Conductor Mechanical Requirements and Characterization

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- **Military, especially Navy & Air Force, has high interest in Coated Conductor for motors & generators**
- **Rotating machinery for military applications is very high-stress environment for HTS coils & tapes, and has special requirements compared to civilian applications**
- ***Reinforced BSCCO has already been engineered to work in large Navy propulsion motor (ONR SuperDrive Program)***
- ***There is confidence that reinforced BSCCO also is suitable for large generators (Ref: DARPA/ONR SuperGEN Study)***

Outline

- Review BSCCO mechanical properties
- Preliminary results & Comments on Coated Conductors
- Summary

Primary Stresses Experienced by Tapes and Pancake Coils in Rotors

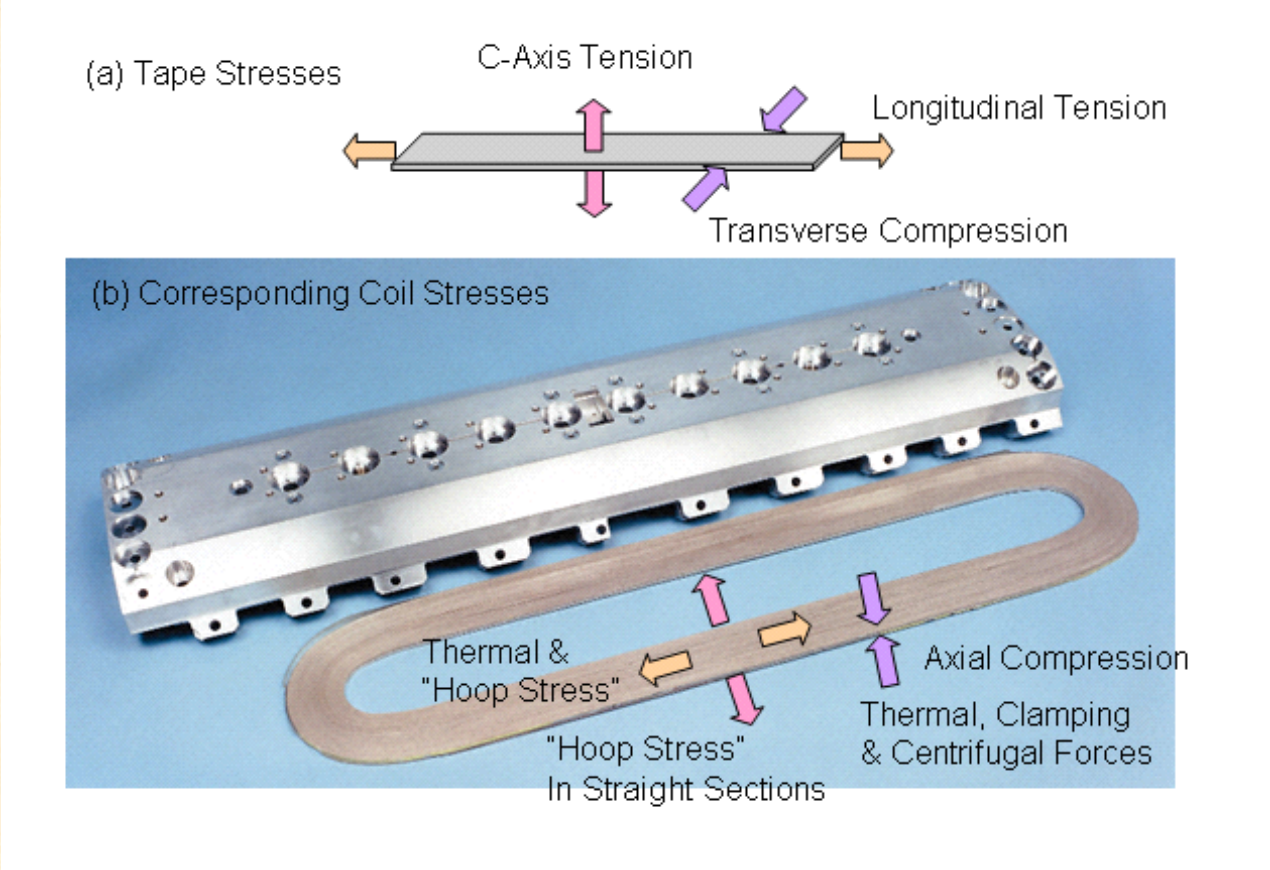
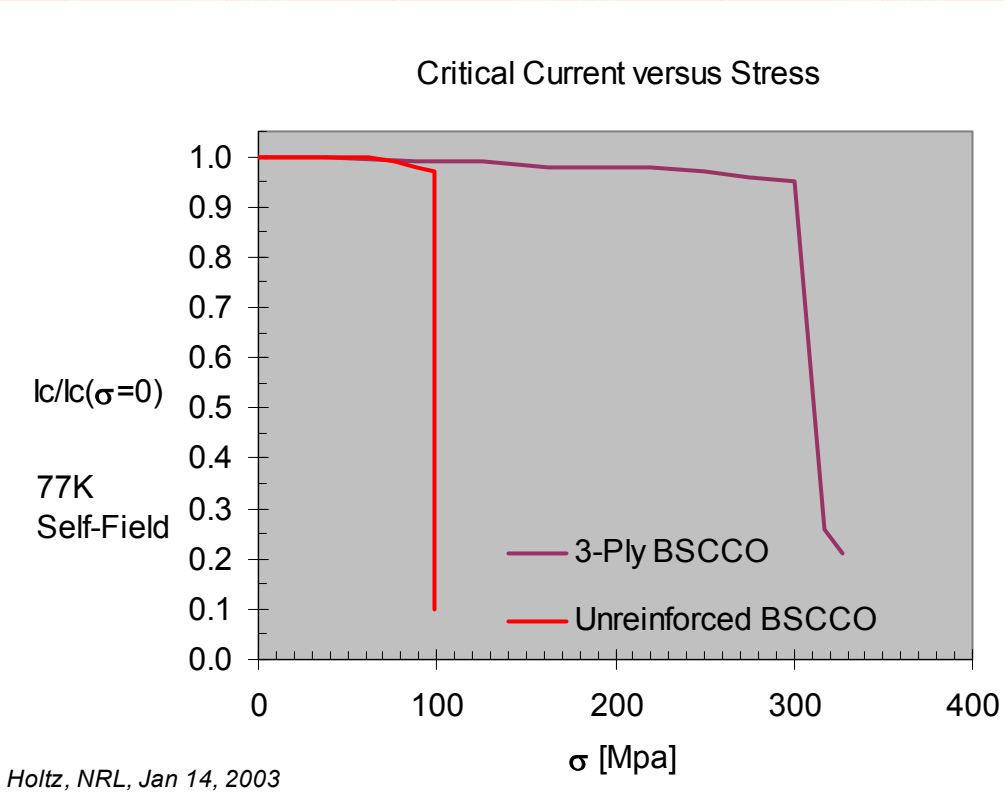


