



Technical Report

ISO/TR 11826

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*

**First edition
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Foreword

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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.

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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

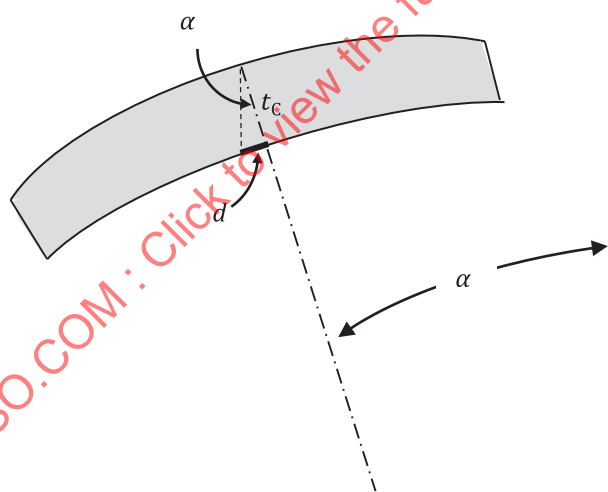
surfacing the prescription onto the back surface. The two permanent alignment reference markings were positioned on the complicated surface, and thus automatically on the front, and were used to generate the reference point for mounting the lenses.

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 \(1\)](#):

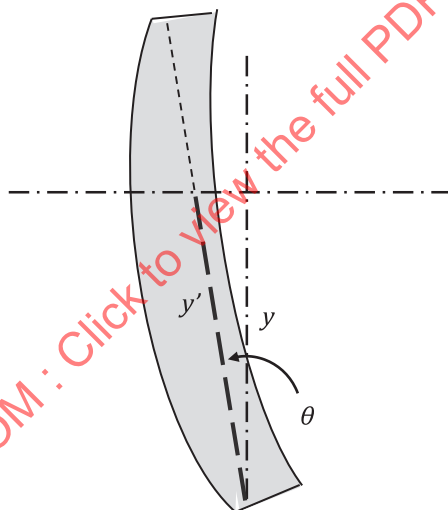
$$d = t_c \tan \alpha \quad (1)$$

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 \(2\)](#):

$$y' = y / \cos \theta \quad (2)$$

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

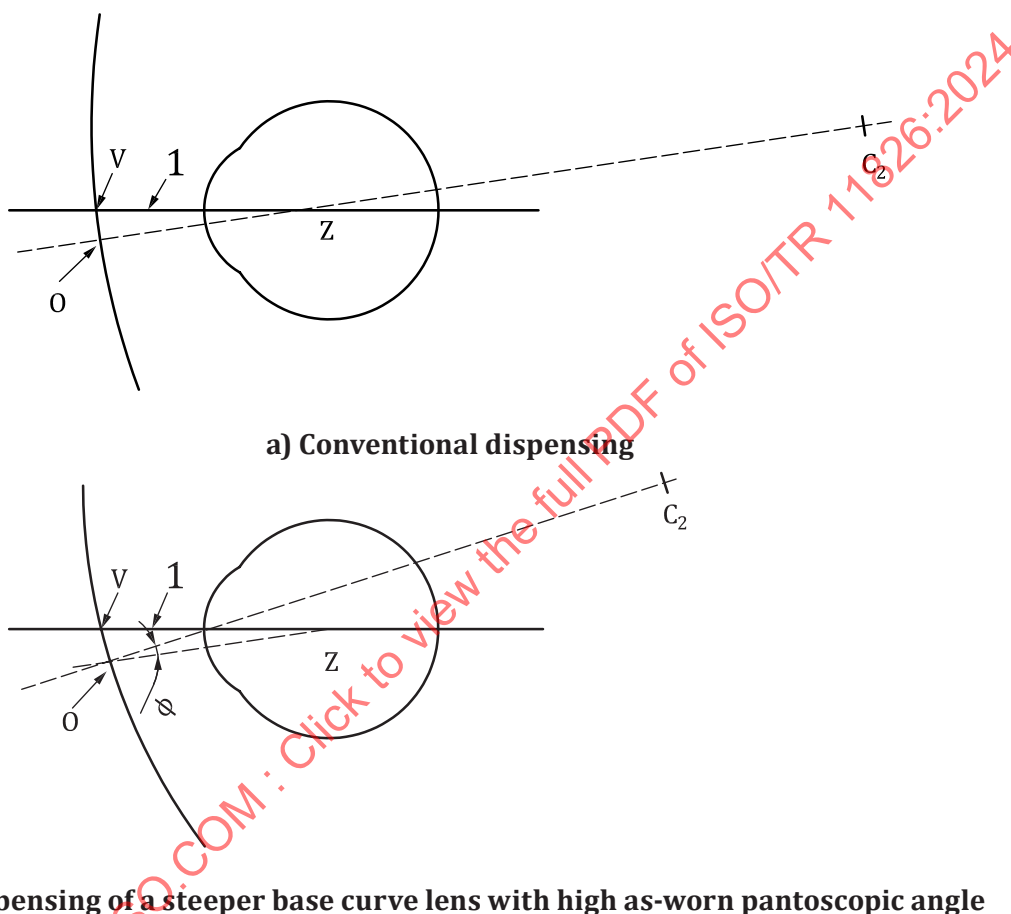
Figure 2 — Potential error in fitting height with the as-worn pantoscopic angle

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.



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

error¹⁾ or the mean oblique error¹⁾. [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 \(3\)](#):

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

where:

