Strain Measurements of Nb_3Sn Composites using Distributed Fiber Sensing

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Introduction

While there has been great success in the finite element analysis models of short dipole magnets and predicting the mechanical behavior of coils, higher granularity FEA models are in demand. As seen in Image 1, the coils within these magnets are made of a composite containing a superconducting material called Nb_3Sn. This experiment was conducted in order to provide a more detailed understanding of the composites mechanical properties and compare them to the multi-level models. This was done by conducting compression test on the coil while measuring strain with a high-resolution fiber optic strain gage as seen in Figure 1. Additionally, the goal in using the fiber was to validate its performance by directly applying them to the composite.

Image 1: Magnification of Nb_3Sn ten stack layers comprised of a stainless-steel core, the conductor itself, reacted S2/Resin/Mica composite, and Pure Resin.

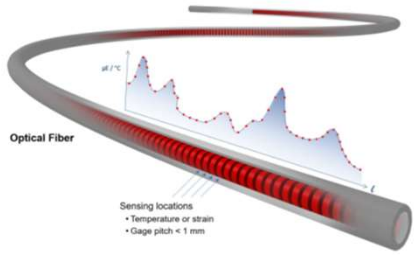


Figure 1: Fiber optic strain gages provide continuous high resolution (gage pitch < 1mm) measurements of strain along the fiber. Each red disk in the fiber is a gage. The graph is an example of the gage read out, each point being a strain measurement at each gage. Source: Luna Tech. Inc

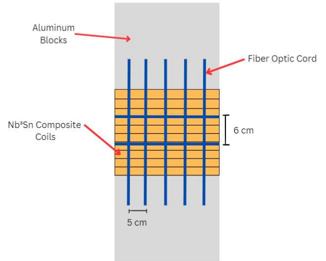


Figure 2: Layout Diagram of 10 stack and fiber cable assembly

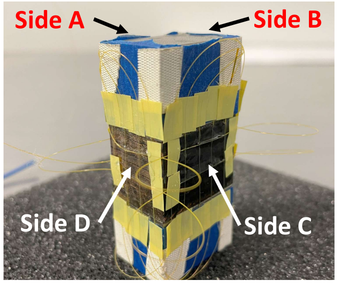
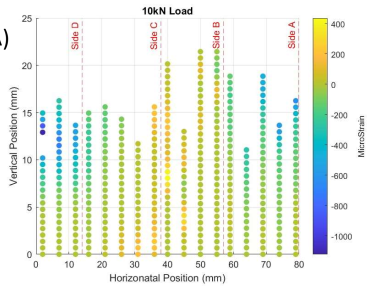


Image 2: Fiber cords epoxied to 10 stack coil from Isometric view

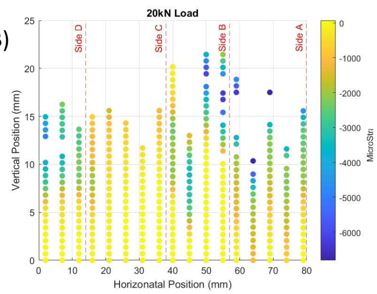
Methods and Materials

A ten stack is a sectioned piece of Nb_3Sn coil sandwiched between two aluminum blocks. The overall size of the ten stack is 0.75 in x 0.75 in x 1 in. To measure strain in the stack, a fiber optic cord was epoxied onto the vertical surfaces of the ten stack in both the vertical and horizontal direction. Having fiber in both directions made it possible to calculate more properties than having fiber in one direction. The vertical fibers were placed increments of 5 cm and the horizontal were centered on the stack 6 cm apart as seen in Figure 2 and Image 2. It is assumed that the layer of epoxy between the stack and fiber is thin enough such that the strain on the surface is directly measured by movement in the fiber. The fiber reads out measurements in units of micro-strain at each gage point along the fiber. With the cords affixed to the stack, it was placed into a uniaxial compression machine. The stack was compressed under 3 different loads: 10kN, 20kN, and 30kN. From the strain data, an overall strain was calculated by averaging the average strain on each surface. Using the overall strain, assuming linear deformation, elastic modulus was calculated using best fit line to data as seen in Figure 4. Finally, to validate the fiber readings, the calculated material property was compared to measurements taken in other studies.

3A)



3B)



3C)

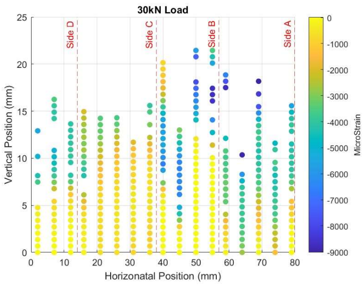


Figure 3: 2D plots of strain across all surfaces of ten stack at varying loads. Each dot presents a gage in the fiber and the darker the dot the higher the strain measured at that gage. Each vertical set of dots are sections of fiber bonded to their respective sides of the coil. Each sets ranges from 0 mm (corresponding to the bottom edge of the coil) to 13 to 20 mm (corresponding to the top edge of the coil).

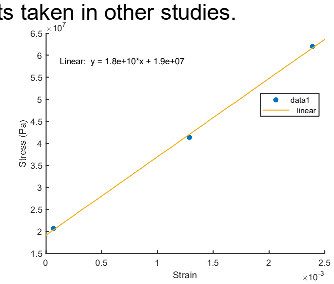


Figure 4: The graph to the right is the Stress vs Strain graph of Nb_3Sn composed from measurements of strain at varying loads. The linear line displays the elastic region of Nb_3Sn stress strain behavior. From this data, the elastic modulus, which was calculated from the slope, is 18 GPa.

Results and Conclusion

The measured elastic modulus in the cable was 18 ± 3 GPa, and these results equal to the expected modulus's measured in other studies [2]. Additionally, the fibers' ability to accurately read strain validates its utility on Nb_3Sn. Moving forward, its important that the glue line thickness is minimized to ensure that the fiber has sufficient contact with the coil. In Figure 3C, the strain measured on side A ranged 0 to 9000 με while the strain measured on side C ranged from 0 to 3000 με. It would be expected that both sides read similar values due to both surfaces being symmetric across the part and the load being uniaxial. One potential explanation for this discontinuity is that the glue line was not adequately minimized in a particular section of the fiber, which, in turn, may have resulted in an incomplete measurement of strain on the surface of the coil.

References & Acknowledgments:

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4. Ten Stacks Assembled by Steve Krave (Mentor)
5. Supervisor: Stoyan Stoynev
6. Fibers Provided by Maria Baldini

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