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Ophthalmic optics – Spectacle lenses – Power and prism measurements

Optique ophtalmique – Verres de lunettes – Mesures de puissance et de prisme

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ISO/TR 11797 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

This document work undertaken by TC172/SC7/WG3 during the systematic review of ISO 21987[6] commencing in 2014. The appropriateness and relevance of the prism and power tolerances and methodologies in ISO 8980-1[1] and ISO 8980-2[2] and ISO 21987 were investigated to help determine whether these spectacle lens standards remain relevant.

Two specific power and prism task groups were established. These two groups were tasked with reviewing tolerances and test methods with respect to current industry practices, as well as conducting a systematic review of the literature. This search of the scientific literature used the keywords ‘tolerances’, ‘prism’, ‘power’, ‘spectacle’ to identify and cross-reference studies/findings in relation to the then current tolerances used in the ISO 21987, ISO 8980-1 and ISO 8980-2, and to investigate what appropriate values might be considered to satisfy spectacle lens wearer requirements. Because the results of this literature survey were inconclusive, it was decided to launch a survey into Australian laboratory practice and yields (see 5.3).

After the review of the available literature, both groups decided that a global survey of the industry into tolerances and measuring methods (see 5.4 and 5.5) would help better to understand current industry practice, thus informing a future review of ISO 8980-1 and ISO 8980-2 and ISO 21987. Its findings could assist in harmonization as to the preferred methodology for measuring power and prism when verifying uncut lenses and finished eyewear.

Ophthalmic optics – Spectacle lenses – Power and prism measurements

1 Scope

This document describes the methods currently used in applying tolerances to the focal powers of spectacle lenses and methods that can be considered for adoption in the future; it also describes methods of measuring the prism imbalance (relative prism error) between the lenses of a mounted pair. The results of a 2014 survey of manufacturing capability for lens power and a 2018 international web survey are discussed, as are possible new methods for applying tolerances to the focal power of spectacle lenses.

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 terminological 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 Background/Technical introduction

4.1 General

Tolerances and methodology for lens power and prism assessment in standards have varied between countries resulting in different criteria for local country standards and international standards. This can lead to potential issues and barriers to trade as globally distributed product can be assessed and qualified against different quality criteria to that applied in the manufacturing country of origin.

During the revision of ISO 21987[6] in 2014 with the edition that was published in 2017, the appropriateness and relevance of the prism and power tolerances and methodologies was discussed. To help identify how relevant spectacle lens standards are, specific power and prism task groups were established. These two groups were tasked with reviewing tolerances and test methods in the light of current practices as well as conducting a systematic review of the literature with a view to informing future revisions.

4.2 Power

Historically the lens power tolerances in ISO standards and regional country standards have not been harmonized. The tolerance values allowed and the methodology of their application to measured lens powers varies internationally. There have been numerous attempts to harmonize this in the past without success.

There are primarily two different methodologies currently used when measuring and applying tolerances for back vertex power assessment of spectacle lenses. To understand these methodologies, it is important to first understand the expression of lens power and the two different cylinder conventions that are applied/used in the industry. This is discussed in detail in Clause 6.

The two different methodologies for assessing lens power and applying tolerances are as follows.

- Three-parameter methodology (sphere meridian 1 value, sphere meridian 2 value, and cylindrical power value).

  This method establishes the two principal lens powers/meridians and applies a tolerance of ± X to each principal spherical power separately, e.g., F_1 ± X tolerance and F_2 ± X tolerance. Assuming a lens has passed these criteria, a secondary level of tolerance is then applied to the Cylinder value (or absolute difference between F_1 and F_2), ABS(F_1 - F_2) ± Y tolerance, or expressed as Cyl ± Y tolerance.

- Two-parameter methodology (Sphere meridian value and Cylinder magnitude value)

  This method applies a tolerance of ± U to only one of the principal lens power meridians. It is applied to the Sphere power meridian (determined by the cylinder convention being used as described in Clause 6), e.g. Sph meridian ± U tolerance. It then applies a tolerance to the Cylinder value (or absolute difference between F_1 and F_2), e.g. Cyl ± V tolerance. This means that the tolerance on the power in the secondary principal meridian is effectively $U + V$, which is greater than that in the three-parameter method.

