CYLINDER LENSES

INTRODUCTION TO CYLINDER LENSES

Cylinder lenses are crucial to the progression of technology for applications ranging from medical diagnostic devices to laser diode correction mechanisms. They are similar to spherical lenses in the sense that they use curved surfaces to converge or diverge light, but cylinder lenses have optical power in only one dimension and will not affect light in the perpendicular dimension ***(see Figure 1)***. This is impossible to accomplish using spherical lenses as light will focus or diverge uniformly in a rotationally symmetric manner. Cylinder lenses have many uses including forming laser light sheets and circularizing elliptical beams.

Figure 1

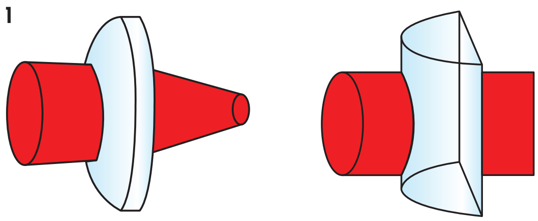

Figure 1: Diagram of a spherical lens (left) and a cylinder lens (right)

Most optics, such as spherical lenses, windows, and aspheric lenses, are rotationally symmetric and their optical power is constant while rotating along the optical axis. If a cylinder lens is rotated along its optical axis, the profile of the lens would change dramatically. For this reason, cylinder lenses require a unique coordinate system to effectively reference features of a lens. The reference system is defined by two orthogonal axes – the plano axis and power axis. The first axis is called the "plano axis" because it runs along the flat length of the lens. The second axis is called the "power axis" because it runs along the curved length of the lens and is the only axis with optical power ***(see Figure 2)***. The length of the cylinder lens along the plano axis has the ability to extend without affecting the optical performance since by definition there is no optical power on this axis. This characteristic enables cylinder lenses to have a variety of form factors, including rectangular and circular shapes.

Figure 2

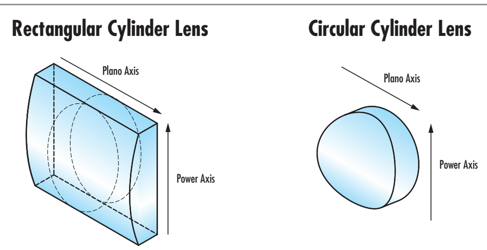

Figure 2: Power and plano axes in both rectangular and circular cylinder lenses

Errors, Aberrations, and Specifications

Misalignment during the polishing process could lead to a number of mechanical errors specific to cylinder lenses, which can cause optical aberrations and negatively impact performance. These errors are defined with reference to the plano and power axes, as illustrated in ***Figure 2***.

Plano Axis Wedge

In an ideal cylinder the plano axis is orthogonal to the edge of the lens. Deviation in this angle is known as the plano axis wedge, which is typically measured in degrees. Plano axis wedge affects multiple aspects of performance such as uneven line thickness across the focal plane, beam deviation along the optical axis, and focal plane tilt ***(see Figure 3)***.

Figure 3

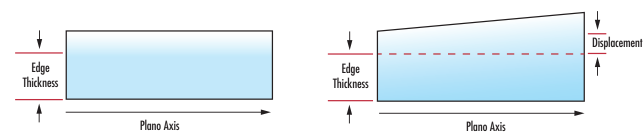

Figure 3: Example of an exaggerated plano axis wedge in a cylinder lens

Power Axis Wedge

Figure 4

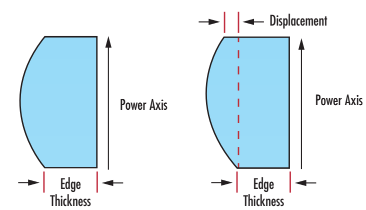

Figure 4: Example of power axis wedge in a cylinder lens

Similar to the plano axis, the power axis should also be orthogonal to the edge of the lens. Deviation present in this angle is known as the power axis wedge or decenter. Since the power axis relates to the surface with curvature, power axis wedge can also be thought of as a displacement of the optical axis. This wedge angle affects the line thickness across the focal plane and causes beam deviation along the optical axis ***(see Figure 4)***.

Axial Twist

Figure 5

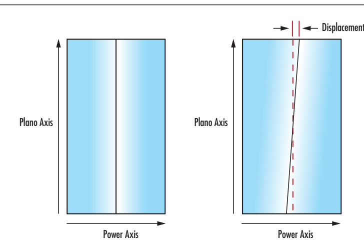

Figure 5: Example of axial twist in a cylinder lens

Axial twist is a misalignment between the optical and mechanical axes, causing a rotation of the image about the optical axis. Axial twist can cause problems when using rectangular elements secured at their edges ***(see Figure 5)***. Circular cylinder lenses can be used to counteract axial twist because the element can be freely rotated during alignment.

Just like other optical components, key parameters of cylinder lenses such as the surface quality and surface irregularity also need to be properly specified for a given application. Surface specifications are also particularly important for cylinder lenses as they are frequently used with lasers.

