Development of MgB_2 superconductor wire and coils for practical applications at Hyper Tech Research

A Status Report

David Doll
Matt Rindfleisch
Mike Tomsic
Jinji Yue
CJ Thong
Xuan Peng

Oral session
3M OrD1
20 June 2013

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

Hyper Tech

Hyper Tech Research Inc

539 Industrial Mile Rd.
Columbus, OH
43228-2412

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

Partners and Collaborators

Universities:

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

Key OSU Personnel
Mike Sumption
Ted Collings
Milan Majoros
Guangze Li
Yuan Yang
Mike Susner
Chris Kovacs
Madhu Kongara

University of Wollongong

Case Western Reserve University, Est. 1826
think beyond the possible

ISEM Wollongong

Industrial:

Siemens
GE
Phillips
ASL
Rolls-Royce
Aurora

Supporting Agencies:

State of Ohio
U.S. DOE HEP
NIH
MIT
NIST
NASA
DOD: USN, USAF
Wollongong
NHMFL
FSU
IEMM
LEI
SMI
MMP

Outline

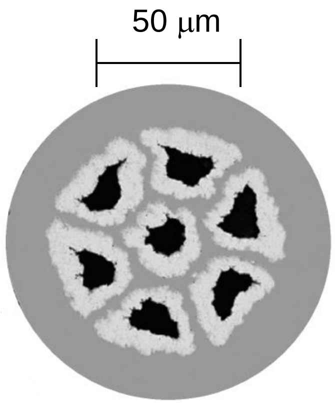
- Hyper Tech's MgB_2 superconductors
  - Strand configurations
  - Conductor properties
  - Next generation
  - Analytical methods development
- Commercial applications of MgB_2
  - MRI
  - Motors and generators
  - Superconducting Fault Current Limiters
  - Cost implications

MgB_2 Strand Architecture

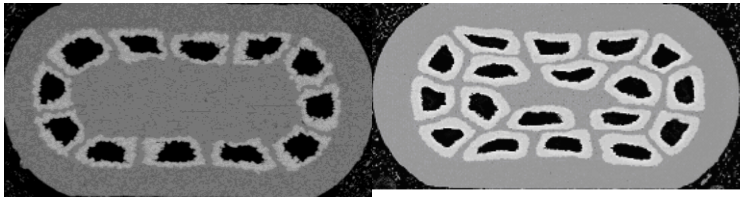
Hyper Tech can match strand configuration to wire specification:

- Powder recipe
- Barrier: Nb, Fe, Cu, Ni, Ti
- Outer sheath: Monel, SS, Ni, ODS Cu, Cu
- Matrix: Monel, SS, Ni, ODS Cu, Cu
- Number of filaments
- Diameter (< 0.1 mm is possible)
- Effective filament diameter
- Shape
- Cu %
- Coil design (e.g., W&R / R&W)
- Insulation

Wire design ⟷ **Spec**



Round and very small diameter

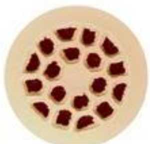
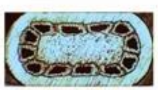
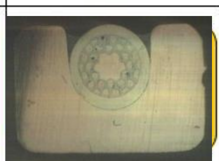


