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R & D Work in Additive Manufacturing at SMU

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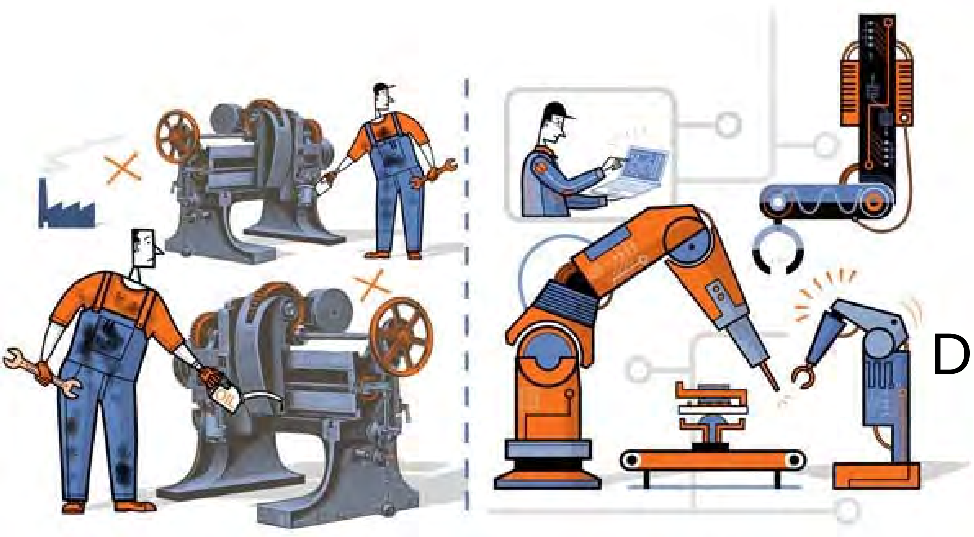


"Everything in the factories of the future will be run by smarter software."[1]

[1] Referenced from "A third industrial revolution," The Economist, Apr 21st 2012, http://www.economist.com/node/21552901

SMU | CENTER FOR LASER AIDED MANUFACTURING

SMU | RESEARCH CENTER FOR ADVANCED MANUFACTURING

Additive Manufacturing at SMU

Fusion-based Techniques

– Laser-based Direct Metal Deposition *(US Patent no. 7,020,539)*

– Electron Beam Melting®

– Gas Metal Arc Welding/Machining

– Micro-plasma Powder Cladding

– High-power Direct Diode Laser Cladding

Solid state-based Technique

– Friction Stir Welding

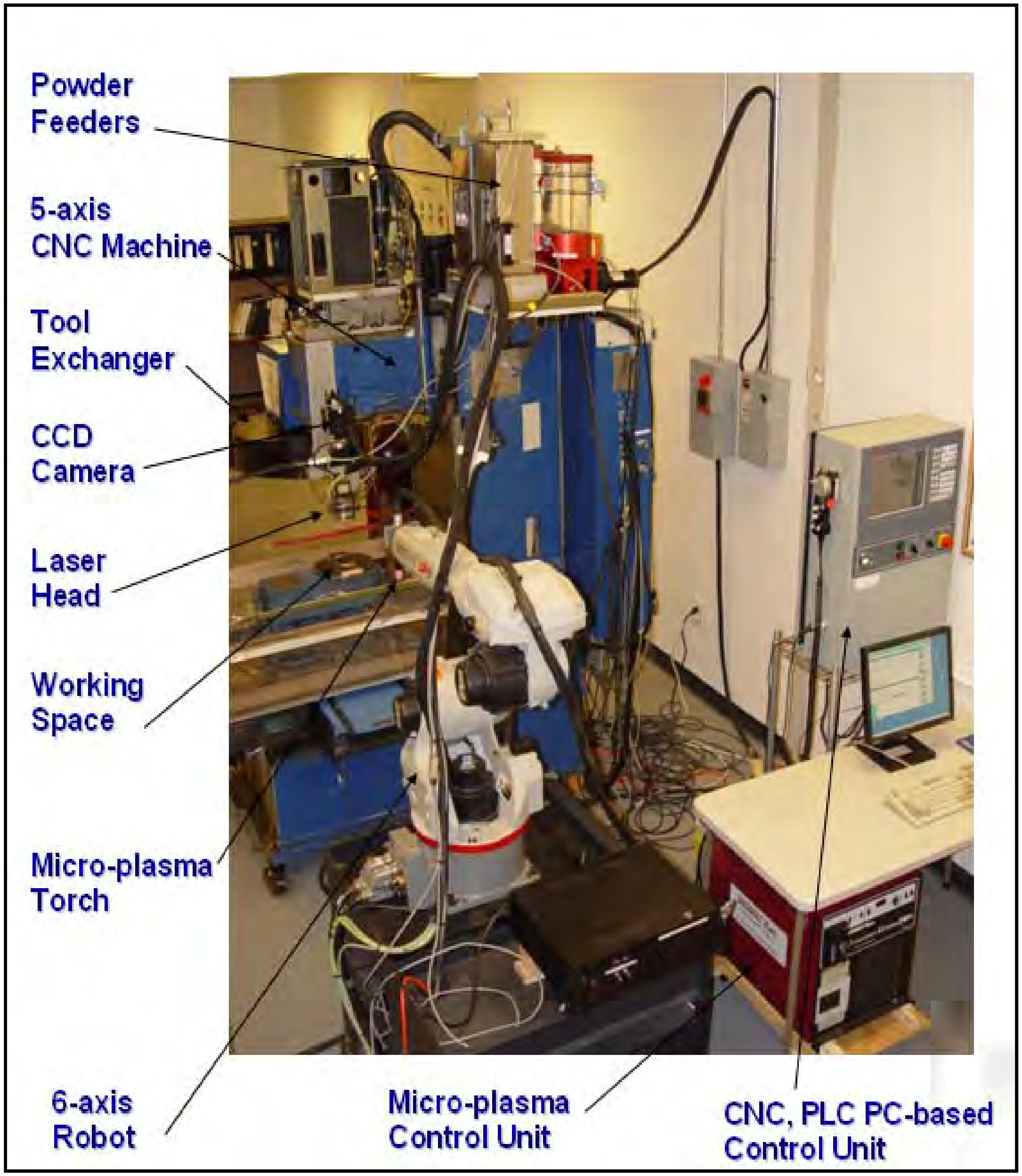
Patents Related to MultiFab Technology

1. Kovacevic, R. and Valant, M.,, "System and Method for Fabrication and Repair Parts", US Patent no. 7,020,539 issued on March 28, 2006.
2. Valant, M., and Kovacevic, R., "Powder Delivery System and Method", US patent no. 7,045,738 issued on March 16, 2006.
3. Kovacevic, R., Hu, D., and Valant, M., "System and Method for Controlling the Size of the Molten Pool in Laser-based Additive Manufacturing", US Patent no. 6,995,334 issued on February 7, 2006.
4. Kovacevic, R., Jandric, Z., Valant, M., and Kmecko, I., "System and Method for Controlling Welding Parameters in Welding-based Deposition Process", US Patent No. 6,940,037, issued on Sept. 6, 2005.

Multi-Fabrication Manufacturing/Repair System (MultiFab)

MultiFab combines depositions by welding and laser cladding, multi-axis machining, and in-situ inspection into one highly integrated system based on a 6-axis robot and a 5-axis high speed CNC machining center, providing the next generation technology for rapid and precise net-shape manufacturing using metals and ceramics.

Prototype of Multi Fabrication (MultiFab) System



LASER:

- Finer geometrical features
- Smaller heat affected zone
- Less porosity
- Multiple material composition
- Better control of material properties

WELDING:

- Larger geometrical features
- Higher deposition rate
- Controlled heat input
- Controlled deposition rate

MACHINING:

- Complex geometrical features
- High dimensional accuracy
- High surface quality

Advantages of MultiFab Technology

- ✓ Repairing high-value components such as dies or molds minimizing cost and production downtime
- ✓ Manufacturing spare parts for legacy equipment "on-demand" from CAD files eliminating expensive inventory stock
- ✓ Producing components with Functionally Graded Material (FGM) compositions with properties unattainable by current manufacturing processes
- ✓ Improve surface resistance to heat, abrasion, corrosion, and erosion via laser cladding
- ✓ Synthesizing materials to achieve specific mechanical and physical properties

MultiFAB Presentation-Rapid Manufacturing Laser-based Direct Metal Deposition

Click the screen to start the Movie

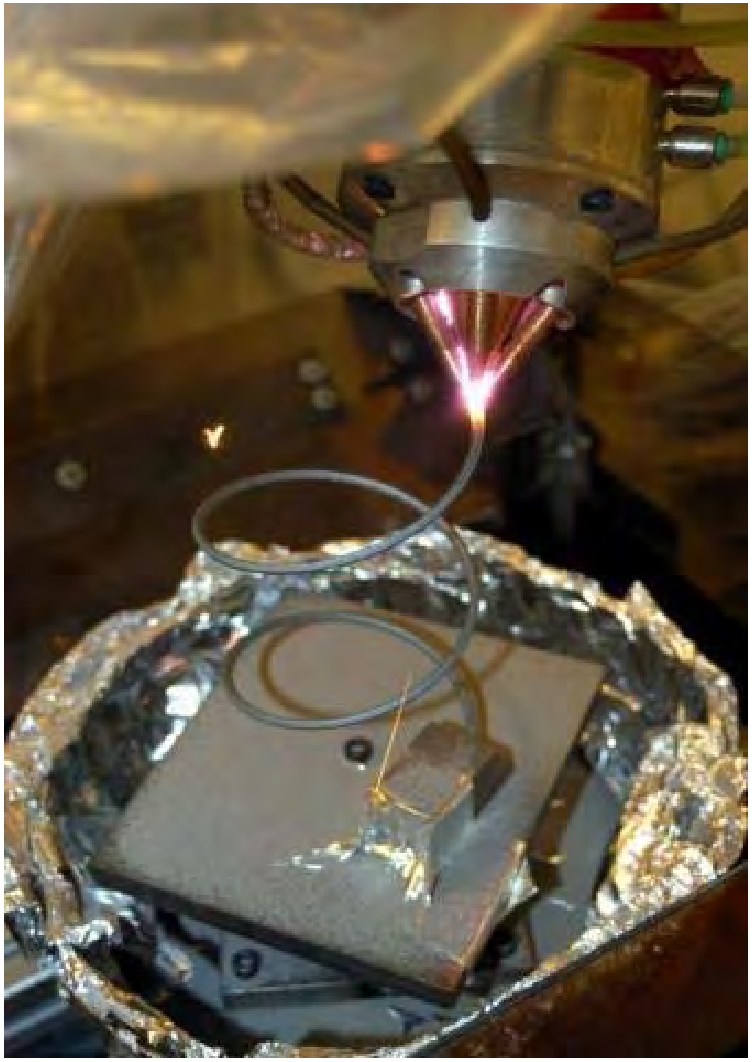
Close-up of MultiFab System

Machining of Sample Built by LBDMD

3D Sample Built by Laser-based Direct Metal Deposition (LBDMD)

