A Hybrid Approach to Accelerate Adoption of Metal 3D Printing

IMTS 2016

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Headquartered in Albuquerque, New Mexico
- New Product Dev. & Adv. Apps. Lab in MSP
- Business Partners in Europe & Asia

3D Printing Focus Since 1997
- LENS® Technology for high value metalworking
- Aerosol Jet® Technology for printed electronics

Full Service Equipment Manufacturer
- Systems, applications, installation, training, service
- Over 200 systems installed in 15 countries

>$35M in Technology & Development
- 35 Patents issued, 50 pending

* LENS is a patented technology developed by Sandia National Labs
* Aerosol Jet is a patented technology developed by Optomec
2 Common Methods for Metal 3D Printing Layers

- **Powder Bed**
  - Part is grown in a bed of powder – powder is laid out first, then the powder is selectively sintered or melted
  - The end result isn’t visible – it is buried in a powder “cake”
  - After processing, the excess powder is removed and the part is revealed
  - Example – Selective Laser Sintering/Melting
  - General features: Can build relatively complex shapes; mechanical properties OK; smaller build volume; cannot repair parts. Requires a flat surface

- **Powder Fed – Directed Energy Deposition (DED)**
  - The material is built up on a part in free space – powder and laser are delivered simultaneously
  - The entire process is visible – powder falls away as you build
  - Examples – LENS Process
  - General features: Mechanical properties good; can build less complex shapes; build volumes larger; good for repair and hybrid manufacturing. Does not require a flat surface
The LENS Metal Powder Fed DED Process

Laser Engineered Net-Shaping (LENS®)

- Powder Fed process
- Developed by Sandia
- Commercialized by Optomec 1998
- Digital input: Scans or CAD model
- Multi-nozzle Powder Delivery
- Metal Powder Melted by Laser
- Layer by layer build
LENS Metal 3D Printing Technology Difference

- Fully Prints Metal 3D Parts or Prints Metal onto 3D Parts
  - Print Structural metals – titanium, steels, superalloys
  - Add material to existing components
  - Industry proven >17 years
  - Excellent mechanical properties, as cast or better

- Provide Value Across the Product Lifecycle
  - Functional prototypes to production
  - Preventative maintenance to part repair
  - Add engineered features to existing parts or shapes

- LENS Open System Approach
  - Fully flexible parameter selection
  - Use commercially available materials
LENS Materials

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In General LENS Produces Fully Dense Materials with Mechanical Properties at Least Equal to or Better than Cast and in some Cases Very Similar to Forged
Factors Driving AM Market Growth

Transformational productivity

**Design**
- Additive: 1 Digital File, 8 Engineers
- Conventional: 300 parts, 60 Engineers

**Manufacturing**
- Additive: 1 Mfg. sources & Inspection Sys., 1 data lake powering PREDIX
- Conventional: 50+ Mfg. sources, 40 data systems

**Services**
- Additive: 1 Repair Source
- Conventional: 5 Repair sources
Metal Additive Manufacturing (AM) Technology Invented > 20 Years Ago
In 2014 ~ 400,000 CNC Metal Working Tools were Sold
In 2014 ~ 800 Metal Additive Manufacturing Machines were Sold

Why So Few?

(1) Source 2015 Wohler’s Report
Barriers to Industry Adoption of Metal 3D Printing

- **High Procurement Cost**
  - Metal AM Systems from $750K to > $1 M

- **Fixed AM System Work Envelope**
  - Ave. work volume ~ 300 mm cubed
  - May Require Development of Custom AM Platform

- **AM Systems Difficult to Learn & Use**
  - Specialized User Interface

- **Slow Build Rates**
  - Based on typical powder-bed build rates (grams/hr)

- **Closed Systems**
  - Materials Available only from System Manufacturer
  - Fixed “Recipe” Processing Parameters

- **Lack of Standards and Controls**
Technical Challenge – Funding Opportunity

Develop A Cost Effective Method to Accelerate Adoption of Metal Additive Manufacturing Technology by US Industry
2014 Proposed Solution – Project Award

Package Optomec Metal Additive Manufacturing Technology into a Modular LENS Print Engine that can be Added to Any CNC Machine Tool
What Is a LENS Print Engine?

