Specifying, Measuring and Meeting Lens Centration

Brandon Light
Optimax Systems, 6367 Dean Parkway, Ontario, NY USA
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This paper defines in detail the parameters used in specifying centration of a lens and techniques used to check location of and position the optical axis. Examples are given of how design specifications are interpreted on the shop floor.
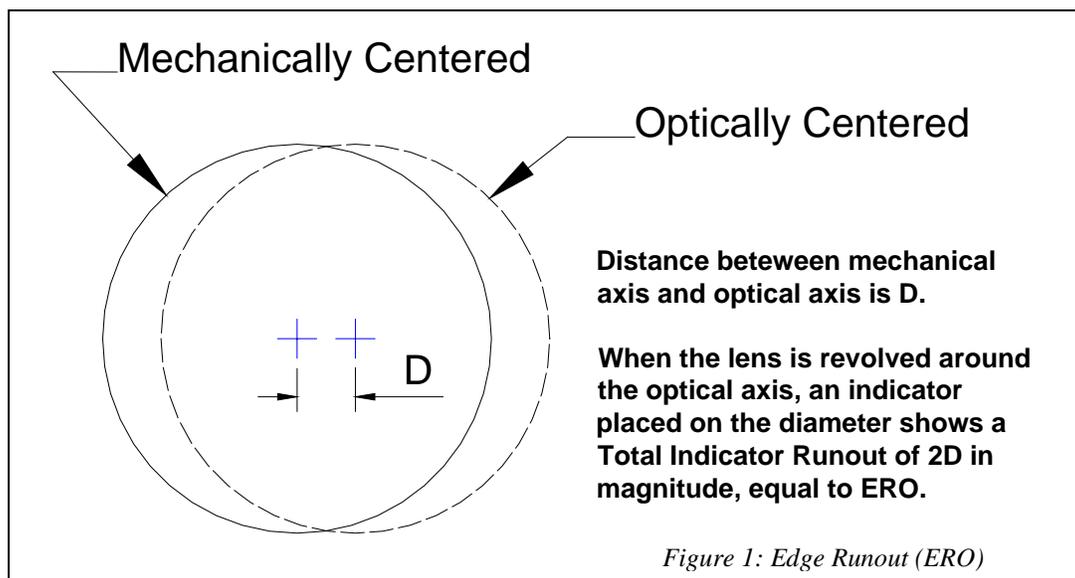
PARAMETERS TO SPECIFY CENTRATION OF A LENS

Contained in any spherical lens, there are two primary axes of interest when talking about centration. The optical axis is the axis passing through the two centers of curvature of the optical surfaces. The mechanical axis passes 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 by deviation from perfect, and errors cause deviation in incoming light rays[1]. One axis may be displaced yet still parallel from the other. This is known as decenter, with the distance between the two axes quantifying this decenter. The other condition, when the two axes become nonparallel to each other, is known as wedge. At some point in space, the axes intersect and form a wedge. Decenter and wedge are two essential terms used when discussing error in lens centration.
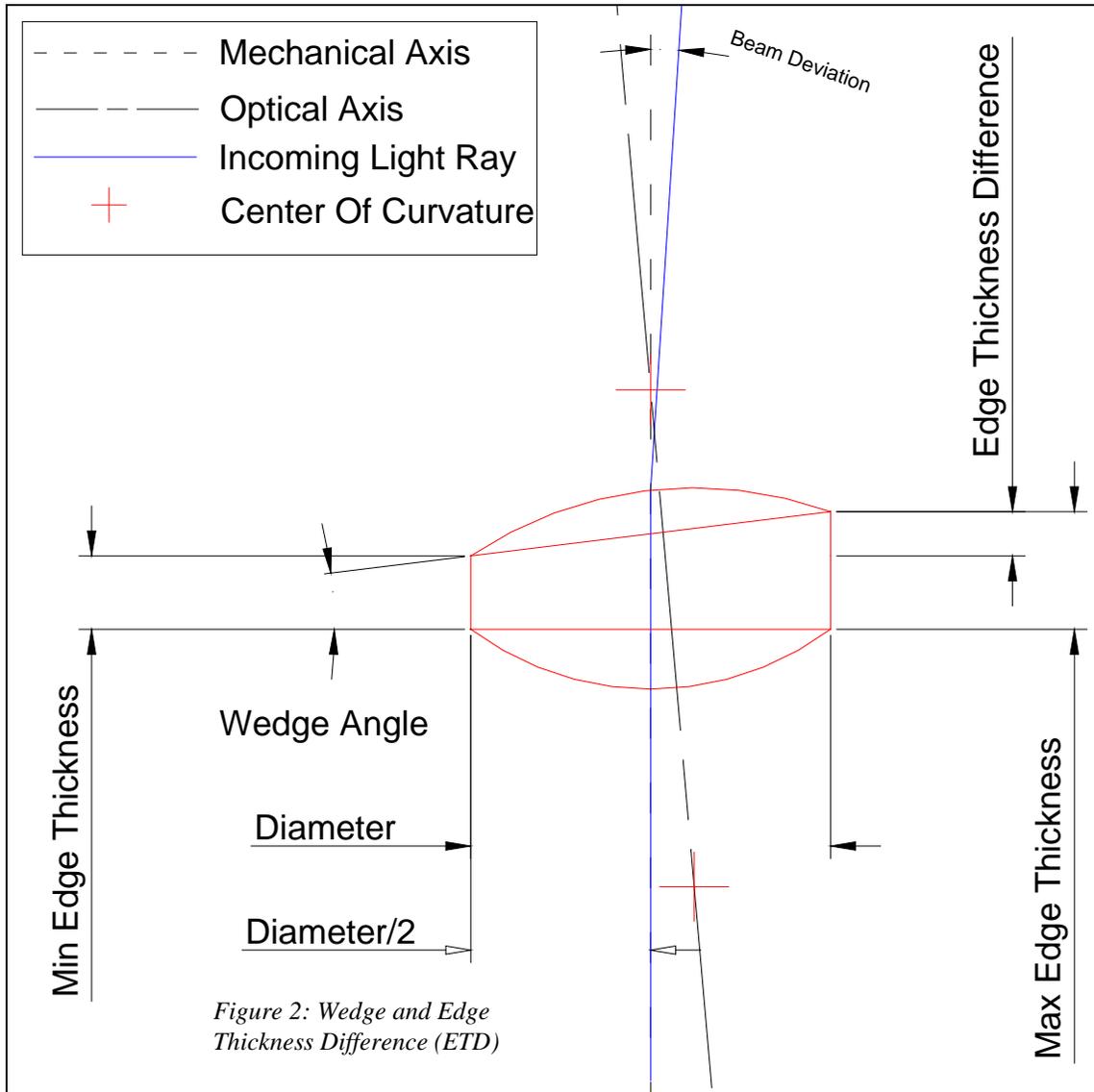
Decenter

