Stable Directed Energy Weapons Start with Qualified Laser Sources

The science fiction laser weapons from our favorite movies when we were young are now reality. Ongoing use of the laser is broadening the horizon of aerospace and defense capabilities, by enabling the warfighter and by additive manufacturing processes that result in components that were previously difficult or impossible to create.

Making this fiction a reality involves incredible advancements in technology over the past several decades. If we consider the laser sources in these weapons and manufacturing systems, we find that they have steadily increased in output power as well as increased in quality and stability. As a result, laser systems are more reliable and durable, last longer, and require lower maintenance times and costs.

Getting laser systems to this point has challenged, and continues to challenge, laser engineers. Laser weapons systems have a current roadmap of achieving 3MW of output power by 2030. But applying high power KW and MW levels of laser light results in a unique set of thermal problems during design of the components used in the laser sources and for the systems in which they are integrated. This applies to directed energy applications as well as laser-based additive manufacturing systems, which push the boundaries of print speeds, part size, focused spot sizes, and reduced porosity. All of these challenges are amplified when the heart of the system, the laser source, is not high quality.

Figure 1. Military equipment can deliver large amounts of laser power. Image: Getty

When developing a high-quality, high power laser source for such systems, there are many factors that must be considered, including which laser characteristics are measured, monitored, and verified,. Let’s discuss the life cycle of these laser sources and how the consideration of these different measurements yields high-quality laser sources that add to the success of these laser systems.

Power, Profiling, M^2: The Laser Performance Footprint

The conception and birth of the high power laser source requires close performance monitoring. Over the years, laser technology has contributed to higher-quality sources which are more stable and durable than the early laser years. The output power or energy, the beam profile, and the M^2 measurement are important laser characteristic measurements that must be considered, continually improved, and communicated to the customer who is considering the purchase of the laser source.

Laser Power / Energy: Laser power or energy measurements quantify the laser light that will eventually be applied to the process in which the overall laser system is used. For the laser source manufacturer, it is important to achieve and maintain a specified laser power or energy over long periods of time, even though the laser will eventually be used for relatively shorter time periods.

It's important to understand that laser power and laser energy are not the same, even though there is a relationship between the two. Many times, power and energy are incorrectly used interchangeably. Laser continuous-wave (CW) power is a measurement of the laser that is continuously on. Laser average power is a measurement of the output from a pulsed laser source, where average power equals the amount of pulse energy over a given time period (P = E / t).

Laser Beam Profile: Another important set of laser characteristics that the laser manufacturer must understand is the measurements associated with the laser beam profile. Beam Profiling is the act of capturing the beam geometry with an imager and analyzing that image using specialized software.

