Laser Beam Delivery and Focusing Optics

Some tips and best practices for maintaining a high production yield in micro welding

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Manufacturing engineers tend to devote a significant amount of time and energy to thinking about the laser, motion, tooling and their process, while sometimes overlooking the delivery of the laser to the work piece, and the focusing of the laser. To maintain high production yields, it is extremely important to understand the basics of beam delivery and follow a few best working practices for implementation, standardization, and maintenance of the optical delivery components.

In many cases there is reliance on the system integrator or laser OEM to provide the necessary optical recommendations and support. To enable complete ownership of the process, it is critical to have a full understanding of beam delivery and focusing optics, machine and process qualification, to enable self-support and troubleshooting, especially when process/yield drift or process failure occurs.

LASER DELIVERY

Figure 1 shows the six essential components of a laser system. The laser must be "delivered" to the workstation. For lasers of a certain wavelength, around 1 micron (corresponding to neodymium-doped yttrium aluminum garnet (Nd:YAG), fiber and diode), the laser can be delivered to the workstation by a flexible fiber optic cable. This offers great convenience for integration because the flexible fiber can be routed by whichever orientation is best for the system. Typically, the fibers are between 5-20 meters in length, so the laser can be situated some distance from the workstation if required.

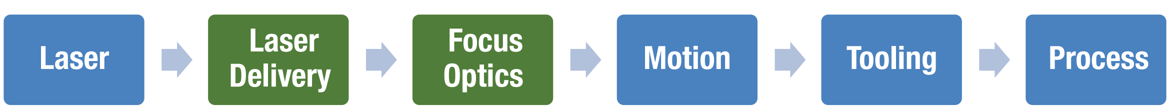

Figure 1 – Essential components of a laser system

LAUNCHING THE LASER INTO THE FIBER

For a Nd:YAG laser, a laser coupling optic is always used to launch the laser into the fiber, with one side accepting the laser and the other containing the fiber connection. There is usually a one-time fiber launch setup, though alignment should be verified by delivered power or pulse energy and beam mode if possible when changing or switching to a small core diameter fiber (< 300 microns).

An external laser coupling optic can be used for a fiber laser, or the delivery fiber can simply be spliced into the lasing fiber. The disadvantage of an internal splice is that replacement of a damaged delivery fiber may require returning the laser to the supplier for repair. The beam coupling method enables fiber replacement in the field with a quick changeover – very important for production uptime.

Figure 2 is a schematic showing the launch of the laser into the fiber. The top graphic shows the laser coupler method for Nd:YAG and fiber lasers, and the bottom shows the splice method, for fiber laser only. The delivery fiber has minimal power loss due to very efficient total internal reflection of the laser inside the fiber.