Samples Built on MultiFab

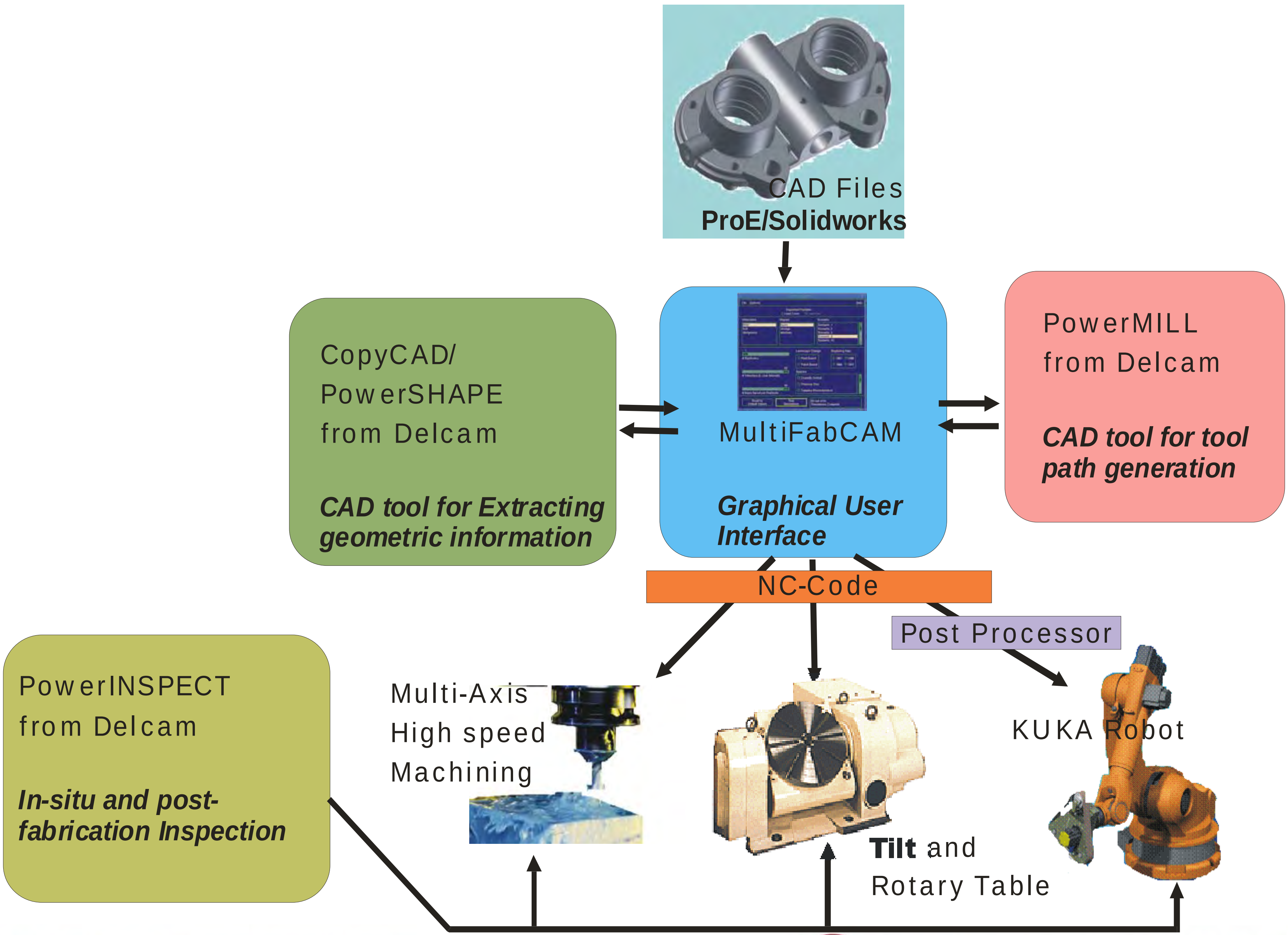
Hollow Spiral



Slender Spiral

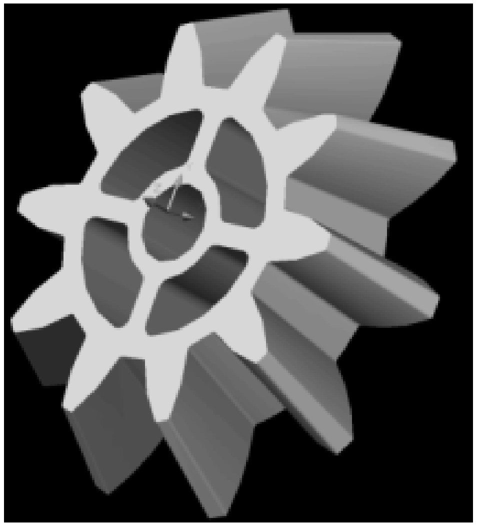
Gear

MultiFab CAM Software Solution

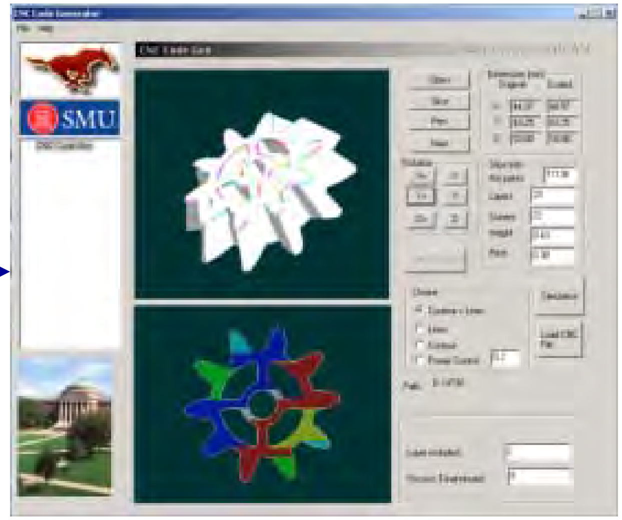


Information Flow in MultiFab

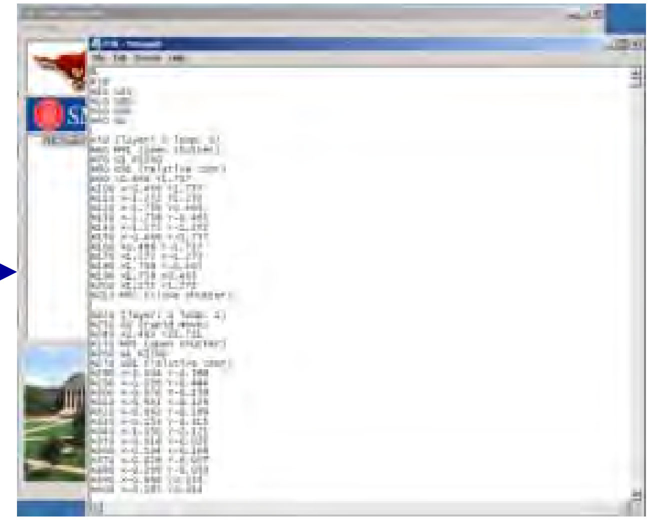
CAD Solid Model



Slicing & Path Planning

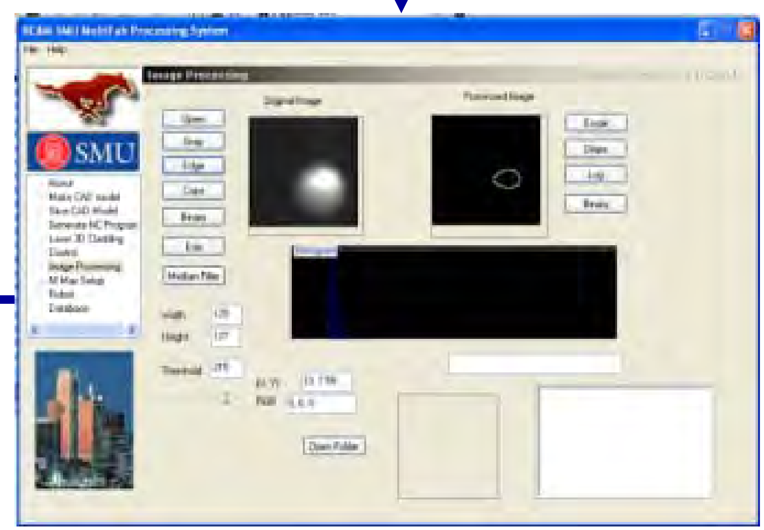


NC - Code



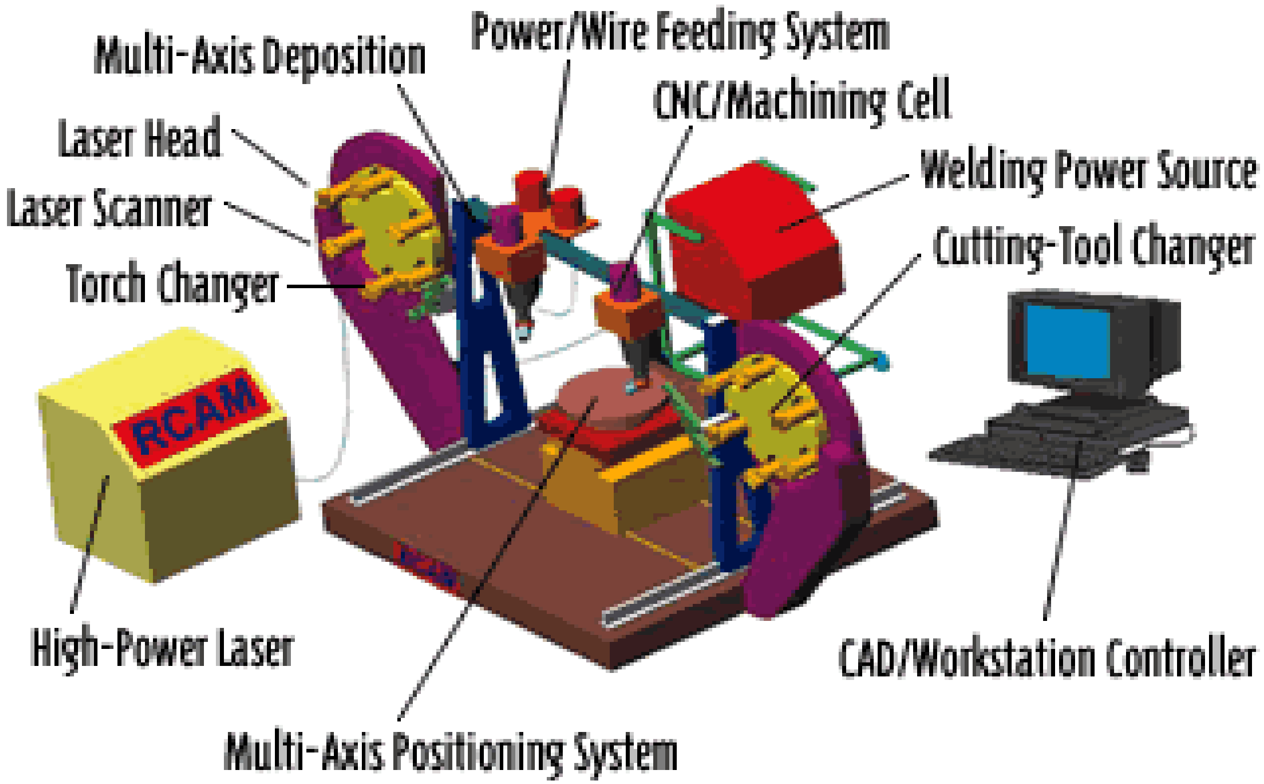
Finished Part

Manufacturing

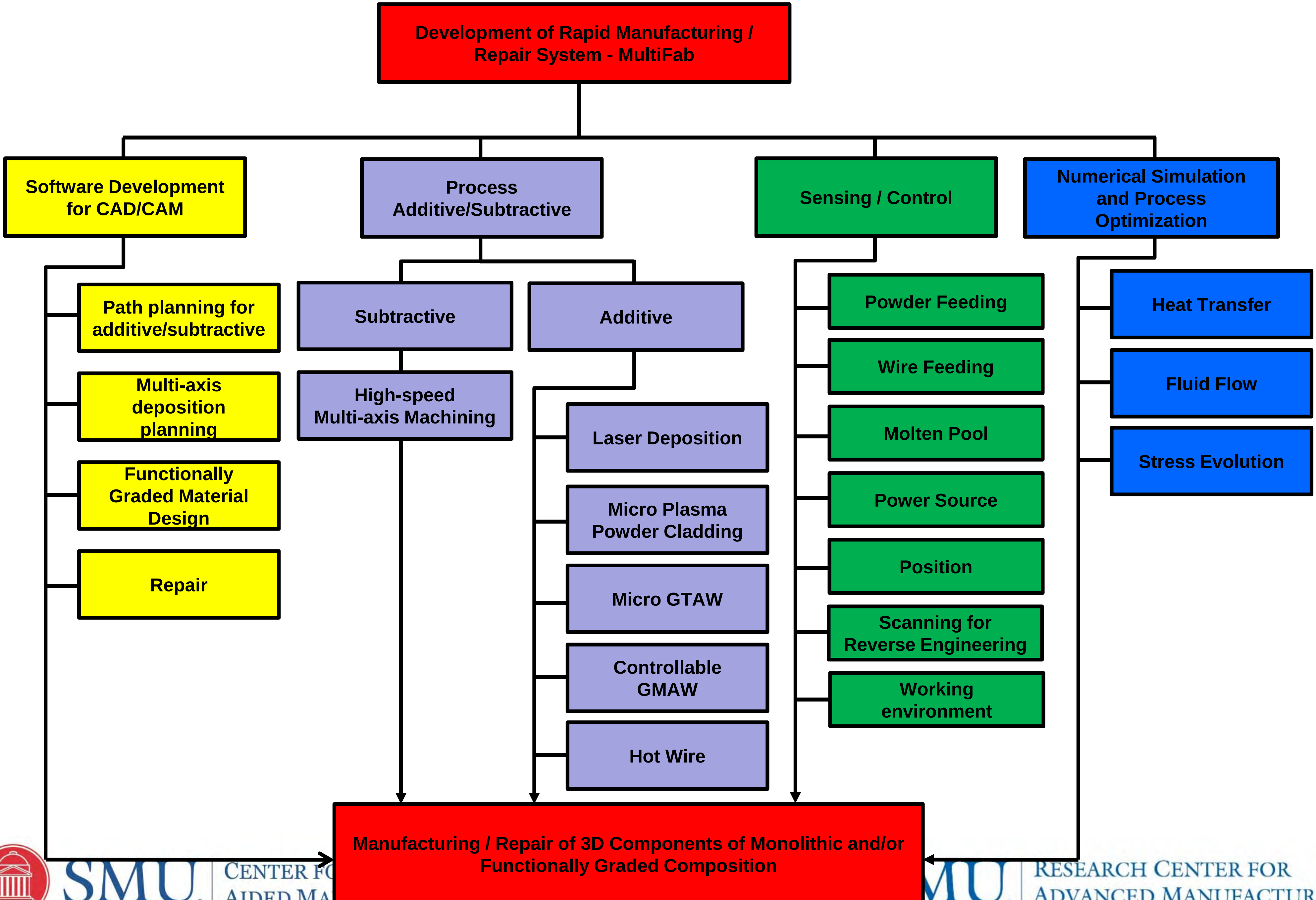