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

F_s is the sagittal power of the lens, given by

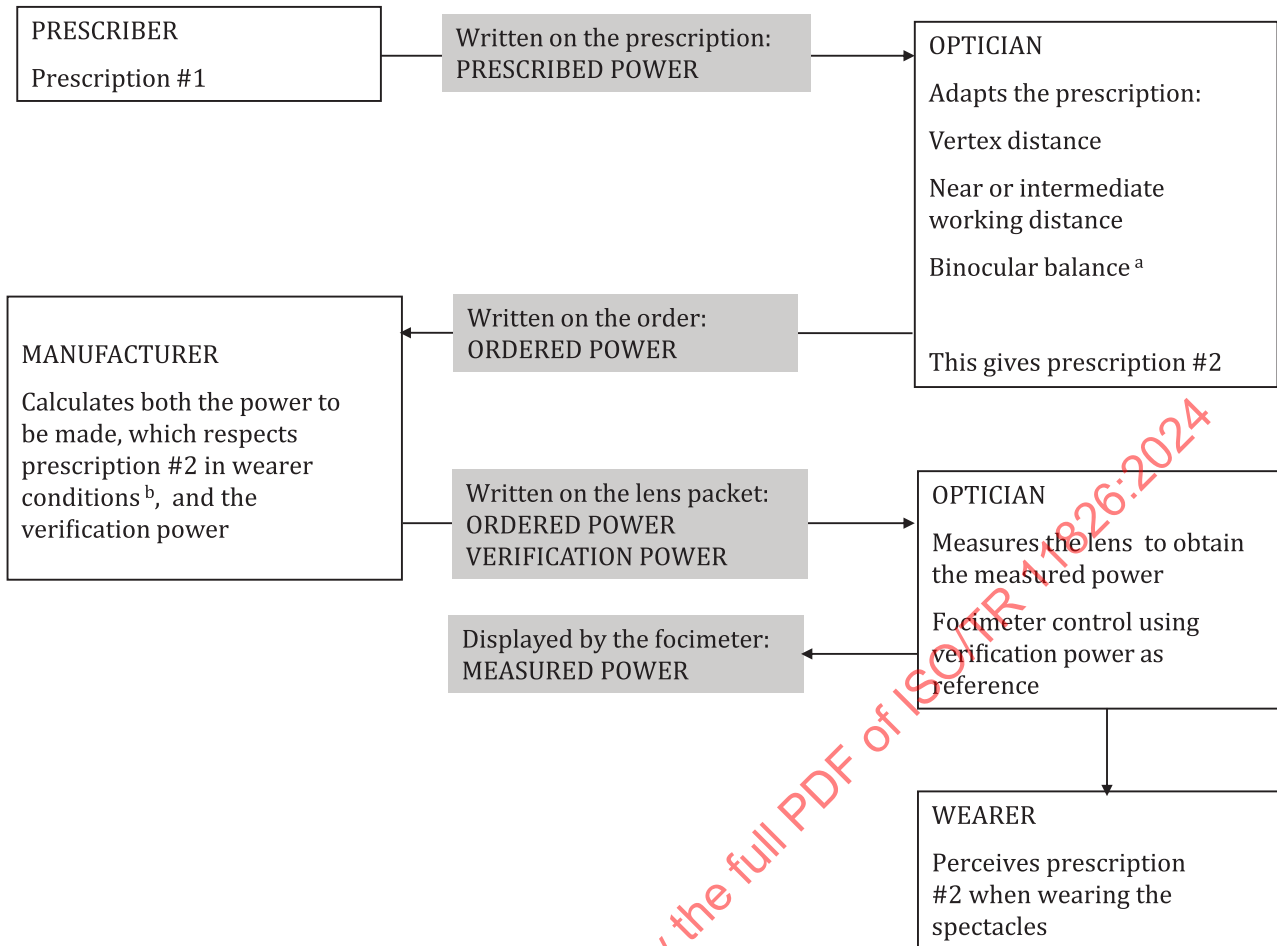
$$F_s \approx \left(\frac{2n + \sin^2 \phi}{2n} \right) F \quad (4)$$

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.



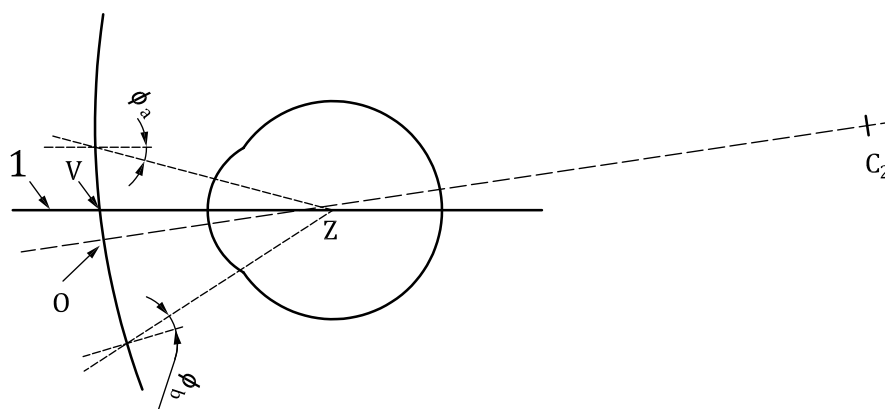
- ^a In some countries, the person dispensing the spectacles is permitted to refine the prescribed power.
- ^b As-worn position and other applicable parameters such as the chosen working distance and physiological factors.

Figure 4 — Relationship between the various powers

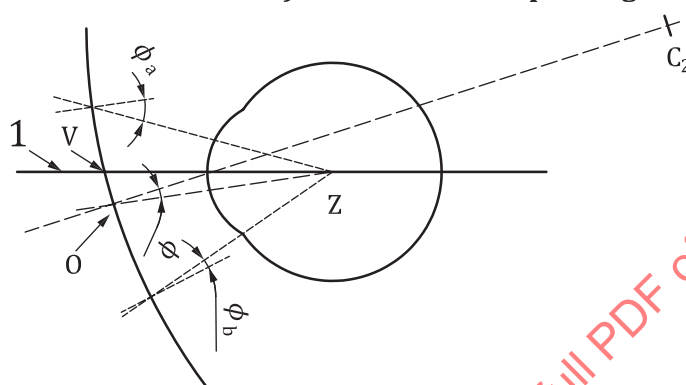
[SOURCE: ISO 13666:2019, Figure 8]

Conversely, in [Figure 5 b](#)), the distance between the eye and back surface of the lens and the angle of refraction of rays leaving the lens varies asymmetrically above compared with below the optical centre. The same effect applies in the horizontal where there is significant face form angle. As pointed out by Jalie^[6], this compensation, if applied to a standard best form single-vision lens, is correct for only the distance design reference point of the lens (in the case of a lens designed for distance vision), not the periphery. Compensation for both the distance design reference point and for the varying angles on incidence in the periphery of the lens can be carried out using modern computing methods and free form lens manufacture. As always with free form technology, the effect of the optimization varies widely with the level of sophistication of the algorithm used²⁾. Since tolerances on lens powers apply only at the reference points, no verification powers or methods for the periphery are specified in the international standards.

2) While a simple toric superimposition does not achieve much more than can be done with conventional tooling, an algorithm providing sophisticated pointwise optimization allows for eliminating power errors due to the as-worn orientation of the lens even in the far periphery. However, there is a growing trade-off between eliminating power errors and generating other unwanted optical effects like image distortion when moving away from the design reference point. This is especially noticeable in binocular assessment of large lenses with high as-worn face form angles. (For a detailed assessment, see Becken et al.^[11]).



