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For Industrial Scale 3D Printing, Technical Maturity Matters

Dr. Wolfgang Lauer
Senior Product Manager, GE Additive

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Walk through any large-scale factory and you will see a variety of industrial equipment. As different as these machines are, they all have several things in common. They are reliable. They achieve high yields. They meet quality expectations. They produce parts with little variance from run to run and from machine to machine. And they do not require constant operator intervention.

They are, in a word, mature. They are easy to use, and their technology and construction have proven themselves through the years. They can run 24/7 if necessary and produce tens or even hundreds of thousands of on-spec parts, repeatedly.

As an additive industry, we are collectively getting there, but technical maturity is a word still not often associated with metal additive manufacturing.

After all, additive is a rapidly advancing technology where competitors all vie to be first on the market with new features. That often results in metal 3D printers that have not been thoroughly tested reaching the market. Instead, debugging takes place on the factory floor. And while these machines may achieve high yields and quality, they may not do it consistently. Their operating parameters vary too much and may drift over time. In a word, they are not mature.

That is why GE Additive developed its new M Line laser powder bed fusion (L-PBF) system. It is designed for true, industrial-scale, volume manufacturing. Its 500 x 500 mm build plate and 400 mm z-height supports the production of both large parts and higher volumes of smaller parts. It is also designed for 24/7 operation and rapid turnaround between production runs.

The M Line is a big step forward in additive manufacturing maturity. Built with input from our colleagues at GE Aviation, it meets the aerospace industry's highest quality standards for printed part geometry, performance, and microstructure.

Multiple machines have undergone validation testing for 18 months, taking more than nine million measurement points, and using statistical methods to ensure minimal variance in production. This enables the M Line to consistently print low-porosity parts with even stitched fatigue strength to stand up to dynamic as well as static loads. It opens the door to many possible applications in aerospace and most other industries.

Adding Flexibility

Technical maturity is critical to manufacturers who want to take full advantage of everything additive manufacturing offers. They know that additive manufacturing cannot compete with conventional machining on a direct part replacement basis. Instead, they see L-PBF-based technologies printing as a way to integrate higher-value functionality into their designs.

Additive also provides greater supply chain flexibility. On one hand, it can consolidate part count and reduce assembly time, simplifying production. On the other, it enables manufacturers to switch seamlessly between different types of parts while still running at high volume. The M Line system can complete these turnovers between runs in as little as one hour. This gives producers the flexibility to switch between parts as needed or to create customized derivatives of a single design.

Many manufacturers could leverage additive's utility, but first they must learn to trust the technology. So, how can producers tell if additive technology is mature enough to work for them?

Critical to Quality

To answer that question, let's look at how GE Additive developed the M Line. This did not happen in a vacuum. It began in 2016, when GE Additive acquired Concept Laser.

After the acquisition, GE and Concept Laser engineers joined together to redesign the company's M2 DMLM printer. Their goal was to optimize the system's critical-to-quality (CTQ) subsystems, the modules that directly impact part quality. Anyone familiar with laser metal printing will be familiar with them. Among them are:

Optics: This includes laser beam power, precision, shape, and stability, as well as the mirrors used to focus and split beams and the hardware used to mount these elements. Laser quality determines the porosity and microstructure of the final part as each layer melts and then solidifies.

Airflow: Air flowing across the build plate whisks away tiny airborne soot particles generated by laser melting and keeps temperatures stable. Laminar airflow enables consistent printing across the entire build plate, right up to the edges. When airflow is inconsistent and causes turbulence, some soot will remain hovering above the workpiece and laser energy, which can alter material properties.

