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(71) Applicant: CARL ZEISS VISION INTERNATIONAL
GMBH [DE/DE]; Turnstrasse 27, 73430 Aalen (DE).

(72) Inventor; and

(71) Applicant (for US only): SPRATT, Ray, Steven [US/US];
1848 Adobe Creek Drive, Petaluma, CA 94954 (US).

(74) Agent: OTTESEN, Christian; Walter Ottesen, P.A., P.O.
Box 4026, Gaithersburg, MD 20885-4026 (US).

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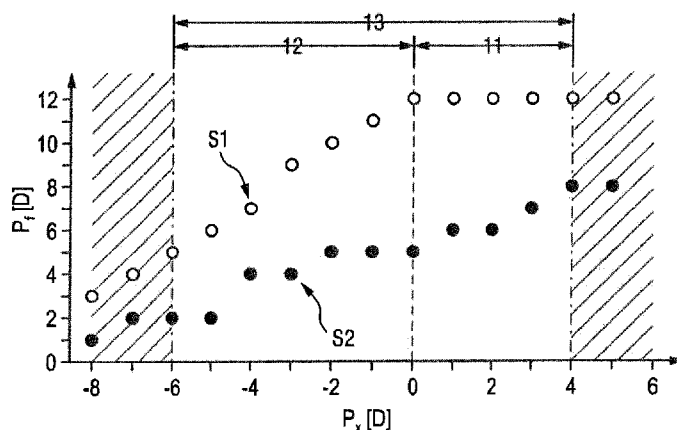


Fig. 2

(57) Abstract: The present invention relates to a series of lenses (20), each lens having a spherical front surface (21) and an aspheric, atoric or freeform back surface (22); wherein each lens of the series provides a focal power P_x between -6 D and +4 D; and wherein at least one lens (20) of the series provides a focal power P_x between at least one of (a) -0.75 D and +2.25 D and (b) -0.5 D and +2.00 D; wherein, for an upper range 11 of focal powers, lenses having same nominal front surface power are provided; and wherein, for a lower range 12 of trough powers, lenses having same minimum nominal back surface power are provided; the spherical front surface having a nominal front surface power P_f and the back surface having a minimum nominal back surface power P_b ; wherein $15.5 \text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5 \text{ D}$ applies for each spectacle lens of the series. The present invention further relates to a method 70 of determining a lens design.

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Reduced distortion spectacle lens

FIELD OF THE INVENTION

[0001] The present invention relates to a series of spectacle lenses. Further, a method for designing a spectacle lens, eyeglasses, a spectacle lens, a method for manufacturing a spectacle lens, and a computer program product are provided.

BACKGROUND OF THE INVENTION

[0002] Conventional lens design teaches that the front surfaces of spherical lenses must follow Tscherning's ellipse to produce high quality lenses.

[0003] Tscherning's ellipse describes a relationship between front surface curvature and focal power. First described nearly 100 years ago, it attempts to identify combinations of lens curvature and focal power which have minimum aberration. The general form of the Tscherning ellipse is shown in Fig. 1 for assumed typical values of lens parameters such as index of refraction, vertex distance, lens thickness, etc. The horizontal axis denotes the focal power P_x in diopters [D], whereas the vertical axis denotes the base curve or front surface power P_f in diopters [D].

[0004] For each focal power there are two front curves or corresponding front surface powers which provide good optics, locally optimal. The lower portion 2 of the ellipse 1 is the so-called "Ostwalt section" which describes a selection of relatively flat front surfaces. The upper portion 3 of the curve is the so-called the "Wollaston section" which describes much more steeply curved lenses. However, such steeply curved lenses have never gained much acceptance as lens forms. A specific case of lenses with steeply curved front spherical surfaces are lenses for treatment of aphakia (absence of the natural lens of the eye as in the case of surgical removal of the lens). Such lenses serve essentially as an eye lens replacement and are characterized by great thickness and high plus power (greater than +5 D and typically +12 D or greater).

[0005] A drawback of Wollaston section lenses is that due to the large front surface curvature such lenses cannot be fitted like panes into a single frame size, but, in fact, each prescription itself would dictate its own specialized frame size and style.

[0006] In this context, US 6,142,624 teaches a lens wherein the front surface is spherical, having a fixed radius of less than 35 mm for all prescription values in the series. Hence, it is suggested that lenses having the same front surface power can be used for the entire series of lenses. Further, a radius of a reference sphere or shell and a location of the lens as worn are such that the center of the reference sphere or shell lies close to or within the centroid of rotation of the eye. Thereby, a large field of view with low aberrations can be provided.

[0007] Nonetheless, conventional spherical lenses closely follow the flatter, lower Ostwalt section front curvature, even though the higher base curve branch produced lenses with less distortion. The vast majority of conventional prescription lenses are relatively flat, single vision, meniscus lenses which are glazed like window panes into flat outline spectacle frames. Conventional aspheric lenses generally use flatter base curves even than suggested by the Ostwalt section of Tscherning's ellipse. This can result in thinner and lighter lenses.

[0008] US 3,960,442 discloses an ophthalmic lens series incorporating an aspheric, atoric design concept which shall allow the selection of lens base curves substantially independently of traditional field of view or marginal error performance criteria. It is suggested to apply an aspheric correction according to a specific formula.

SUMMARY OF THE INVENTION

[0009] It is an object of the present invention to provide an improved series of spectacle lenses that overcome one or more of the difficulties identified above. It would be particularly advantageous to provide a spectacle lenses having reduced distortion without increasing blur or cost.

[0010] To better address one or more of these concerns, according to a first aspect of the invention, a series of spectacle lenses is provided, each lens having

- a spherical front surface and an aspheric, atoric or freeform back surface;
- wherein each lens of the series provides a focal power P_x between -6 D and +4 D; and wherein at least one lens of the series provides a focal power P_x between -0.75 D and +2.25 D, in particular between -0.5 D and +2.00 D;
- wherein, for an upper range of focal powers, lenses having same nominal front surface power are provided, wherein the nominal front surface power corresponds to an (actual) radius of curvature of the front surface; and
- wherein, for a lower range of focal powers, lenses having same minimum nominal back surface power are provided, wherein the minimum nominal back surface power corresponds to an (actual, negative sign) minimum absolute value of a radius of curvature of the back surface;
- the spherical front surface having a nominal front surface power P_f and the back surface having a minimum nominal back surface power P_b ; wherein $15.5 \text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5 \text{ D}$ applies for each spectacle lens of the series.

[0011] The basic idea of the invention is to provide a series of spectacle lenses that follow a high base curve design philosophy and enable reduced distortion while at the same time providing advantages with respect to manufacturing. It has been found that the combination of a spherical front surface and an aspheric, atoric or freeform back surface, in particular wherein the front surface curvature is neither on the Ostwalt branch nor on the Wollaston branch of Tscherning's ellipse, more precisely above the Ostwalt branch and/or below the Wollaston branch, can provide advantageous results regarding reduced distortion compared to existing products. The spherical front surface power in conjunction with the back surface power of the lens (together with parameters such as the lens thickness and the index of refraction of the lens material) determines the optical properties

of the lens. Herein, each lens of the series according to this first aspect is adapted to provide a focal power P_x between -6 D and +4 D. Over 95 % of all prescriptions fall within the range of -6 to +4 diopters. At least one lens of the series, in particular at least two or three lenses of the series, provides a focal power P_x between -0.75 D and +2.25 D, in particular between -0.5 D and +2.00 D. The lower boundary of the range may be one of -0.75 D, -0.50 D, -0.25 D, -0 D, +0.25 D, +0.50 D. The upper boundary of the range may be one of +0.50 D, +0.75 D, +1.00 D, +1.25 D, +1.50 D, +1.75 D, +2.00 D, +2.25 D. In the solution proposed herein, the range of focal powers, i.e. the range between -6 D and +4 D, comprises or is divided into an upper first range of focal powers and a lower second range of focal powers.

[0012] Generally, the ability of a lens to refract and to focus light - by either converging or diverging it - is referred to as its focal power or refractive power, or simply just power of the lens. In the given example, the refractive index of the lens material is assumed to be $n=1.530$, so that nominal powers correspond to actual powers. As a first order approximation, the focal power of a lens is equal to the net effect of its front and back surfaces. In this approximation, the focal power of lens, in diopters, can be given by:

focal power = front surface power + back surface power;

or

$$P_x = P_f + P_b \quad (1),$$

where P_x is the focal power of the lens in diopters, P_f is the front surface power in diopters and P_b is the back surface power in diopters. For example, for a lens with a +6.00 D front surface power (corresponding to a front surface curve of +88 mm radius for a lens material having a refractive index of $n=1.530$) and a -4.00 D back surface power (corresponding to a back surface curve of -0.13 m radius for a lens material having a refractive index of $n=1.530$), the focal power P_x is equal to $P_f + P_b = 6.00 + (-4.00) = +2.00$ D. It will be appreciated that this approximation changes slightly when also the lens thickness is considered which is left out here for simplification. For astigmatic or progressive lenses, the equation may only apply along a meridian, more specifically along the principal meridian with the lower curvature or numerically lower value.

[0013] As can be seen from this approximation, for a constant nominal back surface power, the focal power of the lens scales linearly with the nominal front surface power. Correspondingly, for a constant nominal front surface power, the optical power of the lens scales linearly with the nominal back surface power.

[0014] In the solution proposed herein, it is suggested to divide the range of focal powers into an upper range and a lower range of focal powers. On the one hand, for the upper range of focal powers of the proposed series, lenses having same nominal front surface power are provided. Hence, in this upper range, a variation of the focal power of the lens is effected by a variation of the nominal back surface power. This enables that for the spherical front surface in the upper range of focal powers, a steepest conventional base curve available which fits conventional frames can be selected while at the same time providing various focal powers.

[0015] On the other hand, for the lower range of focal powers of the proposed series, lenses having same minimum nominal back surface power are provided. Hereby, the nominal surface power of the back surface may be limited by the curvature that can be cut and polished with existing freeform generators, i.e. by a minimum absolute value of a radius of curvature that can be manufactured. For a concave back surface, the radius is negative. Since the back surface has a negative curvature, a minimum nominal back surface power, as used herein refers to a maximum absolute value of the nominal back surface power of a lens of the series in any location of the back surface but with negative sign, thus a minimum nominal back surface power. It will be appreciated from the above approximation that for a given steep front surface curve, an even higher nominal back surface power would be required to achieve negative focal powers. Hence, the proposed series of lenses takes this into account and uses the same minimum back surface power over the lower range of focal powers. In the lower range, a variation of the focal power of the lens is thus effected by varying the nominal front surface power of the lens.

