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The History of Transverse Pressure Tests of Nb_3Sn Rutherford Cables

Workshop on Nb_3Sn Technology for Accelerator Magnets
Paris, October 12, 2018

Arno Godeke
Varian Medical Systems Particle Therapy GmbH

Agenda

1. A learning curve for “low J_c“ conductors
2. Converging to stable results
3. A learning curve for “high J_c” conductors
4. Keeping up with magnet performance…
5. In reflection

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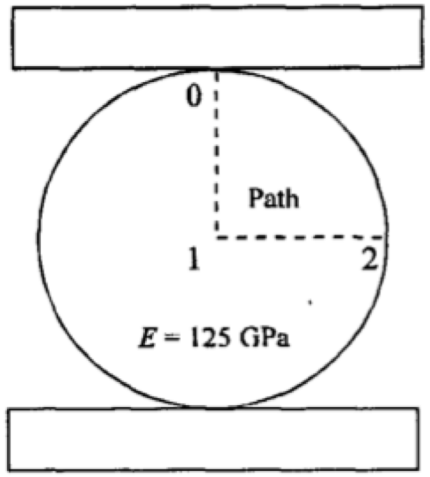
Many Transverse Pressure Experiments on Wires

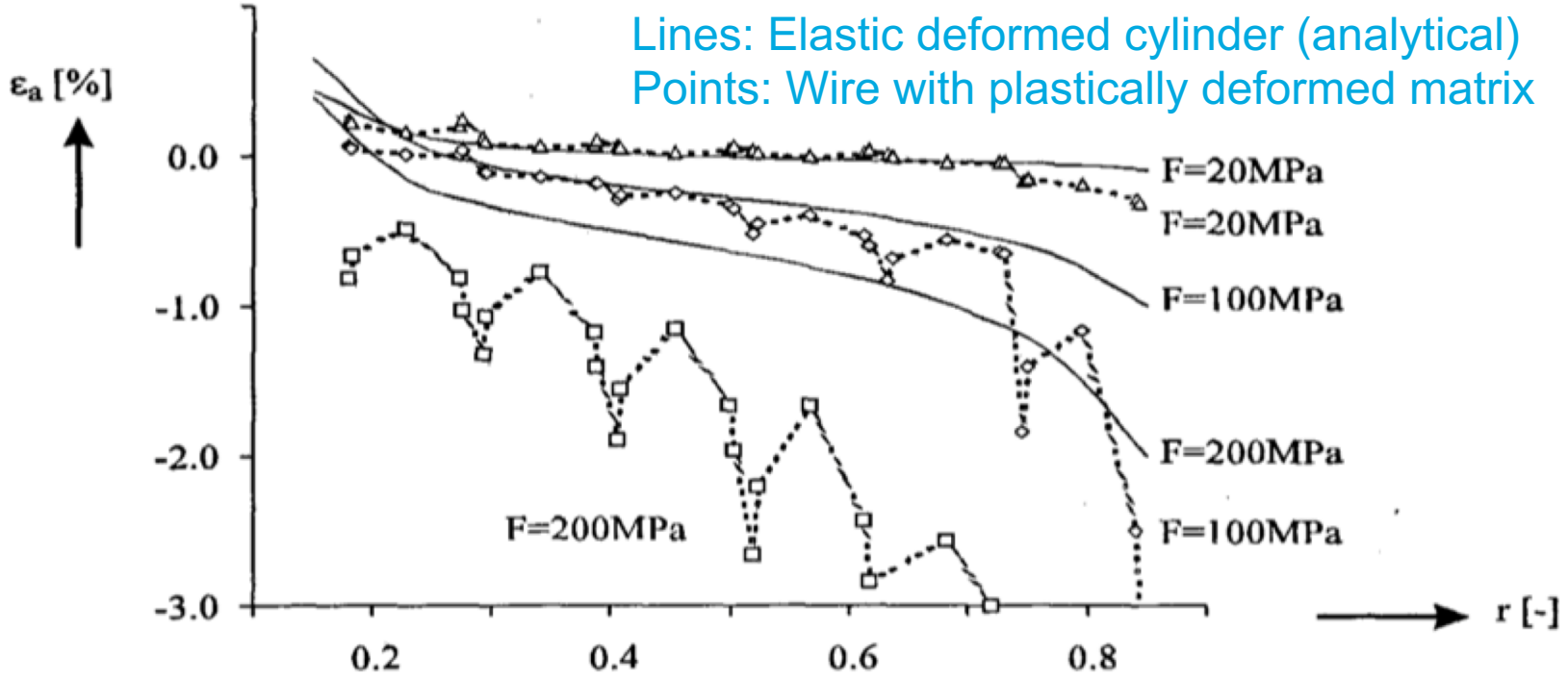
Relatively simple, but not representative for cables in magnets

Cryogenics 1994 Vol 34 ICEC Supplement 513

Modeling of strain in multifilamentary wires deformed by thermal contraction and transverse forces

Bennie ten Haken, Tatjana N. Zaitseva[1] and Herman H.J. ten Kate





Lines: Elastic deformed cylinder (analytical)
Points: Wire with plastically deformed matrix

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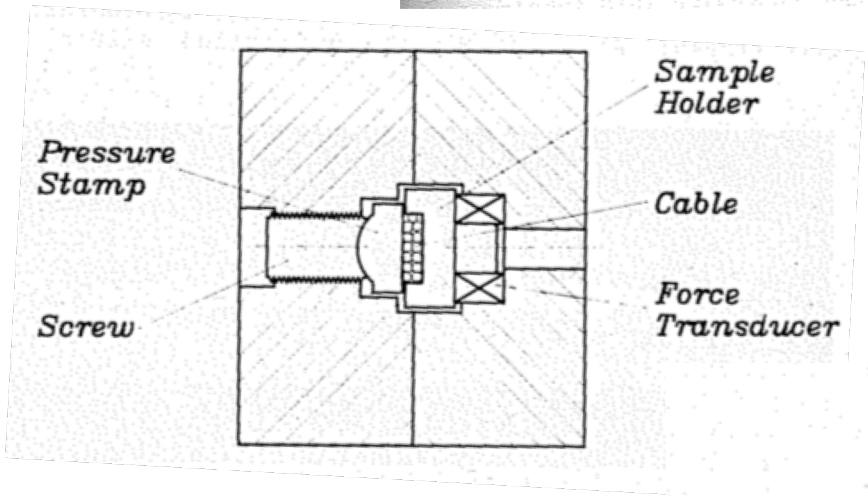
An Early (first?) Nb_3Sn Rutherford "Cable" Experiment

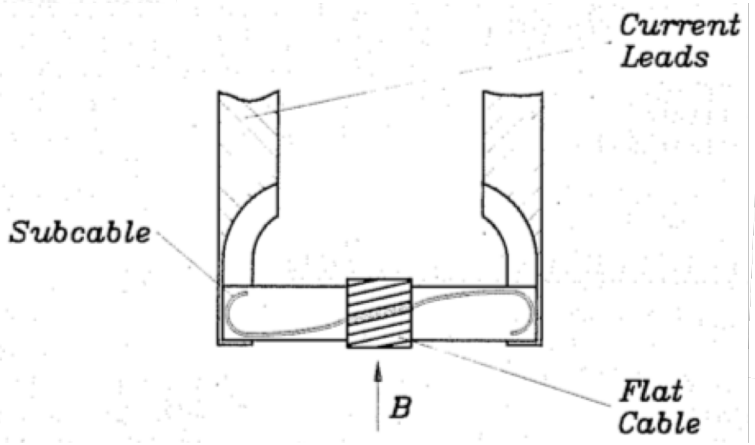
"Three-stage flat" cable for SULTAN: Measurement on one sub-cable