Figure 3.4.1.1-3 Illustration of the primary stresses on BSCCO pancake racetrack coils and tapes in generator or motor applications.

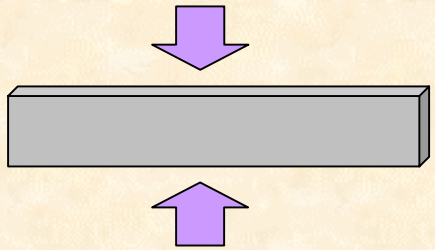
Ic versus Longitudinal Stress of BSCCO Multifilament Tapes



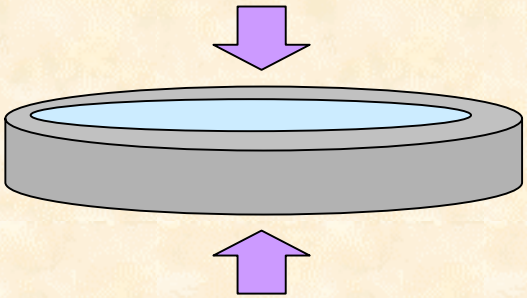
- **Remember that BSCCO has *very rapid* drop in Ic above yield stress**

Figures from www.AmSuper.com

Coil Axial Compression Strength



Tape Transverse Compression



Axial compression of Coil

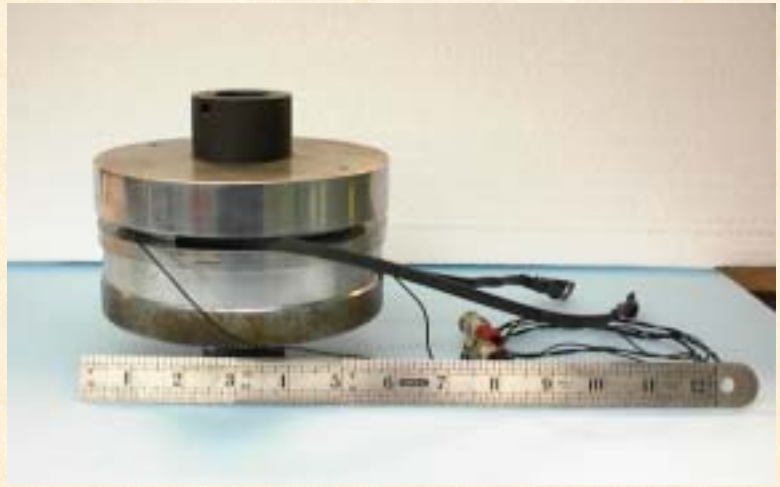
Requirements for Navy Low-Speed Motor:

1 MPa x 1000 Cycles
7 MPa x 1 Cycle

Requirements for Navy Generators
(e.g. 3600 RPM & up to 150 m/s tip speed)

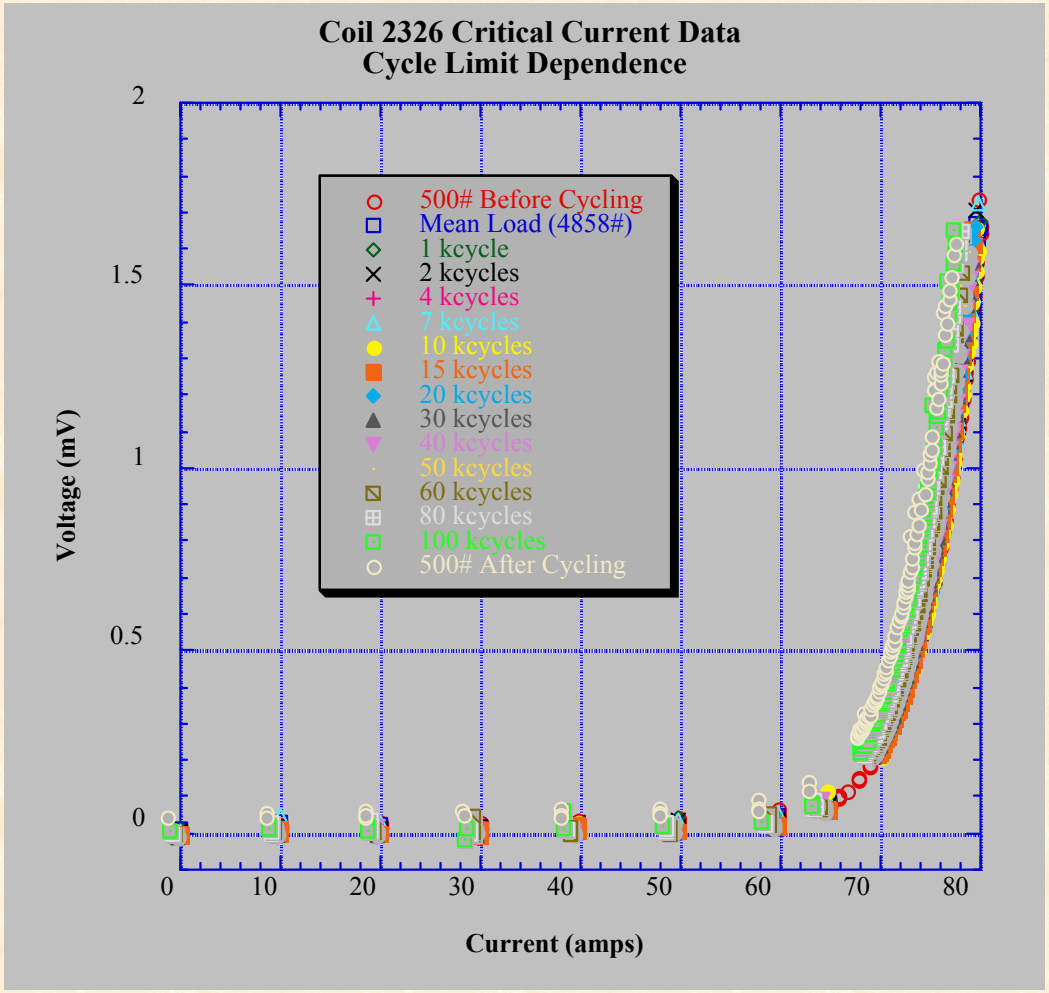
Up to 50 MPa
for up to 30 Years of Operation
(Maximum of 10,000 Start/Stop Cycles)

