Synopsis: "Location of mechanical features in lens mounts" by P. Yoder

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Abstract:

Glass to metal mechanical lens mounting can be accomplished by understanding the interface between the lens and its mount. Standard lens mounts that create this interface include spacers, retainers and cell shoulders. Five common contact types exist, 90 degree sharp corner, obtuse angle sharp corner, spherical, tangent and toroidal. The proceeding paper "Location of mechanical features in lens mounts" was written Paul R. Yoder Jr. for SPIE Volume 2263. In the paper the author describes methods for designing the geometry of the lens mount interface, including equations corresponding to clear graphic representations and examples. The paper is useful as a guide on how to specify the dimensions of the interface of a mount after the optical design has been considered. This synopsis, written for OPTI 521 at the University of Arizona, summarizes the paper, while offering a few humble suggestions at the end.

Introduction:

When designing lens mounts it is critical to know the location of the contact ring, or contact point in a two dimensional half axis representation. This contact point will be used to establish the distance between different optic elements. That distance will be dictated by the optical system and almost always known in advance. Often the distance between the vertices of optic elements is specified along with the diameter of the clear aperture, outside diameter of the lens and the radius of curvature. Usually the mount designer must find the location of the contact point, or mount edge, with respect to the vertex. This is made possible by using equations for first order optics.

Symbols Used:

A = Clear Aperture Diameter, Typically Given

R = Radius of Curvature of the Lens, Typically Given

R_T = Absolute Radius of the Toroidal Surface

V = Vertex of Lens

Δx = Axial Distance between the Vertex of the Lens and the Corner of the Mounting Feature

y_C = Contact Height

y_S = Inside Radius, Typically .505A

ψ = Half Angle of Cone, for Tangent Interface

θ= Angle between the Optical Axis and the Line between the center of the Radius of Curvature and P.

90 ° Sharp Corner Interface:

For a convex lens, $y_C = y_S$ as shown in Figure 1. The equation for the sagittal depth is used to find the axial distance from "V" to the contact point, which in this case is the point "P".

$\Delta x = R - (R^2 - y_C^2)^{1/2}$ EQUATION 1

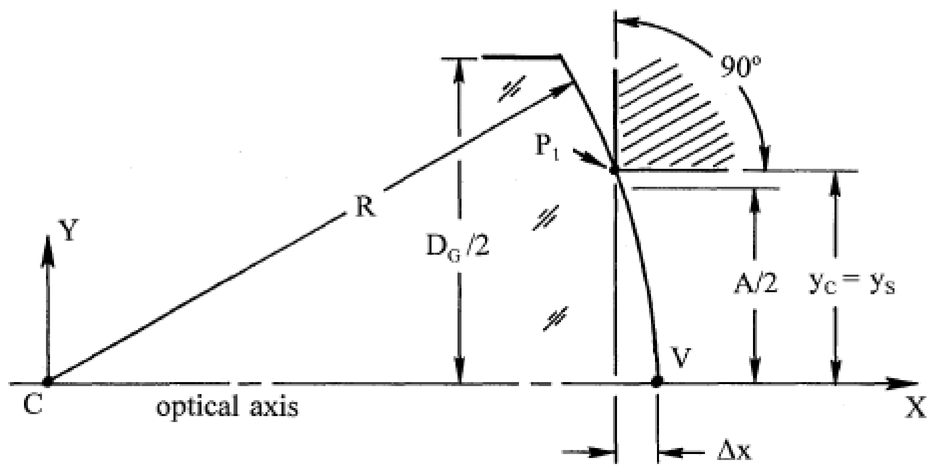

Fig. 1 - Schematic of a 90° "sharp corner" interface on a convex spherical surface.

Equation 1 applies for concave lenses as shown in Figure 2. However in this case, y_C is not equal to y_S . The radial distance between y_C and the radius of the "polished surface edge" is normally the same as the difference between y_C and y_S. The idea of a central location of the contact point is true for the rest of the cases.

