Development of a joint resistance evaluation system (2) -Commissioning results-

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1. Introduction

Joint resistance measurement by using LR closed circuit method

Procedure
1. Set sample temperature (4~90 K)
2. PCS heater ON (locally up to 100 K)
3. Injection coil current (ICC) ON
4. PCS heater OFF
5. Waiting (sample temperature stabilization)
6. ICC OFF
7. Measurement of Hall sensor output (current of HTS sample loop)

Data fitting

\[ V(t) = A + Be^{\frac{-t}{L/R}} \]

A, B: fitting parameters
L: self-inductance of loop (measured)
R: circuit resistance

Injection coil specification

<table>
<thead>
<tr>
<th>Conductor</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding</td>
<td>4725 turn</td>
</tr>
<tr>
<td>Inner/outer diameter</td>
<td>20/35 mm</td>
</tr>
<tr>
<td>Self-inductance, L</td>
<td>0.49 H (measured)</td>
</tr>
<tr>
<td>Coil constant</td>
<td>61 mT/A</td>
</tr>
</tbody>
</table>

Larger \( L \) and smaller \( R \), current decay becomes slower
2. Cooling test

cooling start at $t = 0$

Temperature (K)

Time (hours)

Thermometer position

1. radiation shield flange 30.0 K
2. radiation shield end 31.5 K
3. injection coil bobbin bottom 27.0 K
4. injection coil bobbin top 27.2 K
5. 2nd stage cold head 2.68 K
6. sample holder base 2.75 K
7. sample holder end 2.81 K
8. sample (Hall sensor) 3.03 K
9. sample (loop) 2.77 K
10. sample (PCS heater) 2.82 K

$T_{\text{sample}} \leq 3$ K
3. 10 turn loop sample

<table>
<thead>
<tr>
<th>Conductor</th>
<th>Fujikura FYSC-SCF05 forming</th>
</tr>
</thead>
<tbody>
<tr>
<td>stabilizer</td>
<td>Cu, Sn</td>
</tr>
<tr>
<td>width, thickness</td>
<td>4 mm, 0.13 mm</td>
</tr>
<tr>
<td>insulation</td>
<td>polyimide film (t:25 μm)</td>
</tr>
<tr>
<td>critical current at 77 K</td>
<td>~230 A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>joint</th>
<th>Sn63Pb37 solder, 50 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>winding</td>
<td>10 turn</td>
</tr>
<tr>
<td>inner diameter</td>
<td>100 mm</td>
</tr>
<tr>
<td>self-inductance, L</td>
<td>17 μH (measured)</td>
</tr>
</tbody>
</table>

Solder joint: ~100 nΩ in normal state
Superconducting < ~7 K

Tin layer becomes superconducting < 3.7 K
Temperature dependence

injection coil current (ICC) OFF

![Graph showing temperature dependence with Hall sensor output (mV) vs. time (sec.) for different temperatures. The graph demonstrates that smaller slope corresponds to smaller resistance (R).]
Decay fitting at 10 K

ICC = injection coil current

\[ V(t) = A + B e^{t L/R} \]

ICC: 0.8 A
ICC: 0.4 A
ICC: 0.2 A

Hall sensor output (mV)

Time (sec.)

33.4 nΩ
34.1 nΩ
34.1 nΩ
Decay fitting at several temperatures

Hall sensor output (mV)

6 K

10 K

40 K

77 K

Time (sec.)
3 K measurement

Hall sensor output (mV)

Time (hours)

0 6 12 18 24 30 36 42 48

ICC = injection coil current

injected current ~34 A
current is almost constant over 36 hours

ICC: 0.4 A

~67 A

10^{-10} \Omega

10^{-9} \Omega

~6 hours

0.2 A

0.25 A

0.3 A

0.4 A

ICC: 0.8 A

0.5

0.6

0.7

0.8

0.9

0 5 10 15 20x10^3

Time (sec.)

9/15
Decay fitting at 3 K, injection current ~34 A

- R < 10^{-13} \Omega can be measured
- Persistent current (Tin layer & solder) ~3.5 hours

Hall sensor output (mV)

- Time (sec.)

- Over I_c
Temperature dependence of resistance

<table>
<thead>
<tr>
<th>$T$ (K)</th>
<th>$R$ (Ω) ICC=0.8 A</th>
<th>$R$ (Ω) ICC=0.4 A</th>
<th>$R$ (Ω) ICC=0.2 A</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>$6.69 \times 10^{-9}$</td>
<td>$1.03 \times 10^{-9}$</td>
<td>$1.99 \times 10^{-12}$</td>
</tr>
<tr>
<td>6</td>
<td>—</td>
<td>$2.67 \times 10^{-8}$</td>
<td>$2.68 \times 10^{-8}$</td>
</tr>
<tr>
<td>10</td>
<td>$3.34 \times 10^{-8}$</td>
<td>$3.41 \times 10^{-8}$</td>
<td>$3.41 \times 10^{-8}$</td>
</tr>
<tr>
<td>40</td>
<td>$4.24 \times 10^{-8}$</td>
<td>$4.31 \times 10^{-8}$</td>
<td>—</td>
</tr>
<tr>
<td>77</td>
<td>$5.99 \times 10^{-8}$</td>
<td>$5.99 \times 10^{-8}$</td>
<td>—</td>
</tr>
</tbody>
</table>

~100 nΩ by 4-terminal method at 77 K
4. **1 turn loop sample**

<table>
<thead>
<tr>
<th><strong>Conductor</strong></th>
<th>SuperOX Japan, ST-4-100</th>
</tr>
</thead>
<tbody>
<tr>
<td>stabilizer</td>
<td>Cu</td>
</tr>
<tr>
<td>width, thickness</td>
<td>4 mm, 0.13 mm</td>
</tr>
<tr>
<td>insulation</td>
<td>polyimide film (<em>t</em>:25 μm)</td>
</tr>
<tr>
<td>critical current at 77 K</td>
<td>~140 A</td>
</tr>
<tr>
<td>joint</td>
<td>Sn63Pb37 solder, 50 mm</td>
</tr>
<tr>
<td>winding</td>
<td>1 turn</td>
</tr>
<tr>
<td>inner diameter</td>
<td>100 mm</td>
</tr>
<tr>
<td>self-inductance, <em>L</em></td>
<td>0.47 μH (measured)</td>
</tr>
</tbody>
</table>

Smaller *L* → Faster decay
Temperature dependences

Hall sensor output (mV)

Resistance (nΩ)

70% decay time at 10 K
10 turn loop, ~30 nΩ: ~10 min.
1 turn loop, ~20 nΩ: ~0.5 min.

ICC: 0.2 A

~100 A

3 K
4.3 K
10 K
40 K
77 K

~14.3 nΩ
Current Injection

Injected current was saturated above ICC = 0.4 A

Injected current increases in proportion to ICC

ICC = injection coil current
1. Current decay was successfully measured in the temperature range of 3 to 100 K.

2. Measured decay follows $LR$ decay equation very well.

3. Resistances between $10^{-8}$ and $10^{-14} \Omega$ were successfully evaluated.

**Summary**

- Current decay was successfully measured in the temperature range of 3 to 100 K.
- Measured decay follows $LR$ decay equation very well.
- Resistances between $10^{-8}$ and $10^{-14} \Omega$ were successfully evaluated.