In-Process Sensing

MultiFab as a Base for the Development of a “Mobile Part Hospital”



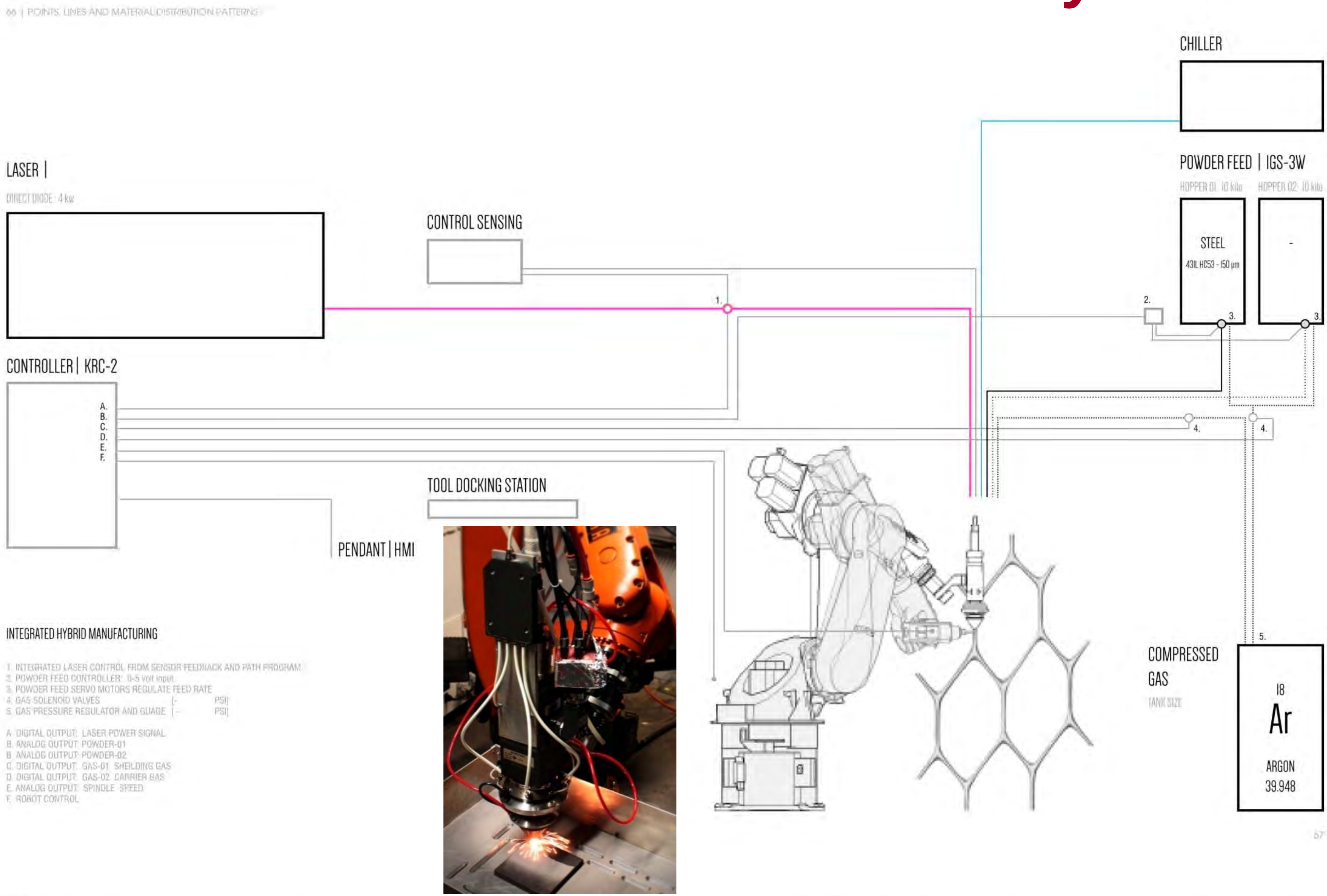
Schematic presentation of activities on MultiFab



A robotized laser-based direct metal deposition system

Click the above title to start the movie

Robotized Additive/subtractive system



A case on manufacturing of propeller

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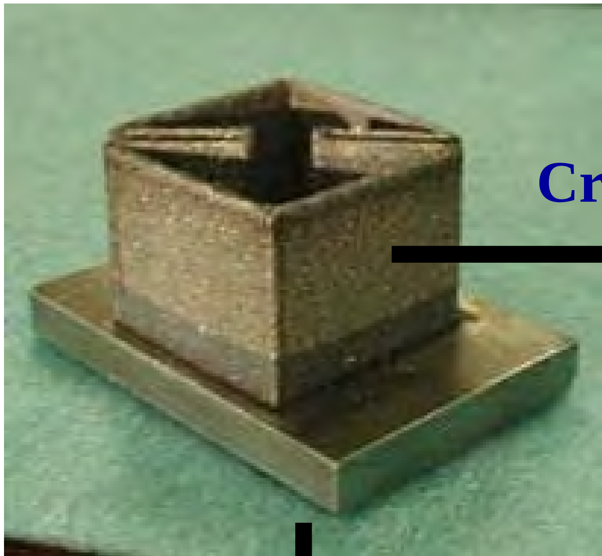
1D FGM-Functionally Graded Material (H13+%WC)

