Superconducting Performance: The Impact of Magnetic Field and Angle on Critical Current

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Introduction

- Superconducting magnets are essential for generating strong magnetic fields to confine plasma in fusion reactors.
- Made from superconducting materials like Nb_3Sn and high-temperature superconductors (HTS) such as YBCO.
- We investigate the performance of superconductor REBCO, with varying angle of attack, applied magnetic field strength at ~77K

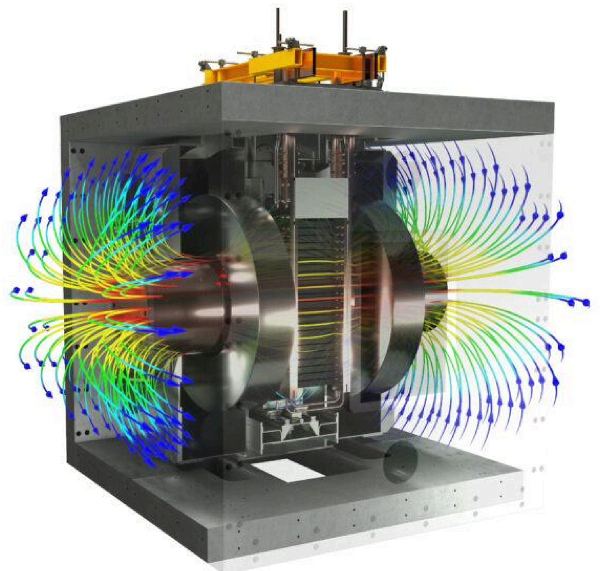

Fig 1: Magnetic field lines for CHIMERA rig [1]

Experimental Apparatus and Methods

Key Apparatus:

1. Ic Probe: Holds the sample, delivers current, and measures voltage.
2. Brass Sample Holder: Secures the HTS tape during soldering and testing.
3. HTS Tape: 80 mm REBCO sample for testing.
4. Polyimide Copper Wire & Pins: For voltage tap connections.
5. Cryogenic Setup (Dewar): Holds the sample in liquid nitrogen.
6. LabView Program: Controls the power supply and records measurements.

Fig 2: Preparing rig by pouring in liquid nitrogen

Methods:

1. Soldering:
   - Pre-tin the sample holder and HTS tape using soldering flux and lead-tin solder.
   - Attach the HTS tape to the sample holder by heating the pre-tinned areas and solder voltage tap wires to the sample.
2. Setup:
   - Mount the sample holder on the Ic probe and connect voltage tap wires to the data system.
   - Place the probe in the Dewar with liquid nitrogen and attach the current leads.
3. Ic Measurement:
   - Use LabView software to control the measurement, adjust the magnetic field and field angle, monitoring voltage and current.

Results

- The critical current (Ic) of the superconductor was analysed in response to varying magnetic field strengths and field angles.
- The background voltage was removed by fitting a linear model to data up to 40% of the maximum current and subtracting this fit from the curve.
- The critical current (Ic) and the n exponent were determined by fitting the data to a power law model using scipy (Eq. 1)
- Ic reaches its maximum at an angle of 90°, indicating optimal performance at this orientation.
- At other angles, Ic is reduced, likely due to factors such as reduced flux pinning [2].
- Magnetic field strength is inversely related to Ic, with increasing field strength leading to a decrease in critical current.

