RF Characterisation of HTS-CC Tapes as Alternative Coating for the FCC-hh Beam Screen

Patrick Krkotić\textsuperscript{1,2}, Joan O’Callaghan\textsuperscript{2}, Montse Pont\textsuperscript{1}, Francis Perez\textsuperscript{1} Artur Romanov\textsuperscript{3}, Joffre Gutierrez\textsuperscript{3}, Teresa Puig\textsuperscript{3}
## Index

<table>
<thead>
<tr>
<th>Beam Screen Design</th>
<th>FCC – hh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coated Conductor Coating</td>
<td></td>
</tr>
<tr>
<td>Requirements</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experimental Setup</th>
<th>Dielectric Resonator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Resistance</td>
<td></td>
</tr>
<tr>
<td>Surface Current Density</td>
<td></td>
</tr>
<tr>
<td>Surface Reactance</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conclusion and Outlook</th>
<th>Summary</th>
</tr>
</thead>
</table>
Beam Screen Design FCC-hh
Coated Conductor Coating

[1] Ignasi Bellafont et al.
Beam Screen Design

FCC-hh

- Nominal aperture:
  - H: 28.37 mm
  - V: 24.4 mm

- Slit height:
  - 7.5 mm

- Beam screen:
  - 1.0 mm steel
  - 0.3 mm copper

- Operating temperature
  - 50 ± 10 K

[1] Ignasi Bellafont et al.
Beam Screen Design
Coated Conductor Coating

- HTS coated conductor stripes
  - commercially available 2 – 12 mm

- Display on several chosen positions
  - e.g. alternating CC and Cu
  - lower ac losses

- Covered with amorphous Carbon to reduce SEY

- Reducing beam coupling impedance
  - low surface resistance
Beam Screen Design
Coated Conductor Coating

- HTS coated conductor stripes
  - commercially available 2 – 12 mm

- Display on several chosen positions
  - e.g. gradually increasing tapes
  - lower ac losses

- Covered with amorphous Carbon to reduce SEY

- Reducing beam coupling impedance
  - low surface resistance

[1] Ignasi Bellafont et al.
Beam Screen Design

Coated Conductor Coating

- HTS coated conductor stripes
  - commercially available 2 – 12 mm

- Display on several chosen positions
  - e.g. double track
  - lower ac losses

- Covered with amorphous Carbon to reduce SEY

- Reducing beam coupling impedance
  - low surface resistance
Beam Screen Design

Requirements

- Operating temperature:
  - $50 \pm 10$ K

- Magnetic field strength:
  - 1 – 16 T

- Emitted synchrotron radiation:
  - 35.4 W/m/beam

- Beam spectrum frequency:
  - up to 3 GHz

- Image current per bunch:
  - $25$ A -> $J_C = 25$ kA/cm$^2$

[1] Ignasi Bellafont et al.
Experimental Setup

Dielectric Resonator
(compatible with a PPMS system)
Dielectric Resonator

Surface Resistance

- Shielded Hakki-Coleman type
- Samples replace upper and lower plates
- Operating in the TE\textsubscript{011} mode
  - insensitive to electrical contact of the sample with the metallic enclosure
  - resonance frequency at 50 K is 7.9 GHz
- Surface Resistance is defined as
  \[
  R_S = \frac{G_S}{2} \left( \frac{1}{Q_0} - p \cdot \tan(\delta) \right)
  \]

\( R_S \) = Surface resistance
\( G_S \) = Geometrical factor
\( Q_0 \) = Quality factor
\( p \) = Filling factor
\( \tan(\delta) \) = Loss factor

FCC Week 2019
We proved that close to FCC conditions (40-60 K, 8 GHz, 0-9 T), HTS surface resistance is lower than that of copper for most manufacturers.

Surface Resistance

Normal Conductor vs Superconductor

\[ R_{SCu} \propto \sqrt{f} \]

\[ R_{SC} \propto f^2 \]
Estimated value of the magnetic rf field for the FCC

- $H_{\text{max}} = 250 \text{ A/m} (0.3 \text{ mT})$

Magnetic field amplitude:

- $A \propto \sqrt{\frac{Q_0 P_{\text{diss}}}{\omega_0}}$
  
  $Q_0 =$ Quality factor
  
  $P_{\text{diss}} =$ Power dissipated
  
  $\omega_0 =$ Resonant frequency

Experimental set-up and losses

Analytical estimation of the distribution of rf magnetic field strength on a sample in the DR
Surface Current Density

Magnetic Field Amplitude

- Estimated value of the magnetic rf field for the FCC
  - \( H_{\text{max}} = 250 \text{ A/m } (0.3 \text{ mT}) \)

- Magnetic field amplitude:
  - \( A \propto \sqrt{\frac{Q_0 P_{\text{diss}}}{\omega_0}} \)
    
\( Q_0 = \text{Quality factor} \)
\( P_{\text{diss}} = \text{Power dissipated} \)
\( \omega_0 = \text{Resonant frequency} \)

<table>
<thead>
<tr>
<th>Sample</th>
<th>( H_{\text{max}}(50 \text{ K,0T}) )</th>
<th>( H_{\text{max}}(50 \text{ K,9T}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SuperPower</td>
<td>29 A/m</td>
<td>7 A/m</td>
</tr>
<tr>
<td>SuperOx</td>
<td>13 A/m</td>
<td>4 A/m</td>
</tr>
</tbody>
</table>