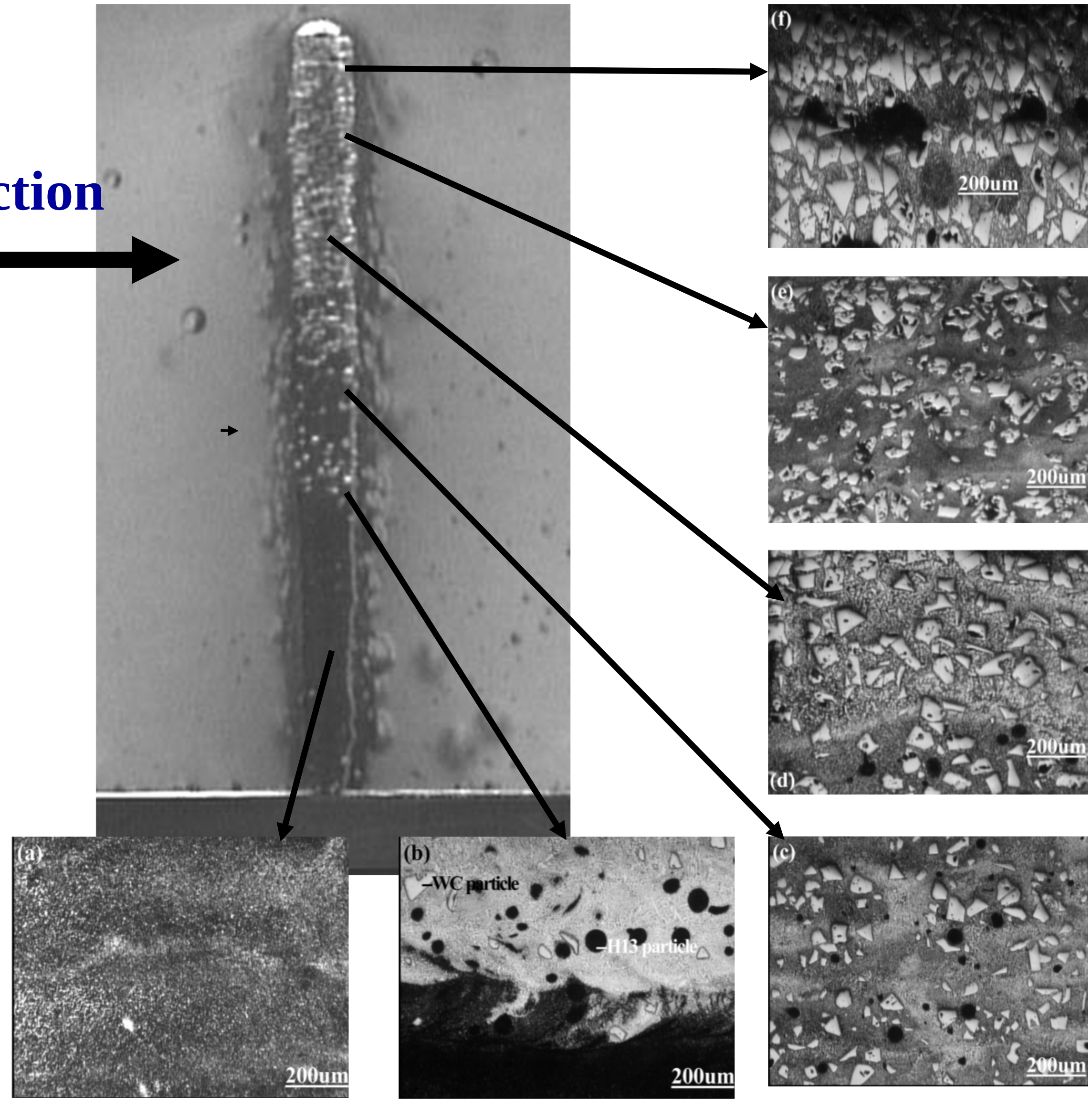
FGM Sample



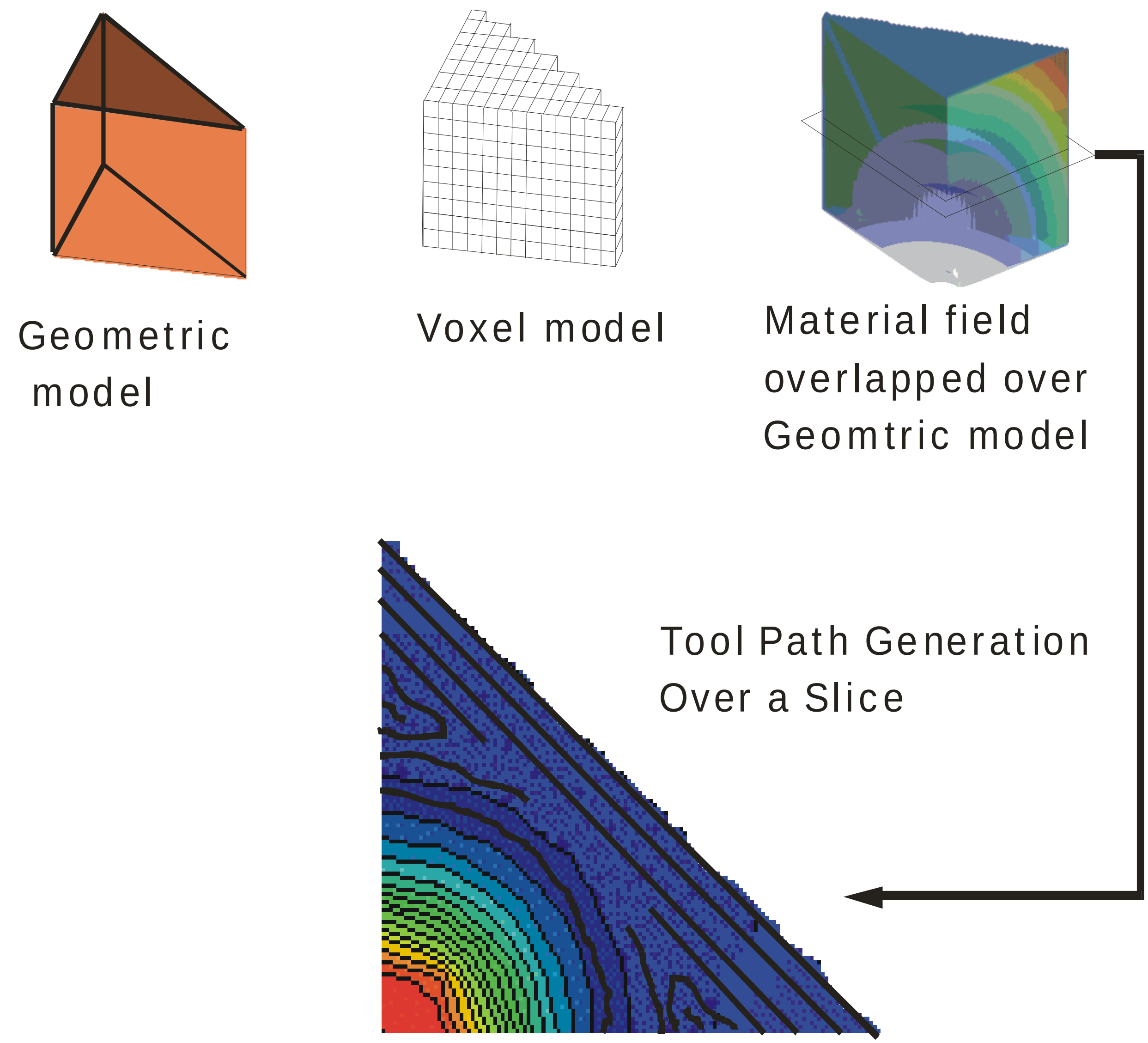
Side View

Cross Section

Microstructure

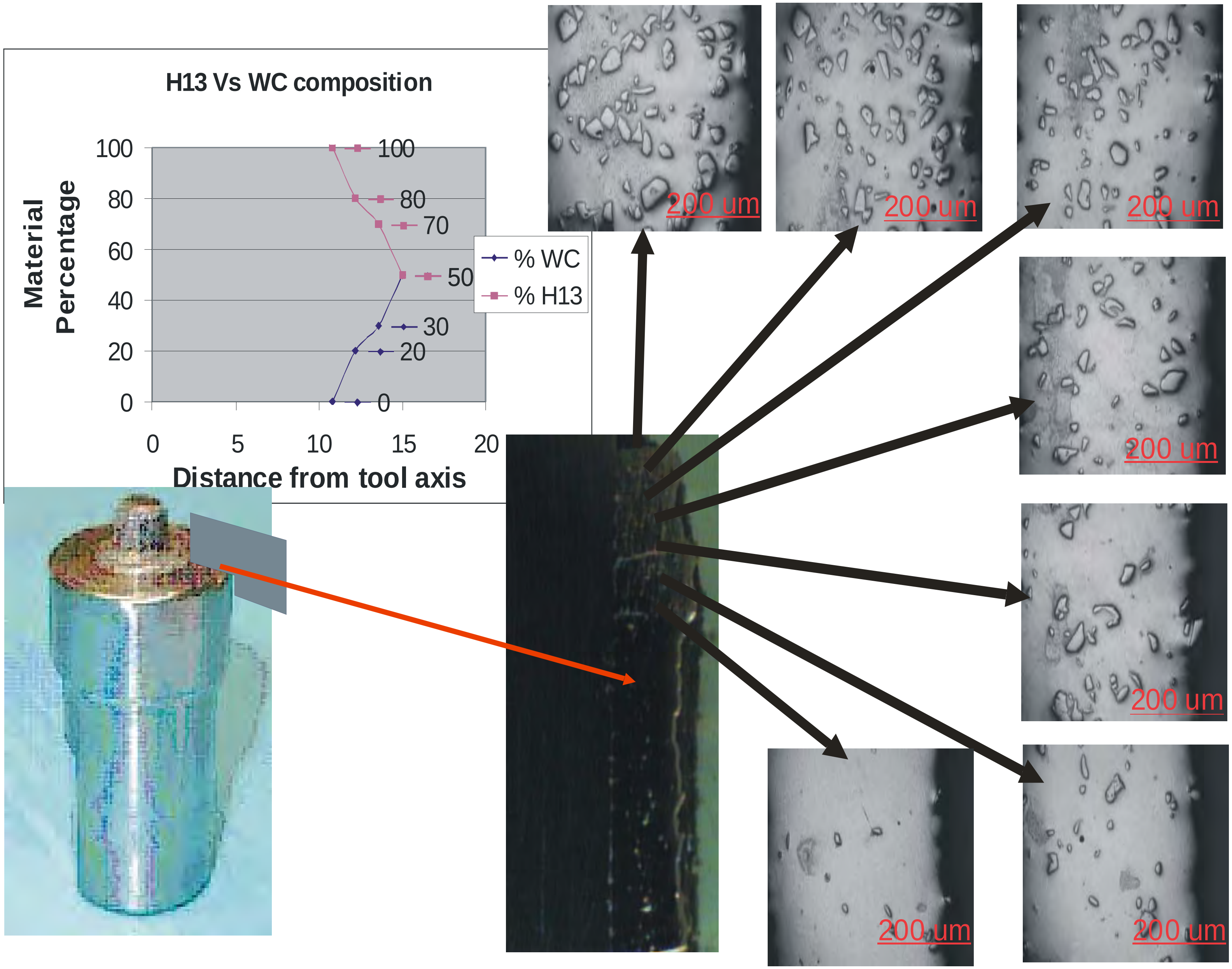


Discretization and Material Field Overlap for FGM Model



Maxel-volume plus material

3D Printed Tool for Friction Stir Welding with FGM Microstructure



Development of powder flow rate sensor

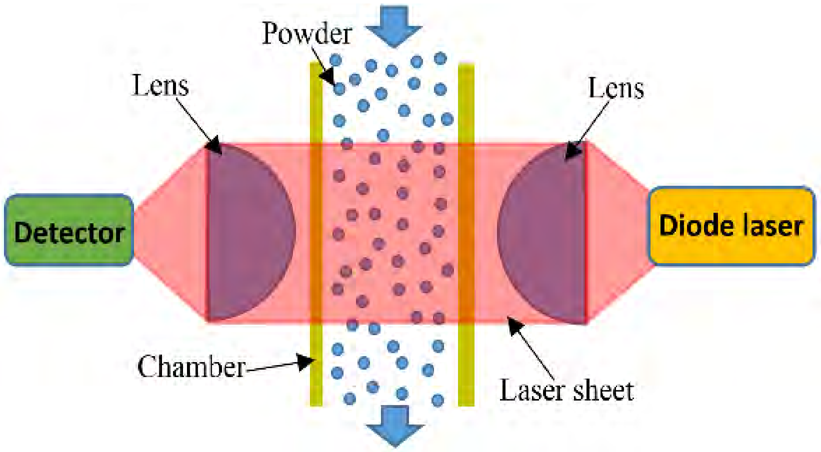
Patent No. 7045738
Issued on May 16, 2006

1. Powder feeder

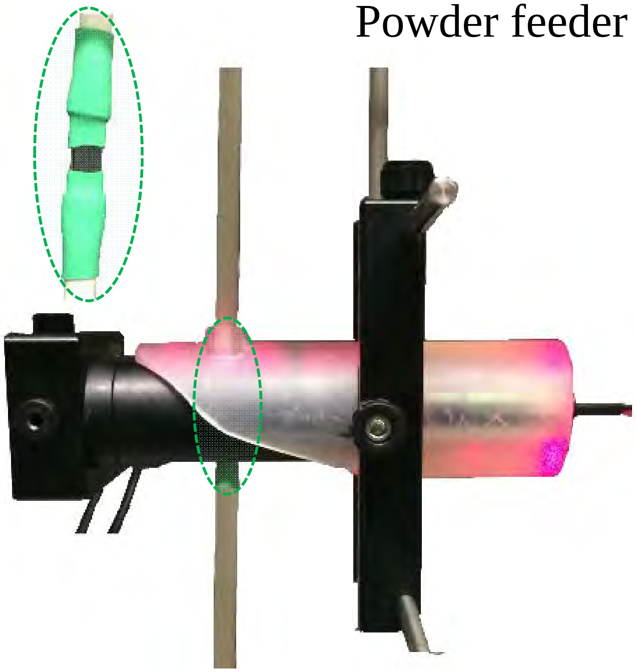
Advantages of new powder feeder:
- Powder delivery based on pressure difference
- Powder mass flow is linear function of the set-point input
- High resolution
- Repeatability
- Scalability
- Flow rate is controlled by controlling the speed of a servo motor

Powder feeder in RCAM

2. Flow rate sensor



Schematic of the flow rate sensor



Flow rate sensor

3. Calibration

Set motor voltage from 0 to 0.5 v with constant interval 0.05 v. Last several seconds at each motor voltage, collect the powder to get average powder flow rate (Fig. 1). During each collection process, average output voltage of the flow rate sensor was calculated (Fig. 2).