Coil Testing Setup

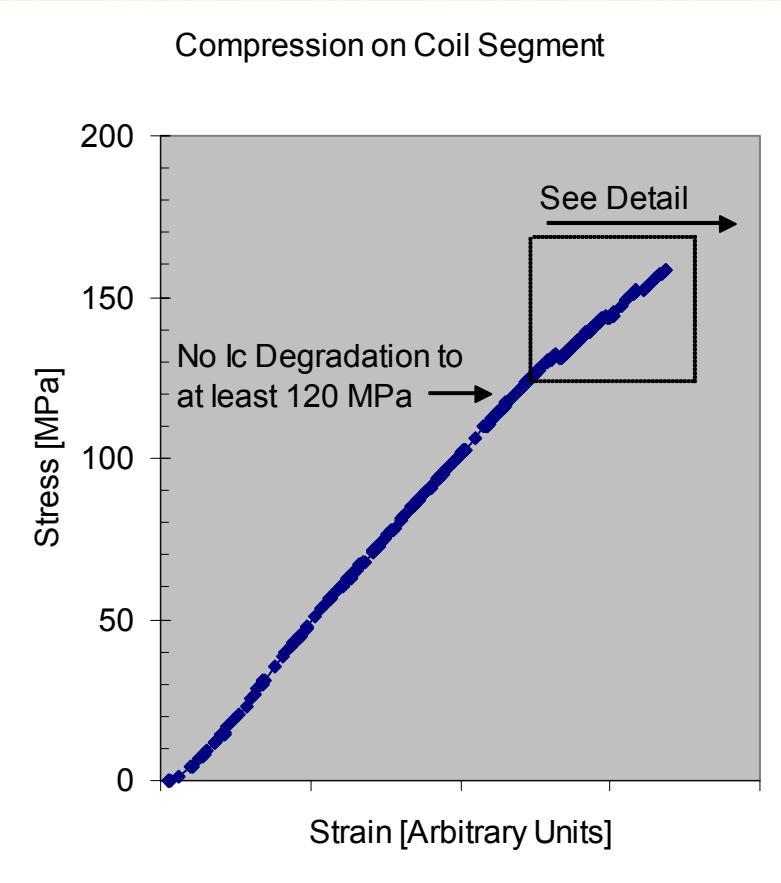


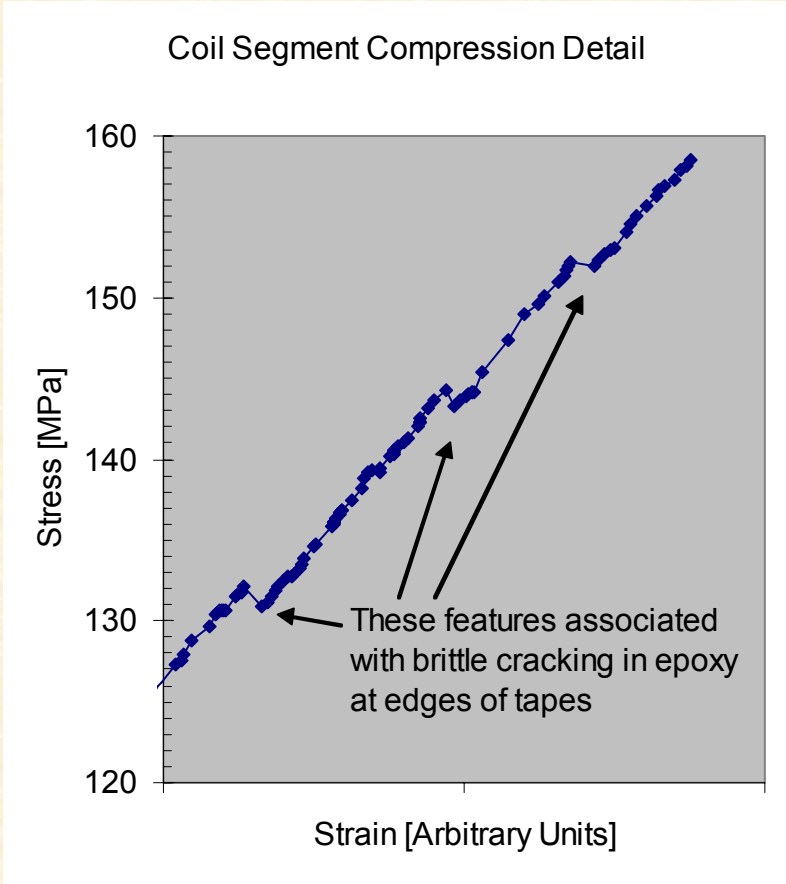
Coil High Cycle Fatigue Tests

- 105 MPa x 100,000 Cycles
  - Well above motor stresses
  - No Ic degradation
- 120 MPa x 1 Cycle
  - Well above motor stresses
  - No Ic degradation
- Mechanical Limit 130 MPa
  - Limited by fracture of epoxy
- OK for Generators



