Synopsis of Technical Report

Techniques for Characterizing Optical System Fabrication by Kevin P. Thomson

Proc. of SPIE Vol.0483, Optical Alignment II,ed. M.C.Ruda (Jan.1984)
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Abstract:

This synopsis is about a published SPIE paper by Kevin p. Thomson, entitled as "Techniques for Characterizing Optical System Fabrication" .

Although the performance of a lens or an optical system can be analyzed in optical design process, the interactions with mechanical hardware and mechanical properties are always ignored, which always cause lots of differences in real world and are essential in fabricating and assembling process.

Coordinate system is always important in design, fabrication and measurement process, in this paper, the author is aim to develop a series of physically local coordinate systems with a set of stationary pivot points whose position is defined by the basic element to a reference axis which can provide a capability to accept, manufacture and test data and reflect true properties in real world. As an optical system is characterized by optical elements, mechanical spacers, mechanical barrels and optical tests, focusing on the first two fields, creating coordinates based on a single lens, the author first introduced some basic concepts that are important for the physical coordinates, like local coordinate axes, optical element units and so on, then introduced the application in fabricating process.

In this synopsis, the concepts that the author introduced and the application in fabricating process will also be discussed. Because the paper is published in late 80s, some sources about modern technologies are also checked.

Basic concepts:

<u>Local coordinate axes</u>

Local element optical axis(LEOA): the line connects two center of curvature of an optical element.
Local element mechanical axis(LEMA): the central axis of the outer envelope of the fabricated element.
From above, we know that the radius of curvature of each surface, the thickness and the edging operation are the properties that define those two axes. Ideally, they should be coincident.

<u>Optical element units</u>

Show in figure 1, a lens in real world because of fabricated errors (tilt and wedge) can be divided into 4 parts, two spherical refracting caps, a tilted plane parallel plate and a wedge. We can also find the difference between LEOA and LEMA.

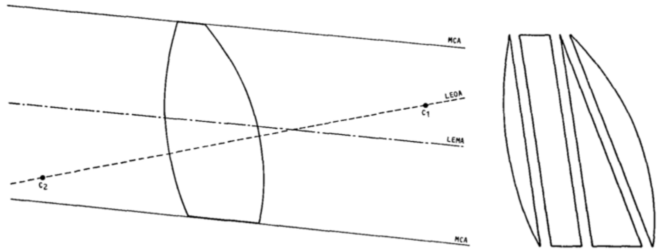

figure 1. single lens with fabricated errors

In scalar system, set r is the radius of the spherical surface, ρ is the radius of circle difined by aperture size, δx is the distance between the local surface plane and the spherical surface which can be shown in figure 2. We can know that $\delta x = \frac{\rho^2/r}{1+\sqrt{1+(\rho^2/r^2)}}$.

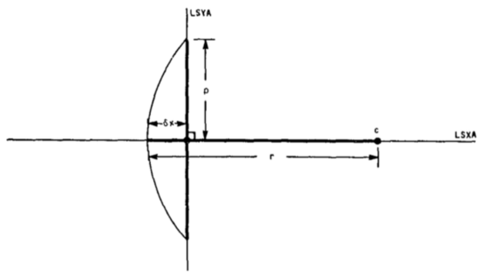

figure 2. geometry relationship in scalar system

In vector system, set $\overrightarrow{t_p}, \overrightarrow{c_1}, \overrightarrow{c_2}$, are individually as the vector between two separate surface, the vector between the center of curvature of surface 1 and the origin of one separate surface, the vector between the center of curvature of surface 2 and the origin of another separate surface. The relationship can be shown in figure 3, from which we can see that the three vectors need not be coplanar. Besides, they are the basis of mechanical properties in optical elements.

