MWES: *ADDere* SYSTEM

Utilizing Layered Metal Deposition, for 3D Additive Manufacturing

A Midwest Engineered Systems White-Paper

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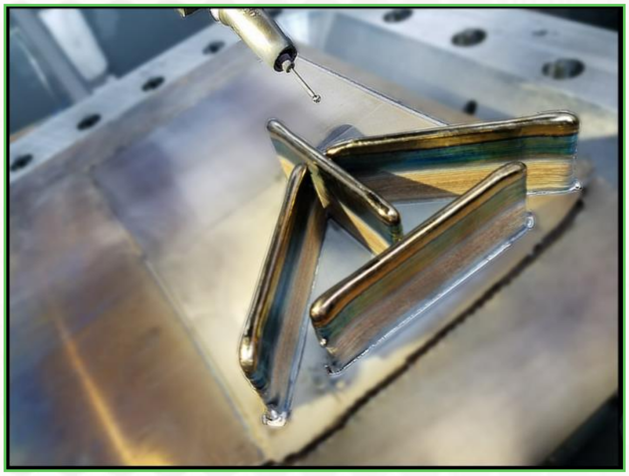
What is Metal Wire Additive Manufacturing?

Additive Manufacturing is the process of building a part from a digital blueprint in the form of a



3D CAD model. Additive Manufacturing (AM), also known as 3D printing, is gaining popularity due to its ability to decrease production times and increase component building capabilities. 3D printing is often associated with plastics, sometimes even food or concrete, whereas Additive Manufacturing (AM) referenced here uses metals to build today's newest products. The ever increasing demand to produce large metal parts, in a quick and efficient manner, is driving the Additive Manufacturing industry to provide systems with high deposition rates and robust, **closed-loop** real-time control systems.

Traditional 3D printing pushes a plastic filament through a heated nozzle, resulting in an experience similar to squeezing toothpaste onto a toothbrush. Heating metal to the point of being completely liquid is impractical, thus Additive Manufacturing uses a delivery system to supply metal in a solid state, which then melts down the metal at the specified location, (known as the melt pool), in a fashion similar to welding. Layers of precisely-located beads of metal are deposited first onto a substrate platform, and then built up by layering on top of one another. Through this process, a part can be manufactured near to the net shape with minimal material and waste and in less time than traditional manufacturing methods. The basic components of metal Additive Manufacturing are a metal delivery system, a motion system, and a heat source.

Metal Delivery System:

Most commonly used metal delivery systems use either metal powder or metal wire. A metal delivery system brings material to the melt pool, a location where the actual melting of the metal takes place. Due to the high temperatures required to melt the metals, a delivery system is a practical way to ensure the consistency of metal in either powder or wire forms.

Metal powder is a metal that has been ground into a fine dust; this form requires significant work to produce. The additional manufacturing step to create the metal powder is costly and introduces additional sourcing challenges. In addition, metal powder requires specialized storage and is associated with health concerns. Metal powder Additive Manufacturing is viewed as a risky endeavor. Some advantages of the metal powder Additive process are:

- Fine Resolution
- Well Suited for Small Parts (up to 6")