[0016] An advantage of this approach is that it becomes possible to use a steepest conventional base curve available (which fits conventional frames) that allows the back surface to be cut and polished with existing freeform generators. In particular, the solution proposed herein can use spherical (semi-finished) lens blanks compatible with

conventional frames, along with an aspheric, atoric or freeform back surface produced by existing freeform generators. In other words, the nominal front surface power used for the front surface can be the steepest curve which is (a) compatible with existing frames, and such that (b) the back surface is not too steep to be cut and polished with freeform generators.

[0017] It shall be understood that as used herein, the same nominal surface power can refer to a value ± 0.5 diopters, in particular to a value ± 0.25 diopters. Hence, already existing spherical lens blanks which may be produced in 1 or 0.5 diopter steps can be used for the front surface. A maximum or minimum nominal surface power can thus also refer to a maximum or minimum practical implementation, in particular wherein existing manufacturing tools, forms or semi-finished lens blanks can be re-used for the high base curve design as proposed herein.

[0018] The high base curve design philosophy, wherein for each lens of the series of spectacle lenses a high curvature is provided for the front and/or back surface both in the lower range and in the upper range can be described by the expression $15.5 \text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5 \text{ D}$. For example, for a focal power of 0 D, a nominal front surface power of $P_f = +12 \text{ D}$ (corresponding to a front surface curve of 44 mm radius) and a nominal back surface power of $P_b = -12 \text{ D}$ (corresponding to a back surface curve of -44 mm radius) may be provided. For a focal power of +2 D, a nominal front surface power of $P_f = +12 \text{ D}$ and a nominal back surface power of $P_b = -10 \text{ D}$ (corresponding to a back surface curve of -53 mm radius) may be provided. For a focal power of +4 D, a nominal front surface power of $P_f = +12 \text{ D}$ and a nominal back surface power of $P_b = -8 \text{ D}$ (corresponding to a back surface curve of -66 mm radius) may be provided. For a focal power of -4 D, a nominal front surface power of $P_f = +9 \text{ D}$ (corresponding to a front surface curve of 59 mm radius) and a nominal back surface power of $P_b = -13 \text{ D}$ (corresponding to a back surface curve of -41 mm radius) may be provided. Unless otherwise stated, the refractive index of the lens material as used herein is assumed to be $n = 1.530$, so that nominal powers correspond to actual powers. Depending on the constraints due to manufacturing or spectacle frames, different boundaries may be selected. For example, a lower boundary of one of 22 D, 21 D, 20 D, 19 D, 18 D, 17 D, 16 D, 15 D, and/or 14 D; and/or an upper boundary of one of 24 D, 27 D, 28 D, 29 D, 30 D, 31 D, and/or 32 D can be set. The

relation $15.5 \text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5 \text{ D}$ shows that a high level of curvature is provided for all spectacle lenses of the series. Nevertheless, an upper threshold is provided indicating that the nominal surface powers of the spherical front surface and of the back surface are preferably selected to ensure good manufacturability. Optionally, lenses in smaller range of focal powers may be provided e.g. having a lower boundary of one of -5 D, -4D, -3 D, and/or -2 D; and/or an upper boundary of one of +1 D, +2 D and/or +3 D.

[0019] Compared to the solution proposed herein, conventional lenses generally use flatter base curves. Conventional aspheric lenses generally even use flatter base curves than suggested by the lower branch of Tscherning's ellipse. The asphericity can maintain a good optical performance in terms of blur, but the lower base curve increases the distortion.

[0020] The aforementioned US 6,142,624 can provide excellent results in terms of distortion, but required unconventional process, had limited focal power coverage and required special frames. The solution proposed herein reduces the complexity in manufacturing in that for the upper range of focal powers, where the nominal surface power of the back surface is not limiting, lenses having same nominal front surface power are provided and, in contrast to US 6,142,624, for a lower second range of focal powers lenses having same minimum nominal back surface power are provided such that the back surface can be cut and polished with existing freeform generators.

[0021] In summary, a high base curve spherical front surface in combination with an aspheric, atoric or freeform back surface under the boundary conditions that the front surface can easily be manufactured and/or be compatible with conventional frames and that the back surface curvature is compatible with freeform generators can provide an advantageous reduction of distortion compared to existing products without increasing the blur or cost.

[0022] According to a second aspect, a spectacle lens is provided. The spectacle lens has a spherical front surface and an aspheric, atoric or freeform back surface, wherein the spherical front surface in conjunction with the back surface of the lens is

adapted to provide a focal power P_x between -0.75 D and $+2.25\text{ D}$, in particular between -0.5 D and $+2.00\text{ D}$; the spherical front surface having a nominal front surface power P_f and the back surface having a minimum nominal back surface power P_b , wherein the nominal front surface power corresponds to an (actual) radius of curvature of the front surface and wherein the minimum nominal back surface power corresponds to an (actual) minimum absolute value of a radius of curvature of the back surface; wherein $15.5\text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5\text{ D}$.

[0023] Optionally, the nominal front surface power can correspond to a predetermined maximum nominal front surface power, in particular a front surface power between at least one of $+8\text{ D}$ (corresponding to a front surface curve or true base curve having a radius of $r=(1.53-1)/8\text{D}=66.3\text{ mm}$) and $+15\text{ D}$ ($r=35.3\text{ mm}$), $+8\text{ D}$ ($r=66.3\text{ mm}$) and $+13.5\text{ D}$ ($r=39.3\text{ mm}$), and $+10\text{ D}$ ($r=53.0\text{ mm}$) and $+12\text{ D}$ ($r=44.2\text{ mm}$), in particular a maximum nominal front surface power compatible with conventional spectacle frames, or the minimum nominal back surface power can correspond to a predetermined minimum nominal back surface power, in particular between at least one of -15 D ($r=-35.3\text{ mm}$) and -8 D ($r=-66.3\text{ mm}$), -14 D ($r=-37.9\text{ mm}$) and -8 D ($r=-66.3\text{ mm}$), and -13.5 D ($r=-39.3\text{ mm}$) and -10 D ($r=-53.0\text{ mm}$), in particular a minimum nominal back surface power compatible with a freeform generator. Alternatively or in addition, the nominal front surface power may correspond to a predetermined nominal front surface power between $+8\text{ D}$ ($r=66\text{ mm}$) and at least one of $+9\text{ D}$ ($r=59\text{ mm}$), 9.5 D (56 mm) and 10 D (53 mm). A positive radius may denote a convex (front) surface, whereas a negative radius may denote a concave (back) surface.

[0024] Thereby, a spectacle lens having one or more of the advantages described above is provided.

[0025] According to a third aspect, there are provided eyeglasses comprising a spectacle lenses, preferably one left and one right spectacle lens, according to the second aspect; and an eyeglass frame including left and right temple pieces and a nose bridge for supporting the spectacle lenses on a face of a wearer. The eyeglasses may comprise left and right spectacle lenses selected from a series as disclosed herein.

[0026] In this way, it is possible to produce eyeglasses which have one or more of the advantages described above.

[0027] According to a fourth aspect, there is provided a computer-implemented method for determining or designing a spectacle lens, in particular through the use of a non-transitory computer readable medium, the spectacle lens having a spherical front surface and an aspheric, atoric or freeform back surface; wherein the spherical front surface in conjunction with the back surface of the lens is adapted to provide a focal power P_x between -6 D and +4 D, in particular between -0.75 D and +2.25 D; the spherical front surface having a nominal front surface power P_f , and the back surface having a minimum nominal back surface power P_b , wherein the nominal front surface power corresponds to an (actual) radius of curvature of the front surface and wherein the minimum nominal back surface power corresponds to an (actual) minimum absolute value of a radius of curvature of the back surface; wherein $15.5 \text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5 \text{ D}$; the method comprising the steps of:

- obtaining data eyeglass prescription data of an eye of a user, the prescription data comprising a focal power;
- determining whether the focal power belongs to an upper first range of focal powers, wherein lenses having same nominal front surface power are provided; or to a lower range of focal powers, wherein lenses having same minimum nominal back surface power are provided;
- if the focal power belongs to the upper first range, selecting said nominal front surface power and determining the nominal back surface power such that the spherical front surface in conjunction with the back surface of the lens provides the focal power, or
- if the focal power belongs to the lower range, selecting said minimum nominal back surface power and determining the nominal front surface power such that the spherical front surface in conjunction with the back surface of the lens provides the focal power.

[0028] In this way, it is possible to design a spectacle lens which has one or more of the advantages described above. It shall be understood that obtaining eyeglass prescription data of an eye of a user, wherein the prescription data comprises a focal power, can more precisely refer to obtaining a design value or desired focal power value to be provided by a stock lens or prescription lens. Stock lenses may, for example, provide power values in 0.25 D steps for spherical and optionally for astigmatic correction.

[0029] According to a fifth aspect, a method for manufacturing a spectacle lens is provided, the method comprising the steps of determining a lens design for a spectacle lens according to the method of the previous aspect; and manufacturing the spectacle lens according to the lens design.

[0030] In this way, it is possible to produce a spectacle lens which has one or more of the advantages described above.

[0031] According to a sixth aspect a, in particular non-transitory, computer program product is presented comprising program code means for causing a computer to carry out the steps of the method according to the fourth aspect when the computer program is carried out on a computer or processing unit.

[0032] According to a seventh aspect, there is provided a machine readable storage medium having stored thereon a computer program comprising program code means for carrying out the steps of the method according to the fourth aspect or one of its refinements.