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
- ϕ_a, ϕ_b angle of refraction on leaving the lens when viewing 25° above and below O

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

Figure 5 — Conventional and sports-vision dispensing

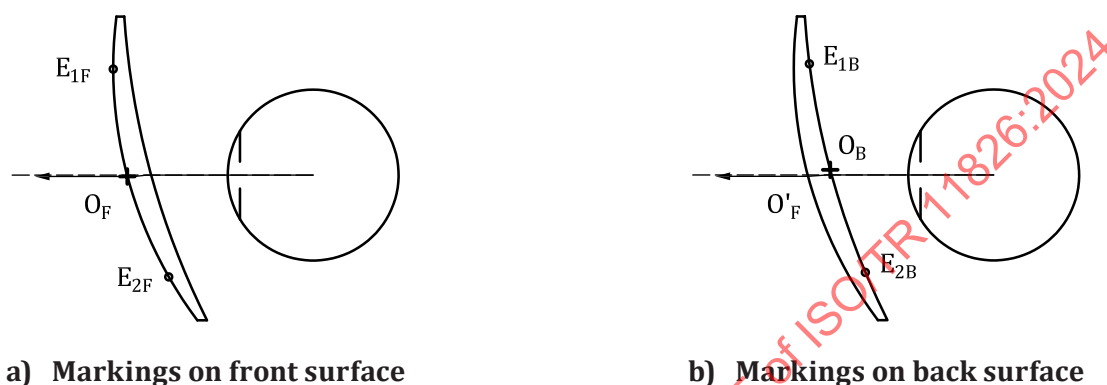
5.2 Reference points on front surface versus back surface meeting the eye in as-worn position

The standards ISO 21987[7], ISO 8980-1[8] and ISO 8980-2[9] stipulate that position-specific single-vision lenses and power-variation lenses such as progressive-power lenses have permanent alignment reference markings comprising two marks located nominally 34 mm apart, equidistant to a vertical plane that passes through the fitting point or prism reference point and contains the normal (perpendicular) to the surface at that point.

When the markings are engraved on the front surface (see Figure 6 a)), the determination of the location of the different reference points can be done with a fair precision as all these points are defined with respect to the front surface according to ISO 13666. The positioning of the lens with respect to the eye's pupil centre in the as-worn condition is done taking into account the prismatic deviation induced by the lens as illustrated with the horizontal ray passing through the pupil centre of eye and deviated by the lens. In Figure 6 a), we

consider that O_F corresponds to the fitting point. When the markings are engraved on the back surface (Figure 6 b)) of the lens, no information is usually provided on how to transfer their position to the front surface's coordinate reference system in order to determine the location of the reference points. This can however influence the fitting of the lens into the frame or the position of the reference points at which the lens is verified.

Indeed, when the markings are engraved on the back surface and one looks at their images produced by the lens's front surface, one can notice that their location changes with the viewing direction. If the lens is, for instance, in a frame with a significant face form angle, the apparent position of the images of the markings on the front surface can be inaccurate with respect to their theoretical position, which then can lead to a shift of all reference points.



Key

E_{1F} and E_{2F}	markings positioned on the front surface (± 17 mm apart from its centre O_F)
O_F	origin of front surface, midpoint between E_{1F} and E_{2F}
E_{1B} and E_{2B}	markings positioned on the back surface (± 17 mm apart from its centre O_B)
O_B	origin of back surface, midpoint between E_{1B} and E_{2B}
O'_F	theoretical centre on the front surface when information is provided on how to pass O_B from the back surface's coordinate system into the front surface's one

Figure 6 — Illustration of markings engraved on the front and the back surface, as viewed from above

This is illustrated in Figure 7 for a +4 D lens with a prism thinning of 2Δ at 270° . The grey dots represent the markings E_{1B} and E_{2B} engraved on the lens's back surface. The black dots are the apparent positions on the front surface of the images of the engravings when viewed with an angle of about 27° from the normal to the front surface at O'_F and with an azimuth of 135° . The black cross represents the midpoint between the black dots projected onto the lens's front surface. Finally, the rectangular boxes show the nominal locations of the markings E_{1F} and E_{2F} if they had been put on the front surface and the white cross shows the nominal centre O'_F on the lens's front surface. As can be observed, the two crosses do not match. The front surface position obtained from the image of the markings does not match the nominal one.