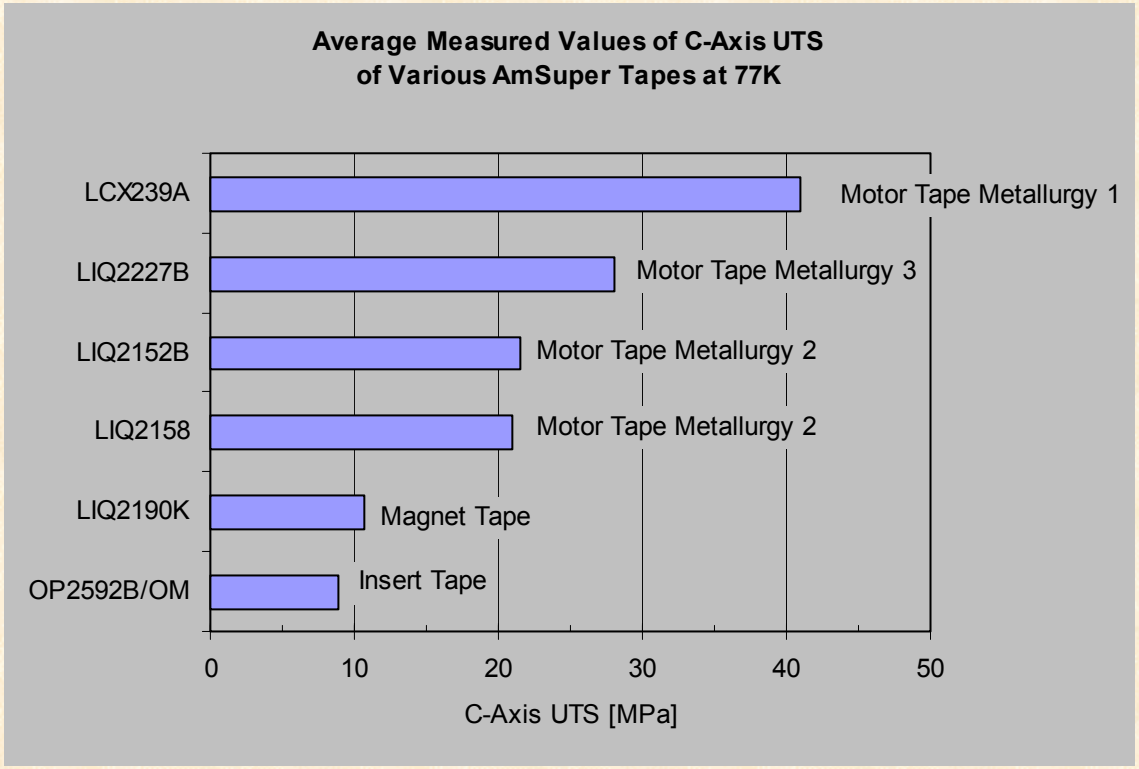
Epoxy-Impregnated Coil Mechanical Behavior





Failure starts with cracks in the epoxy at edges of embedded tapes (stress concentration) which then propagate along tape-epoxy interface.

Dependence of C-Axis Strength of BSCCO on Conductor Design and Composition



- ***BSCCO, C-Axis Strength depends on composition of alloy sheath as well as conductor design***

- "Metallurgy" corresponds to different sheath alloy compositions
- "Insert" tape is the unreinforced tape.
- "Magnet" tape and "Motor" tapes have different cross sectional reinforcement designs, tailored for the different stress configurations of the different applications

Limitations on Small Rotors due to Tape Bend Radius

- **Bend radius of tape limits maximum amount of current carrying cross section in a small rotor. Problem is worse for high pole counts.**

- **Reducing the bend radius of tape allows higher power density in small, high-pole-count machines**

- **Critical for practical use of compact SC generators /motors on military platforms**

