Assessment of stability of fully-excited Nb3Sn Rutherford cable with modified ICR at 4.2 K and 12 T using a superconducting transformer and solenoidal magnet

C. J. Kovacs[1], M. D. Sumption[1], E. Z. Barzi[2], A. V. Zlobin[2], M. Majoros[1]
[1] Center for Superconducting & Magnetic Materials (CSMM), Department of Materials Science & Engineering, The Ohio State University, USA
[2] Applied Physics and Superconductivity Technology Division (APS-TD), Fermi National Accelerator Laboratory, USA

CEC ICMC JULY 21-25 2019 CONNECTICUT CONVENTION CENTER HARTFORD

Introduction

- Multiple conductor options exist for next-generation high field accelerator magnets. Whether or not a hybrid, it is likely these magnets will incorporate Nb_3Sn Rutherford cable.
- The performance targets of the next-generation dipoles hasn't been reached yet for a Nb_3Sn magnet.
- It will be important to have a low-cost, fast turn around measurement program to measure the full excitation J_c and stability performance of Nb_3Sn Rutherford cable magnet scale composite.
- Ideally, this measurement program could include many partners in universities and national labs by requiring lower cost and smaller footprint infrastructure.
- In this research, a low-cost measurement system described in [1] was modified to handle additional instrumentation to perform stability measurements of fully excited Nb_3Sn Rutherford cable in a LHe bath with applied fields up to 14 T.
- The stability diagram generated from the experimental runs was compared to a theoretical analytical stability model.

Nb_3Sn strand and cable specifications

Strand Type	Oxford RRP
Stack design	132/169
Ternary Element (?)	Ti
Production year	2012
Diameter, d, [mm]	0.7
I_c (4.2 K, 12 T), [A]	449
J_c (4.2 K, 12 T), [A/mm²]	2649
I_c (4.2 K, 15 T), [A/mm²]	219
J_c (4.2 K, 15 T), [A/mm²]	1297
Twist pitch, [mm]	13
Cu fraction, λ, [%]	56.0
RRR (273 K/20 K)	153
HT dwell step	210 °/72 h + 400 °C/48 + 640 °C/50 h

Cable	T1
Strand Count	40
Core (?)	Yes
Core width, [mm]	9.5
Lay angle, [degrees]	16.8
Width, [mm]	14.7
Thickness (mid), [mm]	2

Fermilab spiral bifilar probe with 30 kA superconducting transformer: full-excitation stability measurements at 4.2 K with applied fields up to 14 T.

- The Teslatron II measurement station at Fermilab has a 77 mm bore solenoid which can apply fields of 14-16 T at 4.2 K and 2.2 K respectably.
- A spiral bifilar sample holder which is coupled with a 60-multiplication factor NbTi superconducting transformer was designed to reduce the integrated Lorentz forces on the probe and magnet assembly.
- The cable was insulated with S-glass braided sheath but remained unimpregnated and therefore was in good contact with the liquid Helium.
- Voltage taps were soldered near a strain gauge used to generate heat perturbations.

Rutherford cable steady state thermal stability model

Stability Criterion:

$$1 \le \frac{\underbrace{\frac{\rho_{norm}\left(i \times I_c\left(\frac{T-T_{cs}}{T_c-T_{cs}}\right)\right)^2}{PA_{cu}}}_{\substack{\text{Joule Heating}\\ \text{per unit length}\\ \text{and unit surface area}}} + \underbrace{G_d}_{\substack{\text{Heat Perturbation}\\ \text{per unit length}\\ \text{and surface area under heater}}}}{\underbrace{\eta h(T-T_B)}_{\substack{\text{surface cooling}\\ \text{per unit length}\\ \text{and unit surface area}}} + \underbrace{\frac{(T-T_B)\sqrt{2\kappa A_{cu}P\eta h}}{A_s}}_{\substack{\text{Cold-end cooling}\\ \text{per unit length}\\ \text{normalized for spot size}}}}$$

- A steady state analytical stability model for cables in liquid cryogen derived in Kovacs et al. was modified to determine stability of the Nb_3Sn Rutherford cable in LHe [2].
- The resistivity of the stabilizer is mostly constant over the temperatures of concern and determined from *RRR*.
- h is chosen to be 10 kW/m²K < 5.2 K and 1 kW/m²K ≥ 5.2 K.
- T_{cs} = 4.52 K is chosen as when the surface cooling equals the joule heating at T = 5.2 K.
- The model below assumes current sharing at soldered junctions, a linear I_c versus T, and a flat sloped temperature gradient from cold-end cooling.