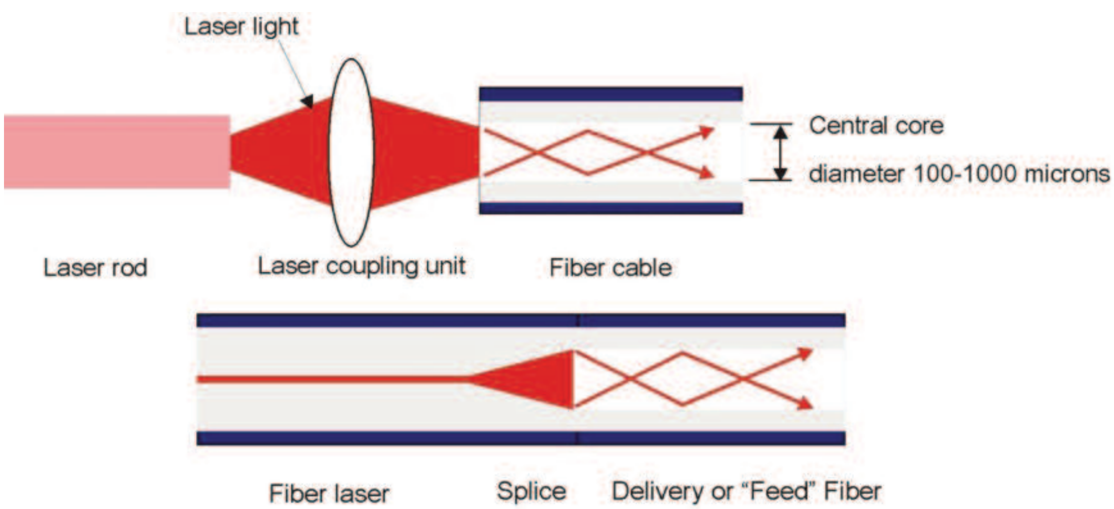

Figure 2 – Options for launching laser into the fiber

ROUTING OF THE FIBER TO THE WORKSTATION

Make sure the delivery fiber does not exceed its minimum bend radius (usually around 6 inches, or 150mm) because bending a fiber beyond this limit may overstress the fiber, leading to potential power losses or in the worst case, a catastrophic failure. It is rare for a fiber to fail, but it is nonetheless serious. The potential can be precluded by equipping the system with fiber breakage detection, which can sense when the fiber has been damaged. The more advanced detection systems test the fiber prior to firing of the laser.

Best working practice is to route the fiber above ground, not touching the floor between the laser and workstation to avoid the possibility of crushing the fiber, then coil and hang excess fiber length at the workstation. If the focus head will be moving, give sufficient slack, and again make sure the fiber's connection to the focus head avoids exceeding the minimum bend radius.

Most system integrators will usually provide the correct space within the workstation, but it is important to note that cable management from the workstation to the laser is the responsibility of the end user. It is also worth noting that increasing the length of the fiber does not result in a significant decrease in delivered power as the delivery of the laser through the fiber is very efficient. The main power losses occur at the fiber's entry and exit from the laser. If the fiber's entry and exit ends do not have an anti-reflective coating, power losses can be up to 2 to 3 percent at each end.

FOCUS HEAD AND OPTICS

Select the right focus head and optics for space, working distance, part access, and tooling accommodation. With each focus head style, the laser diverges from the fiber cable and is "collimated" by a first optic, transforming the diverging light to light that is propagating parallel to the travel direction. The second lens, known as the focus lens, focuses the laser to a spot where processing will occur.

There are a number of different types of focusing heads. **Figure 3** shows a few options, including a schematic of a 90 degree focus head, showing the collimating lens, the 45° reflector, focusing lens and cover slide; a 90° focus head; and an in-line focusing head. Selection will be based on the application, space and budget.

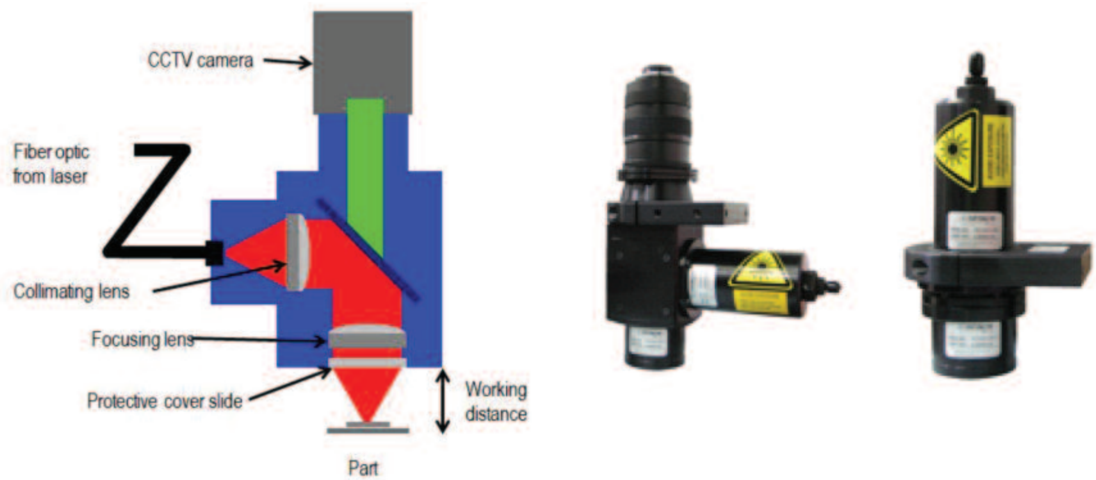

Figure 3 – Focusing head options

A great benefit of using 1 micron wavelength lasers is that these allow an in-line camera to be mounted to the head, providing a view of the weld area. By use of cross hairs pre-aligned to the position of the laser on the monitor, the operator can see the laser's position laser relative to the workpiece. A key factor in welding is the laser-to-joint alignment, and with this type of head operators can make small positional adjustments so the laser correctly aligns to the joint. The adjustment can be made manually or can be automated using a vision system, which removes the operator from the equation and can increase accuracy. However, vision cannot always be used, due to part geometry. Also it is possible to vision-adjust in the xy and rotation but not in the z axis. **Figure 4** shows a view of the workpiece, with the cross hairs indicating the focus beam location. This can be used for either manual or vision-based laser-to-joint alignment.

