Principles of Atoric Lens Design

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BACKGROUND

Industry studies have shown that approximately 70% of all spectacle wearers receive a cylinder correction for astigmatism. Further, 50% of these wearers have corrections with over 0.50 D of cylinder power. This article will show that conventional lens design does not adequately address the peripheral optical performance of lenses with cylinder power. Moreover, it will explain how new 'atoric' lens designs can provide superior optical performance for *all* patients—including those with astigmatism.

IN REVIEW

Our discussion of 'atoricity' expands upon the principles and concepts that appeared in an earlier issue of Lens Talk (July 1998). Before continuing, we should review a few key points from this previous article:

- Spectacle lenses suffer from various '*lens aberrations*' that affect the quality of peripheral vision afforded by the lens. Optical performance can be improved by reducing these aberrations, or '*optimizing*' the lens.
- Lenses produced with optimum spherical front base curves are often referred to as '*best form lenses*,' since these lenses reduce the lens aberrations that can blur peripheral vision. Today, most manufacturers provide best form lenses.
- Early lenses employed spherical curves simply because these were relatively easy to produce in glass using simple tools. With the advent of high-speed computing, plastic lens casting, and numerically-controlled grinding techniques, lens manufacturers developed the ability to rapidly produce more sophisticated lens surfaces like aspherics.
- Although steeper best form lenses provide excellent peripheral vision, they can be relatively thick, heavy, and bulbous. To answer the need for thinner, lighter, and flatter lenses that still maintained excellent optical performance, manufacturers began to use *aspheric* surfaces on spectacle lenses—often in conjunction with higher-index materials.
- In the strictest sense of the word, *aspheric* simply means 'not spherical.' Aspheric lens designs employ a non-spherical surface that changes in curvature from the center towards the edge. This change is the same in every direction—or meridian—of the lens, though. A three-dimensional aspheric surface is created by rotating a non-circular curve about an *axis of symmetry*. Therefore, these surfaces are said to be rotationally-symmetric as illustrated in Figure 1.

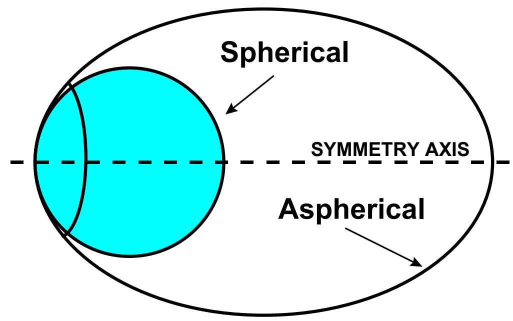

Figure 1. An aspheric surface compared to a conventional spherical surface.

- Ideally, each individual lens power requires its own unique base curve or aspheric design in order to provide optimum optical performance. With semi-finished lenses, small ranges of power grouped together upon common base curves to reduce costs and inventory requirements.

CONVENTIONAL LENS DESIGN

Best form and aspheric lenses that incorporate prescribed cylinder power generally utilize one *toric* surface that has two separate curvatures, as illustrated in Figure 2. Toric surfaces produce two different focal powers, corresponding to the sphere and cylinder meridians, which are perpendicular to each other. A cross section taken through either of the two principal meridians of the toric surface is circular in shape.

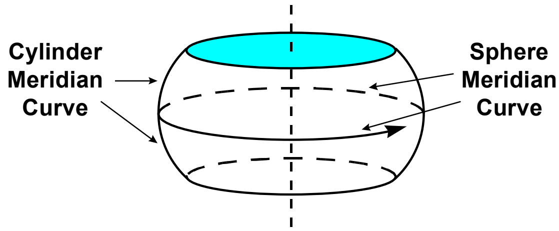

Figure 2. Toric surface with circular cross sections.

