

A Review of Control Methods for the Electron Beam Free Form Fabrication Process

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ABSTRACT: The Electron Beam Free Form Fabrication process is an advanced rapid additive manufacturing process in which the beam is used to melt the material in form of wire towards path of electron beam exposure inside a vacuum chamber. A closed loop control system mechanism which helps in maintaining the distance between the gun and wire with the use of cameras, sensors and measuring devices. This closed loop control system is referred as machine vision system, in which the variation caused by single component in a group of component is sensed by camera and fed to electronic control unit and it actuates the system to alter the position of the variant. The cameras sometimes deviates because of the smog generated while process is going on and hence material accumulates in the substrate due to the improper distance and contact between wire and beam. In order to overcome this closed effective feedback system is being incorporated along with electron gun and wire feeder during the process. Through this, material accumulation on substrate and the separate drive system is avoided. So that uniform layer thickness can be maintained through this controller.

KEYWORDS: Electron gun, Wire feeder.

I.INTRODUCTION

Electron Beam Free Form Fabrication (EBF³) process have been developed by the Researchers at NASA Langley Research Center, a rapid metal deposition process that works efficiently with a variety of weld able alloys The EBF³ process can be used to build a complex, unitized part in a layer-additive fashion, although the more immediate payoff is for use as a manufacturing process for adding details to components fabricated from simplified castings and forgings or plate products. Figure 1 shows a schematic of an EBF³ system. The EBF³ process introduces metal wire feedstock into a molten pool that is created and sustained using a focused electron beam in a vacuum environment (1×10^{-4} torr or lower). Operation in a vacuum ensures a clean process environment and eliminates the need for a consumable shield gas. NASA Langley Research Center has two EBF³ systems, shown in Figures 2 and 3. The ground-based system (Figure 2) is a commercially-available electron beam welder that has been adapted for performing EBF³ process development. This system includes a 42 kW, 60-kV accelerating voltage electron beam gun, a vacuum system, a positioning system, and dual wire feeders capable of independent, simultaneous operation. The two wire feeders may be loaded with either a fine and a coarse wire diameter for different feature definition, or two different alloys to produce components with compositional gradients. Positioning is programmable through six axes of motion (X, Z and tilt on the moving electron beam gun, and Y, tilt and rotate on the positioning table). This electron beam system requires a vacuum on the order of 5×10^{-5} torr and is housed in a vacuum chamber measuring 2.5 m by 2 m by 2.7 m (100 in. by 78 in. by 108 in.).

The second EBF³ system (Figure 3) is portable and comprises a small vacuum chamber, fixed low power electron beam gun, four axis motion control system on the table (X, Y, Z and rotation), single wire feeder, and data

acquisition and control system.[12] This second EBF3 system is housed within a 1 m (38 in.) cubed vacuum chamber with the ability to fabricate a component 30 cm by 30 cm by 15 cm (12 in. by 12 in. by 6 in.) in size. This system is designed for portability so that it can be used in a variety of different locations. It has been successfully demonstrated in flight on an aircraft as well as on the ground in our laboratory. This system is well-suited for fabrication of smaller parts with intricate details due to the finer wire diameters that can be fed as well as higher precision on the positioning system.

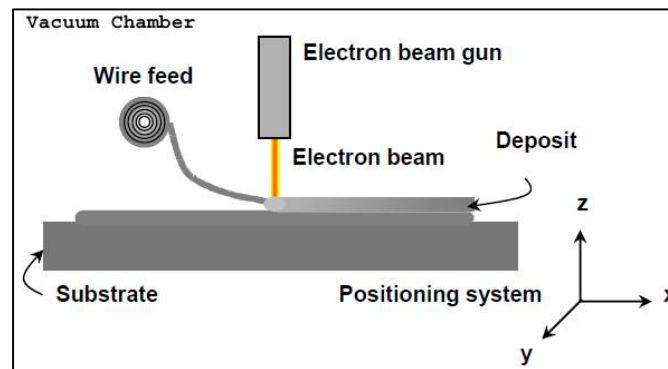


Figure 1. Schematic of electron beam freeform fabrication .[1] (EBF3) system.

