A Cable-Scale Experiment to Predict Training Characteristics of Superconducting Magnets and Explore New Magnet Materials

MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

C. J. Kovacs[1], E. Z. Barzi[2], M. Marchevsky[3], D. Turrioni[2], and A. V. Zlobin[2]

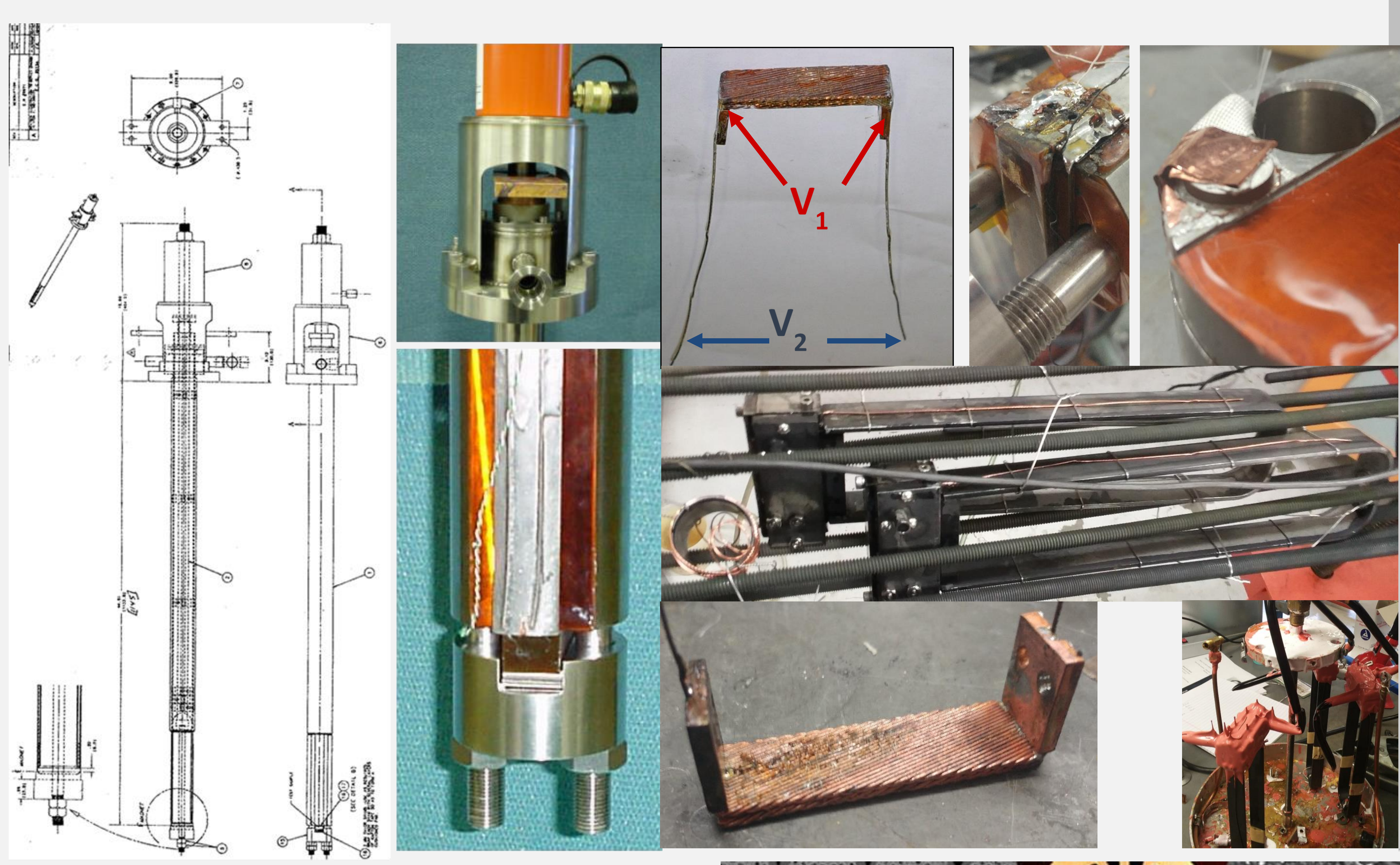
[1] Center for Superconducting & Magnetic Materials (CSMM), Department of Materials Science & Engineering, The Ohio State University, USA
[2] Applied Physics and Superconductivity Technology Division (APS-TD), Fermi National Accelerator Laboratory, USA
[3] Applied Technology and Applied Physics Division (ATAP), Lawrence Berkeley National Laboratory, USA