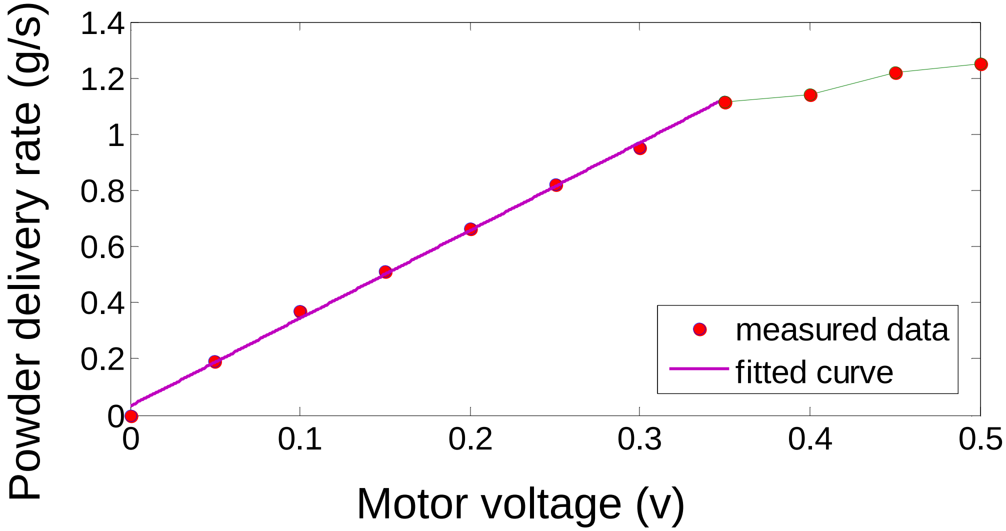


Fig. 1 Relation between motor voltage and powder delivery rate

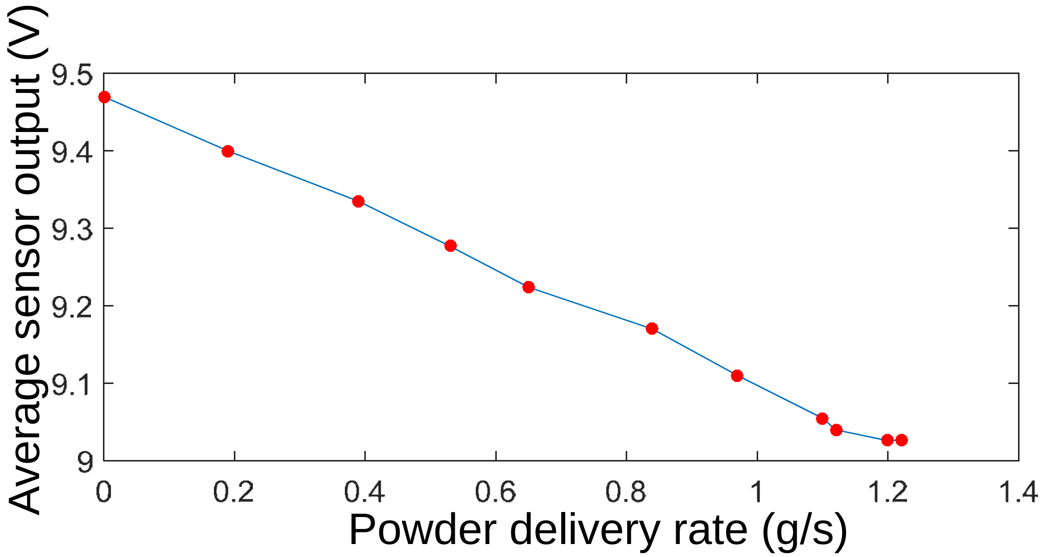
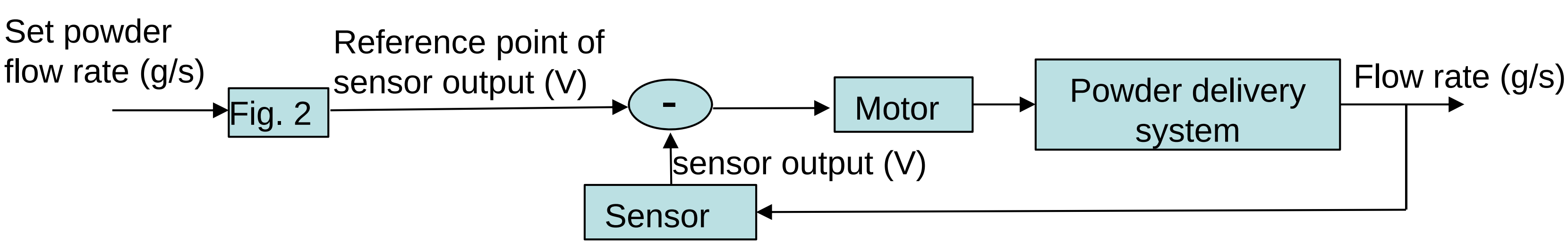


Fig. 2 Relation between powder delivery rate and the averaged sensor output

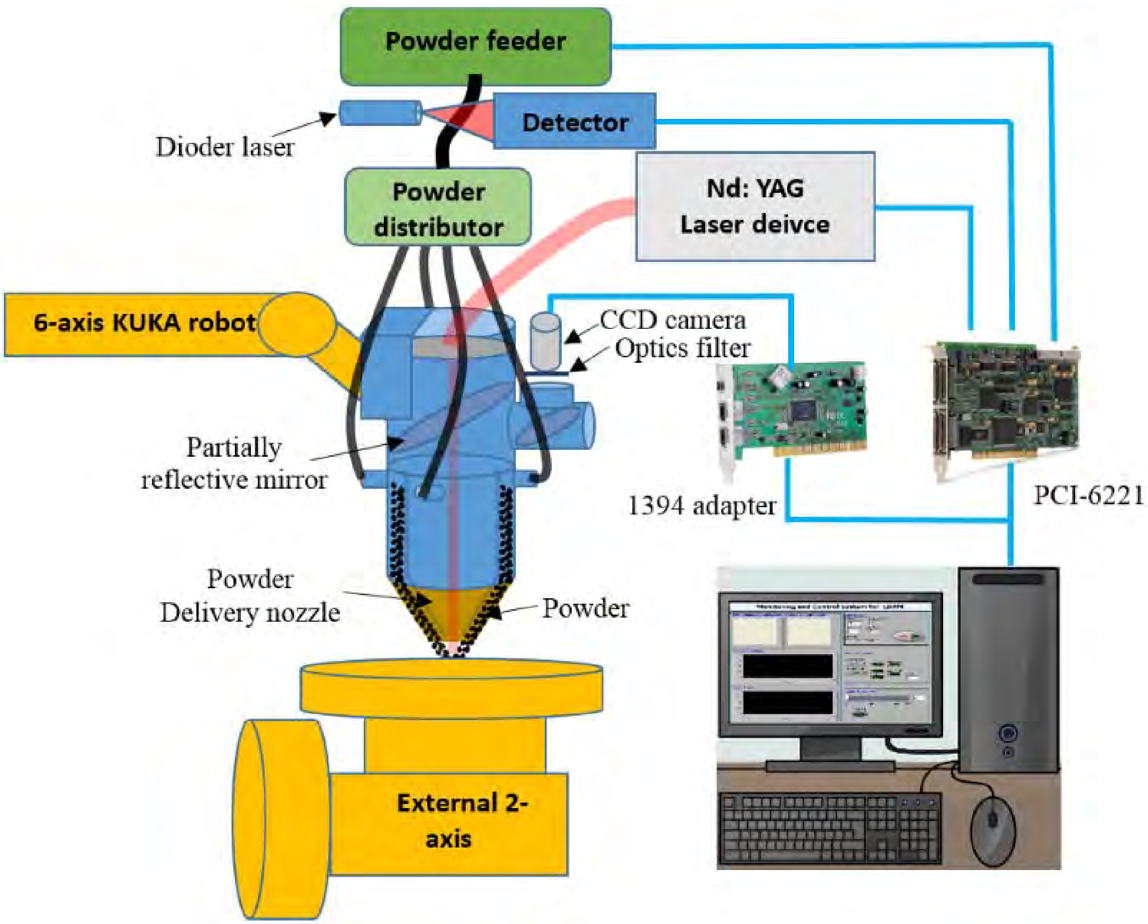
<u>Good linear relationship when powder flow rate is less than 1.1 g/s.</u>