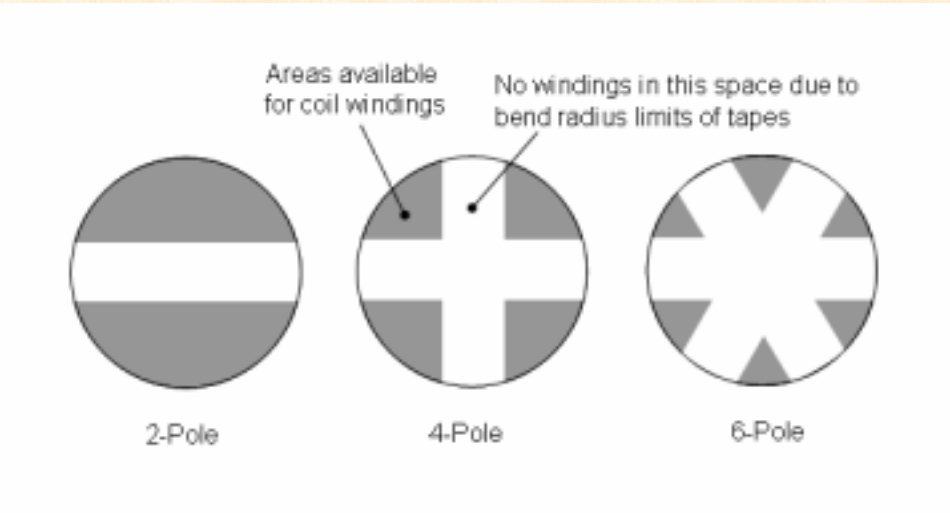


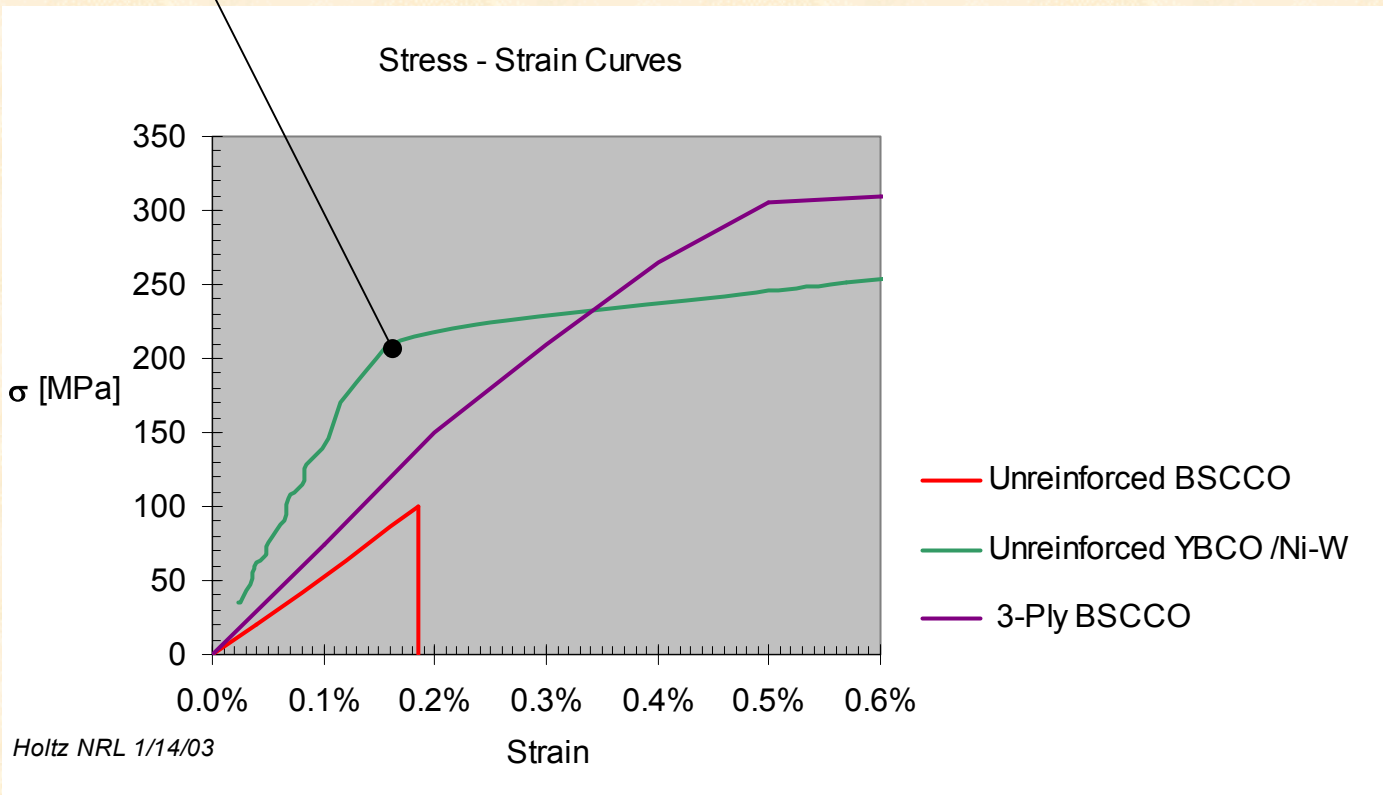
Figure 3.4.1.1-4 Schematic of the effect of tape bend radius and pole count on the fraction of area available for current. Shown for 20 cm diameter rotor with 5 cm tape bend diameter.

