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Get the facts on accuracy, uniformity and continuity

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The overall capability of a laser powder bed fusion (L-PBF) additive system is defined by its consolidation potential. The consolidation potential of an L-PBF system is a product of the machine's capability, its accuracy, the uniformity of the build, and the machine's continuity. In order to optimize the output of an L-PBF machine, that is, to ensure high-volume production of high-quality parts and minimal part-to-part deviation, these factors are critical for ensuring success.

Halima Iqbal, Advanced Lead Project Manager, GE Additive, discusses the importance of accuracy, uniformity and continuity when building parts—especially in highly regulated industries—and how they can be achieved to a high standard, ensuring part build success.

Q: What do we mean by accuracy and why is it important?
With an L-PBF system, we're aiming to ensure that accuracy is well known within the industry on a couple of different points.

The aim of the game when it comes to accuracy is to ensure that, when printing a part, you are meeting the design intent per your CAD model requirements and the material properties required for your application.

Accuracy with L-PBF systems really means that you're hitting the laser on the powder bed in the exact place as intended, and with the right properties. These properties include a consistent beam spot size, shape, and quality, with the laser beam characteristics and energy input needing to be controlled and optimized. These properties drive the quality of the part and allow you to build the part to the right specifications and dimensions. You also need to minimize the variability in positional accuracy—where the laser hits the powder bed—if you want to meet the design requirements.
It is important that you have the right quality of components available to ensure that you are building the intended specifications and material properties. This is even more crucial in highly regulated industries, such as aerospace and medical where certain requirements must be met and demonstrated repeatedly. If you don't have a highly accurate system, you are going to automatically close yourself off to some of the highly regulated markets, as your parts will struggle

to meet the stringent requirements set by those industries.

Q: What are some of the methods used to achieve accuracy?
Ensuring that the optical components are thermally stable and regulated, having high-quality optical components, and ensuring that there is minimal variance in our working level distance. The combination of optical component choice, set up and thermal stability drives the positional accuracy by limiting the drift of components, and positional accuracy is ever-more important when more than one laser is used.

With the improvements made in our design and methods for both spot and position accuracy, we have been able to reduce focal shift in our L-PBF systems by over 70% and demonstrate enhanced stitching capability.

Talk to us about the importance of thermal regulation in terms of accuracy.
The characteristics of the laser beam are very important as it moves from the source to hitting the powder bed. The beam needs to have the right size and energy input to be accurate. This is heavily dependent on the temperature of the different optical components in the system.
If there is a large thermal shift within the optical components, it starts to alter the characteristics of the beam. This can cause a focal shift in the optics, which changes the size or shape of the spot on the powder bed from what was intended and deduced to be optimal for a high-quality build. If you don't have the right spot characteristics, you don't achieve the desired material properties, that is, reduced quality.

Therefore, ensuring the thermal stability of the optics is one of the most critical pieces for ensuring high accuracy, and in our systems, we have optimized both water- and air-cooling systems depending on the type of optical component. This allows us to hit the narrow process windows that we want to achieve to get the right part quality.

Q: And how do you ensure a high optical component quality?
The quality of the components themselves is very important if you want to achieve the desired spot characteristics, and we make sure that we hold our suppliers to a high-quality specification. The products are tested before they leave the supplier, as well as before and after installation in the machine. Off-the-shelf components don't tend to work, so the purchasing of components requires a lot of understanding about how these components behave, undertaking a lot of in-depth analyses, as well as trial and error with different components. There's a careful selection process that goes behind obtaining the right optical components.

Q: And what's important about the working level distance?
The distance between the laser output and the powder bed is the working level distance, and is a very important factor for determining the characteristics of the beam. The shorter or longer the beam is, the different the beam characteristics will be, and this changes how the spot forms on the powder bed. So, you need to ensure that you have the same working level distance, otherwise you will also experience focal shifts within your beam. The main way to do this is through the set up of your recoater blade. The recoater blade spreads the powder across the build plate and sets the working distance. So, you need to pre-calibrate the recoater blade before you put it into the machine to ensure that there are minimal variance issues so that you get a narrow processing window.

Q: What do we mean by uniformity?
Uniformity ensures that whatever you do in one part of your build plate or powder bed can be replicated. So, you're essentially aiming for uniform operating conditions within your process chamber to ensure minimal part-to-part variation. Once you have achieved the desired spot characteristics,

targeting uniformity using technical levers will allow you to achieve the same quality output, regardless of where you are on the build plate—be it from part to part or throughout one large part. It is highly critical to ensure that you achieve uniformity within regulated industries, where part one needs to equal part 10, which needs to equal part 100.

Q: How do we achieve uniformity?
There are a few technical levers that we use to ensure that we achieve uniformity across our builds. These are an efficient gas flow, an optimized recoater design, and the choice of optimal components used. If you do not achieve uniformity within your machine, you're going to have a constant struggle to try to qualify your parts because you will be scrapping half of the build plate. This is not a great business case for any user, so uniformity is key for maximising the output of any additive machine. By utilizing the different technical levers around optimizing recoater design, gas flow distribution and component choice, we have managed to significantly reduce our variation across build plates in our latest products.

