TECHNICAL REPORT

ISO/TR 28980

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Ophthalmic optics — Spectacle lenses — Parameters affecting lens power measurement

Optique ophtalmique — Verres de lunettes — Paramètres affectant le mesurage de la puissance de la lentille

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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ISO/TR 28980 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 7, *Ophthalmic optics and instruments*.

Ophthalmic optics — Spectacle lenses — Parameters affecting lens power measurement

1 Scope

The purpose of this Technical Report is to explain the changes relating to power measurements in the revised editions of ISO 8980-1 [6] and ISO 8980-2 [7].

In order to illustrate the issues raised, an inter-laboratory power measurement study was conducted on ten different lenses measured by nine organizations worldwide. Twenty-five focimeters of different types were used. The test lenses were spherically powered allyl diglycol carbonate (ADC)[1)] hard resin lenses surfaced to –4,00 D, –2,00 D, 0,00 D, +2,00 D, and +4,00 D, each with an addition power of 2,50 D. Five were D28 bifocals and five were progressive power lenses. The measurements were front distance power, front near power, back distance power and back near power, for each lens and for each focimeter used. Each lens was measured nine times: five measurements taken without repositioning the lens and four measurements taken with the lens repositioned each time.

The assessed parameters were divided into three categories:

— discrepancies due to focimeter design and measurement methods;

— systematic errors;

— random errors.

For each parameter, experimental results are given, as well as theoretical ones when needed. Measurement data include front distance portion power, front near portion power, back distance portion power and back near portion power.

NOTE The results of all measurements are available on the ISOTC Server at the address given in the Bibliography[8].

Unless stated otherwise, in order to show relevant information, the results shown are for the D28 bifocals when no different behaviour was found for the progressive power lenses.

2 Discrepancies due to different focimeter designs and measurement methods

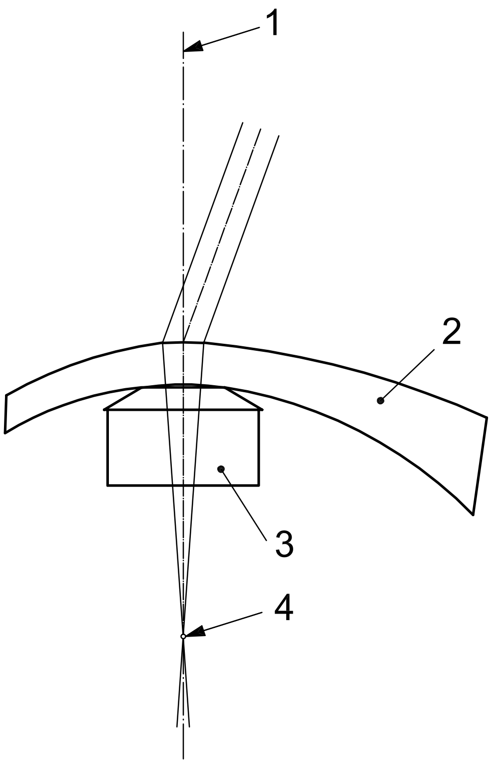
2.1 Focimeter design

Traditional manual focimeters have relied on the user adjusting the instrument to obtain the clearest focus of the test mire. All these instruments are based on the “Focus on Axis” (FOA) design, in which the focal point of the focimeter remains on the axis of the focimeter when the lens under test is measured at a point of the lens where the prism is not zero.

Some automated focimeters also use this optical design, but many use the “Infinity on Axis” (IOA) design, in which the collimated beam coincides with the focimeter axis and the focal point of the focimeter goes off the

1) ADC is often referred to by its original trade name, CR-39®.

axis of the focimeter when the lens under test is measured at a point of the lens where the prism is not zero (see Figures 1 and 2). As automated focimeters can have either a FOA or IOA design, users should ask the manufacturer what design is employed.



