Evaluation of Joint Resistance and Bending Performance of Various Ultrasonic Weld CC Joints

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Introduction

In practical applications, the superconducting coils and magnets impose to use joints to connect the unit lengths of 2G CC tapes and to constitute the termination of winding units such as in the cases of pancakes and double pancakes coils.

Relevant joining technique that recently emerged in superconducting tape joints is ultrasonic welding. The localized high frequency ultrasonic vibration and pressure generated frictional heat and achieve metallurgical bond at contacting interfaces without melting the base metal.

In this study, to further enhance the capability of the UW method to Cu stabilized REBCO CC tape joints, lap- and bridge-joints intended to be embedded in the coils using intermediate CC tapes were considered. The Taguchi Method, as design of experiments in optimizing the welding process parameters, was adopted to minimize the number of experiments.

Joint resistance, $R_j$ and critical current, $I_c$ measurements of UW CC joints were measured at 77 K. Bending performance of UW CC bridge joints as a practical evaluation for magnet and coil applications were carried out and discussed.

Sample specifications

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fabrication process</th>
<th>Structure</th>
<th>Cross sectional views of Sample 1 at UW CC lap-joint interfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1</td>
<td>IBAD/GdBCO CC</td>
<td>Cu surround (&lt;15 ¥m thick)</td>
<td>High $R_j$ for bridge-joints were perhaps due to complex current transfer path and $R$ from voids at the joint interfaces.</td>
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<tr>
<td>Sample 2</td>
<td>IBAD/GdBCO CC</td>
<td>Cu surround (&lt;15 ¥m thick)</td>
<td>After bending, damage interface was only visible along the Ag/GdBCO/Buffer layer at 40 mm bending dia.</td>
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</tbody>
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Ultrasonic welding set-up and procedure

- Sample 1: 4-mm bridge-joint
- Sample 2: Single CC tape

Critical current, $I_c$, and joint resistance, $R_j$, measurement

- The welder can generate power up to 3.5 kW varying the vibration amplitude at fixed frequency of 20 kHz.
- Multiple $I_c$ measurement fixture was used.
- Voltage taps were clipped instead of soldering for an easier attachment.
- $I_c$ was measured using four-probe method at 77 K.
- $R_j$ was derived from the initial part slope of the $V-I$ curve.

Double bending test

- $I_c$ degradation also affects the increase of $R_j$ as the bending diameter decreases.
- 50-60 mm bending dia w/o $I_c$ degradation is considered safe as required in various CC tapes utility devices.
- Incomplete bonding and damages along the joint interfaces, even in the unbend UW CC joints.

Electromechanical properties of UW CC joints

- $I_c$ and $R_j$ of UW CC lap-joints after double bending tests

Results and Discussion

- No substantial $I_c$ degradation: up to 50 mm (0.26% bending strain)
- Abrupt $I_c$ degradation (~70% of $I_c$) at 40 mm bending diameter (0.62% bending strain)
- Sample 2: showed bending tolerance at the smaller diameters, increasing in a less sensitive way down to a 30 mm bending diameter.

Joint configuration

- Lap-joint: overlapping CC tapes on top of one another.
- GdBCO film sides facing each other, face-to-face structure

- Bridge-joint: indirect joint using an intermediate material.
- 4-mm and 12-mm bridges: suitable if the joint is required to extend or replace the CC tapes in the coil winding, like in the case of double pancake coils

Summary

- The retained $I_c$ of CC joints did not show any degradation after the UW process.
- A joint resistance ranging from ~100 to ~200 nΩ could be obtained for a lap-joint structure using the UW method. The double bending test of UW CC joints demonstrated a large tolerance to smaller bending diameter up to 50 mm without any $I_c$ degradation, which particularly within the minimum 100 mm required bending diameter in various CC device applications.
- The results were considered suitable for practical 2G CC device applications. To further improve the joint quality, hybrid UW variants and other joint configurations in CC coil winding application involving intermediate material, such as but, infiltrated, etc., are still needed.