It is important to note that when verifying lens power, the pass/fail results are affected by the lens power tolerance methodology used and, for the two-parameter methodology, the cylinder convention applied during measurement. It is also important to note that since spectacle lens powers are ordered by a spherical and a cylindrical power, it is logical that these two parameters are those that are verified. Annex A highlights specific examples where given lenses are either passed or failed depending on the methodology and the cylinder convention used.

4.3 Prism

When ISO 21987[6] was first being developed, only the UK with BS 2738-1[7][8] and ANSI Z80.1[9] had standards on mounted lenses. Consequently, when 5.3.5 was written, the majority of the project group, who were familiar with the application of ISO 8980-1 to uncut lenses, wished to copy its philosophy in that the standard, ISO 21987:2017, 6.6 a), effectively specified that the prismatic imbalance should be verified by checking the prismatic effects at the reference points, which in this case are the centration points.

The tolerances in ISO 21987:2017, Table 5 and illustrated in its Figures 1 and 2, are written in two forms. There are constant prismatic imbalance values for lower value principal focal powers and for higher focal powers, prismatic powers indicated by Prentice's Rule. This is, effectively, a positioning error given by the multiplier (in cm), i.e., 2 mm (0,2 cm) horizontally and 1 mm (0,1 cm) vertically. Conversely, in ISO 21987:2017, Annex C, the tolerances are expressed directly as a prismatic imbalance error or a centration distance/vertical alignment error.

5 Ad hoc work group activity summary

5.1 Background

This clause discusses the activities undertaken by the Ad Hoc work group and the major outcomes. The three main areas of effort were in conducting a literature search, analysing a surfacing/fitting (edging and mounting) laboratory capability and undertaking a global industry survey/questionnaire as discussed below.

5.2 Literature search

The articles found in the literature search were used as the basis for the revised and extended Annex C.

5.3 Initial spectacle lens surfacing laboratory practice survey

5.3.1 General

A limited study was undertaken commencing in July 2014 in Australia to review the current tolerances/practices applied within a typical spectacle lens surfacing laboratory to determine if the tolerance values applied were appropriate in relation to process capability. The impact of reducing or increasing the tolerances was also evaluated – see Annexes A and B. This work was primarily done to look at the effect of harmonizing the ANSI and ISO power tolerances applied to the sphere power and cylinder values, not specifically looking at the differences in methodology. The data could be re-evaluated for other methods of applying tolerances, but it would be sensible to obtain new data since manufacturing processes have changed significantly since the original data was collected.

5.3.2 Observations and conclusions from the limited study

See Annex B for the data and full conclusions. A summary of the conclusions is given here.

A yield of 96 % was achieved using the ISO tolerances but with the two-parameter method of checking the spherical and cylindrical powers when in the negative-cylinder transposition – see Clause 6.

The reject analysis shows that in the lower power ranges (0 to ±6D), the very small change to the power tolerance from 0,12D in ISO to 0,13D in ANSI would recover approximately 46 % of the rejects in this category (refer to Annex B results, Table B.3).

The graphs in the results B.4 of Annex B show that yield is significantly affected by tightening the tolerances.

Sphere power rejects were more prevalent than Cylinder power rejects (75 % to 25 %).

The significant gap in the cylinder graph analysis reflects the absence of surfaced to prescription jobs in the laboratory in the low power/low cylinder prescription area which are largely filled by Finished Stock Lens product types.

5.3.3 Historical comment

Spectacle lenses are typically available in 0,25 D steps, so it is logical that the tolerance on power was chosen to be half this interval, i.e., 0,125 D. Since the industry works to only two places of decimals, many countries and the ISO standards have used 0,12 D as the tolerance on most spherical and cylindrical powers, though in the USA, 0,13 D has generally been used. Annex B gives some data on the increase in yields that this extra 0,01 D would make.

5.4 Global survey/questionnaire (see Annex D)

The review of the available literature gave no firm conclusions on either the methodology to measure focal power and prismatic imbalance or the tolerances to be applied. Hence the ISO spectacle lens working group decided that a survey of the industry (optometric, dispensing, retail optical and manufacturing) would help it to better understand current industry practice, thus informing this Technical Report to be considered in future revision of the relevant standards used by the industry, specifically ISO 21987 (mounted spectacle lenses) and ISO 8980-1 and ISO 8980-2.