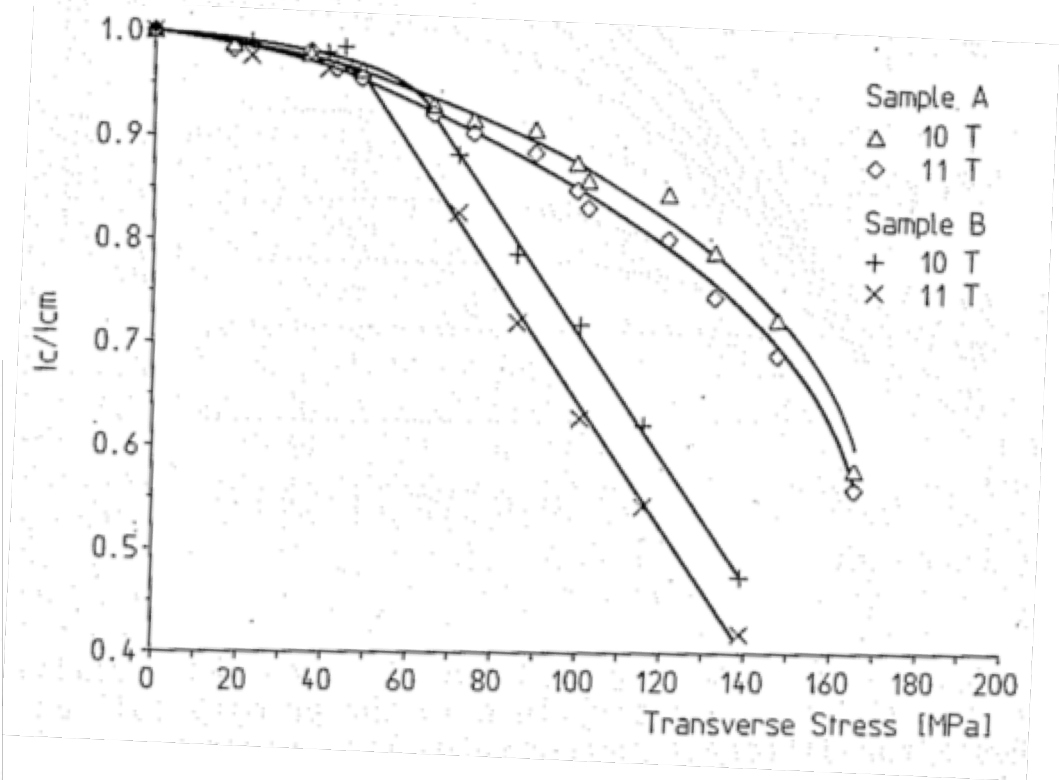
IEEE TRANSACTIONS ON MAGNETICS, VOL. 25, NO. 2, MARCH 1989

EFFECT OF TRANSVERSE COMPRESSIVE STRESS ON THE CRITICAL CURRENT OF CABLED Nb_3Sn CONDUCTOR

B. Jakob and G. Pasztor
Paul Scherrer Institute
CH-5234 Villigen, Switzerland







Pressure adjusted at room temperature

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First (?) Measurements on Full-Size Rutherford Cables

192 filament PIT wire in ECN LHC-B and ECN-SULTAN cables

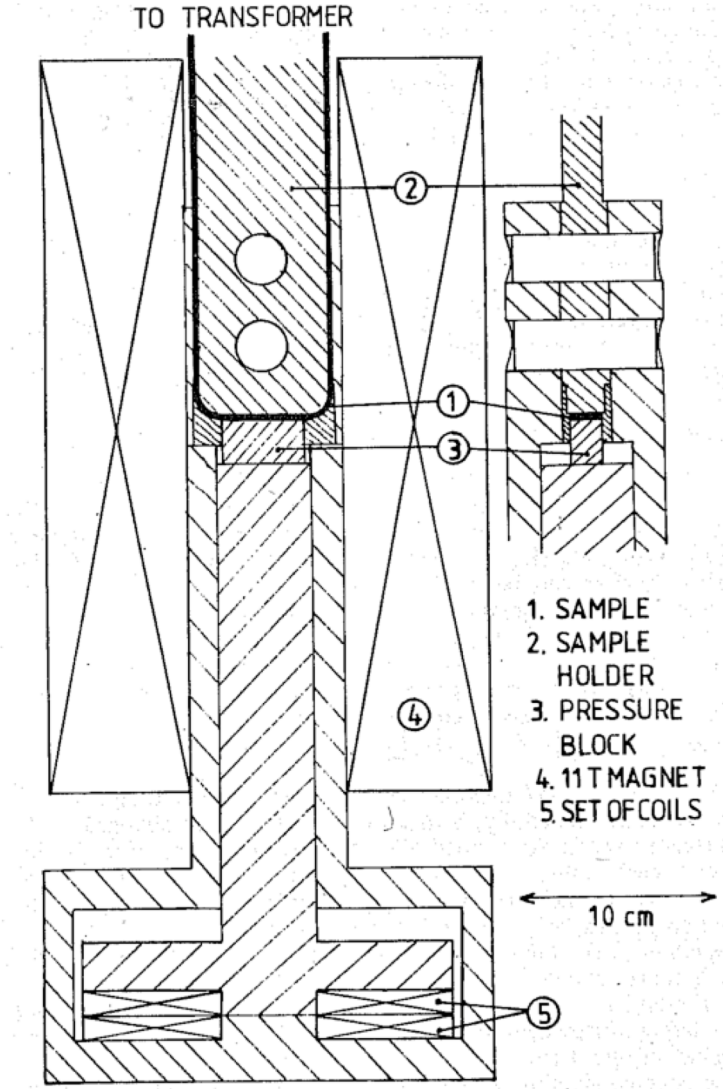


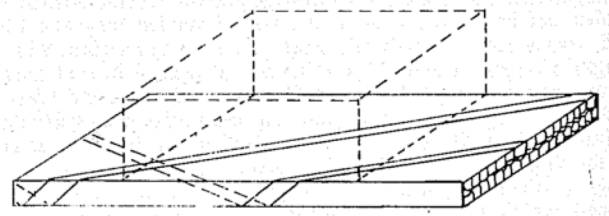
Fig. 1. Schematic view of press-arrangement.

Trans. Magn. V27 n2 1991 1831

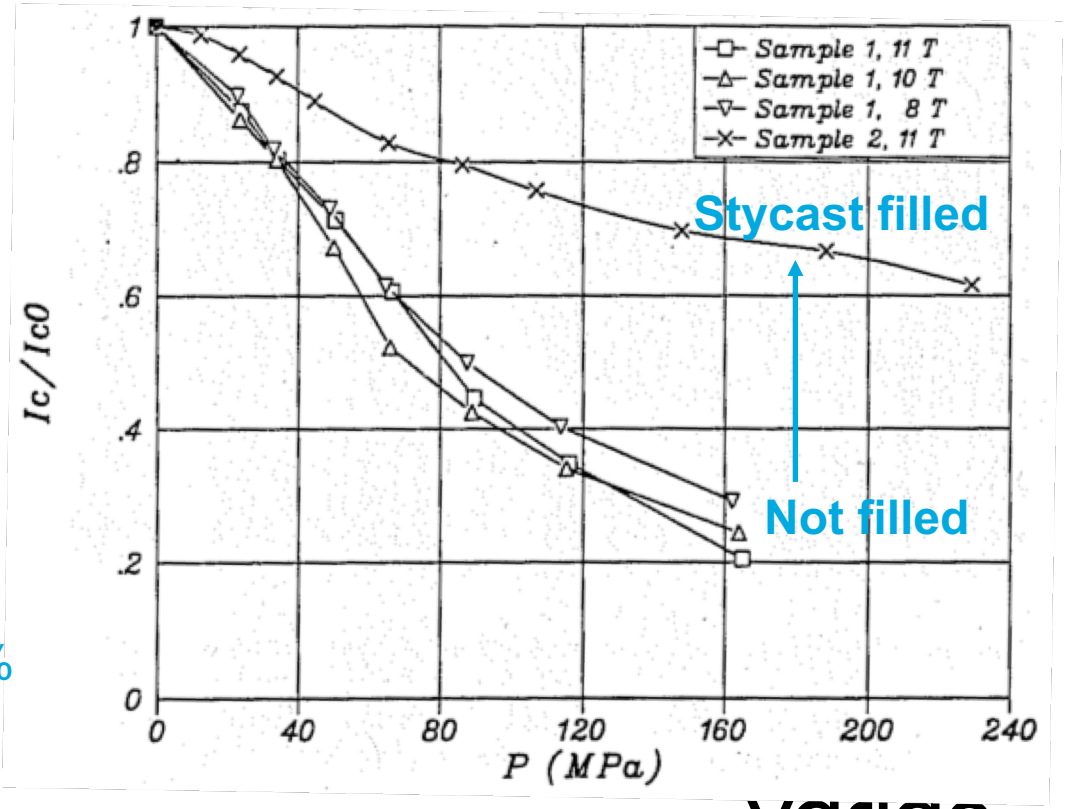
THE EFFECT OF TRANSVERSE LOADS UP TO 300 MPa ON THE CRITICAL CURRENTS OF Nb_3Sn CABLES.