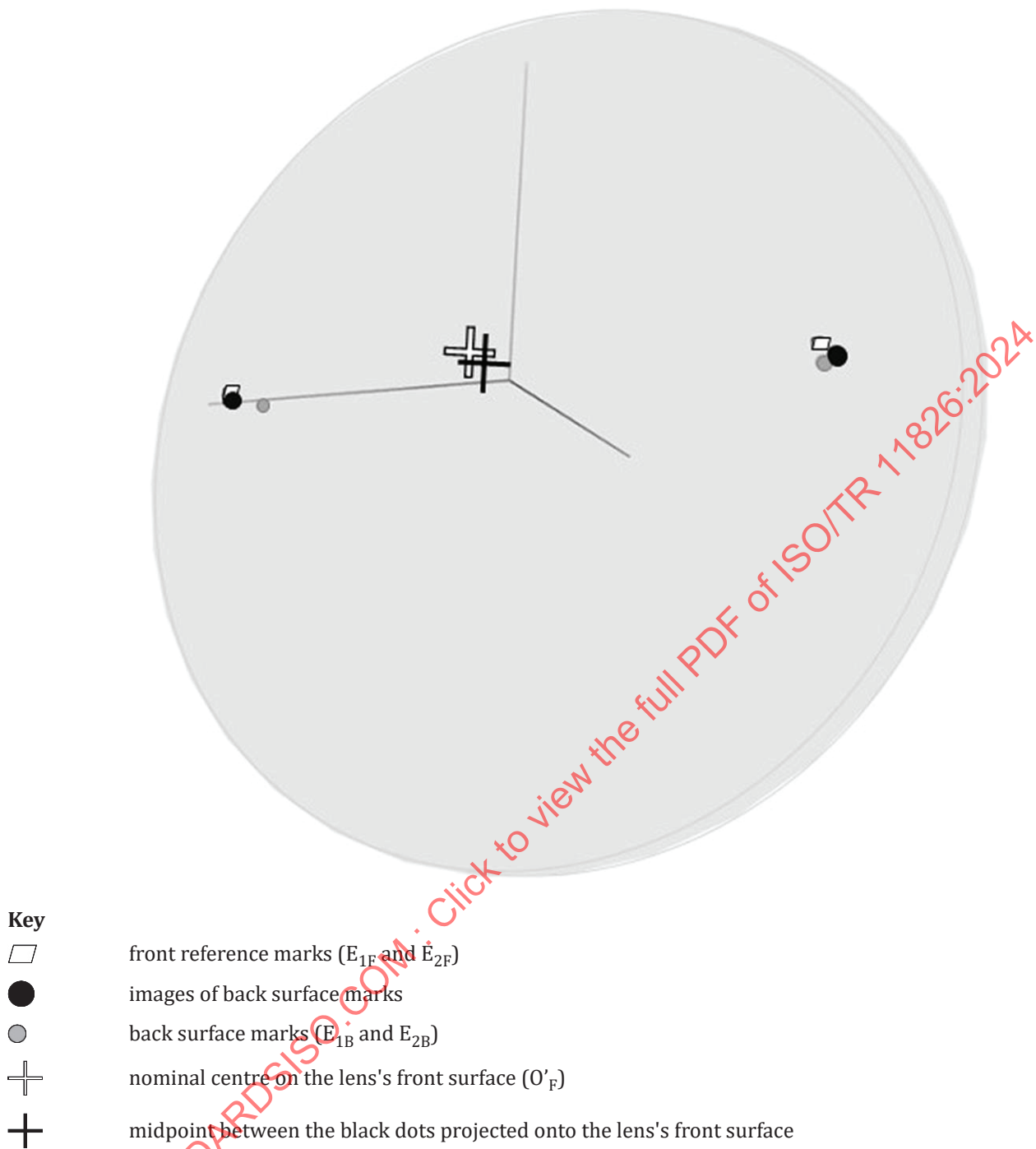


Figure 7 — Apparent displacement of back surface marks when viewed through the lens

Another issue can arise if the lens has semi-permanent (removable) ink markings on its front surface that are not in line or centred with respect to the image of the back surface markings through the lens: is the lens to be fitted with respect to the semi-permanent ink markings or the image of the markings through the lens?

Finally, when calculating a lens in the as-worn conditions (taking into account the as-worn pantoscopic angle, the as-worn face form angle, and the cornea vertex distance), the lens is normally positioned so that the image of the fitting cross (O_F) on the front surface (cross in [Figure 6 a\)](#) is aligned with the centre of the pupil, possibly compensating for the optical deviation induced by the lens. This is illustrated in [Figure 6](#) by the ray that passes through both O_F or O'_F and the pupil centre and that is shifted from the eye's optical axis which is represented by the dashed line. In general, the prismatic deviation induced by the lens in the as-worn condition is small and can be neglected for the fitting. However, if the lens is thick and the face form

angle is significant, it could result in mounting errors if the monocular pupillary distance is strictly applied horizontally to fit the lenses into the frame.

5.3 Positioning errors from the images of markings on the back surface

5.3.1 General

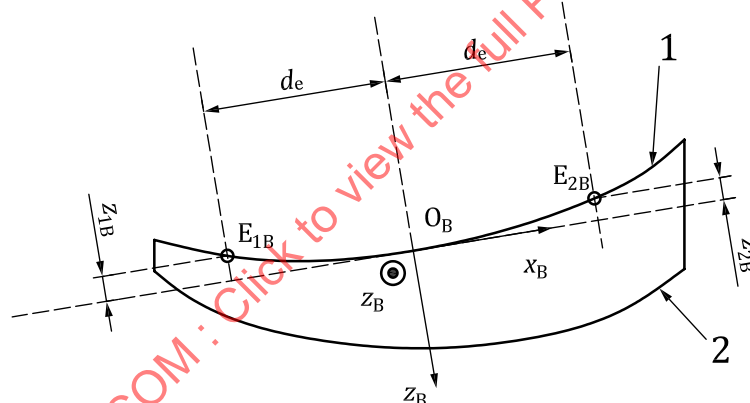
The following study illustrates the influence of the viewing direction and lens deviation effects on establishing the reference point positions on the front surface of a lens when the reference markings are on the back surface, i.e. the errors produced when establishing a front reference coordinate system from markings on the back surface.

This study considers spherical single-vision lenses with markings on their back surface. Raytracing is used to determine the position of the images of these markings on the front surface for different viewing directions and to calculate the positioning error they introduce when they are used to locate the origin of the front reference coordinate system.

In the following, the approach detailed in 6.2.3.3 is used to present the calculations and results found.

5.3.1.1 Back surface marking positions

The markings E_{1B} and E_{2B} are located on the back surface as displayed in Figure 8 with the back reference coordinate system defined with its origin at O_B , with the normal to this point being the z_B axis and the tangent plane being the plane (x_B, y_B) .



Key

- 1 back surface
- 2 front surface

Figure 8 — Horizontal cross-section

In this back surface coordinate system, the positions of the permanent alignment reference markings are given in Formula (5):

$$E_{1B} = (x_{1B}, y_{1B}, z_{1B}) = (-d_e, 0, z_{1B})$$

$$E_{2B} = (x_{2B}, y_{2B}, z_{2B}) = (d_e, 0, z_{2B}) \quad (5)$$

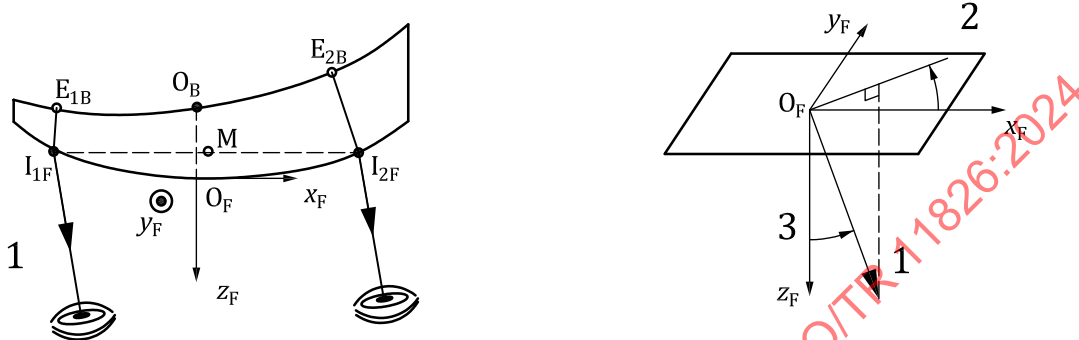
with $d_e = 17 \text{ mm}$

5.3.1.2 Image of markings at the front surface

When looking at the markings E_{1B} and E_{2B} from the front surface side of the lens, their images I_{1F} and I_{2F} can be seen. The point M is defined as the midpoint between I_{1F} and I_{2F} .

The position of I_{1F} and I_{2F} depends on the lens and the viewing direction (see [Figure 9](#)).

The viewing direction is defined with respect to the theoretical front reference coordinate system, which is positioned according to [6.2.3.3](#), and with O_F coinciding with the engraving reference point (ERP) for this study. Its axes are (x_F, y_F, z_F) with z_F being the normal to the front surface at O_F .



