Specifying And Modeling As-Built Centration Errors For Singlets And Cemented Doublets

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Abstract: This presentation will look at sources of lens centration manufacturing errors in singlets and cemented doublets, how manufacturing errors can be modeled in lens design software and how to specify centration tolerances on lens drawings.

1. Error Sources for Lens Centration

Contained in any lens, there are two primary axes, the optical axis, the axis passing through the two centers of curvature of the spherical surfaces, and the mechanical axis, the axis passing through the physical center of the lens in a direction parallel to the edge diameter. In a perfectly centered lens, these two axes are concurrent and coincidental, superimposed on each other. Centration errors arise from deviation from superposition.

Centration errors can introduce aberrations and reduce the performance of an optical system[1], and the fabricator takes steps to avoid them. Lenses are left oversized in diameter, and centration errors are allowed to accumulate to some in-process limit. After surface preparation, the lenses are edged to final diameter with a goal of superimposing the mechanical and optical axes in order to remove centration error.

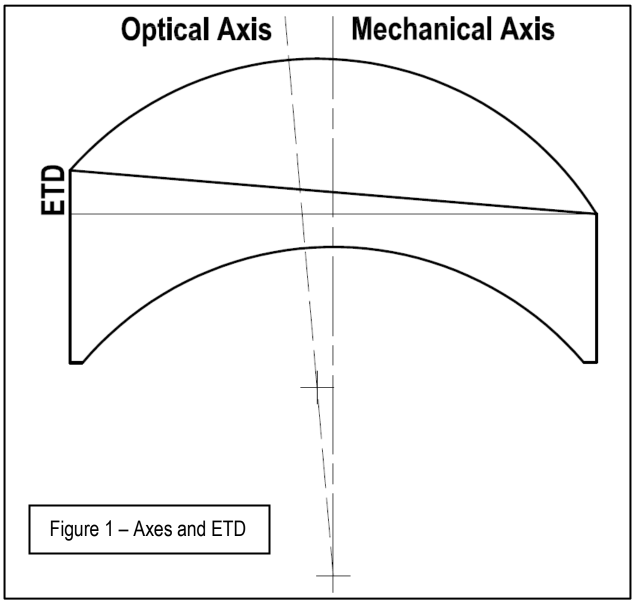

Figure 1 – Axes and ETD

For the centering machines currently in use, a part to be edged is held between two precision rings, one fixed and the other moveable. Barring some easily prevented setup errors, the surface in contact with the fixed ring will be evenly distributed about the machine spindle axis. The mechanical axis, the centerline of the newly created diameter, will be coincident with the machine spindle axis and will pass through the center of curvature of the surface in contact with the fixed ring. The other surface is clamped to a position, but this may not put the second surface's center of curvature on the mechanical axis. Positioning error will leave the optical and mechanical axes at an angle to each other, intersecting at the center of curvature of the surface in contact with the fixed ring. Error will be seen as Edge Thickness Difference (ETD) in the lens formed by the wedge. Figure 1 shows the axes and ETD graphically.

Despite the fabricator's best efforts, there is always an expectation there will be some error. The operator positions the lens in the machine to some accuracy limit, possibly leaving some error. The lenses are clamped into place, but the magnitude of securing force must be balanced with the risk of "chuck rings", cosmetic damage to the lens surface due to clamping. The lens may move between the rings during edging. Strongly curved biconvex or biconcave lenses position well and stay there, but meniscus elements can be difficult to place, are more likely to move and will likely have more error. As the two surfaces approach concentric movement becomes more likely[2].

Cemented doublets are often built using a process called Floater Air Bearing Assembly, which involves using one element as the mechanical reference and aligning the other element (the "floater") to it. During alignment, the floater is rolled around the center of curvature of the interface. As the floater is rolled, ETD present in the floater element is converted to edge runout (ERO). ETD present in the reference element will remain, and there will be wedge in the interface proportional to the ETD in the reference element. If another assembly process is used the errors will be different. Prior to modeling, confirm the assembly method with the fabricator.