Key

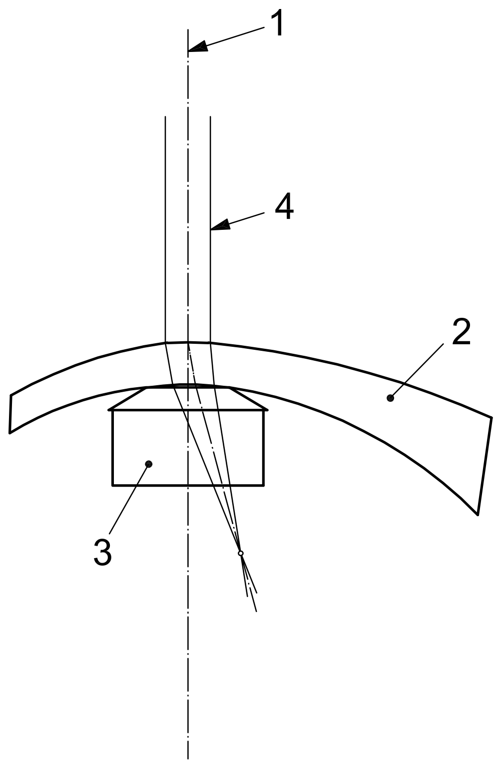
1 focimeter's optical axis

2 lens

3 focimeter lens support

4 focal point on the optical axis

Figure 1 — FOA focimeter



Key

1 focimeter's optical axis

2 lens

3 focimeter lens support

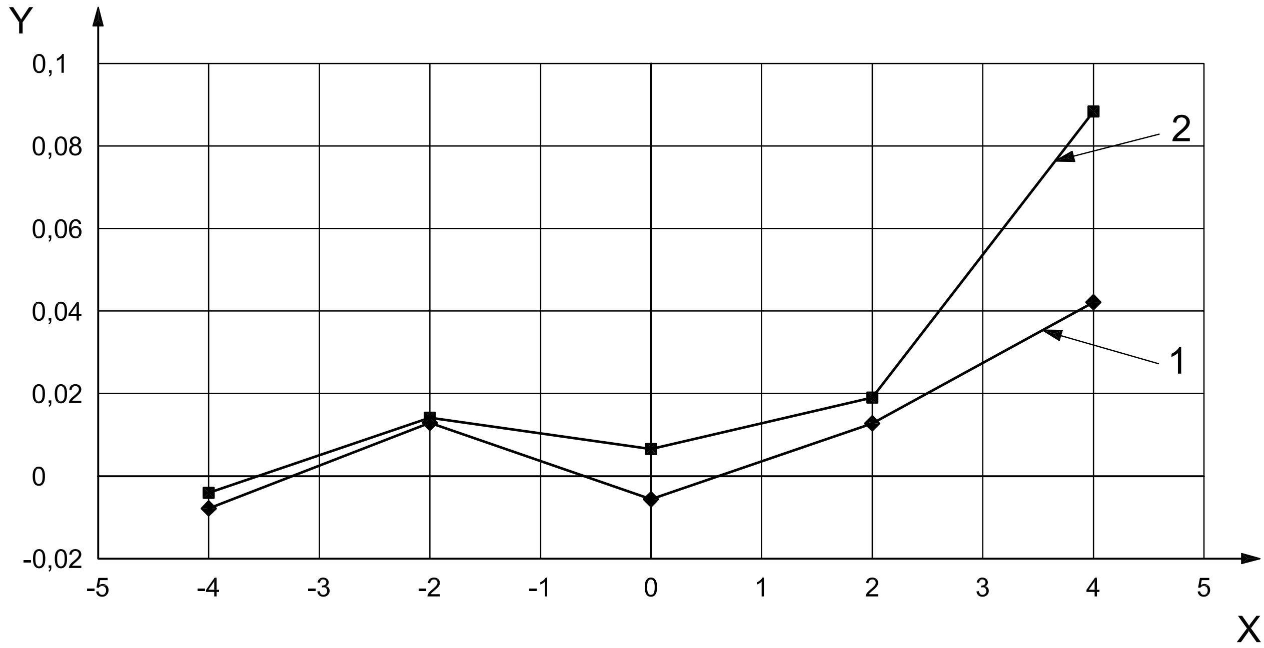
4 infinite on the optical axis

Figure 2 — IOA focimeter

When there is no prismatic effect, the two designs will give the same results. On the other hand, the results will differ if the prism is not zero, as shown by Coddington's equations for oblique astigmatism (for further details, see textbooks on optics).

Figure 3 is a graph of the results from the inter-laboratory measurements study.

As the lenses used had moderate power and prism, the average FOA-IOA difference remains within the power tolerance for focimeters. Nonetheless, even for these lenses, for near power the discrepancy reaches nearly 2/3 of the lens power tolerance allowed by the ISO standards.



Key

X nominal distance power, in dioptres
Y power difference, in dioptres

1 D28 – differences in distance power
2 D28 – differences in near power

Figure 3 — Graph of the inter-laboratory measurements showing the difference in power between the FOA and the IOA focimeter design in the presence of prism
(average value of measurements of the back vertex power made at the sagittal focus, addition power 2,50 D)

2.2 Wavelength dependence

The refractive index of the lens material varies with the wavelength. This variation is given by the Abbe number (for further information, see textbooks on optics).

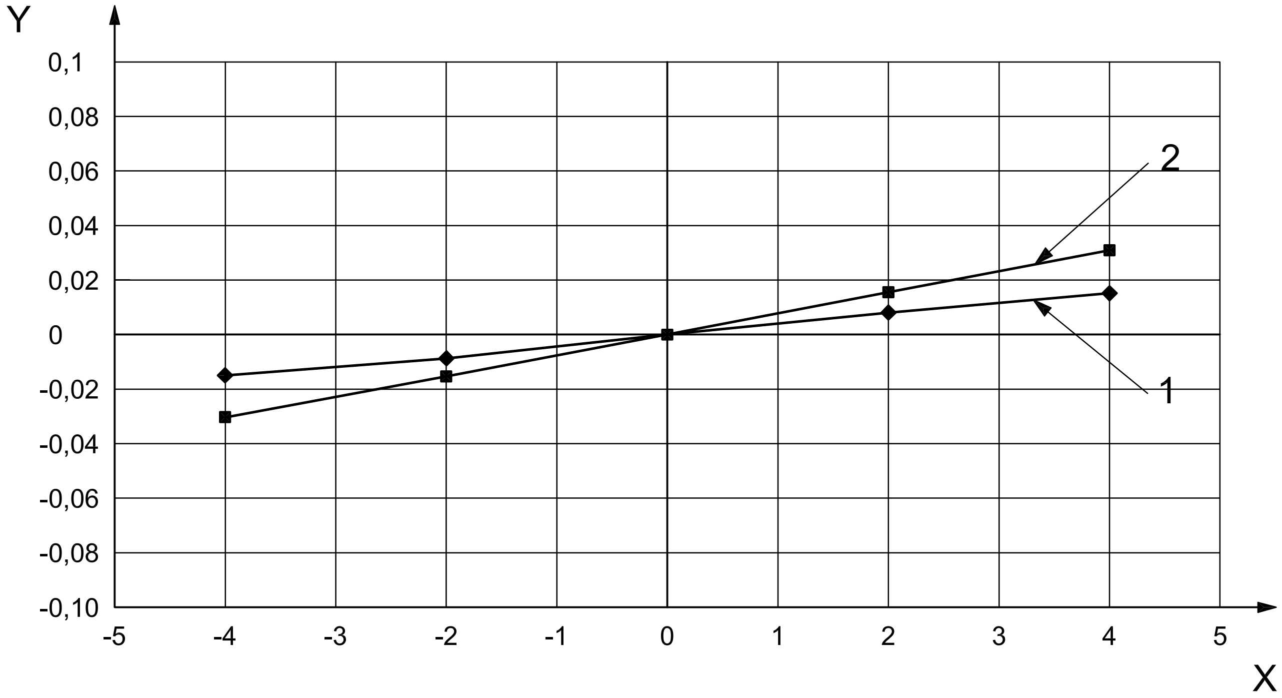
The reference wavelength differs depending on the country. In some countries, the helium d-line (587,56 nm) is used, while in others, it is the mercury e-line (546,07 nm).

Figure 4 shows the effect of the wavelength dependence on the lens power for two materials:

— a material with an Abbe number, ν, of 57,8 and a nominal index, n, of 1,5 (n_d = 1,4977, n_e = 1,4996), and

— a material with an Abbe number, ν, of 30,0 and a nominal index, n, of 1,59 (n_d = 1,5855, n_e = 1,5899).

