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Technologies

NASA's EBF3: The Future of Arc-Net Manufacturing

For reduced lifetime, improved safety, and greater efficiency

Fuentek is developing Commercial Opportunities for Manufacturing Technologies based on NASA's cutting-edge Electron Beam Free Form Fabrication (EBF3) that offers significant performance gains over traditional Computer Numerically Controlled (CNC) machining. NASA's EBF3 system uses a wire-feed design to produce parts that are better than cast and similar to wrought materials while minimizing excess material. Fuentek's Commercial Opportunities for Manufacturing Technologies offer significant benefits to high value-added industries where weight is critical, significantly less tooling than others and includes other cutting-edge technologies such as Automated Process Control and Inert Atmosphere Chamber Operation, and is the expanding cost-saving and enabling additive manufacturing technology.

If you have any questions about the presented Series. For more information about the technology and commercial opportunities, please contact us by phone or e-mail: (616) 240-0327, MSC2200@fuentek.com.

Related technologies:

- Automated Process Control
- Inert Atmosphere Chamber Operation
- Vapor Barrier Vacuum Isolation System

Benefits

- **Lower material costs**: Rivales less material than traditional subtractive manufacturing methods and conventional casting.
- **High strength parts**: Can be produced with properties as high as Ti-6Al-4V in 2014, in standard wire forms, rather than custom cast alloys that are inherently weaker than wrought alloys.
- **Compound material properties**: Allows deposition of multiple alloys to create parts where material chemistry can vary according to functional part requirements (e.g., changing cross-sectional strength or an alloying wire type).
- **Reduced tooling costs**: Unlike casting, EBF3 requires no tooling, and unlike machining, it requires less hardware (carbon vessels, which lowers the cost of operating and provides a safer working environment).
- **Versatile part envelope**: Produces a wide range of part sizes, from a few inches to tens of feet (utilizing recent vacuum chamber improvements).
- **Mobile and portable**: Can be relocated and has been successfully demonstrated on an aircraft C-5 jig that utilizes requiring time-consuming alignment procedures.

Applications

- Medical
  - Implant bone replacement parts
- Automotive and aerospace components
  - Custom and replacement parts
- Rapid prototyping and tooling
  - Near-structural components with high buy-to-fly ratios (such as bulkheads or complex housings)
  - Replacement parts for aging aircraft
- Manufacturing technology transfer to remote locations
  - Military forward bases and facilities
  - Seafaring ships
  - Space stations
  - Final material stations
- Three-dimensional models for new designs
- Rapid prototyping capability
- Mobile deposition and tooling
  - Parting, structural mending, and spot etching and heating

Technology Details

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NASA's innovative Electron Beam Free Form Fabrication (EBF3) system is being developed for the zero-gravity environment of space, offers significant benefits for rapid prototyping and manufacturing here on Earth.

Components currently processed by conventional methods (such as machining from a block) can be produced using EBF3. NASA's EBF3 system is expected than offering lower costs, better advantage of the benefits of a lower manufacturing time (e.g., a wide variety of metal alloys can be used, and complex geometries can be produced without expensive tooling, and parts can be produced in fewer systems (e.g., lengthy casting parts, part size limited by chamber dimensions).

Competitive offering a Electron fabrication will find that EBF3's need for lower accelerating voltages (typically 20kV or less) eliminates many of the safety and planning requirements necessary with higher power (typically 30-150 kV) systems that are derived from a Electron welding technologies.

How it works

The Core Technology

The core of the EBF3 system is an electron-beam gun, wire feeder, and positioning system enclosed in an aluminum vacuum chamber. Electrons are produced by a tungsten cathode and accelerated by a voltage of 20 kV. The electron beam is focused by an accurately deposited layer by layer according to computer-aided design (CAD) data to fabricate a three-dimensional product part without the need for a die or mold.

Electron beam guns operating at 20 kV can operate at 30-200 kV. NASA's technology can create parts using about 20 kV accelerating voltage. The system can be used in a vacuum chamber or in a wide range of pressures (e.g., Vacuum, atmospheric, underwater, etc.). Operating at 20 kV, as well as advanced and beyond parts may be needed. The size of parts will be dependent upon the size of the system's build envelope, which can be as small as a few inches or tens of feet in each direction.

Unique Enhancements

Since the initial patent in 2000, NASA has developed the following innovations, which can be licensed either with NASA's EBF3 or to other Electron beam systems:

- **Automated Process Control**: Monitors deposition and automatically adjusts the parameters to correct for anomalies, resulting in more consistent deposition of higher quality parts.
- **Inert Beam Deflection Control System**: Uses beam rastering to provide a high level of precision and accuracy while reducing the overall deposition time.
- **Vapor Barrier Vacuum Isolation System**: Eliminates the need for a large vacuum chamber, thereby greatly enlarge, lies process operating envelopes to be used.

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Why it is better

Electron beam welding offers the promise of a nearly unprecedented just-build-envelope. Due to the new-power requirements, the complete cost (all-in-cost) of ownership is 30-50% of the 20 kV-rating of a typical Electron welding system. The deposition cost can be reduced by the cost of a desktop computer, with an artificial cost to provide connection to the required power supply and vacuum pumps. A Electron welding system, with its 150 kV power requirements, requires a dedicated room, positioning equipment, and a vacuum system, and is eventually will be capable of building any size or shape structure.