[0033] According to an eighth aspect, there is provided a series of spectacle lenses, each lens having

- a spherical front surface (21) and an aspheric, atoric or freeform back surface (22); wherein each lens (20) of the series (S1) provides a focal power P_x between -6 D and +4 D;

- wherein, for an upper range (11) of focal powers, lenses having same nominal front surface power (21) are provided, wherein the nominal front surface power corresponds to a radius of curvature of the front surface; and
- wherein, for a lower range (12) of focal powers, lenses having same minimum nominal back surface power (22) are provided, wherein the minimum nominal back surface power corresponds to a minimum absolute value of a radius of curvature of the back surface;
- the spherical front surface (21) having a nominal front surface power P_f and the back surface (22) having a minimum nominal back surface power P_b ; wherein $15.5 \text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5 \text{ D}$ applies for each spectacle lens of the series; and
- wherein the series comprises at least three spectacle lenses having different focal powers P_x in said upper range.

In other words, said upper range may comprise at least three pairwise different types of spectacle lens, wherein each of said different types of spectacle lens of said upper range provide pairwise different focal powers P_x .

[0034] Preferred embodiments of the invention are defined in the dependent claims. It shall be understood that the claimed eyeglasses, spectacle lenses, method, computer program and medium can have similar and/or identical refinements or preferred embodiments as the claimed series of spectacle lenses, in particular as defined in the dependent claims and as disclosed herein.

[0035] In the following, some terms which are used throughout the application, shall be shortly explained and defined:

[0036] Unless otherwise indicated, the terminology used in the context of the present application corresponds to the definitions in the standard DIN EN ISO 13666: 2013-10 of the DIN (Deutsches Institut für Normung) e.V.

[0037] The term front surface shall refer to that surface of the lens portion intended to be fitted away from the eye, cf. No 5.8 of the standard DIN EN ISO 13666. The term back surface shall refer to that surface of the lens portion intended to be fitted nearer to the eye, cf. No 5.9 of the standard DIN EN ISO 13666.

[0038] The term spherical surface shall refer to a part of the inside or outside surface of a sphere, cf. No 7.1 of the standard DIN EN ISO 13666. The term aspherical surface shall refer to a part of a surface of revolution having continuously variable curvature from the vertex to the periphery, cf. No 7.3 of the standard DIN EN ISO 13666. Hence, in common usage an aspherical surface refers to a rotationally symmetric non-spherical surface, i.e., not just a surface that is not a sphere.

[0039] A meridian (of a surface) shall refer to any plane which contains the center(s) of curvature of a surface, cf. No 5.7.1 of the standard DIN EN ISO 13666. A meridian (of a lens) shall refer to any plane which contains the optical axis of a lens, cf. No 5.7.2 of the standard DIN EN ISO 13666. The term principal meridians (of a surface) shall refer to those meridians of a surface which show the maximum and minimum curvatures on measurement, cf. No 7.4 of the standard DIN EN ISO 13666.

[0040] The term atoroidal or atoric surface shall refer to a surface having mutually perpendicular principal meridians of unequal curvature, of which the cross-section on at least one principal meridian is not circular, cf. No 7.6 of the standard DIN EN ISO 13666. The term atoroidal or atoric surface can refer to a surface with two orthogonal axes of reflective symmetry.

[0041] The term freeform surface shall refer to a surface not having any type of symmetry. A freeform surface has no axis or point of symmetry. A freeform surface can refer to a surface that can only be described by splines and/or nurbs. A particular advantage of a freeform surface is that it can provide an optical surface that is optimized to the peculiarities of the eye of the wearer. Thereby, a freeform back surface can be optimized for a given position of wear, for example, be optimized for blur for a given position

of wear (e.g. back vertex distance, tilt, and wrap). Optimization can be performed by known optical design tools such as by means of ray tracing design software.

[0042] The term spectacle lens shall refer to a lens intended to be used for purposes of measurement, correction and/or protection of the eye, or for changing its appearance, cf. No 7.6 of the standard DIN EN ISO 13666. In particular, a spectacle lens may refer to a lens with dioptric, in particular focal, power. Spectacle lenses may include finished and/or edged spectacle lenses, semi-finished spectacle lenses, lens blanks or molds therefor. Also included are wafers for forming laminated lenses or lens blanks.

[0043] The term curved-form lens shall refer to a lens having one surface convex (in all meridians) and the other surface concave (in all meridians), cf. No 8.2.2 of the standard DIN EN ISO 13666. Such a lens can also be referred to as a meniscus lens herein. The term spherical lens shall refer to a lens with two spherical surfaces, cf. No 8.2.3 of the standard DIN EN ISO 13666.

[0044] The term diopter shall refer to a unit of focusing power of a lens or surface, or of vergence (refractive index divided by the radius of curvature) of a wavefront, cf. No 9.1 of the standard DIN EN ISO 13666. Commonly used symbols for diopter are D and dpt. Diopters are expressed in reciprocal meters (m^{-1}).

[0045] The term plus-power lens, positive lens or converging lens shall refer to a lens which causes parallel incident light to converge to a real focus, cf. No 9.13 of the standard DIN EN ISO 13666. The term minus-power lens, negative lens or diverging lens shall refer to a lens which causes parallel incident light to diverge from a virtual focus, cf. No 9.14 of the standard DIN EN ISO 13666.

[0046] The term base curve shall refer to a nominal surface power (or nominal curvature), unless stated otherwise of the front surface, cf. No 11.4.1 of the standard DIN EN ISO 13666. The base curve can thus refer to a surface power in diopters for a refractive index of $n=1.530$.

[0047] The term nominal front or back surface power as used herein refers to the surface power assuming a fixed refractive index of the lens material of $n=1.530$. In other words, a standardized refractive index is used, cf. also No 11.4.1 and No. 11.4.3 of the standard DIN EN ISO 13666. The nominal surface power can thus be seen as a (geometric) property of the surface independent of the actual lens material. The nominal surface power can also be referred to as the curvature of the surface and by convenience is also given in the diopters. For a (spherical) lens, the relation between the nominal surface power in diopters and the curve or radius of curvature of the lens surface in meters is given by $r = (n-1)/P = (1.530-1)/P$, wherein r is the radius of curvature, $n=1.530$ the assumed fixed refractive index and P the nominal surface power. Hence, a nominal front/back surface power can correspond to an actual front/back surface curve having a radius. A nominal surface power can be converted into an actual surface power by $P_{\text{actual}} = P_{\text{nominal}} * (n_{\text{actual}} - 1) / (1.530 - 1)$, wherein P_{actual} is the actual surface power that depends on the actual refractive index of the lens material, P_{nominal} is the nominal surface power, and n_{actual} is the actual refractive index of the lens material. Since the curvature of the front and back surface are limited by 'geometric' constraints due to manufacturing or to be compatible with conventional spectacle frames, the nominal and not the actual front and back surface powers are specified in the claims.

[0048] The actual surface power on the other hand refers to the ability of a surface to refract light and therefore requires taking into account the actual material index of the lens material to be used. The actual surface power can thus be seen as an (optical) property of the surface which depends on the actual lens material.

[0049] For the back surface, reference is made to a minimum nominal back surface power. Since the back surface usually has a negative curvature, it will be appreciated that a minimum nominal back surface power essentially corresponds to a maximum power value but with negative sign, thus a minimum nominal back surface power. Alternatively, reference can be made to a maximum absolute power provided at any location on the back surface. For a non-spherical surface, as for example in an astigmatic or progressive lens, reference can be made to the meridian of numerically lower value, cf. No 11.4.3 of the standard DIN EN ISO 13666. While the front surface as a spherical surface has substantially the same curvature over its entire surface, this does not apply to an aspheric,

atoric or freeform surface, wherein different curvatures are present on different parts of the surface. In view of the manufacturing constraint by freeform surface generators, the minimum nominal back surface power may therefore indicate the maximum negative power or curve that has to be manufactured by the freeform generator on the back surface of the lens.

[0050] Unless otherwise stated, the term focal power as used herein shall refer to an actual focal power provided by the spectacle lens. It can be understood as a corrective optical power provided by the spectacle lens as desired by the user. The actual focal power is thus the relevant parameter for the user and therefore used herein. If the actual refractive index of the lens material n_{actual} differs from the nominal refractive index of the lens material of $n=1.530$, the focal power of the lens can be approximated based on modified equation (1) given by:

$$P_x = P_{f,\text{actual}} + P_{b,\text{actual}} = (P_{f,\text{nominal}} + P_{b,\text{nominal}})(n_{\text{actual}} - 1)/(1.530 - 1) \quad (2),$$

wherein P_x is the actual focal power of the lens, $P_{f,\text{actual}}$ and $P_{b,\text{actual}}$ are the actual front and back surface powers that depend on the actual refractive index of the lens material, $P_{f,\text{nominal}}$ (or simply P_f) and $P_{b,\text{nominal}}$ (or simply P_b) are the nominal front and back surface powers for an assumed refractive index of the lens material of $n=1.530$ (corresponding to a radius of curvature of the front/back surface), and n_{actual} is the actual refractive index of the lens material. The focal power can e.g. be measured using an FOA (focal-point-on-axis) focimeter according to No 8.3.2 of the standard DIN EN ISO 13666.

[0051] It shall be understood that the absolute value signs, as for example used in $|P_b|$, provide a positive value. It shall further be understood that, for example, for a prescription with cylinder there are two focal powers as well as different back surface curvatures. As used herein, P_x refers to the smallest (signed) focal power and P_b to the minimum (signed) nominal back surface power. For example, for the minus cylinder convention a +4 D sphere with a -3 D cylinder at 90 degrees corresponds to a smallest focal power P_x of +1 D. Correspondingly, a -2 D sphere with a -1 D cylinder corresponds to a smallest focal power P_x of -3 D.

[0052] In a refinement of the series of spectacle lenses according to the first aspect, each lens can be a meniscus lens having a positive nominal front surface power (corresponding to a positive radius of curvature) and a negative nominal back surface power (corresponding to a negative radius of curvature). Such type of lens can also be referred to as a curved-form lens having a convex or positively curved front surface and a concave or negatively curved back surface. Such a type of lens can also be referred to as a bent lens having a meniscus - which means "crescent shaped" form. Bent lenses use convex front curves and concave back curves.

[0053] In a further refinement of the series of spectacle lenses, said same nominal front surface power in the upper range of focal powers can be between at least one of +8 D and +15 D, +8 D and +13.5 D, and +10 D and +12 D corresponding to a front surface curve having a radius between at least one of +66 mm and +35 mm, +66 mm and +39 mm, +53 mm and +44 mm.