NOTE n_d is the nominal index at the wavelength of the helium d-line; n_e is the nominal index at the wavelength of the mercury e-line.



Key

X lens power, in dioptres

Y power difference, in dioptres

1 V = 57,8 and n = 1,5

2 V = 30,0 and n = 1,59

Figure 4 — Wavelength dependence: Calculated power difference between 546,07 nm and 587,56 nm for two different materials

Hence, the theoretical power discrepancy between the helium d-line and the mercury e-line for a +4,00 D ADC lens with a 2,50 addition would be approximately 0,03 D for a total near power of +6,50 D. It should be noted that reference wavelength dependence is also important in the calibration of focimeters (see 3.4).

Because automated focimeters usually work with red light or infrared radiation, the instrument has a built-in correction for the readings for low dispersion or high Abbe number materials such as ADC. Lenses, especially high powered ones, made from higher index materials with lower Abbe numbers, require the instrument to be adjusted/reset in order to correct for the different Abbe number.

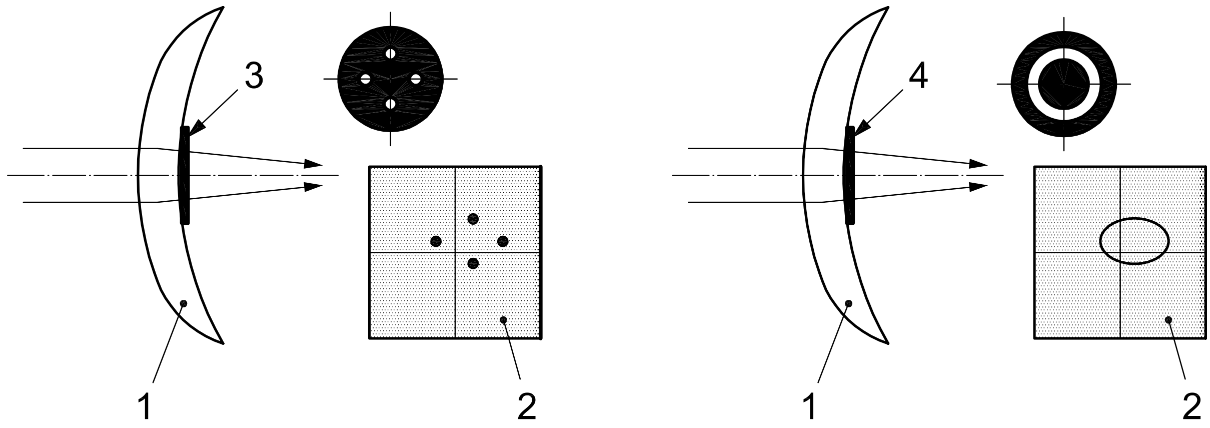
2.3 Target pattern

2.3.1 Manual focimeters

For manual focimeters, the target is a graticule.

2.3.2 Automated focimeters

Automated focimeters have several approaches for the pattern their target uses to determine the focus. Among the most common ones are the “4-rays target pattern” and the “annular pattern”. Note that an annular pattern becomes elliptical when the lens under test is an astigmatic power lens (see Figure 5).



Key

1 measured lens
2 screen
3 aperture with 4 holes
4 annular aperture

a) 4-rays target pattern **b) Annular target pattern**

Figure 5 — Examples of target patterns commonly used in automated focimeters

Figure 6 shows the results from the inter-laboratory studies comparing focimeters using the “4-rays target pattern” and the “annular target pattern”.

It is easy to note that there is very little difference between the two patterns. This can be explained by the accuracy and precision of the focimeters.

In these focimeters, the position of the focus is computed. Therefore, when measuring areas of progressive power lenses with built-in aberrations (such as coma), different target patterns can yield significantly different results, and in certain complex cases, some instruments cannot make a measurement and therefore produce an error message.

2.4 Front vertex versus back vertex measurements

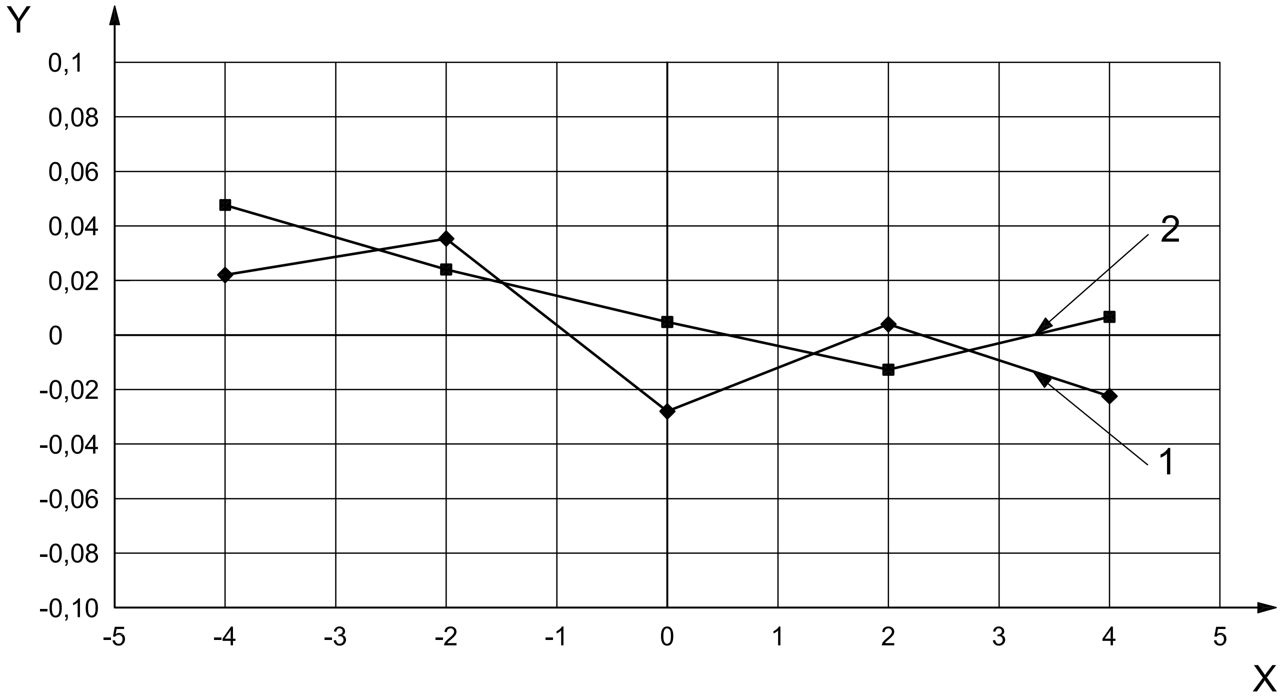
ISO 8980-1 and ISO 8980-2 specify for the addition determination that the measurement for near portion power and distance portion power can be made either at the back or the front vertex. This distinction can lead to major discrepancies in power measurements. Indeed, the more the lens differs from the symmetrical biconcave or biconvex shape, the greater this difference will be.