NASA's EBF3 system is less expensive than other systems. NASA's initial estimate is between $250K. However, a commercialized system is expected to cost between $100K-$150K. Furthermore, the EBF3 is low power design offers significantly reduced operating costs and minimizes the shielding required to comply with radiation safety regulations.

Other advantages of using a Electron welding system include the ability to use a wide range of material compared to other systems. EBF3 uses a full range of wire-feed materials, including titanium, aluminum, and stainless steel. Electron welding is a relatively mature process, and the process parameters are well understood. Electron welding is a relatively mature process, which means technical assistance is far recaptured and reinforced better it can be reused. In addition, parts made with NASA's EBF3 system can be welded to other Electron welding systems, or to conventional welded fabricating.

Because two or more wires can be fed into the system, EBF3 enables the manufacturing of multi-material parts. The system can deposit one wire, then switch to a second wire and continue depositing the second material. This capability can be used to create functionally graded parts. Alternatively, the wires can be fed separately to create layered parts with different compositions. In the case of industrial piping, EBF3 could offer a high-quality alternative to traditional piping (e.g., creating pipelines while allowing manufacturers to better control the composition of the pipeline).

The technology works successfully well with such alloys as Ti-6Al-4V and Ni-22Fe

- Sets optimized for metal, plastic, and brittle ceramics

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Patents

NASA has patented this technology under U.S. Patent No. 7,168,608 and has applied for additional patents.

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Core technology technical specifications

Current build envelope	4 in. x 4 in. x 4 in. (10.16 cm x 10.16 cm x 10.16 cm)
Current build rate	0.5 in. x 0.5 in. x 0.5 in. (1.27 cm x 1.27 cm x 1.27 cm)
Electron beam power	20 kV
Deposition rate	4 cubic in. per hour (65 cubic cm per hour)
Electron positioning accuracy	±0.005 in. (±0.127 mm)
Wire feed	Wire feed system, Electron demonstrated, and experience suggested that minimum of 20 in. (51.27 cm) is not consistently for wire feed system
Calibration	Automatic
Operation	Automatic
Power supply	Max. 20 kV, 120 mA, 2.4 kW
Size	Standard: 15 in. (38.10 cm) wide mounted controls
Chamber system	24 in. x 24 in. x 24 in. (61 cm x 61 cm x 61 cm) Chamber system is 2 in. (5.08 cm) thick
Chamber system is 2 in. (5.08 cm) thick	20 in. (diameter) x 24 in. high (51 cm x 61 cm)
Total system weight	200 lbs. (90 kg)
Process computer	PC, 387 (486DX2 interface
CAD software	Microsoft Windows, Microsoft Windows CAD/CAM (PAM, CATIA, Pro/ENGINEER, Mastercam)
Network	Ethernet, TCP/IP
Certification	Certified operation are seeking aerospace certification

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Frequently asked questions

NASA's EBF3 system operates similar to other wire-feed-based systems where all a power deposition rate (typically 1-6 kW). 20 kV-rating of a typical Electron welding system is 30-50 % of the 20 kV-rating. However, NASA's system wire-feed design and therefore offers the final form of detail. The following provides answers to commonly asked questions regarding how NASA's EBF3 system performs (and, in some cases, how it performs in other systems) in terms of quality, accuracy, cost-down-time, etc.

- Part Quality
- Mechanical Properties
- Residual Stress
- Variety of Metals
- Feature Size and Accuracy
- Building Complex, Intricate Parts
- Tolerances
- Part Build Time
- Power Consumption
- Scalability
- Post-Processing
- Aerospace Certification

Part Quality

What kind of part quality can be expected from the NASA EBF3?

NASA's part quality is better than other electron-beam systems because NASA's system works at a slower deposition rate (typically 4 cubic in. per hour, or 65 cubic cm per hour). Slower deposition rates allow more time for the deposited material to cool. This results in roughness of NASA's first layer deposited, which provides a smoother and better deposition treatment directly after composing the deposition in the a beam chamber. NASA's wire-fed EBF3 system provides a smoother enhanced for the part compared to powder-based systems, which used parts with a rectangular-like finish due to unmelted powder sticking to the sides of the deposit.

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Mechanical Properties

What are the mechanical properties that occur during a weld when using NASA's EBF3?

Tests after standard heat treatments demonstrated that products made using NASA's EBF3 have properties similar to plate products when subjected to equivalent heat treatments. For example, Ti-6Al-4V as deposited using NASA's EBF3 system is similar to a wrought plate of Ti-6Al-4V: ~ultimate tensile strength of 130 ksi, YS: 120 ksi, 850 MPa tensile yield. 120 ksi (825 MPa) tensile ultimate, ~10% total elongation

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Residual Stress

Does NASA's EBF3 system cause any residual stress during electron-beam deposition?