Key

- 1 viewing direction
- 2 viewing azimuth
- 3 viewing angle

Figure 9 — Horizontal cross-section (left) and Viewing direction (right)

Two parameters characterize the viewing direction:

- viewing angle: angle formed between the viewing direction and the z_F axis;
- viewing azimuth: angle formed by the projection of the viewing direction on the (x_F, y_F) plane and the x_F axis.

5.3.1.3 Image positions of the engraved markings in the front surface coordinate system

The theoretical front reference coordinate system is (x_F, y_F, z_F) with its origin at the O_F – see [Figure 10](#).

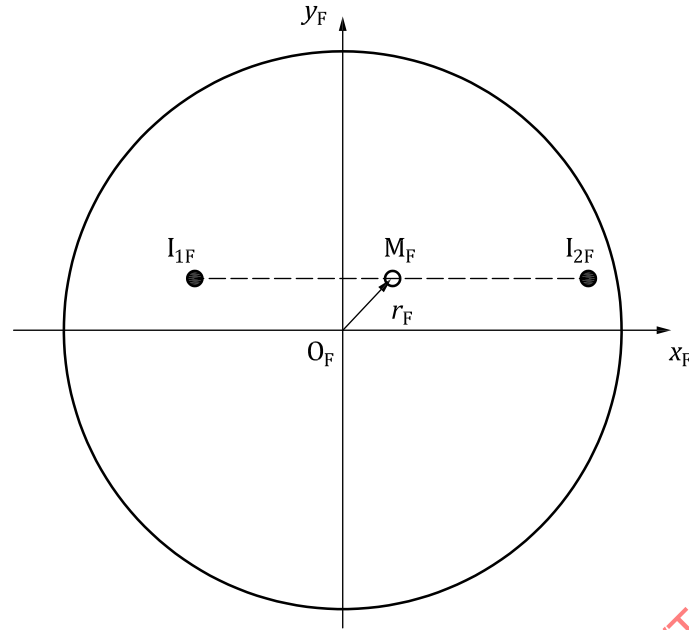


Figure 10 — Tangential plane of front surface at O_F , the real ERP

In this reference coordinate system, the positions of I_{1F} and I_{2F} are given by [Formula 6](#) as:

$$I_{1F} = (x_{1F}, y_{1F}, z_{1F})$$

$$I_{2F} = (x_{2F}, y_{2F}, z_{2F}) \quad (6)$$

and the position of M_F by [Formula 7](#) as:

$$x_{MF} = (x_{1F} + x_{2F})/2$$

$$y_{MF} = (y_{1F} + y_{2F})/2 \quad (7)$$

$$z_{MF} = (z_{1F} + z_{2F})/2$$

Projected in the plane (x_F, y_F) , i.e. the tangential plane to the front surface at O_F , the point M coordinates becomes $M_F (x_{MF}, y_{MF})$. The radial distance r_F representing the positioning error between the reconstructed front reference origin M_F and the front theoretical origin O_F is given by [Formula 8](#) as:

$$r_F = \sqrt{x_{MF}^2 + y_{MF}^2} \quad (8)$$

5.3.2 Simulation results

The following single-vision lenses have been used for these simulations:

- Front surface: spherical
- Back surface: spherical
- Index of refraction: 1,5
- Prescription range:
 - Sphere: [-10 D to +8 D] in 2 D steps

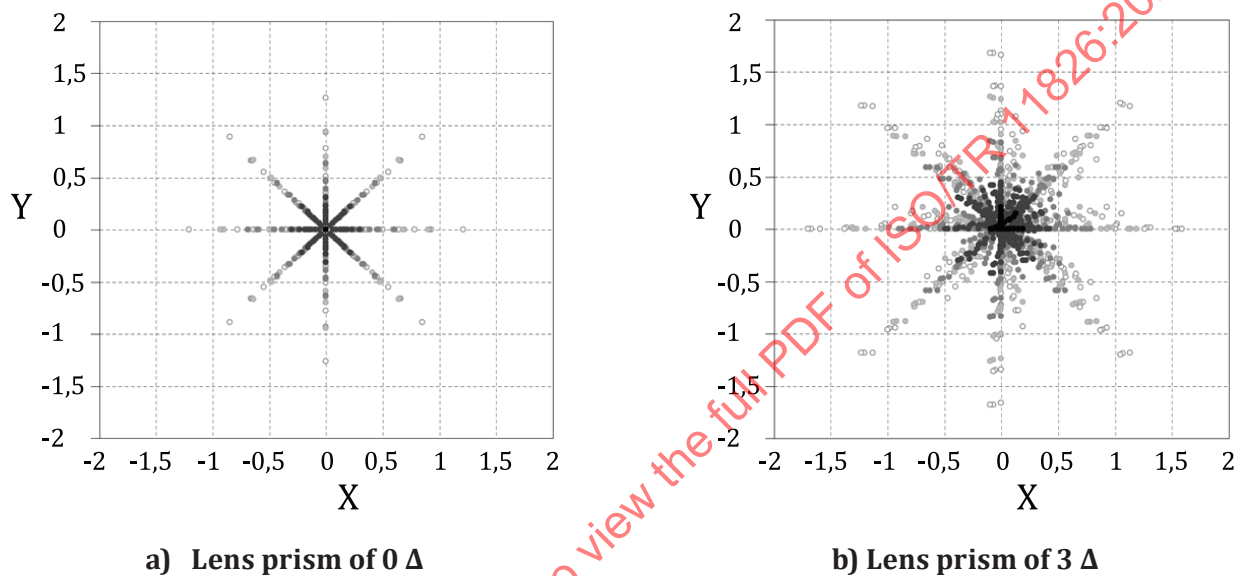
- Prism: 0 Δ and 3 Δ , Base 270°, 315° and 360°

For each lens, the viewing direction was varied as follows:

- Viewing angles = 0°, 5°, 10°, 15°, 20°
- Viewing azimuths = [0° to 315°] in 45° steps

5.3.2.1 Midpoint between the images of the engraved markings measured in the front surface coordinate system

The projection of the midpoints M_F on the theoretical front reference coordinate system plane (O_F , x_F , y_F) of all lenses is shown in [Figure 11](#). The left graph corresponds to lenses with no prism and the right graph corresponds to lenses with a prism of 3 Δ .



Key

Viewing angle (°)

- 20
- 15
- 10
- 5
- 0

X x_{MF} (mm)

Y y_{MF} (mm)

Figure 11 — Projection of midpoint M_F on the front surface coordinate system

As the viewing azimuth step was 45°, a star like pattern can be observed. With the increase of viewing angle, the fluctuation of the projection of the midpoints M_F also increases, i.e. the positioning error between the reconstructed front reference origin M_F and the front theoretical origin O_F can potentially be higher.