II. CAUSES OF THE PROBLEM

Key issues associated with the production of components during space missions depends on microgravity environment on the EBF3 process. In the microgravity environment, body forces of the molten region consists of surface tension and wetting forces. Therefore, molten region cross-sectional may differ during microgravity deposition than during deposition in a 1-g(earth gravity) environment.

This has the effect of governing the topography of the exposed surfaces of the final part by the bead cross section. The surface condition and associated stress concentrations may affect the mechanical properties of the component. Then closed-loop process control schemes may rely on monitoring the shape of the molten portion of the deposited bead. Since the bead shape defers from microgravity than in a 1-g environment.

Initial trials reveal that the process works well in 0-g if the correct distance between the wire and the substrate is maintained. If this distance is too great in 1 -g, small droplets form and fall to the substrate as the gravitational forces exceed the surface tension. In 0-g molten spheres form at the end of the wire and expand as wire continues to feed and melt in the electron beam,.

If the spheres come in contact with the deposit, due to wetting forces the molten sphere deposit to the surface. This results in an uneven deposit height. Vibrations in the equipment have also induced to separate the spheres from the wire before they attach to the substrate, resulting in molten droplets floating loose inside the vacuum chamber.

Maintaining the correct distance between the wire and substrate is more important in 0-g than in 1-g. The system was operated in an open loop mode so that the heights were manually programmed prior to initiating the tests. During the flights the distance between the wire and the substrate was controlled manually by the operator.

III. CONTROL METHOD

Currently, EBF3 processing uses limited closed loop motor control on each of the individual positioning, electron beam, and Wire feeder axes to ensure that each axis is driving to the requested value, e.g., When a signal of “move X axis 4.000 inches at a speed of 10.0 inches/min” is sent to a motor driver, a feedback loop tracks the speed and location to verify that motion occurs as programmed. However, real-time sensing or feedback is lacking on the actual deposition

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process. Anomalies are common, e. g., changing chemistry of the resulting deposit, Wire position control, gradual increase in temperature affecting the size and shape of the molten pool and resulting deposit, over or under build of a target height due to an improperly programmed height, etc. Therefore, process reproducibility issues may result, along With difficulty in certifying EBF3 -fabricated components.

IV. EXISTING CONTROL METHODS

Feed Forward

Here the information only flows forward during the build process, there is no feedback. Figure 8 illustrates the steps used in the process. First, define the part geometry with CAD (Computer Aided Design) software. Second, part definition into commands to build layers in the additive process by CAM (Computer Aided Manufacturing) software. Third, electron beam control parameters into the CAM file by EBP(Electron Beam Process)step. Fourth, electron beam control parameters and tool path commands are given to CNC (Computer Numeric Control),to produce the part.

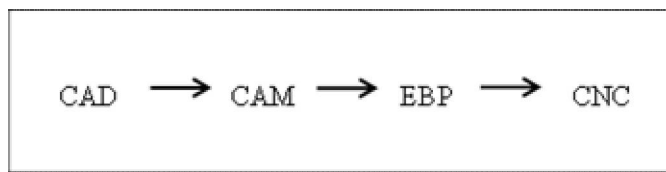


Figure 8. Process flow of feed forward classic approach manufacturing

This open loop deposition with human interference is used to control and build a variety of different shapes with no repeatability and quality control. The feed forward approach helps to improve the repeatability and build quality, but is unable to identify and correct and prevent temporary error and to ensure part accuracy.

Coarse feedback

Coarse feedback feedback is obtained at a broader level. The steps from the classic CAD/CAM/CNC process are used but a feedback path and a comparison functions are added. In this method, the original part drawing is included in the control loop. Figure 9 shows the information flow. With the use of measuring device it compares the two last created layers and sends the feedback to the CAD file before going for CAM path generation and hence with this the path is being corrected in CAM.