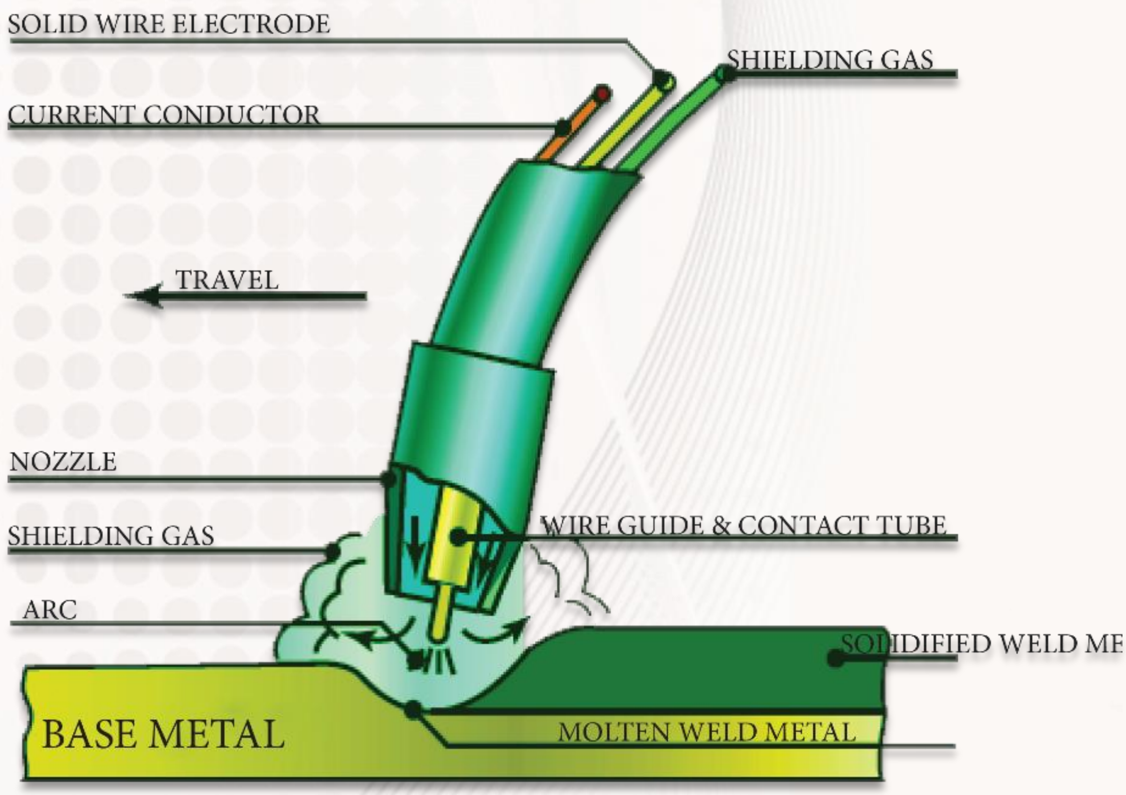
Metal wire is readily available in the form of welding wire. Different compositions and alloys are easily sourced in a multitude of shapes and sizes. Storage and delivery systems have been battle tested over the last century with processes such as, **Gas Metal Arc Welding**. Wire is typically stored on a spool or drum, has a long shelf life, and does not require any costly storage solutions or invite any health concerns. Some advantages of the metal wire Additive process are:

- High Deposition Rate
- Easy to Source
- Readily Available
- Easy to Store
- Less Waste

