Laser beam delivery and focus: best practices for maintaining a high production yield in microwelding

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Manufacturing engineers devote a significant amount of time and energy to thinking about the laser, motion, tooling and process for an application but sometimes overlook the laser's delivery to and focus on the workpiece itself. To maintain high production yields, it is extremely important to understand the basics of laser beam delivery and focus and follow a few best practices for implementation, standardisation and maintenance of the beam delivery components.

While it is tempting to rely on the system integrator or laser OEM to provide the necessary optical recommendations, complete ownership of the process requires a full understanding of not only beam delivery and focusing optics but also machine and process qualification. This knowledge, in turn, enables self-support and troubleshooting, especially when process/yield drift or failure occurs. This article focuses on the basics of laser beam delivery for laser micro-welding.

LASER BEAM DELIVERY BASICS

Figure 1 shows the six essential components of a laser system. The welding energy is created in the laser and must be delivered to the workstation. For lasers around 1 micron in wavelength (corresponding to neodymium-doped yttrium aluminium garnet (Nd:YAG), fibre and diode lasers), the energy can be delivered to the workstation by a flexible fibre optic cable. This offers great convenience for integration because the cable can be routed by whichever orientation is best for the system. Typically, the fibres are between 5 and 20 m in length, so the laser can be situated some distance from the workstation if floor space is at a premium.

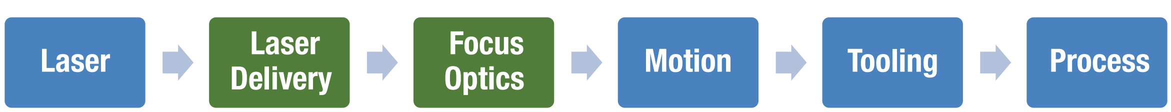


Figure 1: The essential components of a laser microwelding system. The laser delivery and focus optics bring the energy from the laser onto the workpiece.

LAUNCHING OF THE LASER INTO THE FIBRE

One challenge to bringing the laser energy to the workstation is to couple it into the fibre optic cable. A laser coupling optic is always used to launch an Nd:YAG laser into the fibre. This optic is a lens that takes the output of the laser resonator and focuses it into the core of the fibre. The core diameter of fibre optic cables for Nd:YAG and diode lasers is typically in the range of 200–1,000 µm. The good news is that there is a one-time fibre launch setup, after which it is set. However, the fibre alignment and coupling should be verified by delivered power or pulse energy and beam mode any time the fibre optics are changed.

For fibre lasers, the active gain medium is found in the fibre core. The diameter of the core typically ranges from 10–200 µm for the feed fibre. The feed fibre starts internal to the chassis and ends outside the chassis with one of the fibre terminations. This fibre is integral to the laser and, if damaged, cannot be replaced in the field. This can lead to long repair times and companies that need high uptime will often have a spare unit on hand.

The output energy from a feed fibre can be coupled into a larger fibre core diameter, often called a process fibre. Here again, a coupling optic is used to transfer the energy. However, because the process fibre is not directly attached inside the laser chassis, replacement is easier, less time consuming and cheaper.

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

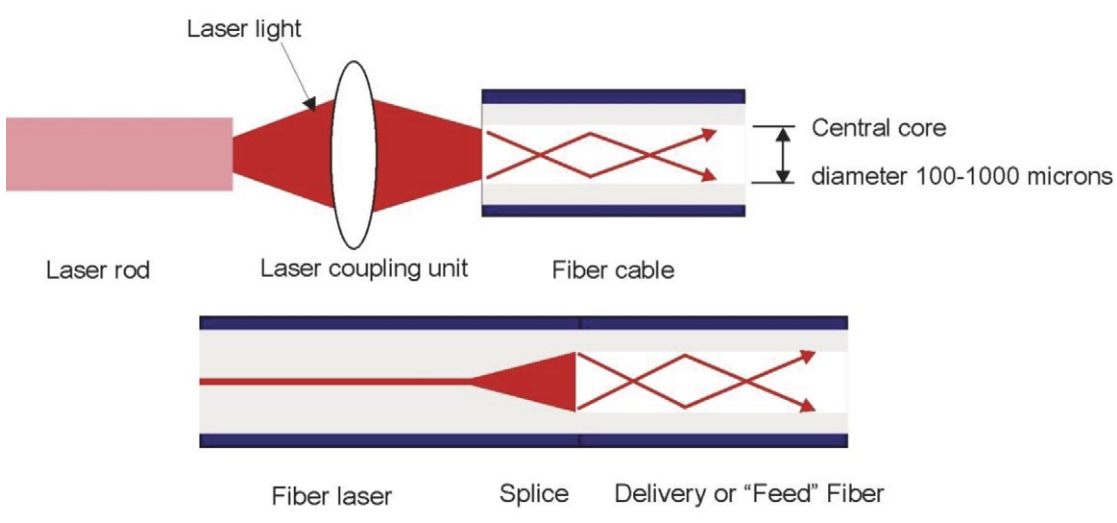


Figure 2: Two options for launching the laser into the fibre – external coupling and internal coupling.

