Choosing the Right Focusing Lens

CASE 1: Determining the optimum input beam diameter when lens focal length is fixed. Often, there are constraints on lens focal length due to system mechanical considerations. For instance, there may be a lower limit on the distance from the focusing lens to the workpiece. In this situation, it's most practical to pick a lens with a focal length that meets the system's mechanical constraints, and then alter the input beam diameter to the lens to achieve a minimum focal spot size.

For determining the input beam diameter, which will provide minimum spot size, we take the equation for spot size, differentiate it with respect to beam diameter, and then set it equal to zero to find the minimum value. This yields the following equation:

Optimum beam diameter for a fixed EFL:

$$D = \left(\frac{4\lambda M^2 f^3}{3\pi k}\right)^{1/4}$$

where,

- f is lens focal length
- D is input beam diameter at the lens (at the $1/e^2$ point)
- k is an index of refraction function
- M^2 is the beam mode parameter
- λ is wavelength

Optimum Beam Diameter

Referring back to our previous example, using a ZnSe best form meniscus lens with focal length constrained to be 5.00" or 127 mm, we get an optimum input beam diameter of 26 mm. Inserting this value into the spot size equation yields a spot size of 86µm, as we obtained by reading the graph in the "Determing Spot Size" section. If we perform the calculation for a 5.00" focal length plano-convex ZnSe lens, we get an optimum input beam diameter of 24 mm, which provides a 96µm focus spot diameter.

If the input beam diameter obtained from this calculation does not closely match the existing beam diameter in the system, then expand or contract the laser beam to this size. The beam can be expanded or contracted using a beam expander/condenser, or by constructing a beam expander/condenser using individual lenses.

CASE 2: Determining the optimum focal length when lens input beam diameter is fixed.
If it's impossible or undesirable to alter the system's beam diameter, then knowing what focal length to use to produce a minimum spot size is beneficial.

To determine the focal length which will provide minimum spot size, we again take the equation for spot size, this time differentiating it with respect to focal length, and then setting it equal to zero to find the minimum value. This yields the following equation:

Optimum EFL for a fixed beam diameter:

$$f = \left(\frac{\pi k D^4}{2 \lambda M^2} \right)^{1/3}$$

where,

- f is lens focal length
- D is input beam diameter at the lens (at the $1/e^2$ point)
- k is an index of refraction function
- M^2 is the beam mode parameter
- λ is wavelength

Optimum EFL

Once the optimum focal length is chosen, choose the stock lens with the focal length closest to the optimum value, or for more critical applications, we can readily fabricate an optic to the exact focal length and tolerances required.

As seen from the preceding discussion, there is a limit on the focus spot size which can be achieved when either focal length or input beam diameter is constrained. If the minimum spot size from the calculation is larger than required for the application at hand, then there is no choice but to change some optical system parameters.

NOTE

With higher power CO2 lasers, it is not generally advisable to use a lens with a diameter greater than 1.5 times the beam diameter (1/e2). Ratios greater than this increase the chance of inducing thermal distortions in the lens. This is caused by too great a thermal gradient across the optic as a result of the greater distance between the heated central beam region and the cooler edge of the lens.