2. Modeling As-Built Errors

Within ray tracing software, there are numerous ways to introduce centration errors into the lens model. Surface, element or multielement tilts and decenters are supported. For singlets, the as-built error most closely resembles a pivoting of one surface around its intersection with the diameter, producing ETD as Figure 1 shows. This is equivalent to the TIRX or TIRY operand in Zemax[3] or the Wedge tolerance in Code V[4].

For a cemented doublet cemented using Floater Air Bearing Assembly, the reference element can be modeled like the singlet above. The floater can be modeled with its interface surface tilted in an amount equal to the interface surface of the reference element. Likewise, the tilt of the whole element could be considered, reflecting the roll of the floater during assembly. The Roll tolerance in Code V[4] or the TETX or TETY operand in Zemax[3] could be employed, with the displacement equal to that of the interface surface of the reference element.

3. Specifying Centration Tolerances On Lens Drawings

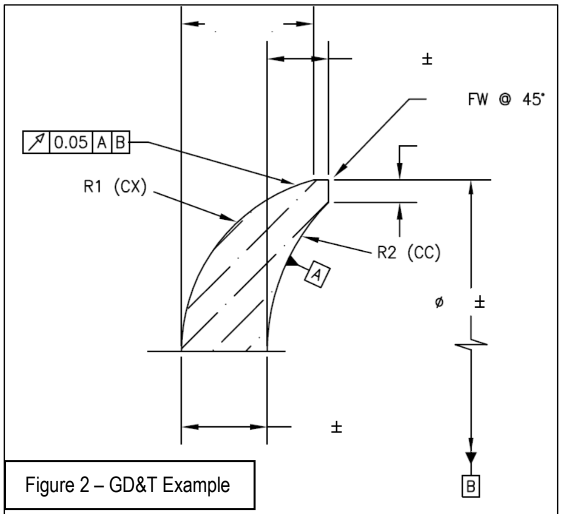

Figure 2 – GD&T Example

For singlets, a good way to specify centration is to use Geometric Dimensioning & Tolerancing (GD&T), using one lens surface and the diameter as datums. The allowable ETD is specified as the Runout of the other lens surface. Figure 2 shows an example of how a 0.050 ETD tolerance can be applied.

Drawings for doublets can be handled in the same manner, with the reference element's external surface and diameter serving as datums and runout of the floater's external surface specified. The drawing for the reference element needs to specify an ETD tolerance equal to the cemented doublet, while the floater must have an ETD tolerance based on the ERO the element is allowed.

ISO 10110 Part 6 allows for a per-surface specification. To match the manufacturing process, specify errors on one surface only, in effect making the other a datum. Generally speaking, with spherical components the lateral displacement component need not be used. The cement wedge angle is useful for capturing an as-built error in cemented doublets.

Datums may (incorrectly) be applied to the mechanical or optical axes, but these can't be physically located. The fabricator uses physical surfaces (lens surfaces, diameters) as datum features[5].

4. Conclusion

- In a perfectly centered lens, the mechanical and optical axes are concurrent and coincidental, superimposed on each other. Centration errors arise from deviation from superposition.

- As-built centering errors can be reflected in the centration errors of the lens model.

- When possible, use the fabricator's references, physical lens features, as datums.

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[1] W. Smith, Modern Lens Design, Pg 577, McGraw Hill, New York City, 2005
[2] H.H. Karow, *Fabrication Methods For Precision Optics*, Pg 517-525, John Wiley & Sons, New York City, 1993
[3] ZEMAX User's Guide, ZEMAX Development Corporation, Bellevue, WA, 2005
[4] Code V Reference Manual Version 10.0, Optical Research Associates, Pasadena, CA
[5] H.H. Karow, *Fabrication Methods For Precision Optics*, Pg 507, John Wiley & Sons, New York City, 1993