[0054] The nominal front surface power in the upper range of focal powers can correspond to a (predetermined or preset) maximum nominal front surface power, in particular a maximum nominal front surface power compatible with conventional spectacle frames. In the alternative or in addition, the maximum nominal front surface power can be determined by available spherical semi-finished lens blanks in manufacturing. Advantageously, spherical semi-finished lens blanks compatible with conventional frames are used in manufacturing. Advantageously, an optical lens or series of optical lenses having a nominal front surface power between +8 D and 10.5 D (between 66 mm and 50 mm), in particular having a nominal front surface power or upper boundary of the range of +8 D ($r=66$ mm), +9 D ($r=59$ mm) or +10 D ($r=53$ mm) can be provided.

[0055] In a further refinement of the series of spectacle lenses, said same minimum nominal back surface power in the lower range of focal powers can be between at least one of -15 D and -8 D, -14 D and -8 D, -13.5 D and -10 D, corresponding to a back surface curve having a radius between at least one of -35 mm and -66 mm, -38 mm and -66 mm, and -39 mm and 53 mm.

[0056] The minimum nominal back surface power of the lower second range can correspond to a (predetermined or preset) minimum nominal back surface power, in particular a minimum nominal back surface power compatible with a freeform generator. Advantageously, the minimum nominal back surface power (i.e., negative value of a maximum amount of back surface curvature) is adapted to be cut and polished with (existing) freeform generators. In an exemplary embodiment the constraint can be that the aspheric, atoric or freeform back surface does not exceed -13.25 D in curvature in any location. Hence, the freeform generator may be capable of cutting a radius of curvature of down to $r=-40$ mm. However, it shall be understood that the given exemplary value is not necessarily a hard limit for freeform generators. It should further be highlighted that a "same" curvature can refer to a given value ± 0.5 D. Hence, spherical semi-finished lens blanks can be used for manufacturing the front surface in particular existing spherical semi-finished lens blanks having integer values of curvature which may already be available in existing manufacturing lines. In the given example, a nominal back surface power of -13 D ($r=41$ mm) instead of -13.25 D ($r=40$ mm) may thus be used in conjunction with an appropriate integer valued nominal front surface power to provide a desired focal power.

[0057] In a further refinement said upper range of focal powers can cover a range between a (predetermined or first) threshold and +4 D; and said lower range of focal powers can cover a range between -6 D and said (predetermined or first) threshold. Alternatively, different thresholds can be used for the upper and lower range. However, advantageously the desired range of focal powers of the lenses of the series are divided into two, in particular exactly two sections, referred to as the lower range and the upper range of focal powers.

[0058] In a refinement said predetermined threshold is indicative of a sum of said (same) nominal front surface power of said upper range and said (same) minimum nominal back surface power of said lower range. For example, the (same) nominal front surface power of the upper range may be indicative of a spherical semi-finished lens blanks compatible with conventional frames. For example, said (same) minimum nominal back surface power of said lower range may be indicative of a maximum negative curvature in any location of the back surface that can be manufactured by a freeform generator.

In a practical implementation of a lens series, the (same) minimum nominal back surface power is likely to have a greater absolute value than the (same) nominal front surface power. For example, assuming a spherical nominal front surface power cannot exceed 12 D ($r=44$ mm) and the nominal back surface power cannot exceed -13.25 D ($r=40$ mm), the predetermined threshold can be set at -1.25 D. However, said predetermined threshold can also be set at integer diopter values for example between -4 D to +1 D, in particular between -3 D and 0 D, preferably one of -4 D, -3D, -2 D, -1 D, 0 D or +1 D.

[0059] In an embodiment the back surface can be further adapted to provide astigmatic correction. Hence, advantageously, the astigmatic correction is provided on the back surface which can be manufactured easily by a freeform generator. It shall be understood that any effect of the astigmatic correction on the curvature may also lead to a shift of the upper and lower range such that the constraints regarding manufacturability are still met.

[0060] In a refinement, the lens of the series of lenses can be adapted as a single vision or progressive lens. Advantageously, contributions to the progressive power are also implemented by shaping the back surface. An advantage is that the back surface can easily be manufactured using a freeform generator, whereby the spherical front surface can be maintained. Hence, semi-finished spectacle lenses and/or lens blanks can be provided wherein the front surfaces of the series of lenses are already finished such that only the back surface has to be processed using a freeform generator.

[0061] In a refinement the (upper range of the) series of lens elements may comprise at least three different spectacle lenses having different focal powers P_x in said upper range. In other words, said upper range can comprise at least three pairwise different types of spectacle lens, wherein each of said different types of spectacle lens of said upper range provide pairwise different focal powers P_x . Correspondingly, in addition or in the alternative, the (lower range of the) series of lens elements may comprise at least three different spectacle lenses having different focal powers P_x in said lower range. In other words, said lower range can comprise at least three pairwise different types of spectacle lens, wherein each of said different types of spectacle lens of said lower range

provide pairwise different focal powers P_x . The focal power P_x may refer to the focal power without cylinder.

[0062] Optionally, the focal power powers P_x of at least two of said at least three spectacle lenses (of said upper range) having different focal powers P_x in said upper range may be spaced by at least 2 D, in particular by at least 3 D. Correspondingly, the focal power powers P_x of at least two of said at least three spectacle lenses (of said lower range) having different focal powers P_x in said lower range may be spaced by at least 2 D, in particular by at least 3 D. Thereby, said lower and/or said upper range each may cover a substantial portion of a range between -6 D and +4 D. In addition or in the alternative, the focal power powers P_x of at least two of said at least three spectacle lenses of said upper range may be spaced by no more than 0.5 D, in particular by no more than 0.25 D. Thereby different ranges may be addressed in a cost-effective manner with spectacle lenses having low distortion.

[0063] Optionally, the series of lens elements, in said lower range may comprise only spectacle lenses wherein the nominal front surface powers are spaced by 1 D ($\pm 25\%$). An advantages of this embodiment is that also in said lower range only a limited number of pucks having a spherical front surface e.g. at 1 D intervals have to be provided. The manufacturing cost may thus be further reduced.

[0064] It shall be understood that a single vision lens can essentially correspond to a far vision zone of a progressive lens. The features provided for the spectacle lenses of the series may apply at least for the far vision zone of a progressive lens. Advantageously, they also apply for one or more further zones of the progressive lens, for instance a near vision zone.

[0065] It is to be understood that the features mentioned above and those yet to be explained below may be used not only in the combination respectively indicated, but also in other combinations or separately, without departing from the scope of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0066] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter. In the following drawings

- Fig. 1 shows a drawing of a Tscherning ellipse including the lower Ostwalt section and the upper Wollaston section;
- Fig. 2 shows a diagram of nominal front surface power versus focal power for two series of lenses;
- Fig. 3 shows a diagram of several exemplary lenses of a high base curve lens series;
- Fig. 4 shows a diagram of distortion reduction versus focal power for the lens series of Fig. 2;
- Fig. 5 shows four graphs of ray-traced grids indicative of the distortion for four exemplary lenses;
- Fig. 6 shows a plot of the RMS blur for the lenses corresponding to Fig. 5;
- Fig. 7 shows a schematic flow chart of a method according to an aspect of the present disclosure;
- Fig. 8 shows a schematic flow chart of a further method according to an aspect of the present disclosure; and
- Fig. 9 shows eyeglasses according to a further aspect of the disclosure.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0067] Fig. 1 shows a drawing of a Tscherning ellipse 1. In 1904, M. Tscherning demonstrated mathematically that there are in fact two recommended or "best form" spherical best curves 2, 3 for each focal power of the lens: A steeper series and a flatter series. The steeper series is also referred as the Wollaston section 3 and is based upon the steeper solutions to Tscherning's formula. The lower series is also referred to as the Ostwalt section 2 and is based on the flatter solution of Tscherning's formula. The flatter Ostwalt branch of the ellipse serves as the basis for modern "best form" lenses.

[0068] Tscherning's ellipse indicates the optimum spherical base curve or nominal front surface power to use for each focal power in order to reduce or eliminate lens aberration. Conventional spherical lenses closely follow the flatter, lower curvature front, even though the higher base curve branch has been found to produce lenses with less distortion. Flatter lens forms, while thinner and lighter, however may produce significant lens aberrations, including larger astigmatic and spherical power errors in the periphery of the lens.

[0069] Conventional aspheric (and atoric) lenses generally use flatter base curves even than suggested by the lower branch of Tscherning's ellipse. This can result in even thinner and lighter lenses. The asphericity can maintain the good optical performance in terms of blur, but the lower base curve increases the distortion.

[0070] According to Tscherning's ellipse 1, each individual focal power should be made using a separate front surface curvature. Early best form lenses utilized this approach, which required a massive and costly inventory of lens blanks.

[0071] Fig. 2 shows a diagram illustrating a nominal front surface power or base curve versus the focal power P_x for a first series of spectacle lenses S1 and the second series of spectacle lenses S2. The lenses can for example be CR39 or allyl diglycol carbonate (ADC) lenses. The horizontal axis denotes the focal power in diopters [D], whereas the vertical axis denotes the nominal front surface power in diopters [D].

[0072] The series S1 shows a series of spectacle lenses according to an aspect of the present disclosure. The lenses feature a spherical front surface having respective nominal front surface powers as exemplarily shown in Fig. 2. The spherical front surfaces in conjunction with the back surfaces of the lenses of the series S1 are adapted to provide various focal powers P_x , in the given example between -6 D and +4 D. Other ranges of focal powers can be provided, for example starting from -5 D, -4 D or -3 D and ranging up to +1 D, +2 D or +3 D. At least one lens, in particular at least two, three or four lenses, of the series S1 provides a focal power P_x between 0.75 D and +2.25 D, in particular between -0.5 D and +2.00 D. It is to be understood that additional lenses can be provided between the items illustrated in Fig. 2, for example a spacing of 0.25 can be provided.

[0073] The series S1 of spectacle lenses provides a range 13 of focal powers comprising or consisting of a first, upper range 11 of focal powers and a second, lower range 12 of focal powers. For the upper range 11 of focal powers, lenses having same nominal front surface power are provided. In the given example a maximum nominal front surface power of 12 D is used. Optionally, at least two lenses of the series, for example two lenses of the upper range and/or two lenses of the lower range, are spaced by no more than 0.5 D, in particular by no more than 0.25 D in terms of their focal power P_x . In addition or in the alternative, at least two lenses of the series, for example two lenses of the upper range and/or two lenses of the lower range, are spaced by at least 2 D, in particular by at least 3 D in terms of their focal power P_x .