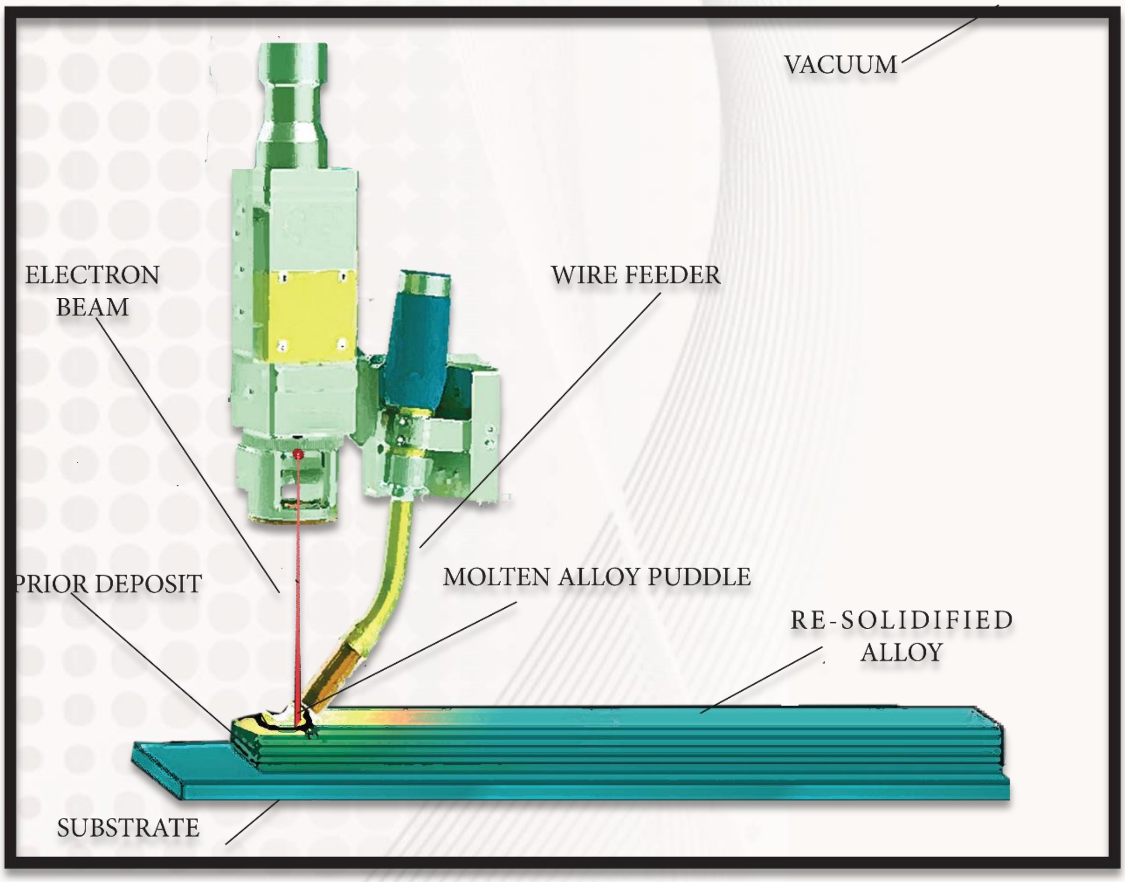
Heat Source

There are three (3) well-known heat sources for bringing the metal to its melting point:

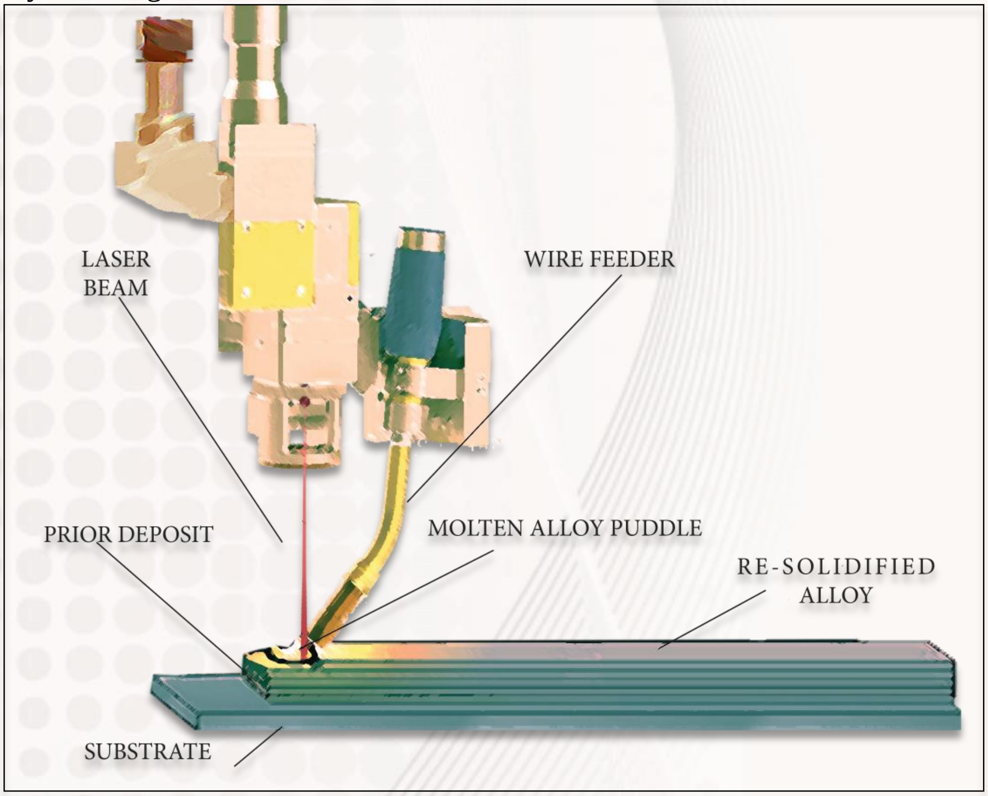
1) *Electricity* as is used in the **Gas Metal Arc Welding** (GMAW) process is one source. Electricity is applied to produce an electrical arc; this arcing produces sufficient heat to melt the metal.



