Methods to measure laser beam metrics from low power to 30 kilowatts with full ISO 11146-1 compliance in real time

Michael Scaggs, Gilbert Haas[a]

[a]*Haas Laser Technologies, Inc., 37 Ironia Road, Flanders, NJ 07836, USA*

Abstract

Measurement of laser beam metrics, whether low or high powers, can be challenging. The most commonly used methods to date are not real time and require scanning of one or more components along the optical axis of the laser beam. Fiber lasers, both single mode and multimode are becoming more ubiquitous and methods to qualify them are in great demand. As laser beam metric measurements are generally complex, methods to make these measurements more user and alignment friendly are equally in demand. We have developed a couple of techniques that provide real time measurement of the laser's M-square or beam parameter product that can be utilized from very low powers to powers in excess of 30 Kilowatts. Two techniques are discussed: a prefocus and post focus. Each method employs a passive optical design that requires no moving parts to obtain the spatial time slices of a focused laser beam that fulfills the ISO 11146-1 (2005) M-square measurement technique.

Keywords: M-square, beam parameter product, ISO 11146-1, beam waist measurement

1. Introduction

ISO 11146-1(2005) outlines the preferred method of measuring the M-square of a laser. This procedure in a few words requires the movement of either a diffraction limited lens or a pixilated camera along the optical axis to establish the beam waist location wherein a minimum of five (5) spots are measured within the first Rayleigh range and five (5) spots beyond the second Rayleigh range. The five spots within the first Rayleigh range established the beam waist and its location and the five spots beyond the second Rayleigh range establishes the slope of the beam from the lens, i.e., its divergence. A second moment evaluation is done on all these spatial times slices and a resulting M-square can be established. The problem is time and motion are required to get minimum of ten (10) spots. This, of course, is not convenient for real time applications, i.e., a production system or dynamic alignment of a laser.

A typical sensor used for beam measurement is a CMOS camera with its protective window removed. These sensors are quite sensitive so the measurement of any laser beam requires a considerable amount of attenuation to prevent saturating or thermal overloading the sensor. This, of course, adds to the complexity and difficulty in measuring a laser beam and especially high power lasers.

This work shows two methods that provide real time M-square measurement of high power laser systems that are compact and easy to use.

2. Prefocus M-square measurement

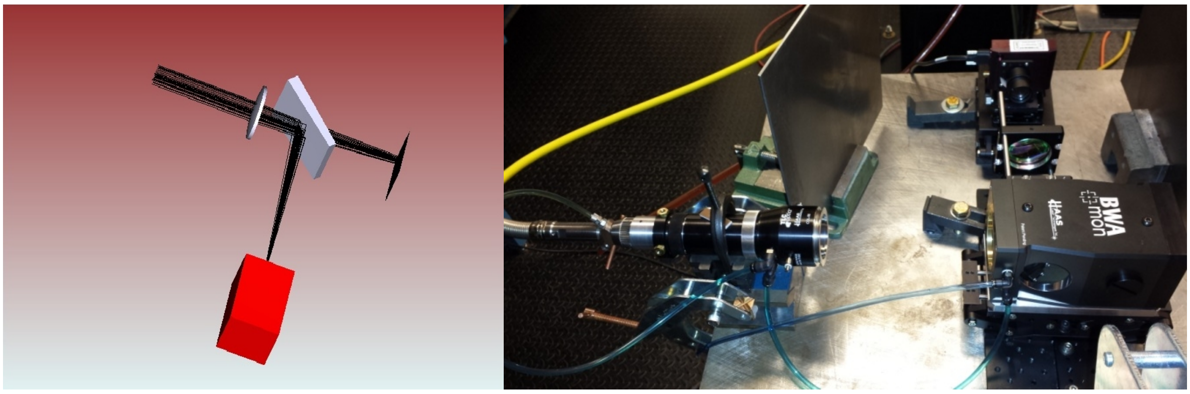

Figure 1: Prefocus measurement system

Error! Reference source not found. shows the optical layout of the prefocus beam waist monitor (BWA-MON®). Here the high power laser is focused onto a wedge prism where the first surface has no coating and the second surface is anti-reflection coated. It is important to use an uncoated surface to avoid the possibility of thermal lensing caused by the coating. While the bulk material may thermal lens, the first surface reflection will not undergo thermal lensing so is the best way to sample the beam. The image on the right shows a measurement of a 10 kilowatt CW fiber laser with the combination of an F160mm collimator and an F250mm focus lens.

