A Study on CCC of Fine Pitch Vertical Probe; Simplified CCC Formula and its Verification

Sanghun Shin
Jong-Hyun Park
Willtechnology Co., Ltd.
Overview

• Background
• CCC Methodology Review
  - ISMI(09’), Current spike(10’), FFI(11’)
• Former CCC Formulae
• Probe CCC Test under Varying Temperature: T-CCC
• Correlation
• Conclusion
• Future Work
Background

• **Shrinking probe pitch**
  – Leads to the probe fusing & burnt
  – Platinum group metals have limitation for the probe

• **Expectation of high temperature performance**
  – Requires higher CCC value with fine pitch
  – Requires more thermal reliability

• **Previous CCC studies were focused on “CRES”**
  – Focus moved to “Temperature” and its relative parameters
  – A study of temperature dependent CCC did not presented in SWTW so far
CCC Methodology Review

• **ISMI (SWTW, 2009)**
  - Step ramp after steady current
    \(\rightarrow\) 20% force reduction test

• **Current spike & Lifetime reliability test (SWTW, 2010)**
  - Step ramp after pulse current
    \(\rightarrow\) Current spike CCC testing
    \(\rightarrow\) Lifetime reliability CCC testing

• **FFI standard (SWTW, 2011)**
  - Continuous ramp
    \(\rightarrow\) Ramp up current until fail
    \(\rightarrow\) Long term stress
Former CCC Formulae

• Joule heating
  – Joule heating equation
    \[ P = I^2 \times Cres \]

• Joule heating upon temperature variation
  – Joule heating equation for temperature dependant
    \[ \Delta V = RI = [\rho_0 + \alpha(T - T_{ref})] \frac{L}{A} I \]

• Power system design
  – CCC predicted equation
    \[ I = \frac{A}{L} \sqrt{\frac{k}{\rho}} \sqrt{\Delta T} \]
Temp-CCC (T-CCC) Mechanism

- **T-CCC mechanism in terms of a probe**
  - The heat generation equals to the dissipation
  - \( Q_{\text{generated}} = Q_{\text{dissip.convection}} + Q_{\text{dissip.conduction}} \)
In case of pin array

- **T-CCC mechanism of the array probes**
  - Temperature gradient when the probes form array
  - Effective factor:
    - Coefficient of convection \((h)\)
    - Ambient temperature \((T_a)\)

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**T-CCC Formulation**

- **New CCC formula including temp. variation: T-CCC**
  - T-CCC parameters:
    - Resistivity @Initial temperature ($\rho_0$)
    - Diameter ($d$)
    - Probe length ($L$)
    - Temperature ($T_{ref}$)
    - Thermal diffusivity ($\alpha$)
    - Thermal conductivity ($k$)
    - Thermal convection coefficient ($h$)
    - Multiplier ($\beta$)

\[
I = A \sqrt{\frac{\Delta T}{\rho_0 + \alpha(T - T_{ref})}} \cdot \sqrt{\frac{k\beta^2}{L^2} + \frac{4h}{d}}
\]
T-CCC Formulation

- New CCC formula including temp. variation: T-CCC
  - T-CCC parameters:
    - Resistivity, function of temperature ($\rho$)
    - Probe length ($L$)
    - Temperature ($T$)
    - Area ($A$)
    - Simplified multiplier ($\beta'$)

Where $k$, $h$ are considered as constant due to:
- Thermal conductivity ($k$) is unchanged in 25°C to 100°C
- The coefficient of convection ($h$) is negligible.

\[
CCC = \beta' \frac{A}{L} \sqrt{\frac{1}{\rho(T)}}
\]
T-CCC Test

- T-CCC measurement setup
  - ISMI CCC test setup + Temperature control system
CCC vs. Temp of P7
(ISMI guideline)

- **T-CCC test temperature**
  - RT, 60°C and 90°C

- **Results**
  - CCC ↑ as probe dia. ↑
    - \( \text{CCC} \propto A \)
  - CCC ↓ as temperature ↑
    - \( \text{CCC} \propto \rho^{-1/2} \)
  - Determinants:
    - Probe tip diameter
    - Temperature is highly relative to resistivity
    - The resistivity affect CCC
CCC vs. Temp of Alloy W1
(ISMI guideline)

- **T-CCC test temperature**
  - RT, 60°C and 90°C

- **Results**
  - CCC ↑ as probe dia. ↑
    - $CCC \propto A$
  - CCC ↓ as temperature ↑
    - $CCC \propto \rho^{-1/2}$

**Alloy W1 has higher CCC**

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Error of CCC prediction for P7 probe
- Error range: ≤ 8%
  - Probe length uniformity
  - The other geometric error
  - Resistivity tolerance

Difference of $k$
- $k \leq 3$
- Almost constant at RT to 90°C
Correlation of Alloy W1 between experimental data and formula

- **Error of CCC prediction for “Alloy W1” probe**
  - Error range: ≤ 4%
  - Probe length uniformity
  - The other geometric error
  - Resistivity tolerance

- **Decisive parameter:** Resistivity!
Conclusion

- The high density of probe pin array causes the increasing temperature in the center region.
  - CCC decreased as the resistivity increased.

- Resistivity of the material was a critical factor in T-CCC formula.
  - Temperature $\uparrow \rightarrow$ Resistivity $\uparrow \rightarrow$ CCC $\downarrow$
  - Thermal conductivity, $k$ was neglected
  - Convection, $h$ was neglected

- Geometric factors—diameter and length of the probe—were also contributed the CCC result
  - Assumed all of the probes were identical
Conclusion

- Will technology designed “Alloy W1” showed much higher CCC than P7 probe.

- Calculated CCC values by T-CCC formula were similar to the experimental results.
  - The effect of neglected parameters in the T-CCC formula is less than 8% of error.

<table>
<thead>
<tr>
<th>Design</th>
<th>Predicted error (25°C~90°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design A (P7)</td>
<td>&lt; 8%</td>
</tr>
<tr>
<td>Design B (P7)</td>
<td>&lt; 4%</td>
</tr>
<tr>
<td>Design A (W1)</td>
<td>&lt; 4%</td>
</tr>
</tbody>
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Future work

• Effect of probe pin array (i.e. array size, pitch, and clearance) in T-CCC

• A research of parametric formulation for a major parameter, CRES

• Effect of surface coating in T-CCC

• A research of CCC variation depending on tip shaping
Reference


• Matthew C. Zeeman, “A New Methodology for Assessing the Current Carrying Capability of Probes used at SORT”, SWTW 2010.


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Sanghun Shin
General manager
Willtechnology Co., Ltd.
(82-31) 240-5580
E: sh.shin@willtechnology.co.kr

Jong-Hyun Park
Assistant Manager
Willtechnology Co., Ltd.
(82-31) 240-5574
E: park.jh@willtechnology.co.kr

Kang-Dae Lee
Assistant Manager
Willtechnology Co., Ltd.
(82-31) 240-5703
E: kd.lee@willtechnology.co.kr

Young-Bu Kim
CTO
Willtechnology Co., Ltd.
(82-31) 240-5588
E: yb.kim@willtechnology.co.kr