Comments on Coated Conductors

- **C-axis strength of as-deposited coated conductor is the adhesive strength of the coatings. Not known at present.**
- **Practical Coated-Conductors may be reinforced. Reinforcement design must consider c-axis strength requirements in addition to longitudinal requirements.**
- **Good goal is to achieve coated conductor properties that will allow compact, high power density, high-speed motors and generators for military platforms:**
  - **Bend radius suitable for 6-pole rotor of 20 cm diameter. (i.e., bend diameter less than about 3 cm, nearly half that now possible with reinforced BSCCO)**
  - **Mechanical strength consistent with rotor tip speeds of up to 200 m/s, at up to 15,000 rpm. (i.e., at least 100 MPa compression, double that of BSSCO)**
- **Must meet Military shock load requirements.**
- **Splices must not create weaknesses. Coated Conductor splicing method not yet known.**

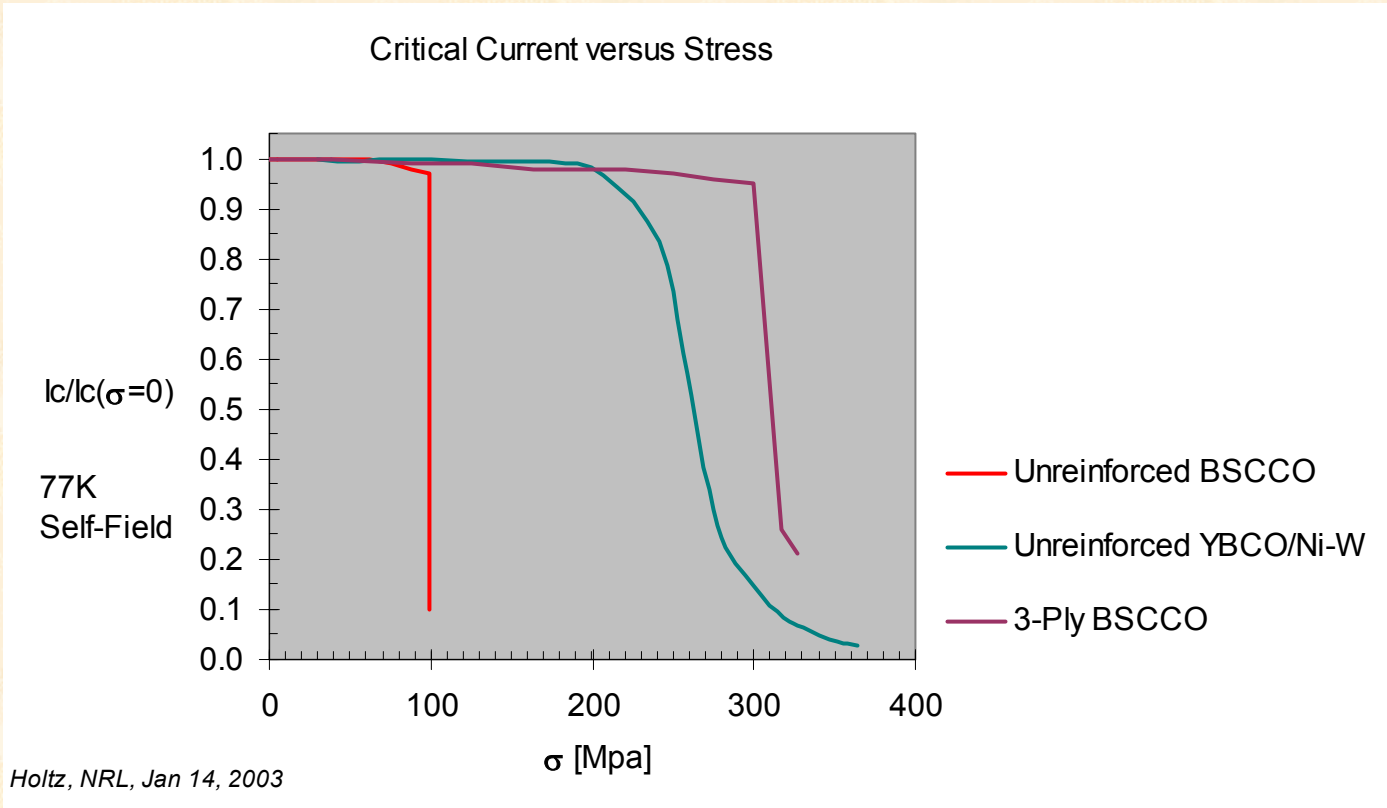
Coated Conductor Stress-Strain Curves

- ***Strain tolerance of unreinforced Coated Conductor is similar to unreinforced BSCCO,***
- ***But yield stress and elastic modulus are twice as high!***