[0074] For example, said upper range may comprises at least three pairwise different types of spectacle lens, wherein each of said different types of spectacle lens of said upper range provide pairwise different focal powers P_x . In this case, the series may not necessarily include at least one lens of the series providing a focal power P_x between 0.75 D and +2.25 D. In addition or in the alternative, said lower range may comprise at least three pairwise different types of spectacle lens, wherein each of said different types of spectacle lens of said lower range provide pairwise different focal powers P_x . The focal power powers P_x of at least two of said pairwise different types of spectacle lens of said upper range may be spaced by at least 2 D, in particular by at least 3 D.

[0075] Advantageously, the series of spectacle lenses uses a maximum nominal front surface power available (which fits conventional frames) that also allows the back surface to be cut and polished with existing freeform generators. It shall be understood that e.g. integer diopter values may be used for the curve for ease of manufacturing and to reduce the inventory and to provide compatibility with conventional manufacturing tools and/or spectacle frames. In an embodiment said (same or constant) nominal front surface power in the upper range 11 of focal powers can be a value, i.e., the same value throughout this upper range for the various lenses of the series, between +8 D and +15 D, preferably between +8 D and +13.5 D, preferably between +10 D and +12 D, corresponding to a radius of curvature between +66 mm and +35 mm, preferably between +66 mm and +39 mm, preferably between +53 mm and +44 mm. In particular, the nominal front surface power of the upper range of focal powers can correspond to a predetermined maximum nominal front surface power, in particular a maximum nominal front surface power compatible with conventional spectacle frames and/or manufacturing tools.

[0076] As shown in Fig. 2, the series of spectacle lenses further comprises a second, lower range 12 of focal powers with lenses having same minimum nominal back surface power. As explained above, the upper range 11 of focal powers can be limited by the maximum nominal front surface power, whereas the lower range 12 of focal powers can be limited by the minimum nominal back surface power to be cut and polished with existing freeform generators. The minimum nominal back surface power herein refers to the maximum negative nominal surface power of the back surface in any location of the spectacle lens.

[0077] In lower range 12 of focal powers the (same or constant) minimum nominal back surface power in any location of the lens can be between -15 D and -8 D, preferably between -14 D and -8 D, preferably between -13.5 D and -10 D, corresponding to a radius of curvature between -35 mm and -66 mm, preferably between -38 mm and -66 mm, preferably between -39 mm and -53 mm. For example, the nominal back surface power cannot exceed 13.25 D, corresponding to a true base curve radius of $r=40$ mm, as a limit given by an exemplary freeform generator for manufacturing. Hence, the minimum nominal back surface power of the lower range may correspond to a predetermined

minimum nominal back surface power, in particular a minimum nominal back surface power or corresponding radius of curvature compatible with a freeform generator.

[0078] The series S1 of spectacle lenses may cover a range 13 consisting of a lower range 12 and an upper range 11 of focal powers. Said upper range of focal powers may cover a range between a predetermined threshold and +4 D and said lower range 12 of focal powers may cover a range between -6 D and said predetermined threshold. In an embodiment said predetermined threshold is indicative of a sum of said (same) nominal front surface power of said upper range 11 and said (same) minimum nominal back surface power of said lower range 12. For example for a nominal front surface power of said upper range of 12 D ($r=44$ mm) and a minimum nominal back surface power of said lower range of -13.5 D ($r=39$ mm), the predetermined threshold may be set at -1.5 D. It will be appreciated that the exact transition between the upper and lower range 11, 12 may depend on the steepest base curve compatible with the intended spectacle frames or manufacturing facilities such as available spherical semi-finished lens blanks on the one hand and manufacturing facilities for the nominal back surface power such as a minimum (maximum negative) curvature that can be provided by a freeform generator on the other hand. Correspondingly, referring to Fig. 2, this will impact the shape of the diagram of the spectacle series S1. In the shown example, the (same) nominal front surface power in the upper range and the (same) nominal back surface power in the lower range are assumed to be +12 D ($r=+44$ mm) and -12 D ($r=-44$ mm) respectively.

[0079] As can be seen from Fig. 2, the shape of the nominal front surface power in the lower range 12 increases almost linearly with focal power. For said same or constant minimum nominal back surface power in the lower range 12, the desired focal power P_x is adjusted by selecting spherical nominal front surface powers accordingly to provide, in conjunction with the back surface of the lens, a desired focal power.

[0080] With the solution proposed herein it is thus possible to follow a high base curve design philosophy without increasing cost for manufacturing. Furthermore it has been found that in contrast to very flat base curve designs a lower distortion can be reached.

[0081] The high base curve design philosophy is advantageously provided throughout the entire series. Hence, even for low focal powers between 0.75 D and +2.25 D, in particular between -0.5 D and +2.00 D the condition $15.5 \text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5 \text{ D}$ is met for at least one lens element, in particular for at least two, three or more (or all) lens elements.

[0082] Referring again to the lower range 12 of Fig. 2, a slope of the increase of nominal front surface power in the lower range 12 with focal power may be greater than one due to an increase in 'aspherization' for increasing minus powers. Therefore, one or more available nominal front surface powers may be skipped to get close to a maximum possible nominal front surface power without exceeding back surface curvature constraints.

[0083] Fig. 3 shows exemplary spectacle lenses of the proposed series S1 of lenses of Fig. 2. As explained above, for the upper range 11 of focal powers, lenses having same nominal front surface powers are provided and the desired focal power P_x is achieved by tailoring the back surface. For the lower range 12 of focal powers, lenses having same nominal back surface power are provided and the desired focal power P_x is adjusted by selecting the spherical nominal front surface power accordingly.

[0084] For the graph of Fig. 3, a refractive index $n = 1.53$ is assumed. It shall be understood that additional lenses as exemplarily shown in Fig. 3 can be provided for further focal powers P_x . In particular, focal powers may be provided at quarter diopter steps. In this case, the spherical front surfaces may nevertheless only be provided in full diopter steps and the nominal back surface power may be adjusted accordingly. This allows efficient manufacturing since only a limited inventory of spherical semi-finished lens blanks for generating the spherical front surface has to be provided and the back surface can be generated using existing freeform generators. Hence, for the lower range 12 of focal powers, as used herein, lenses having same minimum nominal back surface power may refer to lenses having a minimum nominal back surface power within a range of ± 0.5 diopters. It shall be understood that the minimum nominal back surface power may be limited by the minimum (negative) curvature that can be provided by the freeform generator used for manufacturing. The allowable minimum nominal back surface power can thus

lie within a tolerance band of +1.0 to -0.0 D of the said minimum (negative) curvature that can be provided by the freeform generator.

[0085] It shall be understood that also a lens material having a different refractive index may be used. For example a lens material having a refractive index of $n = 1.499$, a high-index material having a refractive index of $n = 1.670$, in general any material suitable for manufacturing a spectacle lens may be used.

[0086] Referring again to Fig. 2, a second series S2 of spectacle lenses is shown for comparison. The second series S2 follows a lower base curve. This lower base curve can be close to the Ostwalt section of Tscherning's ellipse, as shown in Fig. 1.

[0087] Fig. 4 shows a diagram comparing the distortion provided by the series of lenses S1 having a high base curve and the second series of lenses S2. The horizontal axis denotes the focal power in diopters [D], whereas the vertical axis denotes the reduction of the distortion in [%]. The graph thus compares the distortion for a low base curve design series of lenses with a reduced distortion series of lenses as proposed herein. For the graph shown in Fig. 4 the constraint is that the nominal back surface power cannot exceed 13.25 D (corresponding to having a radius of curvature of no less than 40 mm) in any location and the spherical nominal front surface power cannot exceed +12 D (corresponding to having a radius of curvature of no less than 44 mm). As can be seen from Fig. 4, the distortion can be significantly reduced with the series of lenses S1. The distortion can be reduced by more than 50 % over a significant range of focal powers P_x . For the graph shown in Fig. 4, the distortion is calculated as the difference in mean equivalent magnification at a center of a 20 m x 20 m ray-traced grid located at 10 m distance directly in front of the observer and the value at any of the corners. Even for low focal powers P_x improvement has been found as indicated by the exemplary +1 D lens of the series.

[0088] Fig. 5 shows diagrams of ray-grids for four different possible -5 D focal power single vision lenses. The designs have four different spherical front surfaces as indicated in Fig. 5; from left to right a spherical nominal front surface power of $P_f = +0.5$ D, +3 D, +8 D and +18 D (corresponding to a radius of curvature of $r = +1.1$ m, +0.18 m,

+66 mm and +29 mm). The designs corresponding to the first and third graph feature aspheric back surfaces, whereas the designs corresponding to the second and fourth graph feature spherical back surfaces.

[0089] The first design (leftmost in Fig. 5) having the +0.5 D spherical nominal front surface power is a flat base curve aspheric back surface lens. The second design having the +3 D spherical nominal front surface power corresponds to the lower branch (Ostwalt section) of Tscherning's ellipse. The third design refers to a lens design according to an aspect of the present disclosure. The fourth design having a very steep spherical back surface corresponds to the upper branch (Wollaston section) Tscherning's ellipse, as shown in Fig. 1.

[0090] In Fig. 5, the grid is assumed to be 20 m x 20 m located at 10 m distance directly in front of the observer. Hence, a field of view of $\pm 45^\circ$ is covered. Obviously, as can be seen from Fig. 5, the steeper the front curve, the less distortion of the grid. It has been found that by the proposed combination of high base curve design philosophy by using the steepest curve which is (a) compatible with existing frames and such that (b) the back surface is not too steep to be cut and polished with freeform generators an improved distortion lens can be provided with reasonable effort. The design as shown in the fourth figure of Fig. 5 further improves the distortion, however, at the cost of rather complex manufacturing and incompatibility with existing mass production processes and/or conventional frames.