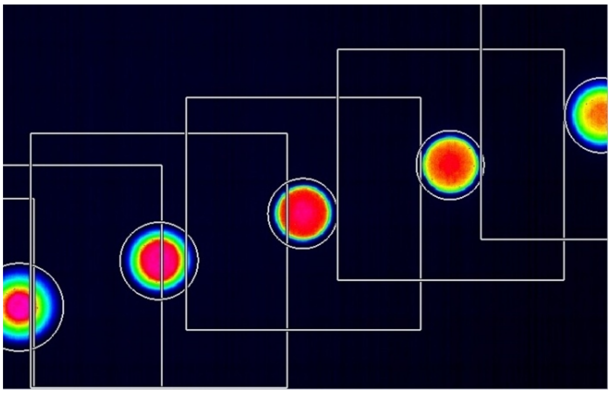

Figure 2: Image of 200 um fiber from 10 kilowatt fiber laser

The heart of the system is the BWA-CAM® which is a patented beam waist analyzer system that creates spatial time slices of the focused beam with no moving parts. This is accomplished through a passive optical design with no moving parts developed by Scaggs et al (2011).

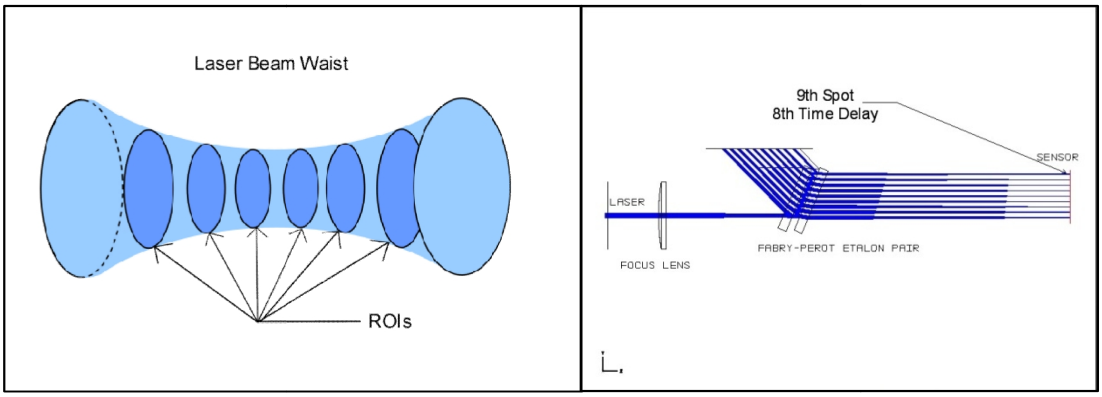

Figure 3: Principle of BWA-CAM®

Figure 3 shows the basic principle of the BWA-CAM®. A convergent laser beam is directed into the sensor and first strikes a pair of Fabry-Perot etalons which are tilted at a small angle to allow the transmitted beam to "walk" up the cavity of the etalon pair. Each round trip from the etalon pair produces a lateral shift of the beam and a uniform time delay of each beam. The image on the right of Figure 3 shows 9 spatial time slices, referred to as regions of interest (ROIs) that have been transmitted through the etalon pair and then onto the sensor. As the etalons have high finesse, the optic pair produces a nominal optical density of ~ -4.0.

The sensor used is a CMOS based GigE sensor with the window removed to prevent interference effects. The sensor can generate images as fast as 50 frames per second, but due to software limitations and laser beam metrics calculations, this number is reduced to about 15 frames per second on an Intel iCore 7 based computer.