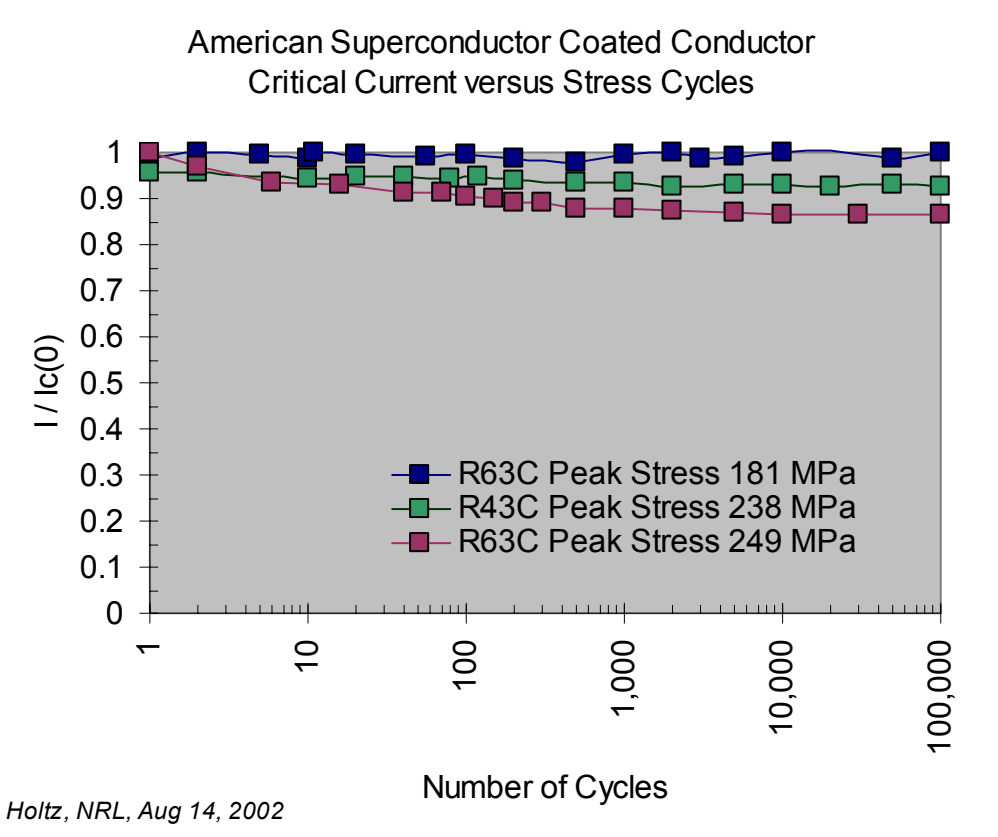
Coated Conductor Critical Current vs Stress

- ***Ic drop vs stress of BSCCO is very sharp***
- ***Ic drop vs stress of Coated Conductor is smooth***
- ***Coated Conductor is "fail safe" relative to BSCCO***



Holtz, NRL, Jan 14, 2003

Fatigue Tolerance of Coated Conductor



- ***Note initial slow drop of Ic, for stress above yield stress***
- ***But at higher cycles, degradation stops, Ic levels off***
- ***Suggests Coated Conductor fatigue damage is self-limiting, "Fail Safe"***

Summary & Talking Points

- **Reinforced BSCCO conductor mechanical properties are the baseline**
- **Preliminary results for unreinforced coated conductor look good**
- **Coated Conductor Issues:**
  - **Adhesion of coatings at low temperature**
  - **Cross-sectional architecture for reinforcing tapes**
  - **All tape mechanical properties unknown except longitudinal tension**
  - **All epoxy-impregnated coil properties unknown**
  - **Splicing method and properties of splices not known**
  - **Shock tolerance and strain rate effects not known**
  - **Coil dynamic testing capability needed**
- **Tape testing capabilities already exist.**