[0091] Fig. 6 shows the RMS (root-mean-square) blur over ± 45 degrees of eye rotation. It can be seen that the blur characteristics of the four lenses of Fig. 5 are similar. Hence, with the design proposed herein, an improved distortion can be provided while at the same time maintaining the good RMS blur performance of best form lenses.

[0092] Fig. 7 shows a flow chart of a method 70 according to an aspect of the present disclosure. Methods, as used herein, can in particular refer to computer-implemented methods. A method may be implemented in particular through the use of a non-transitory computer-readable medium. Fig. 7 illustrates a method for determining a

spectacle lens, the spectacle lens having a spherical front surface and an aspheric, atoric or freeform back surface. The spherical front surface in conjunction with the back surface of the lens is adapted to provide a focal power P_x between -6 D and +4 D, in particular between -0.75 D and +2.25 D, in particular between -0.5 D and +2.00 D. The spherical front surface has a nominal front surface power P_f and the back surface has a nominal back surface power P_b wherein $15.5 \text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5 \text{ D}$.

[0093] Advantageously, for each lens of the series the nominal front surface power P_f is above a nominal front surface power provided by the Ostwalt section and below the Wollaston section of Tscherning's ellipse for the desired range of focal powers. The nominal front surface power may thus exceed the Ostwalt section by at least a first predetermined threshold of, for example, 1 D or 2 D and stay below the Wollaston section of Tscherning's ellipse by at least a second predetermined threshold of, for example, 1 D or 2 D. In this context, Tscherning's ellipse can be derived from the corrected von Rohr equation (after Morgan) solved for point-focal (zero astigmatism) distance vision. It shall be understood that the term determining a spectacle lens refers to (individually) designing a prescription lens for a user or selecting a (finished) stock lens.

[0094] In a first step S101 eyeglass prescription data of an eye of a user is obtained, the prescription data comprising a focal power of the eye of the user. The prescription data may also comprise position of wear information of the user such as tilt, wrap and/or back vertex distance. This enables the (freeform) back surface to be further optimized for the user. For a stock lens, the prescription data can indicate the desired focal power that the stock lens shall provide.

[0095] In a second step S102 it is determined whether the focal power belongs to an upper first range of focal powers, wherein lenses having same nominal front surface power are provided; or to a lower second range of focal powers, wherein lenses having same minimum nominal back surface power are provided. For this purpose, a function as for example shown by the series S1 in Fig. 2 that links focal powers to an upper range 11 of focal powers and a lower range of focal powers can be used. Such a function can be provided as a look-up table in a storage medium or processing unit. It is thus decided as

indicated by block S103 whether the focal power belongs to the upper first range or the lower second range.

[0096] In step S104, if the focal power belongs to the upper range, said (same) nominal front surface power is selected and the nominal back surface power is determined such that the spherical front surface in conjunction with the back surface of the lenses provides the focal power.

[0097] Alternatively, in step S105, if the focal power belongs to a lower range, said (same) minimum nominal back surface power is selected and the nominal front surface power is determined such that the spherical front surface in conjunction with the back surface of the lens provides the focal power.

[0098] In an optional further step S106, the spectacle lens is manufactured according to the aforementioned lens design. Thereby, a method for manufacturing a spectacle lens is provided.

[0099] Referring now to Fig. 8, a more abstract description of the underlying concept is provided wherein in a first step S201 eyeglass prescription data of an eye of a user is obtained, the prescription data comprising a focal power. Based thereon, in step S202, the base curve for the nominal front surface power is selected as the steepest curve which is (a) compatible with existing frames under the boundary condition that (b) the back surface is not too steep to be cut and polished with existing freeform generators. The spherical nominal front surface power is determined such that the spherical front surface in conjunction with the back surface of the lens provides the desired focal power. Based on this lens design, a spectacle lens can be manufactured in a further optional manufacturing step S203.

[00100] Fig. 9 shows eyeglasses 90 according to a further aspect of the present disclosure comprising left and right spectacle lenses 20 selected from a series of spectacle lenses S1 as described above and an eyeglass frame 91 including left and right

temple pieces 92, 93 and a nose bridge 94 for supporting the spectacle lenses on the face of a wearer.

[00101] In conclusion, a reduced distortion series of lenses is provided that enables a high base curve design philosophy while at the same time providing improved manufacturability. Current conventional lens designs tend to use the flattest practical base curve for a given focal power primarily for aesthetic reasons and to reduce the weight of the lens. However, those lenses may suffer from high levels of distortion. The design suggested in the afore-mentioned US 6,142,624 used ideal but very steep base curves producing lenses with very low distortion but required unconventional manufacturing processes, had limited focal power coverage and required special frames. The solution proposed herein, however, may advantageously enable the use of spherical semi-finished lens blanks compatible with conventional frames along with an aspheric, atoric or freeform back surface produced by existing freeform generators. Hence, a reduced distortion lens is provided which can have reduced distortion without increasing the blur or cost.

[00102] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

[00103] In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single element or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

[00104] A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as

part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems.

[00105] Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. A series (S1) of spectacle lenses (20), each lens having

a spherical front surface (21) and an aspheric, atoric or freeform back surface (22);

wherein each lens (20) of the series (S1) provides a focal power P_x between -6 D and +4 D; and wherein at least one lens (20) of the series (S1) provides a focal power P_x between at least one of (a) -0.75 D and +2.25 D and (b) -0.5 D and +2.00 D;

wherein, for an upper range (11) of focal powers, lenses having same nominal front surface power (21) are provided, wherein the nominal front surface power corresponds to a radius of curvature of the front surface; and

wherein, for a lower range (12) of focal powers, lenses having same minimum nominal back surface power (22) are provided, wherein the minimum nominal back surface power corresponds to a minimum absolute value of a radius of curvature of the back surface;

the spherical front surface (21) having a nominal front surface power P_f and the back surface (22) having a minimum nominal back surface power P_b ; wherein $15.5 \text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5 \text{ D}$ applies for each spectacle lens of the series.
2. The series of spectacle lenses of claim 1, wherein each lens (20) is a meniscus lens having a positive nominal front surface power (21) and a negative nominal back surface power (22).

3. The series of spectacle lenses of claim 1 or 2, wherein said same nominal front surface power (21) in the upper range of focal powers is between at least one of +8 D and +15 D, +8 D and +13.5 D, and +10 D and +12 D, corresponding to a front surface curve having a radius between at least one of +66 mm and +35 mm, +66 mm and +39 mm, +53 mm and +44 mm.
4. The series of spectacle lenses of any of the preceding claims, wherein said same minimum nominal back surface power (22) in the lower range (12) of focal powers is between at least one of -15 D and -8 D, -14 D and -8 D, and -13.5 D and -10 D, corresponding to a back surface curve having a radius between at least one of -35 mm and -66 mm, -38 mm and -66 mm, and -39 mm and -53 mm.
5. Spectacle lens (20) having a spherical front surface (21) and an aspheric, atoric or freeform back surface (22), wherein the lens provides a focal power P_x between at least one of (a) -0.75 D and +2.25 D and (b) -0.5 D and +2.00 D; the spherical front surface having a nominal front surface power P_f and the back surface having a minimum nominal back surface power P_b , wherein the nominal front surface power corresponds to a radius of curvature of the front surface and wherein the minimum nominal back surface power corresponds to a minimum absolute value of a radius of curvature of the back surface; wherein $15.5 \text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5 \text{ D}$.
6. Spectacle lens according to claim 5, wherein the nominal front surface power corresponds to a predetermined maximum nominal front surface power between at least one of +8 D and +15 D, +8 D and +13.5 D, and +10 D and +12 D, corresponding to a front surface curve having a radius between at least one of +66 mm and +35 mm, +66 mm and +39 mm, +53 mm and +44 mm), or wherein the minimum nominal back surface power corresponds to a predetermined minimum nominal back surface power between at least one of -15 D and -8 D, -14 D and -8 D, and -13.5 D and -10 D, corresponding to a back surface curve having a radius between at least one of -35 mm and -66 mm, -38 mm and -66 mm, and -39 mm and -53 mm.

7. Eyeglasses (90) comprising a spectacle lens (20) as claimed in claim 5 or 6; and an eyeglass frame (91) including left and right temple pieces (92, 93) and a nose bridge (94) for supporting the spectacle lenses on a face of a wearer.
8. A computer implemented method (70) for determining or designing a spectacle lens (20) the spectacle lens having a spherical front surface (21) and an aspheric, atoric or freeform back surface (22); wherein the spherical front surface in conjunction with the back surface of the lens is adapted to provide a focal power P_x between at least one of (a) -6 D and +4 D and (b) -0.75 D and +2.25 D; the spherical front surface having a nominal front surface power P_f and the back surface having a minimum nominal back surface power P_b , wherein the nominal front surface power corresponds to a radius of curvature of the front surface and wherein the minimum nominal back surface power corresponds to a minimum absolute value of a radius of curvature of the back surface; wherein $15.5 \text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5 \text{ D}$; the method comprising the steps of:

obtaining eyeglass prescription data of an eye of a user, the prescription data comprising a focal power (S101);

determining whether the focal power belongs to an upper range of focal powers, wherein lenses having same nominal front surface power are provided; or to a lower range of focal powers, wherein lenses having same minimum nominal back surface power are provided (S102, S103);

if the focal power belongs to the upper range, selecting said nominal front surface power and determining the nominal back surface power such that the spherical front surface in conjunction with the back surface of the lens provides the focal power (S104), or

if the focal power belongs to the lower range, selecting said minimum nominal back surface power and determining the nominal front surface power such that the

spherical front surface in conjunction with the back surface of the lens provides the focal power (S105).

9. A method for manufacturing a spectacle lens (20) the spectacle lens having a spherical front surface (21) and an aspheric, atoric or freeform back surface (22); wherein the spherical front surface in conjunction with the back surface of the lens is adapted to provide a focal power P_x between at least one of (a) -6 D and +4 D and (b) -0.75 D and +2.25 D; the spherical front surface having a nominal front surface power P_f and the back surface having a minimum nominal back surface power P_b , wherein the nominal front surface power corresponds to a radius of curvature of the front surface and wherein the minimum nominal back surface power corresponds to a minimum absolute value of a radius of curvature of the back surface; wherein $15.5 \text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5 \text{ D}$, the method comprising the steps of:

obtaining eyeglass prescription data of an eye of a user, the prescription data comprising a focal power (S101);

determining whether the focal power belongs to an upper range of focal powers, wherein lenses having same nominal front surface power are provided; or to a lower range of focal powers, wherein lenses having same minimum nominal back surface power are provided (S102, S103);

if the focal power belongs to the upper range, selecting said nominal front surface power and determining the nominal back surface power such that the spherical front surface in conjunction with the back surface of the lens provides the focal power (S104), or

if the focal power belongs to the lower range, selecting said minimum nominal back surface power and determining the nominal front surface power such that the spherical front surface in conjunction with the back surface of the lens provides the focal power (S105); and

manufacturing the spectacle lens according to the lens design (S105).