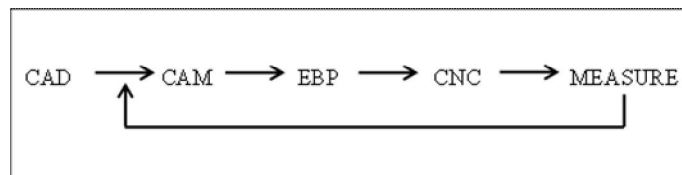


Figure 9. Coarse feedback path to the feed forward approach

Fine feedback

Fine feedback incorporates sensors to monitor and correct the deposition process in real-time. Figure 10 shows the information flow of this method. As with the feed forward and coarse feedback methods, the first to take the CAD drawing, slice into layers with CAM software, and merge the tool path information with EBF3 control parameters. As the electron beam welder is depositing a layer information is immediately send for feedback. An error signal is used to tweak the CNC controller by the measured process features.

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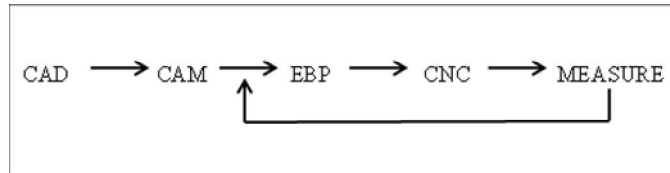


Figure 10. Feedback path of information used to correct the CNC controls in real-time.

Feedback to maintain a relatively constant temperature in the melt pool may affect the repeatability of the EBF3 process from layer to layer .By monitoring temperature can obtain consistent metallurgy.

Proposed method

Input parameters for the EBF3 process include beam power, beam pattern, travel speed, and wire feed rate. Variations in these parameters influence the deposit height and width (geometry), alloy composition (chemistry), residual stresses within the final part, and distortions of the final part.

Electronic control unit

Short for Electronic Control Unit, the ECU is a name given to a device that controls one or more electrical systems in a vehicle. It operates much like the BIOS does in a computer. The ECU provides instructions for various electrical systems, instructing them on what to do and how to operate. Types of ECU include Electronic/engine Control Module (ECM), Powertrain Control Module (PCM), Transmission Control Module (TCM), Brake Control Module (BCM or EBCM), Central Control Module (CCM), Central Timing Module (CTM), General Electronic Module (GEM), Body Control Module (BCM), Suspension Control Module (SCM), control unit, or control module.

Transducer

A transducer is an electronic device that converts energy from one form to another. Common examples include microphones, loudspeakers, thermometers, position and pressure sensors, and antenna. Usually a transducer converts a signal in one form of energy to a signal in another. Types of transducers include sensors, actuators and bidirectional transducers.

Sensors

A sensor acquires a physical quantity and converts it into a signal suitable for processing fig-11 (e.g. optical, electrical, mechanical).Nowadays common sensors convert measurement of physical phenomena into an electrical signal. It is an object whose purpose is to detect events or changes in its environment, and then provide a corresponding output. A sensor is a type of transducer; sensors may provide various types of output, but typically use electrical or optical signals. For example, a thermocouple generates a known voltage (the output) in response to its temperature (the environment). A mercury-in-glass thermometer, similarly, converts measured temperature into expansion and contraction of a liquid, which can be read on a calibrated glass tube.

