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A method for design of spectacle lenses

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ABSTRACT

In this paper, differing from the traditional design methods, which are based on a single optical axis system, considering the habitual conduct of using eyes, we present a new design method for spectacle lenses based on multi-optical-axis system. As an example, an aspheric lens with $-2.0\,m^{-1}$ was designed to compare with the traditional spherical lens, it shows some improvement in the primary aberrations. The design schematics and some relevant formulas are given.

1. Introduction

The optical power of an ophthalmic lens is defined as the reciprocal of its focal length, and is typically expressed in diopters, with negative and positive diopter values signifying eyes with myopia (nearsightedness) and hyperopia (farsightedness), respectively. The application of ophthalmic lenses is well known for the correction of ametropia [1].

In traditional design methods of spectacle lenses, considering the focal length only and ignoring the eye movement while seeing different view ports, design the spectacle lens in a single optical axis system [2–4]. But the eye pupil is much smaller than the aperture of the spectacle lens, and when the eye sees a sights, whenever object is near or distant, only a small part of the spectacle lens is used and for the different object the different part of the spectacle lens is used, so that human eye rotates in the eye socket and the vision line is always varying, that is to say the spectacle lens should have multi-optical-axis. To better be suitable for habitual conduct of using eyes, we introduced a brand new design method for spectacle lenses based on multi-optical-axis system, and the performance comparison indicates that the aberrations have improved [5–8].

As is shown in Fig. 1, to provide the different visual angles and other desired features, the back surface of the spectacle lens is aspherical while the front surface is spherical meaning it has a unique radius. The aspherical back surface is divided into lots of small regions, each of them has an optical axis. We divide the aperture into element spheres with radius of 1 mm, and calculate the rise of the aspherical back surface according the power of the spectacle lens. Within the element sphere, the astigmatism and other aberrations should be less than the one-optical axis spectacle lens designed using the other design methods before, because later ones are designed without considering the human eye rotating when observing.

2. Design programs

Select the back surface of the lens as the processing surface, and the spherical radius of the front surface is R'. In the back surface, we fill small element-spheres as shown in the figure and the radius of the edge circle is ρ, every element-sphere and a small area corresponding in the front surface constitute an element-imaging lens, and each sphere has a corresponding radius of curvature R, the center of the eye shown as a point E, the optical axis of each element-lens through its center and the point E is also called visual axis, on the direction of the visual axis, the distances of front surface and back surface from the point E are l' and l, the thickness between the front and back surfaces corresponding to the direction of the visual axis is $d = l' - l'(R, l', l$ and d are all variable). We choose the point E as the origin, and the direction along the center of the lens to E as the z-axis, vertically down as the y-axis, set up a Right-handed Cartesian coordinate system, and then to design this spectacle lens we only need to give the expression of the processing surface which is the back surface of the lens. We can evaluate the expression of every element-sphere, as in comparison with each element-sphere's radius of curvature, its edge circle is extremely small in micro-scale, and so the successive spheres

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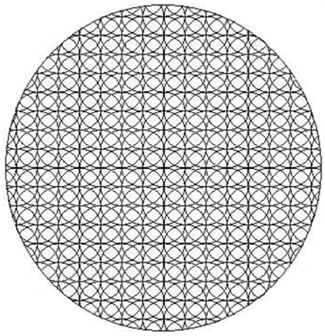

Fig. 1. Back surface of a multi-optical-axis spectacle lens.

have very close vector heights along z-axis. We average the vector heights of overlapping part of the back surface.

2.1. Mathematical model

As we already know the value of the diopter, we can calculate the radius of curvature R corresponding to each small element-sphere according to the refractive index of the material n, the curvature radius of the front surface R' and the thickness along the small element-sphere center to the front surface in the optical axis direction d. From known parameters we can easily get the expression of the element-sphere at the center, then along the horizontal and vertical directions, with the known element-sphere's edge as the adjacent element-sphere's center and individually determine the expressions of all element-spheres covered in the whole processing surface.

