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Get the facts on optics

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Senior Engineer, GE Additive

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There are many components within an additive manufacturing system that are critically important to ensure the printing of a high-quality part every time the machine is used. When it comes to laser powder bed fusion (L-PBF), optics are essential for ensuring the quality of the build.

We caught up with Maik Zimmermann, Senior Engineer, GE Additive, to discuss the importance of optics within laser-based additive methods and how these systems are calibrated to ensure that a high level of part consistency is achieved, across the build plate, between batches and across different machines, when using high throughput systems such as the M Line.

Q: What is a typical optical setup for laser-based additive processes?
The energy source for the metal 3D-printing process is a single-mode fiber laser. The laser radiation is transported using an optical fiber, and the emitted cone is transformed to a low-diverging beam using a collimator. The key system of the optical train is the high-performance 3D scanner, which is used to steer the laser power across the build plate using a high-resolution, advanced full digtal motor control technology. The specific optical configuration depends on the product line, as each machine has a different setup and a various number of scanners. For example, on the M Line, we have four lasers and four scanners with 400W power level and ranging up to 1kW in future releases.

Optical components are very sensitive to dust and contamination, so the 3D scanners are located within an air-conditioned enclosure to prevent any level of particle build-up in the optical train. This is crucial to protect optical systems against harsh production environments to avoid degradation or damage of our high-quality components over time. Additionally, we spend a lot of time performing quality control inspections and measurements on all our optical components.

Q: What's the approach for calibrating multiple lasers, such as those in the M Line?
We have a special automated calibration process in the M Line and use a calibration plate that contains

dozens of photodiodes and pinholes. Each of these pinholes has a microns-size diameter. The pinholes are arranged in pre-determined order with a very high precision, so they act as a reference for the calibration process. Using this process, we can calibrate single scan fields as well as multiple scanners —calibrating each scanner against each other.

The process is automated and the machine switches between the scanners during the calibration process, so the operator needs to start the calibration process only once. Using this calibration process and special scanpath strategies on the M Line creates a stable system that is very repeatable and enables debit-free stitching, even in terms of low-cycle fatigue properties.

Q: Which laser beam parameters can affect the build quality?
In L-PBF systems, the laser beam quality is very important for the lasing process. The laser quality factor characterizes the laser beam and how well you can focus the laser to a certain diameter. We typically have laser beam quality factors (also known as M^2 or “M squared) that are way smaller than 1.3. This allows for a focus diameter in the powder bed of 50 microns.

Another critical parameter is the spot size diameter control in the powder bed. The spot size accuracy is especially important if you want to process different materials, as each material will have its own set of parameters to work with, and the spot size required will be different depending on material selection and printed features. We usually use spot size diameters between 50 and 350 microns, with very small deviations when we digitally call different diameters during the build process to print various features.

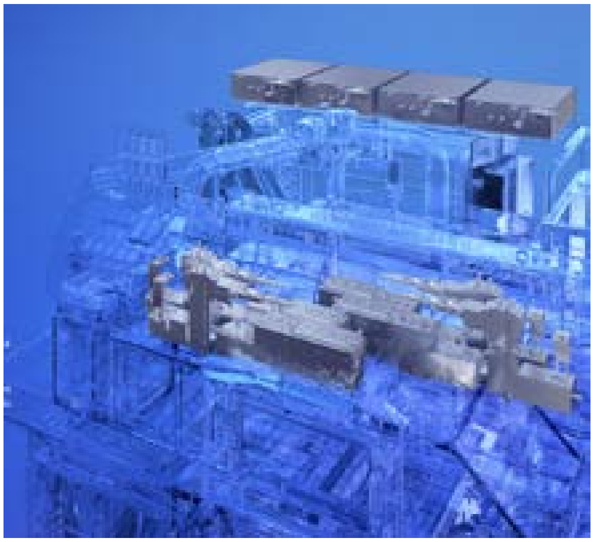
When talking about the spot diameter control, the thermal focus shift must also be considered, since thermal lensing results in deviations in the focus position and the spot diameter depending on laser power. In our optical system a low thermal focus shift is guaranteed by the selection and quality control of the optical components.

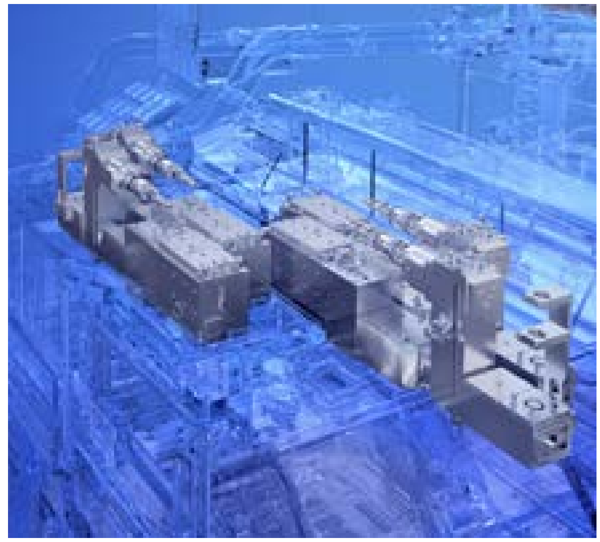
The next influencing factor is the ellipticity of the beam, as you usually want a symmetrical, round spot and power density distribution. This way we avoid variation in line thickness at edges and ensure orientation agnostics of parts on the build plate.