[Table 1](#) shows the maximum radial distances $r_{F,max}$ between the theoretical origin O_F and the midpoint M_F . The left table corresponds to lenses with no prism and the right table corresponds to lenses with 3 Δ prism. The values of $r_{F,max}$ can be found for the different viewing angles and the lens's spherical power.

Table 1 — Values of $r_{F,max}$ in millimetres

		Viewing angle (°)							Viewing angle (°)				
		0	5	10	15	20			0	5	10	15	20
Sph (D)	-10	0,00	0,23	0,46	0,70	0,93	Sph (D)	-10	0,21	0,44	0,67	0,90	1,13
	-8	0,00	0,19	0,39	0,59	0,78		-8	0,17	0,36	0,56	0,75	0,95
	-6	0,00	0,16	0,32	0,48	0,64		-6	0,13	0,29	0,45	0,61	0,77
	-4	0,00	0,13	0,25	0,38	0,51		-4	0,11	0,24	0,36	0,49	0,62
	-2	0,00	0,09	0,18	0,28	0,37		-2	0,08	0,17	0,26	0,35	0,45
	0	0,00	0,06	0,12	0,18	0,23		0	0,06	0,19	0,31	0,44	0,57
	2	0,00	0,09	0,17	0,26	0,35		2	0,04	0,24	0,43	0,62	0,82
	4	0,00	0,16	0,31	0,47	0,63		4	0,05	0,31	0,57	0,83	1,10
	6	0,00	0,23	0,47	0,70	0,94		6	0,07	0,39	0,72	1,05	1,39
	8	0,00	0,31	0,63	0,94	1,26		8	0,09	0,49	0,90	1,30	1,71

lens prism = 0 Δ

lens prism = 3 Δ

Viewing direction normal to the front surface at O_F (viewing angle = 0°):

- If lens prism = 0 Δ then $x_{MF} = y_{MF} = 0$ mm and M_F is located at O_F
- If lens prism = 3 Δ, the maximum radial distance of M_F with O_F , $r_{F,max}$, is 0,21 mm for the -10 D lens

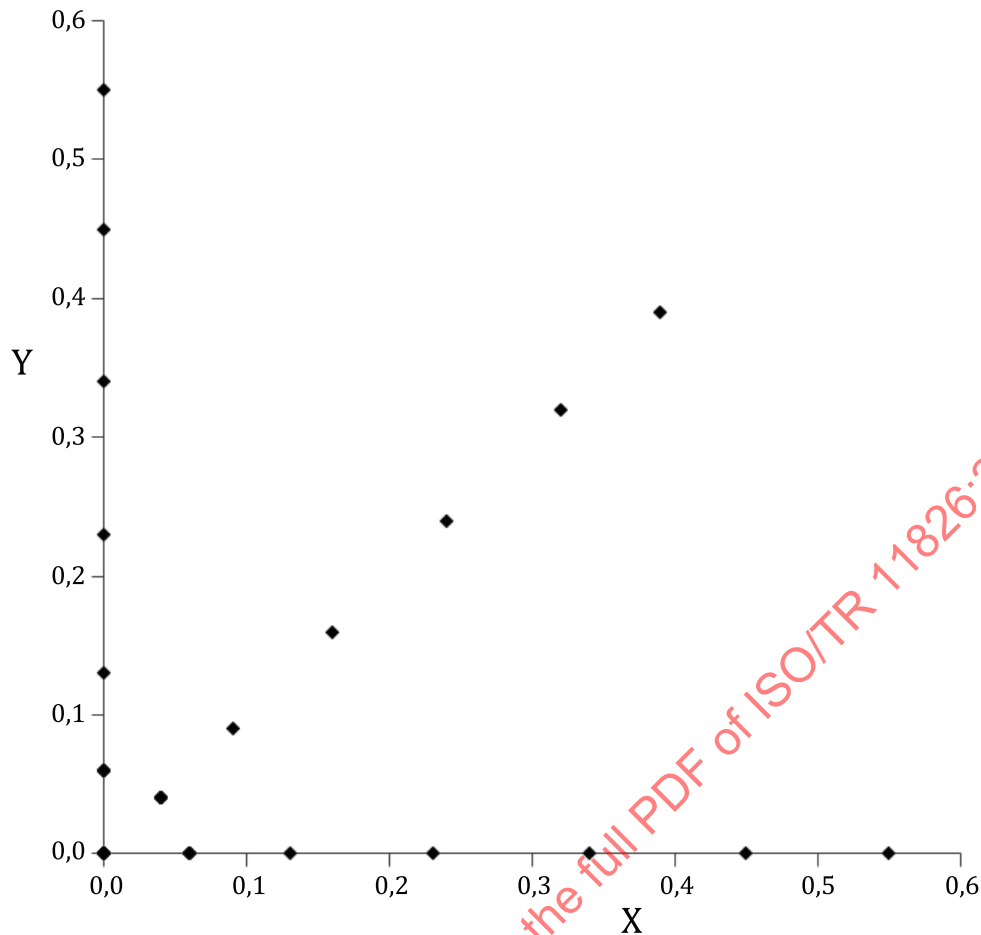
Viewing direction not normal to the front surface at O_F : the maximum radial distance of M_F with O_F , $r_{FS,max}$, is influenced mainly by the

- viewing angle,
- lens centre thickness (high positive powered lenses),
- prism base setting, and
- lens focal power, especially positive powered lenses with their higher front surface powers.

The positioning error between the reconstructed front reference origin M_F and the front theoretical origin O_F can get higher than 1 mm when the viewing angle is above 15° and the sphere power, Sph, is high ($|Sph| > 4$ D).

5.3.2.2 Theoretical front reference surface origin expressed in the back reference coordinate system

To illustrate the requirement to provide information on how to pass from the back reference coordinate system to the front one as mentioned in 6.2.3.3, the theoretical front origin O_F expressed in the back reference coordinate system was plotted in Figure 12. No raytracing was performed in this analysis, just a projection of O_F onto the back surface reference plane (O_B , x_B , y_B).



Key

- X horizontal coordinate of the origin of the front reference coordinate system (mm)
 Y vertical coordinate of the origin of the front reference coordinate system (mm)

Figure 12 — Theoretical front reference coordinate system origin O_F expressed in the back reference coordinate system plane (O_B, x_B, y_B)

For lenses with no prism, the projection of O_F is on O_B . The projection of O_F does not match the position of O_B when the lens has some prism (prescribed prism or prism thinning for example). The points are in the horizontal, vertical and 45° direction as the lenses' prism bases are 270° , 315° , and 360° .

