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The easiest and most repeatable M^2 measurement: as easy as measuring laser power

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Abstract

Ask most laser users who have made an M^2 measurement in their laser use if it is an easy and reliable measurement? One will find the vast majority will agree that it is not easy and has much uncertainty in the measurement. Often, even a simple repeat of an existing measurement, will result in variations of plus or minus 10 %. Measuring a laser's power or energy is an important and simple measurement. Why isn't the M^2 measurement as simple? The laser's power or energy along with the laser's M^2 value are key parameters in determining the power or energy density in a processing zone. Of course, if one looks at the predominate methods for measuring a laser's M^2, it is clear why it is not simple and has uncertainties. A new, innovative approach has been developed that makes measuring the laser's M2 or beam parameter product as simple as measuring the laser's power as a "point and click" method for realtime M^2 values at the frame rate of the camera or in a single laser pulse.

Keywords: M^2*, M-square, Beam Parameter Product, BPP, Laser Beam Analysis*

1. Introduction

The subject of M-square measurement began in the early 1990s by Siegman (1990, 1993), Sasnett (1991) and Johnston (1991). This work then leads to the introduction of the first commercially available M-square measurement device patented by Coherent, Inc. by the inventor Johnston (1991). Fig. 1a shows the first commercial system by Coherent and the Fig. 1b shows a typical state-of-the-art measurement systems on the market. In both cases, there are many moving parts with many components and variables that lead to much uncertainty in the measurement and hard for most users to use.

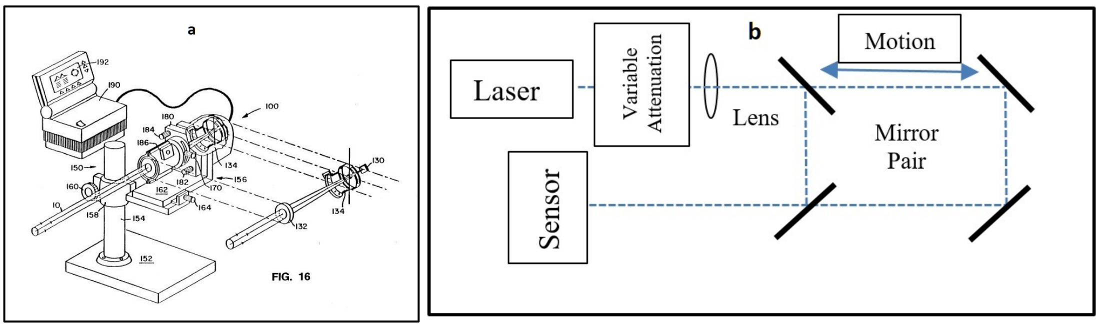

Fig. 1. (a) first commercial M^2 measurement system; (b) most state-of-the-art M^2 measurement systems.

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The International Organization of Standards put out a measurement standard based upon the Coherent system and is referenced as ISO 11146-1 (1999). As pixelated detectors became more abundant and less expensive, the ISO updated the standard which can be referenced as ISO 11146-1 (2005) that accommodates the pixelated detectors as the preferred method for measuring a laser beam. This, of course, lead to more M-square measurement systems on the market but the difficulty of use and poor repeatability remained.

A novel approach by Scaggs (2011) introduced a new method for measuring the beam waist and M^2 of a laser to enable the ability to measure the thermal lensing of a high-power laser system and can be referenced in Scaggs (2011) as well. In this system a passive optical design provided multiple spatial time slices of the beam so that the beam waist caustic could be tracked in real time at the frame rate of the pixelated detector.

The M^2 system by Scaggs (2011) was not able to measure the full beam caustic from the first to the third Rayleigh range to the ISO 11146-1 standard without poor signal to noise ratio in the third Rayleigh range. In order to become ISO compliant, a two-step measurement was required or a dual camera system. In the first instance, it wasn't totally realtime; in the second instance, it was nearly twice the cost. Therefore, further efforts were needed to a) make the measurement ISO compliant; b) be in realtime for the full beam caustic and c) be very easy for a user to use.

2. Point and Click M-square Measurement: BWA-CAM 20/20

We have developed a special intensity filter that provides a means to "flatten" the intensity peaks of the spatial times slices from beyond the third Rayleigh range to the first. Fig. 2 shows the basic layout of the optical system for producing a full beam waist caustic on a sensor with a flat intensity profile. The etalon pair is the means by which the multiple spatial time slices are generated. The second etalon incorporates a patent pending ghost suppression technology that reduces the second surface reflection ghost to below the noise level of the sensor as introduced by Scaggs (2019). Just before the CMOS sensor is the special intensity filter that does the amplitude flattening of the spatial time slices.