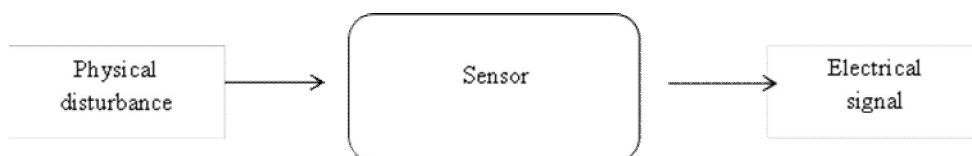


Fig-11 Process of sensor

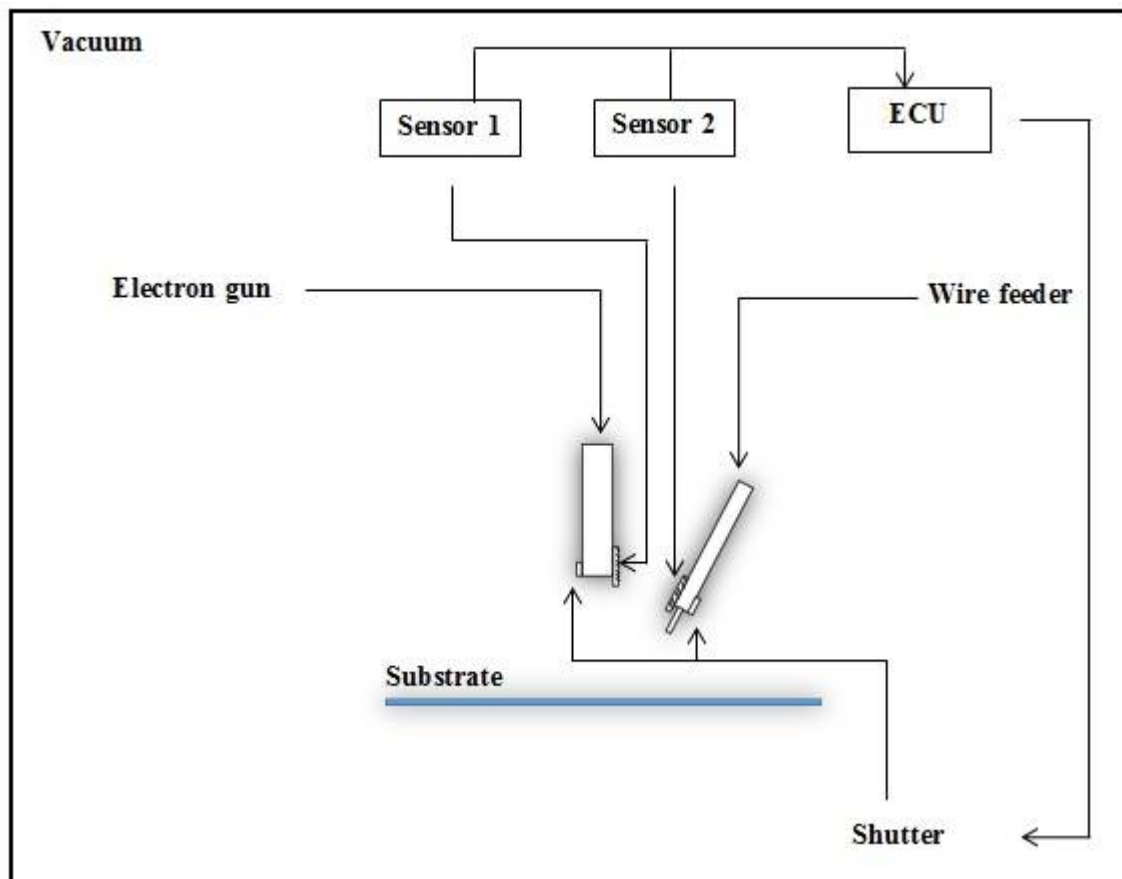


Figure 12. Layout for proposed method

Here the shutter is actuated with the input signal received from the Electronic control unit which gives the input signal by measuring the current scenario of electron gun and the wire feeder and by comparing it with the standard clearance distance of the beam and wire it signals the shutters to actuate independently.

Summary

There are reasons for pursuing sensor interception approach. Serially they represent a development pathway for a simple method from complex methods. The system appears to be a simple developmental step that can be accomplished with off-the-shelf hardware and relatively simple software. This developmental step also adds consideration for repair applications where the topographic features of part are measured and compared the original CAD drawing so that tool paths and EBF3 parameters are issued to add missing material. Selection of successful EBF3 parameters is dependent on work done for open-loop control. Adding fine sensor feedback approach offers the possibility of higher quality control for geometry and chemistry, but with the cost of higher complexity. These components helps in achieving and guiding the input parameters for the EBF3 process include beam power, beam pattern, travel speed, and wire feed rate without any error and failure.

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