2) An *Electron Beam* heat source works by forming electrons into a fine beam and accelerating them. When they collide with the metal at the melt pool, they transfer their energy in the form of heat. Electron-beam additive manufacturing requires a near perfect vacuum to generate sufficient heat.



3) *Laser Light* heat sources are conceptually similar to electron-beam sources. Photons are formed into a fine beam of light and targeted at the metal. Upon impact, the photons release their energy as heat. However, since lasers use photons rather than electrons, no vacuum chamber is required, and manufacturing can take place at room temperature, greatly reducing the cost of this method.

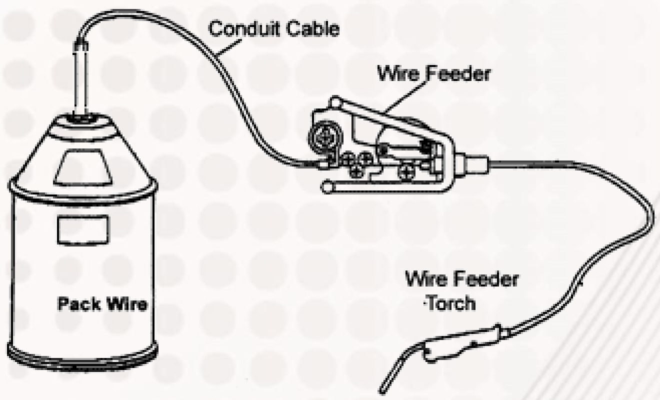


With the combination of heat and metal delivery, the wire can be transformed into a solid part by melting it at a specific location and letting it cool to solidify into a solid block. If this process is dynamically repeated, the basic for the additive manufacturing is created.

Metal Wire delivery System in Additive Manufacturing

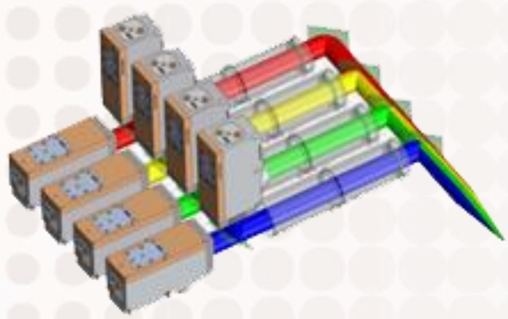
The wire delivery system is designed to be used with common forms of wire packaging such as spools and drums. Different sizes of spools and drums are available. A de-realign system accepts the wire spool and will supplies the wire to the melt pool. A precisely controlled wire delivery system usually has multiple wire drive units what work together in a push-pull operation to provide the correct amount of wire, as this varies throughout the manufacturing process.

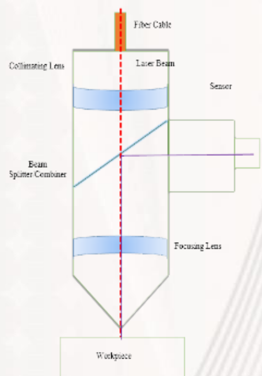
A constant comparison between the requested and the actual wire delivery values is ensured by a closed-loop real-time sensor feedback system for the wire feed speed and direction. Proper wire is required to ensure that there is no cast in the wire upon delivery.