ROUTING OF THE FIBRE TO THE WORKSTATION

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

A best practice is to route the fibre above ground, not touching the floor between the laser and workstation to avoid the possibility of crushing it, then coil and hang the excess at the workstation. If the focus head moves, care should be taken to give sufficient slack to ensure that the fibre's connection to the focus head does not exceed the minimum bend radius.

Most system integrators will 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 fibre does not result in a significant decrease in delivered power as the delivery of the laser through the fibre is very efficient. Power losses tend to occur at the fibre's entry and exit from the laser. If the fibre'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

One end of the fibre is connected to the laser, and the other to a focus head. Manufacturing engineers must 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 fibre cable and is collimated two optical lenses. The first optical lens transforms the diverging light to light that is propagating parallel to the travel direction. The second optical lens, known as the focus lens, then focuses the laser to a spot where processing will occur.

There are different types of focus heads. **Figure 3** shows a schematic of a 90° focus head with collimating lens, 45° reflector, focusing lens and protective cover slide; a photograph of a 90° focus head; and a photograph of an in-line focus head. Selection is determined by the application, space and budget.

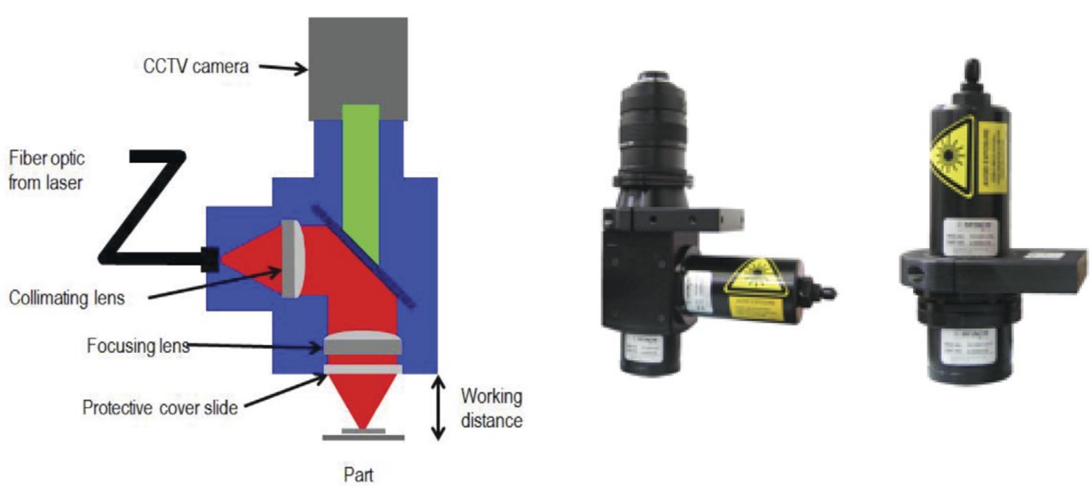


Figure 3: Two examples of focus head options. A 90° focus head (left and middle), which allows for an on-axis camera view, and an in-line focusing head (right), which removes the camera for space considerations.

A significant benefit of using 1 µm wavelength lasers is that they allow an inline or on-axis camera to be mounted to the head, providing a view of the weld area. The operator can use crosshairs pre-aligned to the position of the laser to see the laser's position relative to the workpiece. Laser-to-joint alignment is key in welding, and this type of on axis camera viewing head allows operators to make small positional adjustments so that the laser correctly aligns to the joint. These adjustments can be made manually, or automated using a vision system, which removes the operator from the equation and can increase accuracy. However, a vision system cannot always be used due to part geometry, for example when the weld location is recessed, and it is not possible to illuminate with enough light for the camera. In addition, it is possible to vision-adjust in the X, Y axis and rotation but not in the Z axis. **Figure 4** shows a view of a workpiece with crosshairs indicating the focus beam location. This can be used for either manual or vision system-based laser-to-joint alignment.

Another significant benefit of the inline camera is that its focus can be set to that of the laser. As long as the focus lens is not changed or the camera adjusted, it is possible to rely on the camera image for focus. This is very beneficial for manufacturing when there is a high mix of parts. It is quick and easy to change between two parts, without the need to readjust and find focus.

