Massachusetts Institute of Technology
22.68J/2.64J
Superconducting Magnets

April 10, 2003

• Lecture #7 – Magnetic Instabilities
  ➢ Flux Flow; Bean’s Critical State Model
  ➢ Magnetization; Flux Jumping
Magnetic Instabilities

- Derive from dissipative nature of flux motion in Type II superconductors
- Flux Flow → Flux Flow Resistivity
  - Key to understanding dissipation, local heating, and nature of magnetic instability
  - Requires understanding of the concept of the "critical state"
  - Leads to understanding of magnetization and hysteresis losses in changing magnetic fields
Measured Flux Penetration in a Type II Superconductor
Flux Enters in Quantized Vortices
Technical Type II Superconductors Display a Magnetic Hysteresis

The area under the magnetization loop is proportional to the dissipated energy per cycle, given by:

$$\text{Area} \propto \Delta B \Delta J_c d_{\text{eff}}$$
Measured Flux Jumps in a Magnetization Loop

![Graph depicting measured flux jumps in a magnetization loop.](image)
Fine Filaments in Nb$_3$Sn

**Strand**
(0.81 mm diameter)

**Sub-element Bundle**

**CICC**
(50 mm x 50mm)

**Superconducting Filament**
(~3 μm diameter)
Relevant Superconducting Wires are Complex Composites

Typical SSC Nb-47wt.%Ti strand (OST manufacture).

Typical reacted ITER Nb$_3$Sn strand (IGC manufacture).
Flux Jump Stability of High Temperature Superconductors

<table>
<thead>
<tr>
<th>$T$ [K]</th>
<th>$I_c$ [A]</th>
<th>$J_c$ [MA/m$^2$]</th>
<th>$C_s^*$ [kJ/m$^3$K]</th>
<th>$a_c$ [mm]</th>
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</table>

* Copper heat capacity.
AC Losses

Twisting the superconducting filaments in the composite wire is necessary to electrodynamically decouple them.

Twisting filaments also necessary to reduce coupling losses

Power dissipation $\propto (\text{Twist Pitch})^2$

Hysteresis losses
$\propto$ filament diameter ($\sim 1 \mu\text{m}$)

Hysteresis losses
$\propto$ strand diameter ($\sim 1 \text{ mm}$)
HTS Tape (BSCCO)