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Precision Beam Profiling

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Choosing a Laser Beam Profiler

A laser beam profiler will increase your chance of success anytime you wish to design or apply a laser or when you find your laser system manufacturing subsystems are not meeting specifications. You would never think of trying to build a mechanical part without a micrometer available. So why attempt to build lasers or laser systems with only a power meter? You will produce results quicker if you can measure basic things like beam width or size, beam profile and power.

We believe as Lord Kelvin said: *"You can not improve it if you cannot measure it".*

Four Basic Questions

When choosing a laser beam profiler there are a plethora of choices to do the job including CCD and CMOS cameras, InGaAs and pyroelectric arrays, scanning slits, pinholes and knife edges to mention some. How does one decide which is the proper solution for one's application and from which company to obtain the profiler system? When making the selection there are four basic questions about the laser application that one must answer.

Wavelength?

The first is: What wavelength(s) do you intend to measure? The answer to this question determines the type of detector needed, and what the most cost effective approach may be. For the UV and visible wavelength range from <190nm up to the very near infrared at around 1000nm the silicon detector has the response to make these measurements. For these wavelengths there are the largest number of cost effective solutions including CCD and CMOS cameras and silicon detector-equipped scanning aperture systems. Which of these is the best will be determined by the answers to the other three questions.

For the near infrared, from 800 to 1700nm, the choices become less abundant. In the lower end of this range from 800-1200nm the CCD and CMOS cameras may still work, but above 1200nm InGaAs arrays become necessary. These are quite expensive; five to ten times the cost of the silicon detectors. Scanning slit systems equipped with germanium detectors are still quite reasonably priced, within a few hundred dollars of their silicon-equipped cousins. At the mid and far infrared wavelengths the pyroelectric arrays and scanning slit provide viable alternatives, again the best approach being determined by the answers to the subsequent questions.

Beam Size?

The second question is: What beam width or spot size do you wish to measure? This question determines the profiler type. Arrays are limited by the size of their pixels. At the current state-of-the-art pixels are at best around 6-7µm for silicon arrays, and considerably larger with InGaAs and pyroelectric arrays. This means that a UV-NIR beam should be larger than 50µm in diameter to ensure that enough pixels are lit to make an accurate measurement. Beams smaller than this can be magnified or expanded in order to be measured with a camera. InGaAs pixels are at best 30µm, limiting the minimum measurable beam size to around 250µm; pyroelectric array pixels are even larger at 85µm, meaning the beams need to be at least a half a millimeter to yield accurate results. Scanning slit profilers can measure with better than 2% accuracy beams that are four times the slit width or larger, putting the minimum beam sizes at around 4µm without magnification. Those investigators who want to measure their beams directly without additional optics may find this to be an advantage.

Power?

The third question is: What is the power of the beam? This determines the need for attenuation, beam splitting, as well as the detector type. Array detectors, especially silicon CCD and CMOS cameras will always need attenuation when measuring lasers. Scanning slit type profilers can measure many beams directly without any attenuation, due to the natural attenuation of the slit itself. The slit only allows light to the detector as the slit passes through the beam, and then it only lets in a fraction of the total light. Arrays and knife-edge profilers, by their nature, will allow the entire beam to impact the detector at some point in the measurement, leading to detector saturation unless the beam is severely attenuated. Lasers with powers above 100mW can be measured with the pyroelectric detector equipped scanning slit profiler. Properly designed, these profilers can measure up to kilowatts of laser power. High power lasers in the hundreds to thousand of watts can also be profiled using the spinning or scanned wire techniques.

CW or Pulsed?

The final question is: Is the laser continuous wave (CW) or pulsed? Lasers that operate pulsed at a repetition rate of less than 1-2kHz can only be profiled with an array. Scanning apertures simply cannot make these measurements effectively. For CW and repetition rates above 2kHz can be measured with scanning slits, provided the combination of the repetition rate and the beam size are sufficient to provide enough laser pulses during the transit time of the slits through the beam to reconstruct a good profile.[1] Knife-edge profilers are only able to measure CW beams. Pulsed beams have other considerations, particularly those with ultra short pulses, concerning power levels and pulse energy damage thresholds.[2]

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[1] The conditions for proper measurement of pulsed beams with slit scanners are discussed in detail in the "Laser Beam Measurement: Slit-Based Profilers for Pulsed Beams", Allen M. Cary, Photon Inc., *The 2006 Photonics Handbook,* pp H262-265, Laurin Publishing, 2006

[2] *Ibid.*, pp H264-5

One More Question

Besides these four questions about the physical nature of the laser to be measured, there is one more that needs to be asked: How accurate does the measurement need to be? Not all profilers or profiler companies are equal in this regard. Properly designed, maintained and calibrated slit profilers can provide nanometer precision for both beam width and beam position (centroid) measurements. The accuracy of cameras is dependent on many factors. A state-of-the-art CCD or CMOS array with 6µm pixels can provide a 3% beam width accuracy for a beam larger than 65µm. Accuracy for smaller beams will be worse due to the effects of pixelation. In addition, the effects of attenuation optics, background signal and proper zeroing can have dramatic impact on the accuracy of the measurement. Cameras that are not designed specifically for profiling may be much worse due to the presence of a cover glass on the array, which should be removed for laser profiling to prevent interference fringes. Camera arrays do provide a true two-dimensional picture of the beam and will show fine structure and hot spots, which a slit may integrate out. The accuracy requirement is a question of what the data is to be used for. Accurate collimation or focus control requires the highest beam size accuracy. Checking the laser for hot spots, uniformity or beam shape may dictate that the 2d profile is more important than the absolute size measurement accuracy.