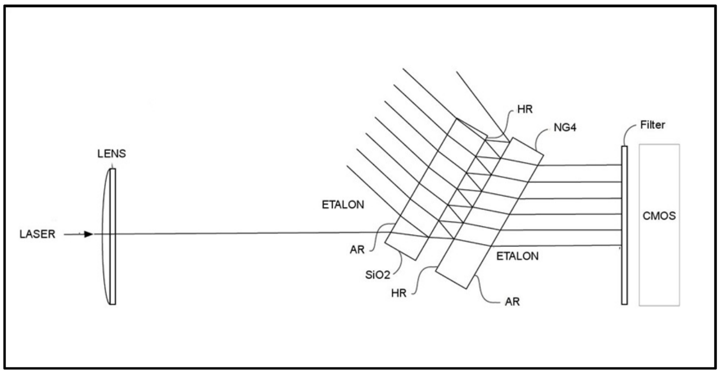

Fig. 2. Optical layout of the BWA-CAM 20/20

Fig. 3 shows a 3-D intensity plot of a Thorlabs 4.5mW, 532nm diode laser without the intensity filter (left image) and with the intensity filter (right image). The image on the right has more spatial slices and the curve is much flatter and much improved signal to noise ratio for the third Rayleigh range spots.

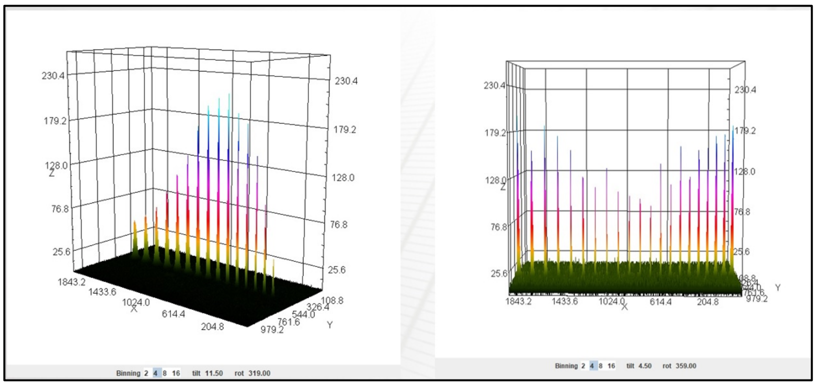

Fig. 3. 3-D plot without filter on left and with filter on right

There is clearly a significant improvement in the performance of the system with this filter. Most importantly, however, is that we can get a completely ISO compliant M^2 measurement in a single row of spots on one sensor in realtime.

In order to make it easier to use and align for any person; whether an expert or a novice, we have fixed the etalons and opto-mechanically designed the system such that one simply align the BWA-CAM 20/20 to a laser in a like manner to a laser power meter. The left image in Fig. 4 shows the simple setup of the system where there is a green diode laser in a tip/tilt mount and the BWA-CAM 20/20 simply mounted on a post with a magnetic base. The user positions the laser and the bezel of the BWA-CAM 20/20, so they are at the same height. Next tilt and center the BWA-CAM 20/20 so the back reflected light from the focusing lens is nearly coincidental with the laser without going directly back into the laser diode to cause interference fringes. In this way, the alignment is adequate to make a measurement. The right image of Fig. 4 shows an actual picture of the BWA-CAM 20/20.

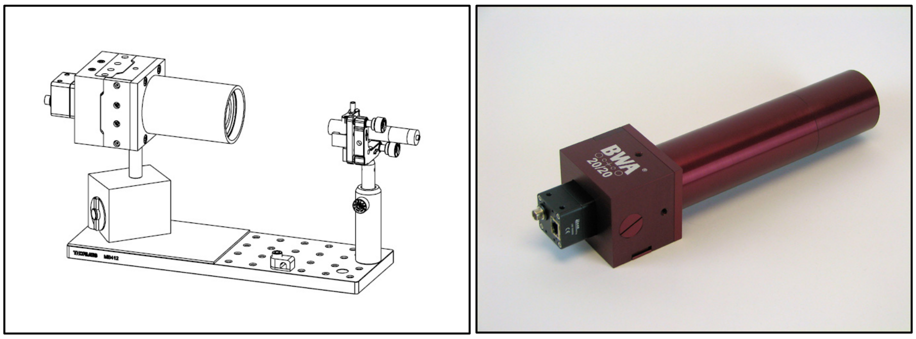

Fig. 4. Point and click setup and picture of the BWA-CAM 20/20.

Once the user has the system aligned, the user enters the wavelength; effective focal length of the measurement lens; the lens to sensor distance and the etalon spacing. This information is provided in a measurement drawing so it is easy for the user to enter into the software. Once this is done, the system is started and at most a „peak finder“ is turned on to locate the spatial time slices for measurement. When the spatial time slices are located, the „peak finder“ is turned off and the measurement is live and instant.