Figure 7 shows the average differences between the back vertex power minus the front vertex power for the distance and near portions of the lenses.

The differences result from the relative surface curvatures and thicknesses and can be significant, especially for positive powered lenses. Consequently, identification of the measurement method is essential.

The distance power of a lens is that given by the back vertex measurement method, while for most multifocal and progressive power lenses, the addition is given by the difference between the two front vertex powers. If the addition power for such a lens is measured as the difference in back surface powers, the error for the addition is the difference between the two lines in Figure 7, i.e. 0,26 D for the +4,00 D distance power lens.

The refractive power at the designed reference point (for distance or near vision) perceived by the viewer is called the “as worn” power of the lens. It cannot be measured with a commercially available focimeter without extensive modifications, and generally differs from both the front and back vertex powers. Some lenses are designed and manufactured to provide the “as worn” power (e.g. “as worn” addition power).



Key

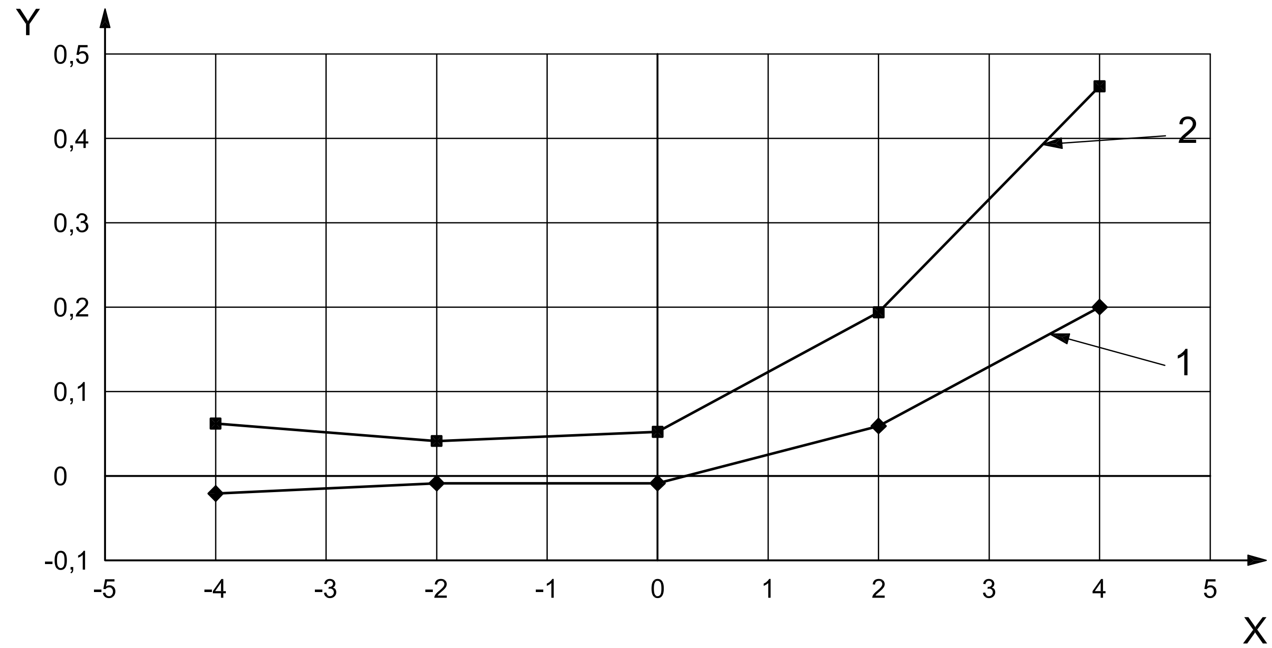
X nominal distance power, in dioptres

Y power difference, in dioptres

1 D28

2 progressive power lens

Figure 6 — Graph of the inter-laboratory measurements showing the average power difference for distance power between two different target patterns



Key

X nominal distance power, in dioptres

Y power difference, in dioptres

1 differences in distance power

2 differences in near power

Figure 7 — Average power differences between front vertex and back vertex measurements on an FOA focimeter using the spherical equivalent for D28 lenses, addition power 2,50 D