H. Boschman, A.P. Verweij, S. Wessel, H.H.J. ten Kate and L.J.M. van de Klundert.
Applied Superconductivity Centre, University of Twente,
P.O.B. 217, 7500 AE Enschede, The Netherlands.

Voltage taps per strand and globally



Field and current within 1%
Pressure within 2%
Voltage within 50 nV



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Better Statistics and Experience (& smaller filaments), Better Results

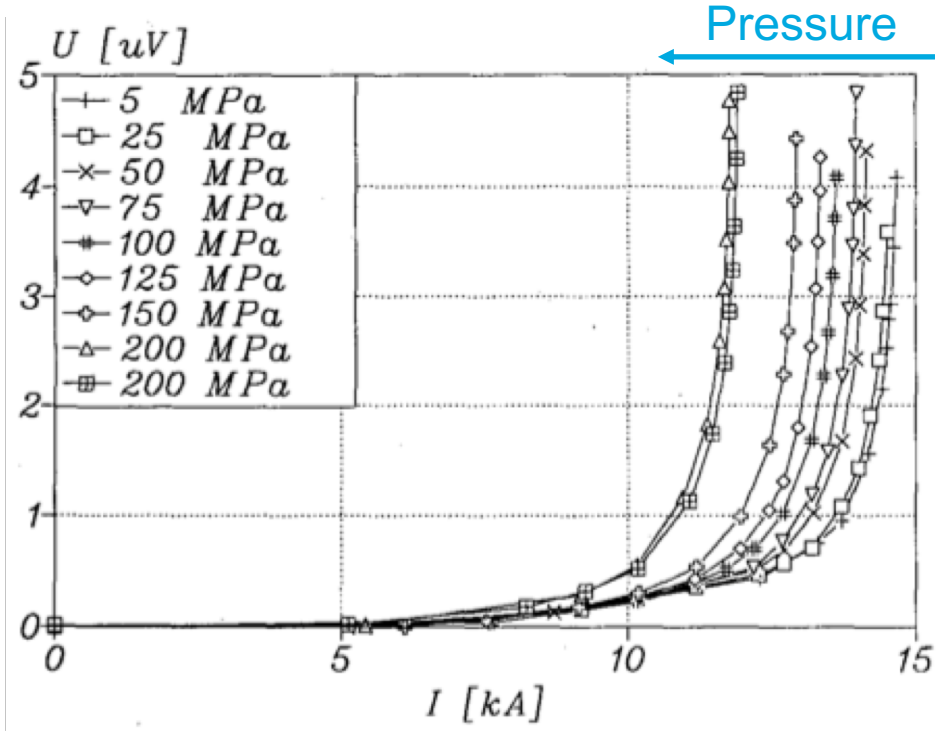
About 15 cables measured in Twente in the early 1990's

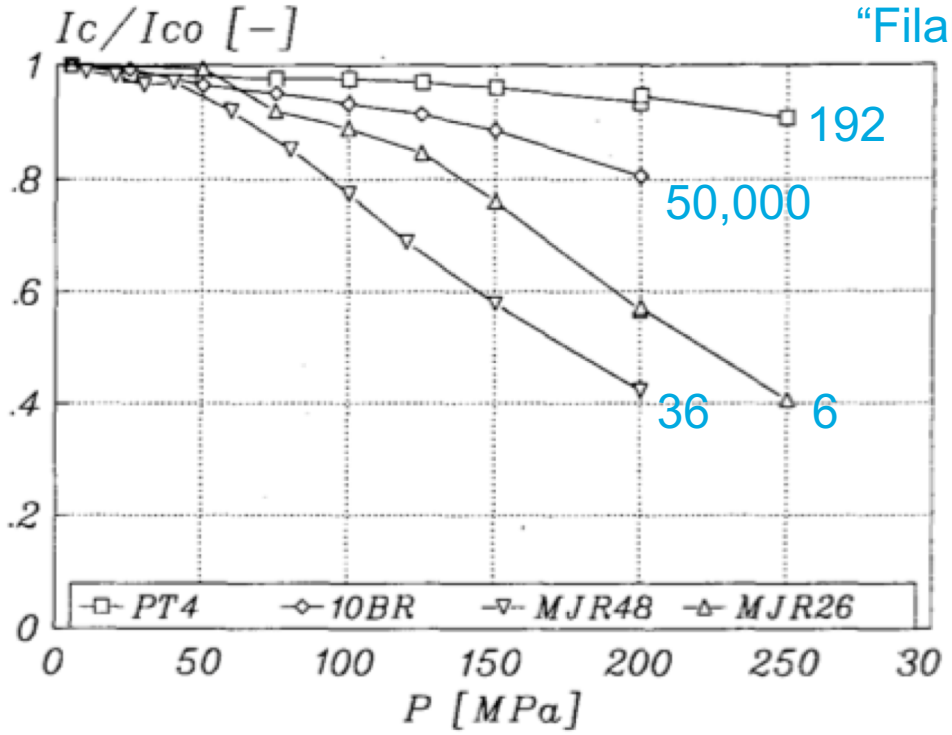
- Twente 11 T MSUT & LBNL 13 T D20
  - Basic studies on 2D samples and wires
  - Full size cable measurements

1334 IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 3, NO.1, MARCH 1993

CRITICAL CURRENT DEGRADATION IN Nb3Sn CABLES UNDER TRANSVERSE PRESSURE

H.H.J. ten Kate, H.W. Weijers, J.M. van Oort#



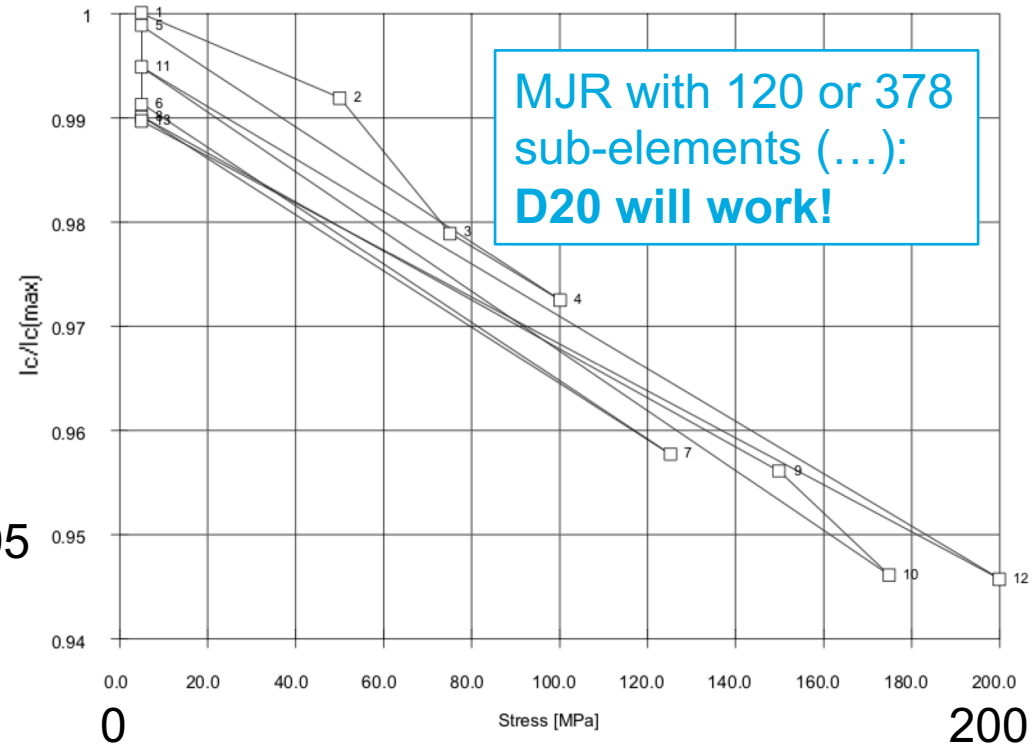


Stable Cable Characterizations

Report on the test of the second keystoned TWCA cable.

