INTRODUCTION TO BEAM PROFILING AND BEAM MEASUREMENT

A laser propagating through space has a different width and spatial intensity distribution along its propagation path continuously changing as a function of its laser cavity, divergence, interaction with optical elements and electronics driver characteristics. Beam profile intensity distribution is an important parameter that indicates how a laser beam will behave in an application and will dictate the overall system performance in a specific setup. Although existing theory accurately predicts laser propagation in a real world involving engineering specification, it is crucial for researchers, system designers, and laser manufacturers to be able to measure accurately these parameters. ISO standard 11146 defines approaches to be used in measuring such beams.

BEAM PROFILE DEFINITION

Laser beam profile in a perpendicular direction to its propagation axis is not defined, and in theory extends to infinity. The commonly used definition of beam width is the width at which the beam intensity is 1 /e2 (13.5%) of its peak value. This value is derived from the propagation of a Gaussian beam and accurately describes the beams distribution for lasers operating in the fundamental TEM00 mode.

However, many lasers are close enough to a Gaussian approximation and applying this simple definition is a common practice in the industry. Another more accurate definition is found as well in the IS011146 standard which specifies the beam width at the second moment. The point of the second moment is a value that is calculated from the raw intensity data and it is very sensitive to measurement noise as well as to random laser noise. A third way is calculated from the beams integral and it is free of noise problems and known as the knife edge method.

Figure 1 describes a beam profile at a certain position at a cross-section perpendicular to the propagation axis. Figure 2 describes the propagation in space of a laser beam and the embedded Gaussian concept.

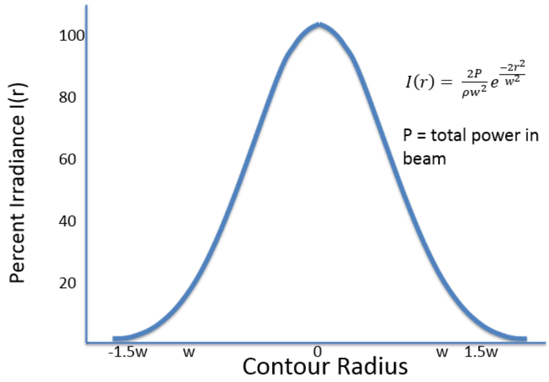

Figure 1 - Beam profile

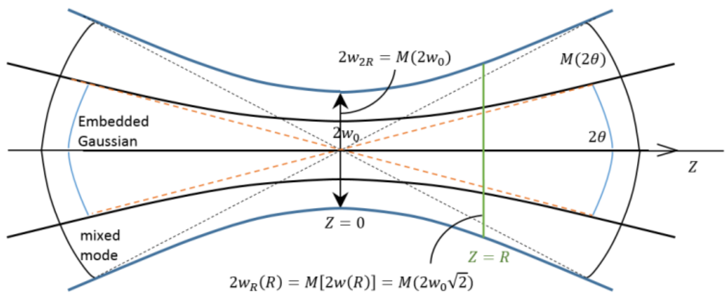

Figure 2 – Embedded Gaussian concept

MEASURING BEAM WIDTH TECHNOLOGIES

There are four main types of beam-profiling measurement instruments, and a proprietary technology introduced by Duma Optronics completes the lineup by introducing a technology that combines between knife edge technology and a camera based system. The basic four are: camera-based systems, knife-edge scanners, slit scanners, and pinhole scanners. Each has specific advantages and disadvantages. Different measurement techniques may result in slightly different results. As rule of thumb measuring pulsed laser is best when performed with CCD beam profilers which offer superior performance when compared with CMOS technology, on the other hand measuring CW lasers is best using knife edge technologies especially tomographic reconstruction as offered by Duma.

Camera-based profilers

Camera-based profilers use a two-dimensional mosaic array to instantly record and display the entire laser beam distribution that impinges on the camera surface. The intensity distribution of a laser beam is recorded pixel by pixel and displayed as either a topographic or three-dimensional contour plot. The image generated is interfaced to a computer and two- and three-dimensional plots of profiles and full analysis are generated and displayed. Cameras can be used with both CW and pulsed lasers. Main disadvantage of these instruments is that their measurement resolution is limited by pixel size (usually between 5 and 10 micrometer), which, in general, limits their use to measuring beams greater than 60 micrometer width. It should be noted that cameras control the amount of energy reaching the detector electronics by changing the image exposure time. This feature is called shutter speed. There are two types of shutters: *rolling* and *global*. The rolling shutter is applied to a strip of pixels and rolled over the detector surface. By rolling the shutter over the image surface, exposure is identical for all pixels but there is a time-lag between rolled strips. This can cause problems when the laser beam moves or is pulsed. Thus, although somewhat cheaper, this technology is not adequate for pulses or moving laser beams.

