Process Monitoring in Additive Manufacturing

High-speed imaging paves the way for optimization

For powder-based additive manufacturing processes, the path to series production is already mapped out. The processes are being optimized, continuously. Therefore, for example, the laser-induced melting process of the powder is monitored and closely examined. Digital high-speed cameras provide the necessary image data for this.

Already today, many industries working with prototypes or samples benefit from additive manufacturing processes such as 3D metal printing. However, for use in series production, the high acquisition system costs still represent an entry barrier. Industries that use this process for series production are, therefore, still producing small quantities or at high prices. These often involve complex structures with low weight and high strength, which are increasingly required by the aerospace industry, as well as in medical technology or racing.

Additive Manufacturing and 3D-Printing

The production of a workpiece by additive manufacturing, e.g. through industrial 3D printing, allows for completely new product designs. In a single operation, it is possible to create structures with a high degree of geometrical freedom that would otherwise have to be assembled from several individual workpieces. The process offers great advantages over subtractive material processing or casting processes.

For the 3D printing process, a workpiece is generated on the computer using CAD and is then optimized for printing. Based on the generated print data, the workpiece is then created in the build space of the printer from layer-by-layer laser melting using a powdery material. The powder is applied in thin layers, which are smoothed to the set layer thickness between 10 and approx. 100 micrometers by using a kind of doctor blade. After the printing, the workpiece is cleaned, removed from the building platform and, if necessary, reworked.

Mostly metals or metal alloys – ranging from stainless steel, aluminum, and titanium to precious metals such as gold – are processed as powdery pressure media. This essentially determines the properties of the product and represents a cost-intensive element of the manufacturing process.

The Printing Process and its Optimization

Standard industrial CW lasers (continuous wave lasers) are used for locally precise melting of the powder, with laser beams being controlled by powerful galvanometer scanners. The type and quality of the exposure, achieved by the laser beam and the resulting melting of the powder, have a major influence on the properties of the workpiece, such as its density and surface quality.

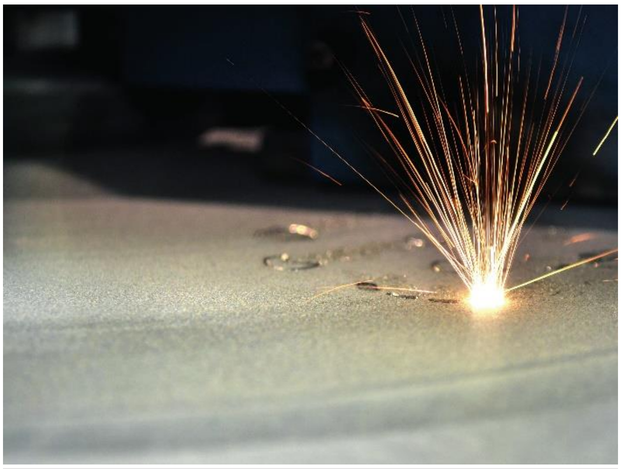

Fig. 1: The lasers performance, focus and speed affect the quality of the work piece.

The control parameters of the laser also affect the setup speed during 3D printing. Optimized process monitoring and control at the melting point can, therefore, have a positive influence on the quality of the process and the product. For this reason, scientists like Tobias Kolb, Chair of Photonic Technologies of Friedrich-Alexander University in Erlangen-Nuremberg, Germany, devote their attention to these processes, which take place in rapid succession and in the tightest of spaces.

“As part of our research project, we use coaxial process monitoring to investigate the thermal radiation generated when melting the powder.”

Here, Kolb describes in one sentence what is, in reality, a complex undertaking. In addition to the complex theoretical background that needs to be mastered, the instrumental use in the laboratory is considerable. There, coaxially integrated high-speed cameras capture the thermal radiation emitted during the melting of the powder by using the optics of the laser. “With these high-speed cameras we obtain a high temporal and spatial resolution and can draw conclusions about process fluctuations, surface roughness in the process or splashes in the powder bed,” explains Tobias Kolb.