A. Godeke, J. M. van Oort* and H. H. J. ten Kate,
Applied Superconductivity Centre, University of Twente,
P.O. Box 217, 7500 AE Enschede,
The Netherlands.
(*) Lawrence Berkeley Laboratory, USA.
August 1993.

1



MJR with 120 or 378 sub-elements (…): **D20 will work!**

0.95

0

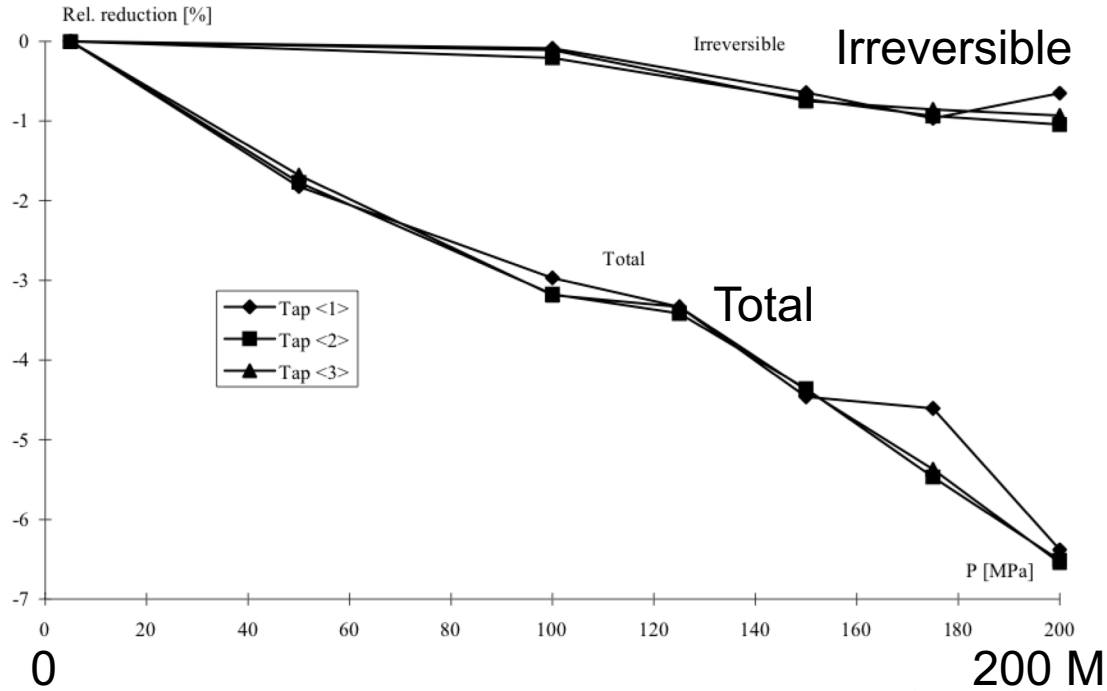
200 MPa

CRITICAL CURRENT MEASUREMENTS AS A FUNCTION OF TRANSVERSE PRESSURE ON EUROPA METALLI Nb_3Sn RUTHERFORD CABLE CONDUCTORS

A. Godeke, W.A.J. Wessel, H.J.G. Krooshoop and H.H.J. ten Kate

November, 1996

0%



Irreversible

Total

-7%

0

200 MPa

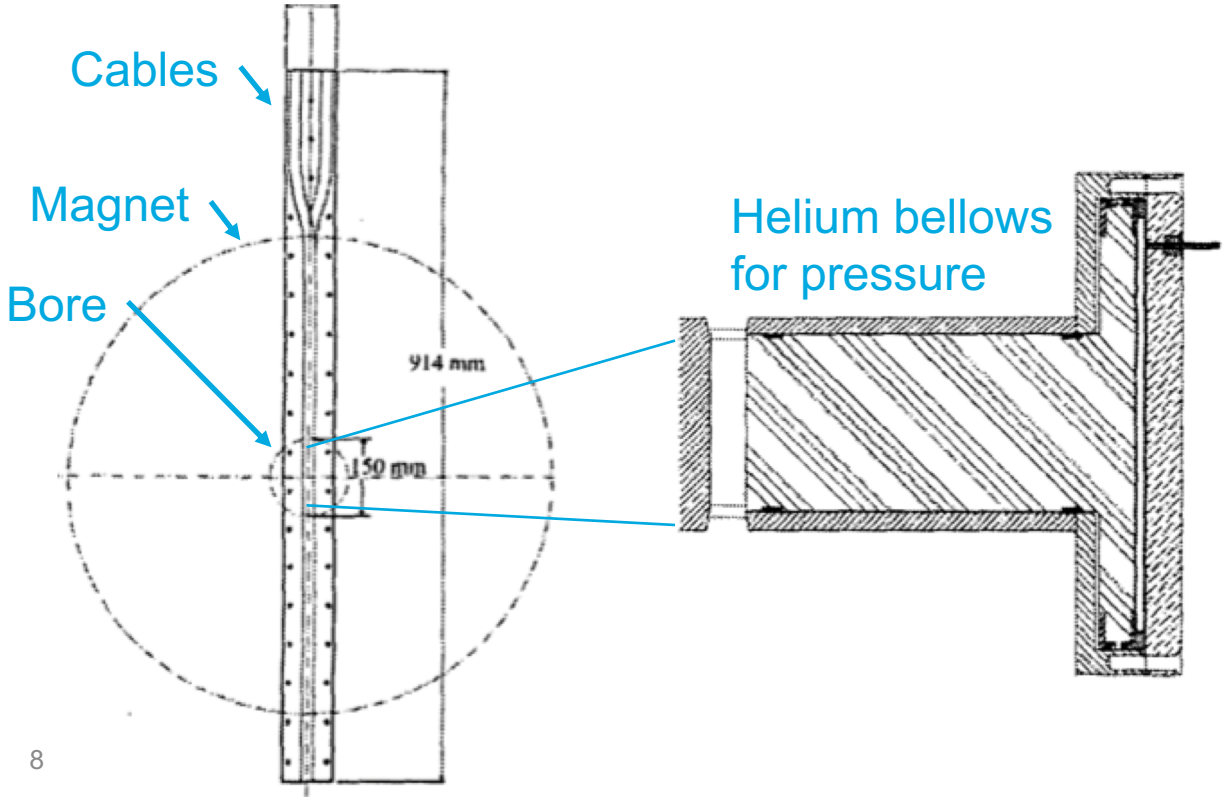
Independent Confirmation by LBNL

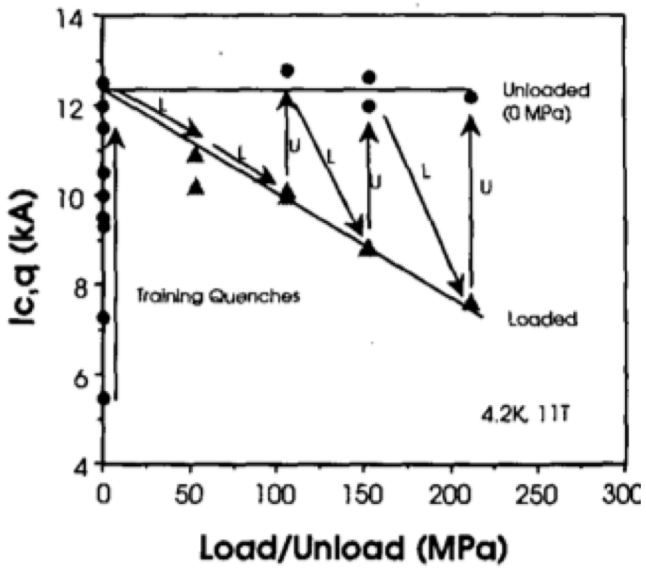
Long straight cable sections with 122 mm pressure in NHMFL 12 T split pair