The questionnaire was produced to gather data on actual ‘industry practice’, standards awareness and interpretation, with a specific focus on the areas of lens power and prism assessment. The questionnaire was sent out world-wide in 2018. There were a number of limitations associated with conducting and analysing the survey. These includes the disproportionate representation of ISO countries and the very large representation of some countries. Some of these limitations were overcome by normalising the data.

The results, which are presented in Annex D, were reviewed at the ISO TC 172/SC7/WG3 meetings in Dallas in November 2019.

The Working Group (WG) decided that an executive summary (see below) be prepared to provide the basis for recommendations for this technical report.

5.5 Executive summary of the global survey sent to ISO/TC172/SC7/WG3

Over 70 % of industry practice use a two-parameter (Spherical and Cylindrical) power tolerance methodology.

A large proportion of respondents use increments of 0,25 D or 0,25 Δ when measuring lenses, (81 % for power and 60 % for prism).

The survey results show that 95 % of the industry now works in minus cylinder convention.

(The two-parameter methodology gives rise to the situation where some specific jobs pass power tolerance requirements when assessed applying the Minus cylinder convention but fail the tolerance requirements when assessed in the Plus cylinder convention (see Annex A). This can be managed by clearly stating the cylinder convention used. Historically with a larger percentage of the industry working in plus cylinder convention, the two-versus three-parameter power methodology had a larger impact. Now that 95 % of the industry work in the minus cylinder convention, the occurrence of these contrary pass/fail situations is minimal).

In general, practice and methodology for prism verification varied significantly with a variety of procedures and ‘interpretations’ of the standard performed, the majority of which, employing a methodology that differed from the reference method in the standard.

A significant section (41 %) of the marketplace demonstrated a lack of understanding of ‘compensated’ verification power and prism check off values. (This is likely to cause many more correctly manufactured jobs to be rejected for power compliance than jobs rejected because of a two-parameter power methodology being implemented.)

The survey suggests that for the next revision, the ISO spectacle lens working group could consider the following points:

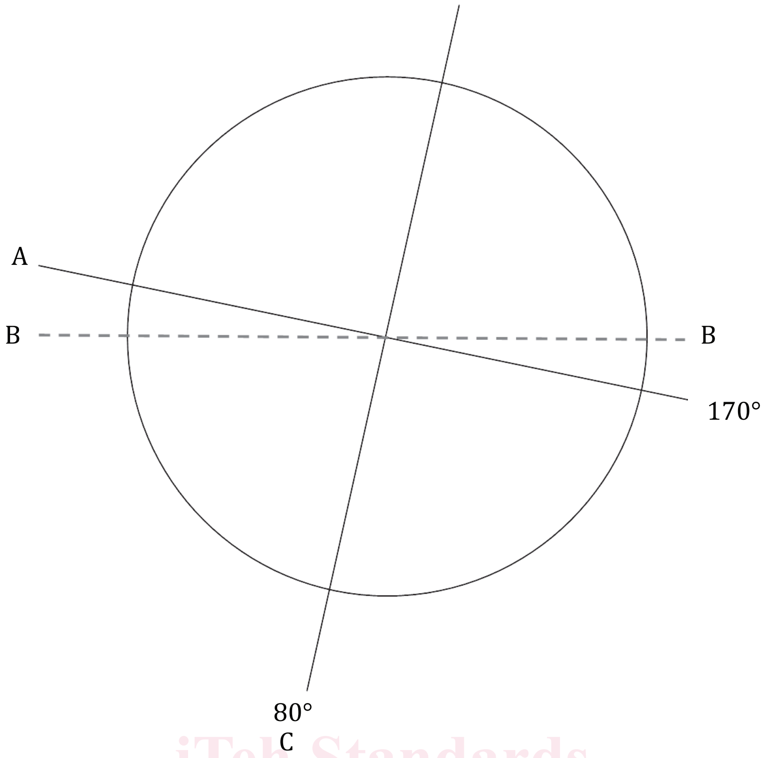
- For the focal power tolerancing clauses in the Standards, based on the general practice occurring in the industry, a discussion on changing the methodology to a two-parameter (Spherical and Cylindrical power) tolerancing approach would be worthwhile. The fact that 95 % of the manufacturing and dispensing industries now work in minus cylinder convention helps support this.
- For the prism imbalance methodology in ISO 21987, given that most users did not follow the current reference method in ISO 21987, it is clear that a different approach is required. It is understood that agreement on this approach is unlikely to be easy to achieve and therefore having a single reference method might not be possible. However, it would be logical if the reference method in the standard reflected the majority’s practice method in the industry.
- Given the confusion still evident in the industry on verifying powers against ordered or verification (supplied compensated) values, development of appropriate educational materials would be helpful while any future revision of the standard could seek to make this clearer.
- The survey conducted has generated a database of useful information that can be accessed and used by WG3 for reference as other standards are revised/created. A more detailed survey result report for all the 18 questions is given in Annex D.