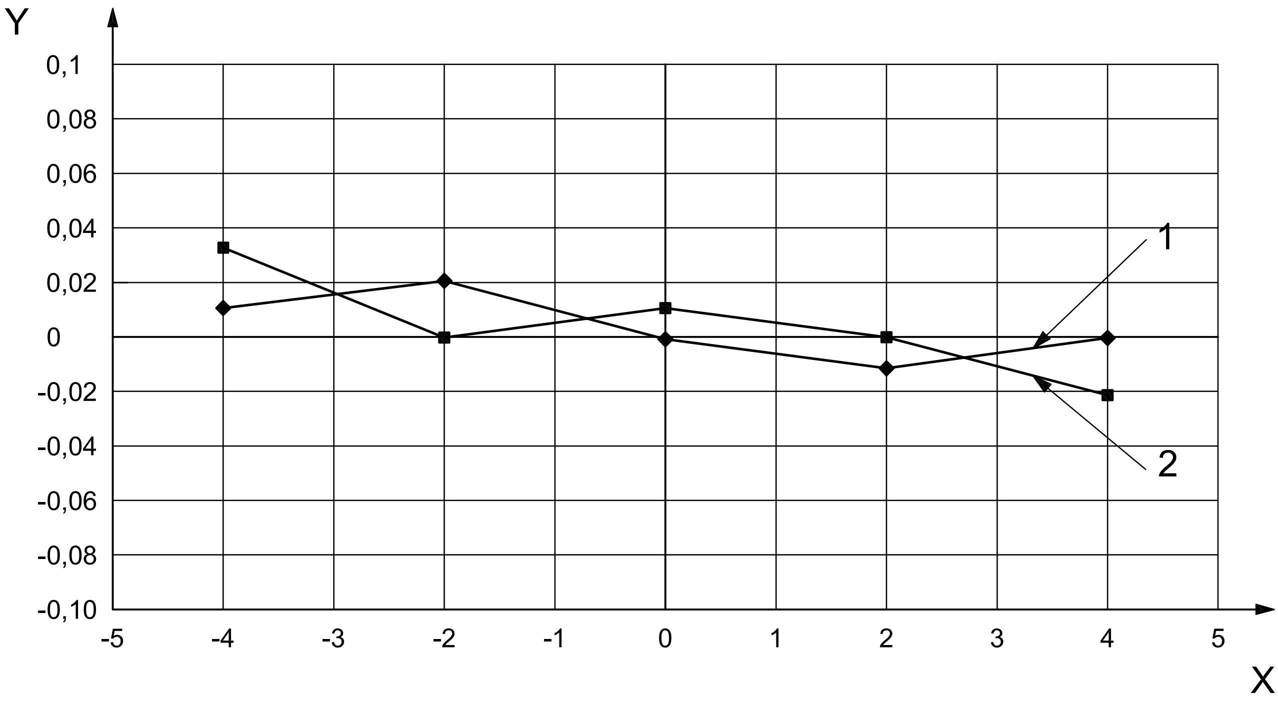
2.5 Choice of focus

ISO 8980-1 and ISO 8980-2 recommend the use of either the nearer to vertical line focus of the target (sagittal focus) or the spherical equivalent which corresponds to the disk of least confusion and to what the human eye perceives. Manual focimeters can use both methods, whereas automated focimeters use the spherical equivalent.

When using the sagittal focus, it is easy to mistake the two focus lines created by astigmatism when the axis is close to 45° and 135°, e.g. using the 45° line for near power and the 135° for distance.

Figure 8 shows the average difference in power measurement between the spherical equivalent power and the power measured at the sagittal focus.

As can be seen, the difference between the two choices of focus point is small and is within the focimeters' accuracy and precision of measurement.



Key

X nominal distance power, in dioptres

Y power difference, in dioptres

1 differences in distance power

2 differences in near power

Figure 8 — Power difference between sagittal focus and spherical equivalent measurements (average value of measurements of a D28 lens measured at back vertex on FOA focimeters, addition power 2,50 D)

3 Systematic errors

3.1 Non-linear errors

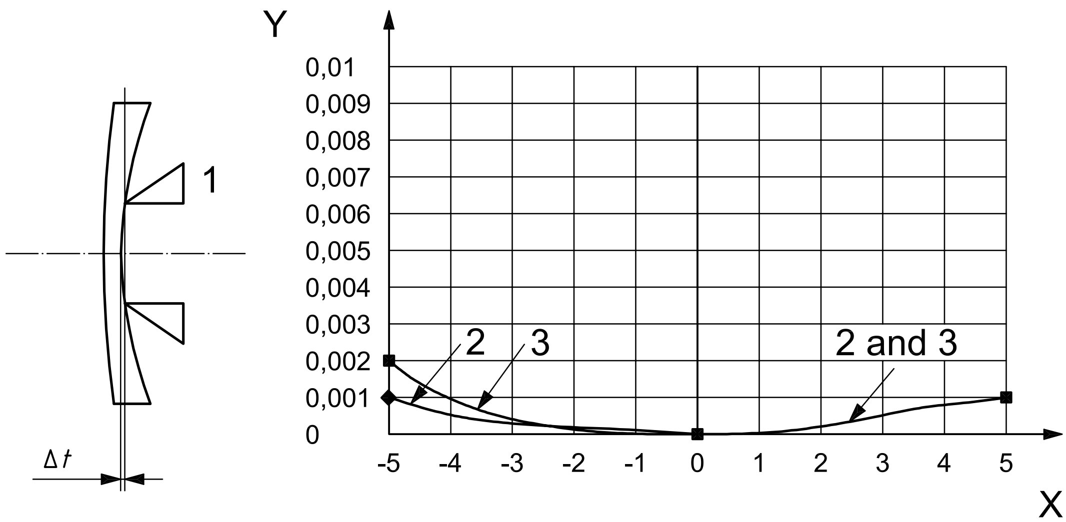
Even when perfectly designed, all instruments have small non linear behaviour of various origins (optical, electronic or mechanical), which lead to systematic measurement errors.

Furthermore, some automated focimeters may present “masking”, which is when the instrument displays 0,00 D for plano lenses with a manufacturing error power smaller than a certain threshold (e.g. ± 0,06 D)[2].

3.2 Lens sag error

Because of the curvature of the lens back surface, the back vertex of the lens cannot lie exactly on the front principal focus of the focimeter lens when placed on the lens mount. The results of simulations showing the deviation caused by the lens sag error on simple spherical lenses for two diameters of lens support are shown in Figure 9.

As expected, this error is larger for negative lenses because of their strongly curved back surface.



Key

X nominal power, in dioptres

Y power error, in dioptres

1 lens support

2 lens support diameter 5 mm

3 lens support diameter 7 mm

Δt lens sag error

Figure 9 — Lens sag error Δt and theoretical results for two diameters of lens support

2) It can be detected by measuring the combination of a +2,00 D lens with a –2,00 D lens. By slightly separating the lenses, the measurement should slowly change; if it jumps to a specific value, e.g. 0,07 D, then the instrument is “masked”.

3.3 Temperature dependence

Temperature affects both the refractive index of the material and the geometry of the lens. Hence, there will be differences in power measurement for the same lens at various temperatures, although there is no difference for glass lenses.

The effect of the temperature is quite small and is proportional to the lens power; variations around room temperature will be under 0,02 D for a 20 °C temperature change for an ADC lens with a power of 4,00 D.

3.4 Calibration

Most of the previous errors, including non-linear ones, can be corrected with efficient calibration, especially for the lens sag error (i.e. the surface that is placed on the lens support of the focimeter) by using test lenses exactly in accordance with ISO 9342-1 and within tolerances specified in ISO 8598. ISO 9342-1 allows test lenses to be made using either the helium d-line or mercury e-line.