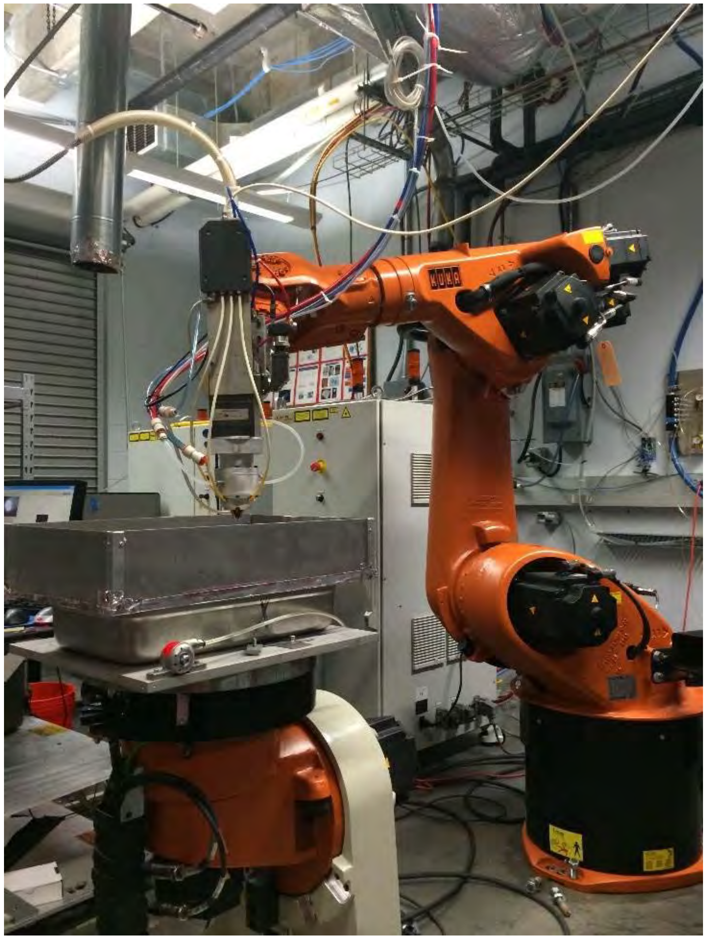
4. On-line sensing and control



Development of Real-time Sensing and Control of the Molten Pool

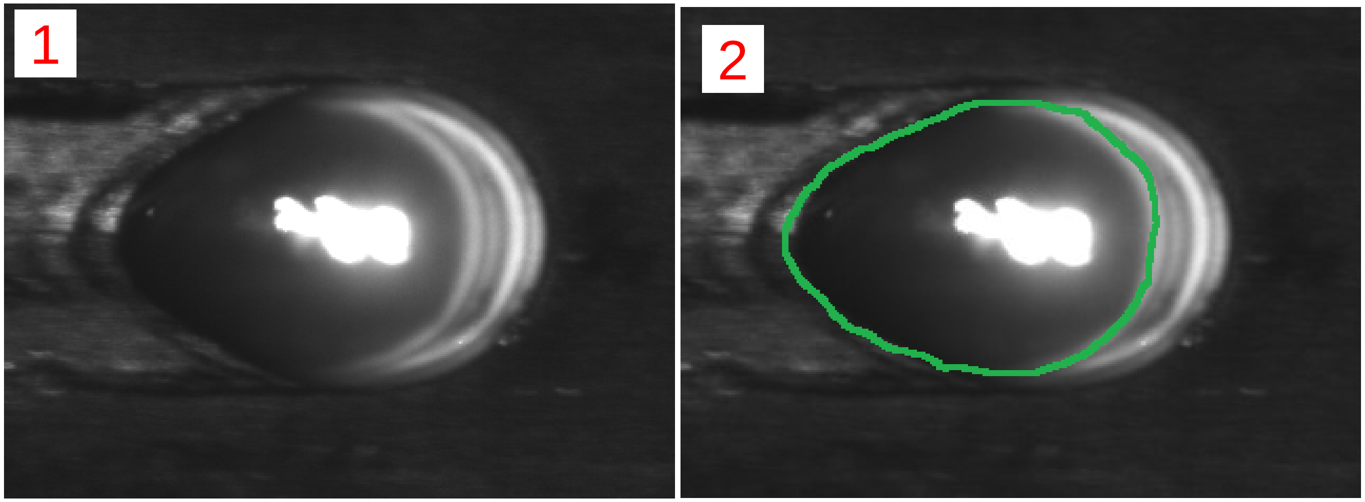
1. Setup



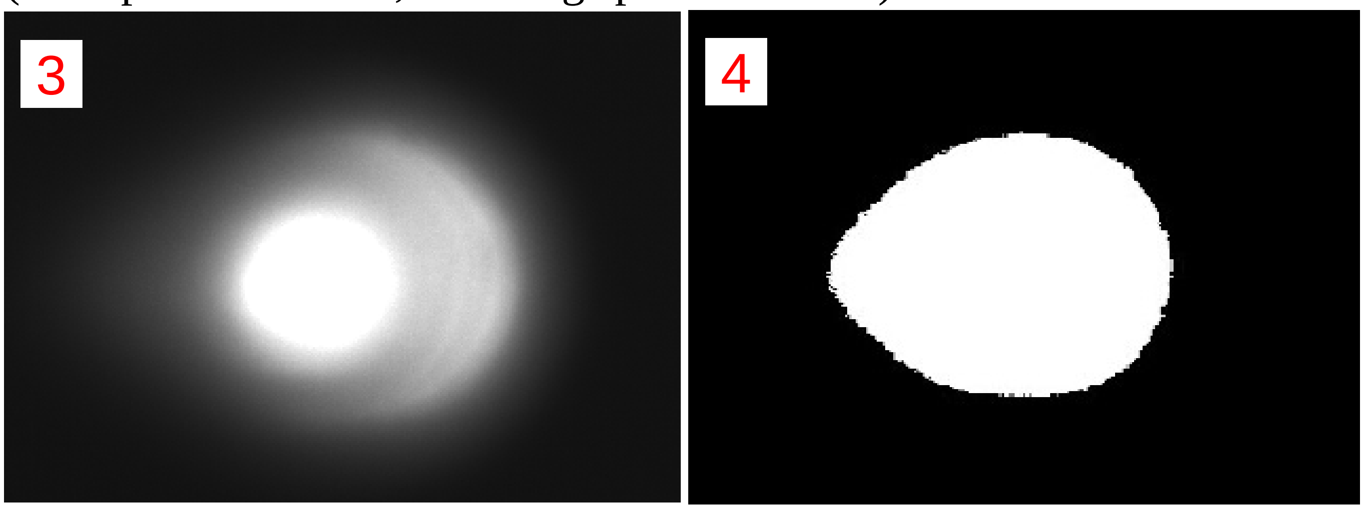


[Patent No. 6995334](#)
[Issued on Feb 7, 2006](#)

2. Calibration of the infrared image of molten pool



Coaxially acquired molten pool image illuminated by a green laser (laser power 1000 W, scanning speed 20 mm/s)



Coaxially acquired infrared image of the molten pool (laser power 1000 W, scanning speed 20 mm/s). Original image (left); overlapped result with grayscale threshold of 97 (right)

Steps:

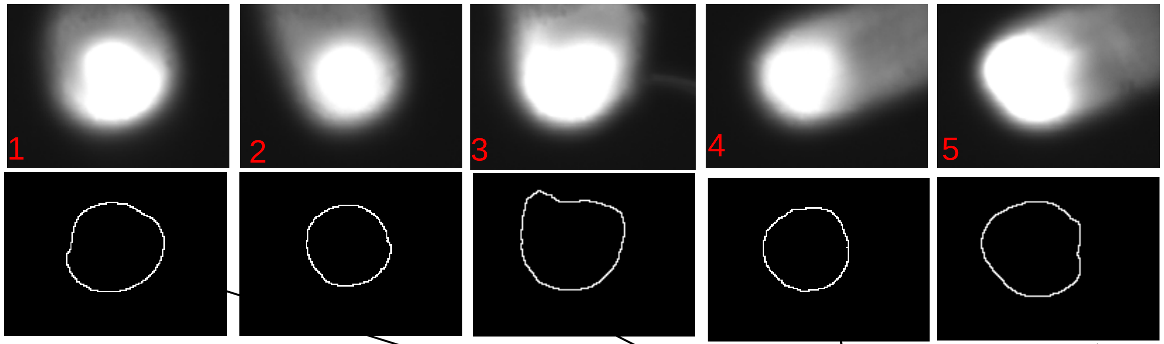
1. Capture video image of the molten pool (without powder);

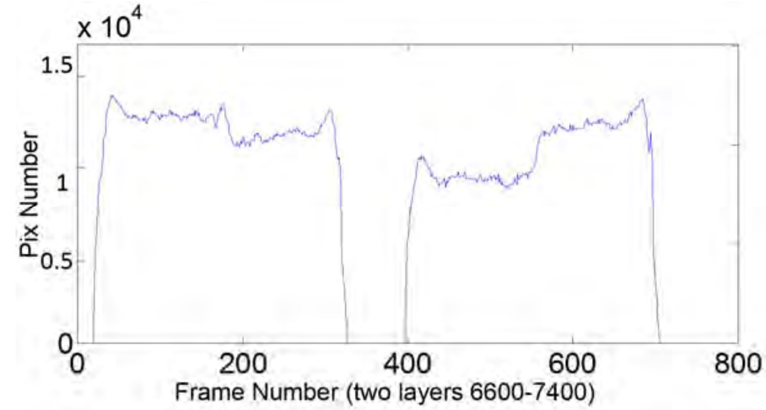
2. Detect contour of the molten pool in video image;

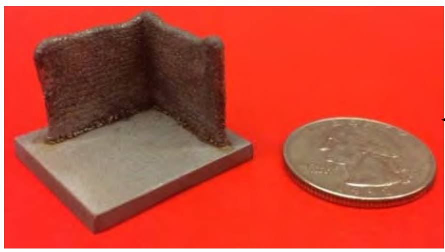
3. Capture infrared images under same scanning conditions;

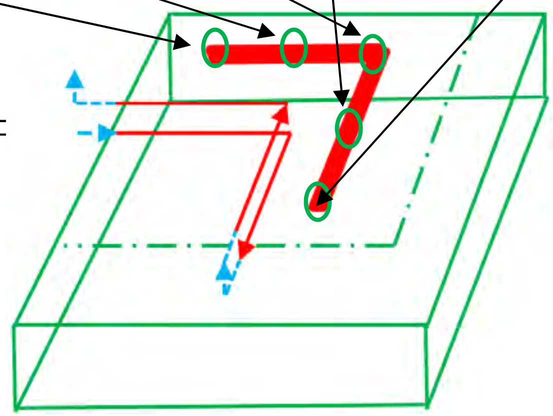
4. Overlap video and infrared images to get contour of the molten pool on an infrared image.

3. Molten pool in LBDMD without closed-loop control

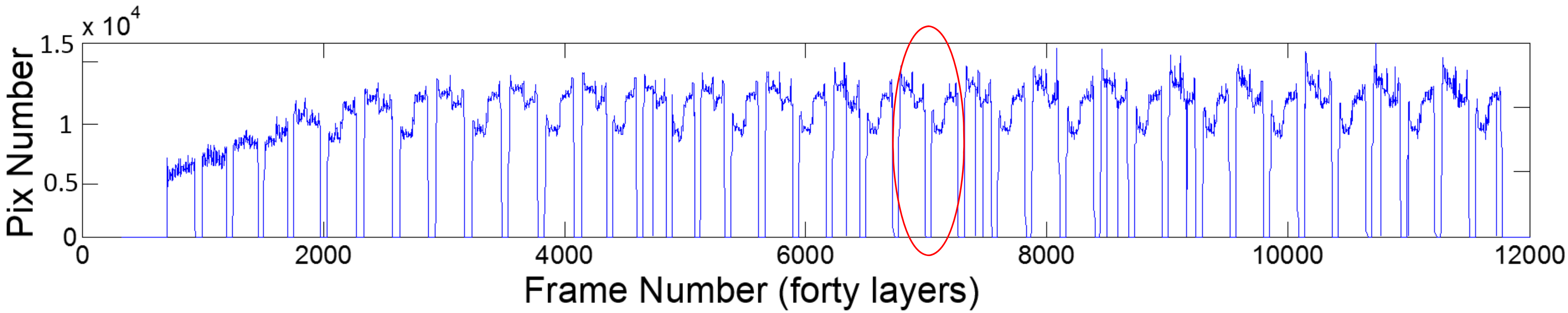




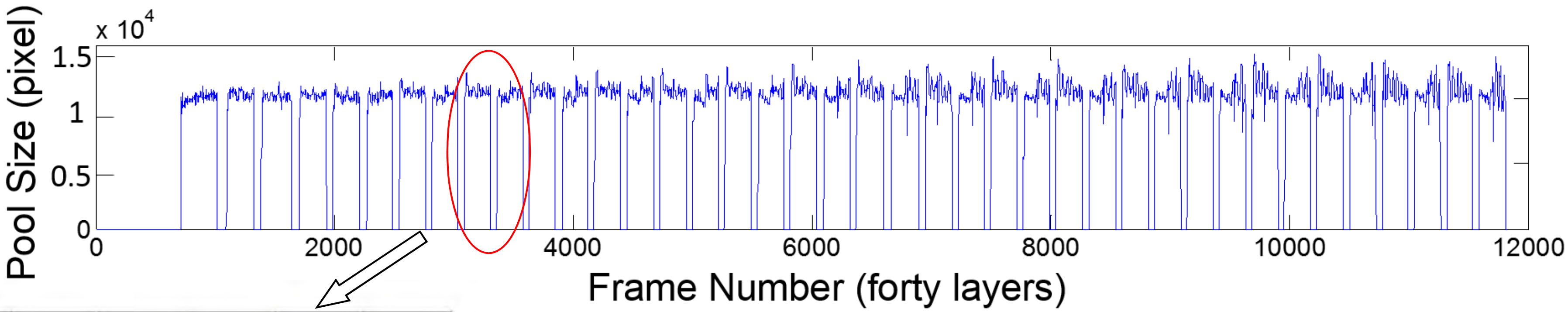


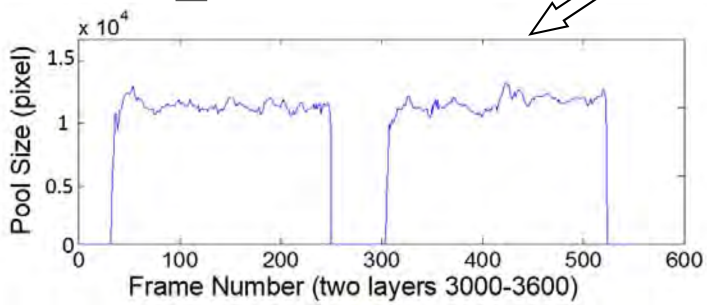


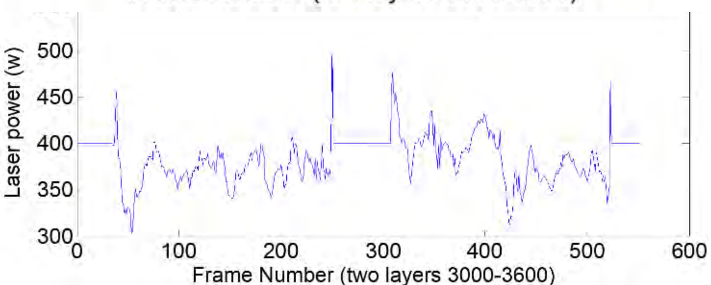
Laser power: 400 W
Scanning speed: 5 mm/s
Powder flow rate: 0.45 g/s