6 Detailed lens power assessment methodologies

6.1 Two-parameter and three-parameter methods

6.1.1 General

When describing spectacle lens powers, the lens is considered to have two principal meridians with back vertex powers of F_1 and F_2 and their orientations in relation to a horizontal reference axis line. (In the case of spherical lens powers, F_1 and F_2 are always nominally the same). There are two principal conventions used in the industry to do this; these depend upon which of these two meridians is used as reference. The example used below is for a lens that has back vertex principal powers of +3,00 and +1,00 along 170° and 80°[1].



Key

A power along 170° meridian = +3,00 D
B 0 to 180 reference meridian
C power along 80° meridian = +1,00 D

Figure 1 — Diagram showing principal power meridians

- **"Minus" cylinder convention** – This convention takes the more positive (or less negative) powered principal meridian as the "Sphere" meridian and the less positive (or more negative) powered meridian as the secondary principal meridian. The cylindrical value is the difference between the power in this secondary principal meridian and the power in the sphere meridian, and hence has a negative power.

  In this example, the two principal powers are +3,00 and +1,00 with the +3,00 meridian considered as the "Sphere" power meridian; its power is along the 170-degree reference meridian – see Figure 1. The lens power is therefore expressed as Sph +3,00/Cyl -2,00, together with a cylinder axis of 170, which is at right angles to the orientation of the second principal meridian and parallel to the sphere principal meridian.

- **"Plus" cylinder convention** – This convention takes the more negative (or less positive) powered meridian as the "Sphere" meridian and the secondary principal meridian as the more positive or less negative powered meridian. The cylindrical value is the difference between the power in this secondary principal meridian and the power in the sphere meridian, and hence has a positive power.

  In this example, the two principal powers are +3,00 and +1,00 with the +1,00 meridian considered as the "Sphere" power meridian; its power is along the 80-degree reference meridian – see Figure 1. The lens power is therefore expressed as Sph +1,00/Cyl +2,00, together with a cylinder axis of 80, which is also at right angles to the axis in the "minus" cylinder convention.

  The two current different methodologies for assessing lens power and applying tolerances have been described in Clause 4. Depending on the method chosen (two- or three-parameter methodology) and

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[1] The degree sign is often omitted, to avoid possible confusion between, say, a badly written 10° and 100 or vice-versa.

the cylinder convention used, the pass/fail criteria is affected, and specific lenses assessed for power that pass under one set of conditions can fail when the alternative methodology is applied. Annex A highlights specific examples where this occurs.

6.1.2 Impact of the differences in the power assessment methodologies

- The requirements of spectacle lens standards vary from country to country depending on the methodology used in a particular standard.
- Implications on yield and processing cost: the three-parameter tolerance method has the potential to fail a small percentage of lenses that would pass the two-parameter method. Lenses that were manufactured and checked using the two-parameter approach and passed a manufacturing Quality criterion could be rejected by an end user who applies a three-parameter methodology on incoming inspection quality assessments. (Some examples of this are illustrated in Annex A).
- Differences in instrumentation used to determine lens power: some instruments can measure and resolve lens power results using either of the two methodologies above. These instruments can record and display results in either the two- or three-parameter formats. Such instruments are usually more sophisticated and expensive. Many instruments measuring lens power (focimeters or lens meters) are configured to determine and report lens power using the “two-parameter” approach, i.e. Sphere and Cylinder values. Typically, these instruments are simpler in operation and more affordable. Often, multiple units are implemented in a lens processing facility and these types of instruments are also more likely to be used in an Eye Care Professional’s or Retail store's environment.
- Interpretation and ‘ease of use’: where instrumentation does not support the three-parameter approach, it is a more complicated process to compute and apply this methodology if the referenced standard requires it.
- Where manual focusing focimeters are used, the ability to determine the lens power for each meridian precisely might be difficult due to the marked scale increment and resolution typically used by such instruments and the subjective interpretation of the two focal endpoints by the operator. For historical reasons, the simpler two-parameter approach is often applied with such instruments.