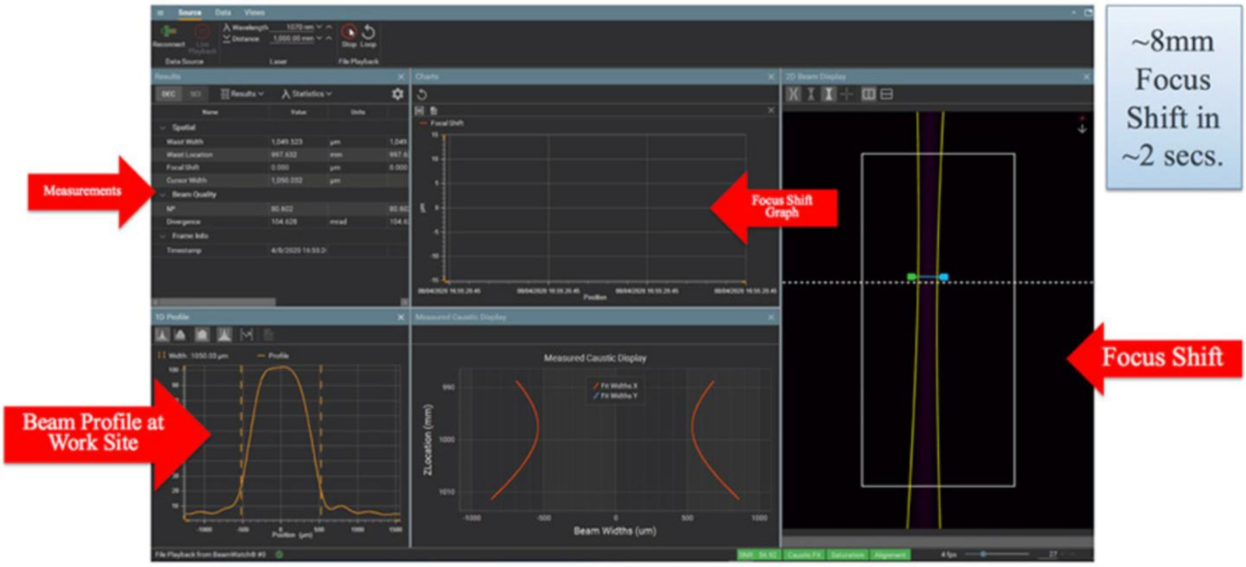

Figure 2. Beam profile of 100kW fiber laser with reflective optics.

It is critical to measure the beam size, whether the collimated beam or the size of the beam at focus, at the laser's conception and throughout the laser's life because it also defines the laser's performance at the process.

Laser beam profiling measurements also include the beam roundness, as well as how the energy is distributed across the beam. Since different beam shapes can be achieved for different processes, the beam profile will also analyze these shapes, like a Gaussian Fit or a Tophat profile.

Some laser beam profilers will also capture the real-time position of the focused spot and any changes in that location due to thermal effects on the laser system components. This is also important to understand in focused laser applications, especially when working with higher-power lasers, because the performance of the laser can exponentially decrease with changes in the location of the focused spot.

Beam Propagation / M²: Since the ability to focus the laser light is critical to the eventual application of the high power laser, beam propagation analysis is given close consideration. Beam propagation is defined as how the beam is behaving as it travels through space and how well it converges to and diverges from the focal plane.

Beam propagation analyzers take a collimated input beam, send it through a tightly-controlled optical plane, and automatically move the created focused spot through the internal imager. The end result is a measurement of the collection of beam profiles to produce a result called the M^2 value. This M^2 value is an ISO industry standard measurement which defines the laser's ability to focus; it is eventually published by the laser manufacturer and provided to their customers.

An M^2 value of 1 is a theoretically perfect value. Most single-mode lasers should have a value of 1.2 to 1.4 and today's multi-mode lasers will have an M^2 value of about 2 to 10.

