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Focusing on laser melting performance

New optical schemes for selective laser melting systems provide more consistent control of laser processing conditions. Dynamic beam focusing offers new possibilities for tighter focus control across the build plate and in varying thermal conditions.

Laser melting basics

Selective laser melting systems direct a small laser spot which heats the metal powder such that it liquefies to create a weld pool. This weld pool is moved across the powder bed and the 'tail' quickly solidifies once the laser energy is removed, creating a strong, fully-dense welded structure.

The amount of energy imparted and the speed with which the weld pool is moved are both carefully tuned to the characteristics of the metal alloy and the layer thickness that is being melted. This process relies upon a controlled spot size so that the energy density and total energy transferred into the powder is consistent.

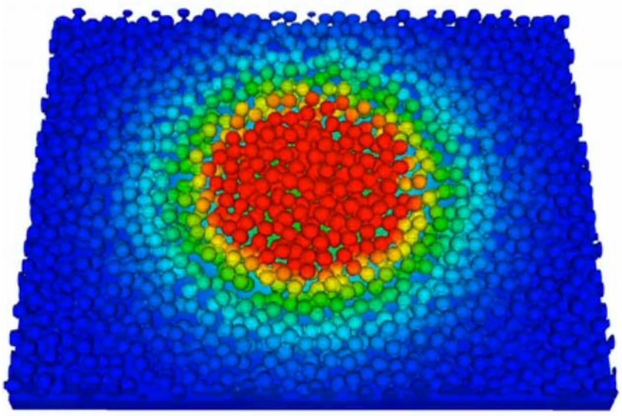
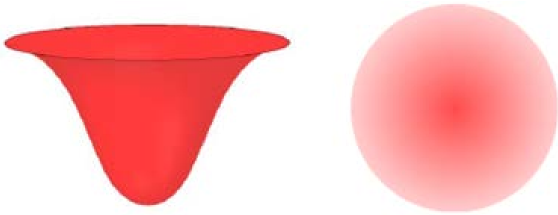


Image above: powder grains are warmed by the laser spot and heat is conducted into neighbouring material

Focusing of the laser beam is thus critical to the performance of the melting process. We need a crisply focussed beam to create the right heating effect. Any de-focusing will result in energy being imparted to material outside of the intended melting zone, potentially leading to dimensional errors and poor surface finish. If de-focusing is such that the spot size increases substantially, then this could result in incomplete melting and variable material properties in the finished component.

The focusing challenge

An ideal laser beam has a Gaussian intensity profile, such that it is at its most intense in the centre of the beam and reduces towards its edges.



Isometric **Plan**

Optical lenses are used to focus the beam from a few millimetres in diameter where it exits the fibre, down to a narrow waist where it intersects with the build plate. As we move away from this focal point, the beam's cross-sectional area increases, reaching twice the minimum size at a distance along the beam called the Rayleigh length (ZR in the diagram below):

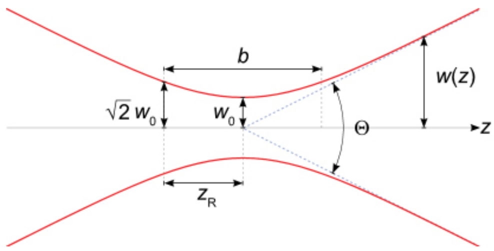
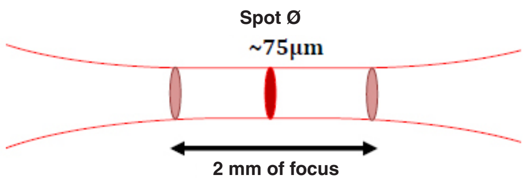


Image from Wikipedia

The Rayleigh length is proportional to the square of the waist diameter and inversely proportional to the laser wavelength. The smaller the waist diameter (which is desirable for producing detailed features) the shorter the Rayleigh length and the more sensitive the system will be to focusing precision. If our focusing is inaccurate and we are a Rayleigh length away from the true focal point, then our spot area will double and our energy density will fall by 50%.

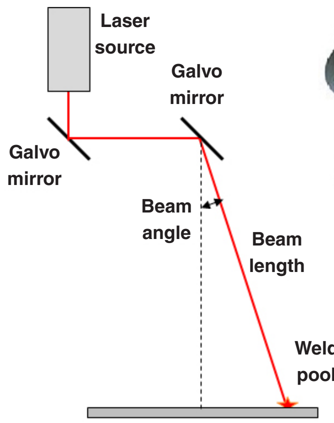
On a Renishaw laser melting machine with a 75 micron diameter waist and a 1,070 nm wavelength, the Rayleigh length is several mm. Of course, halving the energy density moves us far away from the optimum processing conditions for most materials, so in practice the allowable focusing range is really more like ±1 mm:

This means that our optics must be able to maintain focus within this range as the laser spot moves across the bed.