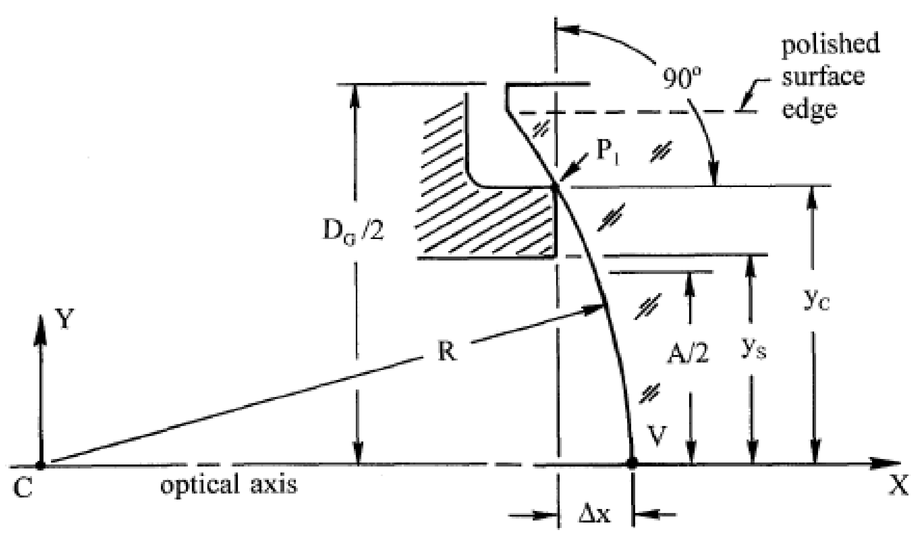

Fig. 2 - Schematic of a 90° "sharp corner" interface on a concave spherical surface.

Obtuse Angle Sharp Corner Interface:

For smoother edges an angle such as 135° is used instead of 90° for the corner at the contact point as shown in Figures 3 and 4. Equation 1 applies here also. Like the 90° sharp corner with the concave lens case, as shown in Figure 2, both obtuse cases require larger outside diameters for the lens mount, compared to the 90° sharp corner with the convex lens case.

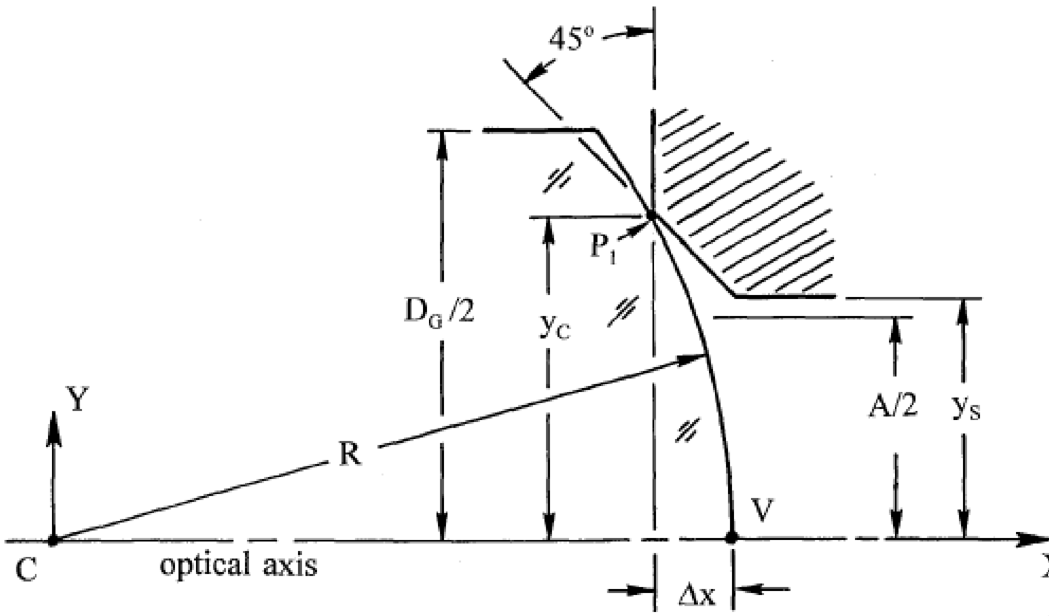

Fig. 3 - Schematic of an obtuse angle "sharp corner" interface on a convex spherical surface.