How and where a profiler is to be used is also an important consideration in the equation. Profilers used by research and development scientists are often homemade, specialized and sometimes downright “klugey.” Ease-of-use and high throughput may be of no consequence. The purpose is to characterize specific optical systems that are well understood by the investigator. On the other hand, when a profiler needs to be used on the factory floor for a manufacturing step, ease-of-use, high throughput, and reproducibility become paramount. In this case the profiler requiring the least “fiddling” is generally the best fit. Here there is a competition between the intuitive and the ease-of-use. Some people find the 2d camera array to be the most intuitive, because they can relate to the idea of “taking a picture” of the laser beam. And X-Y scanning slit may seem less intuitive. Nonetheless in almost every case the slit will be easier to use, require less auxiliary equipment and far less “fiddling.” For any process that uses or works with CW or high frequency pulsed lasers the scanning slit will have the advantage of measuring the beam directly, even at its focus point, without additional attenuation optics. The dynamic range of these systems is also broad enough to measure both the focused and the unfocused beam without changing the level of attenuation. Camera arrays, on the other hand will not be able to handle both levels of power density without adjustment. This means that for applications where the beam needs to be brought into focus or measured in various points along its propagation, such as with the measurement of M^2, the slit will tend to be much more convenient.

Conversely, if the important aspect of the measurement is the two-dimensional image of the beam, or if the laser is pulsed at a low repetition rate, the array will be a much better solution, even if it means that there will need to be additional attenuation optics. A slit profiler will integrate out much of the fine detail of the structure of the laser beam. This means that some beams with additional mode structure will look cleaner with a slit than with a camera. A knife-edge profiler will integrate even more structure out than a slit.

Knife-edge profilers can accurately measure smaller beams than either a camera or a slit, but they have very limited centroid position accuracy, generally no better than 10%.

If the level of accuracy of the camera is sufficient, the wavelength is in the range from 190nm to 1100nm, and the power is not too high, the silicon CCD or CMOS camera system will probably be the most cost effective. There are many packages to choose from with different camera specifications and software packages. Dedicated profilers systems are inexpensive enough that cobbling together your own system is unlikely to save much in the long term. Camera arrays designed for profiling will have had the cover glass removed from the array to eliminate fringes; cameras not so designed will still have the cover glass, which you will need to have removed, especially for any application at wavelengths below 380nm[3].

Recently the “specsmanship” of camera system manufacturers has moved toward the bit-count with companies advertising 10-, 12, and even 16-bit digitization of the signal. Although it may seem that more is better, it is important to understand what this actually means in terms of laser beam profiling practice and accuracy. There is an inherent number of bits that can be output by a particular array chip. If the output of the chip is 9.5-bits, it makes no improvement to digitize this to a higher level. One is merely cutting the same signal into finer slices, not increasing the dynamic range in reality. The dynamic range of measurement can be enhanced with shuttering or automatic gain control, but many times these will impact the accuracy of the measurement appreciably. Various phenomena, such as parasitic light sensitivity, can cause beam size or beam intensity to vary across the array, dependent on the read-out direction. These are often exacerbated by the use of short electronic shutter times or automatic gain control. Accurate beam profiling is best done by attenuating the beam to the proper level and measuring with the standard integration time for the chip.

Some manufacturers make specific accuracy claims for the profiler and others do not, or imply accuracy through discussions of pixel size and pixel metrology. One reason for this is, that for array profilers, accuracy is a function of the beam size. This is due to the fixed size of pixels. The larger the beam, the more pixels lit, and thus the more statistical accuracy possible. With slits and knife-edge profilers the accuracy is more uniform across the range of beam size measurements. With knife-edge profilers there is no theoretical minimum beam size. Minimum beam size will be a function of the sampling interval of the electronics controlling the knife-edge measurement. With slits convolution allows the measurement of any beam four times the slit width or larger to at least 2% accuracy.

Photon profilers are all tested for accuracy with a NIST traceable standard, and the accuracy is reported for specific, reproducible, real-world conditions. You can be assured that these instruments are the most accurate you can buy in any given technology.

[3] Standard glass is opaque to UV radiation below ~380nm. In order to use the inherent response of the CCD or CMOS camera array for these wavelengths, it is necessary to use UV transparent optics.