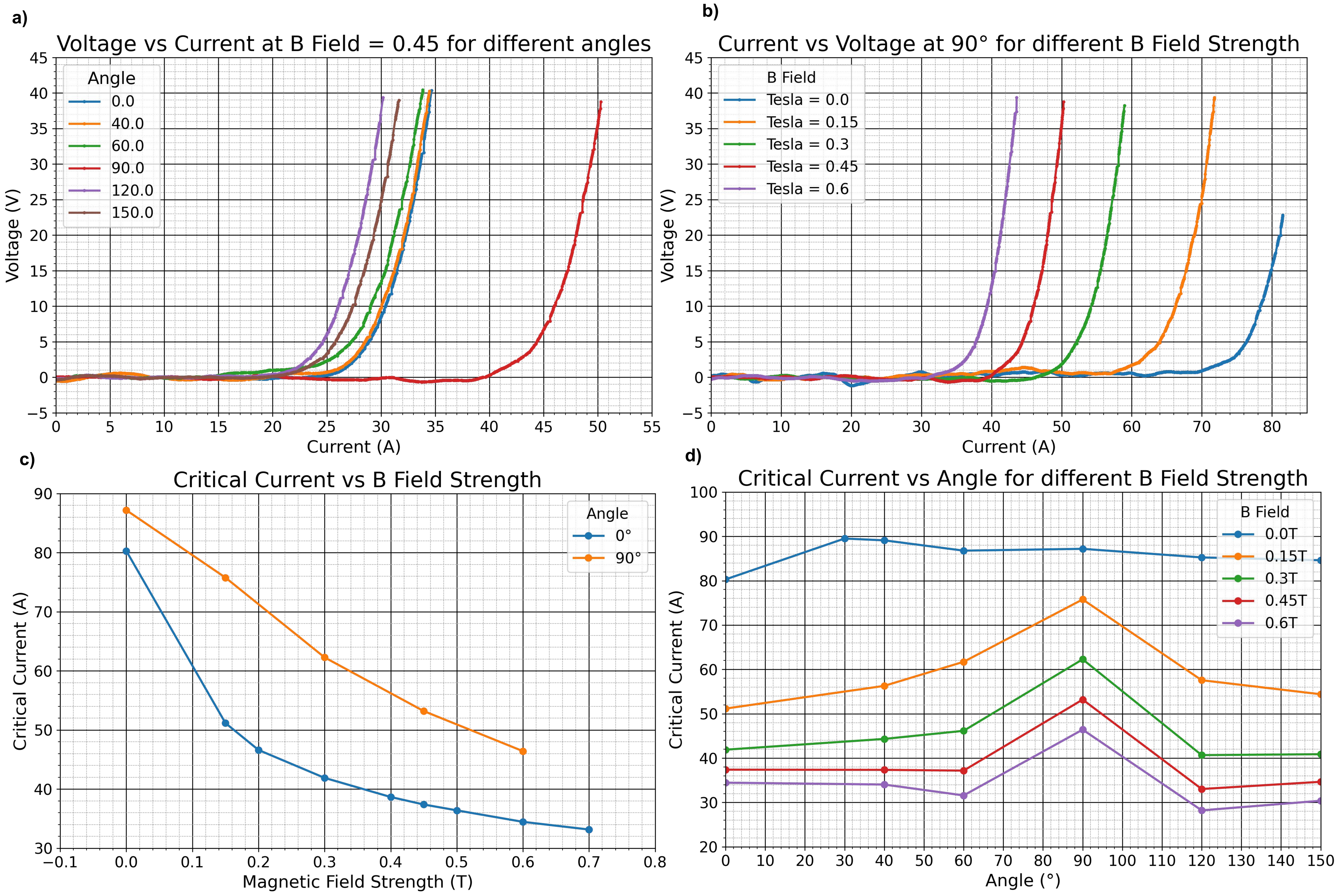

Fig 3: (a) Voltage vs. Current at B Field = 0.45T for various angles (0°, 40°, 60°, 90°, 120°, 150°). (b) Current vs. Voltage at 90° for different Tesla values (0.0T, 0.15T, 0.3T, 0.45T, 0.6T). (c) Critical Current vs. Magnetic Field Strength for 0° and 90° angles. (d) Critical Current vs. Angle for different B Field Strengths (0.0T, 0.15T, 0.3T, 0.45T, 0.6T). Note: B Field Strength stands for Magnetic Field Strength

Conclusion

The analysis of the superconductor's critical current (Ic) shows that the optimal performance occurs at 90° angle, where Ic is highest. As the magnetic field strength increases, the critical current decreases, which is expected behavior for superconductors. At higher fields, such as 0.7T, the current is significantly suppressed. These results provide a better understanding of how the superconductor performs under different conditions and highlight the importance of the magnetic field alignment and strength in determining the critical current.

$$E = E_C \left(\frac{J}{J_c}\right)^n$$

Eq. 1: The power law model used to describe the relationship between the electric field (E), current density (J), critical electric field (Ec), critical current density (Jc), and n (exponent that characterises the non-linear relationship.

References

[1] Image from EUROfusion: CHIMERA to transform fusion component testing - EUROfusion

[2] Matsushita, T., 2007. Flux pinning in superconductors. 1st ed. Berlin, Heidelberg: Springer. Available at: https://doi.org/10.1007/978-3-540-44515-9 [Accessed 28 January 2025].