Instrumentation for laser beam profiling evolved out of a technology that was not sensitive enough for imaging. Even though Spiricon (which stands for Solid state Pyroelectric InfraRed Image CONverter) is one of the major suppliers of laser beam profiling technology in the world today, it did not set out at first to make these products. Laser Beam Profiling emerged from the early users of pyroelectric arrays. When Spiricon’s founder Dr. Carlos Roundy discovered that most of his arrays (figure 1) were bought to make laser beam profilers, he decided to get into the business of providing laser measurement systems. Laser users in scientific research and industrial processing know that undesired structure in the intensity profile of their lasers will result in poor process performance, as many of the processes depend on the irradiance squared, cubed or even raised to the fourth power. Therefore, instrumentation for laser beam characterization is a valuable addition to any laboratory or manufacturing facility. Of course, there are so many different applications that there is not one unique solution for each application. Examples for major categories are scientific research, medical device manufacturing, industrial manufacturing like welding, cladding and cutting, and military and defense. In each of these categories one will find applications specific to their area of interest, although even with these broad categories, it is not unusual to find the same application crossing disciplines.

1 Why laser beam profiling?

The spatial intensity distribution of a laser beam incorporates all the mechanical, thermal and electromagnetic variables that created the beam. The 2 Dimensional and 3 Dimensional spatial laser beam profiles as in figure 2 display the result of an intensity distribution measurement in an intuitive, easy-to-understand and interpret manner. Such profiles have therefore emerged as a universally accepted tool when tuning and adjusting lasers, and a valuable analytical tool when diagnosing laser problems. If all lasers emitted radiation in the visible wavelengths, one could in principle attempt to view the beam on a target and deduce some knowledge of the spatial intensity profile. In practice, this can not be done easily, since on the one hand the human eye responds logarithmically to light intensity (figure 3), and on the other hand many modern laser applications employ lasers in the non-visible wavelengths, whether it is UV or IR, so the human eye is incapable of ‘seeing’ the beam. Even the use of IR and UV conversion ‘cards’ serve only as a rough estimate of the general structure of the beam for the same reasons.

Electronic laser beam profiling using cameras is simpler than other methods (figure 4), it is linear and displays ‘real time’ spatial beam intensity of the entire beam,
does not produce toxic gases\(^1\) and provides not only permanent detailed record of the beam profile, but also quantitative calculations of critical laser beam parameters, that can be used for tuning and diagnostic purposes. It is this feature that makes the concept of electronic spatial intensity profiling so valuable.

Laser beam profiling falls into two major categories, at-line, or spot-checking, and in-line or continuous monitoring. In both cases, it is important to have a continuous stream of images for the user to interpret, and for this reason Spiricon, Inc. has developed camera-based detection systems. Camera systems can produce real time images, can detect short pulses as small as a few femtoseconds, and are relatively robust. Other systems use different techniques for sampling the beam such as rotating slits and spinning wires or needles with microscopic holes (figure 5), but these systems cannot yield real time images, are somewhat more delicate, and in some cases must interrupt the beam for them to perform the measurement; especially, it is in general not possible to analyse pulsed laser beams. In view of the almost endless list of applications, the camera-based systems have many advantages over all the other methods in almost every application.

2 Technology of camera based profilers

Laser beam profilers based on camera technology are integrating devices in that they acquire an image of the entire beam in each frame, which is then transmitted to the software. This enables a camera-based system to present as many as 48 to >100 indivial frames each second with typical cameras. This captures the fine structure in the beam and displays it as it is changing, rather than acquiring a composite time-exposure of a beam over many seconds. In fact, by viewing this data in real time, the user can gain new insights into the inner workings of the entire laser system, as it responds e.g. to the shutter opening, the power supplies reaching equilibrium, and any other factors that can change the beam profile.

Especially systems based upon CCD camera chips have one feature that makes their use difficult in quantitative measurements. The CCD baseline is not stable over time, and the resulting measurements will be incorrect, unless the diagnostic software retains both positive and negative going noise\(^2\) in the calibration signal. Spiricon has patented such a method, which is now referenced in the current revision of the ISO 11146 standard. Instruments that make beam width measurements by this standard are advised that they need to consider this technology\([1]\). At this time, this critical element of beam width calculation is only present in Spiricon systems.

3 Applications for beam profiling

To understand the many uses for beam profiling, it is easier to classify the applications by market segment. Even so, there are instances where totally unrelated markets will use beam profilers in the same way. To clarify this fact, one can also classify basic laser operations into typical beam profiling markets. Major categories include material processing such as cutting, welding, cladding, marking, drilling and ablation, as well as non-material-processing applications, e.g. pumping other lasers, identification of unknown substances (FTIR), or data transmission. Each of these applications requires a certain beam shape for the process to work properly.