- LENS Core Technology in a Modular Package
- Can be added to New or Legacy CNC Machine Tools
- Provides Pathway to Lower Cost than other Additive Systems

LENS PRINT ENGINE – For Structural Metals

- Powder Feeders
- Deposition Head(s)
- Process Controls
- Tool Path Software
In Situ Monitoring and Auto-adjustment of Laser Power

- Closed Loop Control - maintains constant melt pool area during build
- Camera monitors melt pool for area calculation
- Laser power is increased/decreased to maintain constant build area
- Heat input is controlled to ensure consistent metal quality
LENS Print Engine – Hardware Components

LENS PRINT ENGINE

- Proven nozzle technology
- Proven powder feeder
- Melt Pool Sensor
- 500W – 3000W industrial laser
- Customized tool path generation
- CAD/CAM software
- Optomec process knowledge & support
- Connects to a variety of motion systems
LENS Print Engine – Various Integration Applications

- Additive Only Systems
- Laser Cladding / Coatings
- Upgrade/Retrofit Used CNC
- Robotic Systems
- New Hybrid CNC Systems
LENS Hybrid Solution – Additive & Subtractive

Fadal Vertical Mill Retrofitted with LENS Print Engine

- 1990s Fadal
- Laser Safe Hood & Glass
- Dual Powder Feeder Cart
- LENS Print Head on Vertical Stage on CNC Spindle
- IPG 1kW Laser
- One Integrated Controller
LENS Hybrid Solution – Additive & Subtractive

- LENS print head in deployed position
- Enables full metal 3D Printing on conventional CNC platform

- LENS print head in idle position
- Maintains full CNC machining capability
LENS Hybrid Solution – The Evolution

- Identified modular LENS technology elements for LENS Print Engine
- Installed as total retrofit on Fadal for America Makes
- Installed as Additive Manufacturing system upgrade to existing systems with various industry partners
- Installed as fully integrated Hybrid CNC product at Viwa in Mexico
- Continued additional fully integrated options in collaboration with Fryer Machine Systems in the US
VIWA – First LENS Print Engine Hybrid CNC Product

- First machine tool company to integrate LPE
- 4 axis open atmosphere Hybrid CNC system
- First demonstrated at ExpoMaq in Leon, Mexico in April, 2016
- Subsequently demonstrated at RAPID in May, 2016 and here at IMTS 2016
LENS – Additive Open Atmosphere System

Standard LENS 3D Metal Additive Features

- Built on Fryer CM CNC Platform
- Work Envelope 20” x 14” x 20”
- 12”x 24” Table/450 Lb.
- Optional Tilt/Rotate Axis
- CDRH Class 1 laser Safe Enclosure
- 500 W LENS Print Engine
- One LENS Powder Feeder
- Local Shield Gas
- Siemens Controller
Standard LENS 3D Hybrid VMC Features

- Built on Fryer CM CNC Platform
- Work Envelope
  - Milling = 20” x 14” x 20”
  - Additive = 14” x 14” x 20”
- 12”x24” Table/450 Lb.
- Optional Tilt/Rotate Axis
- 8 Station ATC/ 60 - 8,000 RPM Spindle
- CDRH Class 1 laser Safe Enclosure
- 500 W Fiber LENS Print Engine
- One LENS Powder Feeder
- Local Shield Gas
- Siemens Controller
Print and/or finish with one set-up
Near-net-shape prototypes
LENS Hybrid Vertical Mill – Adding features

- Tough to cast, long lead time: 52 weeks
- Combine additive/subtracting processes
  - Machine disk base
    + Partially 3D print vertical thin walls
  - Partially finish machine
    + Repeat above steps
- Delivery Time: 3 Weeks.
LENS Hybrid Vertical Mill: Repair