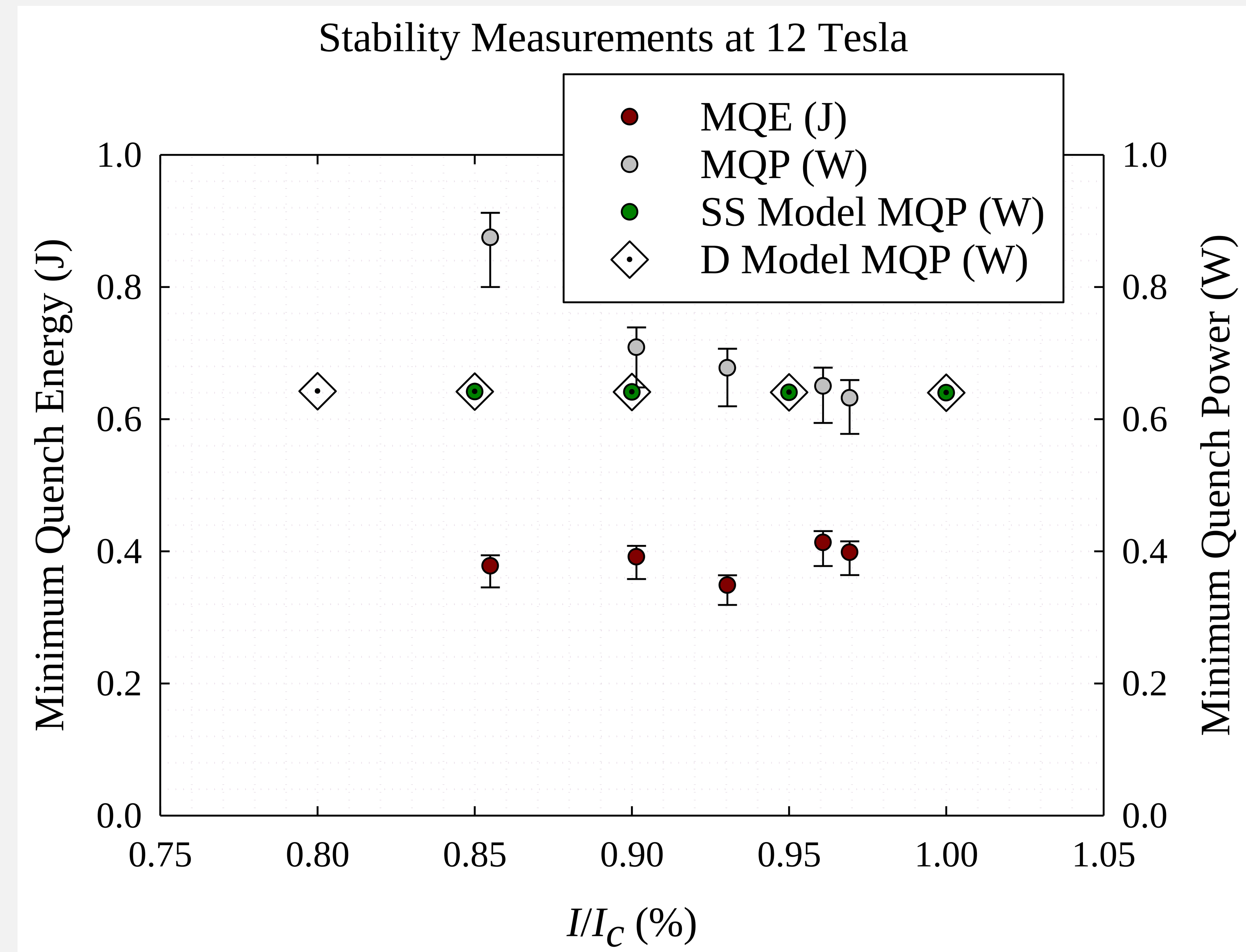
Rutherford cable dynamic thermal stability model

Dynamic Stability Criterion (1s pulses):

$$1 = \frac{C_p(T) \times (T-T_B)}{\underbrace{\frac{\rho_{norm}\left(i \times I_c\left(\frac{T-T_{cs}}{T_c-T_{cs}}\right)\right)^2}{PA_{cu}}}_{\substack{\text{Joule Heating}\\ \text{per unit length}\\ \text{and unit surface area}}} + \underbrace{G_d}_{\substack{\text{Heat Perturbation}\\ \text{per unit length}\\ \text{and surface area}\\ \text{under heater}}} - \underbrace{\eta h(T-T_B)}_{\substack{\text{surface cooling}\\ \text{per unit length}\\ \text{and unit surface area}}} - \underbrace{\frac{(T-T_B)\sqrt{2\kappa A_{cu}P\eta h}}{A_s}}_{\substack{\text{Cold-end cooling}\\ \text{per unit length}\\ \text{normalized for spot size}}}}$$

- C_p calculated from experimental data fit from PPMS data from Nb_3Sn strand at 12 T [3]

Full-excitation thermal stability measurement results



Conclusions

- A laboratory scale system was modified to determine stability of a fully excited Nb_3Sn Rutherford cable.
- A steady state analytical model and dynamic analytical model resulted in similar values as experimental data, but they were not able to capture the I/I_c stability relationship.

References

[1] E. Barzi et al. "Superconducting Transformer for Superconducting Cable Tests in a Magnetic Field" AIP Conference Proceedings, 1218, pp.421-428 (2010)
[2] C.J. Kovacs, M. Majoros, M.D. Sumption, and E.W. Collings, "Quench and stability of Roebel cables at 77 K and self-field: minimum quench power, cold end cooling, and cable cooling efficiency," *Cryogenics*, 95, pp.57-63 (2018)
[3] C.S. Myers, M.A. Susner, L. Motowidlo, J. Distin, M.D. Sumption, and E.W. Collings, "Specific heats of composite Bi2212, Nb_3Sn, and MgB_2 wire conductors", *IEEE Trans. Appl. Supercond.*, 23, 3, (2013)

Acknowledgments

This work was supported by the U.S. Department of Energy, Office of Science Graduate Student Research Program (SCGSR)