Critical Current of Superconducting Rutherford Cable in High Magnetic Fields with Transverse Pressure

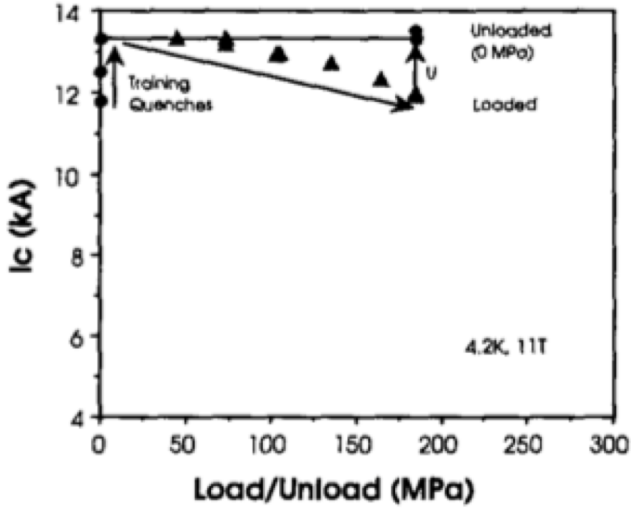
Daniel R. Dietderich and Ronald M. Scanlan,
Lawrence Berkeley National Laboratory, Berkeley, CA 94720

Robert P. Walsh and John R. Miller
National High Magnetic Field Laboratory, Tallahassee, FL 32706





IGC 19 sub-elem.
- 40% at 200 MPa



MJR 122 sub-elem.
- 11% at 200 MPa

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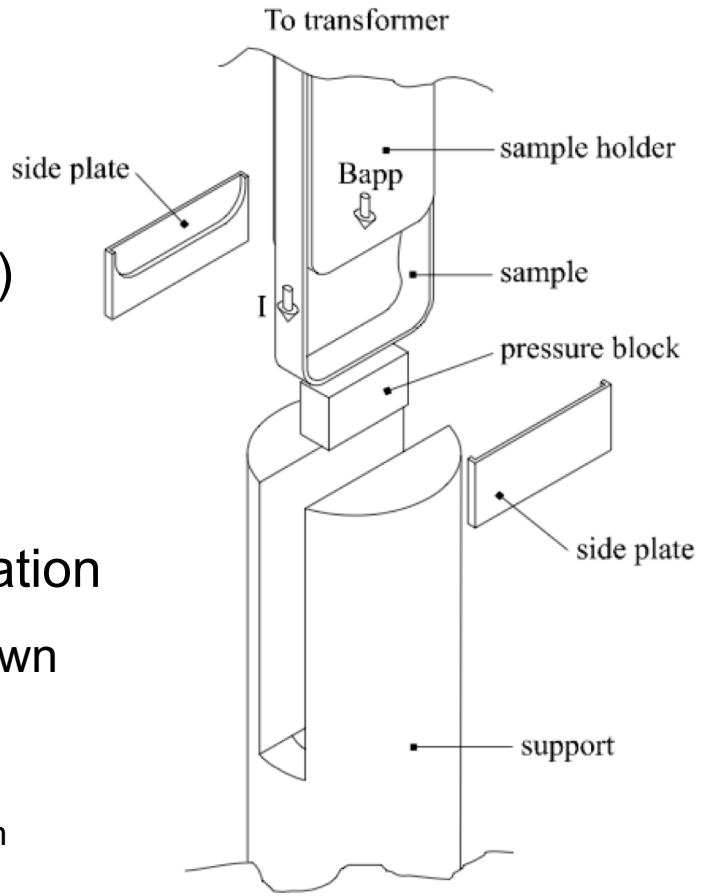
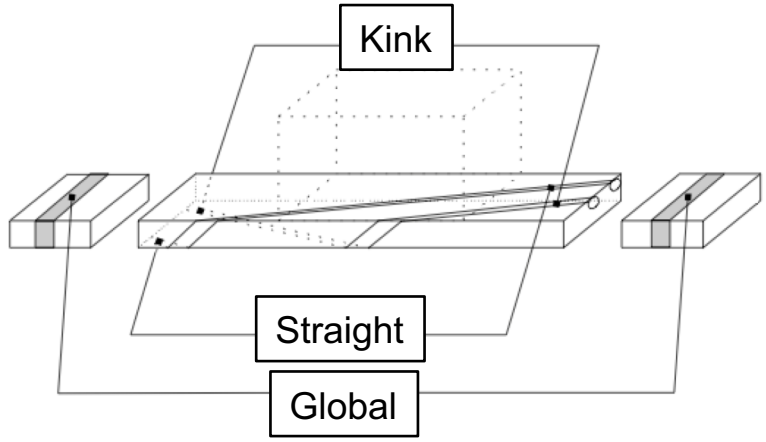
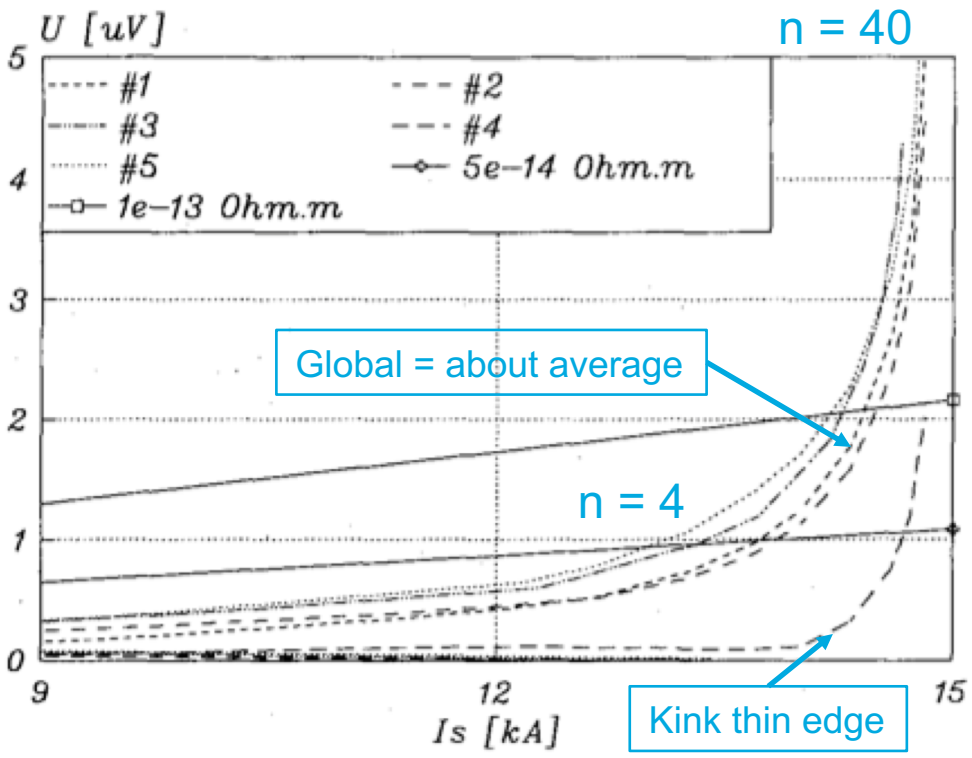
Lessons learned