Sphero-cylindrical lenses that use toric surfaces to produce cylinder power vary in power between the sphere and cylinder meridians of the lens, as shown in Figures 3 and 4. This is not the case with spherical lenses, which have a constant power around each meridian of the lens. Consider the comparison below:

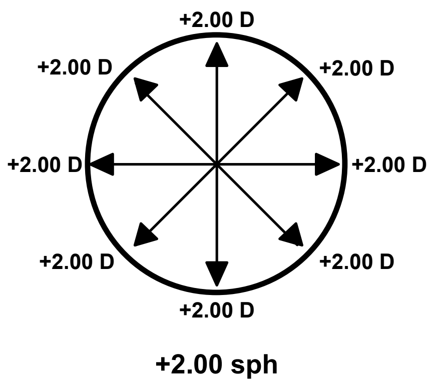

Figure 3. This +2.00 D spherical-powered lens has the same power through every raidal direction (or meridian) of the lens.

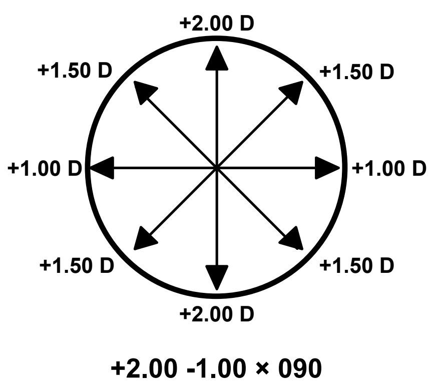

Figure 4. This *sphero-cylindrical* lens varies in power from meridian to meridian. The 90° meridian contains the sphere power of +2.00 D, and the 180° meridian contains the combined sphere *and* cylinder power: +2.00 + -1.00 = +1.00 D.

Because each lens power requires its own lens form to eliminate aberrations, the design of lenses with sphere *and* cylinder powers cannot be entirely optimized using conventional spherical surfaces. The lens designer may choose the optimum front curve based upon the sphere meridian, the cylinder meridian, or the average power (*spherical equivalent*) of the lens. In lenses with low cylinder power the performance differences are generally negligible, but in higher cylinder powers the field of clear vision is often considerably reduced—no matter which approach is used. Best form and aspheric lenses with cylinder power could more accurately be described as a 'best compromise' lens.

ATORIC LENS DESIGN

Over the past few years, additional advances in lens design have provided lens designers with the ability to produce surfaces even more complex than the rotationally-symmetrical aspheric designs described earlier. By literally varying the amount of asphericity from one meridian of the lens to another, an *atoric* surface can be produced. Just as *aspheric* denotes a surface that departs from being completely spherical, 'atoric' denotes a surface that departs from being an exact circular toric. Figure 5 depicts one possible atoric surface.

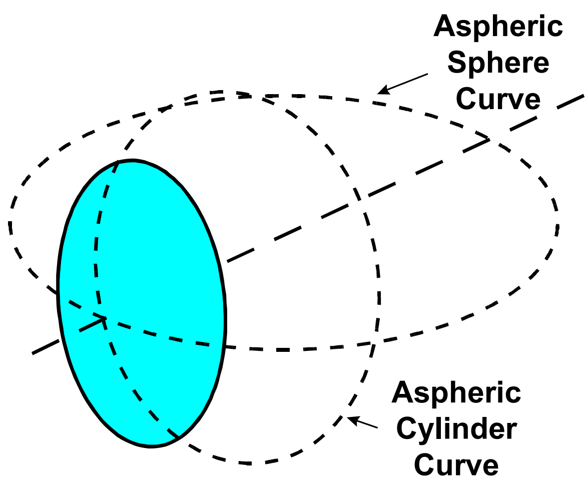

Figure 5. An *atoric* surface with a differing amount of asphericity applied to the sphere and cylinder meridians.

Atoricity is an extension of aspheric design technology, allowing lens designers to optimize for *both* the sphere and cylinder powers of a lens. This ensures that nearly all wearers enjoy the same wide field of vision, especially those with astigmatism. Atoric lenses consistently outperform either best form (with spherical base curves) or rotationally-symmetrical aspheric lenses across a wide range of prescriptions.