In running the EBF3 system, NASA researchers have encountered residual stresses and distortion in the baseplate. If the baseplate is constrained (i.e., removed during post-processing), stresses and distortion are not an issue—only little stress is transferred to the deposited material itself. However, for baseplates that remain attached to the part, the stress exerts about 0.25 in. (6.35 mm) from the baseplate. Stress-relieving the part after the deposition is the Electron heating parameters as well as the deposition rate. Research is underway to understand and mitigate these stresses.

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Variety of Metals

What metals has NASA deposited using its EBF3 system?

NASA's EBF3 system could be used to deposit the following metals:

Pure Al	
Pure Ti	
2219 Al (5.8% Cu)	Demonstrated in NASA's EBF3
Ti-6Al-4V (~1.0kg/kg)	
316L-V	
Inconel 718	
Pure Cu	NASA has performed a beam-deposition engineering assistance to EBF3
Pure Mo	
Any weldable alloys except magnetic ferrous (iron-based)	Could be used easily in EBF3
Wire of:	
Ag	
Pt	
Pd	

NASA has graded from pure Ni to 22% and from pure Ni to 27% both parallel to and perpendicular to the build plate. The starting material was pure Ni wire and the ending material was Ni-22Fe and Ni-27Fe. Microhardness measurements showed that the deposition could be used to measure the gradient of the deposit without the need for or within the build plate, but the second application requirements.

Since the beam-deposition NASA has not enriched the metal are to be deposited, although NASA does use standard welding wire, and work has been successful. Research is underway to understand the effect of alloying in deposition.

The only materials that have been problematic for NASA's EBF3 system to date are magnetic materials (the beam uses magnetism for beam control, so magnetic ferrous-based alloys are challenging to deposit) and non-weldable alloys such as Tosa aluminum alloys which are sensitive to hot cracking).

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Feature Size and Accuracy

What is the typical feed rate and the deposition rates that pertain to accuracy?

The typical bead size for NASA's EBF3 system is between 0.1 and 0.25 in. (between 2.54 and 6.35 mm) across using wire ranging from 0.0625 in. (1.59 mm) to 0.125 in. (3.18 mm). The typical deposition rate is 4 cubic in. per hour (65 cubic cm per hour). However, the process is scalable, so NASA's system could be used for thicker beads and parts and even created small part and thus a better surface finish and part precision (albeit at a slower deposition rate). The smallest bead size that NASA has demonstrated so far is 0.1 in. (2.54 mm) and the largest bead size that NASA has used (though could be enhanced to where the bead is as narrow as 0.05 in. (1.27 mm) active. (More about "Scalability" is presented below.)

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Building Complex, Intricate Parts

What kind of part detail is possible with NASA's EBF3 system?

NASA's system is more flexible than other electron-beam systems in its ability to build complex near-net shape parts. It works best in a 2.5-dimensional arrangement, where a layer of the part is deposited in the x and y planes then the part is dropped down in a for the z-axis. Parts with walls, such as holes, are best created with the wire-feed system rather than attempting to build the hole directly.

What standoff-supports are required to build intricate parts, such as pores?

Rather than incorporate standoff-supports into the design, NASA's EBF3 system uses a positioning system to orient the part with respect to the deposition head to build it directly. By tilting the deposition head perpendicular to the feature being deposited, overhangs can be built without the need for standoff-supports. Standoff-supports are sometimes needed, which would be an advantage for NASA's EBF3 positioning system.

The parts made using NASA's EBF3 so far have not generalized that were "open" enough to allow access of the beam and wire-feed system to the deposition surface. However, NASA's EBF3 system could be used to build a part with a "cage" around it, which would be straight out, parallel to the deposition surface, and then build the part in the cage as an ingot-like. A small wire-feed unit can be had cylinder down (assuming the positioning system is designed to allow "overhead" access) due to surface tension holding the bead in place.

Can NASA's EBF3 system be used to manufacture custom dental implants?

Yes, NASA's EBF3 system could be used to manufacture custom dental implants. Titanium is a dental implant of choice because it is lighter than other metals and has better strength and better biocompatibility. Furthermore, a small amount of metal alloy is required for the surface of the implant to be porous to promote bone ingrowth. A small wire-feed unit can be had cylinder down (assuming the positioning system is designed to allow "overhead" access) due to surface tension holding the bead in place.

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Power Consumption

What is the wattage?

NASA's patented system uses 200 V three phase power and has a maximum power of 3 kW.

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Scalability

To what extent can NASA's EBF3 system be scaled up?

NASA's EBF3 system can be used to make parts ranging from a few inches/centimeters across to up to tens of feet (several meters) long. restricted only by the size of the vacuum chamber and positioning system. Although some components, such as the wire feeder and the electron beam gun, are fixed in size, the system can be scaled up by increasing the size of the vacuum chamber and positioning of-the-shelf (OTS) components. The e-beam gun does not need to be "up-sized," although fabricating larger pieces requires higher power to achieve higher deposition rates.

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Post-Processing

Tolerance

The following steps are commonly used when making parts with NASA's EBF3 system:

- Tolerance is dictated by beam-bead size ("Feature Size and Accuracy" above) and by the positioning system's resolution/accuracy.