The studies are conducted by using CMOS cameras of the type Eo*Sens*® CL from MIKROTRON. They allow for the retrieving of information on the size and shape of the weld pool and on the intensity distribution of the thermal radiation. In the optical system through which the process is observed, there is a dichroic mirror that transmits thermal radiation at a wavelength range of 700 to 950 nanometers to the camera sensor.

Since the process needs a minimum of 500 mm/sec scanning speed to over 1,000 mm/sec, a recording frequency of more than 10 kHz is necessary. This is the only way to achieve the required high spatial resolution. Tobias Kolb describes the particular requirements concerning the cameras as follows: “To obtain a resolution in the order of magnitude of the weld pool (ca. 100 micrometers), a recording frequency of 10–15 kHz is required. “With a macro-optic, we focus on the weld pool and observe the process with the sensor’s recording area reduced to 100 x 100 pixels in order to achieve this high recording frequency.”

The result is an enormous data volume providing information about the weld pool. This data volume must be processed in the shortest possible time. Therefore, the signals delivered by the image sensor are pre-evaluated with FPGA chips (FPGA=Field Programmable Gate Array). A vector is generated from each camera image, which describes the properties of the image. This information is assigned to an exact spatial position based on the data from the scanner system. From this, images of the thermal radiation are generated layer by layer, before being analyzed.

"We are working on the further development of an image processing software to evaluate this data," adds Tobias Kolb. "In the future, this could result in a controlled process, where defects can be detected during printing and then compensated for in the subsequent layers through laser polishing or other methods."

Future Prospects

Modern high-speed cameras from MIKROTRON can deliver what is needed for optimized process analysis in production methods, such as Selective Laser Melting (SLM), Direct Metal Laser Sintering (DMLS) or Selective Laser Sintering (SLS). Thanks to the rapid process analysis, other laser applications, such as laser welding, soldering and drilling with lasers – used to manufacture modern products based on innovative technologies and materials – could also be improved in a comparable way.

Workpieces produced with laser-based manufacturing methods are becoming increasingly complex, light and robust. They will soon be indispensable in every automobile and aircraft, as well as in countless other products ranging from medical technology to high-quality consumer goods. In fast and further refined production processes, even faster high-speed cameras, such as the new Eo*Sens*® 1.1 CXP or the new super-fast Eo*Sens*® 1.1 CXP2 from MIKROTRON, will continue to optimize process monitoring and control.

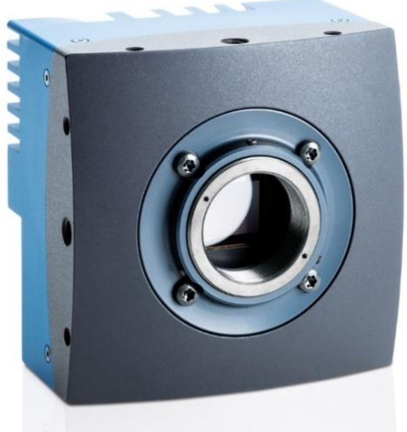

*Fig. 2: **The Camera** EoSens® 1.1 CXP2* offers up to 150.000 pps with high sensitivity and broad dynamic

Both cameras will have a resolution of 1.1 megapixels and a sensitivity of 20 V/lux*s at a light wavelength of 550 nm. With reduced ROI, the Eo*Sens*® 1.1 CXP achieves a frame rate of up to 80,000 fps. The Eo*Sens*® 1.1 CXP2, which will be equipped with a CoaXPress V2.0 interface, will even deliver frame rates of up to 150,000 fps with reduced ROI. These cameras will be available from July 2019.

With the new camera models, the manufacturing experts in the companies are taking a big step toward the goal of improving production processes based on image information that is acquired and evaluated at extreme speed.