2022
CASE STUDY

A High-Speed Look at Additive Manufacturing

How a Phantom high-speed camera enabled researchers to better understand the laser-matter interaction in additive manufacturing processes.

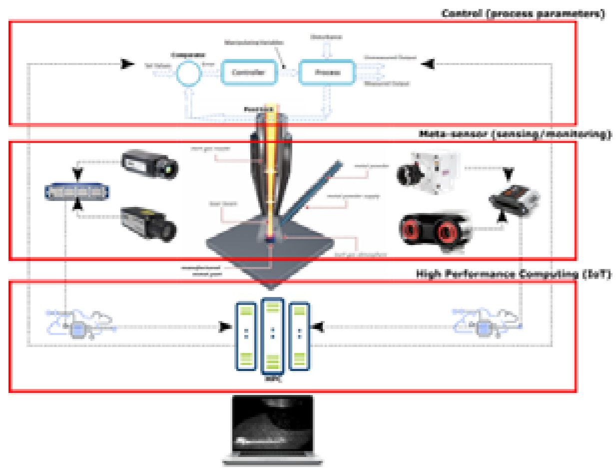
According to Dr. Ángel Iván García Moreno, additive manufacturing is currently one of the most popular trends in manufacturing. It enables the creation of three-dimensional objects based on CAD designs, and it finds applications in many industries — from medicine to aerospace. Yet despite its popularity, Dr. García-Moreno admits there are still several technological barriers that must be addressed to understand the process. "Our research group is working on solving several of these challenges," he says.

When it comes to additive manufacturing, Dr. García-Moreno is an expert. He received his doctorate in advanced technology from the Research Center for Applied Science and Advanced Technology (CICATA) in Mexico, and he is currently a researcher at the Center for Engineering and Industrial Development (CIDESI). He also serves as an R&D coordinator and member of the National Research System of Mexico.

With a focus on direct energy deposition technologies, Dr. García-Moreno's work includes the study of laser-matter interaction, which helps model the conduction, convection and radiation phenomena that occur in additive manufacturing processes. "We're looking to better understand the influence of certain manufacturing parameters — the laser power, beam diameter, manufacturing pattern and scanning speed, for example — on the physical phenomena associated with the layer-by-layer deposition process," Dr. García-Moreno explains.

THE ROLE OF PHANTOM IN RECENT EXPERIMENTS

According to Dr. García-Moreno, the National Institute of Standards and Technology (NIST) in its Measurement Science Roadmap for Metal-Based Additive Manufacturing places great importance on the development of monitoring techniques that can assure the quality and repeatability of additive manufacturing processes. Currently, the interaction between the molten pool, powder stream and substrate, along with the influence of their respective properties, are critical in laser metal deposition (LMD) processes, and the study of these interactions can only be performed using advanced sensors capable of high-acquisition rates.



An overview of the experimental setup.

Recently, Dr. García-Moreno and his research group studied the influence of particle velocity and powder stream dynamics on the LMD process. "Since the behavior of the particles between the nozzle and the substrate influences the particles' ability to absorb energy, it's important to study their dynamics so we can optimize the quality of additively manufactured parts." To this end, he has developed a new adaptive particle image velocimetry (PIV) method that measures the in-flight velocity of metal particles — information that makes it possible to identify the specific convergence zone for the nozzle using the powder stream behavior.

For these experiments, Dr. García-Moreno and his lab used a Phantom VEO 710 high-speed camera, which captured the LMD process at very high frequencies without losing resolution.

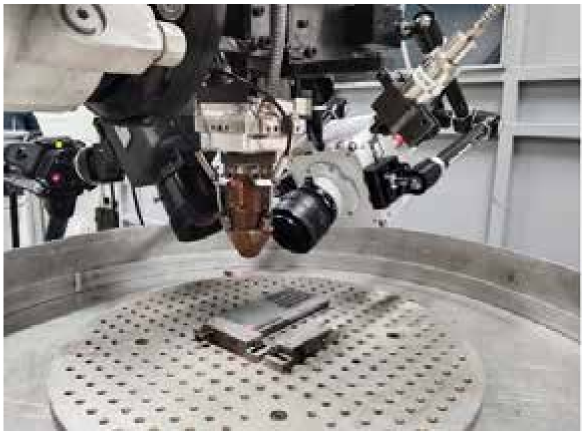
RUGGED, LAB-FRIENDLY AND LIGHTNING FAST

Ensuring high-quality image acquisition, the VEO 710 features a custom 1-megapixel (Mpx), 35-millimeter sensor. It can capture images at 7,400 frames per second (fps) at a full resolution of 1280 x 800, as well as up to 1,000,000 fps at reduced resolutions and with the export-controlled FAST option. In addition to featuring a high data rate of 7 Gpx/second, VEO cameras are designed to perform in extensive shock, vibration and temperature environments to ensure long term reliability.

Using the images captured by the Phantom camera, Dr. García-Moreno and his lab could calculate the velocity of the metal particles.

In addition to the camera, these experiments incorporated many advanced equipment, including a TRUMPF TruDisk 6002 laser source, a ABB IRB 6620-120 robotic arm, a double-hopper Medicoat Flowmotion Duo vibratory powder feeder and a three-port coaxial laser LMD processing nozzle. To monitor the LMD process, the researchers used a multi-sensor monitoring platform consisting of various sensors — cameras and pyrometers — to acquire data in the visible and infrared wavelengths in both 1D and 2D directions.