Laser Heat Source System in Additive Manufacturing

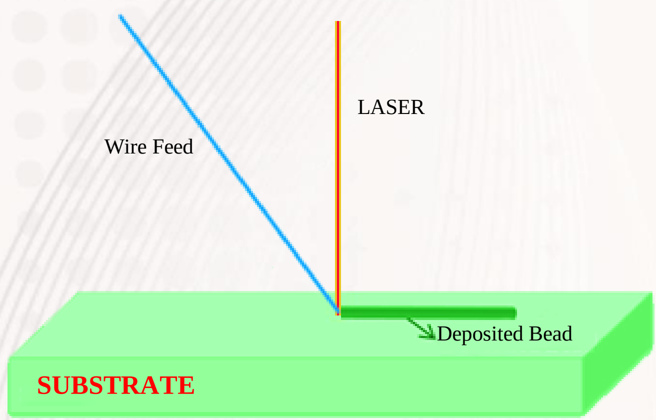
A laser energy source is used in Additive Manufacturing with metal wire. Electrically-powered diode packs generate a high power light beam which is delivered to the molten pool through an optical fiber cable. The raw light beam enters a laser head which shapes the beam for use in the Additive Manufacturing process.





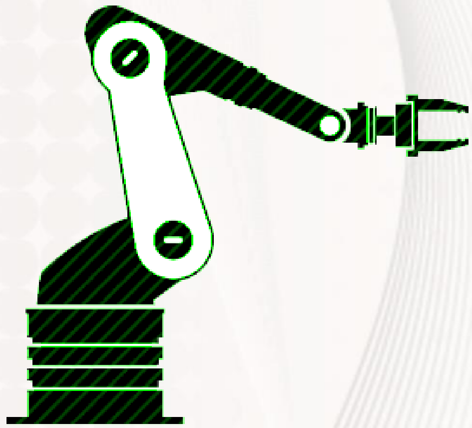
Substrate

The substrate is a pre-manufactured piece of material onto which the additive process deposits material. This platform can be part of the final piece, or can be removed after the Additive Manufacturing process. In some occasions, the substrate can even be composed of a different metal.



Motion System

To facilitate the manufacturing of items more intricate than a block of steel, the heat source and wire feeding system are placed on a motion device. Typically a 6-axis robot is used, enabling the manufacturing of most parts.



Challenges of the Metal Wire Additive Manufacturing

- Consistent Wire Feed Speed and Direction

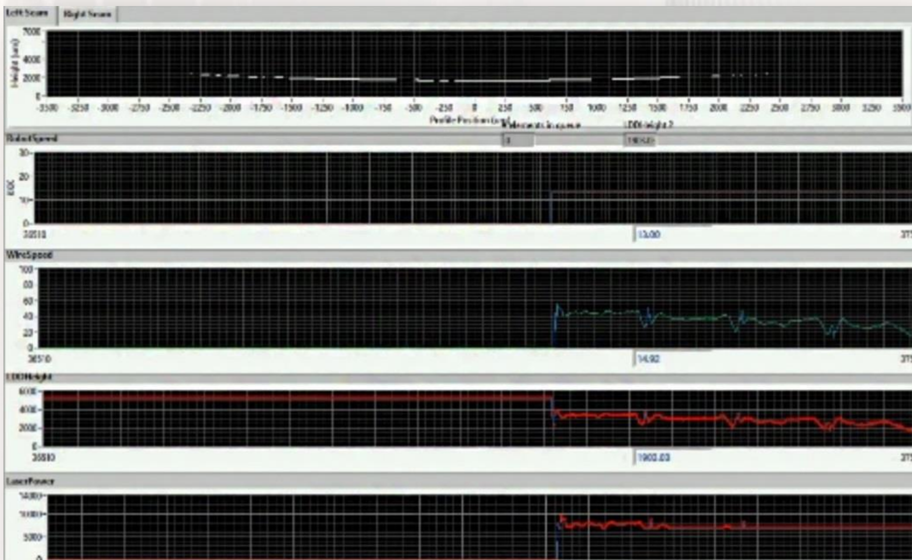
  Closed-loop wire feed system are required to precisely control the amount of wire that needs to be processed. The process of controlling the heat and melt pool are highly dependent on the position and feed rate of the incoming wire material.