It is critical that the refractive index used in making the test lenses matches the reference wavelength to which the focimeter is to be calibrated. Failure to do so can cause calibration errors of 0,11 D at the ends of the range of the test lenses specified in ISO 9342-1.

In order to maintain proper measurements over time, this calibration should be periodically repeated. Extra care is needed for manual focimeters with a focusable eyepiece.

Finally, in order to cancel all the systematic errors for a specific instrument, one can characterize the systematic errors as a function of the power and type of lens, using lenses with precisely known power. These errors can be used later as correction values for measurements.

3.5 Accuracy versus display step

The display step chosen on an automatic focimeter is not an indication of the accuracy of measurement. For example, an automatic focimeter set to a display step of 0,01 D does not mean that the instrument can evaluate the lens to this level of accuracy. Reference should be made to the manufacturer’s technical specifications to establish the instrument’s true accuracy.

4 Random errors

4.1 General

Random errors are mostly caused by the instrument operator, either when positioning the lens or determining the position for best focus during the measurement.

4.2 Focusing issues: Theoretical limit

Because the focimeter is not perfect, the image of a single point is not a single point, but a spot of finite size. The spot size can be characterized theoretically by diffraction and optical aberrations and is the source of uncertainties in the power measurement.

Most of the parameters involved in this depend on the aperture size. Diffraction determines the minimum spot size. The bigger the aperture, the smaller the spot diameter. Depth of focus, also aperture dependent, is additive to diffraction.

Additional contributions to the spot size come from optical aberrations. Spherical aberration produces symmetrical blur and is negligible with low power spectacle lenses. Coma produces an asymmetrical blur of the image, and is especially present with progressive power lenses (see Figure 10).

NOTE Detailed theory of aberrations and diffraction can be found in textbooks on optics.

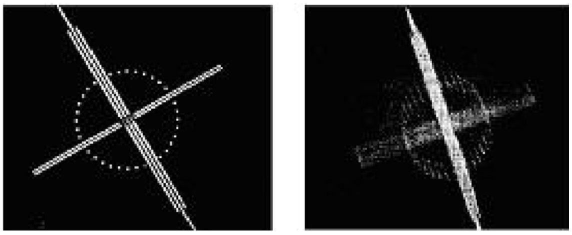
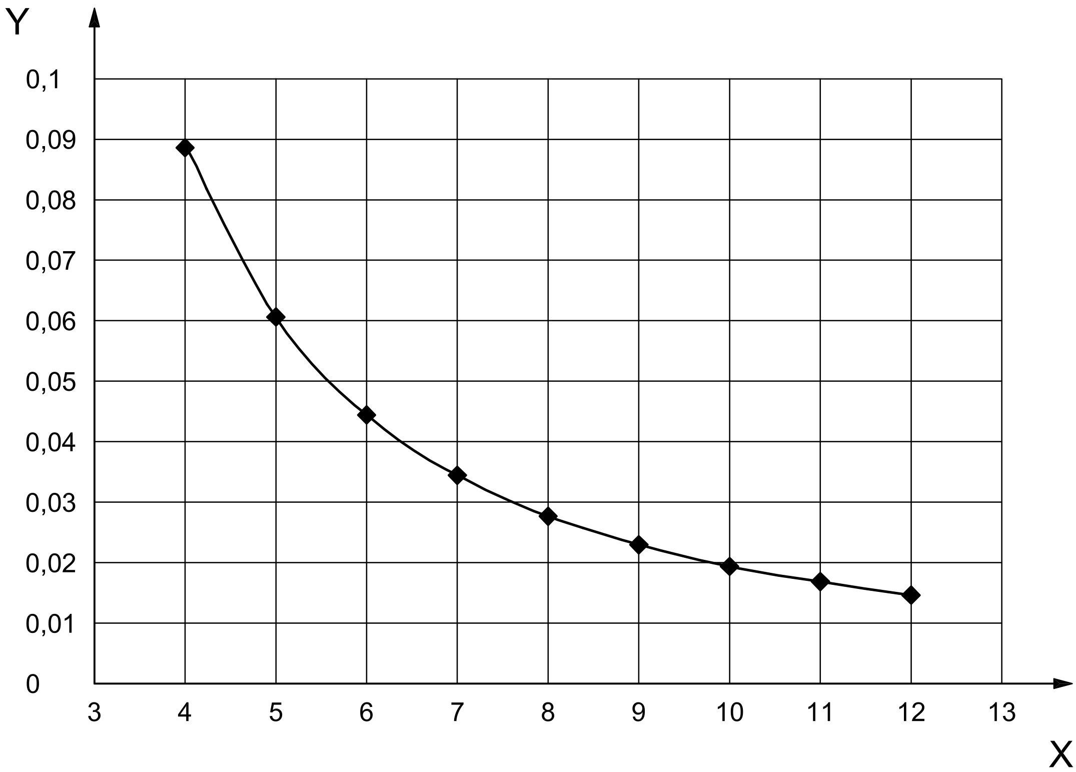


Figure 10 — Test pattern images on a manual focimeter

Figure 11 shows the calculated results for the power measurement error due to the diffraction as a function of the aperture for a manual focimeter.

The presence of aberrations will add errors in addition to those caused by diffraction.



Key

X aperture size, in millimetres

Y power error, in dioptres

Figure 11 — Aperture size dependence: Theoretical limit of the measurement error due to diffraction plus depth of focus for various apertures for a manual focimeter

4.3 Positioning issues

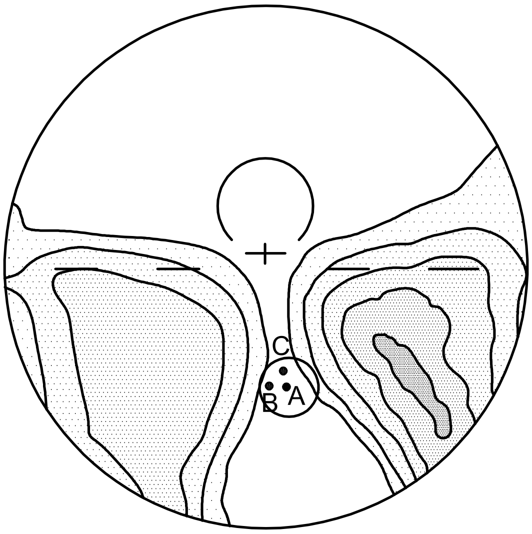
Another source of measurement error is the positioning of the correct area of the lens on the focimeter aperture. This issue is particularly important when measuring progressive power lenses. Indeed, if the focimeter axis is not centred on the reference point of the lens, as indicated by the manufacturer, the power and astigmatism differ from that specified. In addition, the non-permanent reference marking is normally applied to the front side of progressive lenses. When measuring such lenses at back vertex, there is increased difficulty in positioning the back vertex point accurately in relation to the markings on the front side.

