

Cylinder Lenses for Beam Shaping

Understanding specifications of a cylinder lens is crucial for the performance of an optical system.

Daniel Adams

Precision manufacturing relies on laser machining. Cylinder lenses have a direct effect on the performance of these systems.

Lasers are a critical part of many new technologies. Fields like manufacturing, measurement, medical treatments and scientific research depend on lasers. The quality of the beam in all application areas is crucial. Cylinder lenses are commonly used to shape and manipulate a laser beam and any errors or aberrations they introduce will affect the beam quality. Manufacturing methods for cylinder lenses differ from traditional spherical optics and as a result, there are additional specifications to be considered. Without properly specifying and controlling these parameters problems such as uneven line thickness, beam deviation and image rotation can reduce system performance. This article will line out the unique specifications of cylinder lenses that need to be considered in the process of system integration and their potential effect on the performance.

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, its profile 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 first axis is called plano axis because it runs along the flat length of the lens. The second axis is called power axis because it runs along the curved length of the lens and is the only axis with optical power (Fig. 1). The length of the cylinder lens along the plano axis can be extended without affecting the optical

performance since, by definition, there is no optical power on this axis. This enables cylinder lenses to have a variety of form factors, including rectangular and circular shapes.

Errors, aberrations, 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 (Fig. 1a).

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 (Fig. 1b).

Power axis wedge

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 (Fig. 1c).

Daniel Adams, Edmund Optics, Isaac-Fulda-Allee 5, 55124 Mainz, phone: + 49 6131 5700-0, e-mail: da@edmundoptics.eu

Axial twist

Axial twist is a misalignment between the optical and mechanical axes, causing a rotation of the image around the optical axis. Axial twist can cause problems when using rectangular elements secured at their edges (Fig. 1d). 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 surface quality and surface irregularity also need to be properly specified for a given application. Surface specifications are particularly important for cylinder lenses as they are frequently used with lasers (Fig. 2).

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 important for scanning, measurement, and alignment applications. With low cost laser diodes now 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 be considered a light sheet, although it 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 (Fig. 3). Each lens acts on a different axis and the combination

of both lenses produces a diverging sheet of light.

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 (Fig. 4).

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 challenging when trying to collimate them because divergence affects the allowable length of the system, as well as the required size 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:

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

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.

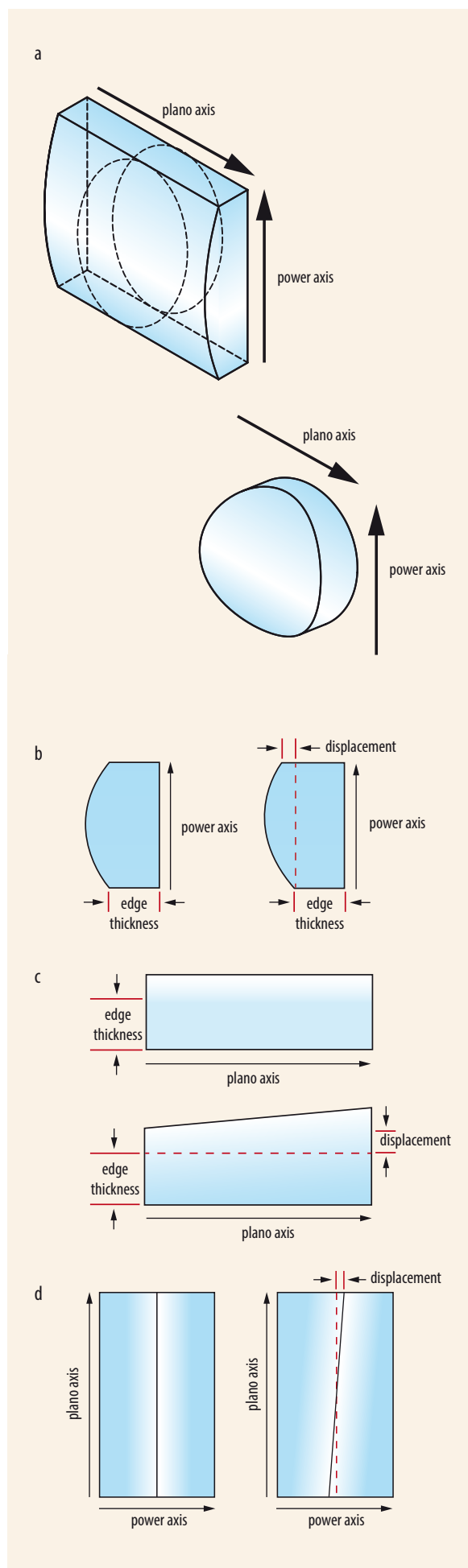


Fig. 1 Power and plano axes in both rectangular and circular cylinder lenses (a); power axis wedge in a cylinder lens (b); example of an exaggerated plano axis wedge in a cylinder lens (c), and of axial twist in a cylinder lens (d)