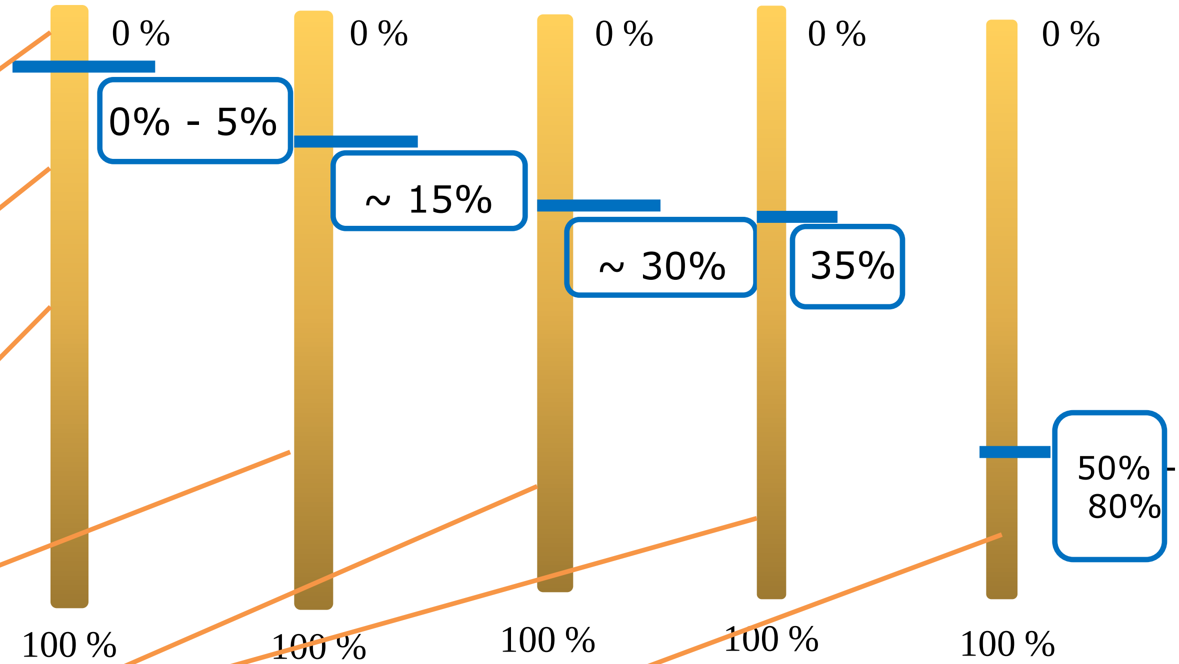
Shaped Architecture

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

MgB_2 Strand Design: % Cu

Higher Filament Counts (54)		Lower AC Loss for Stator
Al_2O_3 Dispersion Strengthened Copper		Lower AC Losses for Transformers
Resistive Matrix		Wire for Fault Current Limiter
Rectangular Wire		Better Packing for electro-magnetic coils
Nb Barrier All Copper Matrix		Improved Wire Stability
Wire-in-Channel		Stability and Strength



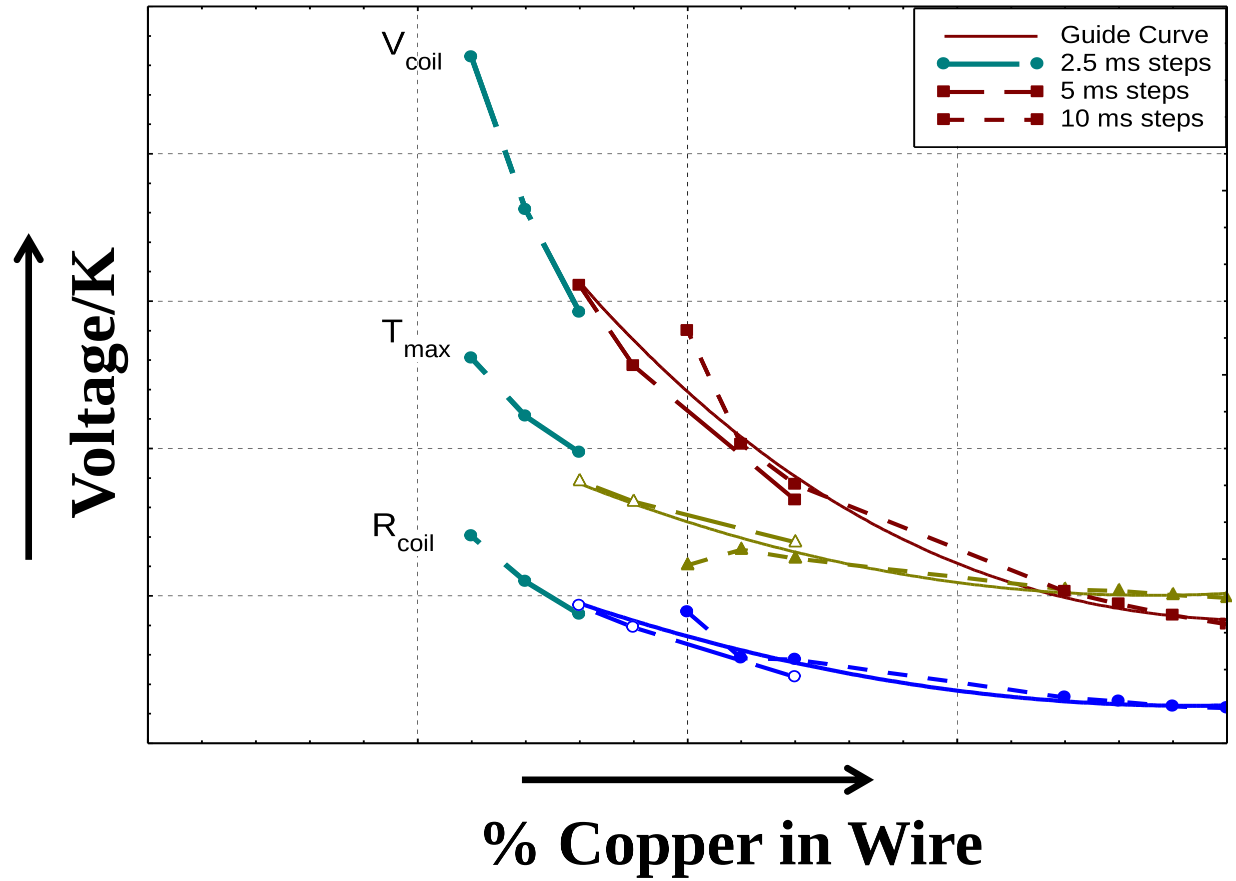
Optimize $J_{e,coil}$ using minimal amount of Cu

