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Gaussian Beam Propagation

Optimum Collimation

Typically, one has a fixed value for w_0 and uses the expression

$$w(z) = w_0 \left[1 + \left(\frac{\lambda z}{\pi w_0^2} \right)^2 \right]^{1/2}$$

to calculate $w(z)$ for an input value of z . However, one can also utilize this equation to see how final beam radius varies with starting beam radius at a fixed distance, z . The figure below shows the Gaussian beam propagation equation plotted as a function of w_0 , with the particular values of $\lambda = 632.8$ nm and $z = 100$ m.

The beam radius at 100 m reaches a minimum value for a starting beam radius of about 4.5 mm. Therefore, if we wanted to achieve the best combination of minimum beam diameter and minimum beam spread (or best collimation) over a distance of 100 m, our optimum starting beam radius would be 4.5 mm. Any other starting value would result in a larger beam at $z = 100$ m.

We can find the general expression for the optimum starting beam radius for a given distance, z . Doing so yields

$$w_0(\text{optimum}) = \left(\frac{\lambda z}{\pi} \right)^{1/2}$$

Using this optimum value of w_0 will provide the best combination of minimum starting beam diameter and minimum beam spread (ratio of $w(z)$ to w_0) over the distance z . For $z = 100$ m and $\lambda = 632.8$ nm, $w_0(\text{optimum}) = 4.48$ mm (see example above). If we put this value for $w_0(\text{optimum})$ back into the expression for $w(z)$,

$$w(z) = \sqrt{2} (w_0)$$

Thus, for this example,

$$w(100) = \sqrt{2} (4.48) = 6.3 \text{ mm}$$

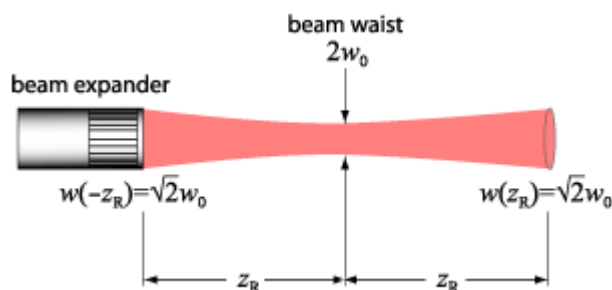
By turning this previous equation around, we can define a distance, called the Rayleigh range (z_R), over which the beam radius spreads by a factor of the square root of 2 as

$$z_R = \frac{\pi w_0^2}{\lambda}$$

with

$$w(z_R) = \sqrt{2} w_0.$$

If we use beam-expanding optics that allow us to adjust the position of the beam waist, we can actually double the distance over which beam divergence is minimized. By focusing the beam-expanding optics to place the beam waist at the midpoint, we can restrict beam spread to a factor of the square root of 2 over a distance of $2 z_R$, as opposed to just z_R



Focusing a beam expander to minimize beam radius and spread over a specified distance

This result can now be used in the problem of finding the starting beam radius that yields the minimum beam diameter and beam spread over 100 m. Using $2(z_R) = 100$, or $z_R = 50$, and $\lambda = 632.8$ nm, we get a value of $w(z_R) = (2\lambda / \pi)^{1/2} = 4.5$ mm, and $w_0 = 3.2$ mm. Thus, the optimum starting beam radius is the same as previously calculated. However, by focusing the expander we achieve a final beam radius that is no larger than our starting beam radius, while still maintaining the square root of 2 factor in overall variation.

Alternately, if we started off with a beam radius of 6.3 mm, we could focus the expander to provide a beam waist of $w_0 = 4.5$ mm at 100 m, and a final beam radius of 6.3 mm at 200 m.

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