3.7 What is $M^2$?

$M^2$ or Beam Propagation Ratio, is a value that indicates how close a laser is to being a single mode $\text{TEM}_{00}$ beam, which in turn determines how small a beam waist can be focused. For the perfect Gaussian $\text{TEM}_{00}$ condition the $M^2$ equals 1.

For a laser beam propagating through space, the equation for the divergence, $\theta$, of an unfocused beam is given by:

$$\theta_0 = \frac{M^2 4\lambda}{\pi D_0}$$

For a pure Gaussian $\text{TEM}_{00}$ beam $M^2$ equals 1, and thus has no impact on the calculation. The calculation of the minimal beam spot is then:

$$d_0 = \frac{4\lambda}{\pi \theta}$$

Again with $M^2$ equal to 1, the focused spot is diffraction limited. For real beams, $M^2$ will be greater than 1, and thus the minimum beam waist will be larger by the $M^2$ factor.

How is $M^2$ measured?

$M^2$ cannot be determined from a single beam profile measurement. The ISO/DIS 11146 requires that $M^2$ be calculated from a series of measurements as shown in the figure above. $M^2$ is measured on real beams by focusing the beam with a fixed position lens of known focal length, and then measuring the characteristics of the artificially created beam waist and divergence.

To provide an accurate calculation of $M^2$, it is essential to make at least 5 measurements in the focused beam waist region, and at least 5 measurements in the far field, two Rayleigh ranges away from the waist area. The multiple measurements ensure that the minimum beam width is found. In addition, the multiple measurements enable a "curve fit" that improves the accuracy of the calculation by minimizing measurement error at any single point. An accurate calculation of $M^2$ is made by using the data from the multiple beam width measurements at known distances from a lens, coupled with the known characteristics of the focusing lens.

$M^2$ Measurement Solutions

Ophir-Spiricon and Photon have a number of solutions for the measurement of $M^2$ ranging from simple manual processes to fully automated dedicated instruments, depending on the frequency of the need to measure $M^2$ of lasers and laser systems. We have a system that will meet most needs, whether for research and development of new laser systems, manufacturing quality assurance, or maintenance and service of existing systems.