6.1.3 Power assessment methodologies considered in the survey

Although the two-parameter and three-parameter verification methods are the ones in common use, and hence investigated in the world-wide survey and in detail in this document, other methods of applying tolerances that could be considered in future revisions of the relevant standards are summarised and presented in 6.2 to 6.5. 6.1.4 includes a comparison of the tolerance ranges applicable to most lenses under the two- and three-parameter methods and a method based on the mean spherical and cylindrical powers. This shows that the two-parameter method has a more relaxed tolerance for the secondary principal meridian.

6.1.4 Numerical comparison of the two- and three-parameter methods

In the three-parameter method, the same tolerance is applied to the powers in both principal meridians. – see the top rows of Table 1 for an example of a lens of nominal power Sph +3,00 D/Cyl -2,00 D, which has a nominal power of +1,00 D in the second principal meridian.

Table 1 — Comparison of three and two-parameter methods and effects on the mean sphere

		Primary principal power	Cylindrical power	Secondary principal power	Mean sphere
Nominal		**+3,00**	**-2,00**	**+1,00**	**+2,00**
Three-parameter	Error	+0,12	correct	+0,12	+0,12
	giving	+3,12	-2,00	+1,12	+2,12
Two-parameter	Error	+0,12	+0,12	**+0,24**	**+0,18**
	giving	+3,12	-1,88	+1,24	+2,18

The two-parameter method can, however, be criticized for allowing cumulative errors on the second principal meridian if the errors in both the spherical and cylindrical powers are in the same direction. (The permissible error in the second meridian is the tolerance on sphere plus tolerance on cylinder.) Thus, in the example above, the lens could be made as Sph +3,12 DS/Cyl -1,88 DC giving a power of +1,24 D in the second principal meridian, an error of 0,24 D; see the lower rows of Table 1. Moreover, as the cylindrical power increases, the permissible tolerance increases, allowing the power in the second meridian (and therefore also in the mean sphere) to deviate even further from its intended value.

Furthermore, because the two-parameter method specifies that the minus cylinder convention is used, the method can give rise to different tolerances when a cylinder is present for positive and negative lenses of the same absolute powers (i.e. when the + or – signs are ignored). In the example in Table 2, the positive lens has a higher spherical or primary principal power. Taking table 1 from ANSI Z.80 as an example, the plus lens falls into the >6,50 D category, the minus lens in the <6,50 D category. The three-parameter method on the other hand always chooses the tolerance band on the meridian with the higher absolute value.

Table 2 — Tolerances for plus and minus lenses of the same absolute powers

		Primary principal power	Cylindrical power	Secondary principal power	Mean sphere
Plus lens	Nominal	**+7,50**	-4,00	+3,50	+5,50
Minus lens	Nominal	**-3,50**	-4,00	-7,50	-5,50

Summing up, the two-parameter method does not only allow for increased blur but also introduces asymmetric distribution between the two meridians and a difference in tolerances between plus and minus powered lenses of the same absolute power. Neither of these has any technological nor any physiological justification but only originates from the sign convention for writing prescriptions and orders.

6.2 A mean sphere (spherical equivalent power) and cylinder method

Rather than applying the tolerances to one or both principal powers, a tolerance could be applied to the mean sphere[2]. This gives a result that is between those for the two- and three-parameter methods. If the tolerances are applied to the two principal meridians, the mean sphere therefore also cannot deviate by more than this tolerance, as in the top example of Table 1. For the lens at the bottom of Table 1, the principal powers are +3,12 D and +1,24 D, giving a mean sphere of +2,18 D instead of the ordered +2,00 D, which is outside the tolerance if the same value of 0,12 D is applied. (For the mean sphere, the two-parameter method gives a permissible error of the tolerance for the sphere plus half of the value of the tolerance for cylinder.) If the present 0,12 tolerance is applied to the mean sphere and the cylindrical power, then the powers with the largest error are Sph +3,12 D/Cyl -2,00 D or Sph +3,18 D/Cyl -2,12 D (or the opposite error equivalents) – See Tables 1 and 3.