The following example, illustrated in Figure 12, demonstrates the sensitivity of displacement and what a focimeter would read on a +3,00 D lens with 2,00 D addition power. At the near reference point (NRP, point A in Figure 12), the reading is 0,05 D of cylinder, while at a point only 2 mm away, the measurement can go up to 0,35 D of cylinder. Note that different designs of progressive power lenses will give different results.

Figures 13 and 14 provide graphs of the inter-laboratory measurements showing the average range (difference between minimum and maximum values) of five measurements taken with repositioning of the lens on the focimeters, and four measurements taken without repositioning the lens on the focimeters.

As explained before, positioning is more sensitive when measuring the near power on progressive power lenses, and this error can take more than half of the ISO addition power tolerance when measuring near power.

In other cases, the range remains within the focimeter's accuracy. Nevertheless, it should be noted that for the near power of a 0,00 D bifocal lens, measured with lens repositioning, a value lying outside the expected range was obtained from the measurement study.



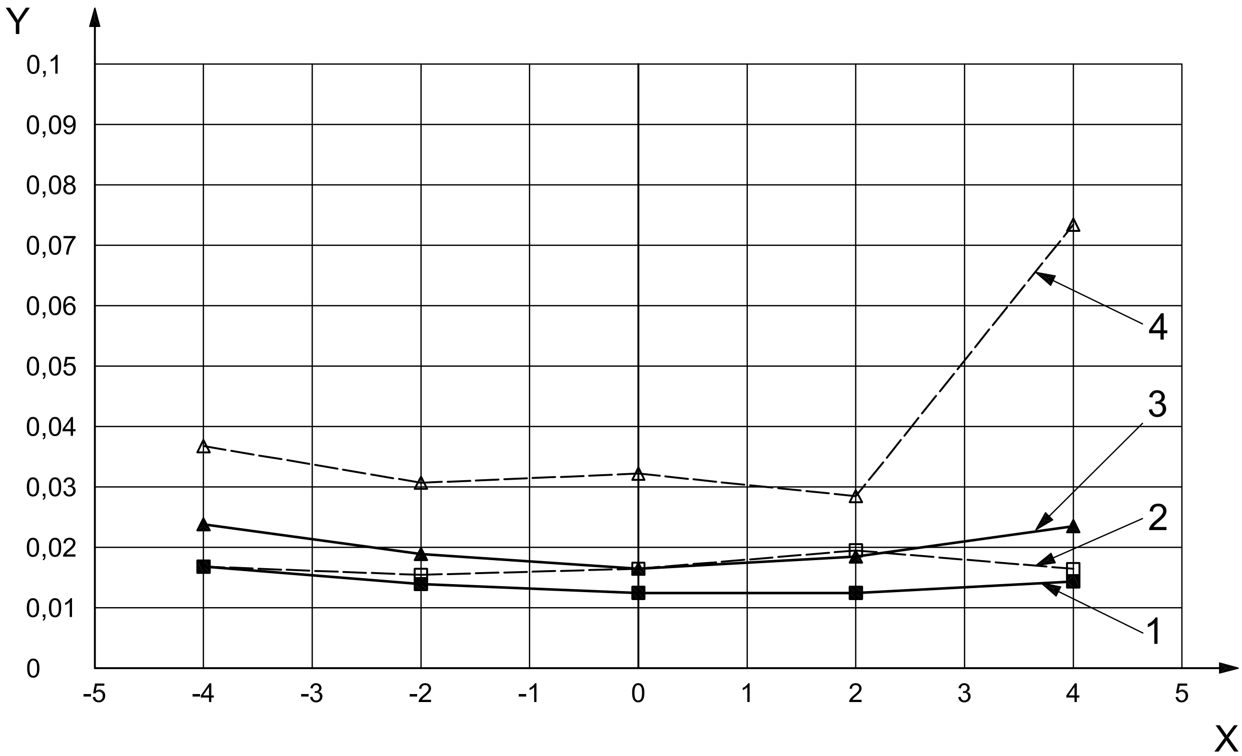
Key

A near reference point (NRP), cylinder reading 0,05 D

B a point 2 mm away from the near reference point A, cylinder reading 0,35 D

C a point 2 mm away from the near reference point A, cylinder reading 0,10 D

Figure 12 — Measurements of cylinder power done by a focimeter on the NRP (point A) and on points B and C, both 2 mm away from the NRP