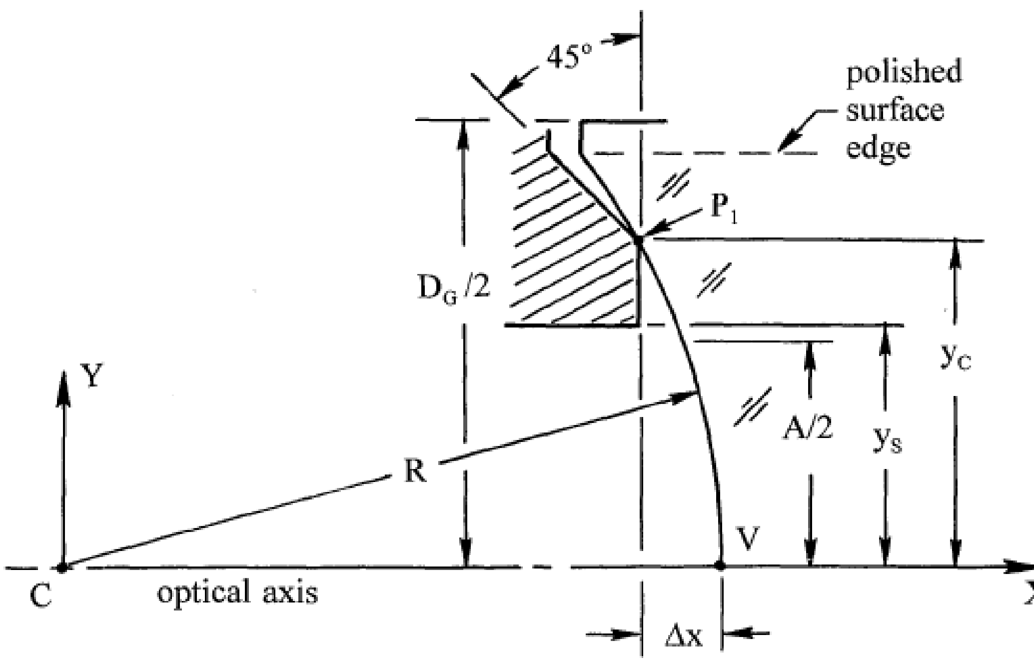

Fig. 4 - Schematic of an obtuse angle "sharp corner" interface on a concave spherical surface.

Spherical Interface:

As shown in Figures 5 and 6, the contact point is at the center of the land of the mounting surface at y_C. Note that this point is <u>not</u> point P, which is also true in all remaining cases. For fabrication P is important to define. The x component of point P continues to be Δx from V. To find the Δx Equation 1 can be used by replacing y_C with y_S.