The atoric lens provides a significantly wider field of perfectly clear vision, and consistently provides optical performance superior to conventional lens designs over a wide range of lens powers—especially higher cylinder powers. Let's look at the differences between best form, aspheric, and atoric optimization strategies using an actual prescription. Figure 6 compares the '*relative asphericity*' (an abstract correction concept used here for illustrative purposes) of three different lens designs for the following prescription: +2.00 -1.00 × 090.

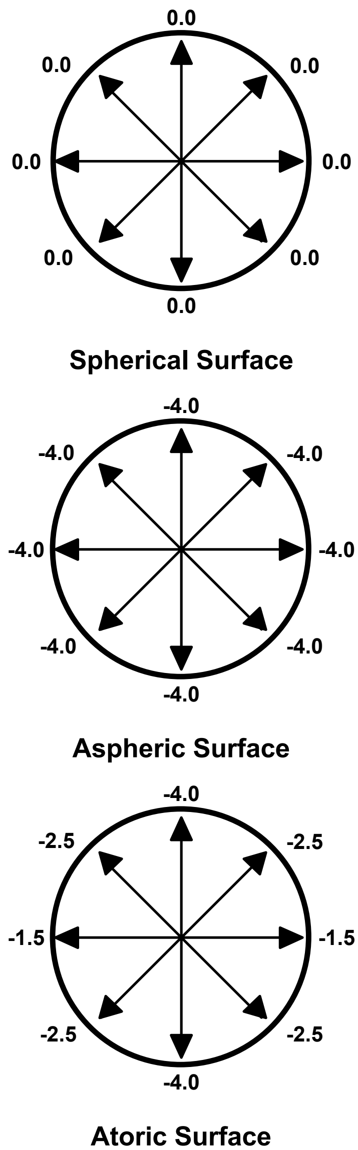

Figure 6. Relative asphericity (or correction factors) for spherical, aspheric, and atoric surfaces.

These values more or less represent the relative departure of the surface from a perfect circle through each meridian, and can be thought of as the amount of *asphericity* present through that meridian. The further this value departs from 0.0, the more aspheric (or non-circular) the curvature of the surface is through that meridian. We can think of this relative value as the '*correction factor*' for now (again, strictly for our purposes).

Spherical surface. It has a relative value of 0.0 in every direction (or meridian)—meaning that it is perfectly spherical in every direction. Therefore, the +2.00 D sphere meridian receives the same correction factor of 0.0 as the +1.00 D cylinder meridian does. We know these two powers should be optimized differently, since a +1.00 D power requires a flatter base curve than a +2.00 D power.

Aspheric surface. It has a relative value of -4.0, indicating the aspheric lens departs significantly from the spherical lens in every direction (or meridian). This is what is meant by the phrase '*rotationally-symmetric*'—the lens surface have the same curvature in every direction, and can be produced by simply rotating a single curve with the appropriate relative asphericity about an axis. Again, the aspheric lens provides only the one correction factor of -4.0 through every meridian.

Atoric surface. Note how the relative asphericity changes from meridian to meridian. The +2.00 D meridian has a correction factor of -4.0, while the +1.00 D meridian has a factor of -1.5. In essence, each meridian of the lens has been adjusted with the correction factor specifically required for that particular power. This ensures that both the sphere and cylinder meridional powers—as well as all of the powers in between—are properly optimized.

Unfortunately, conventional spectacle lens surfacing equipment was not designed to manufacture these rather complex surfaces. For instance, modern cylinder machines and lap tools—which are used for fining and polishing the generated lens surface—can only produce spherical and circular toric surfaces because of the geometry and motions involved. Although there are systems available that use either a 'cut and coat' process or a numerically-controlled milling machine along with flexible-pad polishing, these systems are quite expensive and cost-prohibitive for most laboratories at this point.

