

Application Note

M² Measurement Solutions

Photon has a number of solutions for the measurement of M² ranging from simple manual processes to fully automated dedicated instruments. Depending on the frequency of the need to measure M² of laser and laser systems, Photon has 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.

Automated M² Measurements

Photon has two dedicated ModeScan instruments for automating the measurement of M². Our newest is the ModeScan 1780 that measures the M² Beam Propagation Ratio and all associated ISO 11146 parameters instantaneously in **real time** at video rates to over 20Hz. The measurement technique, patented by Photon Inc., uses 10 reflective surfaces to form simultaneous images of the propagating beam at 10 locations on a 12-bit CCD array camera. With all ten measurement positions acquired at once, the instrument is suitable for measurement of both CW and pulsed lasers down to single-shot rates. Beam diameters are obtained with NIST-traceable accuracy to better than 2% using the Photon Model 2512 12-bit FireWire BeamPro. This translates to M² measurements with accuracy to better than 4%. The ModeScan 1780 is suitable for the measurement of lasers with wavelength of 250 to 1100nm.

For lasers outside these wavelengths Photon has the NanoModeScan, which is also a dedicated, fully automated turnkey M² system using the NanoScan slit profiler to make the

measurements either according to the ISO 11146 Method or a fully automated Rayleigh Method. The ISO method requires that the user input ten measurement points along the axis of propagation, five around the waist and five measurement points that are at least two Rayleigh ranges distal to the test lens. Once these have been set up the system can make the entire M² measurement in as little as 20 seconds. The dedicated NanoModeScan software reports the k-factor (1/M²), the actual beam waist diameter and location, and the beam's Rayleigh range in addition to the value for M² for each axis.

The NanoModeScan can also determine the M² using the Rayleigh Method as a fully automated process. By selecting the Rayleigh method, the ModeScan will find the waist and then the Rayleigh points for both axes. It will then report the propagation parameters as with the ISO method. This method is fully automated and requires no intervention from the operator, other than the initial set up and input of the wavelength and lens parameters. It does take longer than the ISO method to make the measurements since it must find the actual waist and Rayleigh points on its own. The time required for the entire measurement is dependent on the laser being measured, but is usually no more than 2 or 3 minutes. It has the advantage of being fully automated and it can be left to run while the operator does some other task.

Manual M² Measurement

Photon's scanning slit and camera-based profilers all have an M² "wizard" available in their software packages. It is called the k-factor wizard, from an earlier nomenclature, in the BeamScan and BeamPro_{filer} products and is a standard feature. In the NanoScan it is a new software package, called the M² Wizard, and is available as a software option. These wizards walk the user through the process of measuring M² using the Rayleigh Method. Photon also has a manually operated fixture called the Rayleigh Fixture (RAL-FXT) that can be used in conjunction with the wizards to make the process easier to accomplish.

Rayleigh Method for M² Measurement

M² is a measurement of the propagation of a laser and it quantifies the quality of the laser beam. A perfect TEM₀₀ Gaussian laser beam will have an M² of 1.0. This is the theoretical "best" laser propagation. It means that in the lens equation:

$$M^2 = \frac{\pi}{4\lambda} d_0 \theta$$

If you solve for the minimum focus spot,

$$d_0 = M^2 \frac{4\lambda}{\pi\theta}$$

the minimum beam size possible, d_0 , will be dependent on the wavelength, λ , and the divergence angle, θ . The M², being 1, will have no effect on the value of d_0 . This is the reason that most laser manufacturers want to have a laser with the M² value close to 1.0.

The Rayleigh Method uses a test lens and some means of translating the profiler along the axis of propagation. The profiler finds the location of the waist, formed by the test lens, and measures its diameter. The profiler is then moved to the point proximal to the test lens where the diameter is $\sqrt{2} \times d_0$. This location is recorded and the profiler is then moved to the point distal to the test lens with the same diameter. These points are

called the Rayleigh points. The distance between the Rayleigh points and the d_0 values are then plugged into the formula to obtain the M² value:

$$M^2 = \frac{d_0^2}{2z_r} \frac{\pi}{2\lambda}$$

where:

- $2z_r$ is the distance between the Rayleigh points
- d_0 is the waist diameter
- λ is the wavelength of the laser

The M² (or k-factor) wizard walks the user through these steps and calculates the M² when it is done. The following screen captures show the 5 steps in the NanoScan M² Wizard (the k-factor wizard displays are quite similar.)

