OPHTHALMIC LENS FOR PRESBYOPIA AND APHAKIA

This application is a continuation-in-part of my pending application Ser. No. 322,488, filed Jan. 10, 1973, now abandoned.

This invention relates to an improved ophthalmic lens, either of spectacle lens or contact lens type, primarily intended for the relief of the refractive error and the accommodative insufficiency or absence of accommodation in presbyopia and aphakia. Ordinarily the optical treatment of said insufficiency or absence of accommodation is accomplished with either simple reading glasses, or bifocals, or trifocals in spectacles, or with bifocals in corneal contact lenses. In the lens of this invention, the change in optical power of the ophthalmic lens required to supplement the failing or absence of accommodation in presbyopia and the lack of accommodation in aphakia is accomplished in a continuous and regular manner, without discontinuities in the field of vision through the lens, and with minimal distortion in the field. The design of the lens in its principal embodiment is such that, in gaze at distant objects through the upper portion of the lens as it is worn in spectacles, or worn as a corneal contact lens, vision is clear, and as objects are observed through lower and lower portions of the lens, they must be closer and closer to the wearer to be seen clearly. The continuous and regular increase in refractive power from the upper distance portion to the lower border results from the combination of a conicoid back surface of eccentricity zero or greater or a toric back surface, the toric being used when ocular astigmatism is to be corrected, and a unique front surface which increases in curvature continuously and regularly in an accelerated manner from said upper portion to provide the increasing refractive power for the correction of the accommodative insufficiency or absence of accommodation.

Throughout the remainder of this specification and in the clamis, I shall speak of conics as sections of the unique front surface of the lens of this invention. I intend including within the definition of said conics those slight modifications which are dependent upon and are a consequence of the shape of the edge of a circular cam follower and the shape of the edge of a circular abrading tool which are used in the method and apparatus of this invention to produce said unique front surface.

A conic can be described in terms of its focus, f, and eccentricity, e, that is, in terms of magnitude and shape. The eccentricity, e, of a conic is a constant and is given by the differential equation:

$$e = df/dx \tag{1}$$

where f is the focal radius of the conic and x is the coordinate along the axis containing said focus with the apex of the conic as the origin. Should df/dx vary with x, then a more appropriate mathematical description of the resulting modified conic in terms of eccentricity can take the form of a Taylor series which takes into account the rate of change of eccentricity. Using MacLaurin's formula:

$$e_g = df/dx + (d^2f/dx^2)x + \frac{(d^3f/dx^3)x^2}{2!} + \frac{(d^4f/dx^4)x^3}{3!} \tag{2}$$

where e_g given by equation (2) is defined as the generalized or effective eccentricity. When the derivatives of eccentricity are small, the modified conic can osculate a conic over a relatively large extent about their common apex. Hence, for the purpose of simplifying the description of this invention, both the osculating conic and the modified conic will be described as of the focus and eccentricity, or of the apical radius of curvature and eccentricity, of the osculating conic, it being understood that differences in the two curves manifest themselves when the curves are extended.

For the purpose of simplifying the description of this invention, the points of intersection of the major and minor axes of an ellipse with the ellipse will hereinafter be called the prolate and oblate points respectively.

In the drawings:

FIG. 1 is a diagrammatic view of the lens of this invention showing the horizontal and vertical principal planes cutting the variable surface of the lens in the great arc and principal curve respectively;

FIG. 2 is a diagrammatic and geometric view of the variable surface WQVP in the first embodiment of the lens of this invention showing the principal curve QBP and transverse sections of the variable surface as circular arcs above the circular great arc WBV at R, S and T, and as conics at F, M and H below the great arc;

FIG. 3 is a diagrammatic view used to represent several embodiments of the variable surface WQVP of the lens of this invention. Arc QBP is the principal curve. Point B is the axial umbilical point. In one embodiment, point B is the oblate point of elliptical arc BP and the prolate points of elliptical arc QB and elliptical great arc WBV. In this embodiment, all transverse sections of the variable surface are conics of eccentricity greater than zero with their apices along the principal curve, selected apical points shown at R, S, T, B (the axial umbilical point), F, M and H. Transverse sections through F, M and H increase successively in curvature at their apices and in eccentricity, the curvatures at the apices of said transverse sections or transverse curvatures being substantially equal to the corresponding vertical curvatures at said points. In another embodiment, principal curve QBP is an elliptical arc with its oblate point at B, the axial umbilical point. Great arc WBV is circular. Transverse sections through F, M and H are conics which increase in curvature successively at apical points F, M and H, and in eccentricity, the transverse curvatures through said points being substantially equal to the corresponding vertical curvatures. The remainder of the variable surface is identical to that just described, the surface being symmetrical about great arc WBV. In another embodiment, the two portions of the variable surface on opposite sides of the great arc WBV are similar to that just described but not identical;

FIG. 4 is a diagrammatic view of one of the embodiments of the lens of this invention in which the variable surface WQVP has a circular great arc WBV which is umbilical along its entire extent and along which the derivative of curvature of said surface vanishes. At each of points 1, 2, 3, B, 4, 5 and 6 along said great arc, vertical and horizontal curvatures are equal and curvatures at all of said points are equal in magnitude;

FIG. 5 is a diagrammatic view of one of the embodiments of the lens of this invention in which the variable surface WQVP has an elliptical great arc WBV with its prolate point at axial point B at which the variable surface is umbilical and at which the derivative of cur-