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

Copper in a MgB_2 Wire for Quench Protection

Important Trade Between Je and % Copper in Wire for Each Coil Design



Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

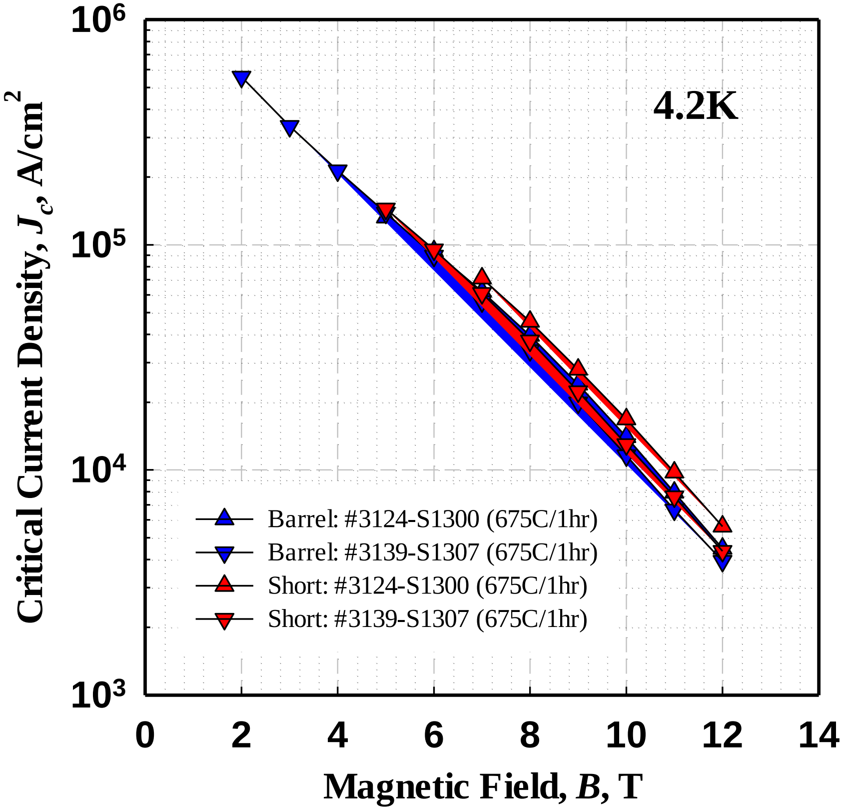
Analytical Methods Being Developed

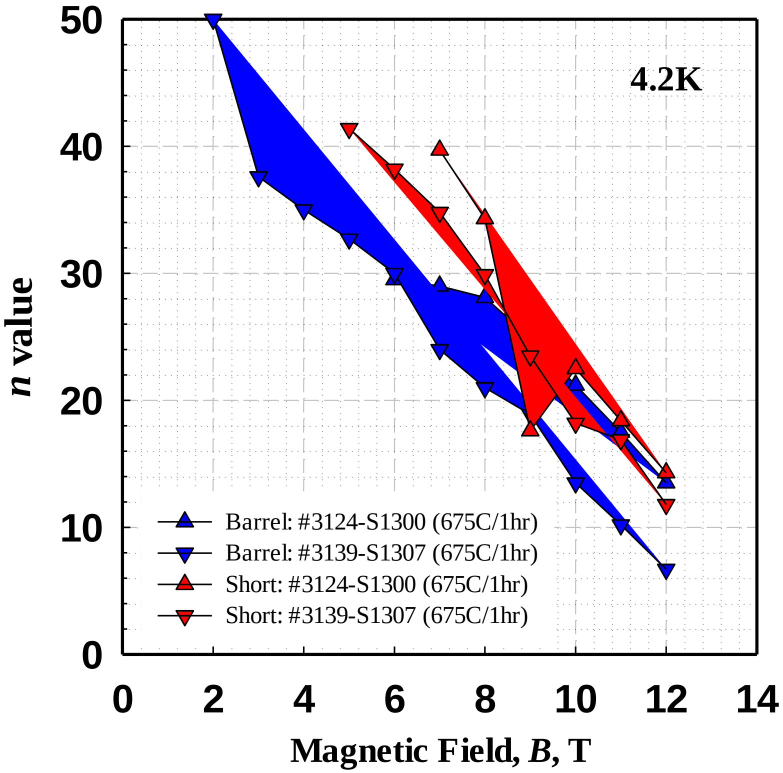
- Wire drawing process
  - Predicts limiting strain
  - Optimizes wire drawing speed
  - Estimates thermal management
- Magnet quench protection
  - Simulates quench event beginning with wire
  - Predicts maximum wire temperature
  - Predicts current decay and peak voltage
  - Establishes Cu:SC ratio for safe operation
  - Provides 3D flux profile
  - Multi-coil coupling capability
- Coil design
  - Calculate stress, strain and deflection in coil
  - Accounts for winding, cool-down and energizing
  - Includes former, all wire layers and interfaces
- FE thermal and stress capability