The shape of a cylinder lens greatly influences its manufacturability. While it is possible to make double-convex and double-concave cylinder lenses, the presence of a planar surface provides more options for both manufacturing and testing. It is also relatively simple to produce high quality planar surfaces, giving plano-convex cylinder lenses the best price to performance ratio. Cylinder lenses with a small f/# are more difficult to manufacture because the relatively small radius of curvature will affect each edge thickness more drastically than in lenses with a higher f/#. This results in a more severe power axis wedge. The same amount of edge thickness variation may lead to vastly different amounts of power axis wedge for cylinder lenses with the same diameter but different f/#s ***(see Figure 6)***.

Figure 6

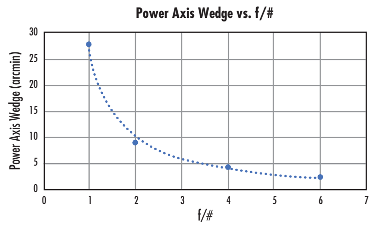

Figure 6: Sample plot of power axis wedge vs. f/# for the same amount of edge thickness variation

Applications

Cylinder lenses are most commonly used in laser beam shaping to correct an asymmetric beam, create a line, or generate a light sheet. Modern scientific methods such as Particle Image Velocimetry (PIV) and Laser Induced Fluorescence (LIF) often require a thin laser line or an even laser light sheet. Structured laser light is also an important tool for scanning, measurement, and alignment applications. With low cost laser diodes now readily available, another common application is simply circularizing the elliptical output from a diode to create a collimated and symmetric beam.

Forming a Light Sheet

A light sheet is a beam that is diverging in both the X and the Y axes. Light sheets include a rectangular field orthogonal to the optical axis, expanding as the propagation distance increases. A laser line generated using a cylinder lens can also be considered a light sheet, although the sheet has a triangular shape and extends along the optical axis.

To create a true laser light sheet with two diverging axes, a pair of convex or concave cylinder lenses orthogonal to each other are required ***(see Figure 7)***. Each lens acts on a different axis and the combination of both lenses produces a diverging sheet of light.

Figure 7

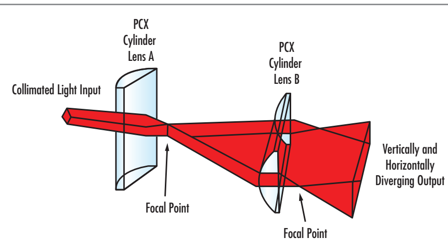

Figure 7: Example of orthogonal cylinder lenses used to generate a rectangular light sheet

Circularizing a Beam

A laser diode with no collimating optics will diverge in an asymmetrical pattern. A spherical optic can not be used to produce a circular collimated beam as the lens acts on both axes at the same time, maintaining the original asymmetry. An orthogonal pair of cylinder lenses allows each axis to be treated separately ***(see Figure 8)***.

Figure 8

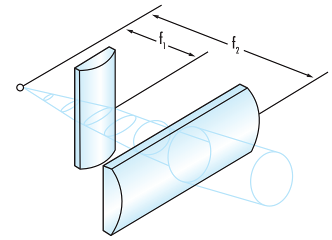

Figure 8: Example of circularizing a beam using cylinder lenses

To achieve a symmetrical output beam, the ratio of the focal lengths of the two cylinder lenses should match the ratio of the X and Y beam divergences. Just as with standard collimation, the diode is placed at the focal point of both lenses and the separation between the lenses is therefore equal to the difference of their focal lengths.

Laser diodes may have a very large divergence, which can be a challenge when trying to collimate them because divergence has a direct effect on the allowable length of the system, as well as the required sizes of the lenses. As the relative positions of each component are fairly fixed due to their focal length, it is possible to calculate the maximum beam width at each lens with the following formula:

$$d = 2f(\tan(\theta/2))$$

By using the focal length of the lens and the divergence angle of the axis it is collimating, the maximum beam width (d) can be calculated for the lens. The clear aperture of each lens must then be larger than the corresponding maximum beam width.

Conclusion

Lasers are becoming more and more important in the modern world and are critical components in areas including measurement and alignment, 3D scanning, laser induced fluorescence microscopy, particle image velocimetry, optogenetics, and even autonomous vehicles. Cylinder lenses play an important role in the manipulation and shaping of laser light. Regardless of beam shape, the quality of the resultant laser beam is often critical to the success of the application.

Due to the asymmetric nature of cylinder lenses and the specialized manufacturing processes required, it is important that both of the wedge angles and axial twist are specified and properly controlled. A lens with a high surface quality (10-5) and high surface flatness (λ/10) of the planar face is of limited use without these additional specifications.

The shape of the lens and mechanical tolerances significantly affect the ease of integration. For example, circular cylinder lenses are often much easier to integrate into a system of other circular optical components and also remove issues associated with axial twist. Just as with other optical components, a cylinder lens with high quality and tight tolerances makes assembly and alignment much easier, allowing for the creation of complex multi-element systems by dropping in standard parts. While higher quality lenses might be more expensive, they often reduce the overall cost of a project.

Cylinder lenses require specialized equipment and skills to manufacture. Although standard stock components are readily available, your application may require custom cylinder lenses based off of your specification requirements. Contact our technical support to discuss your requirements and ensure the correct cylinder lens is chosen for your next application.