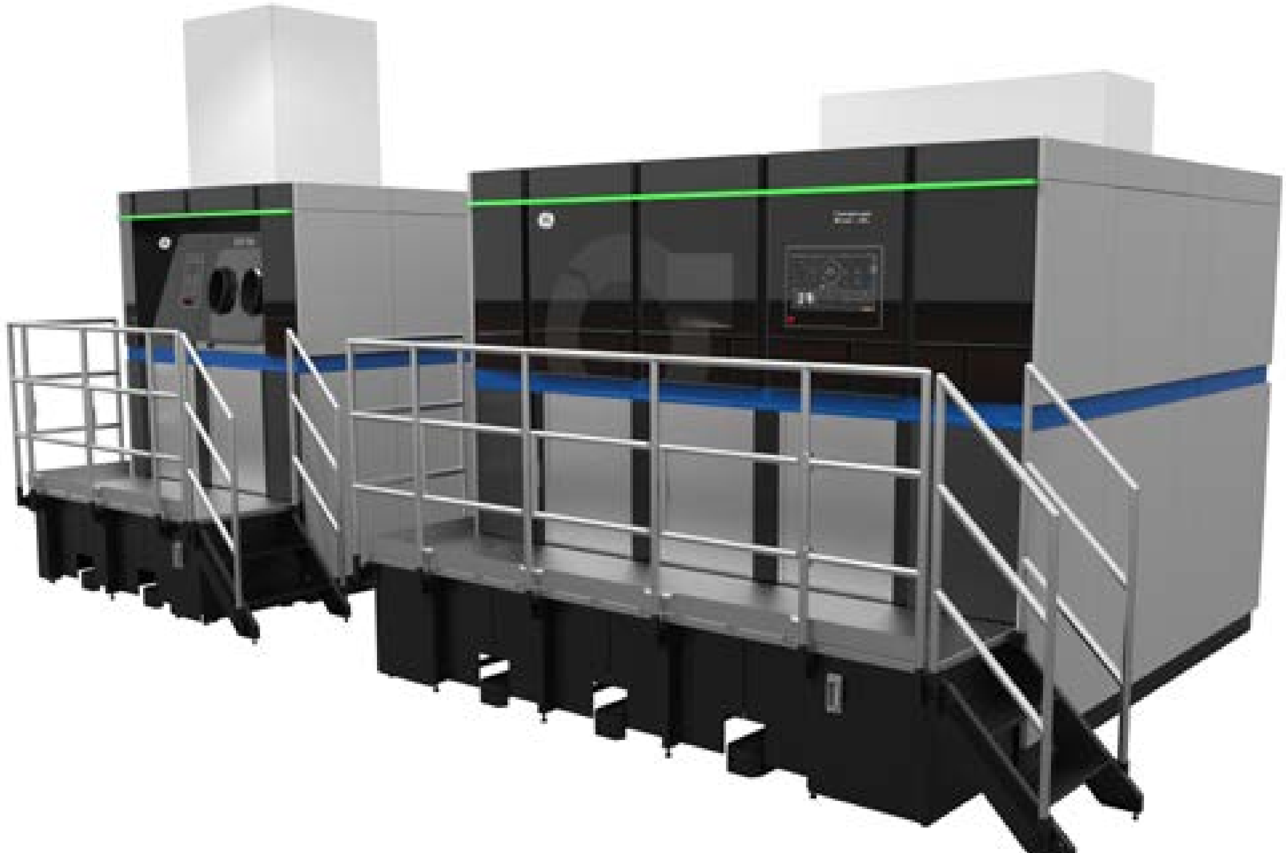
Layer thickness: DMLM systems melt thin layers of powder as thick as 50 microns or more. After each layer solidifies, the printer lowers the build plate and coats the build with the new layer of powder. When done correctly, this produces parts with uniform geometry and microstructure whose properties resemble those of wrought metals. Micron variations in thickness alter the amount of laser energy reaching the powders, changing the material properties of the final part. Since each small change is multiplied by several layers, even small changes in layer height will cause the print process to fail.

We have addressed each of these and other CTQs, ensuring that each one could meet the specifications necessary to produce high-quality parts. We then integrated them into the final M2 printer and double-checked to ensure they continued to hit their marks on a system level.

