A breakthrough in High Temperature Superconductors

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ABSTRACT

There has been a breakthrough in using long continuous fibers to reinforce High Temperature Superconductors (HTS) [1]. This has led to two innovations: a) Cosmic Ray Magnetic Shields protecting satellites and b) a Dipole Coilgun to magnetically launch projectiles including missiles and space payloads. Low Temperature Superconductors (LTS) require cooling to 4°K using rare and problematic liquid helium. Reinforced HTS only needs cooling to 95°K which can be achieved using cheap and readily available liquid nitrogen. These higher operating temperatures mean better performance and reliability at much cheaper cost. Reinforced HTS should expand existing superconductor markets for magnetic bearings, power industry Superconducting Fault Current Limiters (SFCL), diagnostic Magnetic Resonance Imaging (MRI) and Nuclear Magnetic Resonance (NMR). A future of huge, but practical superconductor magnetic fields and current transmission offers opportunities for innovations such as the two described in this paper.

Keywords: superconductors, HTS, radiation shield, coilgun, satellites.

1 BREAKTHROUGH

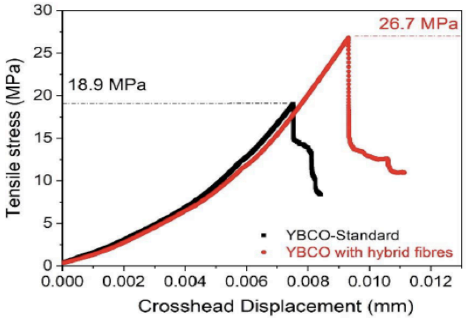
HTS were discovered in 1986 but have found little practical use due to a fundamental problem: HTS is a fragile, single crystal which breaks easily. Once broken, superconducting permanently stops.

Over nearly 35 years, attempts have been made to strengthen HTS using internal reinforcement (like straw in bricks or steel bars in concrete). These failed because HTS is made by melting powders at high temperatures ~1200°C and then crystallizing under oxygen. The reinforcement material, once heated, reacted at such high temperatures with oxygen, contaminating the crystal making it weaker.

Attempts to boost HTS strength focus on external reinforcement and manufacturing methods such as powder-in-tube (PIT) and using Chemical Vapor Deposition (CVD) to crystallize HTS on a substrate. These techniques produce thin HTS with reduced capacity with limited usefulness. One institute even encased HTS in solid stainless steel, producing a world record magnetic field indicating that strength or reinforcement of the material is critical for improving practical application.

Our innovation was to pacify internal reinforcement with long, continuous silicon carbide (SiC) fibers. SiC forms a durable silicon oxide coat that prohibits further oxidation and contamination of the HTS crystal. This passivation is similar to how chromium prevents rust in stainless steel or how volatile elemental aluminum can be used in foil. The experimental reinforced HTS sample boosted strength by 40% with only three hair-sized SiC fibres in a one inch tablet [1]. More fiber should raise strength even more.

Figure 1: Reinforced High Temperature Superconductors



Tensile strength measured for single grain YBCO samples fabricated with and without embedded mono-filament hybrid SiC fibres containing a W-core. (from Namburi, et.al. 2020)

2 COSMIC RAY SHIELDS

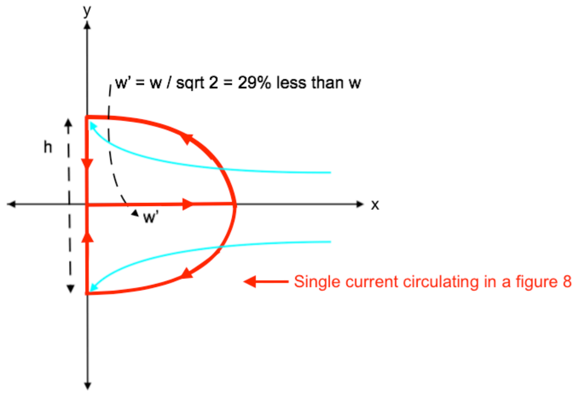
2.1 The Threat to Satellites and Humans

Solar charged particles now hurt satellites and astronauts. They will become more threatening as satellites adopt more complex electronics, and as humans travel longer and deeper into space. Future Coronal Mass Ejections (CME) like the Carrington Event (1859) and New York Railroad superstorm (1921) will also wreck havoc on an earth which now depends highly on electricity and electro-magnetics. One estimate calculated the probability of another similar CME at 12% between 2012-2022 [2]. Ironically in July 2012, just five months after the estimate's publication, a CME event went through earth's orbit just missing us [3]. Current shielding relies on conventional solid material absoption, which a) is heavy, and thus expensive, for use in space, b) fails at high particle energies, and c) still creates destructive radiation and secondary particles when hit by charged particles.