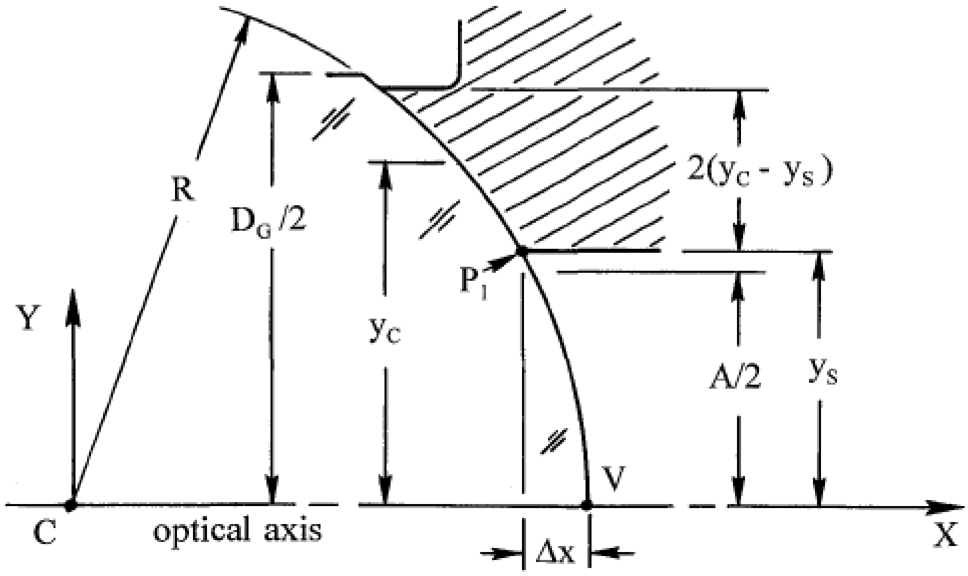

Fig. 5 - Schematic of a spherical interface on a convex spherical surface.

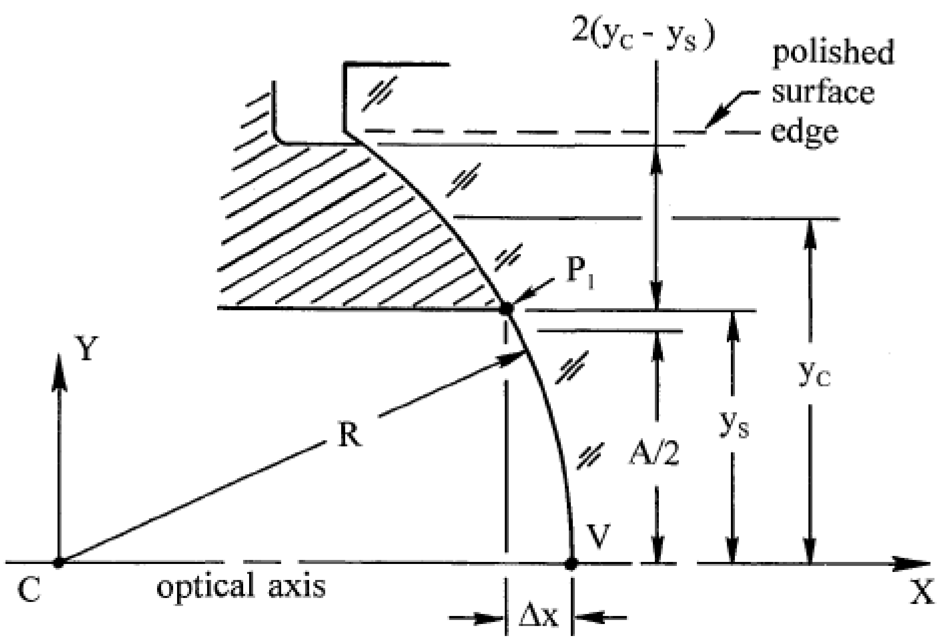

Fig. 6 - Schematic of a spherical interface on a concave spherical surface.

Tangent Interface:

The section of the conical mating surface is shown in Figure 7. This interface cannot be used for concave lenses. The half angle of the cone is an important parameter for fabrication.

$\psi = 90° - \arcsin(y_C/R)$ EQUATION 2

$x_S = y_S / \tan\psi$ EQUATION 3

$x_2 = R / \sin\psi$ EQUATION 4

$x_1 = x_2 - x_S$ EQUATION 5

$\Delta x = y / \tan\psi$ EQUATION 6

Example #1 - A lens has a convex surface of radius 91.500 mm and aperture 64.000 mm. Tangential contact on this surface is desired at y_C = 30.000 mm. Assume y_S = 0.505A = 32.320 mm. Then:

$\psi = 90 - \arcsin(30.000 / 91.500) = 70.8605°$
$x_S = 32.320 / \tan 70.8605° = 11.217$ mm
$x_2 = 91.500 / \sin 70.8605° = 96.854$ mm
$x_1 = 96.854 - 11.217 = 85.637$ mm
$\Delta x = 91.500 - 85.637 = 5.863$ mm
$2(y_C - y_S) = (2)(30.000 - 32.320) = 4.640$ mm.