10. Method as claimed in 8 or 9, wherein the nominal front surface power (21) in the upper range (11) of focal powers corresponds to a predetermined maximum nominal front surface power.
11. Method as claimed in any of claims 8 to 10, wherein the minimum nominal back surface power (22) of the lower range (12) corresponds to a predetermined minimum nominal back surface power.
12. Method as claimed in any of claims 8 to 11, wherein said upper range (11) of focal powers covers a range between a predetermined threshold and +4D; and wherein said lower range (12) of focal powers covers a range between -6 D and said predetermined threshold.
13. Method as claimed in 12, wherein said predetermined threshold corresponds to a sum of said nominal front surface power (21) of said upper range (11) and said minimum nominal back surface power (22) of said lower range (12).
14. Method as claimed in 12 or 13, wherein said predetermined threshold is between -4 D to +1 D.
15. A computer program product comprising program code means for causing a computer to carry out the steps of the method (70) as claimed in any of claims 8 to 14 when the computer program is carried out on a computer or processing unit.
16. A series (S1) of spectacle lenses (20), each lens having

a spherical front surface (21) and an aspheric, atoric or freeform back surface (22);

wherein each lens (20) of the series (S1) provides a focal power P_x between -6 D and +4 D;

wherein, for an upper range (11) of focal powers, lenses having same nominal front surface power (21) are provided, wherein the nominal front surface power corresponds to a radius of curvature of the front surface; and

wherein, for a lower range (12) of focal powers, lenses having same minimum nominal back surface power (22) are provided, wherein the minimum nominal back surface power corresponds to a minimum absolute value of a radius of curvature of the back surface;

the spherical front surface (21) having a nominal front surface power P_f and the back surface (22) having a minimum nominal back surface power P_b ; wherein $15.5 \text{ D} \leq |P_f| + |P_b| + |P_x| \leq 31.5 \text{ D}$ applies for each spectacle lens of the series; and

wherein the series comprises at least three spectacle lenses having different focal powers P_x in said upper range.

17. A series (S1) of spectacle lenses as claimed in claim 16, further comprising at least three spectacle lenses having different focal powers P_x in said lower range.
18. A series (S1) of spectacle lenses as claimed in claim 16 or 17, wherein the focal power powers P_x of at least two of said at least three spectacle lenses having different focal powers P_x in said upper range or lower range are spaced by at least one of at least 2 D and at least 3 D.

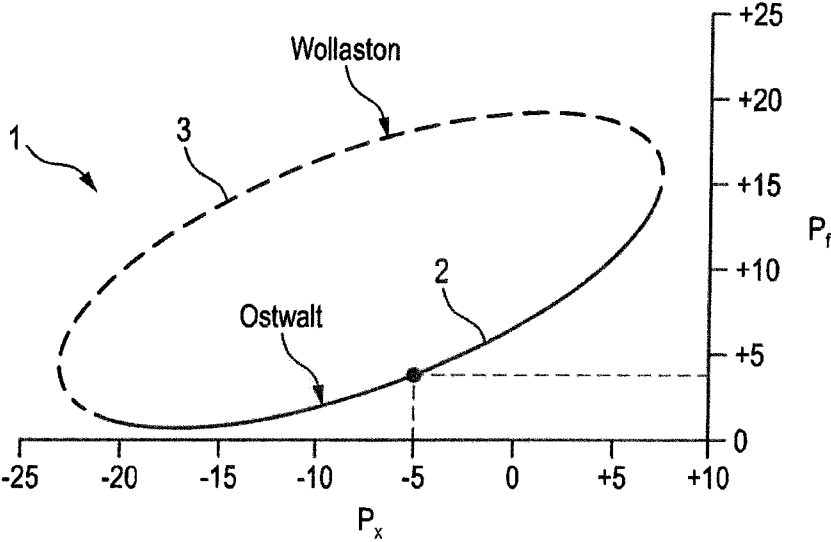


Fig. 1

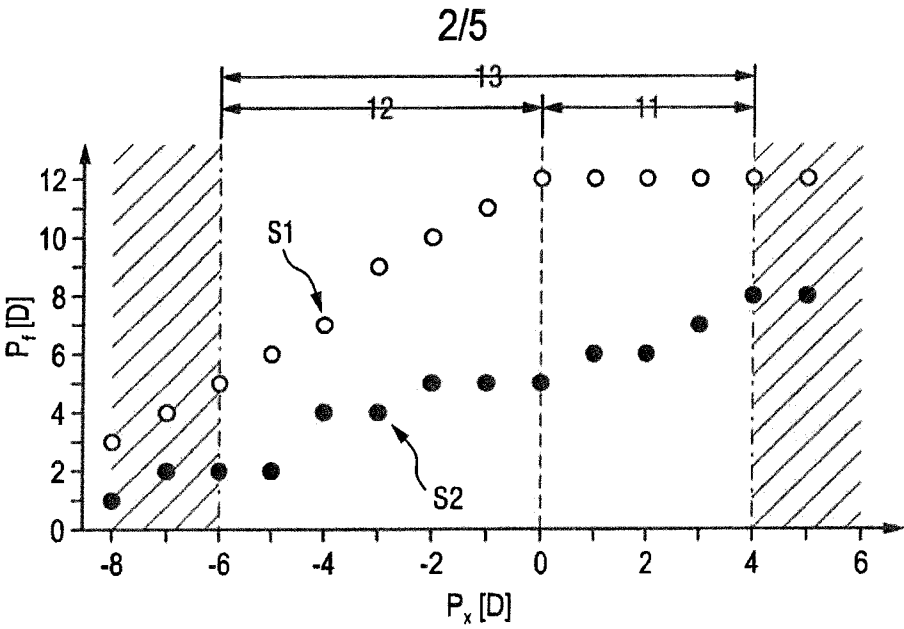


Fig. 2

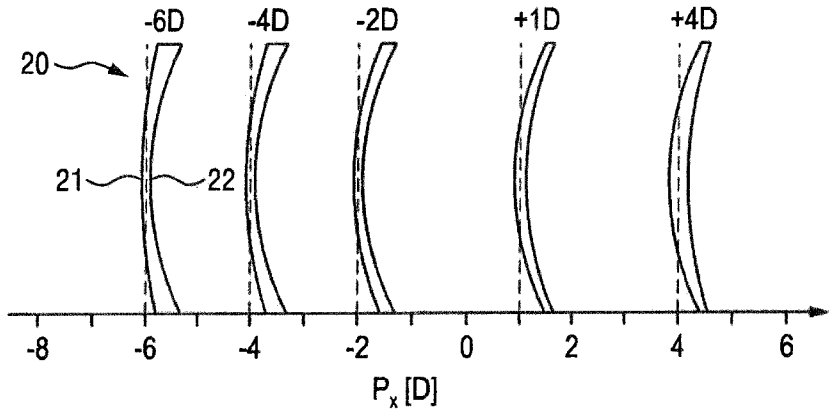


Fig. 3

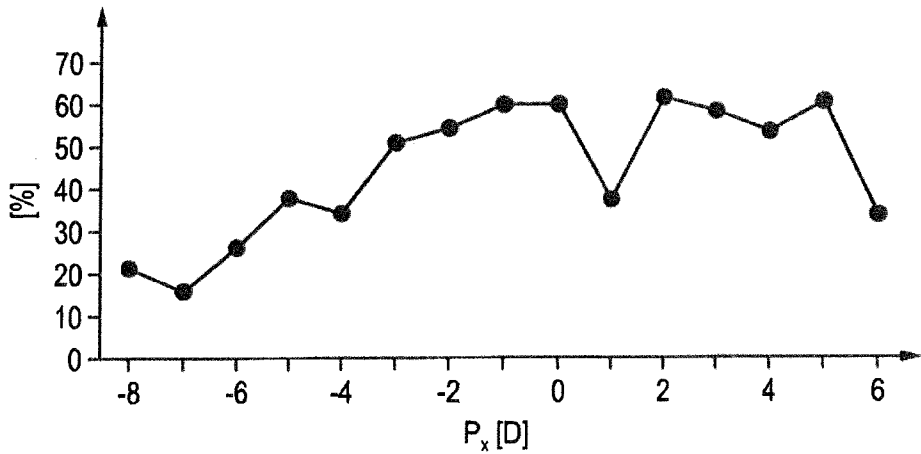


Fig. 4

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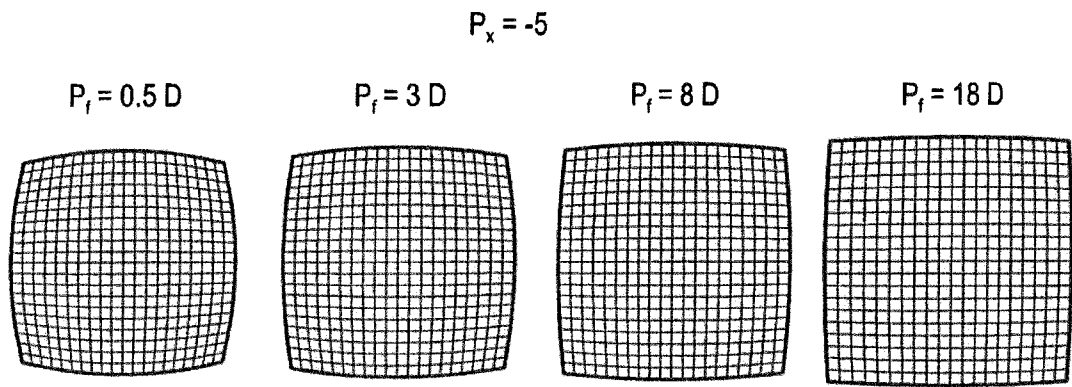