Restore Worn/Damaged Components

- Combine additive/subtractive processes
  - machine worn area
  + add material
  - finish machine
- LENS low heat input reduces distortion
- Integration of processes used at Anniston Army Depot
- Local (Albuquerque, NM) salsa company
- Broken gear in processing machine – New gear 12 week delivery
- Optomec repaired using Inconel 718 – 1 day.
LENS Print Engine: Summary Advantages

- Lowers Deployment Cost < half the cost of current Metal AM systems
  - Utilize industry-proven lower cost platforms, robots, machine tools, work cells
  - Accommodates unique part sizes based on conventional or existing custom CNC designs
  - Eliminates need to develop a custom platform just for additive
- Familiar CNC HMI eases additive learning for the user
- Flexibility - combine additive & subtractive process in a single tool.
  - Still use Hybrid Machine for subtractive machining operations
  - Also use Hybrid Machine for additive builds
  - Also use Hybrid Machine to combine additive/subtractive operations on a single part
- LENS is proven metal 3D Printing technology >17 years
  - Closed Loop Process Controls Assures Part Quality and Consistency
<table>
<thead>
<tr>
<th>Barrier</th>
<th>Traditional 3D Metal Printing</th>
<th>LENS Print Engine-based Solution</th>
<th>LENS Print Engine Reduction of Adoption Barrier</th>
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<tbody>
<tr>
<td>System Cost</td>
<td>High</td>
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<tr>
<td>Work envelope</td>
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<td>Flexible as CNC</td>
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<tr>
<td>User interface</td>
<td>Specialized</td>
<td>Conventional as CNC</td>
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<tr>
<td>Build rate</td>
<td>Low (powder-bed)</td>
<td>0.5kg/hr with 2kW laser</td>
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<tr>
<td>System architecture</td>
<td>Typically closed with parameters controlled by the OEM</td>
<td>Totally open parameter selection</td>
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<tr>
<td>Materials</td>
<td>Typically limited to materials purchased from OEM</td>
<td>All commercial powders available for use</td>
<td>☑</td>
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</table>
Hybrid Challenges for Metal 3D Printing

Hybrid impact on metal additive processes

- Environmental control in open atmosphere CNC
  - Inert gas shielding (chamber vs open air and local shielding)
  - Fine powders – human, mechanical, electrical hazards
  - Laser exposure – human, mechanical, electrical hazards

- Non-continuous deposition process
  - Thermal profile discontinuities, microstructural control

- Clean & active surface
  - Just like any welding process

- Qualifications & approvals
  - Conventional fabrication methods vs additive vs hybrid
When Is Atmosphere Control Needed?

**Glovebox (Inert)**
- Air tight chamber that isolates internal gas from room air
- Entire chamber is Argon with Oxygen level maintained < 10ppm
- Ante-Chamber or “Air Lock” to pass parts & tooling through
- Door System offers direct access, then chamber must be purged.

**Open Atmosphere (Shield Gas)**
- Laser Deposition process that incorporates shield gas nozzle in open air
- Laser Cladding (2D coatings) uses a similar shield gas method
  - Nozzle design differs
  - Cladding = 2-3 layers
  - 3D Printing = Many layers
- Shield Gas has been used for years in keyhole & conduction welding.
Alloys That Have Good Results In Open Atmosphere

- **Steel Alloys**
  - High strength steels
  - Stainless Steels
  - Tool Steels

- **Nickel based alloys – Inconels, Hastelloy**

- **Cobalt based alloys – aka Stellite alloys**

- **Tungsten Carbide matrix (typically in a nickel alloy)**
Titanium — Oxygen causes embrittlement of Titanium. Recent study by UC Berkley and published in the journal *Science*, Andrew Minor - Associate Professor stated: “Oxygen is like poison to titanium. With more oxygen, the material gets harder and more susceptible to cracks, qualities that are not desirable for structural materials.”