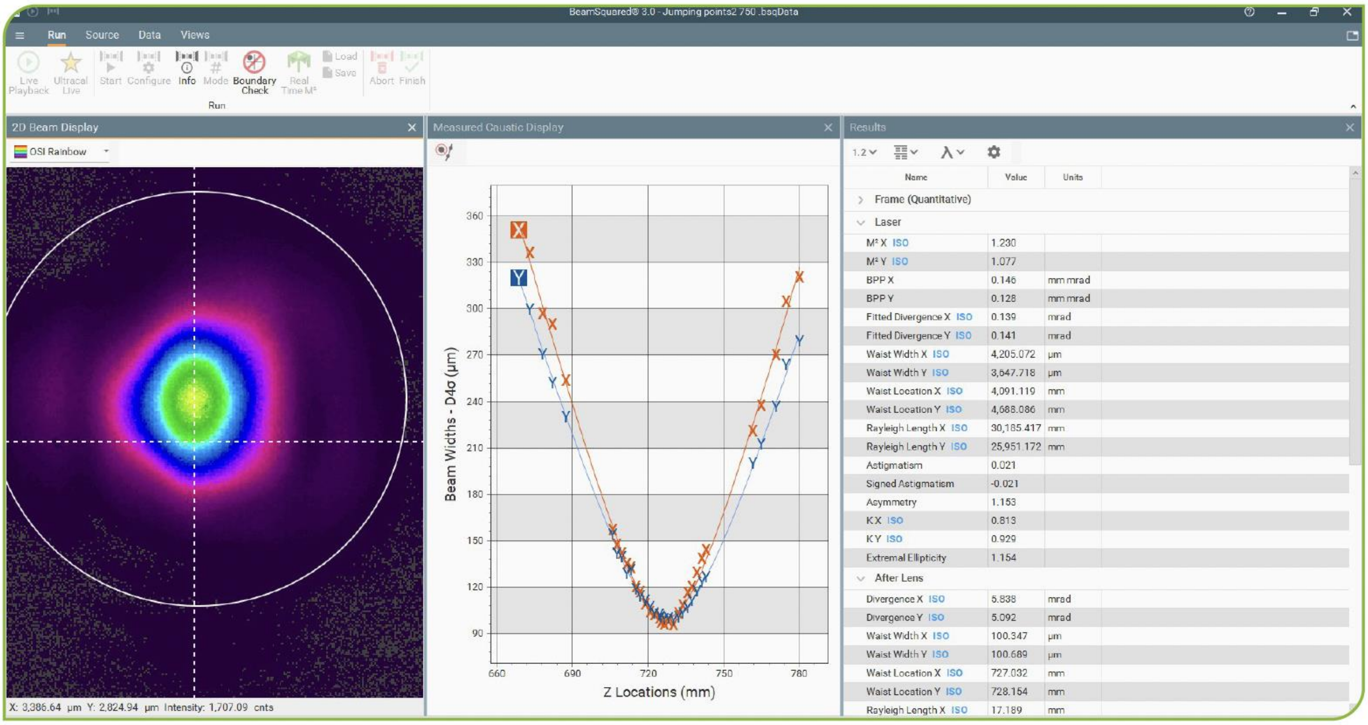

Figure 3. Ophir BeamSquared SP204S Pro M2 measurement.

Integration and Testing, Established Baseline

Once the laser system is manufactured under extreme scrutiny to ensure its long-term success, it's then used to develop the application system. Applications engineers in a lab environment will study how changes in laser power, beam size, wavelength, pulse energy, pulse width, and repetition rate make changes to the materials being processed by the laser.

In the application of the laser for a directed energy weapon, the sheer brute force of massive amounts of photons to destroy a target is often what is needed. However, with the use of a laser to weld exotic metals of varying compositions and thicknesses, more application work is needed to dial in the best set of parameters to achieve the desired result.

Once the application parameters of the laser are defined, the design of the system that houses the laser takes place. Careful consideration is given to the selection of and sourcing of components so that the quality of the laser source and the integrity of the developed application are maintained, thermal effects are minimized, and long-term durability of the system is ensured.

Measurement and understanding of laser system performance at this stage is needed for a couple of reasons. First, it is important to establish a baseline of laser performance at its peak efficiency, after the laser application parameters are developed and as the system is in a relatively new state. Periodic measurement of key laser performance parameters will ensure, long-term, that the laser system is running as it was designed to. Degradation of system components will occur and the system will need to be maintained. The frequency of this maintenance can be better predicted with comparisons to baseline measurements. Second, when (not "if") something happens to the laser system and maintenance must be performed, it is valuable to collect a set of baseline measurements ahead of time to establish a snapshot of performance for restoring the laser system to its designed efficiency. This could be following a planned maintenance routine or a during a corrective maintenance event.

Deployment & Maintenance: Long-Term Consistency

Once the system is commissioned and deployed, it will be susceptible to long-term use and abuse. Often times, these industrial high-power laser systems are exposed to very harsh working environments that can do damage to the system's components, in addition to natural physical degradation. Over time, the laser system will experience a decrease in efficiency and need to be maintained or repaired. This decrease in efficiency will usually result in an undesired interaction with the material being processed.

At a minimum, laser power or energy and a beam profile, specifically the beam size at the process, are recommended for frequent measurement because these two sets of measurements establish the laser's "power density," or the amount of laser light applied to the process with respect to the beam size. Power density defines how the laser interacts with the processed material and should ideally be maintained through the life cycle of the laser system.

Conclusion

Lasers are, overall, proving themselves to be a reliable and repeatable tool for industrial processing and weapons systems. It's clear that they are changing the face of material processing, whether constructive or destructive. However, since the laser system is made of physical matter, the system will change over time, usually resulting in a decrease in system efficiency.

Starting with a high-quality durable laser source which has been proven by industry-standard measurements is one of the best ways to ensure that the laser system will have long-term reliability. In addition to system design considerations, the measurement of key laser performance parameters, specifically laser output power or energy and beam size, is a good practice to consider when designing, commissioning, and maintaining the system. The laser is a valuable tool that is making changes to industry and defense applications for the greater good. It should be respected and protected.

For more resources on Directed Energy laser applications, see the full range of white papers, videos, and products from MKS Ophir.

About the author

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