Galvo laser positioning and focusing

Most laser melting systems use galvanometric ('galvo') mirror systems to direct the laser beam to different locations across the powder bed. A pair of mirrors are positioned above the centre of the bed and these direct the beam at a range of compound angles to the required XY positions on the build plate.

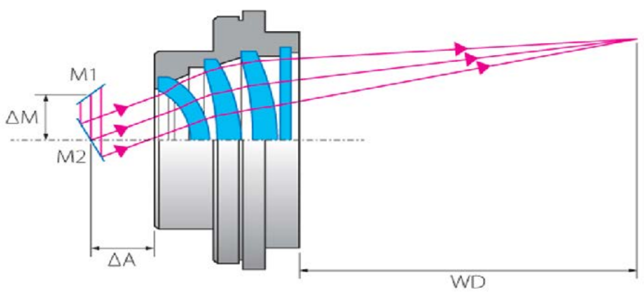


The beam therefore has to travel different distances before it strikes the bed as these angles vary. The further away from the centre of the bed we move the weld pool, the longer is the laser beam path from the galvo mirrors to the bed.

This means that the laser beam focal length has to be varied precisely with the beam angle. There are two main ways to do this: passive F-theta systems and dynamic variable-focus systems.

F-theta systems

Renishaw uses an F-theta system on its AM400 machine. It comprises a multi-element lens assembly that focuses an incident beam onto a flat plane. The F-theta lens has a focal length that varies with the angle at which the beam enters the lensing element. The intention is to keep WD constant across the complete range of incident beam angles:



F-theta systems provide a simple, passive control design that allows for high speed operation. They do, however, face some design challenges when high laser power is used:

- To avoid stray light within the assembly, anti-reflective coatings are used, but these can result in heat generation of up to 0.3% of incident power at each surface. Coupled with absorption in the lenses, this can result in 10W's of heat generation, which increases with laser power. Temperature variation in the lens assembly can lead to variation in focal length.
- As the focal length is a function of the incident angle, the positioning of the galvo mirrors relative to the F-theta optics is key. Any variation in this, which again can arise from temperature variation, could de-focus the laser.
- Finally, multi-laser systems will require multiple F-theta systems, resulting in increased system cost and complexity.

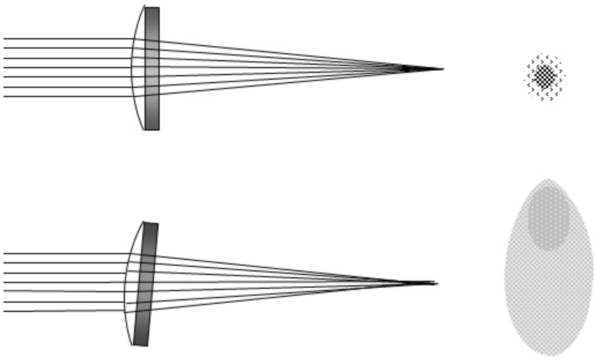
Dynamic focusing systems

Dynamic systems place a much smaller lens in the beam line upstream of the galvo mirrors and move it relative to the source location, allowing a change in the optical system focal length. Renishaw has switched to this method of focus control on its new RenAM 500M machine, which features a 500W laser.

This controlled lens movement corrects for the near-parabolic focal length change required as the galvo system scans the beam across the bed. This gives us some important advantages:

- The focal length changes are servo controlled, so any known distortions caused by the scanning system can be mapped to the lens position demand.
- We have full programmatic control of focusing - if we wish, we can deliberately de-focus the laser to create different processing effects.
- Because we are no longer constrained by a rigid lens assembly, we can adapt the focus to suit the current conditions, tracking thermal effects as heat flows impact the machine structure as processing proceeds.
- With fewer optical elements and anti-reflective coatings, dynamic focusing systems exhibit less unwanted heat generation.
- Feedback from the focusing servos can be logged along with galvo positions to increase process traceability.
- Compared to F-theta systems, dynamic focusing systems are compact and cost-effective, making them more scalable for multi-laser systems.

It should be noted that it is critical to control the alignment of the focusing lens to the optical axis to ensure accurate focusing and positioning of the beam spot. Small errors in alignment can result in significant de-focusing, so the optical system must be carefully aligned and thermally controlled to prevent this.



Summary

High quality manufacturing requires consistency, control and traceability. Tight focal length control is critical to consistent and productive laser melting performance.

As AM systems become more sophisticated and run at higher powers with multiple lasers, dynamic focusing becomes increasingly useful.

About the author

Marc Saunders, Director of AM Applications

Marc Saunders has over 25 years' experience in high tech manufacturing. In previous positions at Renishaw, he played a key role in developing the company award-winning RAMTIC automated machining platform, and has also delivered turnkey metrology solutions to customers in the aerospace sector.

Marc manages Renishaw's global network of Additive Manufacturing Solutions Centres, enabling customers who are considering deploying AM as a production process to gain hands-on experience with the technology before committing to a new facility.

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