Building Better Machines

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GE Additive

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Real-world additive innovation versus half-baked attempts

By Rene du Cauze de Nazelle, Senior Product Manager, GE Additive

As the popularity of home baking soared during lockdown, making crusty bread, cakes, or perfectly polished macarons appeared so easy on television that many rushed out to buy a fancy new oven.

Some manufacturers embraced metal additive manufacturing with the same enthusiasm. At any trade show, they could see wildly imaginative designs and impossible-to-machine shapes. Companies were inspired and bought expensive metal laser printers. They thought they could simply press the print button and create something wonderful.

Unfortunately, neither baking nor 3D printing works that way. Making the perfect loaf takes more than just a good oven. It also takes the right ingredients and tools. It takes recipes that nail down every detail. And, most of all, it takes someone who understands exactly how to combine everything at exactly the right moment.

The same is true for metal additive manufacturing, though the procedures and equipment are far more complicated than those used to make a cake. Humanity, after all, has been baking since the earliest days of civilization and has thousands of years of experience. Metal additive technology, on the other hand, is only around 30 years old. We are still developing the ingredients, recipes, tools, and knowledge needed to get the most out of this extraordinarily adaptable process. Buying a machine without the right platform of technologies, materials, and knowledge to support it, is unlikely to yield positive and repeatable results.

Still, a good oven—or, in our case, a reliable laser metal printer—still counts. Thanks to real-world innovation, today's metal additive printers, like our M Line system, are evolving rapidly to provide the support, ease-of-use, and even recipes that manufacturers need to turn their ideas into cost-effective parts that add value to their products. This started by rethinking design.

Turning CAD on Its Head

Starting in the 1990s, computer-aided design (CAD) began to sweep through the design world. Today, nearly all engineers rely on sophisticated CAD software for its speed, simplicity, ability to handle design changes, and ease of collaboration.

Yet CAD came with limitations when it came to designing for metal additive manufacturing. This is because most CAD designs inevitably started with defining the X, Y, and Z axes, drawing straight lines to create blocks, and then fleshing out parts built around simple geometries. This design process is well defined and taught at engineering schools. It reflects the type of geometries metal machining can produce.

3D printing turns the CAD rulebook on its head. Now, engineers can take a digital pen and sketch any shape they want. Still, all this freedom raises lots of questions: What happens if I do not draw straight lines, shave off material I am used to seeing to reduce weight, or add protrusions inside a channel to modify the flow of gas moving through it? Can the machine actually print anything I design? Can I meet my specifications repeatably? Can I do all this cost-effectively?

Not surprisingly, these types of questions can cause a certain amount of anxiety, especially when an executive-level manager expects you to answer them. Among engineers who have been sold on the myth that 3D metal printing is easy to do, it might even cause panic.

The truth is, like baking, it takes an ecosystem of tools, ingredients, and recipes—plus a knowledgeable "chef"—to create something that adds value.

This is why support is so important. This might range from a printer that warns if parameters are drifting or software that provides step-by-step recipes to print parts. This type of support enables engineers to start with simpler projects and work their way up to complex components that add value and functionality to their products yet are repeatable and cost-effective to manufacture. Think of it as moving from a simple pound cake to a gravity-defying souffle.

This all starts with selecting the right oven, or in our case, printer.

Building Better Machines

Anyone who takes baking seriously knows that even the best ovens have a lot of variability. Set it for 177 degrees C, but the actual temperature will vary depending on the height of the rack and the depth of the food. A loaf of bread on a bottom rack may never brown properly, while the one on the top might char the crust.

Such variability might be acceptable when making a loaf or two at home, but it is unforgivable when printing high quality metal parts. The M Line system, for example, prints parts using laser powder bed fusion (L-PBF), a process that melts thin (as small as 20 microns) layers of metal powders and fuses into components hundreds or thousands of layers high. The resulting parts are dense, with wrought metal-like properties that are used in aerospace, biomedical implants, and other demanding applications.

L-PBF printers orchestrate the interaction of many complex subsystems, from precision lasers and thermal management to powder handling and advanced software. The goal is to create parts with highly precise physical properties, dimensions, and microstructures with little variation from build-to-build and machine to machine.

To meet this requirement, every layer printed on an M Line system—some as thin as 1/3 of a human hair laid end on end—must be perfect. There is no room for the variability found in even the best commercial ovens.

Yet stability alone is not enough for L-PBF printers to find a niche on the factory floor. Like the M Line, they must also raise their productivity game.

