# OPHTHALMIC LENSES HAVING PROGRESSIVELY VARIABLE REFRACTING POWER

## BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to ophthalmic lenses used to correct an amplitude of accommodation and, more particularly, to ophthalmic lenses having a progressively variable refracting power.

2. Related Background Art

Various types of conventional ophthalmic lenses having a progressively variable refracting power are known as auxiliary ophthalmic lenses for correcting an amplitude of accommodation of an eye when accommodation astheny occurs to fail to observe an object near the eye. An ophthalmic lens of this type has an upper distance vision correction area (to be referred to as a portion for distance vision hereinafter), a lower near vision correction area (to be refereed to as a portion for near vision hereinafter), and a progressively variable refracting power area (to be referred to as an intermediate portion hereinafter) which is defined between the portions for distance vision and near vision and a refracting power of which is continuously changed.

In ophthalmic lenses of this type, wide clear vision areas of the portions for distance vision and near vision are generally assured, and an intermediate progressively variable refracting power area connects these portions. In general, lens aberration is concentrated in side areas of the progressively variable refracting power area. The presence of these areas causes blurring and distortion of an image. Therefore, a user experiences uncomfortable shift of an object when he moves lines of sight.

In order to solve the problems of these visual characteristics, various proposals for design and evaluation have been made regarding the known ophthalmic lenses having a progressively variable refracting power. An intersection line between a cross section along a meridian vertically extending almost the center of a lens surface and an object-side lens surface is used as a reference line of a lens surface shape for an additional power of a lens or the like. In ophthalmic lens design, this intersection line is used as an important reference line. Even in ophthalmic lenses having asymmetrical portions for near vision which are designed in consideration of the fact that the portions for near vision come close to a nose of a user who wears the lenses, a vertical central line extending through the centers of the portions for distance vision and near vision is used as a reference line. According to the present invention, the above-mentioned reference lines are defined as "principal meridional curves".

Conventional ophthalmic lenses having a progressively variable refracting power have a surface shape with a so-called umbilical line in which microscopically spherical surfaces continue along the entire principal meridional curve, and a surface shape which is not umbilical in part of the principal meridional curve, but in which two radii of curvature perpendicular to each other are different in this part of the curve. In other words, surface shapes on the principal meridional curve are classified into two shapes, i.e., a surface shape which is umbilical along the entire principal meridional curve; and a surface shape which is not umbilical on at least part of the principal meridional curve, but in which a radius of curvature along the principal meridional curve (vertical direction) is different from that in a direction (horizontal direction) perpendicular to the principal meridional curve.

According to the law of Minkwitz as in Optica Acta, Vol. 10, No. 3, 1963, July, at least an intermediate portion of the principal meridional curve must not be umbilical. More specifically, according to the law of Minkwitz, an astigmatic difference in the refracting power on the surface of the lens increases at a rate twice a change in refracting power on the surface along the umbilical line in a direction (horizontal direction) perpendicular to the principal meridional curve. It is, therefore, difficult to widen a clear vision area.

Even if the visual characteristics of the intermediate portion are improved to some extent by differentiating the values of the major radii of curvatures perpendicular to each other in the intermediate portion on the principal meridional curve in a conventional technique according to the law of Minkwitz, there are limitations to widening of the clear vision of the portions for distance vision and near vision on the basis of only the law of Minkwitz. In order to minimize an astigmatic difference in the surface, a change in refracting power on the surface must be moderated along a long surface. However, in practice, since the length of the progressively variable refracting power area is limited, the above countermeasure is insufficient.

Various other types of conventional arrangements can assure wide clear vision areas to some extent. However, it is difficult to obtain excellent visual characteristics of all three areas, i.e., the portions for distance vision and near vision and the intermediate portion while a distribution of an astigmatic difference which is inevitably present in the ophthalmic lenses having a progressively variable refracting power is minimized, that is, a maximum value of aberration called astigmatism and its gradient are minimized. It is, therefore, very difficult to realize practically excellent ophthalmic lenses having a progressively variable refracting power by specifying only the state of a change in refracting power along the principal meridional curve. In addition, techniques for improving the visual characteristics are mostly based on trials and errors. A definite design technique is not available, or a definite reference for evaluating lens performance is not established.

Conventional ophthalmic lenses having a progressively variable refracting power are disclosed in Japanese Patent Publication Nos. 49-3595, 52-20271, and 59-42285.

In the above prior-art techniques, it is possible to improve the visual characteristics to some extent, but such an improvement is insufficient in practice. More specifically, in the lens disclosed in Japanese Patent Publication No. 49-3595, as for the shapes of intersection lines formed between a plane perpendicular to the principal meridional curve and lens refracting surfaces as follows, only an intersection line at a point almost corresponding to the center of the intermediate portion has a circular shape. A radius of curvature of the intersection line is reduced in a portion above the center of the intermediate portion as the intersection line is separated from the principal meridional curve, thus constituting a noncircular shape. A radius of curvature of the intersection line is increased in a portion below the center of the intermediate portion as the intersection line is separated from the principal meridional curve, thus constituting a noncircular shape.