Fig. 5

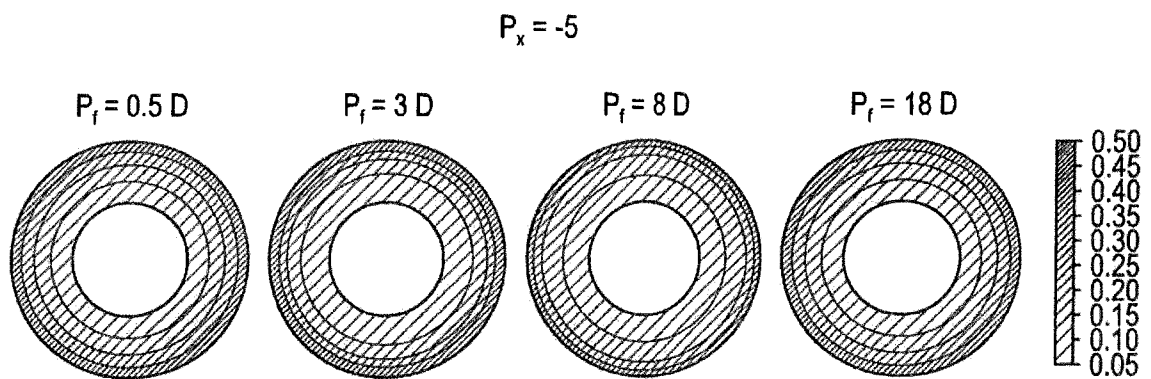


Fig. 6

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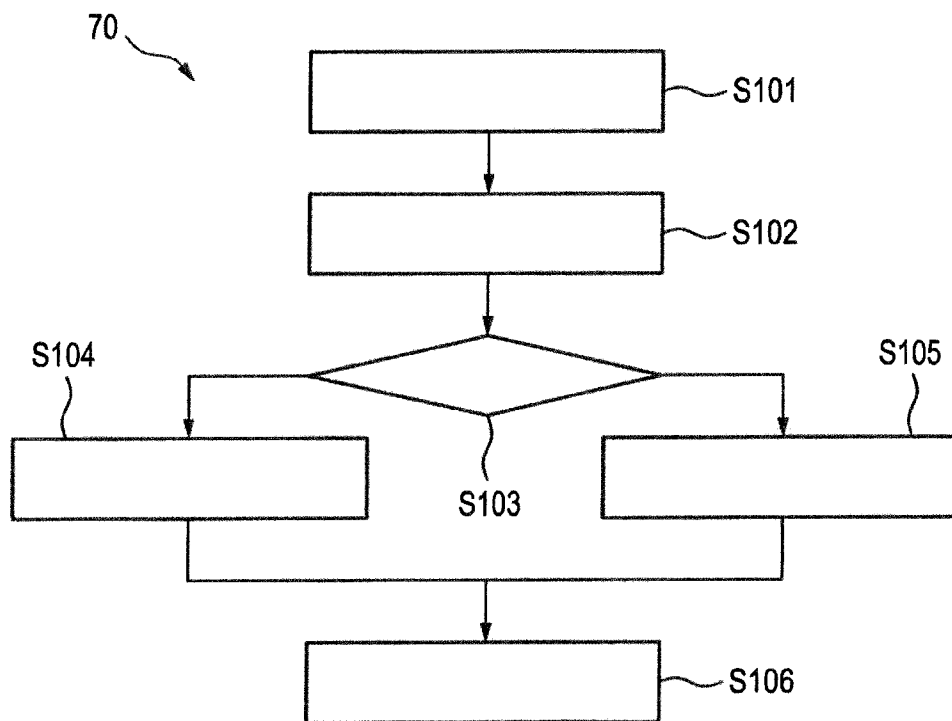


Fig. 7

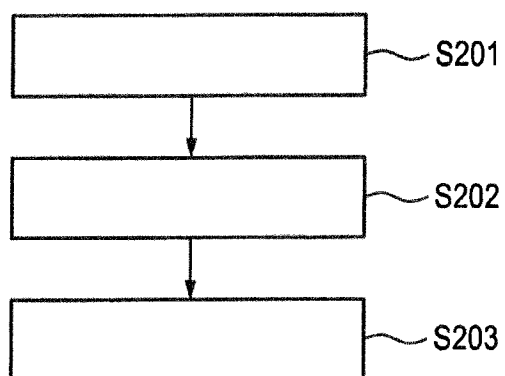


Fig. 8

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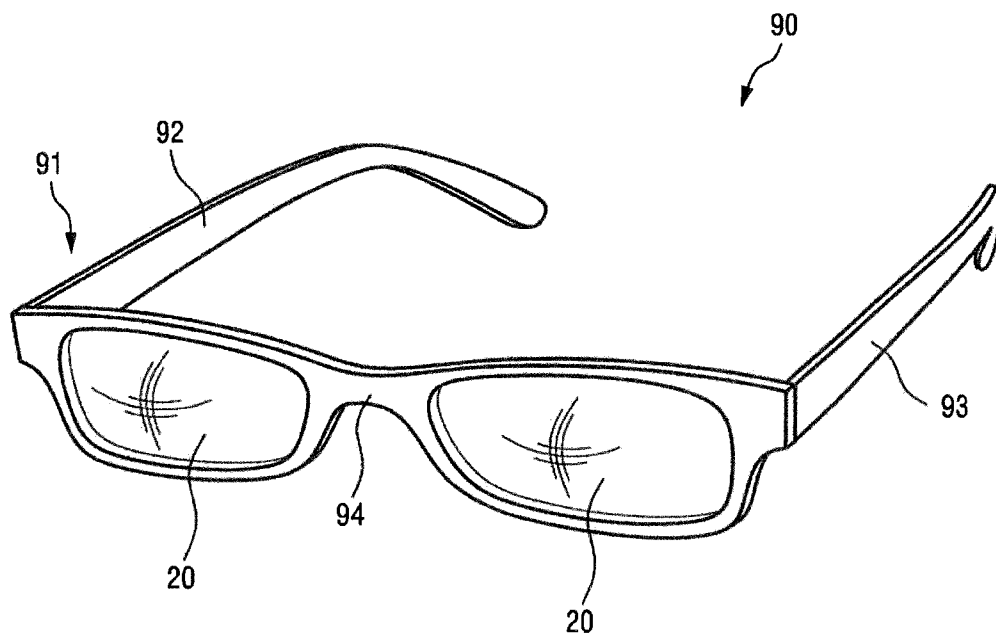


Fig. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/056618

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02C7/06
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G02C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 3 960 442 A (DAVIS JOHN KING ET AL) 1 June 1976 (1976-06-01) figures 1, 9 claim 1 column 9, lines 13-14 -----	1-4, 16-18 5-15
X A	US 2003/169397 A1 (REICHOW ALAN W [US] ET AL) 11 September 2003 (2003-09-11) figure 12 paragraphs [0017], [0063], [0066], [0069] -----	5-7 1-4,8-18
A	US 6 142 624 A (MORRIS MICHAEL ALAN [US] ET AL) 7 November 2000 (2000-11-07) cited in the application figures 4, 5 ----- -/--	1-18



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

11 January 2018

Date of mailing of the international search report

30/01/2018

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

de Lajarte, Gilles

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/056618

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2013/081592 A1 (ZEISS CARL VISION INT GMBH [DE]; ZEISS CARL VISION INC [US]; CARL ZEISS) 6 June 2013 (2013-06-06) figures 7, 8 -----	1-18
A	EP 2 246 729 A1 (ESSILOR INT [FR]) 3 November 2010 (2010-11-03) figure 5 paragraphs [0042], [0045] -----	1-18
A	WO 98/48315 A1 (SOLA INT HOLDINGS [AU]; PERROTT COLIN MAURICE [AU]; EDWARDS SIMON JOHN) 29 October 1998 (1998-10-29) figures 13, 23 page 33, lines 26-27 -----	1-18
A	EP 1 031 063 A1 (SOLA INT HOLDINGS [AU]) 30 August 2000 (2000-08-30) figure 8 -----	1-18

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/056618

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 3960442	A	01-06-1976	NONE	
US 2003169397	A1	11-09-2003	AT 328558 T AU 3386499 A CA 2327873 A1 DE 69931768 T2 EP 1069878 A1 EP 1726277 A2 EP 2305189 A1 ES 2267262 T3 JP 4780259 B2 JP 2002511594 A US 6129435 A US 2003169397 A1 WO 9952480 A1	15-06-2006 01-11-1999 21-10-1999 16-05-2007 24-01-2001 29-11-2006 06-04-2011 01-03-2007 28-09-2011 16-04-2002 10-10-2000 11-09-2003 21-10-1999
US 6142624	A	07-11-2000	AR 018871 A1 KR 20010031467 A MY 120075 A US 6142624 A ZA 200001504 B	12-12-2001 16-04-2001 30-08-2005 07-11-2000 17-10-2000
WO 2013081592	A1	06-06-2013	EP 2786200 A1 WO 2013081592 A1	08-10-2014 06-06-2013
EP 2246729	A1	03-11-2010	BR P11013907 A2 CN 102439511 A EP 2246729 A1 EP 2425293 A1 JP 5738276 B2 JP 2012525599 A US 2012188504 A1 WO 2010124991 A1	11-10-2016 02-05-2012 03-11-2010 07-03-2012 24-06-2015 22-10-2012 26-07-2012 04-11-2010
WO 9848315	A1	29-10-1998	BR 9806075 A CA 2269324 A1 EP 0938693 A1 US 6334681 B1 US 2002149739 A1 WO 9848315 A1	31-08-1999 29-10-1998 01-09-1999 01-01-2002 17-10-2002 29-10-1998
EP 1031063	A1	30-08-2000	AR 018453 A1 BR 9906510 A CA 2292909 A1 CN 1263606 A EP 1031063 A1 JP 2002511158 A NO 995946 A TW 411401 B US 6454408 B1 US 2003086055 A1 WO 9963392 A1	14-11-2001 19-09-2000 09-12-1999 16-08-2000 30-08-2000 09-04-2002 03-02-2000 11-11-2000 24-09-2002 08-05-2003 09-12-1999