The basic elements that make up a beam profiling system include the same functional parts. The block diagram (figure 6) shows these basic functions. It is always helpful to refer to this diagram when designing a spatial beam profiler, because each part has to be matched to the specific characteristics of the application.

3.1 Scientific research

Pure scientific applications include pumping one laser with another, generating extremely short pulses, and a number of...
other applications that are now coming on stream in industrial use. In addition, new sampling techniques enable to image radiation in the deep Ultraviolet range, a regime not easily detected (figure 7). For beam profiling systems to be used in the scientific community, flexibility is the key, for each experiment is different, e.g. covering a wide wavelength range. Researchers need a wide variety of camera options to select from.

3.2 Medical device manufacturing
Laser processing has become almost routine in the manufacturing of medical devices such as stents, yet beam profiling in this segment is especially important because for obvious reasons, the products manufactured are closely monitored by regulatory agencies. Also the slightest change in beam performance can result in a high rate of rework or scrap materials. Many of these devices use high strength alloys (figure 8) making them more difficult to establish a large processing window. In this case, the use of laser beam diagnostics has proven to be a cost-saving device, often paying for itself in just a few months. Here too, on-line monitoring is starting to be employed as new workstations come on line, so the technician can ‘see’ the laser beam while processing (figure 9). The shape and height of the image can often alert the technician to impending failure, and by stopping the process and correcting the fault, optimum performance can be maintained. Using the Active-X feature of the software even can enable this information to be transmitted to other process monitoring programs to perform ‘trend analysis’ of the data, so as to alert the operator proactively.

3.3 Industrial processing
Industrial applications for lasers increase every day. Laser processing is a non-contact method that is characterized by a very small heat-affected-zone, making it ideal e.g. for welding. It is difficult to spend one day and not come into contact with some product than has not been processed in some way with a laser. From easy-open plastic packages in the supermarket, to cars and clothes – it is likely that a laser has been involved in the manufacturing of that product.

For this reason, in manufacturing technology it is common to find almost all types of lasers at many wavelengths in both low and high power applications. The overriding reason the laser has been selected over other competing techniques comes down to cost per part. In this case, an undesired change in the beam profile can degrade a profitable process and run up high losses quickly. Continuous beam profiling that can be integrated or retrofitted into the optical beam path is an essential part of process optimization systems.

For industrial processing applications, it is the high power and the relatively large raw beam width that present the biggest challenges to transparent sampling. Spiricon has joined with II-VI Inc. (www.ii-xi.com) to develop and market a high power CO₂ in-line beam monitoring system, that can be installed anywhere in the beam path (figure 10). The system is transparent to the process, providing an in-process view of the condition and health of the laser. Real time in-process monitoring reveals much about the laser that cannot be seen with any other means, and can point to processing problems that previously could not be explained. Since workstation capital costs are often in the millions, every minute of downtime is a significant drain on a company’s profitability.

3.4 Military, defense and aerospace
Laser applications in the defense-related area range from small targeting lasers to ground and air-based defensive weapons, to data transmission, just to name a few. In many of these applications, the Mid or Far Infrared wavelengths offer the best combination of utility and safety. Measuring beam profiles at these wavelengths requires detectors sensitive in this range, and to both pulsed and cw radiation. The standard camera for these applications is the Pyrocam III (figure 11). This camera has even been used to detect the new free-electron TeraHertz lasers being developed. InGaAs-detectors and phosphor-coated...
except it is the laser being checked. This natural extension of continuous monitoring of critical process parameters will increase in the coming years. Having the latest technology allows processes to operate at peak efficiency, increases productivity, reduces costs, and produces better parts.

4 Conclusion
Laser beam profiling has come of age. It is no longer a laboratory curiosity, but can be used in real world applications, and can be economically justified. The modern laser is an exceptionally useful tool. In the industrial context, laser in-line monitoring is especially beneficial. It is not different from any other well-known process monitoring, except it is the laser being checked. This natural extension of continuous monitoring of critical process parameters will increase in the coming years. Having the latest technology allows processes to operate at peak efficiency, increases productivity, reduces costs, and produces better parts.

References:

Figure 11: Pyrocam III is suited for the detection of Far IR energy with its 124 x 124 array of 100 µm square pixels (14-bit dynamic range). Behind this: 3D profile of a TeraHertz beam, wavelength 1.55 mm (equivalent to 0.2 THz), integrated power 57 mW (320 mW/cm² at peak)

Figure 12: 150 kW continuous CO₂ laser can have an unfocused beam width over 300 mm

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