Thus, when the tolerances are applied to the mean sphere and the cylindrical power, the potential blur on the wearer's retina is better controlled than with the two parameter methods while at the same time relaxing tolerances on the individual meridians.

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[2] The mean sphere is half the algebraic sum of the two principal powers.

Table 3 — Comparison of the mean sphere method on the principal and cylindrical powers

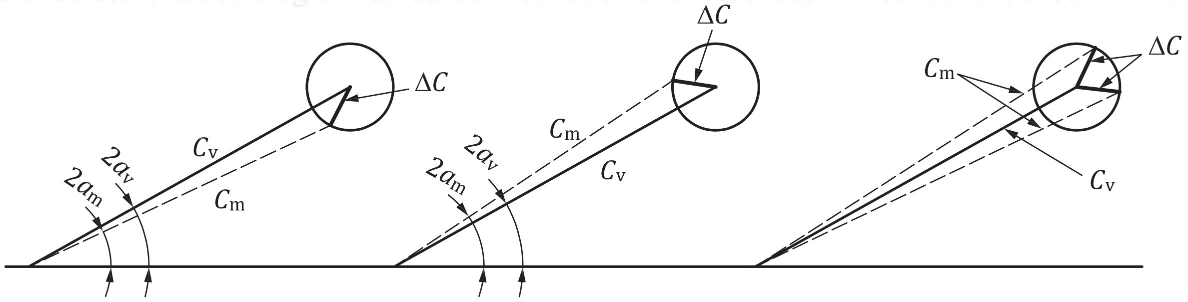
		Primary principal power	**Cylindrical power**	**Secondary principal power**	**Mean sphere**
Nominal		**+3,00**	**-2,00**	**+1,00**	**+2,00**
	Error	+0,18	-0,12	+0,06	+0,12
	giving:	+3,18	-2,12	+1,06	+2,12
	Error	+0,06	+0,12	+0,18	-0,12
	giving:	+3,06	-1,88	+1,18	+2,12
	Error	-0,18	+0,12	-0,06	-0,12
	giving:	+2,82	-1,88	+0,94	+1,88
	Error	-0,06	-0,12	-0,18	-0,12
	giving:	+2,94	-2,12	+0,82	+1,88

Calculating the mean sphere for this example of ordered power is relatively simple. For other ordered powers, such as Sph +3,25/Cyl -1,75 or verification powers or measured powers such as Sph +3,21/Cyl -1,83 is somewhat more difficult and requires a pen and paper or a calculator[3].

6.3 A mean sphere (spherical equivalent power) and astigmatic difference method

Another issue is the tolerance on astigmatism. At present, cylindrical power and cylinder axis are toleranced as separate entities although they act together, errors in either or both giving rise to an unwanted astigmatic error. This can be demonstrated with a focimeter or lens meter, any two cylindrical powers at any orientation with respect to each other except for a 0° or 90° angle compound to a spherocylindrical power. This applies also to differences between cylindrical powers or axes. Moreover, the greater the cylindrical power, the greater the unwanted astigmatic error for the same error in cylinder axis. To take this into account, the tolerance on axis is stricter for higher cylindrical powers than for lower ones.

A more systematic way might be to tolerance the difference in astigmatic effects[4] directly. Geometrical and mathematical methods of calculating this difference are given in F.2 in the Annex. Using the geometrical method described there, Figure 2 shows a verification cylindrical power of -1,00 × 15, with measured powers of, from left to right, -0,90 × 13, -0,90 × 17 and -1,10 × 13 and × 17.



Key

C_v	is the verification or ordered power
C_m	is the measured power
ΔC	is the induced unwanted cylindrical power

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[3] However, even with the two-parameter method today, more complex calculations can be necessary, e.g., when using ANSI tolerances for a single vision lens with +2,50 D sph and 4,75 D cyl, obtaining the tolerance in the cylindrical power requires the calculation of 4 % of +4,75D (= 0,19 D).

[4] The astigmatic effect is the combination of the cylindrical power and cylinder axis.