- Impregnate cable
- G10 above and below (UT)
  - Or dummy cables (LBNL)
- Solid side support
- No correlation to V-tap location
  - Current distribution not known
  - Global is not equipotential
- U(I) is not proportional to I^n
- **Small filaments survive > 150 MPa**
  - If the experiment is done properly
- (And a couple of anecdotes…)







High J_c Strands in Copper Dummy Cables

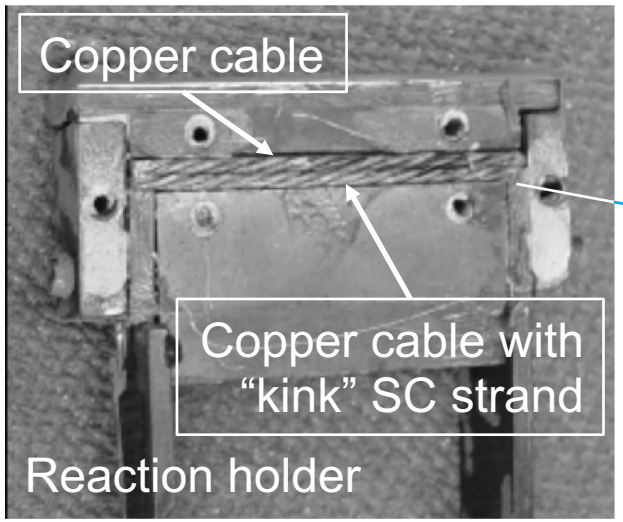
A possible cheap and fast way to characterize "cables"?

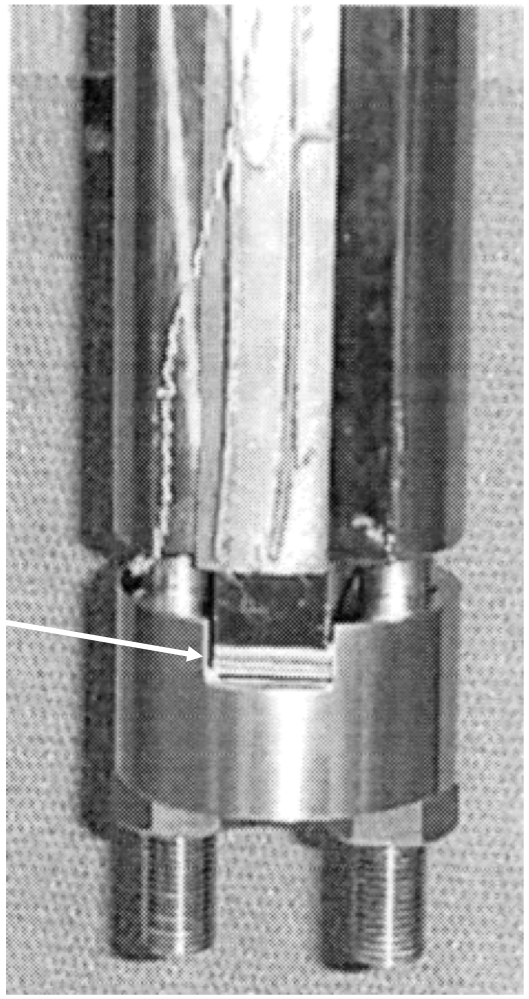
A DEVICE TO TEST CRITICAL CURRENT SENSITIVITY OF NB_3SN CABLES TO PRESSURE

E. Barzi [1], M. Fratini[1], and A. V. Zlobin[1]

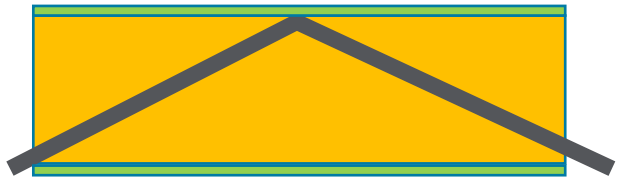
[1] Fermi National Accelerator Laboratory
Batavia, Illinois 60510, USA

CP614, *Advances in Cryogenic Engineering:*
Proceedings of the International Cryogenic Materials Conference - ICMC, Vol. 48,
edited by B. Balachandran et al.





- Impregnated
- Dummy cable below
- G10 side plates ?
- SC strand in Cu cable ?
- Kink under pressure block with "soft" surroundings ?



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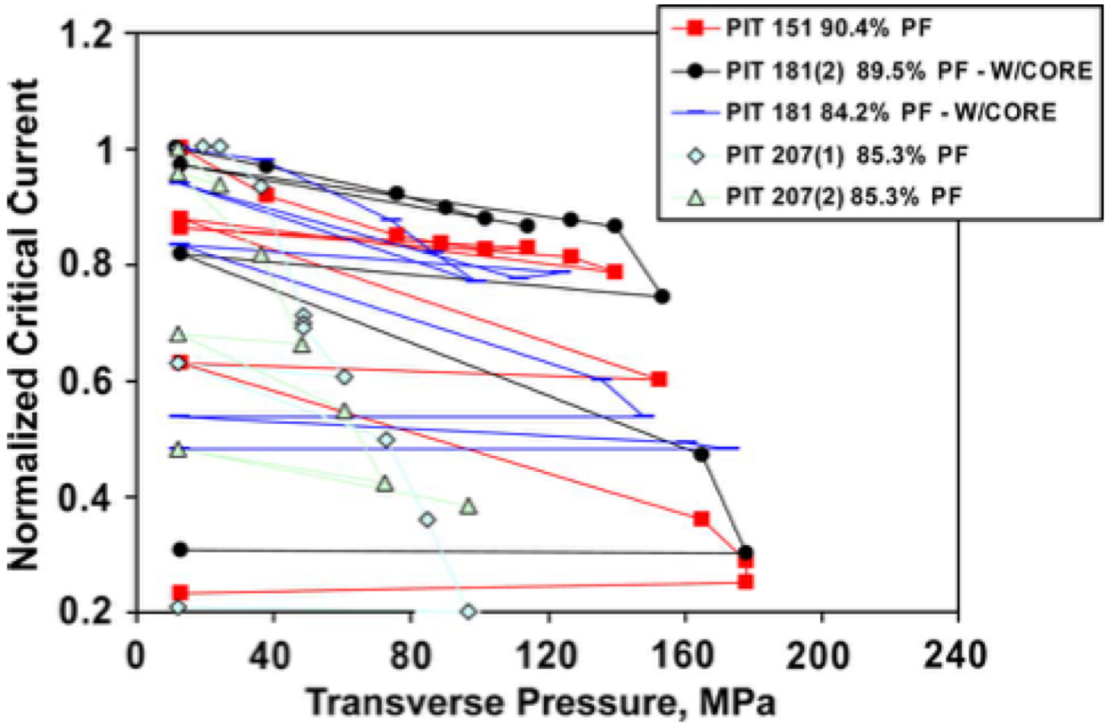
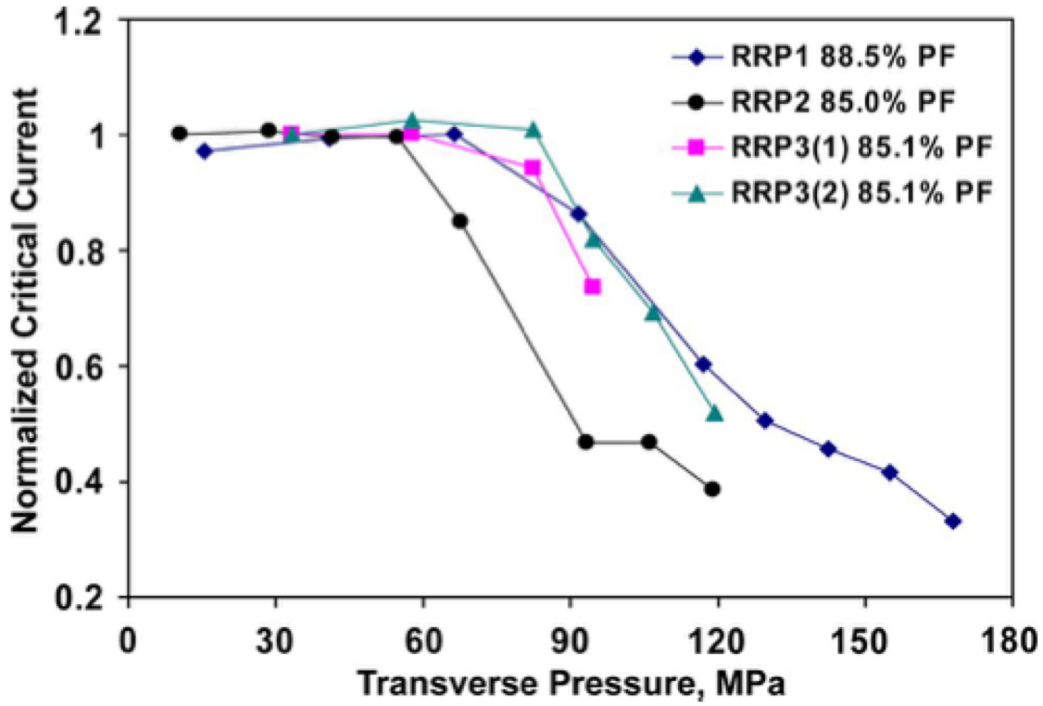
High J_c Strands in Copper Dummy Cables