Global shutter technology is more expensive, but is adequate for general purpose laser measurements – pulsed and CW.

A new class of camera-based profiler, the MicroBeam, overcomes this size limitation by magnifying the laser beam, in a calibrated manner, by a factor of up to x100. This allows profiling of beams less than 0.5 micron in diameter but limits the maximum beam diameter to about 50 micrometer. Another disadvantage is limited spectral range to about 1350 nanometer.

Duma Optronics uses superior types of image detectors—charge-coupled device (CCD) detectors, In general, CCD detectors have a great dynamic range and low noise combined with high sensitivity and recently introduced systems with sensitivities starting from 190-1350 nanometer. Special Phosphoric coated CCD beam profiler will measure up to 1550 nanometer. High end Beam profilers such as BeamOn HR-AFW are offered with a built in automatic filter wheel.

Furthermore, a new technology defined as WSR (Wide Spectral Range) was developed to allow measurements of laser beams over a wide spectral range (190 – 1600 nm) by a single mosaic detector with high resolution (2.4 Megapixels) and small pixel size of 5.86 microns. The BeamOn WSR system and BeamOn U3 by Duma are a totally new and revolutionary beam diagnostics measurement systems for real-time measurement of continuous or pulsed laser beams, measuring laser beam parameters, such as: intensity profiles, beam width, shape, position and power. Software also provides report function for beam analysis settings and results.

Features

- Wide spectral range 190nm to 1600nm
- Complete test station, for CW and Pulsed Lasers
- Based on a USB 2.0 & USB 3.0 interfaces
- 2D/3D plot of the laser beam in real time
- Beam profile, beam centroid and position
- Data logging and detailed real time statistics

Figure 3 – BeamOn U3

· User friendly software, on-line help routine

Knife-Edge, Slit, and Pinhole Profilers

These technologies generate a profile by mechanically scanning across the beam with some type of aperture. The scanning is performed in an orthogonal direction to beam's propagation, thus showing the profile at one location along the propagation axis. All mechanical instruments will generate the profile by a single detector, sensitive to the appropriate wavelength and mechanical scanner obstructing the light before the detector with an aperture moving in a correlated mode (usually at a constant speed). The amount of light reaching the detector is modulated by mechanical means while adequate data processing measures the laser beam profile. Unlike camera-based sensors, usually these profilers will measure in only two dimensions (x,y profile) while camera-based sensors measure in three dimensions- the third dimension being the intensity profile in a mosaic manner. An exception was created by Duma Optronics, enabling mechanical scanning and 3-dimensional reconstruction by using tomographic techniques combined with multiple scanning knives.

SCANNING KNIFE-EDGE IN DEPTH Knife-edge profilers use an aperture large enough to pass the entire beam. The aperture has one sharp, straight edge (knife edge). As the aperture traverses the beam, the system measures the portion of the beam that is not blocked by the blade (see figure 4) and plots the differential (rate of change in intensity) vs position of the power through the aperture. As the knife edge passes through the beam the system approximately calculates the beam size and a sophisticated electronic circuit samples across the beam 12000 times per sweep, to be further processed to yield over 1000 useful points per profile regardless of beam size. Very small beams in the micron region are sampled with lower resolution. This auto zooming procedure offers highest possible accuracy independent of beam size. This is advantageous when compared to a slit or pinhole scans: The beam intensity is not limited by the size of the pinhole or slit; resolution is not limited by the size of the aperture, allowing beams of a few microns in diameter to be measured. Moreover accurate power measurement is also provided since at some point the full unobstructed power incidents the detector surface. A special Power Scope function will analyze power stability at high bandwidth of a few Megahertz and will display in real time calibrated power values.

The scanning technology is advantageous for its wide dynamic range of beams from less than 3 microns up to 9 mm. Using special sensitive detectors, it can measure beams up to a wavelength of 2.8 microns.