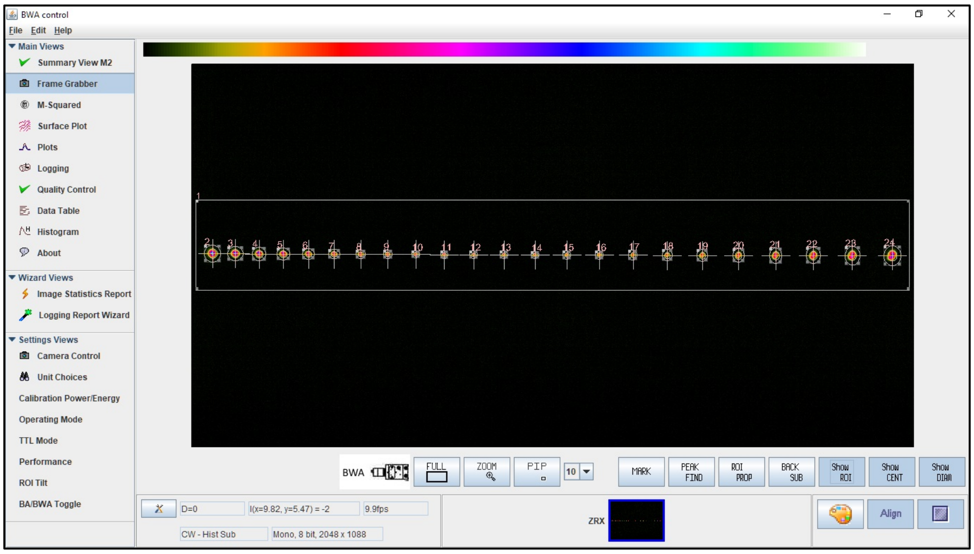

Fig. 5. Optical layout of the BWA-CAM 20/20

Fig. 5 shows the spatial time slices of the measured 532nm diode laser. Here we see 23 spatial time slices. Without the intensity filter we usually can only get about 15 spots but not with the best signal to noise ratio. With the intensity filter we have 8 more spots and with very good signal to noise ratio. Fig. 6 shows the measured beam caustic for this 532nm laser diode. The M^2 is measured to be (1.045, 1.074) for the X and Y axes respectively with a corresponding standard deviation of (0.0079, 0.0094). The beam waist measured 62.4 microns for X and 58.13

microns for the Y axis. Fig. 6 further shows a very nice fit from the first through the third Rayleigh range. The laser tested was specified as a TEM 00 laser and we found that the laser had and $M^2 < 1.1$ so would well classify as a TEM 00 laser and meets specification.

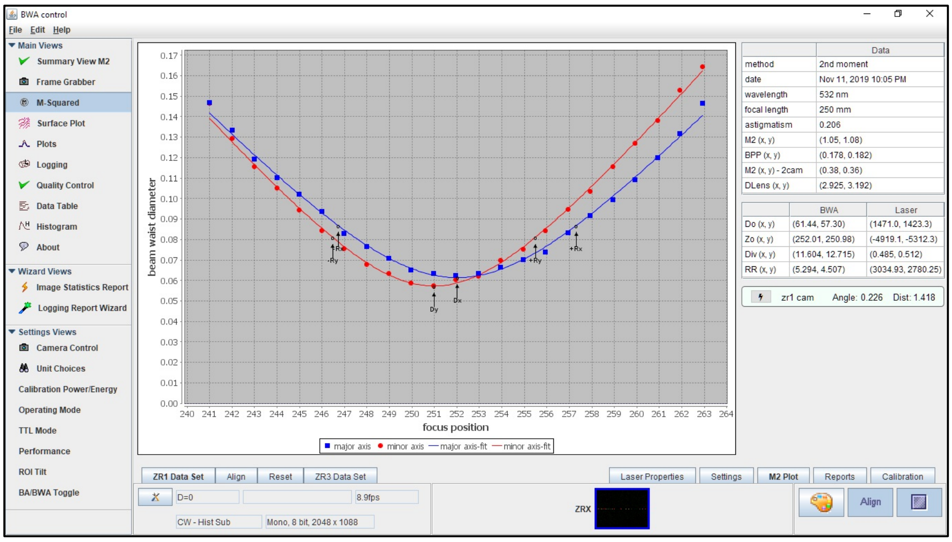

Fig. 6. Beam waist caustic of the BWA-CAM 20/20

3. Summary

We have developed a very easy to use and implement M-square measurement system that anyone with basic laser alignment skills can operate with confidence. We have found that whether an expert makes the measurement with this system or a complete novice, the same measurement results agree to better than +/- 1% repeatability for the laser tested.

The unit worked so well that we had two administrative staff who had never touched a laser before making a measurement by following very simple instructions and was able to do the measurement in less than 30 seconds from start to finish. This is a significant advance in the ease of use for M-square measurement devices.

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