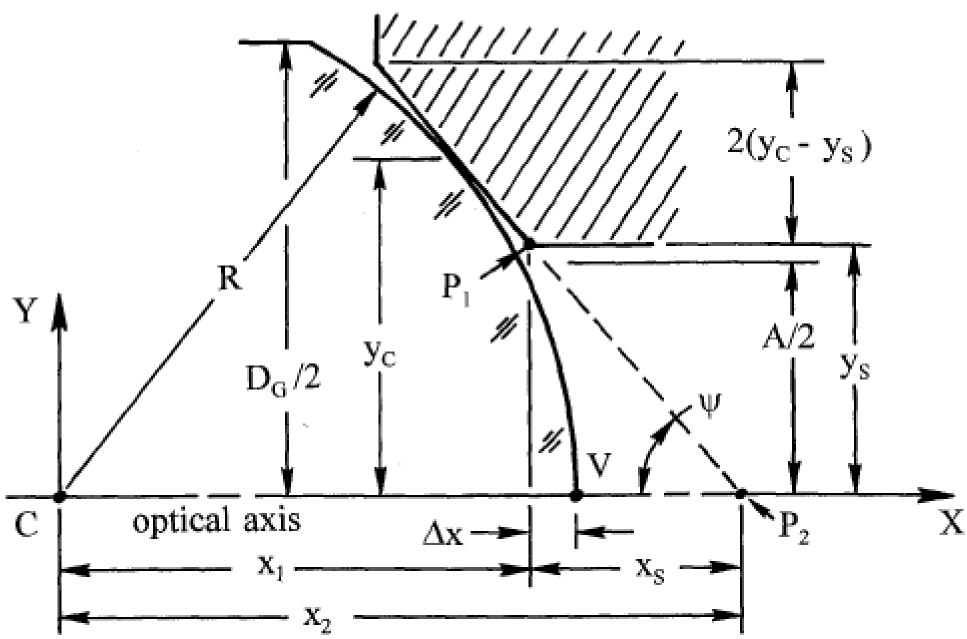

Fig. 7 - Schematic of a tangential interface on a convex spherical surface.

Toroidal Interface:

Figures 8 and 9 both show the case of the convex lens, with 9 being a close up of 8.

$\theta = \text{arc sin } (y_C / R)$ EQUATION 7

$h = (R + R_T) \cos \theta$ EQUATION 8

$k = (R + R_T) \sin \theta$ EQUATION 9

$x_1 = h - [R_T^2 - (y_S - k)^2]^{1/2}$ EQUATION 10

$\Delta x = R - x_1$ EQUATION 11

For concave lenses, as shown in Figure 10, use Equation 7, then Equations 12 though 14 below, and finish with Equation 11.

$h = (R - R_T) \cos \theta$ EQUATION 12

$k = (R - R_T) \sin \theta$ EQUATION 13

$x_1 = h + [R_T^2 - (y_S - k)^2]^{1/2}$ EQUATION 14

Example #2 - Consider the same lens as in Example #1 with a convex surface of radius 91.500 mm and aperture 64.000 mm. In this case, we want toroidal contact at y_C = 30.000 mm. We assume $R_T = -10R = -915.000$ mm. Once again using absolute values for radii, y_S = 0.505A = 32.320 mm, while:

$$\theta = \text{arc sin } (30.000 / 91.500) = 19.1375^\circ$$
$$h = (91.500 + 915.000) \cos 19.1375^\circ = 950.875 \text{ mm}$$
$$k = (91.500 + 915.000) \sin 19.1375^\circ = 329.967 \text{ mm}$$
$$x_1 = 950.875 - [915.000^2 - (32.320 - 329.967)^2]^{1/2} = 85.640 \text{ mm}$$
$$\Delta x = 91.500 - 85.640 = 5.860 \text{ mm.}$$
$$2(y_C - y_S) = (2)(30.000 - 32.320) = 4.640 \text{ mm.}$$

The sagittal depth of this spherical surface at a height of 32.320 mm is 5.898 mm so the clearance in the X-direction to the point P_1 on the toroid is 0.039 mm.