2.2 Superconductor Magnetic Deflection

We have invented a superconductor magnetic shield which deflects solar charged particles similar to how earth's magnetic field protects the atmosphere. Rather than destructively absorbing particle energy, particles are simply deflected away.

Figure 2: Magnetic Cosmic Ray Shield



➢ No secondary radiation nor particles from chemical reaction.

➢ Deflection is efficient because magnetism acts perpendicular to an incoming charged particle's path.

➢ Low weight means low cost.

➢ Energy needs are minimal since force is only needed when charged particles are around.

2.3 Where we are now and next steps

✓ Concept proven with conventional magnets and electron beams.

✓ Theoretical projections show a superconductor prototype is feasible.

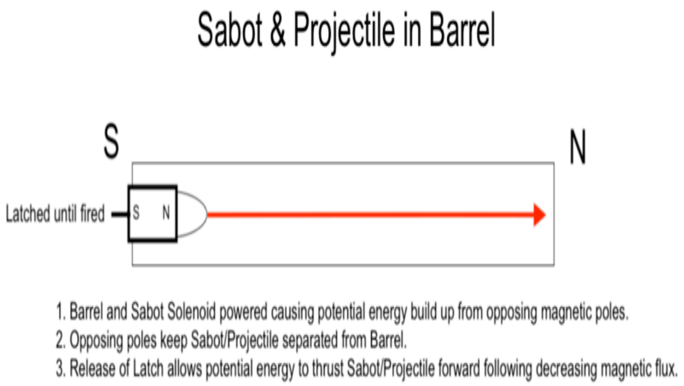
Phase I: design a superconductor prototype for testing against solar charged particles on a LEO satellite, Space Station, or GEO satellite.

Phase II: build prototype for testing in space.

3 DIPOLE COILGUN

Our Dipole Coilgun uses HTS magnetic fields to create a declining magnetic gradient which ¨pushes¨ a projectile down a solenoid barrel. An HTS projectile sabot creates a strong opposing magnetic field to an HTS solenoid barrel.

Figure 3: Dipole Coilgun

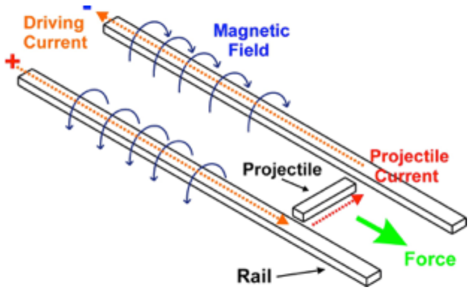


1. Barrel and Sabot Solenoid powered causing potential energy build up from opposing magnetic poles.
2. Opposing poles keep Sabot/Projectile separated from Barrel.
3. Release of Latch allows potential energy to thrust Sabot/Projectile forward following decreasing magnetic flux.

3.1. Addresses Magnetic Gun Challenges

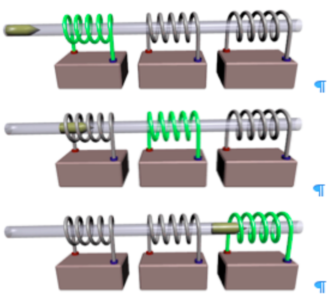
Our design addresses faults in previous magnetic launching designs such as the Railgun and conventional Coilgun, both of which did not use superconductors. Railguns generate magnetic fields by forcing electricity down a single conductor. Unfortunately, this generates excessive heat both in conductor resistance as well as junction friction.

Figure 4: Conventional Railgun



Conventional Coilguns magnetically ¨pull¨ projectiles along a solenoid barrel. But this requires rapid electric switching ahead of a projectile which becomes impractical at high projectile speeds.

Figure 5: Conventional Goilgun



3.2. Superconductor Magnetic Launching

- No explosions (no energetic materials involved):
    - Smaller and lighter equipment;
    - Much less equipment fouling, wear and tear;
    - Rapid repeat firing;
    - Force efficiently focused along barrel axis.
- Uses electricity, not bulky propellant:
    - Can be used to fire projectiles from Space
    - Cartridges are mostly payloads, not propellant;
    - Projectile sabots recoverable and recyclable.
- No infrared heat signature.

3.3. Where we are and next steps

- ✓ Concept proven with conventional magnets.
- ✓ Theoretical projections show a superconductor prototype is feasible.

Phase I: design a superconductor prototype to test launch a projectile up to Escape Velocity either on Earth or from LEO satellite / Space Station (space testing may be more expensive but could yield quicker results).

Phase II: build prototype for demonstration on earth or in space.

REFERENCES

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