INFLUENCE OF THE COOLDOWN AT THE TRANSITION TEMPERATURE ON THE SRF CAVITY QUALITY FACTOR

Oliver Kugeler, Julia Vogt, Jens Knobloch

SRF 2013 Paris, France
Introduction

• Many new accelerator applications require CW SRF. Focus shifts to dynamic losses.
• Cryogenics = cost driver
• Minimize cryogenic load \( P_{\text{diss}} \sim R_{\text{surf}}E_{\text{acc}}^2 \)
  – Want low surface resistance at moderate gradients

\[
R_{\text{surface}} = R_{\text{BCS}}(f, T) + R_{\text{residual}}(?)
\]

  physics originates to great fraction from trapped vortices (incomplete Meissner effect)

• We found that cavity cooldown procedures have an impact on \( R_{\text{res}} \)
  – presumably due to the generation of additional flux from thermo currents
Flashback to SRF 2009

- Measured Q increase upon “thermal cycling” to about 40 K
- Effect not understood back then. New investigations have yielded an explanation: thermocurrents
Q₀ vs T measurements

- HoBiCaT test facility used
- Horizontal, fully equipped industrial cavity welded into Helium tank
- Configuration like in accelerator module
- Temperatures down to 1.5 K
- All measurement done with one cavity in one measurement run!
- Double magnetic shielding (warm shield + cryoperm)
  Small residual fields < 1 µT
- TTF-III coupler, near critical coupling (0.8 < β < 2.5)
- Verification of RF measurements with LHe-loss measurements and Lorentz detuning
  Error assumed smaller than 10%
Cavity cooldown procedure

Start of cooldown
\( \text{lHe @ 4.1 K} \)

Helium inlet used only during initial cooldown of cavity

Dynamics of Helium filling leads to large temperature gradients
Initial cool down

\[ \Delta T = 160 \text{ K in the instance of the sc transition} \]
Materials interfaces in cavity with tank

- gaseous Helium
- liquid Helium
- pump
- heater
- heater
- niobium
- titanium
- Temperature sensors
- Interface weld
- Coupler
- Tuner
- Cx 1
- Cx 2
- Cx 3
- Cx 4
Thermocurrents

- Cavity forms thermoelement
- Different Seebeck coefficients for Nb and Ti

\[ U_{\text{thermo}} = (S_{\text{Niobium}} - S_{\text{Titanium}}) \cdot \Delta T \]
Cycling temperature profiles

Temperature difference between cavity ends when one end is making transition

Generated temperature differences between 5 K and 90 K
Surface resistance measurements

Arrhenius plot:
Residual resistance from asymptote

Initial cooldown
$Q_0 = 1.6 \times 10^{10} @ 1.8 \text{ K}$

$E_{\text{acc}} = 4 \text{ MV/m}$

Oliver Kugeler, SRF 2013, Paris, France
Influence of the cooldown at the transition temperature on the SRF cavity quality factor
Results

Initial cool down (very different temperature profile due to LHe filling from bottom) → difficult to “compare apples with oranges”

Corresponds to 3µT trapped flux

Clear increase of $R_{res}$ with $\Delta T$

Lowest limit achieved
Residual resistance due to other mechanisms or ambient magnetic field

$$U_{\text{thermo}} = (S_{\text{Niobium}} - S_{\text{Titanium}}) \cdot \Delta T$$

$U_{\text{thermo}}$ drives thermocurrent and thus generates extra ambient field
Discarded reasons for $R_{\text{res}}$ variation

<table>
<thead>
<tr>
<th>Hypothetical reasons for the improvement of $R_{\text{res}}$</th>
<th>Not the reason here because</th>
</tr>
</thead>
<tbody>
<tr>
<td>surface morphology</td>
<td>same cavity</td>
</tr>
<tr>
<td>RRR</td>
<td></td>
</tr>
<tr>
<td>crystallinity, granularity</td>
<td></td>
</tr>
<tr>
<td>total hydrogen content</td>
<td></td>
</tr>
<tr>
<td>systematic differences</td>
<td>measurement taken in same run</td>
</tr>
<tr>
<td>calibration errors</td>
<td></td>
</tr>
<tr>
<td>magnetic shielding efficacy</td>
<td>shield $\mu_r$ constant</td>
</tr>
<tr>
<td>adsorbate removal</td>
<td>process irreversible</td>
</tr>
<tr>
<td>Q-disease</td>
<td>never leads to decrease of $R_{\text{res}}$</td>
</tr>
</tbody>
</table>

Chronological order of measurements

<table>
<thead>
<tr>
<th>Procedure</th>
<th>$R_{\text{res}}$ (nΩ)</th>
<th>$\Delta R_{\text{res}}$</th>
<th>$\Delta T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooldown</td>
<td>11.7</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>Cycle 1</td>
<td>6</td>
<td>decrease</td>
<td>~5.5</td>
</tr>
<tr>
<td>Cycle 2</td>
<td>5.6</td>
<td>decrease</td>
<td>~5.5</td>
</tr>
<tr>
<td>Cycle 3</td>
<td>13.9</td>
<td>decrease</td>
<td>90</td>
</tr>
<tr>
<td>Cycle 4</td>
<td>5.4</td>
<td>increase</td>
<td>~5.5</td>
</tr>
<tr>
<td>Cycle 5</td>
<td>5.5</td>
<td>increase</td>
<td>~5.5</td>
</tr>
<tr>
<td>Cycle 6</td>
<td>7.2</td>
<td>increase</td>
<td>45</td>
</tr>
<tr>
<td>Cycle 7</td>
<td>5.5</td>
<td>decrease</td>
<td>~5.5</td>
</tr>
<tr>
<td>Cycle 8</td>
<td>9.6</td>
<td>increase</td>
<td>67</td>
</tr>
</tbody>
</table>

Change in $R_{\text{res}}$ reversible
Conclusion and outlook

• Improve residual resistance by thermal cycling
• Factor of 2 improvement and reduction is demonstrated depending on cycling conditions.
• Thermocurrents most plausible explanation as a source of additional magn. flux that is trapped during the SC transition.
• Implement additional step in standard cavity cooldown procedure.
  – Pause cooldown a little above $T_c$ long enough to reach thermal equilibrium (presumably > 12 hours)
  – Alternatively, introduce additional short thermal cycle above $T_c$.
• Implemented in HoBiCaT procedure, but cryoplant currently down so that tests have not yet been possible.