Q: How is build quality influenced?
The stability of the laser intensity over time and the calibration of the scanners directly influence the quality and dimensional accuracy of the parts that we print. In addition, constant laser parameters must be provided at every point on the build plate. This is extremely important for the quality of the stitched zones in multi-laser processing, as you can easily see the effects of poor stitching on the part, such as a lot of surface roughness or poor dimensional accuracy. The laser beam quality and intensity directly influence the surface finish of the part. In addition, the mechanical stability of the part is of course very important. Pores negatively affect the mechanical stability, especially the fatigue behaviour. In order to ensure low porosity, a stable process control and constant laser parameters are necessary.

Q: How are these process parameters controlled to optimize the build quality?
The quality of the optical components is vitally important. Our optical systems are specially engineered for use in laser powder bed melting additive processes. So, we use specially designed high-power coatings and high-quality glass materials in our systems to guarantee that we can use a high laser power without debit in optical performance caused by thermal influences such as thermal lensing.

The cleanliness of the optical components is important, so we need to implement quality control measures to guarantee that we have no





dust, contamination, or damage on our optical components. This ensures that we can achieve and maintain a good beam quality. On a system level, we need to implement a high level of thermal stability in our optical components. Our optics are usually cooled using either water-cooled or air-cooled systems so that we can guarantee a high stability over time.

Finally, we need to ensure that our optical components have good alignment with other sub-systems, because it's not only the optics that are responsible for creating a high-quality part. We need good alignment with the thermal management, with the gas flow management, the recoater system, and finally the mechanical design and PLC/software that connects all sub-systems of the machine. The gas flow, for example is particularly important for ensuring that the laser radiation is coupled properly to the metal powder and the process chamber window is protected from soot and other contamination. So, it is another key factor to guarantee a good build quality.

Q: How do we go about measuring and testing those key quality parameters?

Measuring and testing are some of the main tasks that are performed by the interdisciplinary engineering team during the development of a machine. We are very data driven, so we measure all the key parameters, and the system parameters (such as temperature and pressure) are monitored over time to learn about the machine's behavior. We evaluate all our testing equipment using a Gage repeatability and reproducibility (GR&R) process. With this, we control and validate our measurement systems across multiple quantitative measurements, with one or more operators on multiple parts and on multiple machines. This is the first step to certify that our measurement process is stable and accurate.

For the M Line, for example, we are verifying our calibration process on a special pattern. We perform an exposure on a validation plate containing a pattern of concentric circles.

This pattern is measured with a coordinate measurement machine (CMM) to identify the single-laser and multi-laser mismatch. We then perform additional measurements at different power levels—from low to maximum power levels—to identify power stability, as well as the power stability over time. We also measure the caustic, spot size, and ellipticity using camera-based measurements systems for all power levels of the machine.

The approach we take allows us to obtain a very deep system knowledge of our machines and enables us to monitor the machines and their performance over time. We collect a large number of data points to ensure that the build quality and critical process or environmental parameters—such as the temperature of the optical components—are monitored and logged in our machines. Therefore, if we see any issues, we can go back into the log files and identify if there are any issues with the cooling or other system parameters. During the validation of the M Line, we collected, analyzed, and connected more than nine million data points from all the sub systems. This was a huge amount of data, but it was necessary to get to a deep system understanding of the machine.

Conclusion

Additive machines can create high-quality parts, thanks to the use of properly calibrated, contamination-free, and highly-quality optical components. For the M Line specifically, it utilizes fully digital, high-performance 3D scanners alongside a special motor control with a high spatial resolution that facilitates a high laser beam quality, high scan speeds, and a low drift.

As the metal additive industry scales and starts to look towards greater levels of industrialization and production scale-up, reliable and repeatable optical systems are going to play a key role in enabling additive high-volume manufacturing. Beyond this, another key aspect for ensuring a wider adoption of additive is going to rely on having a deep understanding of the machine itself (obtained through data, continuous monitoring, and statistical process control) and knowing a lot about the routine behavior of the machine, as well as what factors are going to impact the quality of the critical parameters.

To find out more how the M Line has been specially designed for larger scale production, or for more information about how high-quality optical systems can be utilized to create high quality parts for your application and industry, get in touch.