One way to do this is to increase the size of the print chamber. Larger chambers deliver two important advantages. First, they can print more small parts in a single run with potentially lower unit costs.

Second, they can print larger components that consolidate multiple parts into a single build. GE Aviation's new Catalyst advanced turboprop engine, for example, uses 12 large 3D-metal-printed sections to replace an astonishing 855 discrete parts—and all the welding and assembly that would have been required to put them together. In this case, laser printing not only yielded lighter weight and more durable components but did so at a substantial cost savings.

Yet enlarging the print chamber presents new challenges. The larger the chamber, the more difficult it becomes to generate the consistently laminar gas flow over the powder bed needed to produce one perfect layer after another. This can be overcome with improved components, simulations based on lots of data, and iterative engineering.

Still, larger chambers also require more time to build parts, which reduces their productivity. To speed things up, printers add lasers so they can print multiple parts or regions of larger parts simultaneously. Using two lasers raises productivity about 80 percent, but raising that to four lasers boosts productivity only 60 percent further. Over time, the productivity gains from adding additional lasers flatten out and, at some point, the system's complexity and inability to operate all lasers at the same time, far outweighs any productivity gains.

So, consider how this plays out in the M Line's build chamber. The chamber itself measures 500 x 500 x 400 mm, which is four times the area and nearly five times the volume of our M2 Series 5. The M Line also uses four 400-watt lasers and plans to introduce a unit with four 1kW lasers. The lasers, which all run at once, generate a very high thermal load that makes it even more difficult to manage gas flow over such a large volume.

To do this consistently, we launched a program to understand and control thermal load and every other critical-to-quality (CTQ) component and subsystem that went into the M Line printer. This ultimately involved identifying more than 2,000 different CTQ variables and taking multiple measurements of them over time and during an increasingly complex series of builds. We developed control strategies based on this information using statistical methods to minimize build-to-build and machine-to-machine variations. The validation program involved multiple printers and lasted more than 18 months—and it yielded printers that are inherently stable.

Smarter Sensing

Most good bakers understand their oven. They know the oven's hot and cold spots, and they often use precise sensors to measure temperature and humidity so they can achieve the best possible outcome.

Our CTQ program has eliminated the M Line's equivalent of cold and hot spots. In fact, it achieves consistent builds up to the edge of the build plate.

As for sensors, the M Line uses an array of them to boost the system's intelligence and provide valuable feedback to operators. This is an important change from the past, when most 3D metal printers sensed only critical parameters like oxygen, humidity, and thermal load. Operators would track their data to see if they were in or out of spec and adjust the printing process accordingly. This took a lot of time and a skilled workforce.

Today, printers use more sensors and process the data they collect to provide more operator guidance. Take, for example, the M Line's build plate. Additive manufacturing systems print from the bottom up, melting and solidifying one layer after another. After each layer, the printer recoats the part with a fresh layer of metal powder and begins the process again.

The quality of the part depends on the thickness of the layer. If the layers are too thin, the lasers may melt or deform previously printed layers. If the layers are too thick, the lasers may leave behind layers that are not bound uniformly to one another. To measure this, the M Line uses a camera to make sure the recoating step fully covers all previously printed sections of the part. Smart software then compares the image of the build plate superimposed over a second image taken after recoating. If there is a short feed, the machine will alert the operator to redose.