In the case of decenter, either surface is equally distributed about the optical axis as a function of radial distance from center. If the lens were rotated about the optical axis, there would be no difference in edge thickness at any radial point away from the optical axis. However, when the lens is rotated about the mechanical axis, there is a difference in edge thickness at some radial distance from the mechanical axis. This edge thickness difference (ETD), also known as edge thickness variation (ETV), forms the basis for detecting and quantifying the centration error contained in a lens. When rotated about the optical axis, a lens with decenter error will exhibit edge runout (ERO)[2]. Two times the distance between the parallel but noncoincedent axes corresponds to the edge runout. Figure 1 shows how decenter and ERO relate.

Figure 1: Edge Runout (ERO)

Within the figure:

Mechanically Centered

Optically Centered

Distance beteween mechanical axis and optical axis is D.

When the lens is revolved around the optical axis, an indicator placed on the diameter shows a Total Indicator Runout of 2D in magnitude, equal to ERO.

Wedge

With wedge, one surface is distributed equally about the mechanical axes. Error in the other surface is proportional to the wedge angle formed by the mechanical and optical axes. When the lens is rotated about its mechanical axis an indicator placed on the other surface will show ETD. Figure 2 illustrates the connection between Wedge Angle, ETD and Beam Deviation.

Figure 2: Wedge and Edge Thickness Difference (ETD)

THE CENTERING PROCESS

Wedge is the case of most interest to the optical fabricator. For commercial centering machines, machine geometry most closely resembles the wedge case. A part to be edged is held between two precision rings, one fixed and the other moveable. Barring some easily prevented source of error[3], the surface in contact with the fixed ring will be evenly distributed about the machine spindle axis[4]. 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 with the moveable ring, but doesn't always put the second surface's center of curvature on the mechanical axis[5]. 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. Positioning error will be seen as ETD in the lens, which matches the wedge case.

INTERPRETATION OF CENTRATION ON THE SHOP FLOOR

On the shop floor a fixture is used to quantify centration errors. The fixture consists of a reference surface for the diameter and a reference ring for one optical surface, plus an indicator for gathering data. A lens is placed into the fixture, and with reference surfaces constrained the lens is rotated about the diameter. An indicator is used to measure runout of the other optical surface. With one spherical surface used as a reference, and with the diameter representing the mechanical axis, the indicator movement is the ETD[6].

Even if the wedge per surface is specified, as can be done in lens design software, the measurement of one surface tells the whole story if the clamping bell of the centering machine is running true. Since one optical surface is used as a reference surface when the lens is placed in the centering machine, it will be free of wedge relative to the diameter once the part is edged.

CENTRATION IN ASPHERES

With aspheres there is now a third axis. The aspheric axis is the line about which a nonspherical symmetric form is evenly distributed. Within the manufacturing process steps are taken to have the aspheric axis and the mechanical axis concurrent and coincidental, and have there be no detectable edge thickness difference when the part is rotated about its mechanical axis. However, errors do occur, and they aren't always spotted with traditional techniques.

Once the aspheric surface is finished, the center of curvature of the spherical surface on the other side must be on the aspheric axis[7]. If it is not, when an asphere is loaded into a centering machine, the aspheric axis will be positioned at a non-zero angle to the mechanical axis of the edged lens. This wedge is permanent and cannot be removed. Traditional centering error detection may not see the wedge between the two axes.

CONSIDERATIONS FOR THE OPTICAL DESIGNER

Whether centering errors are specified in terms of decenter or wedge, it all comes back to ETD. The geometry of the machines used to center lenses and to measure centering error work in terms of the wedge case detailed above, and the wedge case sees centering error as ETD. No matter how centering error is specified (ERO, decenter, beam deviation, wedge per surface), to match manufacturing methods, the fabricator converts to and measures ETD.

[1] R.E. Fischer, B. Tadic-Galeb, P. Yoder, *Optical System Design*, Pg 492, McGraw Hill, New York City, 2008

[2] H.H. Karow, *Fabrication Methods For Precision Optics*, Pg 509, John Wiley & Sons, New York City, 1993

[3] Ibid, Pg 532

[4] R.E. Fischer, B. Tadic-Galeb, P. Yoder, *Optical System Design*, Pg 501, McGraw Hill, New York City, 2008

[5] Ibid

[6] H.H. Karow, *Fabrication Methods For Precision Optics*, Pg 508 - 509, John Wiley & Sons, New York City, 1993

[7] B. Braunecker, R. Hentschel, H. J. Tiziani, *Advanced Optics Using Aspherical Elements*, Pg 91, SPIE, Bellingham, WA, 2008