- Deposition Rate

  High deposition rates of high quality are certainly desired by any Additive manufacturer. Rates of up to 23 lbs. per hour are demanded for steel. These deposition rates are determining factors for the build time. The weight of the actual part divided by the deposition rate results in average build time. Be prepared to allow additional time for unproductive movements of the motion system.

➢ Process Speed

The process speed is determined by multiple factors. The most important factor is the heat source. A 20kW diode laser power source is used in the MWES ADDere additive manufacturing system. This high power system increases the build speed but brings additional challenges with it, i.e. protective measures need to be implemented to protect humans and to prevent the machine from thermal and reflective characteristics of beam.



To further increase the deposition rate, even more power is required. This additional power is supplied by utilizing the hot wire process. The hot wire process will preheat the metal wire to a temperature where it has a buttery consistency but still maintains its form. Pre-heating the wire means less laser energy is needed and the laser can move faster. A 500 amp hot wire power source delivers the preheat power.

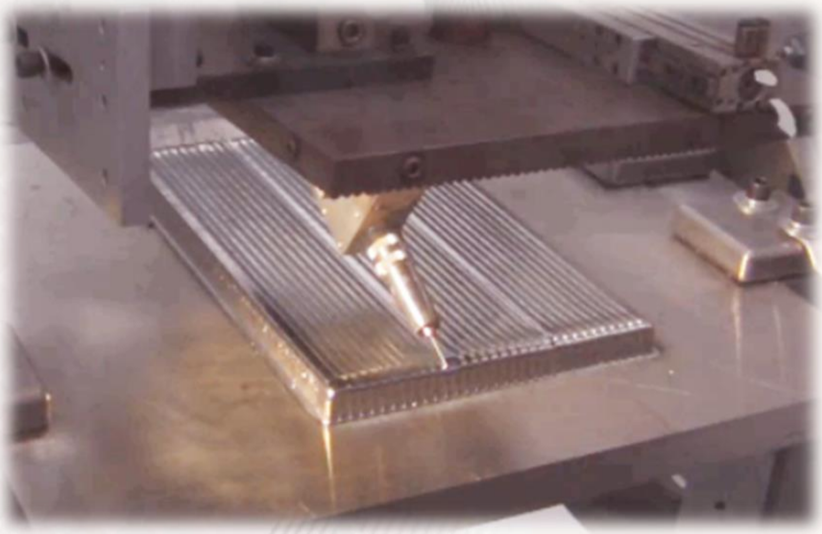
➢ Energy Input

Due to the extreme energy input from the combined system, preventions must be installed to focus the energy where it is needed and to reduce the stray energy where it is undesirable. This can be accomplished through multiple cooling circuits inside the equipment as well as actively cooled heat shields.

Even in locations where the energy is required for the process, heat is an issue that needs to be controlled in order to maintain a stable melt pool and to create a quality part. Heat soak or a 'too cold' substrate material would result in warping and, in extremes, to a self-destroying part due to internal material stress. Therefore it is essential that the heat input be monitored and controlled.

➢ Bead Size

The high deposition laser wire Additive Manufacturing process typically produces a bead size 1.0-2.0 mm high and 6.0-11.0 mm wide. These dimensions determine the resolution of the part being built. In order to enlarge the bead size even more, additional laser power and additional wire can be added.