Refractory Metals

Aluminum

- Melting temperature of aluminum alloys is around 1,200F
- Melting temperature of aluminum oxides is 3,700 F.
- Aluminum oxide is not melted during the welding process and if it is present to an excessive degree, it can easily cause lack of fusion and oxide inclusion type defects.
Optomec is introducing its “Industry First” atmosphere controlled Hybrid CNC system

Expands the capability of Hybrid CNC into the realm of oxidation sensitive materials

Combines proven CNC machine tool fabrication capabilities from Fryer with Optomec’s proven experience with controlled atmosphere LENS technology.
LENS – Hybrid CNC Controlled Atmosphere System

LENS HY20 + INERT ATMOSPHERE GLOVEBOX ENCLOSURE
(Similar to MR7)

Replace upper enclosure with MR-7 style glovebox enclosure
LENS – Hybrid CNC Controlled Atmosphere System

Gas Purification System
Maintains $O_2$ at 40 ppm max, Oxygen Sensor Closed Loop Control

15” Antechamber:
For moving parts into and out of system without breaking atmosphere

Glove Box
Convenient access to table, antechamber, and head from operator area. Door for easy access during open atmosphere processing
LENS 3D Hybrid VMC Inert Features:

- Built on Fryer CM CNC Platform
- Work Envelope
  - Milling = 20” x 14” x 20”
  - Additive = 14” x 14” x 20”
- 12”x24” Table/450 Lb.
- Optional Tilt/Rotate Table
- 8 Station ATC. 60-8,000 RPM Spindle
- CDRH Class 1 laser Safe Enclosure
- Hermetically Sealed Chamber
- 500 W LENS Print Engine
- Gas Purification Maintains Chamber O₂ at 40ppm max
- Glove Ports/15” Antechamber
- Siemens Controller
LENS Systems Line-up for Metal 3D Printing

**LENS CLASSIC SYSTEM SERIES**

- 450 Education
- MR7 Research
- 850R Production

- Built on Optomec Automation Platforms
- Controlled Atmosphere Glove Box System
- Oxygen/Moisture Level <10 PPM
- Three AM Only Configurations
- Best in Class Metal AM Systems

**LENS MACHINE TOOL SERIES**

- LENS 3D Metal Hybrid VMC Inert System
- LENS 3D Metal Hybrid VMC System
- LENS 3D Metal Additive System

- Built on Fryer CM Series CNC Platform
- Shield Gas & Controlled Atmosphere Systems
- Oxygen/Moisture Level ~ 40 PPM for CA
- Hybrid & AM Only Configurations
- Low Cost High Value Metal AM & Hybrid Systems
Fine Powder/Laser in Open Environment

- Impacts:
  - Human interaction
    - Eye safety
    - Breathing hazard
    - Combustion hazard
  - Mechanical
    - Potential to accelerate wear
    - Better shielding methods
    - More frequent maintenance
  - Electrical isolation/protection
    - More insidious than fluids?
Discontinuous Builds

- Build interruptions have typically been avoided with additive processes
- Modeling of additive only processes is already a major development area
- Introduce additional levels of complexity for designers and their modeling tools
  - Not just structural geometric considerations, as in cast or wrought materials (e.g. distortion)
  - Also requires multi-variable microstructural considerations (e.g. grain size)
What About Subtractive Machining Aids?

Conventional machining methods utilize liquid cutting aids which reduce tool wear and improve cutting efficiency.

- Contamination of deposition surfaces
- Quenching of hot deposits
- Impacts powder recycling cost models previously applied to DED methods
- Alternatives
  - “Dry” machining
  - MQL concepts
- Development of “restart” procedures
Conventional subtractive methods have decades of history and experience as foundations for acceptance.

Additive alone has struggled to gain acceptance and wide commercial adoption by many industries.

- Important to note that the F42 committee of ASTM has recently approved F3187 - Standard Guide for Directed Energy Deposition of Metals!

The combination of these methods in a hybrid machine and process is more complex than the simple sum of the two.
Conclusions about Hybrid Metal 3D Printing

- Hybrid manufacturing has the potential to revolutionize not only the additive, but the entire manufacturing landscape.
- Barriers to adoption will continue to be reduced.
- The challenges are all manageable, especially with industry collaboration.
- Wise investment in Hybrid product and process development will continue to prevail.
A Hybrid Approach to Accelerate Adoption of Metal 3D Printing

Thank You for Your Attention

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