NEW LOW-COST CO₂ BEAM PROFILER ELIMINATES NEED FOR ACRYLIC MODE BURNS

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Abstract

Acrylic Mode Burns have historically been universally used because they are the lowest cost alternative to the budget-minded end user. This method, however has been cited for producing dangerous, cancer-causing airborne materials, and is not a real time technology. On the other hand, Real-time beam profiling has been historically too expensive for the average user to acquire.

We discuss a new technology that enables the design of a new low-cost real time CO₂ high power beam profiler that is within reach of almost all end-users. This design does not produce dangerous fumes, and runs in real time. We will provide examples and results of testing with this device, and compare some of them to traditional camera based methods.

Introduction

The high power CO₂ laser has been the mainstay in welding and cutting, because of the advantage of a non-contact method of processing, making it possible to process rapidly over large areas. Laser processing also creates a much smaller heat-affected zone (HAZ), which reduces post-processed material dimensional issues, and lends itself to precision parts manufacturing. As long as the laser beam is stable and focused at the workpiece, laser processing can offer significant cost advantages over non-laser processing.

Beam mode quality for cutting and especially welding is critical for successful operation. There are many references in the literature relating beam quality and weld quality, and both end-users and laser manufacturers alike are well aware of the relationship, both theoretically and from empirical proof. Yet most laser manufacturers and end-users still use acrylic mode burns as the primary measurement technique for determining the mode quality of the beam. The most commonly used method for a CO₂ laser is an acrylic mode burn, where the unfocused laser beam is directed to an acrylic block, and the energy delivered to the block vaporizes the material in proportion to the spatial energy profile of the beam itself. The resulting profile represents the spatial energy distribution of the beam, integrated over the time the acrylic is exposed to the beam, usually over many seconds.

The drawbacks of using acrylic mode burns are well known, the mode burn itself represents a ‘time exposure’ of all the laser output, so it cannot detect transient effects during start-up, for example, or during processing. Acrylic mode burns produce toxic, carcinogenic fumes and must be exhausted properly to prevent worker exposure. Finally, the technique is highly dependent on many poorly-controllable variables and is subjective. It is also well known that a poorly shaped cutting or welding beam will increase scrap rates, and result in higher per-part costs, so there is an economic benefit to properly tuning the laser. Figure 1 shows typical mode burns.

Figure 1: Successive mode burns of the same laser. Each mode burn is slightly different, and open to interpretation by the technician. No quantitative data can be derived from this method.

Current Technology

Spatial beam profiling is the one measurement that combines all the variables that create a laser beam into one intuitively easy to understand visual image. This holds true for all laser beams, not just CO₂ lasers. In current materials processing environment, new technologies such as power mode shaping require the end-user to determine that the beam intensity follows the power supply commanded envelope. This is impossible to do with either an acrylic mode burn or even with a power meter, since neither method can respond in the short time frames commanded by the power supply. It now becomes as important to determine the transient beam profile and actual power, as well as the steady-state values.
Current technology is available to measure transient beam profiles\textsuperscript{3,4}. The Ophir-Spiricon Pyroelectric camera is ideally suited to measuring the beam profile of any CO\textsubscript{2} laser at frame rates up to 100 per second. Many innovative beam sampling techniques enable the user to stream continuous beam profiles in either 2D or 3D to a computer. Unless the potential loss in income from not measuring the transient response of the laser to the commanded power levels is high, these instruments are often difficult to justify economically. Nevertheless, for mission-critical applications, this technique is both well documented and in use at many facilities worldwide. Figure 2 shows the Pyroelectric camera and the patented Hybrid Pyroelectric array. Figure 3 shows the images taken from a 15 kW CO\textsubscript{2} laser with a beam diameter of about 50 mm from a Lambertian surface as an example of an indirect measurement that is possible with the Pyrocam III.

Figure 2: Pyrocam III, the standard for measuring IR sources, uses a Hybrid Patented Pyroelectric array.

This leaves the majority of industrial CO\textsubscript{2} laser users with little else to make real-time measurements of their laser. W. Edwards Deming, who many consider the father of modern industrial manufacturing, has been quoted as saying, “If you can't describe what you are doing as a process, you don't know what you're doing.” It follows in laser processing that if one cannot measure the spatial profile of the laser, then one cannot fully understand what that laser is doing at the work surface. As laser processing keeps moving the bar higher, knowing as much as possible about the beam in real time becomes more important than ever.

Figure 3: 2D and 3D images taken from a Lambertian surface on a 15 kW CO\textsubscript{2} laser. Detailed quantitative analysis is possible, even with this technique.

Figure 4: Beam Profiles taken only 500 ms apart of a 6 kW CO\textsubscript{2} welding laser. The beam width changed by 10 percent, illustrating the transient effects not measurable with non-electronic methods.
A New Twist on an old Technology

Faced with this situation and the increasing demands of the welding and cutting laser community, Ophir-Spiricon has developed a low-cost instrument that can now measure the unfocused CO₂ laser beam profile in 2D and 3D in real time, based on a technology that has been used for many years. The primary objective of this instrument was to enable the user to measure in real time the spatial output of a multi kW CO₂ laser. Cost was a prime consideration, because numerous users have indicated that the payback for such an instrument should be less than a few months, when compared to current techniques. Last, and certainly not least, the instrument had to be easy to use and understand by the average laser welding technician.