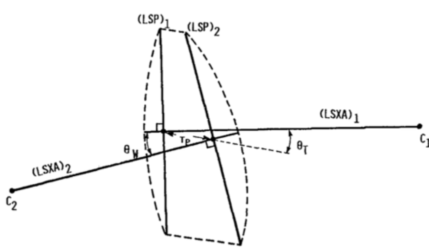

figure 3. geometry relationship in vector system

Spacers

Spacers are to separate two optical elements, take ring spacers as an example. Say that the spacer contacts three points in a circle at the surface of an optical element, we can find out that the local spacer mechanical axis is defined to lie along the line connecting the origins of the local surface coordinate axes, the local spacer optical axis is defined to lie along the line connecting the centers of curvature of contacting optical elements, besides, the optical properties of the system are rotationally symmetric about the local spacer optical axis.

The author defined the pivot points are at the origins of the local surface coordinate systems for fabrication errors, and at the centers of curvatures for interface between elements, which can be shown in figure 4.

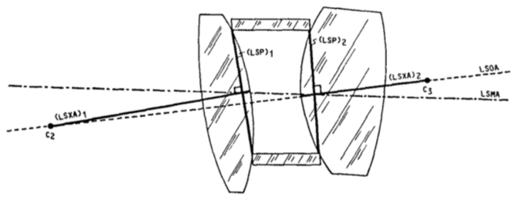

figure 4. geometry relationship in spacers

Application to the fabrication process:

There are four major operations in fabricating a single optical element, which are the selections of the glass blank, the generation of the first radius of curvature, the generation of the second radius of curvature while keeping the correct thickness, and the edging operation (low speed rotating around the mounting axis). Among the four operations, the last one plays more important role in mounting/assembling process. Two functions it performs, one is determining the mechanical axis, another is determining the mechanical aperture.

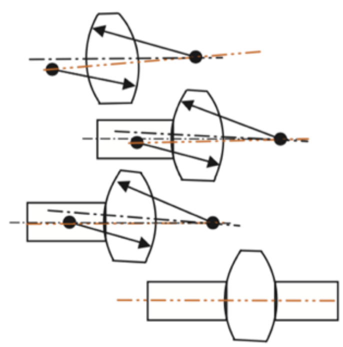

figure 5. edging mounting

Actually, there are two types of fabricating error in single lens which are shown in figure 6, one is tilt which is show above, another is decenter. We can see that in decenter situation, the optical axis is parallel to the mechanical axis.

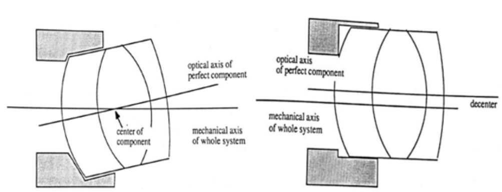

figure 6. tilt and decenter situations

Once fabricating started, the mechanical values, radii, outer diameter, wedge, thickness, plane parallel plate tilt can be measured in this coordinate system, according to figure 2 and figure 3.

Outer diameter ρ

The measurement is always made directly on the surface that is normal to the mechanical axis by spherometer, and always be used to calculate the mechanical aperture radii for each surface.

For the first surface $\rho_1 = \rho / \cos\theta_t$,   for the second surface $\rho_2 = \rho / \cos(\theta_t - \theta_w)$.

Plane parallel plate tilt α

Show in the figure 7, the tilt angle α is $\frac{max-min}{D} = \frac{ETD}{D}$, where ETD is the edge thickness difference. If the element is centered on a high-production mechanical centering machine, thw limit on the accuracy of the concentricity obtained is determined by the residual difference in edge thickness, which is always 0.0005 inch.

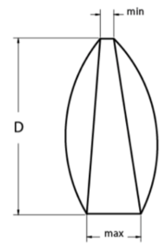

figure 7. plan parallel plate tilt angle

Summary:

In this synopsis, basic concepts for building a local coordinate systems for real world fabricating and measurement are introduced, as well as the application in fabricating, especially for the edging and centering operation.

Other references:

1. W. Smith, "Modern Optical Engineering," The McGraw-Hill Companies, 3th edition (2000)
2. Ray. Williamson, "field guide to optical fabrication," SPIE Field Guides Volume FG20 (2011)
3. OPTI 521 classnote, specifying optical components
4. Geoffery Peter Adams, "Tolerance of Optical Systems", PhD. dissertation (1987)