Introduction

- A major difficulty facing the future of Nb_3Sn accelerator magnets is training, 10s of positive training quenches are needed to reach close to optimum field. If excessive training remains unsolved, even if the target fields are reached, it will be exceedingly difficult to commission a next generation discovery machine.
- Most of the investigations on training today are done through magnet testing, a lengthy and costly method. While a prototype magnet will more accurately represent operational conditions:
  - Investigating new material selections, structures, and processing is exceedingly difficult.
  - Independently controlling stresses, current, and magnetic field is not performed, the load-line is followed.
  - Once a training quench happens, the system is totally reset for another cycle.
- In this research, a sub-scale experiment was developed to investigate training-like behavior in cable, insulation wrap, and impregnated (acronym "CWI") magnet scale composite.

Transverse Pressure Insert (TPI) for characterizing magnet scale composite

- The Transverse Pressure Insert (TPI) measurement system, shown below, was previously commissioned to determine J_c degradation due to a fixed transverse stress [1]. To characterize training-like behavior in CWI composite, in addition to sample voltage taps, the TPI was equipped with a piezoelectric acoustic sensor. Voltage tap, pressure data, and acoustic data was acquired with a fast and sensitive NI-9238 in a NI cRIO-9073.



Measurement Procedure and Results

13 T I_c measurement

1st Press: 13 T *i* measurement with applying pressure, hold at each pressure for 20-60 seconds.

- 13.7 MPa "touchdown" → 41 MPa → 55 MPa → 68.5 MPa → 55 MPa → 41 MPa → 13.7 MPa
- systematic error of pressure $^{+6}_{-3}$ MPa
- ~16.5 MPa/min ramp rate

13 T I_c measurement

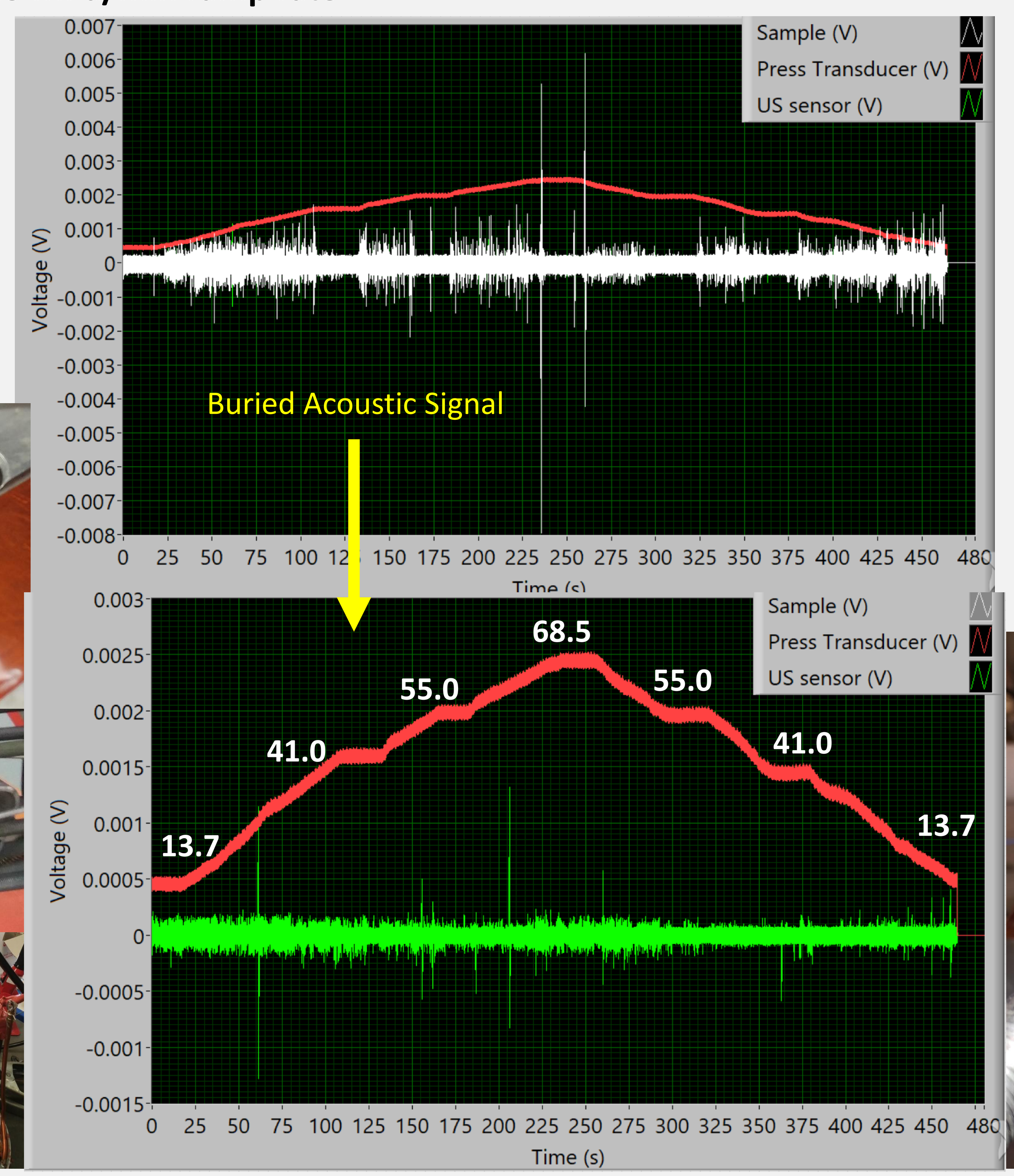
2nd Press: 13 T *i* measurement with applying pressure, hold at each pressure for 20-60 seconds.