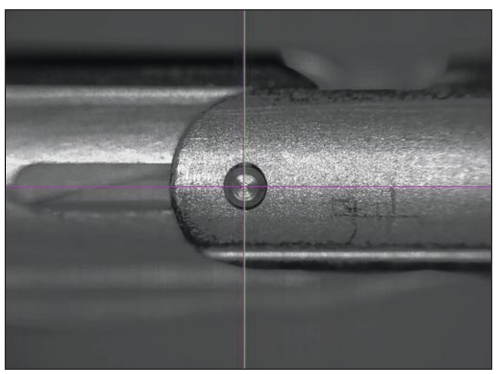


Figure 4: Through-the-lens viewing of the part and process. Crosshairs (dashed lines) show where the incident radiation will be fired.

If space is a concern and fit-up tolerances are more forgiving, the inline head without camera option will work. Knowing the optical spot size is an important part of determining the necessary weld size. As shown in **Figure 5**, the optical spot size is a function of the core diameter of the fibre 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 image the end of the fibre. For example, a 400 µm fibre with a 100 mm collimator and 100 mm focus focal length produces an optical spot size of

400 µm. 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.

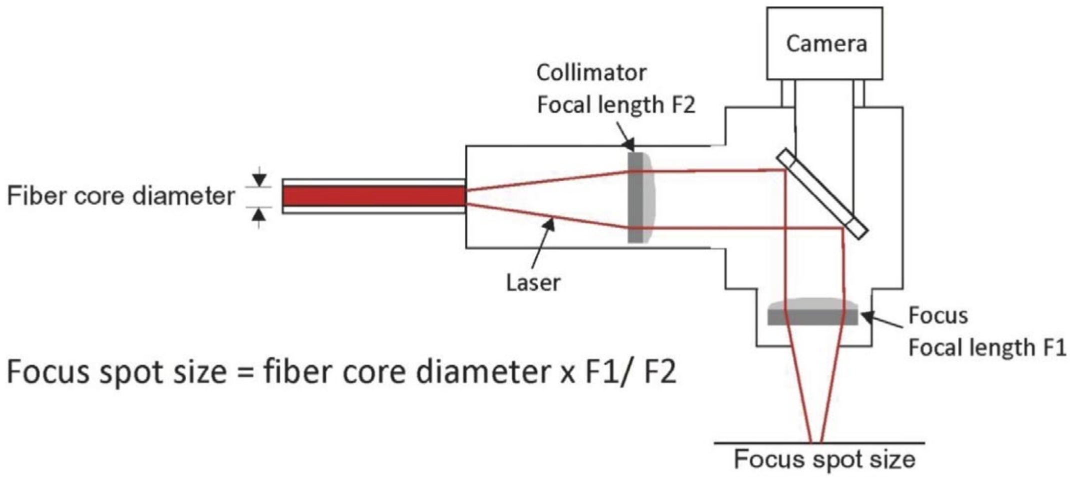


Figure 5: Optical spot size is related to the fibre core diameter and the ratio of optics selected for the collimator and focus lens.

The selection of both the core diameter of the fibre and focal lengths for the collimator and focus lenses may seem limitless, but one should follow these three simple rules:

- the focal lengths should be maximised to provide sufficient working distance;
- the magnification ratio should be 1:1 (x 1) and no less than 1:2 (x 0.5); and
- the largest core diameter fibre should be selected to ensure compliance with the first two rules.

Table 1 summarises the selection considerations.

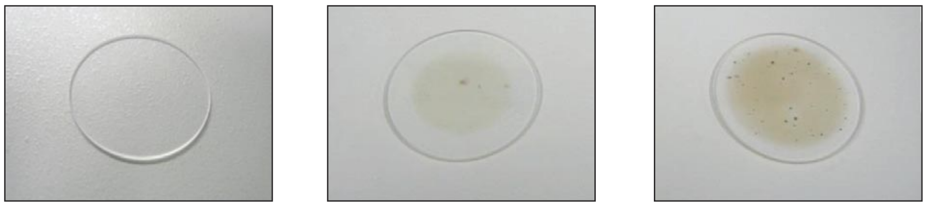
Beam Delivery Component	Recommended Selection	Comments
Focus lens	Longest under 150mm	Maximises working distance for easy part load/unload, clearance for tooling and operator access to focus head, and ensures enclosure height is not excessive.
Collimator lens	Match to focus lens such that the magnification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

Table 1 – Focus optics selection recommendations

PREVENTATIVE MAINTENANCE

Manufacturing engineers must 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, which will result in process degradation. **Figure 6** shows the effect of contamination on transmitted laser power. A regular check of the output power at the part using a power meter is recommended.

Clean *Medium dirt* *Heavy dirt*



Measured power =13 W *Measured power =12.5 W* *Measured power=11.8W*

Figure 6: The effect of contamination on transmitted laser power.

The collimator and focus lenses also need to be cleaned and replaced over time. It is important to ensure the correct lens orientation when inserting clean or replacement lenses. The lenses are curved on one side and flat on the other, and the efficiency of the lens and the resulting optical focus spot size and position are affected by the lens orientation.

CONCLUSION

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.