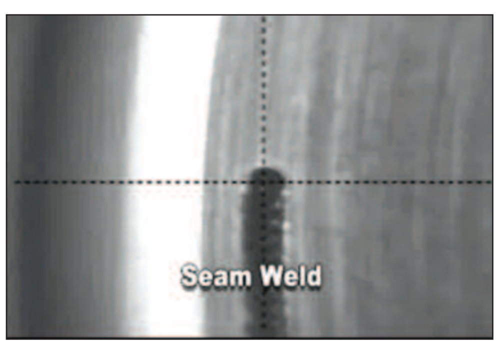

Figure 4 – Through the lens viewing of part and process

Another great benefit of the in line camera is that the focus of the camera can be set to that of the laser, therefore if the camera image appears out of focus the laser will also be out of focus.

Where space is a big concern, the in-line head without camera option offers a solution that can work well for lap welds that have much larger fit-up tolerances, such that the camera is not essential for laser to joint alignment verification.

Knowing the optical spot size is an important part in creating the weld size needed for the parts and to accommodate any fit-up tolerances. As shown in **Figure 5**, the optical spot size is a function of the core diameter of the fiber and the magnification of the focus head, defined by the ratio of the focus lens to the collimator lens. The optics in the focus head effectively images the end of the fiber. For example, a 400 micron fiber with a 100mm collimator and 100mm focus focal length produces an optical spot size of 400microns. Note that the actual size of the weld is usually larger than the optical spot size and can be fine-tuned using pulse width for pulsed welding and speed for continuous wave seam welding.

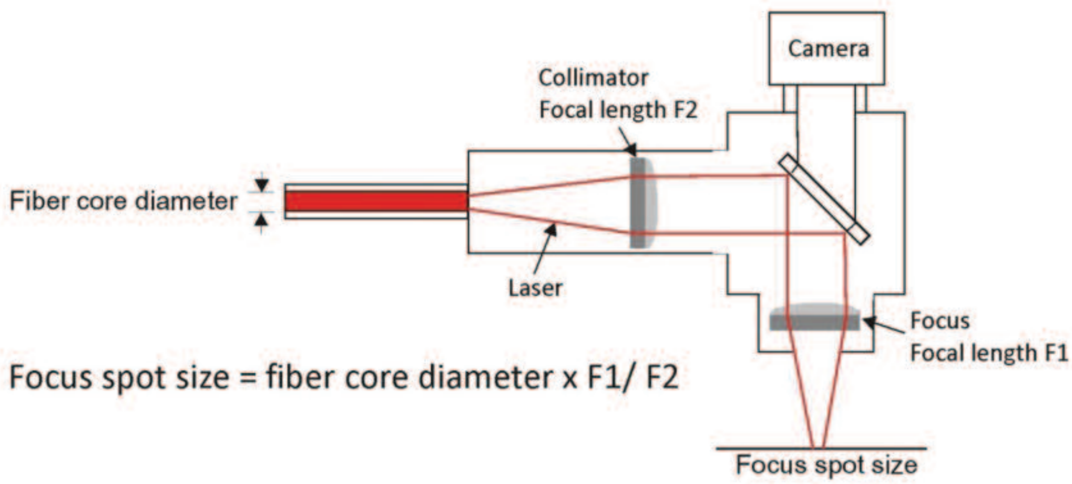

Figure 5 – Optical spot size

Selection of the fiber diameter and focal lengths for the collimator and focus lens may seem limitless, but be sure to follow these simple rules:

- The focal length should be maximized to provide sufficient working distance.
- The magnification ratio should be 1:1 (x1) and no less than 1:2 (x0.5).
- The largest core diameter should be selected to ensure the first two rules.

Table 1 summarizes the selection considerations.