Pursuant with ISO 11146-1 (2005), we use the BWA-CAM® to capture 5 spots within the first Rayleigh range and 5 spots beyond the second Rayleigh range. Figure 4 shows a typical beam caustic from the BWA-CAM® for a measurement of an IPG Photonics YLP-1/100/20/20-HC pulsed fiber laser which has a nominal M-square of 1.5.

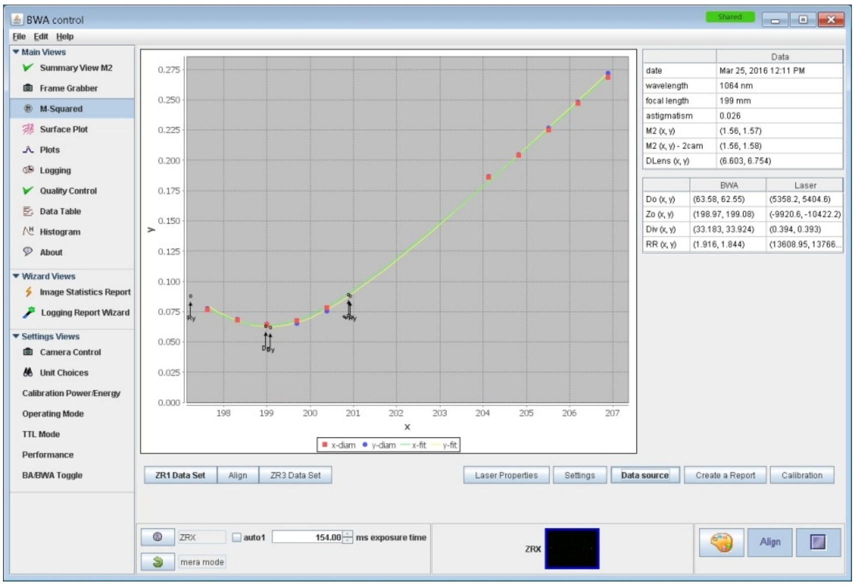

Figure 4: BWA-CAM m-square measurement

In the image we can see the 5 points within the first Rayleigh range that gives the beam waist and its position and the five points outside the second Rayleigh range which establishes the divergence from the F199mm focus lens in this particular measurement.