Q: How does gas flow affect the ability to create uniform parts?
The gas flow across the build plate is a big factor for achieving uniformity as it allows a clean melting process to take place. A lot of soot gets generated when you laser metal powder, so you need an effective gas flow.

It is important that the flow is uniform across the powder bed and build plate so you're not getting clean and dirty regions as that will ultimately lead to differences in part quality across the build plate. Otherwise, regions of soot will remain. If you're lasing through soot, you will have a lower part quality, so a uniform gas flow is key to achieving a uniformly clean and homogenous build environment. This ultimately leads to an overall improvement in quality, density, and surface roughness of your parts.

Additionally, how the gas flow is calibrated is key to ensure uniform airflow, as it ensures that the machine is within the right tolerances before use.

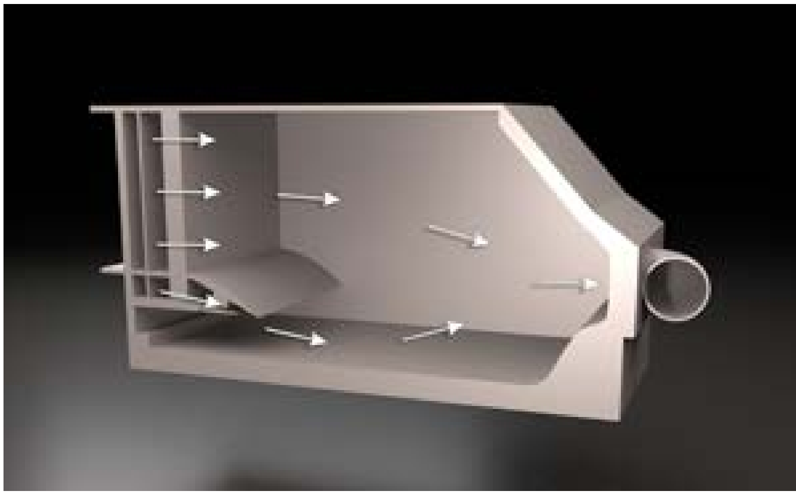

Figure 4: Flow concepts of the GE Additive Concept Laser M2 Series 4 machine.
Source: GE Additive

Q: What effect does the recoater design have on uniformity?
Having an optimized recoater design enables you to minimize the turbulence in the build environment, allowing you to have a clean flow.

Q: And what about the impact of optical component choice on uniformity success?
The choice of optical components is a major player for minimizing the variability in the spot characteristics and how that can be demonstrated repeatedly across the build plate. The goal is to be able to hit a small enough spot size to allow for fine feature resolution in your parts, while maintaining the beam shape with minimal variation. So, as you move across the build plate, if your optical components are of a high quality, the deviation in the focal shift is going to be minimal compared to poor-quality parts, allowing you to achieve a repeatable output on the build plate.

Q: How does continuity contribute to a maximized output?
Once you've perfected the spot characteristics and you've demonstrated that you can replicate

it across the build plate uniformly, you need to set the machine up for success by optimizing the output and reducing the total cost per part. An L-PBF system should be designed so that your operational effectivity is high, and any losses are kept to a minimum.

Continuity aligns with your ability to have the machine available to you as much as possible, so that you can continuously print parts without facing operational losses. One big aspect to this is powder handling, as a lot of time is spent loading and unloading the powder. We are actively trying to optimize this area so that the user can have more laser-on time and spend less time on factors that don't add value.

Maximizing the laser-on time of the machine allows the user to hit the build times required to meet their part demand schedules, while also ensuring residual stresses in the part are kept to a minimum.

By doing as much of the vector calculation work (especially for complex parts) offline, on your office desktop, more time can be spent printing and delays can be kept to a minimum during the build. This maximizes the laser-on time, allows for faster builds, and reduces the amount of residual stress in the part, because you're not waiting around for the calculations to take place—which can cause some thermal differences between layers during the wait, increasing the stress on the part.

To achieve the maximum laser-on time, the machine needs to be easy to maintain and have an easy-to-handle design. In addition, implementing certain maintenance procedures to ensure minimal downtime and undertaking specific training can help any user to become self-sufficient with their machine, maximizing laser-on time, and in turn, reducing the cost per part.

Overall Outlook

Overall, you need a combination of accuracy to hit the powder bed in the right spot, a high degree of uniformity to ensure the same part quality across the whole build plate, and a high degree of continuity in your machines so that you can maximize your laser-on time and reduce the total cost per part. By ensuring these three factors are met, you will be able to create a large volume of parts that are uniform and of a high quality, which will be able to meet the most stringent of industry and regulatory requirements.

If you'd like to find out more about how our teams can support you throughout this initial optimization process, and once you start printing parts, get in touch.