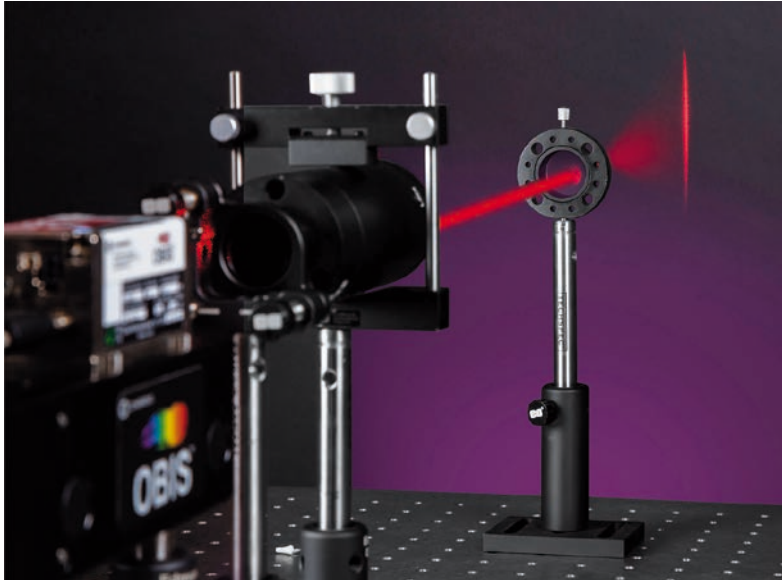


Fig. 2 A simple laser line generation setup with a cylinder lens

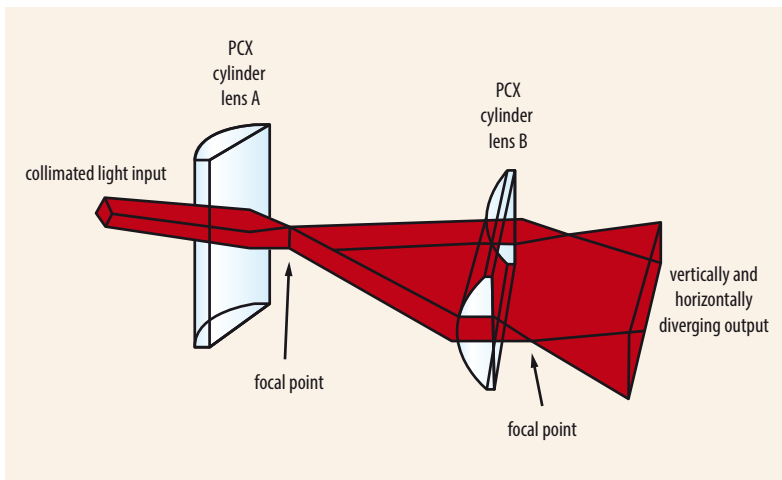


Fig. 3 Example of orthogonal cylinder lenses used to generate a rectangular light sheet

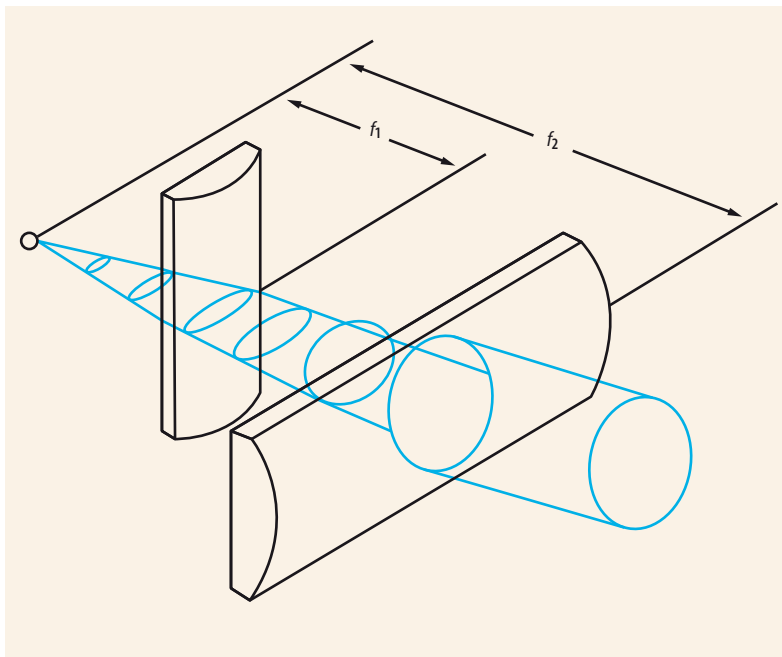


Fig. 4 Example of circularizing a beam using cylinder lenses

Conclusion

Cylinder lenses are critical parts when manipulating and shaping laser light. Because of the huge increase in the use of lasers and the availability of low cost diodes cylinder lenses are becoming increasingly important in new technology.

Due to the asymmetric nature of cylinder lenses and the specialized manufacturing processes required, it is important that both wedge angles and axial twist are specified and properly controlled. A lens with a high surface quality (10^{-5}) and high surface flatness ($\lambda/10$) of the planar face is of limited use without these additional specifications. For beam shaping, it is recommended to have wedge angles of < 5 arc minutes and axial twist of < 3 arc minutes. For ultra-high precision applications, this drops to < 2 arc minutes for wedge angles and < 1 arc minute for axial twist.

Like all optical components a cylinder lens with high quality and tight tolerance makes assembly and alignment much easier, allowing for the creation of complex multi-element systems by dropping in standard parts. It is also important not to over specify as this can lead to unnecessary additional costs. The level of precision must always be adapted to the application requirements in order to optimize both price and performance. For cylinder lenses understanding what their unique specifications actually mean and how they might affect performance is a critical step during system integration.