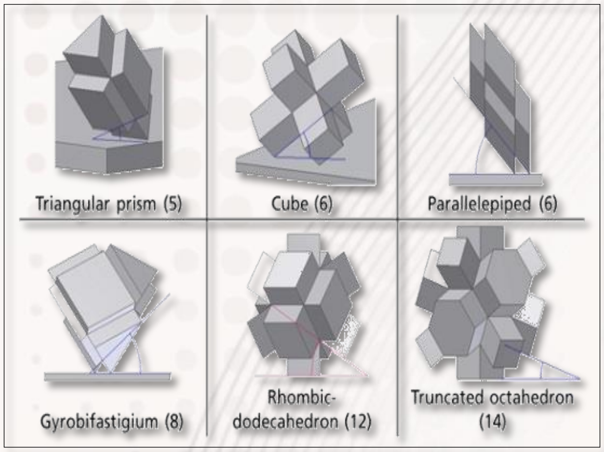
In order to achieve such large bead sizes, the laser beam needs to be focused but still be able to "melt" such a large surface. This is achieved by moving the laser beam independently from the motion system with a servo controlled galvo laser head. The freely programmable galvo allows for different moving pattern of the laser beam. Circles, ovals or figure 8 shapes can be achieved for the different beat sizes.

➢ Part Size

The limiting factors for part size are the motion system and the delivery systems for the heat and metal source. Large parts (+ 6” cube) are well suited for this process, but smaller parts can also be created. Current systems are capable of 20’ wide x 120’ long x 6’ high. However, recognize that ever larger parts and their associated thermal control issues are design specific challenges that require careful consideration in determining the correct build strategy.

➢ Part Geometry and Limitations

Additive manufacturing process limitations need to be considered when designing the part that will be manufactured. The laser wire Additive manufacturing process is suitable for out of position building of up to 15 degrees bead-to-bead and about 3 – 5 degrees in the travel direction. “Overhangs” can be produced by rotating the substrate during the build phase. This manipulation of the substrate requires an additional one or two axis substrate positioning device that needs to be integrated into the motion system of the Additive Manufacturing system.



Complex geometries with multiple planes need to be evaluated prior to the build and strategies need to be developed to build the part in multiple steps. Geometry changes resulting from voids and mounds need to be addressed during the actual build of the part since these vary based on the process and cannot be predetermined.

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➢ Build Consistency

Consistency during the build process is the most important property for Additive Manufacturing because the layers are being built on top of one another and early small errors will grow to large ones by the end of the piece. This consistency is achieved by monitoring the process and adjusting the build parameters like deposition rate, melt pool location, and heat input throughout the build process.

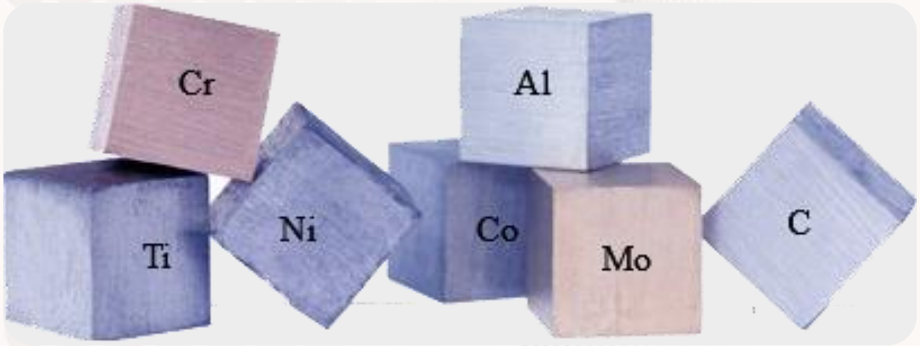
Sensors need to monitor the build process and send the information to a control system which will evaluate the readings, compare them to the planned values and adjust the actual values immediately to eliminate any voids in the build process. This sensor system needs to be a real-time closed-loop system that will communicate not only with the motion system but also with the heat source and the metal delivery system. The monitoring and adjusting of values is performed by a separate control system that controls the entire additive manufacturing system.

➢ Build Quality

With the help of the real-time closed-loop control system, weld defects such as porosity and cold fusion can be detected early and the build process can be interrupted to repair the voids prior to continuing building the part. The grain structure of the metal is also influenced by the heat input into the part and can be maintained by monitoring the heat input and adjusting the build path, sequence, and speed. Build quality data can be stored offline to create a reference digital part should the quality of the manufacturing process be scrutinized in the future.