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

MgB_2 Wire Performance at 4.2 K

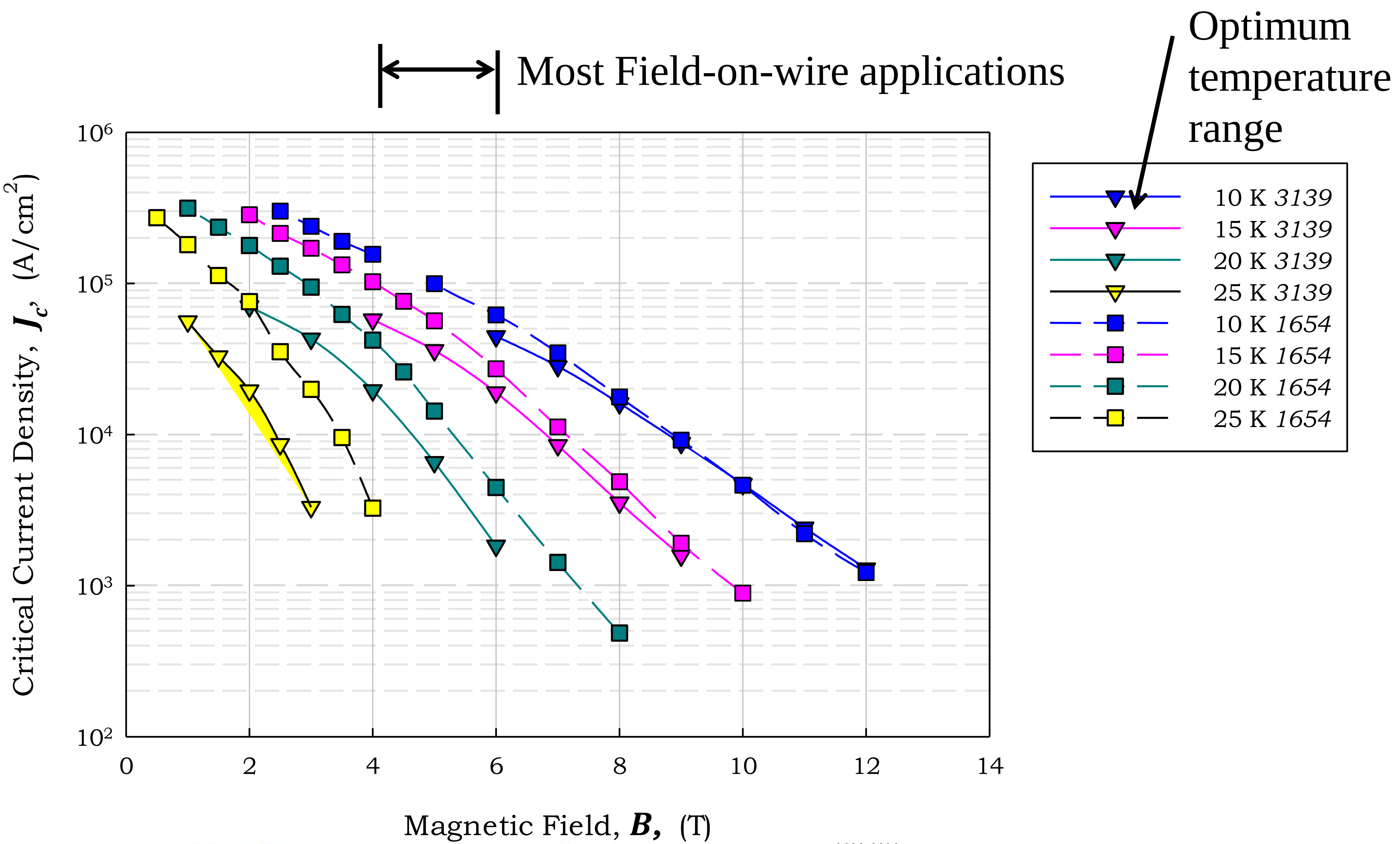




Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

Jc Values in Acceptable Range

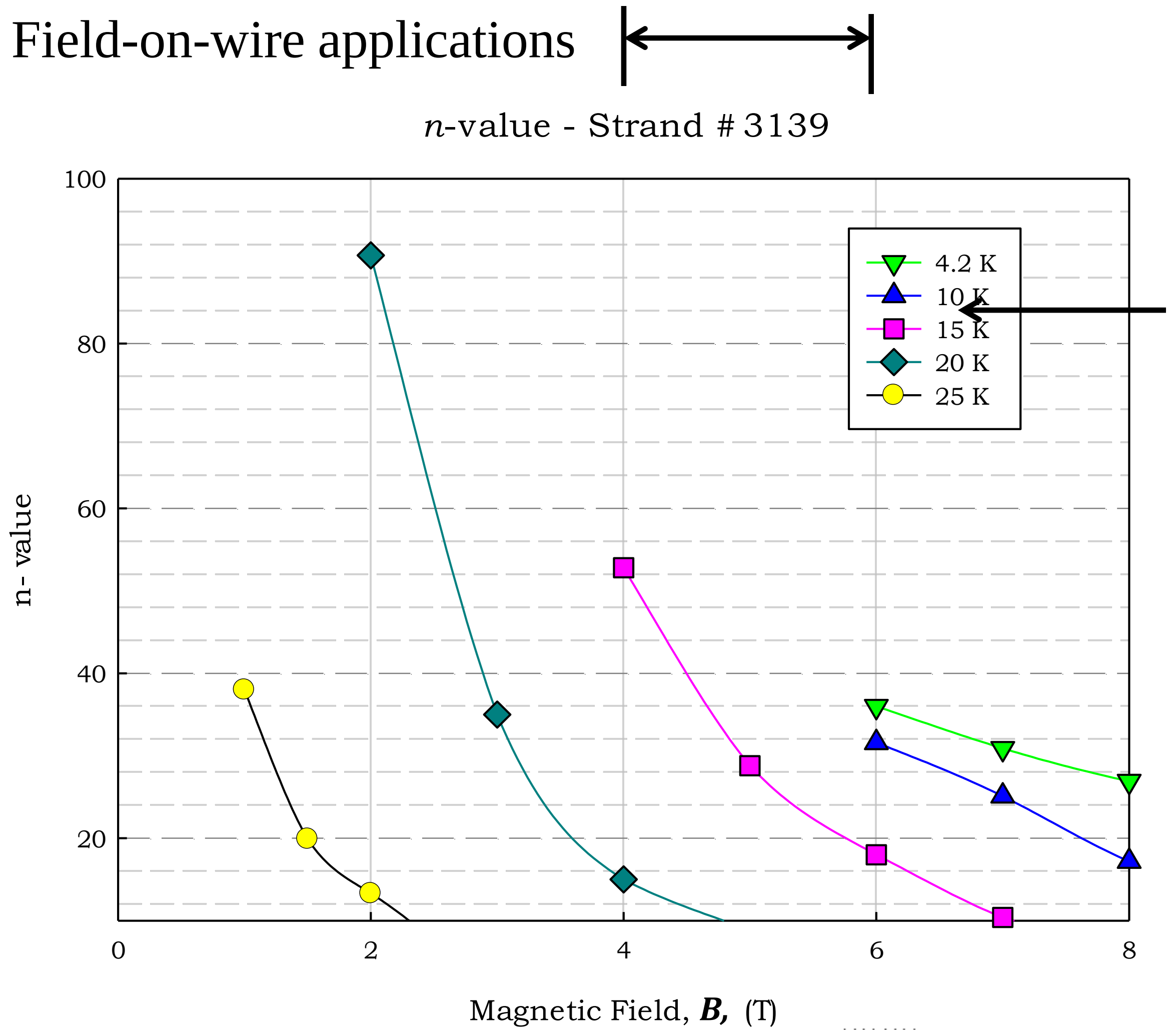


Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

MgB_2 N-Values

Most Field-on-wire applications

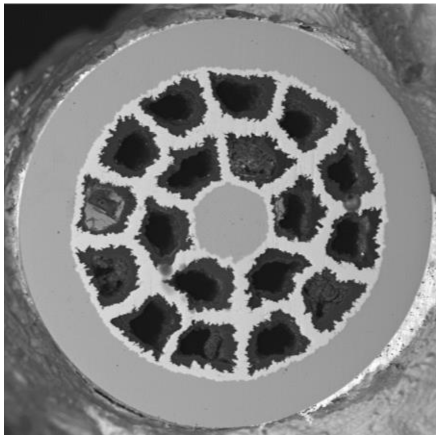


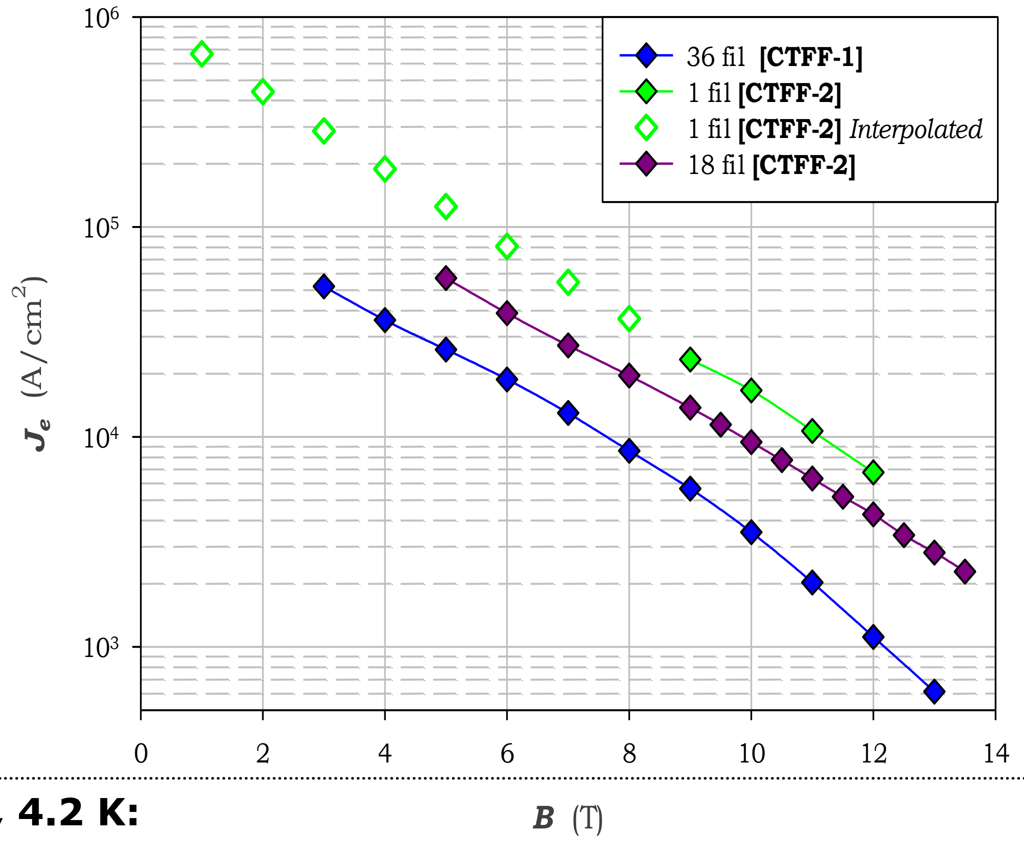
Optimum temperature range

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