Step 1—User inputs the wavelength and measurement method

M² Wizard is an interactive program for determining the M² by the Rayleigh Method. For a discussion of the M² and help on optical alignment and measurement refer to the NanoScan Manual. Next to start the Wizard.

Wavelength [nm] 633

BeamWidth
 Slit 4 Sigma Next

Measurement Summary					
Wavelength[nm]	633.00				
Aperture	Dmin[μm]	Dr[μm]	Zneg[mm]	Zpos[mm]	M ²
A1					
A2					

Step 2—Wizard reports current beam waist measurement.

Step 1: Beam Waist measurement
Enter the laser wavelength in nanometers. Clear the values of Dmin using the Reset button. Slowly translate the NanoScan head through the lens focal region. The minimum beam waist diameters are automatically entered. The current values of the beam diameter, Dcurrent are shown below Dmin.

Reset D min [μm] Aperture 1: 82.66 Aperture 2: 81.57
D current [μm] 83.38 82.59

BeamWidth: Slit 4 Sigma

Measurement Summary					
Wavelength[nm]	633.00				
Aperture	Dmin[μm]	Dr[μm]	Zneg[mm]	Zpos[mm]	M ²
A1	82.66				
A2	81.57				

Step 4—User enters position of Zneg. Wizard provides target value for distal Rayleigh point, Zpos.

Step 2 continued: Rayleigh Range measurement
The calculated Rayleigh diameters for the current beam waist diameter are displayed below. Move the scanhead away from the lens until Dcurrent for aperture 1 approximates DRayleigh for aperture 1. Enter the position in Z Positive position. Repeat procedure for aperture 2.

Z positive [mm] Aperture 1: 72 Aperture 2: 72
D Rayleigh [μm] 116.892 115.363
D current [μm] 118.02 115.93

BeamWidth: Slit 4 Sigma

Measurement Summary					
Wavelength[nm]	633.00				
Aperture	Dmin[μm]	Dr[μm]	Zneg[mm]	Zpos[mm]	M ²
A1	82.66	116.89	55.00		
A2	81.57	115.36	56.00		

Step 3—Wizard provides the target value for proximal Rayleigh point, Zneg.

Step 2: Rayleigh range measurement
The calculated Rayleigh diameters for the current beam waist diameter are displayed below. Move the scanhead toward the lens until Dcurrent for aperture 1 approximates DRayleigh for aperture 1. Enter the position in Z Negative position. Repeat procedure for aperture 2.

Z negative [mm] Aperture 1: 55 Aperture 2: 56
D Rayleigh [μm] 116.892 115.363
D current [μm] 112.92 115.79

BeamWidth: Slit 4 Sigma

Measurement Summary					
Wavelength[nm]	633.00				
Aperture	Dmin[μm]	Dr[μm]	Zneg[mm]	Zpos[mm]	M ²
A1	82.66	116.89			
A2	81.57	115.36			

Step 5—User inputs position of Zpos. Wizard calculates and displays M² value.

M² Wizard

BeamWidth: Slit 4 Sigma Start Over

Measurement Summary					
Wavelength[nm]	633.00				
Aperture	Dmin[μm]	Dr[μm]	Zneg[mm]	Zpos[mm]	M ²
A1	82.66	116.89	55.00	72.00	1.00
A2	81.57	115.36	56.00	72.00	1.03

Using the Rayleigh Range Translation Test Fixture with the Wizards

The Raleigh Fixture features a base plate, sliding carriage and digital micrometer. The base plate (5.4×10.2×0.38in.) provides a series of ¼-20 threaded mounting holes at 2-inch centers to facilitate convenient fixturing of the assembly with respect to the focusing lens. The sliding carriage accommodates the combination of the 0.125-in. dowel pin and the ¼-20 mounting hole found on any Photon scan head's rotation mount, and enables smooth movement of the scan head assembly over a 6-in. range of travel. A Mitutoyo micrometer with a handy re-zeroing feature and accompanying slide provides precise determination of the scan head location and/or travel distance with a resolution of tens of microns.

Measure the Beam Waist

Using the fixture, the user can slowly translate the profiler through the waist created by a test lens. The M² Wizard (NanoScan) software will record the minimum waist diameter for both the X- and Y-axes of the beam.

Determine the Rayleigh Range (2Z_r)

Using the fixture translate the scan head to the Raleigh point proximal to the test lens and record the position value from the micrometer. Do the same for the distal Raleigh point. The wizard will calculate and display the M² values both axes of the beam.