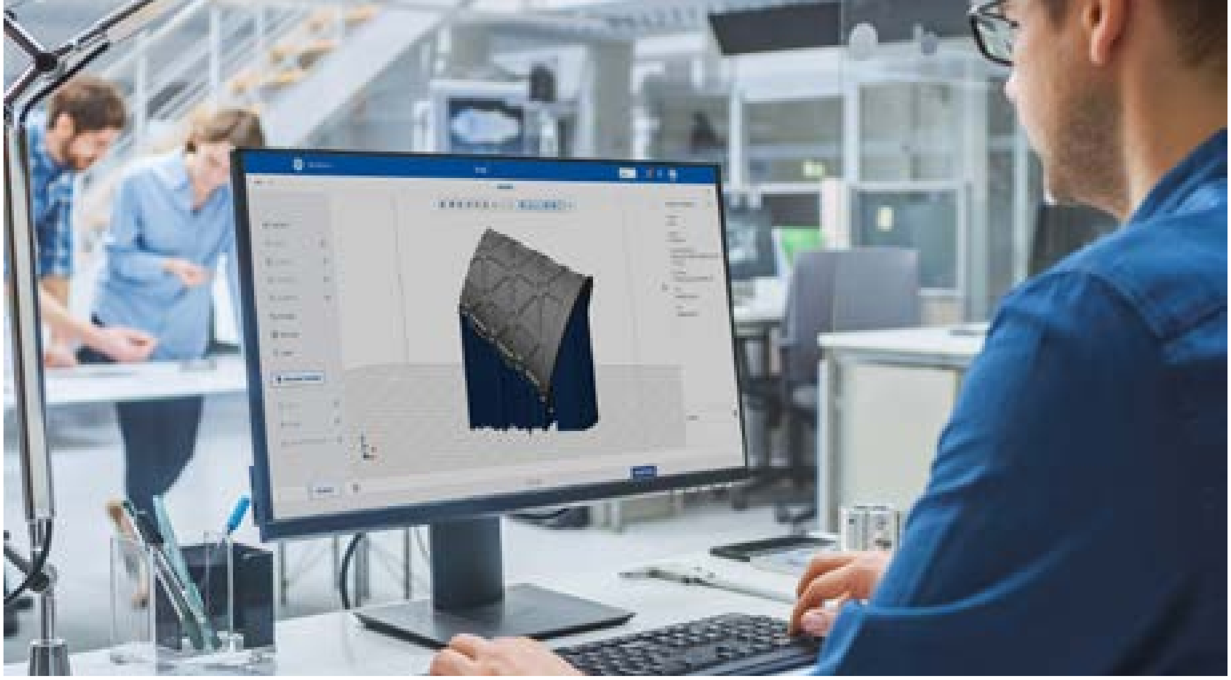
Imaging technology can also monitor the melt pool to ensure the uniformity of the melt pattern. This ensures the laser is delivering the precise amount of power needed. Sometimes, the images can also detect defects.

It is worth noting that M Line's sensors are not just measuring variables. They are using those measurements to make inferences and alert operators when they see a problem. Ultimately, as sensor and control technology evolve and manufacturers grow more familiar with the technology, we will begin to see closed-loop control systems that automatically measure and adjust printing parameters to meet operator goals.

System Support

If additive manufacturing hardware has grown smarter and more dependable, software has become more helpful. CAD software has begun to move into the 3D-printing age. It is not just leaving behind the simple geometric forms of the past, it also provides entirely new functions, like automatic design optimization. It can, for example, remove unnecessary mass while retaining strength, creating parts that often emulate the curved and irregular shapes found in nature.

We recently launched our own software solution, Amp™, to help engineers bridge the gap between their advanced CAD models and metal 3D printing. The cloud-based software simulates print runs to ensure parts are arranged for maximum productivity and ensures that iterative melting/solidification cycles do not cause stress buildups. It also prepares CAD models for metal 3D printing without the need for manual healing and revision and manages multiple workflows so engineers can collaborate with each other as their concepts move from design to printed part.



Another key feature of Amp, especially for manufacturers just getting started in additive production, are its materials-specific "recipes." These are based on GE Additive's extensive characterization of metal powders and blends and our own best practices. Like the recipes in a good cookbook, they provide a list of ingredients and step-by-step directions to everything from machine calibration to print orientation and laser power.

The M Line system has its own internal software, which has also grown more sophisticated. Build Explorer, for example, leverages data from the system's sensors and warns operators if potential issues arise during the build. This software will eventually automate many of the checks operators now perform on their machines before starting a job, while guiding them through steps that must be done manually. The system will also log successful builds so operators can compare them to new builds to make sure the parts in the build chamber are within tolerance.

Software functionality will continue to grow with the release of new versions. Eventually, it will be able to check and automatically calibrate the printer and monitor and control the production process.

The goal of GE Additive's software, as well as its printers and sensors, is to consistently support the M Line operator to produce the highest-quality parts possible. Yet, what about ingredients? We have solutions for that as well. We sell our own line of powders optimized for GE Additive printers and work closely with customers to help characterize the performance of new alloys and powder blends.

We also have a solution based on our vision of how manufacturers will use the M Line in the future. While most factories are likely to start with a single printer or two, we believe they will eventually be running ten or more printers and making thousands of parts.

That calls for a new way to move, sift, recycle, and blend new and recycled powders. Today, this is often done manually. We have developed an automated, industrial-scale system that can extend to an entire bank of machines. It is faster and less labor-intensive than manual-feed systems and produces a very high grade of powder.

We provide this ecosystem of support because additive manufacturing is not easy. But through continuous product improvement, more sensors, and upgraded software, it is getting easier. You may not be baking souffles the first time you start a project, but everything is now in place to get you to that level of excellence in as short a time as your resources allow.