Key

X nominal distance power, in dioptres

Y range, in dioptres

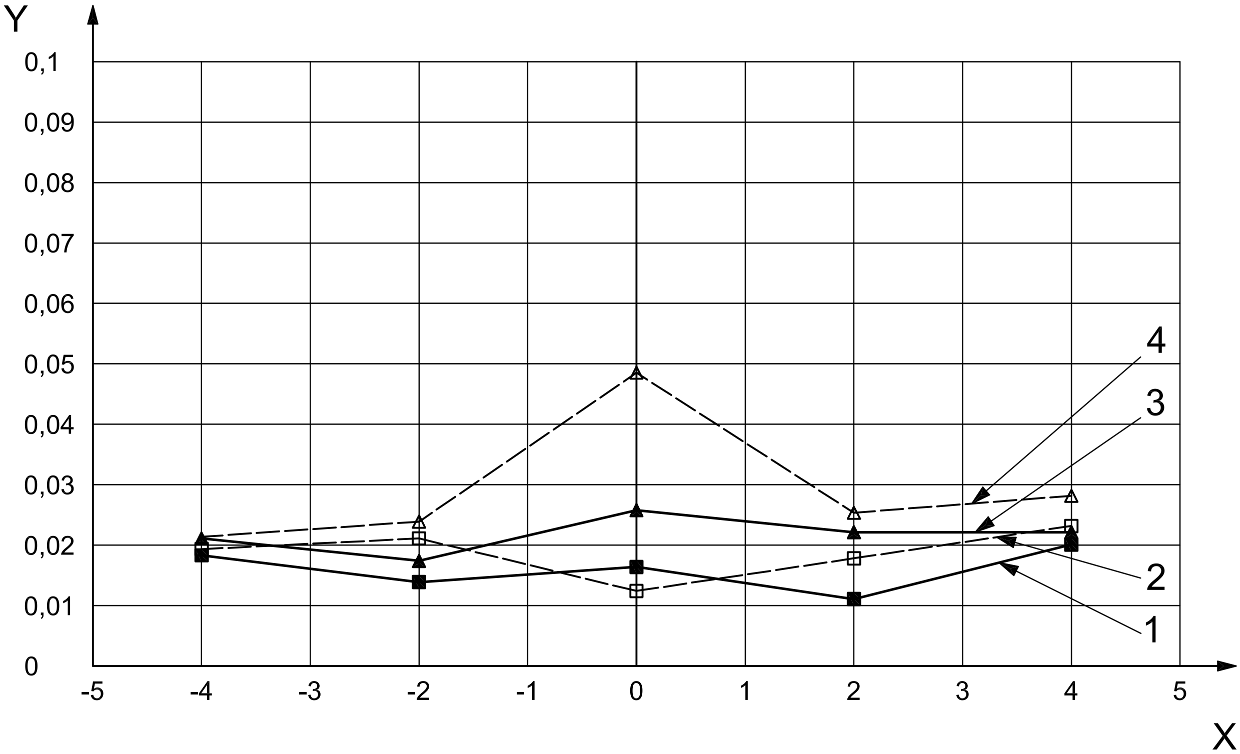
1 range for distance power, without repositioning

2 range for distance power, with repositioning

3 range for near power, without repositioning

4 range for near power, with repositioning

Figure 13 — Average range of five measurements taken with repositioning of the lens for the progressive power lenses, and four measurements taken without repositioning
(back vertex powers measured on FOA focimeters at the spherical equivalent, addition power 2,50 D)



Key

X nominal distance power, in dioptres

Y range, in dioptres

1 range for distance power, without repositioning

2 range for distance power, with repositioning

3 range for near power, without repositioning

4 range for near power, with repositioning

Figure 14 — Average range of five measurements taken with repositioning of the lens for the bifocal lenses, and four measurements taken without repositioning
(back vertex powers measured on FOA focimeters at the spherical equivalent, addition power 2,50 D)

5 Conclusion

This Technical Report considered the influence on the power measurement of:

— focimeter optical design,

— target pattern,

— front vertex versus back vertex measurement,

— reference wavelength for measurements,

— temperature of measurements,

— choice of focus, and

— lens positioning.

The largest error values under normal conditions and after calibration for each parameter are summarized in Table 1 for bifocal and progressive power lenses in the distance power range of –4,00 D to +4,00 D and addition power of 2,50 D, as used in the inter-laboratory study.

Table 1 — Summary of the inter-laboratory measurement and theoretical results

	Measurement discrepancies					**Systematic errors**		**Random Errors**	
	FOA – IOA designs	Wave-length	Target pattern	Choice of focus	Front vs. back vertex	Lens sag Error	Tem-perature	Manual focimeter focusing issues (7 mm aperture)	Lens posi-tioning
Largest error value[a]	0,09 D	0,03 D	0,04 D	0,03 D	0,46 D	< 0,01 D	0,02 D	< 0,04 D	0,07 D

[a] Under normal conditions and after calibration, for bifocal and progressive power lenses in the distance power range of –4,00 D to +4,00 D and addition power of 2,50 D.

The major difference is between front vertex and back vertex measurements. Addition power measurement is strongly dependent on near power measurement, but may show different results, e.g. a discrepancy of 0,26 D for front vertex versus back vertex power measurement. It is therefore strongly recommended to specify the addition power measurement method with the measurement result.

The second largest errors are linked to lens positioning and to focimeter design (FOA-IOA). Lens positioning error can be corrected by averaging measurements and an efficient positioning system. Nonetheless, it is not possible to relate the measurement result from an IOA focimeter to an FOA focimeter without knowing all the lens and instrument properties, and using proper software.

The effects of all other parameters fall within the accuracy of most instruments (0,02 D to 0,04 D).

It should also be pointed out that some of the errors shown in Table 1 (lens sag error, temperature dependence and reference wavelength) are theoretical and were not measured in the inter-laboratory study. Lens sag error can be corrected with good calibration, provided the base curve (curvature of the back surface) of the test lens is similar to that of the lens. Lens sag error becomes significant only for higher powers.

Finally, it should be noted that the errors shown in Table 1 are those for lenses used in the inter-laboratory study. Lenses outside the power range used in this study may give greater errors, as may astigmatic lenses.

Bibliography

[1] BORN, M. and WOLF, E. 1975, Pergamon Press Principles of Optics, New Physical Notebook

[2] SHANNON, Wyant 1980 Applied Optics and Optical Engineering, New York, Academic — 13 volumes

[3] MALACARA, D. and MALACARA, Z. Handbook of Lens Design, Marcel Dekker, Inc.

[4] ISO 8598, *Optics and optical instruments — Focimeters*

[5] ISO 9342-1, *Optics and optical instruments — Test lenses for calibration of focimeters — Part 1: Test lenses for focimeters used for measuring spectacle lenses*

[6] ISO 8980-1, *Ophthalmic optics — Uncut finished spectacle lenses — Part 1: Specifications for single-vision and multifocal lenses*

[7] ISO 8980-2, *Ophthalmic optics — Uncut finished spectacle lenses — Part 2: Specifications for progressive power lenses*

[8] "ISO_TR_28980_Interlaboratory_study_-_Summary.xls" available at: http://isotc.iso.org/livelink/livelink.exe/4178757/_ISO_TR_28980_Interlaboratory_study_-_Summary.xls?func=doc.Fetch&nodeid=4178757

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