Example #3 - If the same lens surface as above were concave and toroidal contact with $R_T = 0.5R = 45.750$ mm at $y_C = 30.000$ mm were desired, we would find once again that $y_S = (0.505)(64.000) = 32.320$ mm and:

$$\theta = \text{arc sin } (30.000 / 91.500) = 19.1375^\circ$$
$$h = (91.500 - 45.750) \cos 19.1375^\circ = 43.222 \text{ mm}$$
$$k = (91.500 - 45.750) \sin 19.1375^\circ = 14.998 \text{ mm}$$
$$x_1 = 43.222 + [45.750^2 - (32.320 - 14.998)^2]^{1/2} = 85.566 \text{ mm}$$
$$\Delta x = 91.500 - 85.566 = 5.934 \text{ mm}$$
$$2(y_C - y_S) = (2)(30.000 - 32.320) = 4.640 \text{ mm.}$$

The clearance in the X-direction from the sphere to the point P_1 on the toroid is, in this case, 0.036 mm.

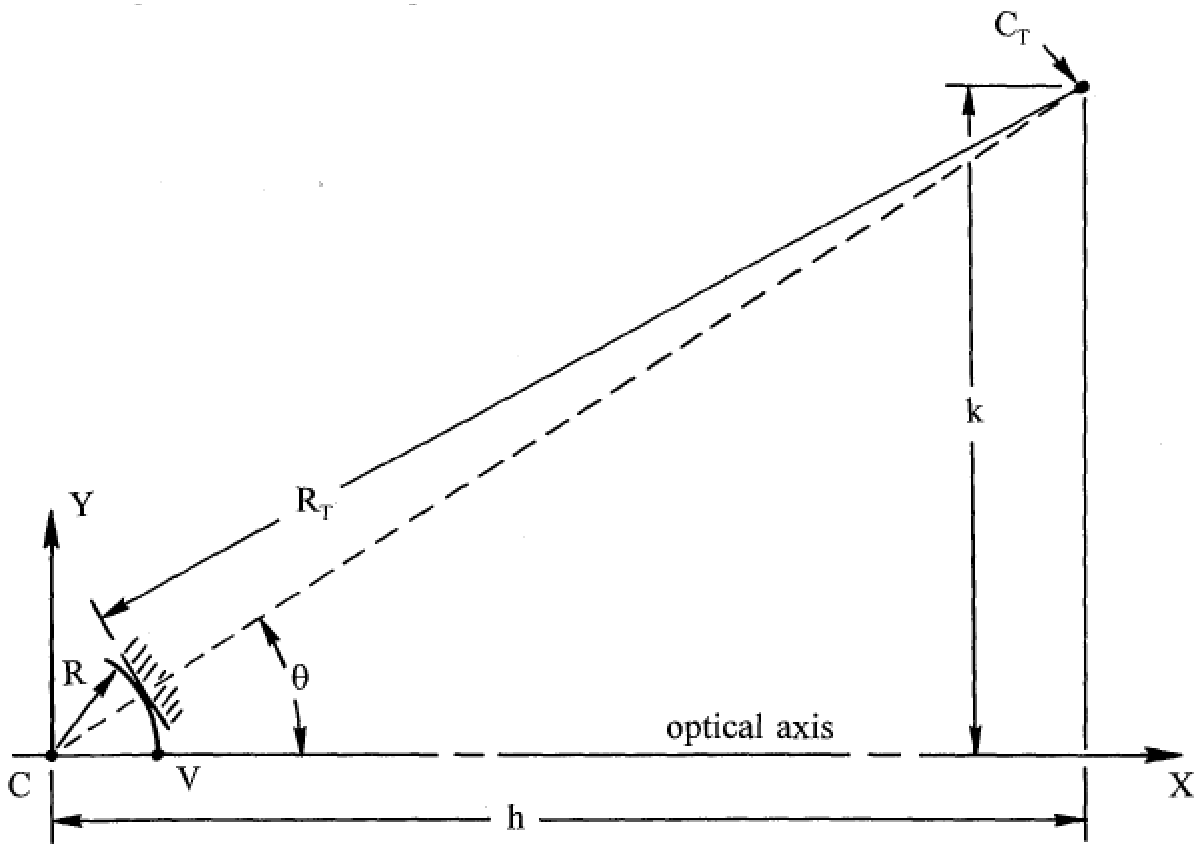

Fig. 8 - General schematic of a toroidal interface on a convex spherical surface.

