Lecture -9

Distortion

The last of the five primary, monochromatic aberrations is distortion.

Its origin lies in the fact that the transverse magnification, MT, may be a function of the off-axis image distance, yi. Thus, that distance may differ from the one predicted by paraxial theory in which MT is constant.

In other words, distortion arises because different areas of the lens have different focal lengths and different magnifications.

In the absence of any of the other aberrations, distortion is manifest in a misshaping of the image as a whole, even though each point is sharply focused.

Consequently, when processed by an optical system suffering ***positive or pincushion distortion***, a square array deforms, as in Fig. 6.34b. In that instance, each image point is displaced radially outward from the center, with the most distant points moving the greatest amount (i.e., MT increases with yi).

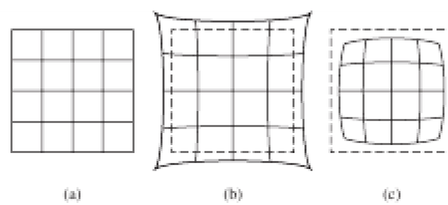
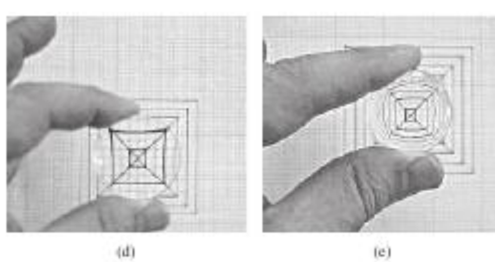


Figure 6.34 (a) Undistorted object. (b) When the magnification on the optical axis is less than the off-axis magnification, pincushion distortion results. (c) When it is greater on axis than off, barrel distortion results.

Similarly, ***negative or barrel distortion*** corresponds to the situation in which MT decreases with the axial distance, and in effect, each point on the image moves radially inward toward the center (Fig. 6.34c).

Distortion can easily be seen by just looking through an aberrant lens at a piece of lined or graph paper.



(d) Pincushion distortion in a single thin lens. (e) Barrel distortion in a single thin lens.

Fairly ***thin*** lenses will show essentially ***no distortion***, whereas ordinary **positive** or **negative**, ***thick***, simple lenses will generally suffer **positive** or **negative** distortion, respectively.

The introduction of a stop into a system of thin lenses is invariably accompanied by distortion, as indicated in Fig. 6.35.

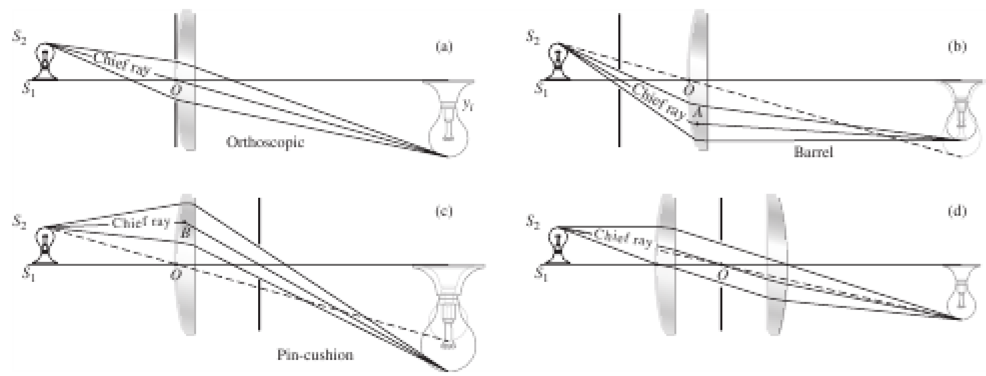


Figure 6.35   The effect of stop location on distortion

One exception is the case in which the aperture stop is at the lens, so that the chief ray is, in effect, the principal ray (i.e., it passes through the principal points, here coalesced at O).

If the stop is **in front of** a positive lens, as in Fig. 6.35b, the object distance measured along the chief ray will be greater than it was with the stop at the lens (S2A > S2O). Thus x_o will be greater and [5-26 from Newtonian form of the lens equation] MT will be smaller-ergo, barrel distortion.

$$M_T = -\frac{x_i}{f} = -\frac{f}{x_o}$$

****In other words, MT for an off-axis point will be less with a front stop in position than it would be with out it.***

* The difference is a measure of the aberration, which, by the way, exists regardless of the size of the aperture.

In the same way, **a rear stop** (Fig. 6.35c) decreases x_o along the chief ray (i.e., S2O > S2B), thereby increasing MT and introducing pincushion distortion.

- ***Interchanging the object and image thus has the effect of changing the sign of the distortion for a given lens and stop.*** The aforementioned stop positions will produce the opposite effect when the lens is negative.
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- All of this suggests the use of **a stop midway** between identical lens elements.
  The distortion from the first lens will precisely cancel the contribution from the second. This approach has been used to advantage in the design of a number of photographic lenses. To be sure, if the lens is perfectly symmetrical and operating as in Fig. 6.35d, the object and image distances will be equal, hence MT = 1. (Incidentally, coma and lateral color will then be identically zero as well.) This applies to (finite conjugate) copy lenses used, for example, to record data. Nonetheless, even when MT is not 1, making the system approximately symmetrical about a stop is a very common practice, since it markedly reduces these several aberrations.

- Distortion can arise in ***compound lens*** systems, as for example in the telephoto arrangement shown in Fig. 6.36. For a distant object point, the margin of the positive achromat serves as the aperture stop. In effect, the arrangement is like a negative lens with a front stop, so it displays positive or pincushion distortion.

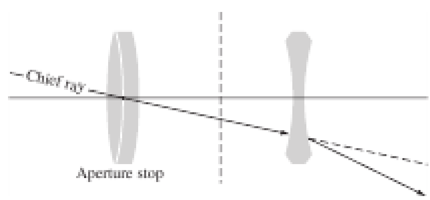

Figure 6.36 Distortion in a compound lens.

Suppose a chief ray enters and emerges from an optical system in the same direction as, for example, in Fig. 6.35d. The point at which the ray crosses the axis is the optical center of the system, but since this is a chief ray, it is also the center of the aperture stop. This is the situation approached in Fig. 6.35a, with the stop up against the thin lens. In both instances the incoming and outgoing segments of the chief ray are parallel, and there is zero distortion; that is, the system is orthoscopic.

This also implies that the entrance and exit pupils will correspond to the principal planes (if the system is immersed in a single medium—see Fig. 6.2).

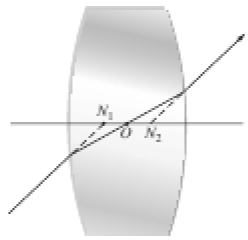

Figure 6.2 Nodal points.

Bear in mind that the chief ray is now a principal ray. A thin-lens system will have zero distortion if its optical center is coincident with the center of the aperture stop.

By the way, in a pinhole camera, the rays connecting conjugate object and image points are straight and pass through the center of the aperture stop. The entering and emerging rays are obviously parallel (being one and the same), and there is no distortion.