The heart of the system is a sensor that responds to the intensity of the CO₂ laser beam that can be imaged by conventional means, thereby eliminating the need for an expensive Pyroelectric array. This technology has long been used to ‘eyeball’ the beam shape of a laser by observing the light and dark pattern of a beam leaving the rear mirror of a laser. In fact, it is a staple of many a laser manufacturer technicians’ gear.

When used by the technician to estimate the beam shape, the fact that the human eye responds well to logarithmic changes in light intensity makes the method highly subjective. Obviously, if this sensor were to be of any quantitative use, a means to make linear measurements of the extinction of the sensor was required. Fortunately, modern CCD and CMOS cameras make these measurements reliably and accurately. It is interesting to note that an early qualitative version of this instrument was installed in Coherent General lasers over twenty years ago.

The next challenge was to devise a sampling technique that directed a small portion of the beam towards the sensor. This was successfully adapted from an early sampling design used in commercial lasers. By changing the percentage of sampling, the instrument can measure beams over a wide dynamic power range, from 500W or less to over 5 kW.

The final challenge was to adapt the widely-used Spiricon Laser Beam Analyser software to the peculiarities of the sensor plate. Because the image is the inverse of the beam intensity, new algorithms were developed so that the image is automatically changed to show the beam profile on the computer screen in the normal convention, where higher intensity results in higher peaks on the screen. To do this required the design of new software, BeamGage, which has only recently been released, and writing a special application within the structure.

Mode Check®

ModeCheck® has been designed with the industrial technician in mind. It has no special alignment requirements, can be used in a standard industrial environment by people with no special skill level, gives real-time beam images, displays detailed beam images in real time and is far safer to use the Acrylic mode burns. For those users with power meters, the system can be adapted to measure the power output of the laser simultaneously with the beam image. If a power meter is not used, then the beam that passes through the instrument is captured by a conventional beam dump.

The sampled beam is detected by a low-cost, high resolution USB II camera, and the signal is then processed by the software. The software has been specially modified to display 2D and 3D beam images in real time, along with critical beam parameter calculations.

Figure 5: Black and White image of a 3 kW CO₂ laser showing the rough outline of a donut shape mode.

Figure 6: When the same signal from the camera is processed by the Spiricon LBA, the mode quality of the laser is clearly seen.
Figure 7: Mode Check is a compact, portable and robust low-cost CO₂ beam profiler.

Figure 8: New software enables detailed image analysis in real time.

Industrial Imaging Examples

To illustrate the versatility of the ModeCheck, a number of welding and cutting lasers were tested in a manufacturing environment. In all cases, the set up time was less than 1 or 2 minutes. Representative views of each example are shown below.

The first example studied a flat bed cutting laser system with a 60” X 120” cutting bed, and the 3.2 kW laser operating at full power. The laser had just had the RF generator and the output coupler replaced.

The image was taken at the cutting head, with the focusing optics removed. Ten images were saved. Analysis of the images indicated that from the first to the last image (ten images are collected in less than 1/3 of a second) the beam size changed by almost ten percent.

The next example is a different cutting laser, rated at 4 kW, also operating at full power. This laser has about 6,000 hours on the output coupler. The mode structure of this laser is completely different than the 3.2 kW laser. Nevertheless, the beam width in this case also changed by about ten percent as well. Note the lack of symmetry of the peak of the beam. This beam should produce different cut quality depending on the cut direction.

The next example is a 1.7 kW drilling laser. The beam was sampled at full power in two locations. The first is at the resonator exit, and the second is at the head. Figure 11 shows the beam profile at the resonator output, and Figure 12 shows the same beam taken at the cutting head. Even though the beam is highly irregular at the resonator, it forms up well at the head, although there is a double peak, rather than a full Gaussian shape.
Summary

It is clear from these examples that the instrument is capable of continuously measuring the beam shape and size of high power CO₂ lasers. The detail is comparable to the standard Ophir-Spiricon laser beam profilers, and the speed of the streaming images enables the user to either observe the beam or make adjustments and see the results immediately. It is also clear from these examples that a strong economic case can be made to use this instrument in place of Acrylic mode burns for a number of reasons. First, the detail and quality of the beam profile image data is better than that from mode burns. The instrument can image transient effects and store them, unlike mode burns that can only create a time-exposure of the beam profile. ModeCheck does not create any hazardous or toxic vapors that must be carefully exhausted from the workspace. ModeCheck does not create a fire hazard like Acrylic mode burns. Lastly, ModeCheck produces data that is reproducible and independent of the user.

Future Work

Now that the first commercial images have been collected, direct comparisons between ModeCheck and images taken with the Pyrocam III may be performed. The sampling system lends itself to other industrial laser applications at other wavelengths. Using parts of this system, it may be possible to analyse very high power fiber lasers, for example. ModeCheck application list may grow rapidly as new opportunities present themselves to this unique sampling, detection and analysis method.

References:

1. Engel, S., "Industrial Laser Processing: Validation with the Use of Beam Diagnostic Instruments", SPIE Workshop, January 2003