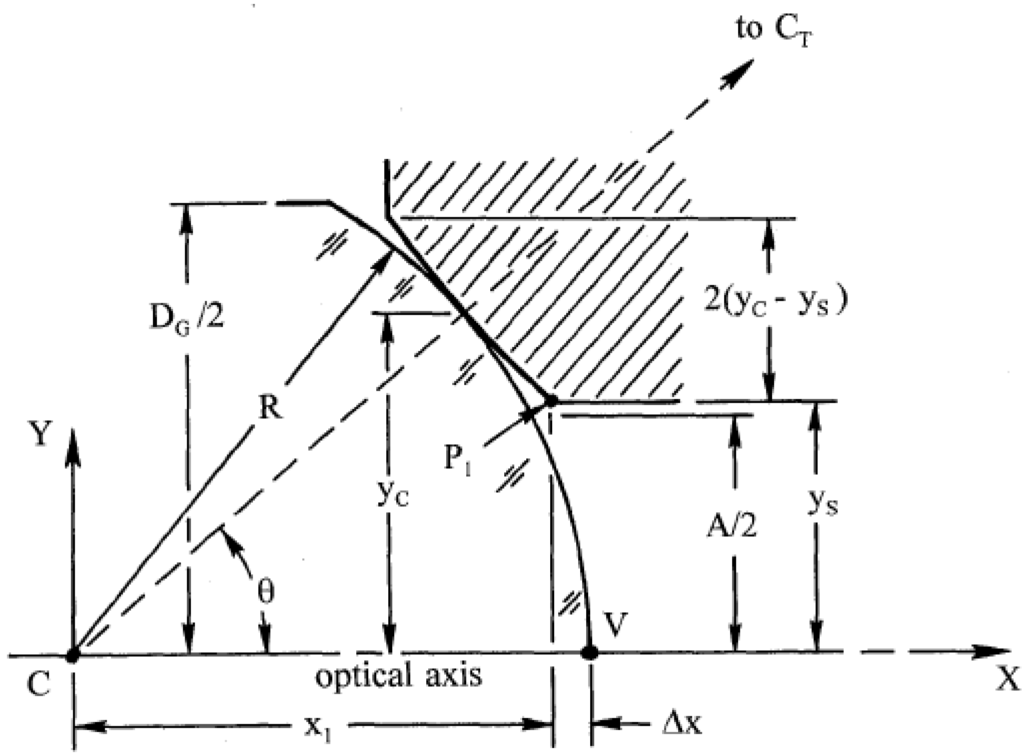

Fig. 9 - Detailed schematic of a toroidal interface on a convex spherical surface.