Currently, most atoric lenses are available in either of two forms: factory finished stock lenses—which have had the atoric surface molded at the factory, and custom-ground semi-finished lenses—which have had the atoric surface ground using the equipment described above (typically also at the factory level).

The atoric design strategies that we've discussed so far are generally applicable to any single vision (or even multifocal) lens design. Certain manufacturers have begun offering 'atoric' progressive addition lenses, but it should be noted that these atoric designs differ slightly from the design that we have looked at so far. These designs still optimize for both the sphere and cylinder powers of the lens. In addition, however, these manufactures advertise that their lenses can also be optimized for other parameters, like aberrations produced by prism or by viewing through the near zone of the lens obliquely. This additional freedom is possible since each lens is custom ground (unlike finished, stock lenses). These surfaces are even more complex, or arbitrary, than the atoric surfaces used for stock lenses, and each lens has to be individually designed and fabricated using expensive equipment—usually at the factory level. Consequently, such lenses require additional shipping time and are considerably more expensive.

Because of their obvious superiority to conventional lens designs over a wide range of prescriptions, we should expect to see more atoric single vision and progressive addition lenses in the future. We can now look at some optical performance comparisons between the three lens designs for plus and minus sphero-cylindrical prescriptions. All three of the lens designs shown in Figure 7 are from the same manufacturer. The white area within the frame represents the field of perfectly clear vision, while the shaded area represents the region of reduced optical quality and potential blur for the wearer.

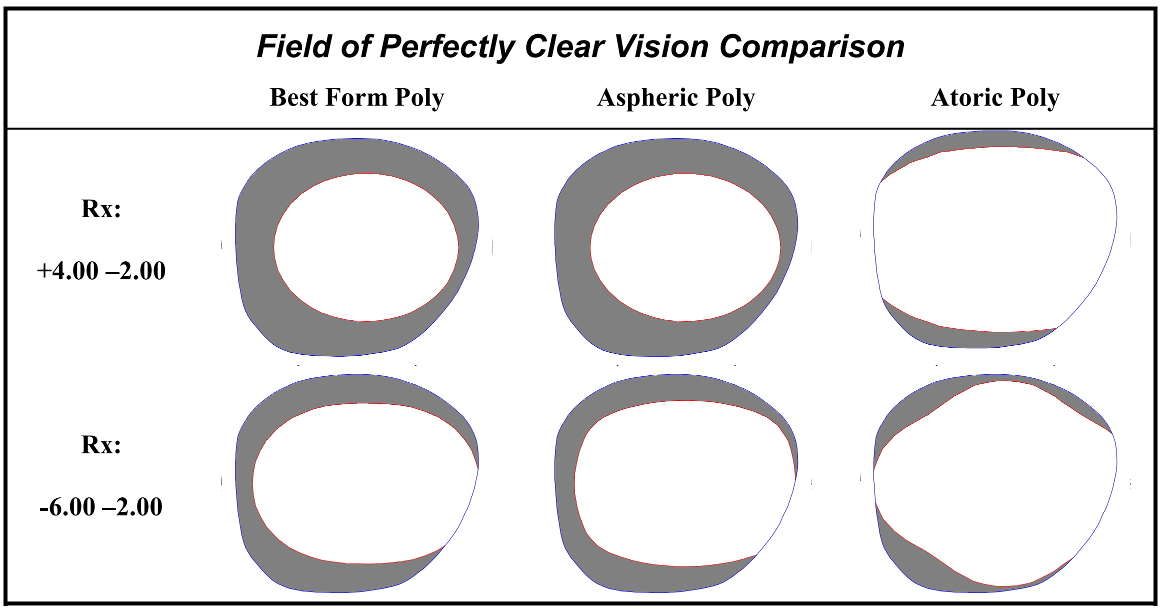

Figure 7. Comparison of the fields of perfectly clear vision for best form, aspheric, and atoric polycarbonate lens designs. Two prescriptions are shown. Note that the atoric lens design consistently provides a larger area of clear vision.