Our M2 Series 5 printers have been proven by GE Aviation and other aerospace and medical customers, producing hundreds of thousands of parts in industrial environments. Because we are intimately involved in supporting these machines, we have learned a great deal about their performance over time.

Improvements

This experience is the foundation upon which we have built our new M Line system—but only the foundation. Although the M Line builds on M2's subsystems, there are some significant differences. Take, for example, airflow. The M Line's build plate is twice as wide as the M2's. To achieve the same consistent air speed and laminar flow, significant reengineering was required.



The M Line is, quite simply, a mature, proven technology that manufacturers can rely on to scale, by delivering repeatedly debit-free stitching quality at highest stability: this is the future of industrialized additive manufacturing.

We also had to rethink the trade-offs between the various components. Take, for example, the laser system. The M Line uses four 400 W lasers, compared with up to two 400 W lasers configuration in the M2, and generates far more heat. That heat causes the mirrors to deform slightly, reducing their ability to direct the laser beam precisely. We attacked that problem by not only improving our mirror cooling system, but also by cooling the mirror frame and housing. We also respecified the construction of these components to use materials with lower thermal expansion coefficients to minimize their dimensional variation when heated.

We also wanted to improve the M Line's control over material properties even further. We were already using very high-quality lasers, and further improvements would have been extremely costly. Instead, we invested in contour countermeasures via special stitching algorithms, so we improved material properties just as much as if we had invested in a more precise laser and made the process very stable and robust.

This is especially important when building large parts, where M Line's four lasers work together to create a single monolithic structure. Typically, the point where two lasers meet while printing a single part creates a seam. This edge is often strong enough to withstand static loads. Under dynamic loads, however, the interface must be completely homogenous, or it will concentrate stress and lead to failures. The M Line's improved laser cooling and stitching algorithms ensure the microstructural uniformity needed to handle the dynamic loads generated in aerospace applications.

Proof

While improving critical-to-quality subsystems was important, we wanted to go beyond the generation-to-generation advances most competitive metal laser printer manufacturers undertake periodically. Instead, we wanted to commercialize a truly industrial-ready printer with unmatched reliability and repeatability from run to run and machine to machine.

To do that, we launched a systematic campaign to test and understand each CTQ and subsystem at a level of detail never attempted before. We tested every measurable variable—more than 2,000 in all—on each CTQ and subsystem to understand what drove its behavior. Using that knowledge, we redesigned those units to control their parameters better than ever before.

Even that was not enough. 3D printers have long struggled with variability. Runs on the same machine would drift and the output from two models of the same machine was not always precisely the same. To improve consistency, we needed to reduce variability. The only way to do that was to ensure that when we measured our CTQs, the data showed a statistically significant narrow range of tolerances. We also paid close attention to how CTQ subsystems interfaced with one another in the final system. This enabled us to create a more stable machine that retains the tight tolerances of its components. That was the only way our customers could count on the M Line to make parts that could withstand the extreme aerospace environment and dynamic forces.

We did not record this data in a vacuum. Instead, we did it while printing increasingly complex parts over one-and-one-half years to make sure our CTQs retained their tight variances over a variety of operating conditions.

We also built parts from a variety of materials and measured their properties, from their dimensions and physical specifications to their homogeneity and the orientation of their microstructure. This way we accrued enough data to validate the M Line's performance statistically.

It is one of the reasons the M Line consistently achieves yields of high-quality parts that manufacturers associate with industrial machinery.

And that, after all, was our goal. We built the M Line to redefine L-PBF printers as a mature industrial technology that could meet the demands of aerospace, medical, and other demanding applications—at scale.

We believe the M Line's consistency makes it more than competitive on a dollar per cubic centimeter of output. It is a machine that excels at printing large, complex components with properties unmatched by other printers, and smaller parts for high-volume applications.

The M Line is, quite simply, a mature, proven technology that manufacturers can rely on to scale by delivering repeatedly debit-free stitching quality, at highest stability: this is the future of industrialized additive manufacturing.