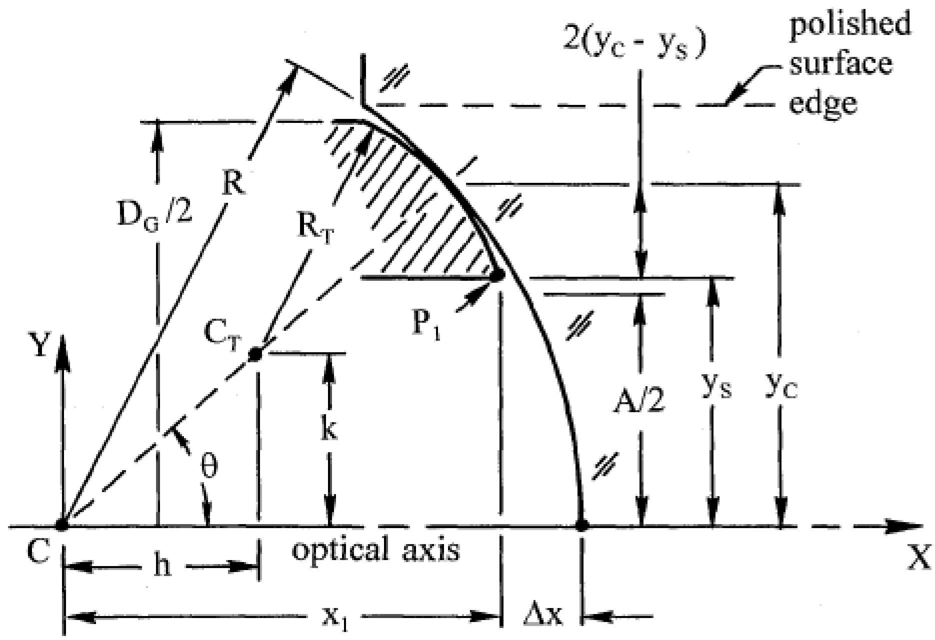

Fig. 10 - Schematic of a toroidal interface on a concave spherical surface.

Conclusion:

The author provides what was advertised very well. The piece describes, in a concise manner, how to find the geometry needed to make a detail drawing used by the manufacturer to fabricate the lens mount. The graphic figures very clearly show the different hatch for the glass and metal sections. The drawings are well labeled with the optical axis in the horizontal as expected. The equations provided are intuitive and easy to understand. They can be easily derived, with Trigonometry. For the most complex cases, that use multiple equations, examples are provided with numbers. It is very useful knowing that the topic is still relevant after more than a decade.

Although it would increase the complexity of the paper a little bit, two things stand out as being good to improve the papers usefulness. First, it is important to note that the spherical case is a theoretical special case of the toroidal interface. When attempting a spherical interface, in reality the radii will never match "exactly". Even with lap polishing, at the optic shop as described in the textbook[2], a very close, but never exact, match can be achieved. Yoder presents the concave lens case with the toroidal, convex interface in Figure 10. Like the spherical interface it distributes the preload better compared to a sharp interface. It would be interesting to show the toroidal interface case where a convex lens makes contact with a concave lens mount. The interface would be useful in a similar way as the spherical case in Figure 5, in order to get better load distribution. Second, to be accurate, it is good to note that when specifying a sharp edge, usually a radius of .002" can be expected[2]. The reason is that even with sharp cutting tools, it can be hard to leave no burr. Some light deburring is often required. Also a small radius can be desirable for handling later, in order to protect against small dings, especially if there is any post processing.

There are a few smaller things that I would offer for improvement. One thing is probably an accident, but is very important to understand. Equation 1 is incorrect in the original paper, and is shown below missing the square for y_C.

$$\Delta x = R - (R^2 - y_C)^{1/2}$$

The formula is made from the formula for lens sag, which is derived from Pythagoras Theorem. Below is the Pythagorean Theorem with our variables.

$$R^2 = y_C^2 + (R - \Delta x)^2 \qquad \text{EQUATION 15}$$

With some algebra we can derive Equation 1 from Equation 15. Most likely this is a typographical mistake and most readers will understand and make the correction automatically.

Two other typographical errors can be found, and are almost too small to mention. One is that in the discussion section describing the five interface types, each section is numbered next to the title of the section. The last two sections, tangent and toroidal, are both labeled “4”, on accident. Finally Figure 8 labels the angle θ as “0”.

Even though the paper was limited to exclude most reasons for choosing different interfaces, some guidance would be a good addition to this piece, even if only one sentence. For example, spherical radius interface can be used if high axial preload is required.

Overall, Yoder’s paper is a very useful resource. It will be used by me and others for a long time, to break down the geometry of a lens to mount interface. It is useful because it is easy to understand without wordiness. He gives just enough information to get the job done.

References:

1. Paul R. Yoder Jr., “Location of mechanical features in lens mounts” in *Current Developments in Optical Design and Optical Engineering IV (Proceedings Volume)*, ed. R E Fischer, W J Smith, proc. SPIE Volume 2263 (Sep 1994)

2. Paul R. Yoder Jr., *Opto-Mechanical Systems Design*, Third Edition, pp 197-198 (CRC Press, 2006)