“This acquisition platform consisted of multiple networked sensors with communication capabilities,” Dr. García-Moreno explains. “The whole net can be thought of as one meta-sensor that can be controlled. In addition, each sensor had certain degrees of freedom that allowed the system to self-calibrate. Depending on the task or query, the monitoring system could control the data acquisition process to acquire the ‘most informative data’ for the specific task.”

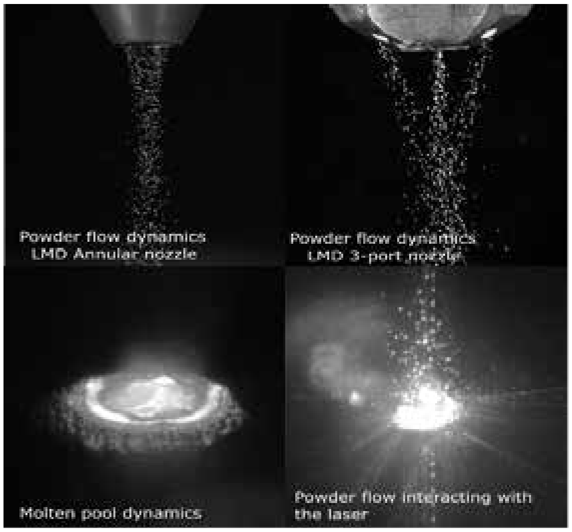

The researchers positioned the Phantom VEO 710 orthogonally to the plane of the phenomena — i.e., the powder flow or deposition process.

Incorporating the Phantom VEO 710 high-speed camera into the “meta-sensor” allowed the researchers to observe phenomena — such as the solid-to-liquid-to-solid state changes of the raw material, as well as the speed of the metallic particles — occurring at high speeds. The researchers configured the camera to acquire images between 5 and 10 kiloHertz at a 1280 x 720-pixel resolution and with an exposure time of 50 microseconds. In addition, the camera’s Extreme Dynamic Range (EDR) function was critical to observing this type of manufacturing process since, according to Dr. García-Moreno, “the emissivity when melting the raw material saturated the sensor.” By setting the EDR to < 4 microseconds (μs), the team achieved the exposure necessary to capture these additive manufacturing processes with a high level of detail.

BROADENING OUR UNDERSTANDING OF ADDITIVE MANUFACTURING

Thanks to the Phantom VEO 710 camera, Dr. García-Moreno and his team of researchers could better understand the physical phenomenas that occur during the laser-matter interaction in the additive manufacturing process:

- The camera allowed the team to observe the flow of metallic particles from the time they left the nozzle to the time they were melted by the energy source. Using post-processing techniques, the researchers used the images to measure the speed of the particles and their direction. They found that the particles reached speeds up to 20 meters per second over only 16 millimeters.
- The camera allowed the researchers to observe the surface flows of the molten pool to study possible segregations that occur in the deposit, as well as to predict defects — pores, for example — in the components manufactured or repaired by LMD. The camera also let them measure the geometric characteristics of the molten pool.
- The camera helped the researchers characterize the state changes of matter — e.g., solid-liquid-solid — and study the impact of process parameters on the mechanical properties of manufactured components.



The interaction between the molten pool, powder stream and substrate during LMD processes can only be studied using cameras with high-acquisition rates.

ENABLING REAL-TIME PART INSPECTION

The sensors and controls used in the lab's monitoring platform are poised to improve the performance of the fabrication environment in real time. "These newly developed image processing and non-destructive evaluation techniques allow us to optimize both in-situ and post-process part inspection," Dr. García-Moreno says. "For example, the ability to monitor part geometry layer by layer lets us validate parts in real time, allowing us to mitigate any distortions and residual stress in the parts."

By bringing the lab's knowledge into production environments, along with on-site measurement capabilities, additive manufacturers can evaluate key process parameters in a way that optimizes performance and achieves part-to-part reproducibility.

Looking ahead, Dr. García-Moreno plans to use the Phantom VEO 710 camera for additional projects at CIDESI. "For example, I'm interested in measuring the frequency of the ripples in the molten pool and correlating them with the formation of defects," he says. Also of interest to him is measuring and analyzing the segregation of certain materials during the deposition of metal matrix composites (MMC) — both micro- and nano-sized — particularly, Inconel 718 + Al2O3 and Stellite + WC12Co.

"I'm also considering extending the current scope of my work to other available additive manufacturing technologies like powder bed fusion, wire arc additive manufacturing and electron beam melting."

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A PIONEER IN ADDITIVE MANUFACTURING RESEARCH

Dr. García-Moreno has developed several techniques based on high-speed and infrared image processing to monitor and extract the thermal and geometric characteristics of the additive manufacturing process — particularly, the molten pool — in real-time. He has even proposed a new superpixels technique to reduce the dimensionality of images and facilitate segmentation and tracking tasks. This algorithm is called gravitational superpixels.

In addition, Dr. García-Moreno has developed new software applications for use in micrograph processing tasks acquired by scanning electron microscopy (SEM) and field emission scanning electron microscopy (FESEM). One example is the segmentation and classification of defects — like pores and cracks — in additively manufactured components. These segmentation tasks are based on novel image processing techniques developed in Dr. García-Moreno's research group, and the classification tasks implement machine learning techniques like self-organizing maps (SOM) and random forest.