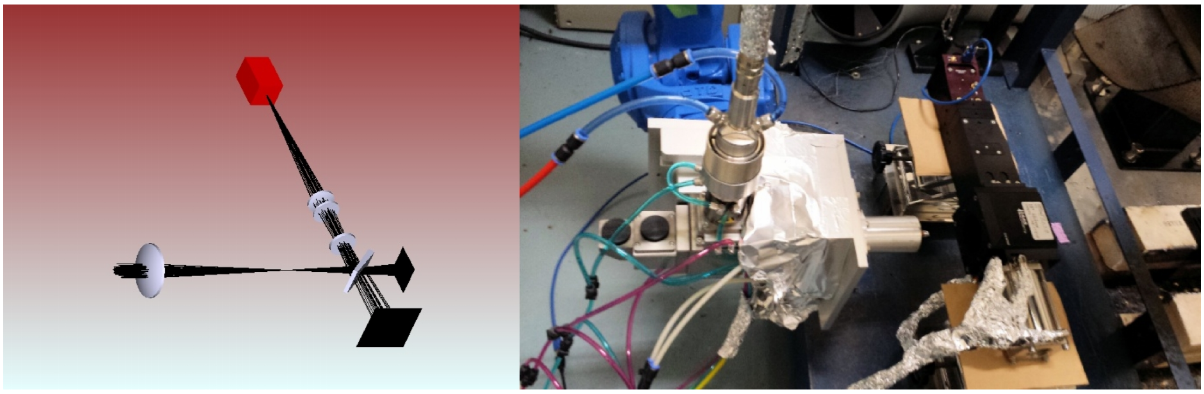

Figure 5: Post focus measurement system

3. Post focus M-square measurement

Figure 5 shows a post measurement system that was employed on a 30 kilowatt cw fiber laser system. The image on the left shows a laser beam passing through the focus lens and then is focused and the divergent beam from the focus strikes a wedge prism where the first surface is uncoated and the second surface is anti-reflection coated. The first surface reflection then strikes a high reflective partial reflector to further attenuate the beam and the transmitted beam through the partial reflector. The divergent beam is recollimated and then focused again into the BWA-CAM® as a 1:1 relay image. The wedge prism represents attenuation of about 4% (1.2 kW of the 30 kW). The partial reflector, further attenuates this to about 24 watts which is sufficient power for the BWA-CAM®. The image on the right of Figure 5 shows the actual system. The customer's fiber laser and focus head are on the left and is directed into the BWA-MON®. At the lower right hand side of the image is a beam dump for the back reflected 1.2 kW from the partial reflector. Beyond the BWA-MON® and out of the range of the picture is a power meter where the majority of the light is directed to during the measurement.

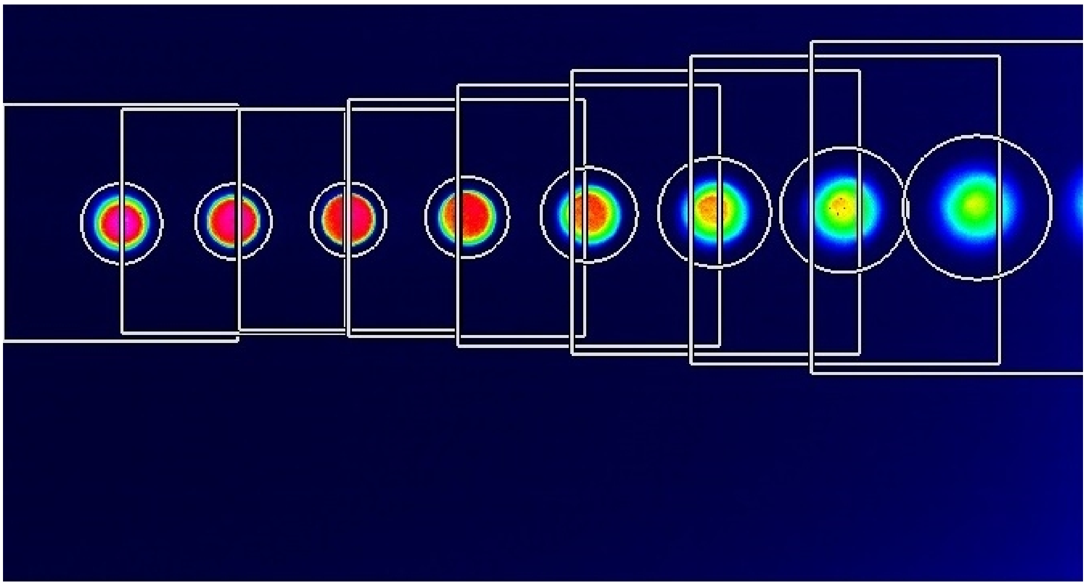

Figure 6: Post focus measurement of a 30 kW cw fiber laser

At 30 kW significant thermal lensing could be seen within the first 30 seconds of the measurement. In Figure 6 the best focus is between the second and third spots where as at the start of the measurement the best focus was at the fifth spot.

4. Conclusions

We have shown that it is possible to provide real time laser beam metrics in either a prefocus or a post focus situation. More importantly, we have shown this capability with laser powers as high as 30 kW. Utilizing the right attenuation, the methods can be used from milliwatts to over 30 kilowatts. Although not shown in this work, it is possible to implement real time monitoring of a laser beam while in process when utilizing back reflected surfaces from the focus lens and a suitable pick off prism is employed.

References

ISO 11146-1:2005(E), "Lasers and laser-related equipment – Test methods for laser beam widths, divergence angles and beam propagation ratios – Part 1: Stigmatic and simple astigmatic beams"

Scaggs, M., and Haas, G., "Real time laser beam analysis system for high power lasers", Proc. SPIE Vol. 7913 (2011)