Some selected results

Effect of Transverse Pressure on Brittle Superconductors

E. Barzi, D. Turrioni, and A. V. Zlobin





Are high J_c cables more sensitive to transverse pressure?

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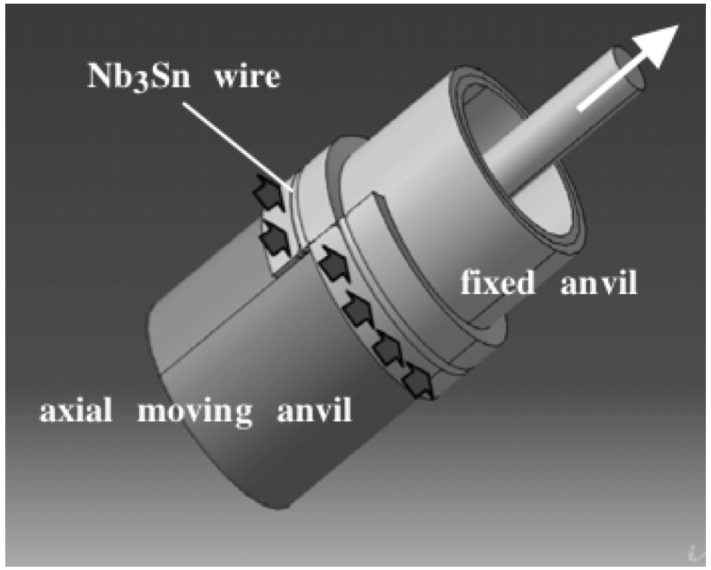
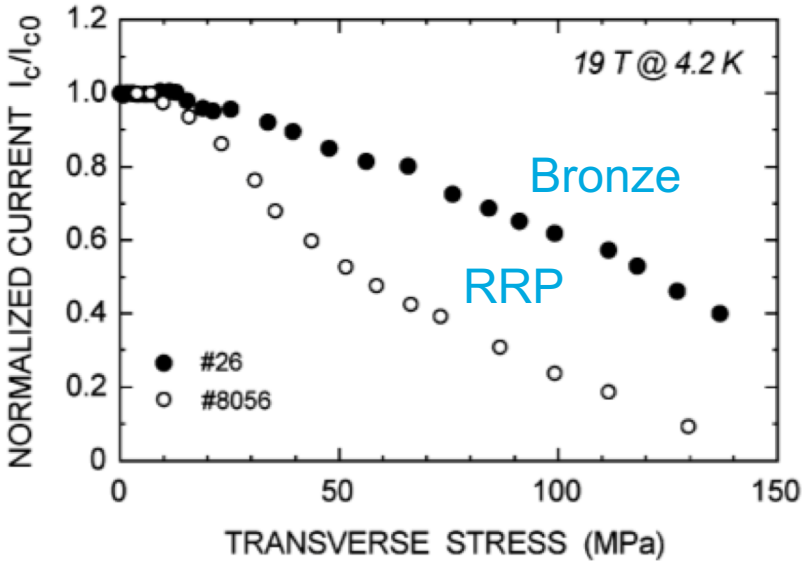
Transverse Pressure on High J_c *Wires*

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 17, NO. 2, JUNE 2007 2643

Transport Properties up to 1000 A of Nb_3Sn Wires Under Transverse Compressive Stress

B. Seeber, A. Ferreira, V. Abächerli, T. Boutboul, L. Oberli, and R. Flükiger





Initially on bare wires
Later on impregnated wires

Seeber, *et al.* 2007:

It is worth to be mentioned that a similar Nb_3Sn RRP wire (OST—ID 6445) has successfully been used for the construction of the world record 16 T dipole HD1 [14]. This wire was cabled and a maximum compressive stress near the horseshoe of 170 MPa has been expected. The magnetic field to which the conductor is exposed during operation is lower from the here-applied 19 T, showing the importance of expanding our measurements to other magnetic fields.

Barzi, *et al.* 2008:

siderably with billet quality. Both the results and their spread as measured for the PIT samples were consistent with the several PIT magnets tested at FNAL, where I_c cable degradation at 10 T was between 5 and 33% [7], [8]. These tests may therefore be good predictors also of the RRP behavior in magnets. For instance, the reduced magnet performance in [9] was consistent with the results herein obtained for the RRP strands. Within

…so, is there, or is there not, a problem with the stress sensitivity of high J_c cables? (LBNL attempted to test high J_c cables at the NHMFL but the experiment failed)

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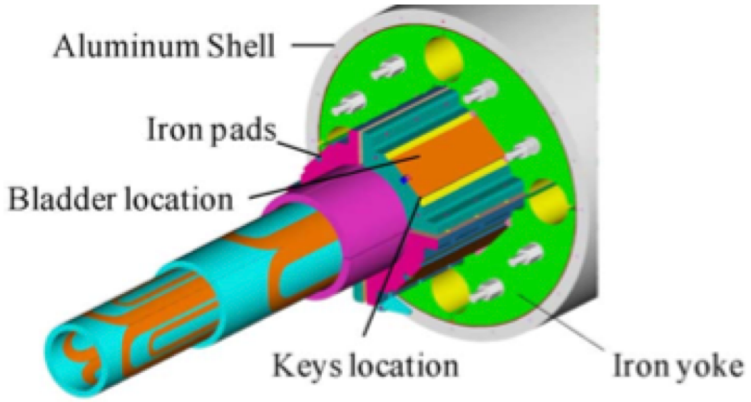
What do Magnets Tell Us?

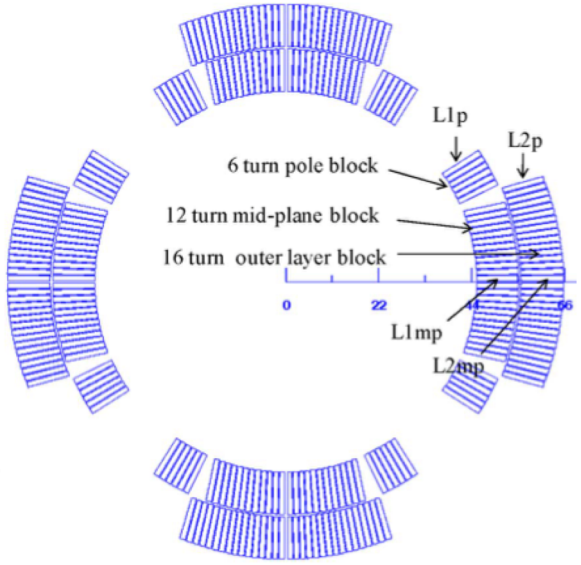
US LARP Technology Quadrupole TQS03 tested at CERN under high stress

