Process Control for Additive Manufacturing

Lesson 1
Acoustic Emission Monitoring
Outline

• Need for Mass Flow Monitor in AM
• Current Use of AE in Welding Processes
• Discoveries Critical to AE Monitoring of Powder Flow
• System Testing Protocol
• Future Research Goals
Powder Flow Rates

- Powder mass flow balanced with laser power controls build quality in direct laser sintering
- Current DED systems run open loop on mass flow
- Powder flow rates are fixed set-points
  - Calibrated before build campaign (no recommended practice on frequency)
  - Rogue full, or partial, blockage between hopper and build head ignored
- Flow related discontinuities may, or may not, be discovered during post-build inspection(s)
- Build quality index identifies
  - Level of post-build inspection
  - Pinpoints location(s) for inspection
Non-Invasive Monitoring

- Current flow sensors can disrupt laminar gas flow, or alter mass flow rates
  - Turbine, vortex
- Existing multi-phase mass flow meters rely on empirical data to achieve optimal flow
  - Fracking, oil, steel industry
- Need for
  - In-situ flow monitor
  - Non-intrusive
Direct Flow Measurement

• Current powder flow rate measured indirectly
  – Impeller rotational speed
  – Cannot detect if powder supply tube is restricted or completely clogged
  – Effect of flowability of powder cannot be considered

• AE data has correlation coefficient greater than .95 with respect to actual flow rate
AE in Manufacturing

- Widely used to track quality in welding processes
  - Monitors structural integrity based on analyzing acoustic signature of a manufacturing process
- ASTM E749-07 provides guidelines for AE monitoring of weldments
- AE is proven monitoring technique in bridge, pressure vessel, and pipe monitoring
Project Discoveries

• Proper sensor placement produces linear root mean square response to powder mass flow rate is changed
  – Straight bore cavity for unimpeded powder flow
  – AE sensor covers multiple bore diameters for signal averaging & high signal-to-noise ratio
  – AE sensor acoustically isolated from build head and build platform motion noise
Normal Build Conditions

- AE data from normal build conditions
- RMS ≈ 625 µV
- Satisfactory outcome
Excessive Gas Pressure

- AE data from build with excessive argon gas pressure
- RMS $\approx 1150 \mu V$
- Unsatisfactory outcome
Experimental Methods

- Flexible tubing attached to each nozzle
- Tubes send powder to reservoirs
- Scale weighs reservoir assembly as powder feeder settings are adjusted (@ 10Hz)
- AE sensor recording
Order of Operations of Signal Conditioning

1. RMS of AE
2. Resample
3. Lag Shift
4. Regression
Results

• Mathematical relationship AE RMS to powder mass flow rate

\[ \dot{m} = \beta_3 \text{rms}^3 + \beta_2 \text{rms}^2 + \beta_1 \text{rms} + \beta_0 \]

Equation 1: Function of RMS

<table>
<thead>
<tr>
<th>( \beta )</th>
<th>Value</th>
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<tbody>
<tr>
<td>( \beta_3 )</td>
<td>8.16e-15</td>
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<tr>
<td>( \beta_2 )</td>
<td>1.76e-9</td>
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<td>7.8e-6</td>
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<td>( \beta_0 )</td>
<td>.822</td>
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</table>
Results

- $r^2 > .97 \rightarrow$ Very strong Correlation

![Graph showing flow rate measured and flow rate calculated from AE (rms)]

- Polynomial: $8.1607e-15 \text{rms}^3 + 1.7592e-09 \text{rms}^2 + 7.8019e-06 \text{rms} - 0.82221$

Correlation Coefficient ($r^2$): 0.97448
User Interface

Motor Setting

Set Flow Rate

Actual Flow Rate From AE Data
Future AE Development

- Frequency Spectrum Analysis
- Two sensor time difference
- Individual nozzle monitoring
- Real-time powder feed control system
Resources

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