Specifying, Measuring and Meeting Lens Centration

Brandon Light
Optimax Systems, 6367 Dean Parkway, Ontario, NY USA

This paper defines and details 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 lens, there are two primary axes of interest when talking about centration. The optical axis of a spherical lens 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 perpendicular 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 the ideal. 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 situation is when the two axes become nonparallel to each other. At some point in space, the axes intersect and form a vertex of a wedge at that point. This condition is known as tilt. Decenter and tilt 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). Two times the distance between the parallel but noncoincedent axes corresponds to the edge runout. Figure 1 shows how decenter and ERO relate.

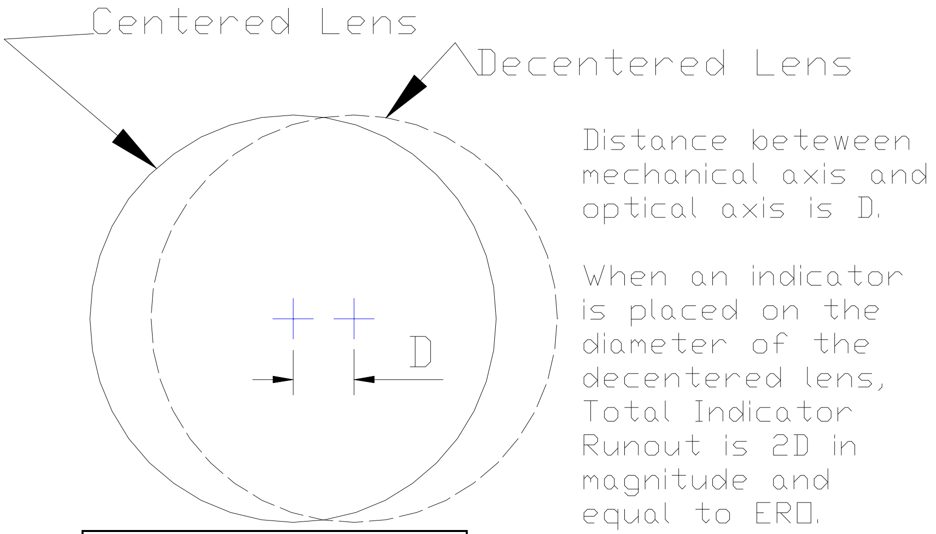

Figure 1: Edge Runout (ERO)

Tilt

With tilt, one surface is distributed equally about both the optical and mechanical axes, and the other surface is not. The error is proportional to the angle of the wedge formed by the mechanical and optical axes. Tilt is referred to as wedge because of the wedge formed by the intersection of axes. Tilt is a primary concern to edge mounted lenses. When the lens is rotated about its mechanical axis, and since only one of the surfaces is distributed evenly about the axis, an indicator placed on the other surface will show ETD.

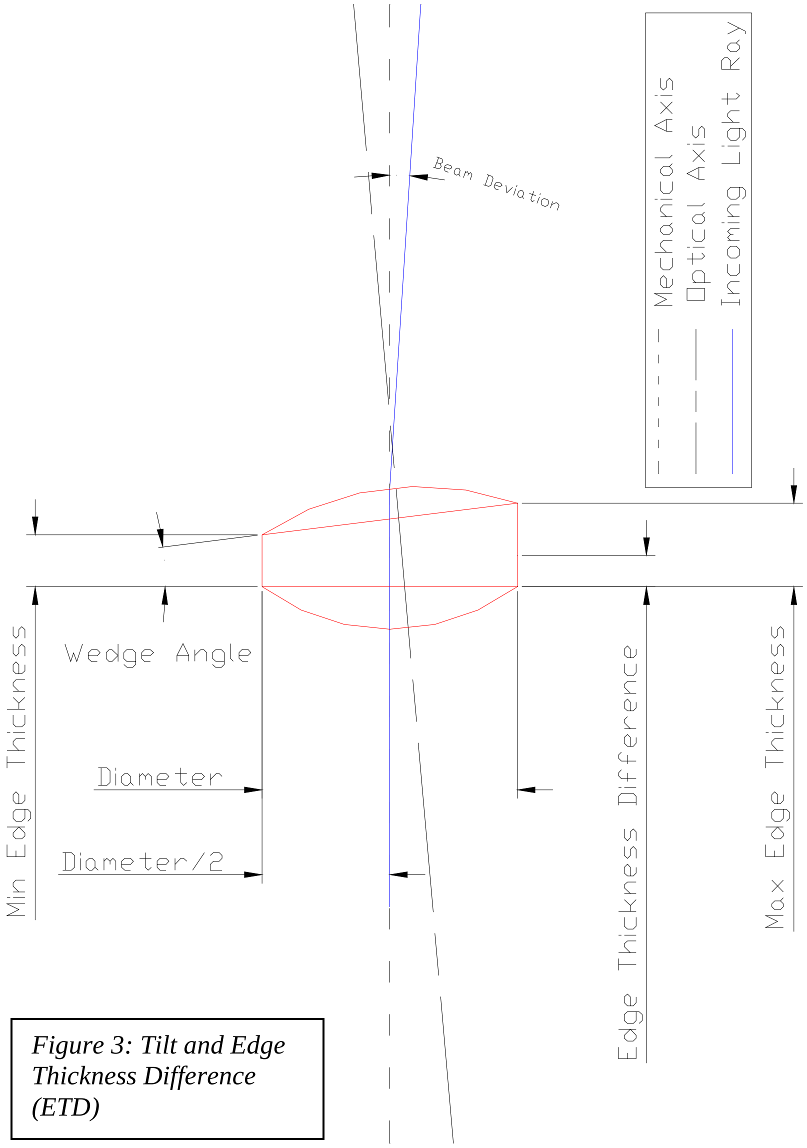

Figure 3: Tilt and Edge Thickness Difference (ETD)

THE CENTERING PROCESS

The case of tilt, as discussed above, is the case of most interest to an optical fabricator. In centering machines currently in use and even in the case of lens centering on a CNC mill or vertical machining center, the geometry of the machine most closely resembles the wedge case. Barring some easily prevented source of error[1], one surface will be running true to and evenly distributed about the mechanical axis. In this case, the newly created diameter represents the mechanical axis, which must be coincident with the machine spindle axis. The other surface is clamped to a position, but this clamping may or may not put the second surface's center of curvature in proper position. Any error in putting that center where it needs to go will be seen as ETD in the lens.

INTERPRETATION OF CENTRATION ON THE SHOP FLOOR

On the shop floor a fixture is used to quantify centration errors. The fixture consists of reference surfaces for the diameter and one optical surface, plus an indicator for gathering data. A lens is placed into the fixture, where it contacts the reference points. With one optical surface and the diameter contacted to and constrained by the reference surfaces, the indicator tip is placed in contact with the other optical surface. The lens is rotated about the diameter, and a measurement is taken. With one spherical surface used as a reference, and with the diameter representing the mechanical axis, the indicator movement is the ETD.

Even if the tilt per surface is specified, as can be done in lens design software, the measurement of one surface tells the whole story only 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 tilt 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. 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 tilt 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 tilt, 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 tilt case detailed above, and the tilt case sees centering error as ETD. The fabricator converts ERO, decenter, beam deviation, tilt per surface, and whatever is specified by the designer, into ETD. No matter how centering error is specified, for ease of manufacturing, the fabricator converts to and measures ETD.

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[1] H.H. Karow, *Fabrication methods for precision optics*, Pg 532, John Wiley & Sons, New York City, 1993