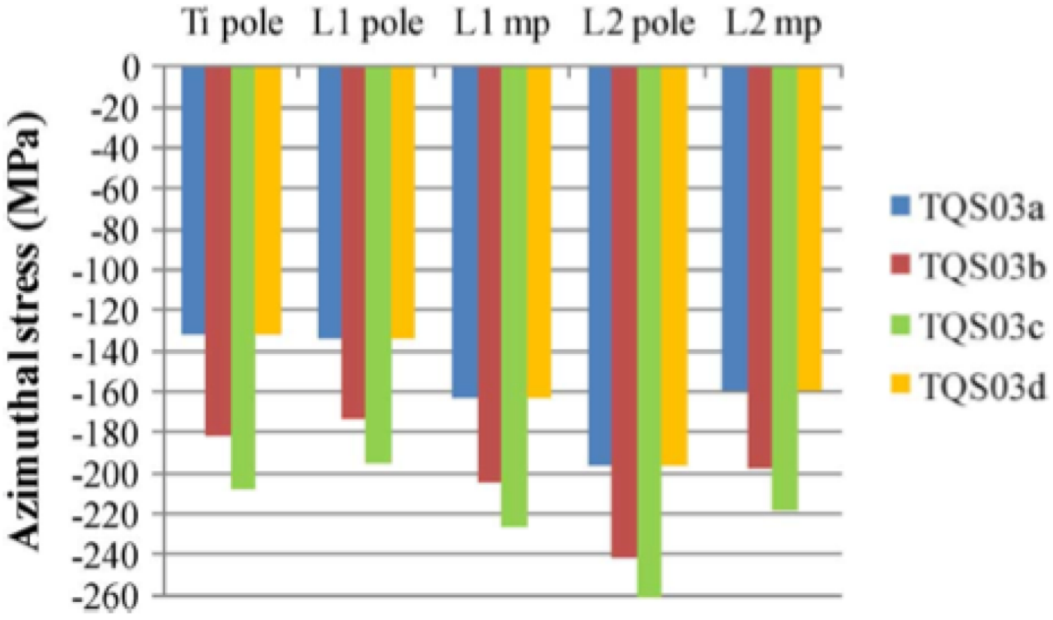
IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 21, NO. 3, JUNE 2011 1849

Performance of a Nb_3Sn Quadrupole Under High Stress

H. Felice, M. Bajko, B. Bingham, B. Bordini, L. Bottura, S. Caspi, G. De Rijk, D. Dietderich, P. Ferracin, C. Giloux, A. Godeke, R. Hafalia, A. Milanese, L. Rossi, and G. L. Sabbi







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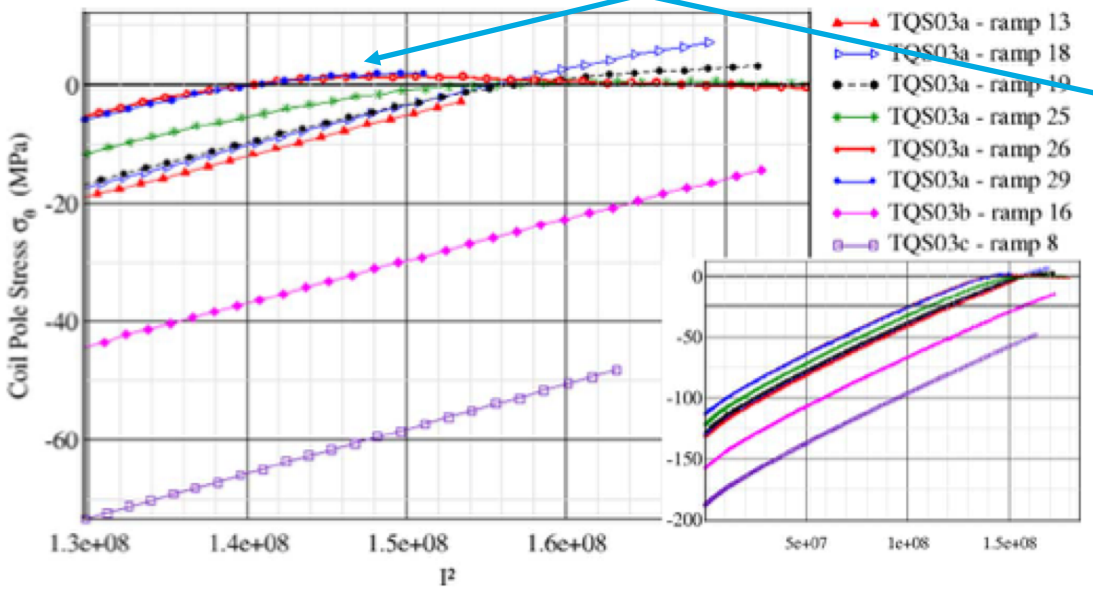
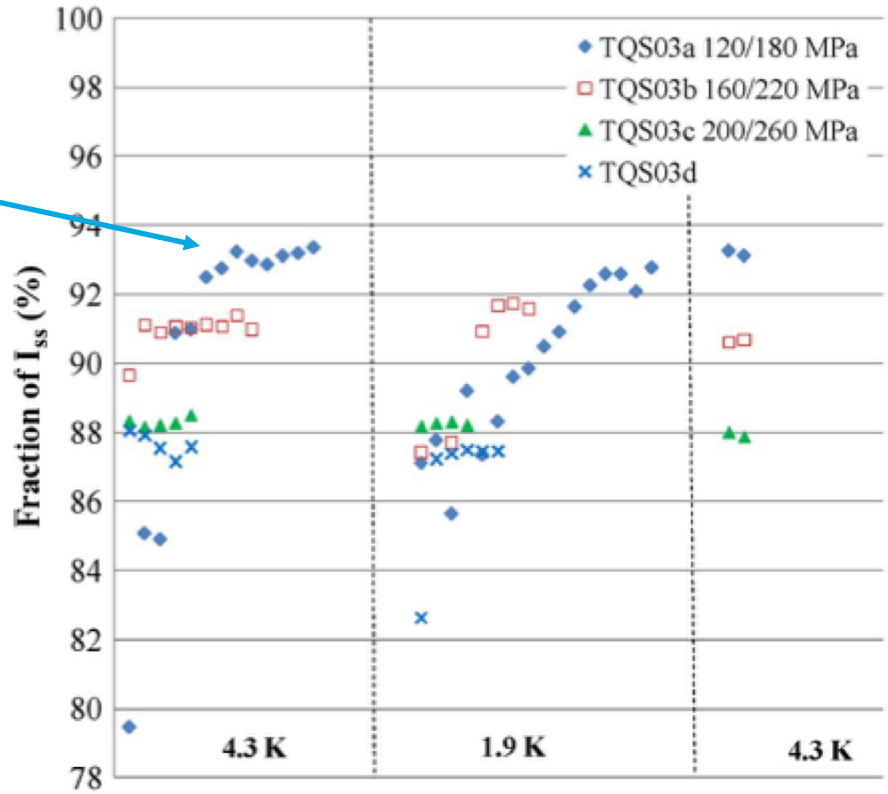
TQS03 Performance Under Intentionally High Stress

Unloading during magnet excitation and corresponding training

Insufficient pre-load and training but closest to short sample





Higher pre-load has reduced I_c

Higher pre-load has again reduced I_c

All reductions seem irreversible since the limit is measured at minimal load!

Discussion points:

We observe that above 180 MPa permanent damage does occur (?)

We still not seem to know if reaching 93% of short sample is caused by damage at 180 MPa (?)

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Summary

Proper cable measurements are tough!

1. A learning curve for “low J_c“ conductors
2. Converging to stable results
3. A learning curve for “high J_c” conductors
4. Keeping up with magnet performance
5. In reflection…some provocative thoughts!

Data showing less stress sensitivity is the better measurement…
(…similar to a critical current measurement where the highest value is correct!)

Discussion:
Are cable measurements indeed necessary as long as filaments are small?
Was the TQS03 test indeed undecisive, even for 180 MPa?

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Less than 3% of cancer patients that would benefit from proton therapy has access

(Thank You)