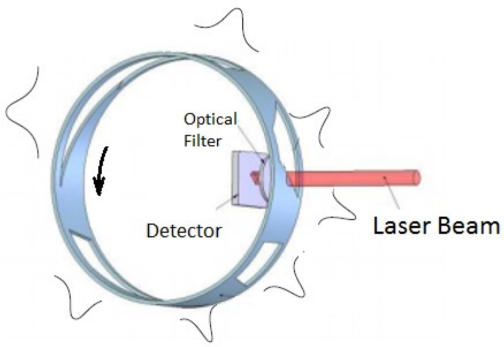

Figure 4 – Multiple scanning knife, each generating a different profile

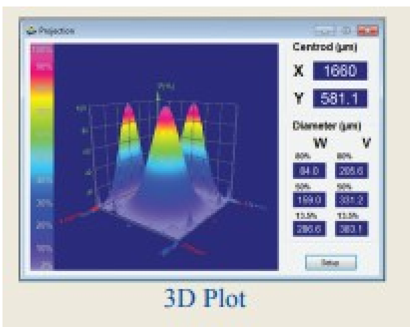

Figure 5 – 3D reconstruction of profiles by tomographic techniques

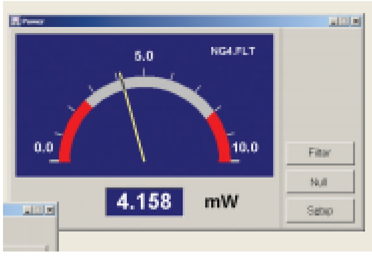

Figure 6 – Accurate power measurement

Focused Laser Beam Measurement

Figure 7 – Beam Analyzer Standalone

In today's technologies, laser beams are widely used in several applications where micronic beams (or near micronic beams) are used. To mention a few, the most widely known are used in storage technologies and digital video technologies, such as Compact Disc and DVD. Other technologies include microscopy, material processing and many others. The laser's minimum spot size is primarily defined by the laser's wavelength and the objective lens used to focus the incoming beam. The minimum achievable spot size according to the laws of physics and optics is given by $d_0 = 1.22 * \lambda/NA$.
From this equation it is clear that the larger the *NA*, d_0 decreases and as λ decreases, d_0 will be affected accordingly. Therefore, for high resolution applications the wavelength should be as short as possible, wherein for medium resolution such as laser printer, wavelengths in the IR region are still in common usage. We at Duma Optronics offer an apparatus capable of measuring laser micronic beams down to 0.5 microns. Our uBeam is based on several primary sub-assemblies. The first and most important is the objective lens, which is an infinite conjugate interchangeable objective lens. This lens is specified according to the minimum beam size to be measured and its wavelength. The second sub-assembly is the measuring head, based on a powerful zooming imaging device. This zooming feature allows to start observing a relatively wide field of view and pin points to the beam's location. Once the beam is found, the system is centered the zooming-in by a factor of x25 allows beam measurement at the highest possible resolution. Currently, the minimum measureable beam size is about 0.5 microns, and the upper limit is about 1 mm.

Objective Type	X 10	X 20	X 50	x100
Min. Beam Size	50 microns	10 microns	2 microns	0.5 microns

For processing, the apparatus is equipped with advanced electronics streaming data to a computer where accurate measurements are generated and displayed. This apparatus is offered under the brand name of uBeam.

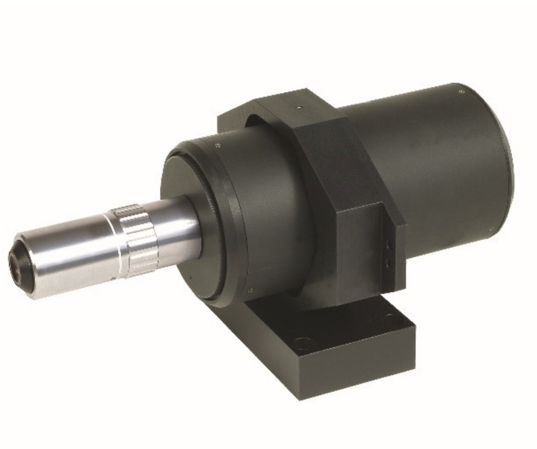

Figure 8 – uBeam