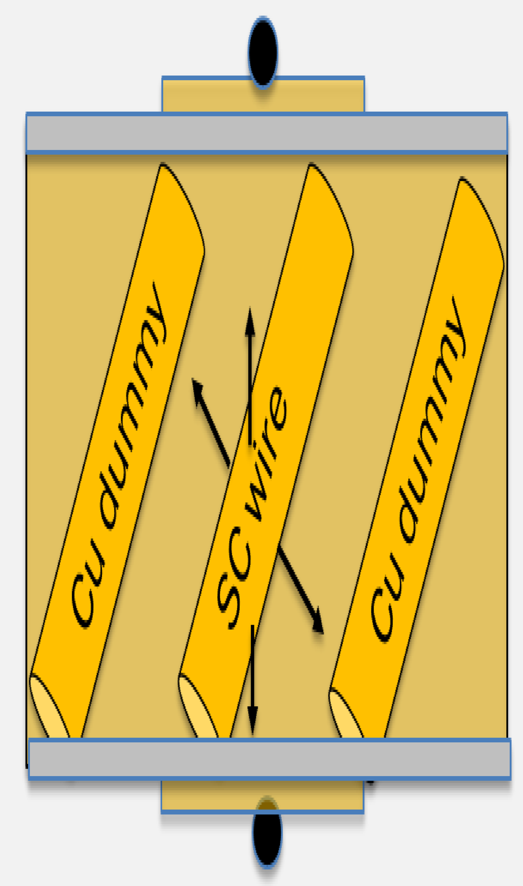
- 13.7 MPa "touchdown" → 41 MPa → 55 MPa → 68.5 MPa → 55 MPa → 41 MPa → 13.7 MPa
- systematic error of pressure $^{+6}_{-3}$ MPa
- ~16.5 MPa/min ramp rate

10 T I_c measurement

3rd Press: 10 T *i* measurement with applying pressure, hold at each pressure for 20-60 seconds.