2.2. Center element sphere

For the center, visual axis is the z-axis, the lens center thickness is defined $d = d_0$, and the distance from the eye center to element-sphere center is defined $l = l_0$, then the distance between the front surface to the eyeball center is $l'_0 = l_0 + d_0$. It is easy to get the radius of curvature of the center element-sphere

$$R = R_0 = \frac{(n-1)f'_0[(n-1)d_0 - nR'}{nR' - n(n-1)f'_0} \tag{1}$$

then we can get the expression of the center element-sphere

$$z = R_0 - l_0 - \sqrt{R_0^2 - x^2 - y^2} \tag{2}$$

2.3. Element spheres with center-points are on the vertical meridian

For every element-lens, the tangent planes of the two opposite faces are parallel to each other, no aberration carries influence to our following expressions. Take negative part of the y-axis as an example, according to the elementary geometry relationship, we can get the distance from the center of the element-sphere $(0,i)$ to the center of the eyeball

$$l_{(0,i)} = \sqrt{\rho^2 + s_{(0,i+1)}^2 + l_{(0,i+1)}^2 - 2l_{(0,i+1)}(s_{(0,i+1)}\cos\theta_{(0,i+1)} - \rho\sin\theta_{(0,i+1)})} \tag{3}$$

where

$$s_{(0,i)} = R_{(0,i)} - \sqrt{R_{(0,i)}^2 - \rho^2}$$

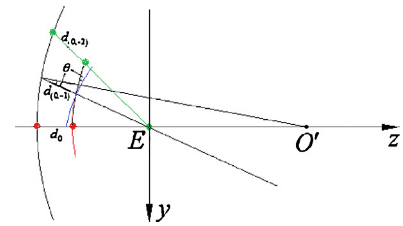

Fig. 2. The left view of the vertical meridian of the spectacle lens.

The angle between the ball diameter of the front surface that crosses the intersection between the current optical axis and the front surface and the current visual axis is

$$\theta_{(0,i)} = \arccos\frac{l'^2_{(0,i)} + 2R'l'_0 - l'^2_0}{2R'l'_{(0,i)}} \tag{4}$$

The angle between the visual axis of element-sphere $(0,i)$ and the visual axis of the previous element-sphere $(0,i+1)$ is

$$\alpha_{(0,i)} = \arccos\frac{l_{(0,i)}^2 + l_{(0,i+1)}^2 - \rho^2 - s_{(0,i+1)}^2}{2l_{(0,i)}l_{(0,i+1)}} \tag{5}$$

Along the visual axis direction of the element-sphere $(0,i)$, the distance from the point E to the front surface is

$$l'_{(0,i)} = \left|\left[(R' - l'_{(0,i+1)})\cot\alpha_{(0,i)} - \sqrt{R'^2\cot^2\alpha_{(0,i)} - l'^2_{(0,i+1)} + 2R'l'_{(0,i+1)}}\right]\sin\alpha_{(0,i)}\right| \tag{6}$$

Then, the thickness of the small lens in the visual axis direction of the current small element-sphere can be determined

$$d_{(0,i)} = l'_{(0,i)} - l_{(0,i)} \tag{7}$$

According to focal length formula of thick lens, we can get the spherical radius of the element-sphere

$$R_{(0,i)} = \frac{(n-1)f'_{(0,i)}\left[(n-1)d_{(0,i)} - nR'\right]}{nR' - n(n-1)f'_{(0,i)}} \tag{8}$$

Let $\phi_{(0,i)} = \sum_{j=i}^{0}\alpha_{(0,j)}$, then ϕ is the angle between the visual axis of current element-sphere and the z-axis (counterclockwise positive).

According to the data derived above, we can figure out the expression of the small element-sphere plane

$$z = -\sqrt{\begin{aligned}&\left[l\cos\phi - R(\sin\phi\sin\theta + \cos\phi\cos\theta)\right]^2 - x^2 - y^2 - l^2\\&-2\left[R(\sin\phi\cos\theta - \cos\phi\sin\theta) - l\sin\phi\right]y + 2Rl\cos\theta\end{aligned}} + R(\sin\phi\sin\theta + \cos\phi\cos\theta) - l\cos\phi \tag{9}$$

2.4. Element spheres with center-points are on the horizontal meridian

It is very similar to the vertical meridian, we can just change the negative y-axis to the positive x-axis in Fig. 2. Take positive part of the x-axis as an example, according to the elementary geometry relationship, we can get the distance from the center of the element-sphere $(i,0)$ to the center of the eyeball

$$l_{(i,0)} = \sqrt{\rho^2 + s_{(i-1,0)}^2 + l_{(i-1,0)}^2 - 2l_{(i-1,0)} = (s_{(i-1,0)}\cos\delta_{(i-1,0)} - \rho\sin\delta_{(i-1,0)})} \tag{10}$$

where

$$s_{(i,0)} = R_{(i,0)} - \sqrt{R_{(i,0)}^2 - \rho^2}$$