Beam Delivery Component	Recommended Selection	Comments
Focus lens	Longest under 150mm	Maximize working distance for easy part load/unload, clearance for tooling, easy operator access to focus head and ensure enclosure height is not excessive.
Collimator lens	Match to focus lens such that the magnification ratio is 1:1 or not smaller than 1:2. Typically 70 – 150 mm.	Keep optics standard, ensures optics are functioning correctly with reference to F number (focal length/beam diameter at lens)
Fiber core diameter	Largest fiber size to match collimator and focus lens selection guidelines	Maximizes power handling capability, promotes flat top power distribution across beam diameter for stable welding.

Table 1 – Focus optics selection recommendations

PREVENTATIVE MAINTENANCE

Be sure to clean the lens cover slide, and replace it as required by the particular process, because contamination may lead to power transmission loss. For non-critical welds a loss of 5 percent is not significant, but heavy dirt on the cover slide can lead to a 10 percent power loss, and this is a problem. **Figure 6** shows the effect of contamination on transmitted laser power.

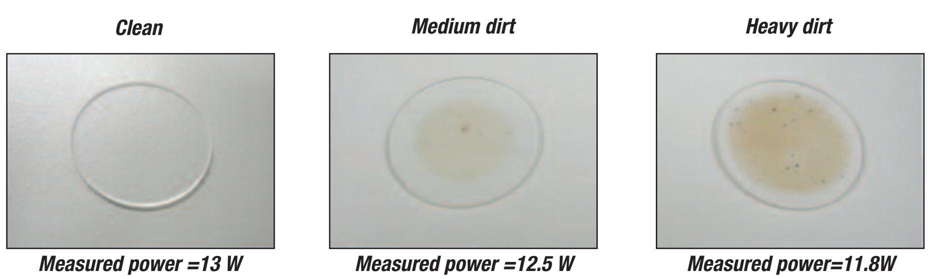

Figure 6 – Effect of contamination on transmitted laser power

The focus optic and the collimation optic may need replacing over time, and make sure you ensure the correct lens orientation when returning cleaned or new lenses. The lenses have a curved shape on one side and a flat on the other, and the efficiency of lens and the resulting optical focus spot size and focus position are affected by the lens orientation.

Figure 7 shows how changing the specific orientation of the collimator and focus lens can change the optical spot size.

Manufacturing engineers who use the best practices discussed for beam delivery and focus optics will be able to benchmark and troubleshoot the optic side of the laser system equation. Knowing what can go wrong, conducting preventive maintenance, and developing a benchmarking testing plan, are all steps that can be taken to maintain a high production yield. Gaining familiarity with the beam delivery and focus optics part of the system will empower engineers to have "24/7" coverage of their system and give them the tools they need to know what to do if something goes wrong.

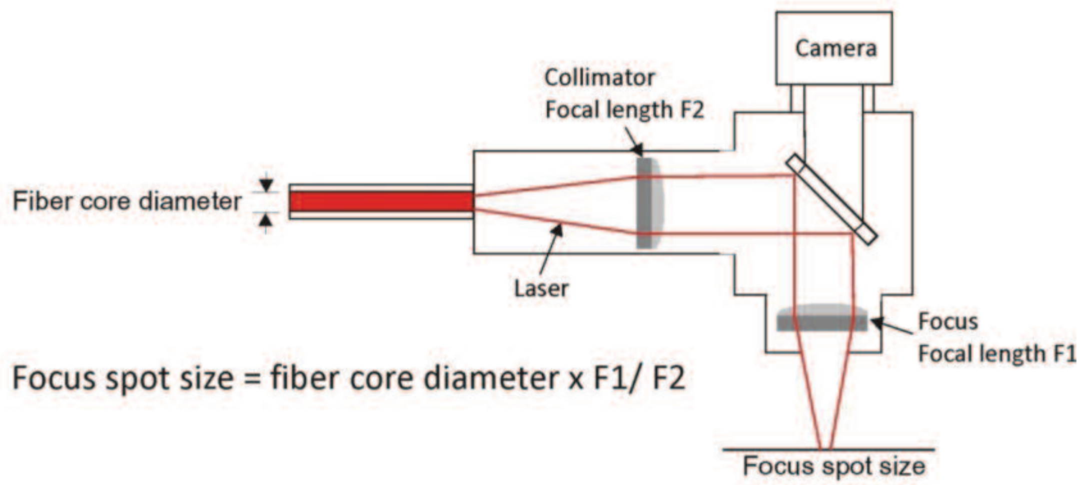

Figure 7 – Effect of lens orientation on spot size

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