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Get the facts on critical sub-systems

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When it comes to additive manufacturing and printing a functional part, many people are still led to believe that you simply plug in the machine and away you go. But that is not the case, and there is an entire ecosystem behind the machine that comes together to work in unison. It is this coming together of critical sub-systems behind the machine that really enables high part quality consistently.

Understanding how an additive machine works requires a good understanding of fundamental physics. But beyond that, it is the validation of different systems, the collection of large amounts of data, and the interdisciplinary nature of the work that goes on behind the scenes of machine development that really enable an additive machine to be developed to its fullest. Mack Redding, Engineering Leader - M Line, GE Additive, and Jon Ortner, Senior Manufacturing Engineer, GE Additive, discuss the role that the different critical sub-systems play in additive to ensure that the machines are designed to be as reliable as possible.

Q: How do we define critical sub-systems and what are they?
One way to define which sub-systems are critical (and which are not) is by leveraging years of experience using the machines. Teams across GE are not just building additive machines and systems, but our businesses are also using them on a regular basis. This has given us a deep insight into which sub-systems affect the quality of the parts. There are some obvious areas—such as z-axis, recoater and optics—that were identified early on, and you really need those three to work together to get a high part quality.

There are also less obvious sub-systems—including the gas flow, software and parameter sets—that have now been defined as a part of the critical sub-systems but are not a part of the machine itself. These three areas also need to work closely together, because you need to ensure that you get a good gas flow, your software is controlling all the other systems together properly and that you're thermally controlling the process via the thermal control sub-system. You can design the other sub-systems to get a good part quality, but you need that thermal control on top to make sure all the critical sub-systems are working together as they should.

Beyond having years of experience, if you can understand the fundamental physics of the solidification process of the material and what you need to enable that, then you can define which sub-systems are critical. The years of knowledge that you gain are based on a good understanding of the fundamental physics of the problems, and this in turn translates to better understanding the sub-system design and sub-system control.

Q: How do we ensure that we have the correct machine design for each of those critical sub-systems?

When you understand the physics of what is going on, you can better leverage all the tools you have at your disposal. For example, we took this approach to make sure that our gas flow is consistent across the full platform and the complete build height. Before we went and produced the M Line, for example, we undertook a considerable amount of computational modeling of the gas flow. We then modified the machine and design space multiple times, so we really optimized the inlet/outlet design and the shape of the process chamber to obtain a good physics-based gas flow system design. Once we had a good design of the gas flow, we tested it on a test rig and verified the models before we integrated and tested on a full machine.

Computational fluid dynamics (CFD) modeling allows us to conceptualize different ideas quickly about how we want the gas flow to look, which for us, is avoiding any recirculation zones in the process chamber and achieving a high-speed flow across the top of the powder bed. It also goes beyond this, as well, into regulation validation, sub-system validation and full machine validation, as well as the validation of third-party suppliers' components. All the components we use are validated in both our new machine validation process and in the production process of every machine. We focus on designing the right machine to ISO and ANSI standards, even if it might take a little bit longer.

Q: How do you verify that the machine is within those specifications?

At the end of the whole process. You perform your initial modeling design and that determines how you will build your test rig. You then test the sub-systems and the modules, and you test the z-axis and recoater by themselves. This is the first step for collecting the data to show that the sub-system design is what it's expected to be. After that you move onto validating the full system.

We learned a lot from the M2 machine and took a learning-based approach to the M Line. We made sure that we consistently tracked all the critical measurements from all the critical sub-systems over a defined test plan. The test plan lasted a year and we tested multiple machines. This resulted in over 9.3 million data points, which allowed us to adopt a Six Sigma-driven approach when checking our capability limits.

We perform due diligence across the validation and testing protocols, and this continues long after a product is launched. We also test every machine before it leaves the factory. Once it's in the field, there are elements that are re-verified as part of the installation process.

Q: How do you verify the corner case of the sub-systems when they're at the edge of their limits?

It is something that you do within the general testing to make sure that the machine is within specification. There is always going to be some degree of manufacturing variability, and there is the potential that all your sub-systems are going to be at the edge of what is acceptable. So, we ensure that even when all the sub-systems are at the worst-case scenario, users will still be able to get good results.

One of the main ways this is achieved is during the parameter development process. When we develop the parameters (be it spot size, laser speed or laser power), we not only develop them at nominal conditions, but we also test at boundaries outside of the ideal conditions. So, we check the parameters at increased and decreased spot sizes, various layer thicknesses and various gas flows. When we develop a parameter set, we want to

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make sure that it is still stable, near a boundary edge of the machine, and it can withstand the variations that the machine could throw at it because of manufacturing tolerances.

Q: So, after all this, are the results worth it?
Yes. It's a lot of work to do the due diligence up front, but then we saw from those 9.3 million data points that you could put two machines next to each other and make them do the same print and get the same high-quality results. Many of the test engineers' comment on the quality of the parts that come out of the machines as well as the reliability from machine to machine and build to build on the same machine.

For multi-laser machines like the M Line, we're seeing great stitched regions. With all the sub-systems working together as we've designed them, coupled with the stability of that thermal system and good parameters, we're getting extremely high-quality material results and geometry results in that stitched region, and in single laser results. That quality is worth the effort we put in. The ability to see the quality parts that we can do on the M2, and then seeing that level of equivalency or better on the larger format size, is something that you don't see on other larger formats on the market. The M Line has already been a success with our early customers, such as Erofio. They now have the ability to deploy their system quickly and drive production outcomes, thanks to the validation process in place. Erofio has already been able to do great production work with their 500 builds. They've been able to come up to speed without any significant challenges or the need to contact the services/engineering teams for support. This is where the proof is, and it is worth it.

Q: What are you and the team most proud of?
All the leaders of the critical sub-systems and ourselves agree that the ability to get a beautiful part as the end product and the interdisciplinary approach at GE Additive are the two things that we are most proud of. The work we do is possible only because of the interdisciplinary approach across the sub-systems and with teamwork across all functions of our business. The results we get are not achieved by just obtaining a good z-axis. You do this by making sure that your software, parameters and machine all work together with the customer in mind.

Another proud moment is the response that we've heard from our colleagues at GE Aviation. GE Aviation has experience in running different large-format machines and the response that we received about the M Line's ability to produce high-quality parts on the first try has been excellent. The initial thought was that some of their parts couldn't be printed at all, never mind to such a high specification. Beyond aerospace, our work with Erofio is another source of pride. We were able to transfer a parameter set from the M2 Series 5 onto the M Line relatively easily—which is what we designed the machine to do.

Overall Outlook

Additive technologies are rooted in the fundamental physics of the process, regardless of whether the method is laser-based, electron beam-based or binder jet. The ability to understand the physics behind the process enables us to control the manufacturing environment of the print, including controlling the machine over time (between calibrations) and determining which sub-systems are critical for designing a machine that consistently produces high-quality parts.

The validation of the machine, its processes and the sub-systems in use doesn't end with the design. Machines undergo continuous testing and validations, allowing us to make more iterations to machines, as well take our learnings to continuously improve and create better machines. The validation of our machines continues once they are out in the field, and we use this constant flow of data to build the next generation of additive machines.

If you'd like to find out more about how our different sub-system teams work together to deliver results to our customers, or how the M Line can support you in scaling up your manufacturing processes, get in touch.