pantoscopic angle - the "dispenser's rule". In most cases, the frame manufacturer's choice of vertical boxed lens size, bridge dimensions (including bridge height) and angle of side (or ‘frame pantoscopic angle’) means that the horizontal centreline of the frame is usually 4 mm to 5 mm below the pupil centre so that very little vertical decentration from the horizontal centre line is often needed. See Figure 3 a), which illustrates the back surface of the spectacle lens and the eye.



a) Conventional dispensing



b) Dispensing of a steeper base curve lens with high as-worn pantoscopic angle

Key

1	primary direction
O	optical centre of the lens
V	visual point in the primary position
Z	centre of rotation of the eye
C_2	centre of rotation of the back surface of the lens
ϕ	angle of obliquity on leaving the lens when viewing in the same direction as in the upper diagram

Note that the centre of rotation rule is satisfied in a) but not in b).

Figure 3 — Conventional and sports-vision dispensing

Satisfying the centre of rotation condition means that when the eye rotates away from the optical axis of the lens, relatively simple spherical surfaces can give good optical performance in the periphery when using one of the various types of “best form” lens, for example, the choice of minimising the oblique astigmatism error[1)] or the mean oblique error[1)]. Figure 5 a) shows that the angles of refraction ϕ_a and ϕ_b at angles of gaze 25° above and below the optical centre are equal.

Frames with deeper lens shapes and probably smaller angles of side to avoid the lower rim resting on the cheeks and, conversely, frames, often for sports-vision, with larger angles of side giving larger as-worn pantoscopic angles and probably with significant face form angles are likely to make it difficult to apply the dispensing rule mentioned above without creating excess lens thickness at the upper or lower rim. Figure 3 b) shows the situation of a steeper-than-normal base curve for the lens combined with a high as-worn pantoscopic angle so that the optical axis of the lens does not pass through the eye's centre of rotation. Even when viewing through the optical centre of the lens, positioned in the same relative place as in the Figure 3 a), the oblique ray path induces oblique astigmatism. An approximate expression for this astigmatism, *A,* is given by Jalie[4] in Formula (3):

$$A \approx F_s \cdot \tan^2 \phi \qquad (3)$$

where:

ϕ is the angle of obliquity, and n is the refractive index;

F_s is the sagittal power of the lens, given by

$$F_s \approx \left(\frac{2n + \sin^2 \phi}{2n} \right) F \qquad (4)$$

and F in Formula (4) is the power of the lens.

This oblique astigmatism compounds with any cylindrical correction required in the lens. The obliquity also produces the very small change in the spherical component of the lens power from F to F_s. For example, for a +5,00 D sphere lens in 1,6 index material tilted through 12°, F_s = +5,068 D and A = 0,23 D.

Provided the lens manufacturer is supplied with the dispensing data (centration point and visual point positions for single-vision lenses and just the centration point position for power-variation lenses vertically and horizontally relative to the frame, vertex distance, as-worn pantoscopic and face form angles), the lens manufacturer can calculate the compensated power of the lens at the optical centre or design reference point that gives the wearer the ordered power when viewing through the lens. To take care of any potential difference between the power experienced by the wearer and the power displayed by a focimeter (see ISO/TR 18476[1] and ISO 13666:2019, 3.10.15, Note 2 to entry, for details) the manufacturer can provide the value of the power (termed “verification power” in ISO 13666) that is expected to be found as the measured power when verifying the lens on a focimeter according to ISO 21987[7], ISO 8980-1[8] and ISO 8980-2[9]. Figure 4 gives an idea of the relationship between the various powers mentioned.

[1)] BS 3521-1[5] defines this as the difference between the tangential and sagittal oblique vertex sphere powers, the latter being subtracted algebraically from the former.