**Microstructural and Superconducting Properties of Persistent Mode Joints Between NbTi Conductors (3A-WT-P-03.08)**

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### Introduction

- Joints with resistance $R_c > 10^{13}$Ω are a requirement for persistent mode magnet manufacture.
- Although mature jointing techniques exist, fundamental knowledge of NbTi joints remains limited [1].
- In this study, the microstructural and superconducting properties of soldered, spot welded, and cold pressed joints between monocrystal NbTi wires have been investigated, highlighting key metallurgical factors.
- A possible solution is presented which may allow for Pb-free, high field NbTi joints.

### Soldered Joints

Soldering with superconducting PbBi is the industry standard jointing technique for NbTi. In this study, soldered joints were made by the standard “matrix replacement” technique, which minimises filament oxides:

1. Dissolve Cu matrix from wires in molten Sn @ 350°C. Filaments coated with protective Sn.
2. Dissolve Sn layer in PbBi (80–85 wt.%) @ 350°C. Filaments coated with PbBi.
3. Twist filaments together and re-dip in PbBi. The pair are coated with PbBi over a joint length ~5 mm.

### Cold Pressed Joints

- NbTi can also be joined by cold pressing bare filaments. Hydrofloric acid (HF) is often used to remove oxides however, which is undesirable. Here HF etching was omitted to gauge requirement, and joints were made by:
  1. Etching off the Cu matrix in nitric acid: $\text{HNO}_3 \cdot 5\%$ (50 vol.).
  2. Twisting together the oxidised filaments and sliding inside an annealed Nb creep.
  3. Pressing in a die at various pressures up to ~600 MPa.

### Joint Microstructure

![Joint Microstructure](image)

**Superconducting Performance**

- A novel SQUID magnetometry technique was developed to measure joint superconducting properties [2].
- Miniature NbTi coils (of diameter 25 mm) are wound, joined, and loaded into a Quantum Design PPMS XL-7.
- Currents $I_c$ are induced and measured from coil moment $(j_0 t (H, T))$ versus field $(H)$ and temperature $(T)$.

### Hysteresis Loops

- Hysteresis loop width reflects joint (LB-T) – Bean’s model analogy.
- At $H = 0$ kG, jumping is suppressed and vastly different characteristics become evident for each joint.
- Current path and performance limitations evident by relating joint $I_c(B,T)$ the real joint materials.

### Resistance

- Resistance ($R(B,T)$) was measured from the time decay of the moment.
- A typical resistance data set for the spot welded joint is shown, with other joints showing similar behaviour.
- Resistances are within the persistent mode regime and grow sharply as $I_c$ is approached.

### Conclusions and Further Work

- The microstructural and superconducting properties of a range of NbTi joints have been measured.
- Spot welding forms joints with high $B_c$, however the process is difficult to control.
- Soldering yields a clean superconducting interface, but joints are limited by low solder $B_c$.
- Inter-filament bonding in nitric etched cold pressed joints is poor - joint performance is limited by the crimp.
- Use of matrix replacement vastly improves interfilament bonding, and use of Pb-based solders and warm pressing may produce a Pb-free, high performance joint.

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