6 Different approaches to specifying measurement positions and alignment

6.1 General

For specific cases, where numerical references are needed, this report suggests using a three-dimensional coordinate system and specifying the position of the relevant points therein. As this is only relevant in a business-to-business context, the scheme can either be agreed between the parties involved reflecting an individual company's features, follow an existing specification like the DCS^[10], or use some of the concepts presented in this clause.

For general use, including by the eye care and dispensing professionals, the current system as specified in ISO 21987^[7], ISO 8980-1^[8] and ISO 8980-2^[9] or the like using non-permanent ink markings, permanent engravings and the appropriate centration charts for the lens design works very well. A numerical approach is too difficult.

6.2 Reference coordinate systems defined by engravings

6.2.1 General

Irrespective of whether the engravings are on the front or the back surface, the reference points are located on the lens's front surface according to current standards³⁾. The positions of the reference points from the front surface are defined in 2D (x, y values or horizontal, vertical distances) after orthogonal projection of those points onto a two-axes reference coordinate plane (orthonormal coordinate system Oxy). The origin O_F of this reference plane is the engraving reference point (ERP), which in turn is located on the front surface and defined by the two engravings according to the system used. For lenses with spherical front surfaces, the reference plane⁴⁾ is the plane tangential to the front surface at the engraving reference point. For lenses with a non-spherical front surface (e.g. frontside progressive-power lenses, double-sided progressive-power lenses, lenses with aspherical front surfaces), the manufacturer can define a different orientation of the reference plane, if needed.

NOTE 1 The orientation of the reference plane is defined by the intended surface of the lens. Any deviations of the actual surface, e.g. due to defects, do not change the orientation of the reference plane from that intended.

NOTE 2 For lenses with non-spherical front surfaces, the orientation of the tangential plane depends on the actual design of the front surface. This design can vary with the addition and other parameters, even within lenses of the same series. Therefore, the orientation of a reference plane defined as a tangential plane can also vary. Furthermore, it can become uncertain in case of high curvatures.

NOTE 3 The prism reference point can coincide with the engraving reference point to allow for easier prism checking.

The horizontal orientation, i.e. the x -axis, is based on the alignment of the two reference engravings – see for examples 6.2.2 and 6.2.3. With $Oxyz$ being an orthonormal coordinate system, this also defines the y -axis lying within the reference plane and the z -axis being normal to the Oxy plane.

According to ISO 21987, the alignment reference marking comprise two markings located nominally 34 mm apart, equidistant to a vertical plane through the fitting point or prism reference point. In Figures 13 to 17 these markings are assumed to be located (Figures 13, Figure 14, Figure 15 and Figure 17) at the distance of $d_e = 17$ mm from their midpoint or appear at this distance, when viewed from the front (Figure 16).

6.2.2 Reference coordinate system for front side engravings

The pair of permanent engravings at 34 mm on the front surface together with a left/right or up/down marking (e.g. the permanent marking indicating the power variation or the manufacturer) and the front surface contour (but not the lens's outer shape) are used to define the lens's position and the reference points' position on the front surface for blanks and for uncut or cut finished lenses.

Horizontally, the ERP is a point on the front surface that is midway between the two engravings when viewed by an observer looking at the front surface of the lens, positioned at an infinite distance from the lens and viewing along the z -axis as defined in Figure 13. Vertically, the position of the ERP can differ from the midpoint between the permanent reference markings. This difference (measured in the reference plane) is to be stated by the manufacturer.

NOTE This vertical offset is used e.g., in cases when the permanent markings are applied at the height of the fitting point to allow for easier checking of the centration once the lenses are mounted and the non-permanent markings removed. Schemes doing without this offset, on the other hand, allow for an easier retrieval of the coordinates in an automatized setting.

The horizontal direction is provided by the orthogonal projection of the line joining both engravings onto the reference plane Oxy . Figure 13 shows the situation in absence of any vertical offset between the ERP and the engravings.

3) See also ISO 13666:2019, 3.2.15 to 3.2.23, 3.2.34 and 3.16.10.

4) This plane is defined independently of the plane of the lens shape (see ISO 13666:2019, 3.2.41) and will typically differ.

In a simple 2D approach, parallax errors arise when selecting a midpoint on the front surface by viewing this 3D front surface with a bad viewing direction.

The definition given in the first two paragraphs of this subclause is universally accepted among the lens manufacturers.

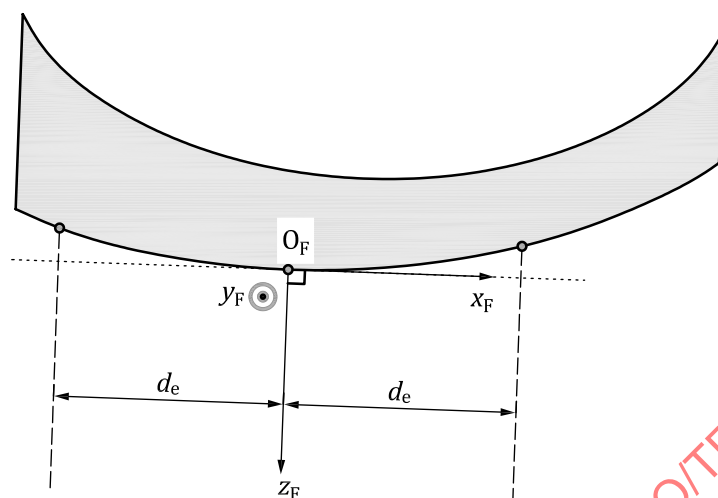


Figure 13 — Front side engraving

6.2.3 Reference coordinate system for back side engravings

6.2.3.1 General

A pair of permanent engravings at 34 mm on the back surface together with a left/right marking and the contour of both back and front surfaces (but not the lens's outer shape) are used to define the lens's position and reference points' position on the front surface for finished lenses in uncut, cut, and mounted states.

Compared to frontside engravings, the case of backside engravings is much more complex. Moreover, higher parallax effects arise due to the refraction effect when viewing back side engravings through the lens from the front side (see 5.2 and 5.3).

Unfortunately, contrary to the case of frontside engravings, there is no universal approach, resulting in significant differences between manufacturers as evidenced below. Therefore, it is of the highest importance for every manufacturer to use and/or provide clear recommendations and appropriate tooling for accurate lens positioning and verification.

As for front surface engravings (see 6.2.2), the vertical position of the ERP can differ from the midpoint between the permanent reference markings with the offset (measured in the reference plane) to be stated by the manufacturer.

Examples of methods used to transfer back surface permanent reference engravings to the reference points on the front surface are presented in the following subclauses. For easier reading, this is done for the case without any vertical offset between the ERP and the mid-point between the engravings. However, such an offset can easily be included.