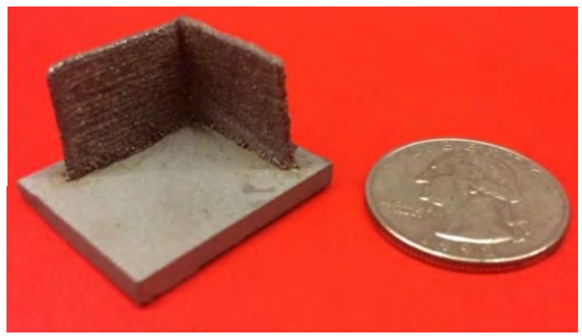


4. Molten pool in LBDMD with closed-loop control (PID)



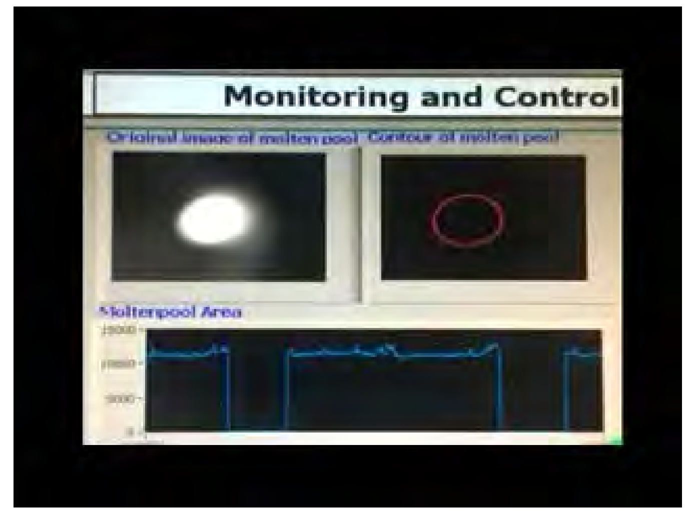


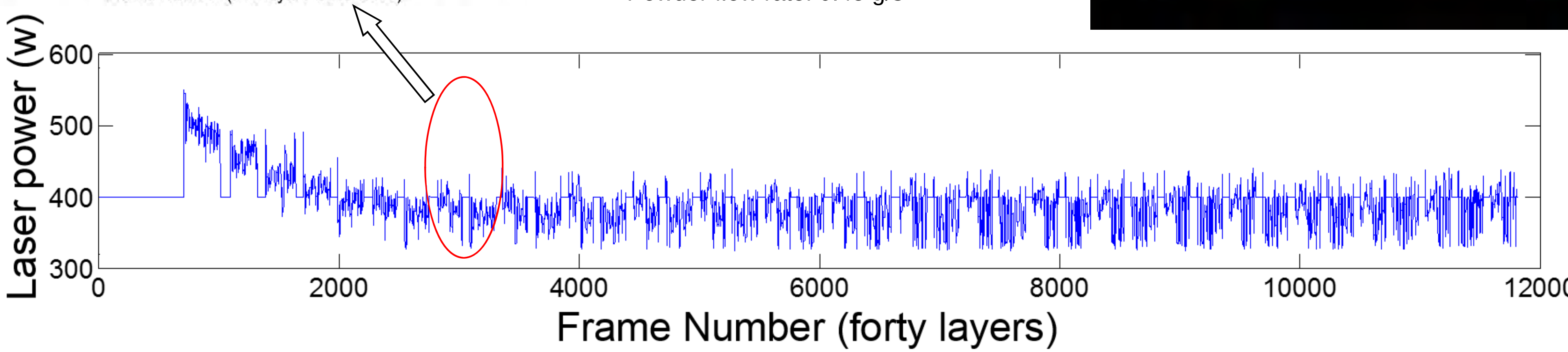




Set pool size: 12000 pixels
Scanning speed: 5 mm/s
Powder flow rate: 0.45 g/s

Click the screen to start the Movie



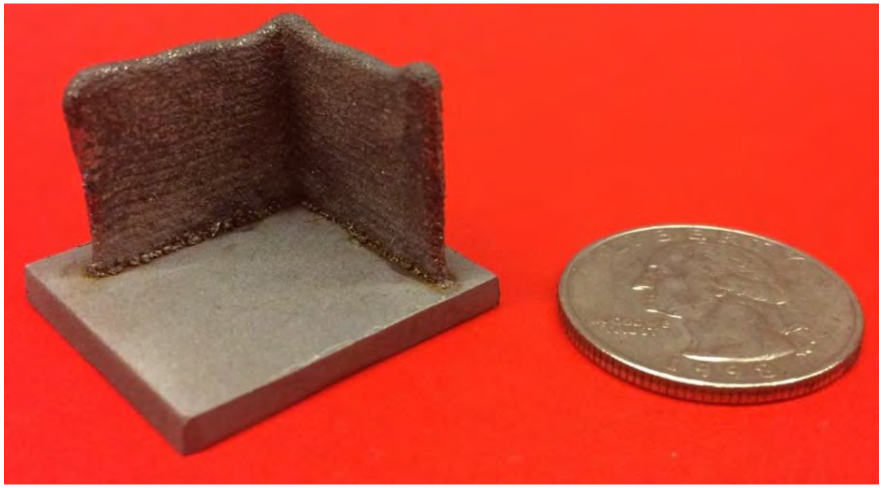


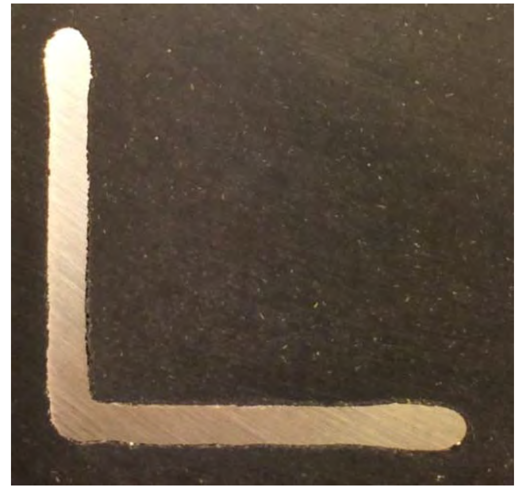
5. Comparison between non-controlled and controlled molten pool in LBDMD

Horizontal cross section

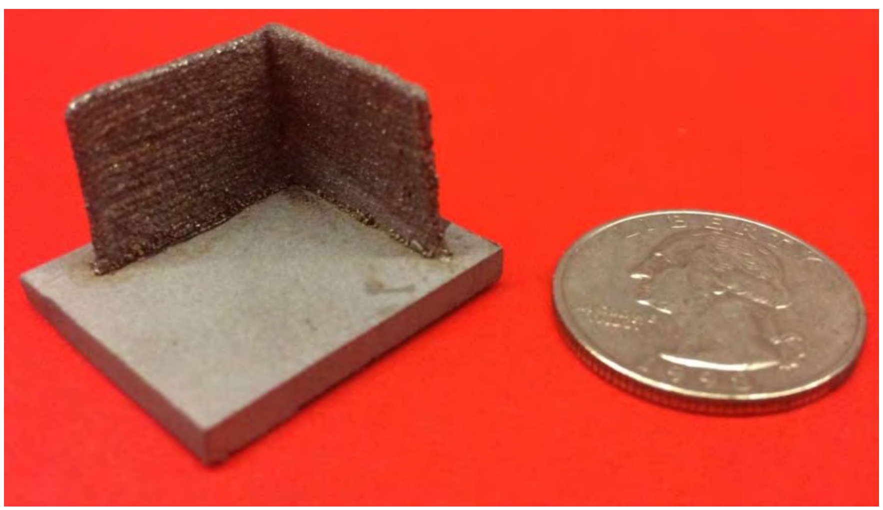
Vertical cross section

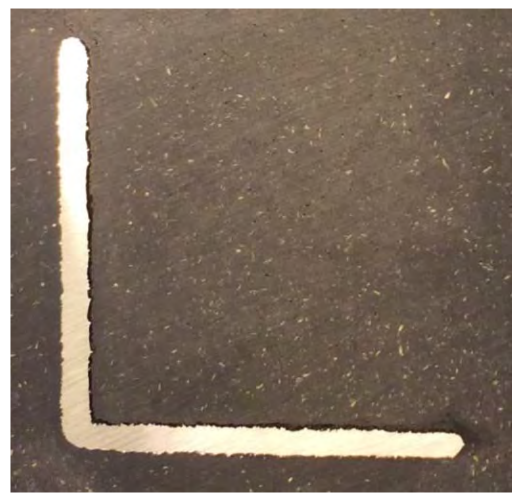
without control





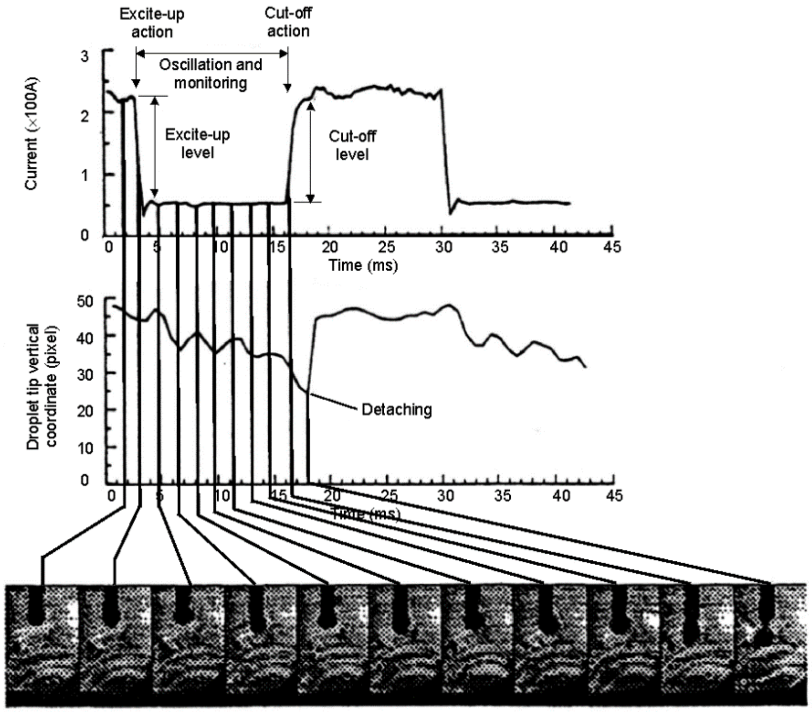
with control



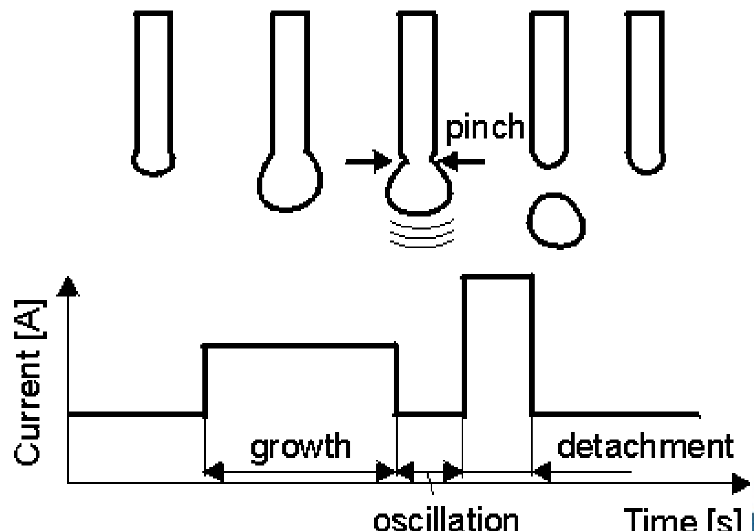


Hybrid Rapid Manufacturing/Repair Based on Deposition by Welding and CNC Machining