Analytical estimation of the distribution of rf magnetic field strength on a sample in the DR.
Surface Current Density
Magnetic Field Amplitude

- Estimated value of the magnetic rf field for the FCC
  - $H_{\text{max}} = 250 \text{ A/m} \ (0.3 \text{ mT})$

- Magnetic field amplitude:
  - $A \propto \sqrt{\frac{Q_0 P_{\text{diss}}}{\omega_0}}$

  - $Q_0 = \text{Quality factor}$
  - $P_{\text{diss}} = \text{Power dissipated}$
  - $\omega_0 = \text{Resonant frequency}$

- Experimental set-up and losses

Analytical estimation of the distribution of rf magnetic field strength on a sample in the DR
Surface Current Density

Power

- Estimated value of the magnetic rf field for the FCC
  - \( H_{\text{max}} = 250 \text{ A/m} \) (0.3 mT)

- Magnetic field amplitude:
  - \( A \propto \sqrt{\frac{Q_0 P_{\text{diss}}}{\omega_0}} \)
    - \( Q_0 = \) Quality factor
    - \( P_{\text{diss}} = \) Power dissipated
    - \( \omega_0 = \) Resonant frequency

- Experimental set-up and losses

FCC Week 2019

25/06/2019
Surface Current Density

Thermal Runaway – R. Vaglio & S. Calatroni

- Transversal thermal resistance is the sum of individual thermal resistances

Surface Current Density

Thermal Runaway – R. Vaglio & S. Calatroni

- Transversal thermal resistance is the sum of individual thermal resistances

\[
R_{\text{surface}} = R_n = \text{Surface resistance}
\]

\[
R_T = \text{Thermal resistance}
\]

\[
P_{\text{RF power dissipated}}
\]

\[
R_S(f, T) = \frac{T - T_0}{R_T} \frac{R_{nCu}}{P_{rfCu}}
\]

- Linear relationship

Increase in temperature

Increase in Power

Increase of surface resistance

Thermal Runaway

Thermal Equilibrium

FCC Week 2019
Surface Reactance
Magnetic Field

- A perturbation in temperature or/and magnetic field produces a relative change in resonant frequency according to

\[ -2 \frac{\Delta f_0}{f_0} = \frac{\Delta X_S}{G_S} + \frac{\Delta X_m}{G_m} + p \frac{\Delta \varepsilon_r}{\varepsilon_r} \]


- \( f_0 \) = Resonant frequency
- \( X_S \) = Surface reactance of SC
- \( X_m \) = Surface reactance of Brass
- \( \varepsilon_r \) = Permittivity of dielectric
Surface Reactance
Magnetic Field

- A perturbation in temperature or/and magnetic field produces a relative change in resonant frequency according to

\[-2 \frac{\Delta f_0}{f_0} = \frac{\Delta X_S}{G_S} + \frac{\Delta X_m}{G_m} + \phi \frac{\Delta \varepsilon_t}{\varepsilon_r}\]

Temperature stability

**CC with Nanocomposites**

<table>
<thead>
<tr>
<th>Magnetic Field [T]</th>
<th>Sample 1</th>
<th>Sample 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>200</td>
<td>-200</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>-400</td>
</tr>
<tr>
<td>3</td>
<td>-200</td>
<td>-600</td>
</tr>
<tr>
<td>4</td>
<td>-400</td>
<td>-800</td>
</tr>
<tr>
<td>5</td>
<td>-600</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-800</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>-800</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>-800</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>-800</td>
<td></td>
</tr>
</tbody>
</table>
Surface Reactance
Magnetic Field

- A perturbation in temperature or/and magnetic field produces a relative change in resonant frequency according to

\[-2 \frac{\Delta f_0}{f_0} = \frac{\Delta X_S}{G_S} + \frac{\Delta X_m}{G_m} + p \frac{\Delta \varepsilon_r}{\varepsilon_r}\]

- Study the different influences of the real and imaginary part of beam coupling impedance on the beam stability.
Surface Reactance
Magnetic Field

A perturbation in temperature or/and magnetic field produces a relative change in resonant frequency according to

\[-2 \frac{\Delta f_0}{f_0} = \frac{\Delta X_S}{G_S} + \frac{\Delta X_m}{G_m} + p \frac{\Delta \varepsilon_r}{\varepsilon_r}\]

This measurement can be used to determine the depinning frequency:

\[\Delta X_S \approx f^2 + f_{dep}^2 + f_{dep} \approx 3.7 \text{ GHz}\]

Study the different influences of the real and imaginary part of beam coupling impedance on the beam stability.
Conclusion & Outlook

- Surface Resistance in all samples is significantly lower than that of copper at 8 GHz up to 9 T

- RF magnetic field strength on the sample at FCC condition does not significantly change the surface resistance value

- Extrapolation to FCC working conditions is favourable for Coated Conductors

- First tests showed that the thermal runaway is no problem
  - Continue studies

- Investigation of the depinning frequency
  - Beneficial for surface impedance to operate below depinning frequency

- Getting closer to FCC conditions

- Improving resonator configurations to lower frequencies, temperature stability

- HTS behaviour under synchrotron irradiation
  - ‘HTS REBaCuO coated conductors for the FCC-hh beam screen: Performance under photon irradiation at the ALBA Synchrotron Light Source’
References


