The Effectiveness of Resistance vs. Current Control of Submerged-arc Furnace Electrode Penetration in Selected Scenarios

4 June 2009

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Introduction

• Background of submerged-arc furnaces
  – Circuit
  – Electrode considerations

• Control of submerged-arc furnaces
  – Various methods

• Reasons for this study
  – May be circumstances where one is preferable to the other
  – Evaluate this from all angles, not just power input
Submerged-arc Furnace

- Power supplied by three transformers
- Søderberg self-baking electrodes
- Electrodes interconnected via molten metal bath
Self baking
  – Steel casings
  – Paste blocks
    • Melted and baked solid by heat from the electrode’s own current
    • Baking rate depends on (electrode current)$^2$

Slipping
  – Compensates for erosion of electrodes
  – Over/under slipping results in long/short electrodes
  – Slip rate needs to be matched with baking rate otherwise risk of breakage
Basic Circuit of Submerged-arc Furnaces

Reactances (~fixed - furnace geometry)

Resistances (variable by raising or lowering electrodes)

Metal bath in furnace
The Interaction Effect

Electrode
Current
Resistance

1
2
3
The Interaction Effect (2)

Electrode  | Current | Resistance
-----------|---------|-----------
1           |         |           
2           |         |           
3           |         |           

Diagram showing interaction effects at different points.
Control of Electrode Penetration

• Traditionally current control
  – Availability of measurements
  – Suffers from interaction effect
  – Variable penetration at different loads

• Impedance/Resistance control
  – Less sensitive to interaction effect
  – Difficult to measure reliably due to
    • Hearth connection
    • Induced errors in measurements due to magnetic fields

• Calculated resistance control
  – No hearth connection required
  – Can be calculated from primary side which can be measured more accurately
• Resistance control generally accepted as superior to current control

• But: in upset/unstable conditions some furnace operators attempt to balance furnace:
  – current control
  – manual operation (invariably using current as a reference)

• Is this course of action justified under certain circumstances?
  – Consider from all aspects
Aspects Considered

- Overall power input
  - Production

- Power distribution
  - Electrode consumption, build-ups, efficiency

- Hoist position
  - Efficiency

- Current asymmetry
  - Energy supply penalties

- Sum of squares error in current
  - Affects baking rate → maximum slip rate
Scenarios Considered

- All Electrodes Free (FR) ↑↑↑
  - Analogous to having all electrodes near their correct, ideal lengths.
  - All electrodes operate within the limits of travel

- One Electrode On Bottom Stops (BS) ↑↓↓
  - Analogous to a short electrode on an industrial furnace
  - Electrode lowered to the bottom of its travel range in order to achieve the setpoint for resistance or current.

- One Electrode On Top Stops (TS) ↑↑⇑
  - Analogous to a long electrode on an industrial furnace
  - Electrode lifted to the top of its travel range in order to achieve the setpoint for resistance or current.
Test Platform

- Mintek Submerged-arc Furnace Simulator
  - Models entire electrical circuit
  - Disturbances simulated by adjusting metal bath level
    - Effectively alters tip-bath resistance/distance
    - Configurable rate and range
    - Configurable per electrode
  - Eliminates any effects caused by metallurgical conditions
    - Allows evaluation of electrical behaviour

- Simulation parameters
  - Furnace
    - 48 MVA Furnace
    - 88 kA electrode current limits
    - Power factor $\approx 0.85$
  - Control
    - 35 MW Power setpoint
    - 2.0 m$\Omega$ resistance setpoint
  - Conditions
    - Slow rate of change – tapping cycle
    - Rapid rate – burden collapse etc.
    - Disturbances simulated on electrode 3
Results – Total Power Input

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Resistance Control</th>
<th>Current Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BS</td>
<td></td>
<td></td>
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<tr>
<td>TS</td>
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</tbody>
</table>

Power (MW)
Results – Electrode Power Distribution

- **FR** Resistance
- **FR** Current
- **BS** Resistance
- **BS** Current
- **TS** Resistance
- **TS** Current

<table>
<thead>
<tr>
<th>Scenario</th>
<th>El1</th>
<th>El2</th>
<th>El3</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR Resistance</td>
<td>12</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>FR Current</td>
<td>11</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>BS Resistance</td>
<td>10</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>BS Current</td>
<td>9</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>TS Resistance</td>
<td>8</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>TS Current</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>
Results - Asymmetry

![Graph showing asymmetry results for different scenarios]

- Asymmetry (%)
- Scenario: FR (slow), FR (fast), BS, TS
- Categories: Resistance Control, Current Control
Electrode Penetration – Free Travel

Average Deviation of Tip-Bath Distance

Scenario

Deviation (mm)

Res (slow) | Res (fast) | Curr (slow) | Curr (fast)

EL1 | El2 | El3

MINTEK
Electrode Penetration – Free Travel (2)

Average Deviation of Tip-Bath Distance (multiple power factors)
Electrode Penetration – Free Travel (3)

**RESISTANCE CONTROL**

**CURRENT CONTROL**
Explanation:

A. Resistance 3 drops
B. Electrode 3 already at top stops
C. Current 3 (and 1) exceeds limits
D. Controller taps down to reduce currents
E. Current 2 drops

*If under current control:*

F. El 2 would be pushed in to restore current;
G. El 3’s current would increase further!
H. Further tap down actions required yielding lower power
### Summary

<table>
<thead>
<tr>
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<th>Resistance Control</th>
<th>Current Control</th>
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<tbody>
<tr>
<td><strong>Free Travel</strong></td>
<td>Similar to current control in stable conditions, high pf</td>
<td>More unbalanced/more electrode movement in upset conditions (interaction effect)</td>
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<tr>
<td>‣ ‣ ‣</td>
<td></td>
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<tr>
<td><strong>Bottom Stops</strong></td>
<td>Balanced power, avoids chronic imbalance</td>
<td>MW on shallow electrode – low efficiency Chronic imbalance</td>
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<tr>
<td><strong>Top Stops</strong></td>
<td>Better MW</td>
<td>Lower power Better penetration, symmetry &amp; $I^2$ -&gt; better baking</td>
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<td>‣ ‣ ‣</td>
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Options/Conclusions

• Better to use resistance control under all scenarios, including top stops, unless baking of electrodes is a major issue.

• With a flexible control platform one could monitor electrode conditions, slipping, baking zone etc and intelligently adapt control method.

• Little justification, however, since power input is typically the main objective from a production perspective.
Thank you

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