➢ Materials

Exotic metals like Titanium, duplex stainless steel, Inconel, Cobalt, and others can be used as metals along with more common materials like ferrous steel and aluminum. Additional preventions such as specialized shielding gasses and enclosures need to be taken into account when building with these materials to maintain the structural integrity of the metal used.



Auxiliary System components

➢ Motion Systems

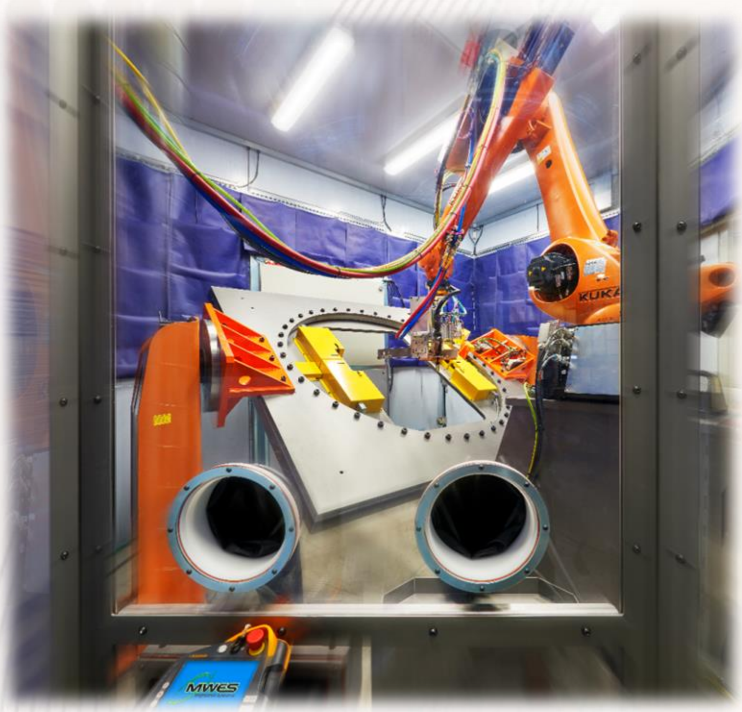
Industrial 6 axis robots are well suited as motion systems for metal Additive Manufacturing systems. The robot needs to be chosen to carry the heavy payload of all the equipment and it is certainly preferred that the robot controller be open source to be able to communicate with the real-time closed-loop process controller. Additional external axis can be implemented to the robot controller to manipulate the substrate and/or increase the travel range of the robot.

➢ Laser Safety Enclosure

High laser power in combination with a six or more axis robot system require a laser safety enclosure. This enclosure needs to be able to prevent stray light or the actual laser beam to exit the enclosure. Access doors need to be monitored and locked while the laser is in operation.

➢ Argon Chamber and Monitoring System

In the case where specialized materials such as Titanium are used as a build material, special attention needs to be paid to the environment. Titanium reacts with the oxygen in the surrounding air when heated to the melting point. This needs to be addressed by building an inert environment around the build process. This argon atmosphere needs to be monitored and maintained until the part is cool enough to not react with the surrounding air. Also, this argon environment is dangerous to people and care needs to be taken to ventilate the area prior to an operator entering the chamber.



➢ Automatic Load System

Especially important for larger systems, an automated loading system for the substrate and unloading system for the build part is introduced. This automated load system allows separating the part from the main build area for the cooling phase while the Additive Manufacturing system builds the next part.

➢ Soot Collection System

When using titanium or aluminum, special care needs to be taken for the removal of the highly explosive soot generated during the melting of the metal. Soot collection systems with specially designed disposal chambers are used for a safe disposal of the soot.

➢ Video Process Surveillance

A process monitoring system will allow the operator to monitor and record the process for archiving and later investigation of the build parameters.

➢ Video Room Surveillance

It is a best practice to install a video surveillance camera system since access to the Additive Manufacturing system is restricted during the build phase.

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