ACTIVE METAL TRANSFER CONTROL IN GMAW
US Patent No.6013896, January 11,2000



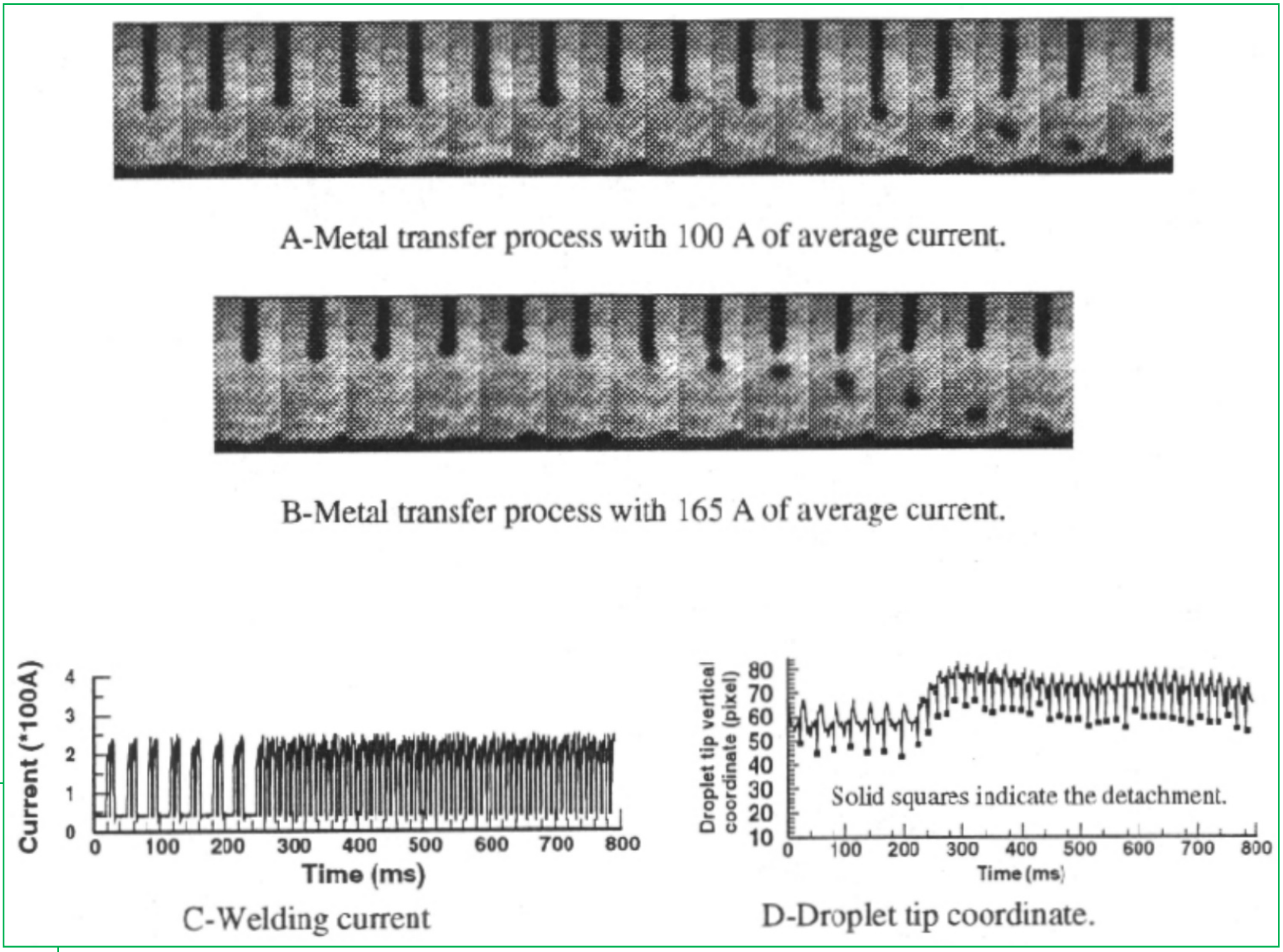
- Goal is to keep the ***droplet size*** and ***droplet transfer rate*** within a certain range.



- A pulse period is divided into two periods:
  - growth period and
  - detachment period.

Metal Transfer Control in GMAW

Heat and mass transfer



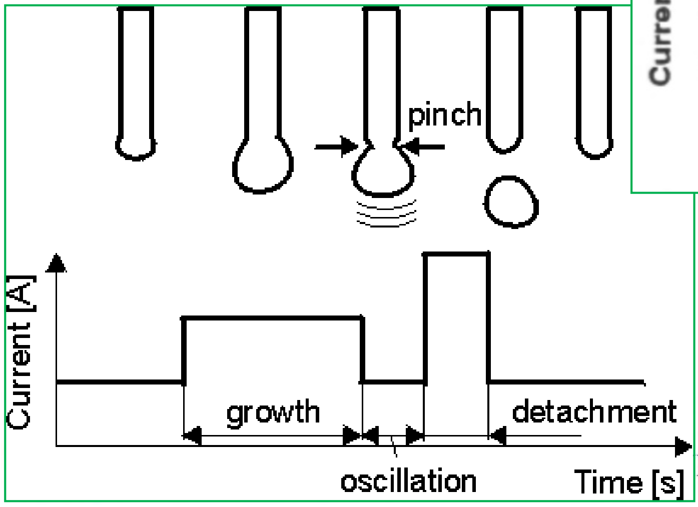
A-Metal transfer process with 100 A of average current.

B-Metal transfer process with 165 A of average current.

C-Welding current

D-Droplet tip coordinate.

Active metal transfer control

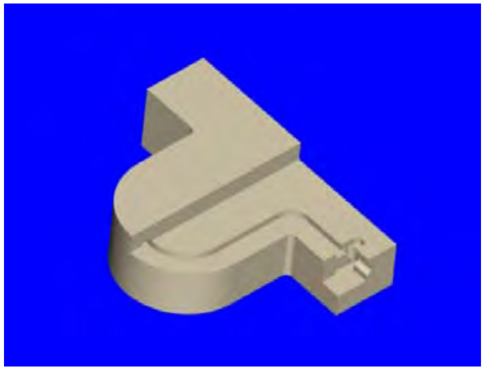


RING

SMU. RESEARCH CENTER FOR ADVANCED MANUFACTURING

Manufacturing Procedure in Building Part with 3D – Conformal Cooling/Heating Channels by GTADMD

CAD Model

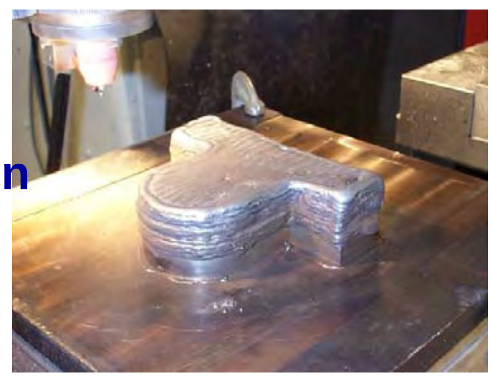


Making cooling channel

Machining

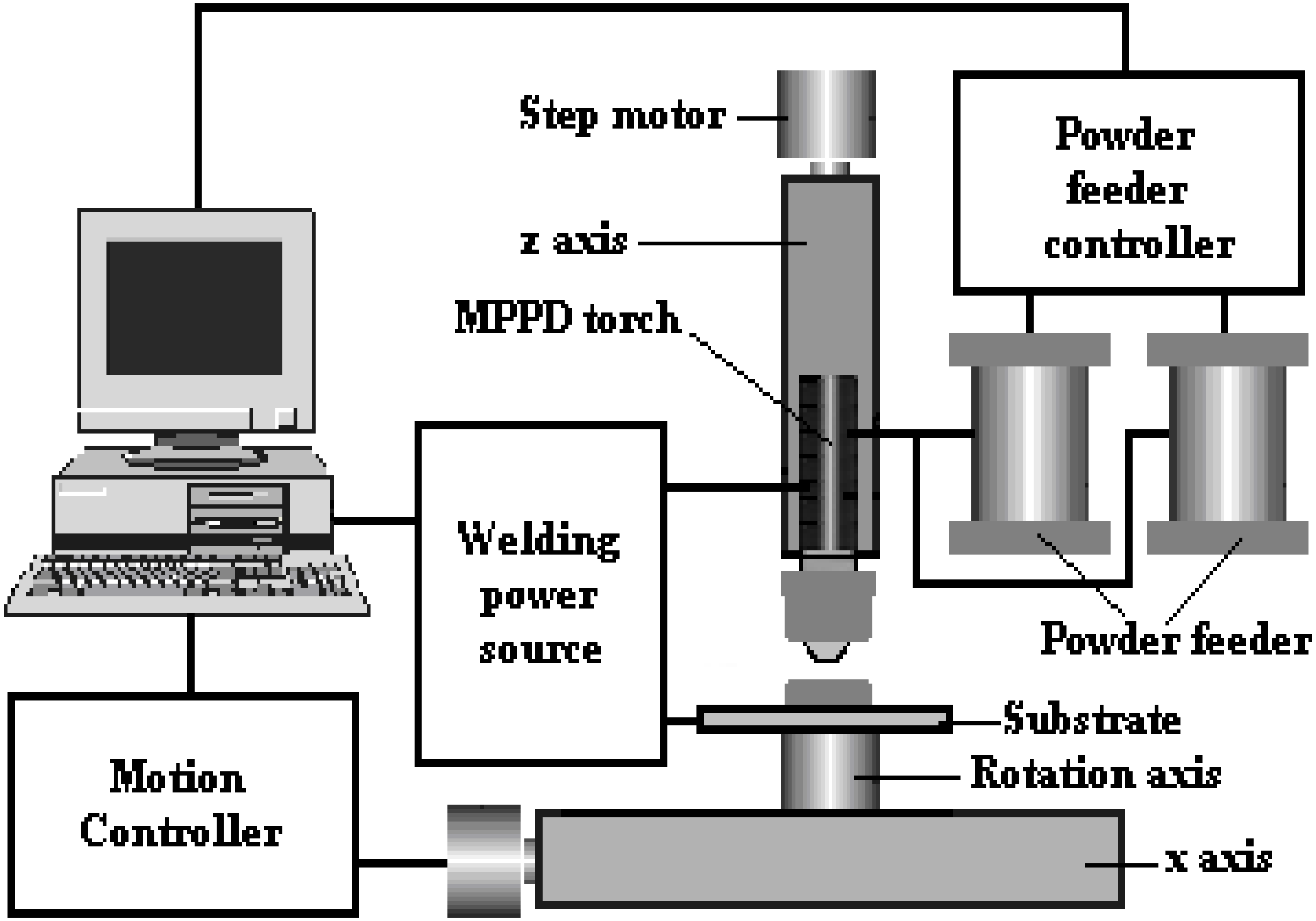
Support Structure for cooling channel

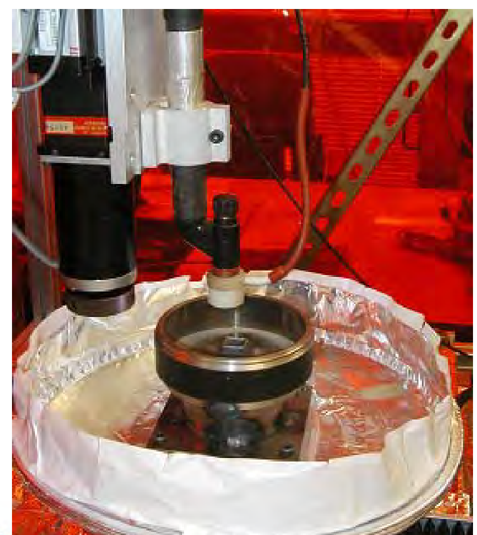
Computer controlled Gas Tungsten Arc-based Direct Metal Deposition



Final part

Experimental Set-up for Micro-Plasma Powder Cladding (MPPC)





Samples Built by MPPC

Direct Aluminum Deposition by Variable Polarity Gas Tungsten Arc Welding (VPGTAW)

- **Rapid manufacturing/repair techniques have been under development at SMU's RCAM using Variable Polarity Gas Tungsten Arc Welding (VPGTAW) with aluminum alloys. The controllable shape and duration of the current pulse guarantees low dilution and high quality buildup formation.**

- **The system components consist of a precision five-axis CNC, the VPGTAW power source, sensing control units, wire feeder and a host computer with a custom software interface to coordinate communications.**

Samples Built by VPGTAW

"Cylinder" shape part

"Cone" shape part

"Pipe reducer" shape part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