Detection of side-arc conditions in Vacuum Arc Remelting (VAR)

Presented by Matt Cibula, PhD

TITANIUM 2016
Value Proposition

• Decreased maintenance costs
• Decreased down time
• Increased safety
Outline

• Arc Position Sensing (APS) – background and theory
• Motivation
• FEM method side-arc simulations
• Inducing side-arcs during VAR
• Results
• VARmetric
Vacuum Arc Remelting

- Material refinement process that increases the homogeneity of the input material for high performance metals such as Titanium
- Input consumable electrode is heated by arc in vacuum and into a water-cooled copper crucible
- Arc is made of cathode spots
- Cathode spot current density on the order of $10^{12}$ A/m$^2$
- Enough power to melt the copper crucible, if in contact!

Sketch Courtesy of ATI Allvac
Arc Position Sensing (APS)

- APS uses Maxwell-Ampere law to locate currents in 2-D
  \[ \nabla \times \vec{B} = \mu \left[ \vec{J} + \frac{\partial \vec{D}}{\partial t} \right] \n\]
- All electric current sources generate superimposed magnetic fields – including the arc!
- Arc movement induces changes in source current paths
- Only need vector direction to current source and geometry of furnace
Background

• Arc location during melting is relevant to melt safety, quality, and yield
• Real time measurements of arc location provide new information for process improvements
• APS initially developed at NETL, Albany, OR with the SMPC (Specialty Metals Processing Consortium)
• Technology tested on coaxial and non-coaxial commercial VAR furnaces
Background

- Arc location during melting is relevant to melt safety, quality, and yield.
- Real time measurements of arc location provide new information for process improvements.

VARmetric gives real-time arc position data side-by-side with standard process measurements, and is able to detect furnace dynamics that were previously unseen.
Motivation

- Problems related to side-arcs
  - Small side-arcs may pit the crucible, weakening the side-wall and may cause future problems
  - Damage to crucibles can be costly
    - Crucible repair
    - Down time
  - Can introduce copper into the ingot
  - Can melt through the copper crucible & release cooling water into furnace
- Side-arcs are not detectable with standard VAR process measurements (current, voltage...)
- Measureable effects of side-arcs
  - Strength/cause are largely unknown
  - Causes a change in the current pathway through furnace
  - Magnetic field around furnace is a superposition of side-arc and normal arc contribution
  - Changes in magnetic field are readily detected by VARmetric sensors
Even in side-arcs very close to the melt pool, there are measurable differences in the current density.
Simulated Magnetic Fields

Normal Arc

Side-Arcs

\( B_N = \text{Total magnetic field (} B_x, B_y, B_z \text{)} \)

Vertical symmetry is strongly broken by side-arc
Experimental Validation

- Experiments on industrial scale, commercial VAR furnace at ATI
Side Arc Results

- Here, side-arc lasted 0.17 seconds, data collected at 120 Hz
- Prominent peak detected by sensors near the pin location
Sensor measurements during side-arc

- Black – experimental data before/after side-arc (+/- 1 second)
- Red – experimental data during side-arc (0.2 s)
Conclusions

- Side-arcs are costly, uncontrollable events
- Side-arcs are not detectable with standard VAR process measurements
- Simulations show that side-arcs are measureable by VARmetric
- AmpSci ran tests in a production furnace to generate side-arcs under controlled conditions
- Measurements of the side-arc agree with the changes predicted by simulations
- VARmetric detects side-arcs in real time and alerts operators of this hazardous condition, improving melt safety and preventing monetary losses
Other VARmetric Features

**Current Features**
- Measurements of process inputs at 120 Hz, synchronized with arc location
- Embedded controller for data acquisition and logging
- Software options:
  - *ObserVAR™* – Real time APS and analysis; primary use in safety applications
  - *AnalyVAR™* – Offline post-processing of data; primary use in quality applications
  - *OptiVAR™* – Combination of *ObserVAR* and *AnalyVAR*, and includes *AmpSci* support to produce quarterly optimization reports that will be used to improve furnace operations and ingot quality

**In Development**
- Automated control systems
- Integrating solidification models into OptiVAR
- Automated event characterization
Other AmpSci Services

We also provide:

• Camera/spectrometer solutions for arc furnaces and other industrial applications
• Data acquisition/control solutions
• Certified COMSOL users
• Consulting on arc furnace operations, specializing in post processing of data to help firms to better understand their furnace operations
Thank You

Thank you for your attention! If you would like to know more about Arc Position Sensing, VARmetric, have questions, or just want to chat, come meet the Ampere Scientific team at Booth #319.