Contrary to the case of front engravings, in the general case of backside engravings, it is possible that the horizontal direction is not provided by a simple orthogonal projection of the line joining both engravings onto the plane tangent to the surface at the engraving reference point.⁵⁾

The engraving reference point position differs significantly when applying different manufacturers' rules for a given lens. An easy example is provided by comparing the ERP positions from [Figures 14](#) and [15](#). This effect is greater with higher 'centre' thickness and prism values. As an illustration, [Figure 12](#) provides simulated ERP distances for the "projection perpendicular to the front surface" (see [6.2.3.3](#)) option, to be compared to the "projection perpendicular to the back surface" (see [6.2.3.2](#)) option where the prism reference point would be at (0,0).

The "optical projection" option from [6.2.3.4](#) ([Figure 16](#)) 'mimics' the rules applied to the front side engravings.

6.2.3.2 Projection perpendicular to the back surface

The midpoint O_B between the two back surface engravings is projected to the front surface along a line that is normal to the back surface at O_B (see [Figure 14](#)). This projected point becomes the origin O_F of the reference coordinate system on the front surface and is the ERP.

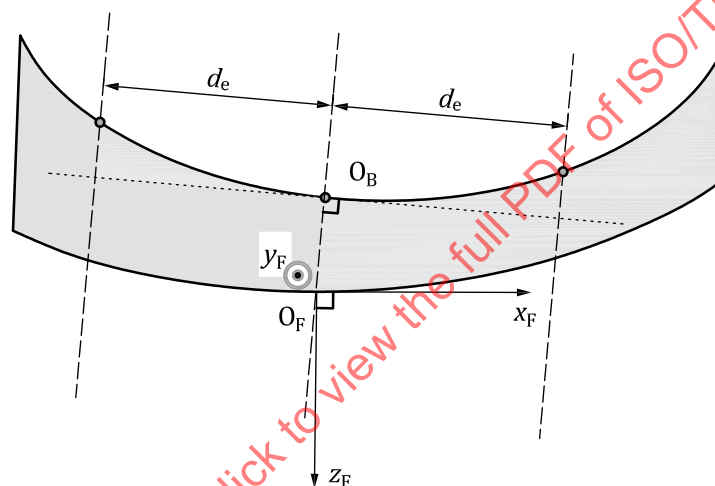


Figure 14 — Back side engraving with projection perpendicular to the back surface

6.2.3.3 Projection perpendicular to the front surface

The midpoint O_B between the two back surface engravings is projected to the front surface along a line that is normal to the front surface at the projected point O_F (see [Figure 15](#)). This projected point becomes the origin O_F of the reference coordinate system on the front surface and is the ERP.

5) An example is provided by the case of optical projection (see [6.2.3.4](#)) where the line segment joining the two images of the engravings as viewed on the front surface is used to define the horizontal direction by the orthogonal projection of the line joining both engraving images onto the plane tangent to the surface at the engraving reference point. With a prism at 225° resulting from a horizontal prism in addition to thinning prism, the lens thickness is not the same for both engraving positions and the line segment joining the two images of the engravings as viewed on the front surface is not in the same plane as the segment line joining both engravings on the back.

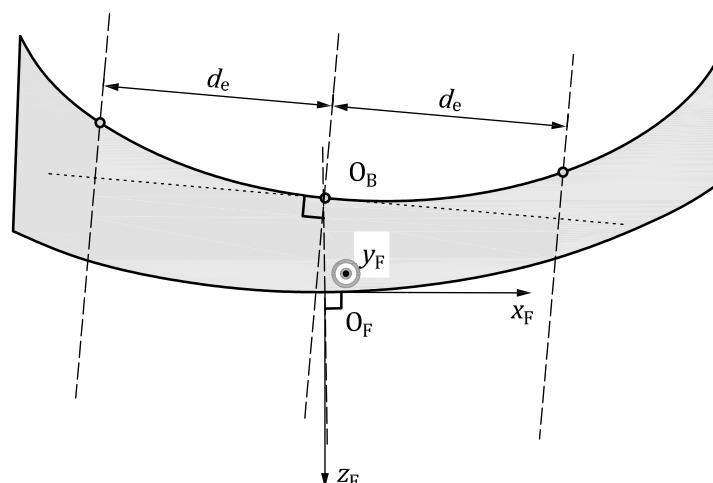


Figure 15 — Back side engraving with projection perpendicular to the front surface

6.2.3.4 Optical projection of engravings

The ERP is a point on the front surface that is midway between the apparent positions of the two engravings when viewed through the front surface of the lens by an observer positioned at an infinite distance from the lens and with the viewing axis perpendicular to the front surface at the ERP (see Figure 16). The origin O_F of the reference coordinate system on the front surface is the ERP.

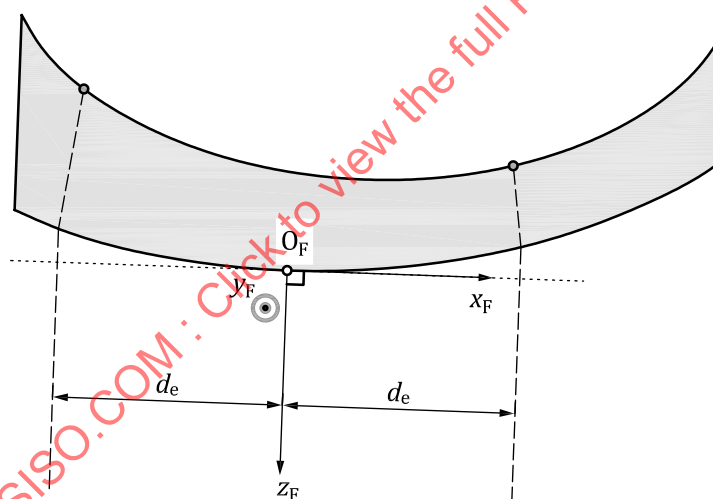


Figure 16 — Back side engraving with optical projection of engravings

6.2.4 Data Communication Standard (DCS) from the Vision Council

Due to the large diversity of the rules used by various manufacturers, instead of communicating the option to be handled in each case, the following flexible approach is used in the DCS^[10]. However, the shape of the back surface is needed for some of the transformations mentioned in 6.2. For example, it does not allow a vertical offset between the ERP and the engravings to be defined without establishing a back surface coordinate system.

The more complex case of back side engravings led to the need of the BRERA angle from the DCS standard providing the orientation according to a selected reference orientation.

The existing rules (see 6.2.2) for front side engraving have been transferred to the case of back side engravings for defining a transitional reference coordinate system ($Oxyz$) – see Figure 17. This back reference coordinate system with its origin BRP (back engraving reference point, O_B , from 5.2 and 5.3) on