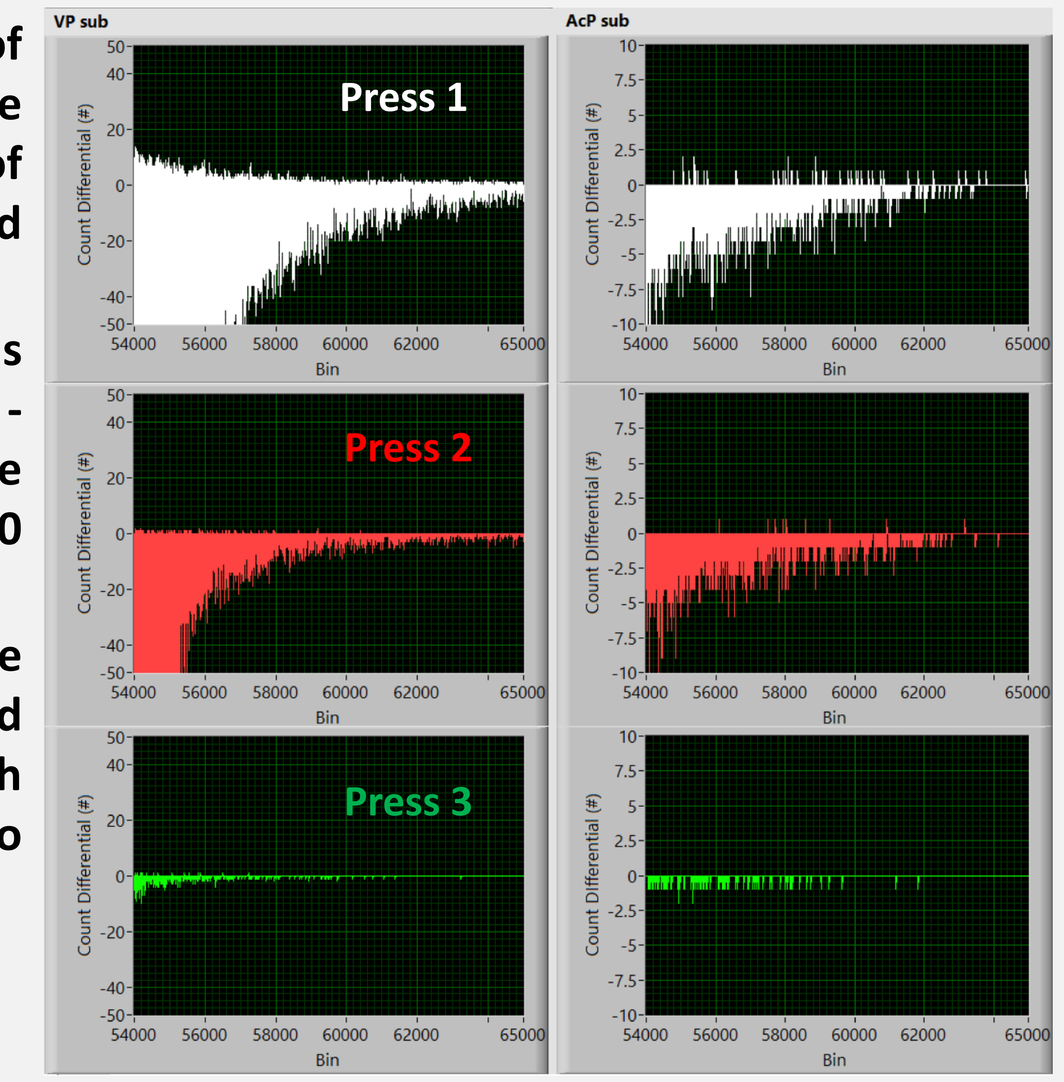
- 13.7 MPa "touchdown" → 41 MPa → 55 MPa → 68.5 MPa → 55 MPa → 41 MPa → 13.7 MPa
- systematic error of pressure $^{+6}_{-3}$ MPa
- ~16.5 MPa/min ramp rate





Material Study: CTD-101K versus NHMFL Mix-61

- Shown to the right is subtraction of the NHMFL Mix-61 sample by the CTD-101K sample histograms data of the (normalized) voltage tap and acoustic sensor signal.
- The voltage tap histogram for this analysis had 100000 bins from -0.0005 V to 0.0005 V and the acoustic signal histogram had 100000 bins from -0.01 V to 0.01 V.
- The range shown for the (normalized) voltage tap data and acoustic data corresponds with 0.00004 to 0.00015 V and 0.0008 to .0030 V respectively.



- It is clear the CTD-101K had a higher frequency of higher amplitude disturbances and subsequent pressing cycles resulted in a lower frequency of detected disturbances

$$A_{loop-side}=6.2\times10^{-5}\ m^2,\quad A_{loop-top}=7.1\times10^{-4}\ m^2,\quad \frac{dr}{dt}=1\ \frac{m}{s},\quad r=\frac{\text{cable width}}{2}=0.007\ m$$

$$\frac{d\Phi}{dt}=\frac{\overbrace{-\frac{\mu_0 I}{\pi r^2}}^{\frac{dB}{dr}}\times\frac{dr}{dt}}{A_{loop}} \longrightarrow \Delta V = 255\ \mu V \text{ to } 2.9\ mV \text{ (dependent on motion direction)}$$

Conclusions

- Previous measurements investigating the influence of impregnation cracking on training have had similar setups [2,3], what makes this one special is that:
  - The excited superconducting strand itself behaves like an internal motion sensor while the acoustic sensor picks up impregnation fracturing.
  - The composite is similar to what is seen in an accelerator magnet.
  - The reaction fixtures and TPI can handle a multitude of sample types and sizes
- It is possible to perform a series of sub scale experiments to investigating new material selections, structures, and processing [4].
- Similar systems can likely perform the same role in such a research program [5].

References

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Acknowledgments

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

The Ohio State University
CSMM Center for Superconducting and Magnetic Materials
Department of Materials Science and Engineering