Improving connectivity





2nd Generation MgB_2 wire

18% Superconductor Fraction

Engineering Current Density

100 m long CTFF-2 type fabricated

Engineering Current Density, J_e, 5 T, 4.2 K:

CTFF-1 (best of class 36 filament) .... 26,000 A/cm²
CTFF-2 (18 filament) .... 58,000 A/cm² 2.2x increase
CTFF-2 (monofilament, extrapolated) .... 122,000 A/cm² 4.7x increase

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

In-House Capabilities

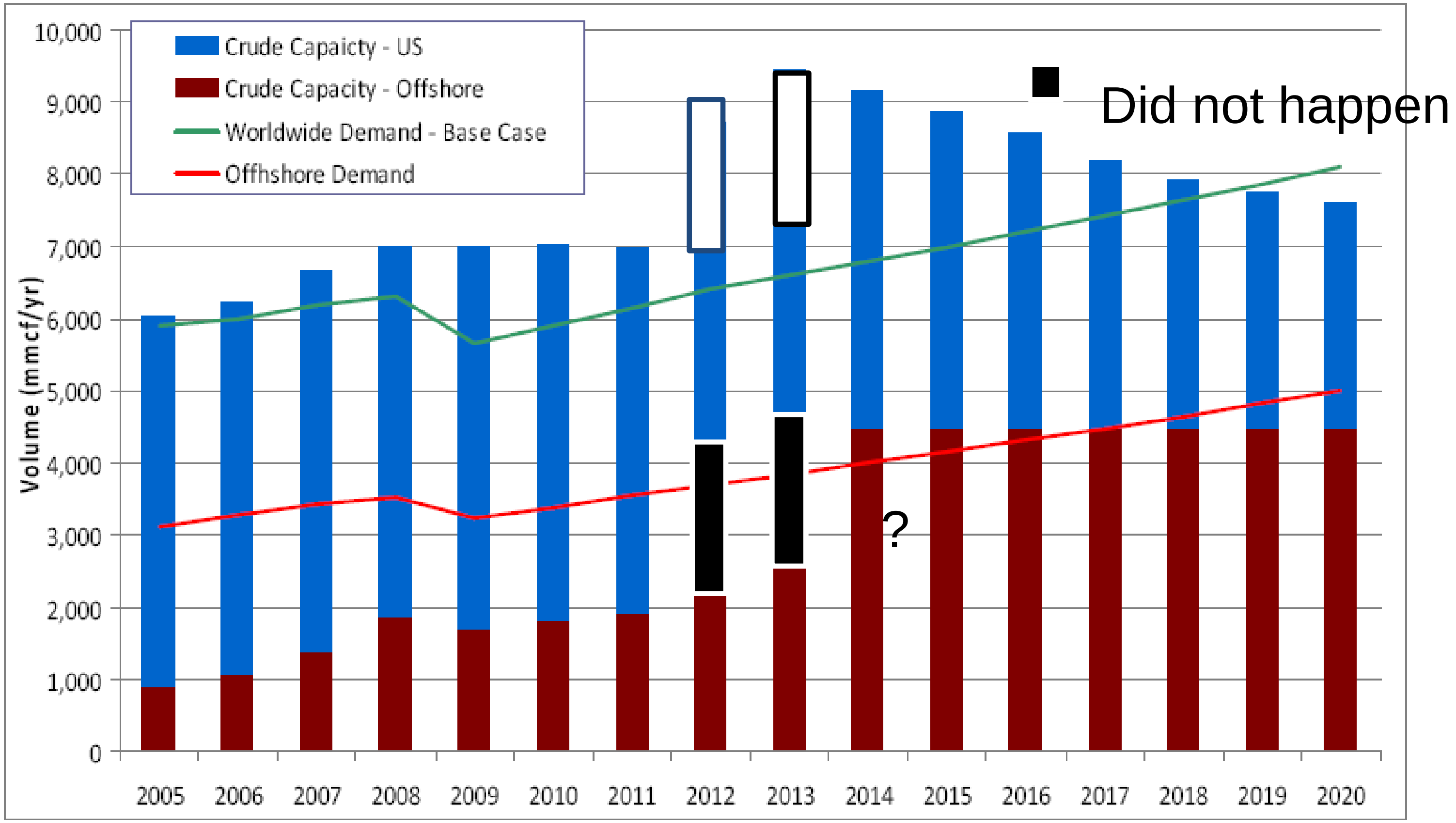
Newly Added Process Equipment for Strain-Sensitive Superconductors:

- Welded seam CTFF process for mono- and multi-filament wire
- Large capacity twisting
- Wire-in-channel soldering
- Insulation braiding
- 1m+ coil winding capacity designed for strain-sensitive wire
- 6 km lengths (currently)
- Equipment in place for 60+km lengths
- Large conduction cooled coil testing at OSU

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

Helium Shortage Worldwide



Actual (2005 to 2008) and estimated (2009 to 2020) demand and capacity for crude helium in the United States and in other countries.

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

Hyper Tech's Commercialization Activity

MgB_2 Enables Economical Superconducting Systems

Companies and Institutions Working with Hyper Tech on MgB2 Applications :

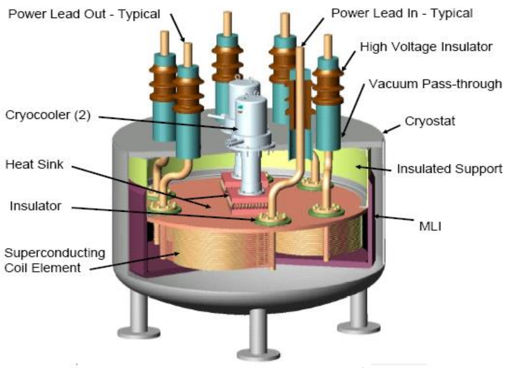
- MRI – 8 as part of Hyper Tech's magnet program for imaged guided radiation therapy MRI background magnet.
- Wing Turbine Generators – 6 on Hyper Tech's electric power generator development project
- SFCL- 2 organizations covering both resistive and inductive type FCLs
- DC cable - 2 projects
- SMES - 1 project

Hyper Tech

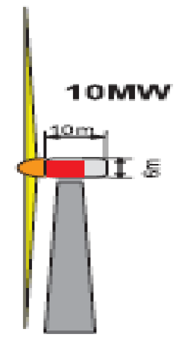
Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

MgB₂ wire – platform technology

Superconducting Fault Current Limiter

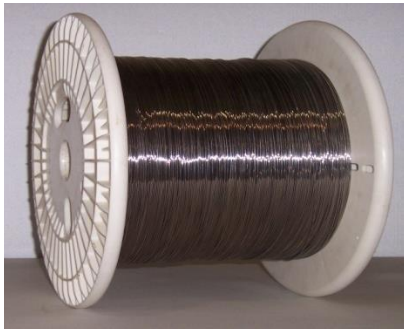


10MW and greater off shore wind turbine

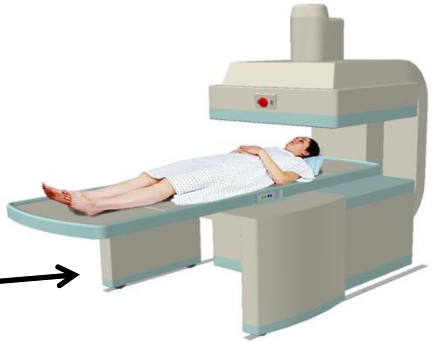


1.5 & 3.0 T MRI

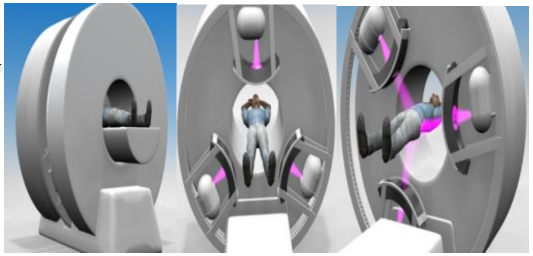
MgB_2 Superconducting Wire



Specialty MRI



Custom MgB_2 MRI magnet



Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

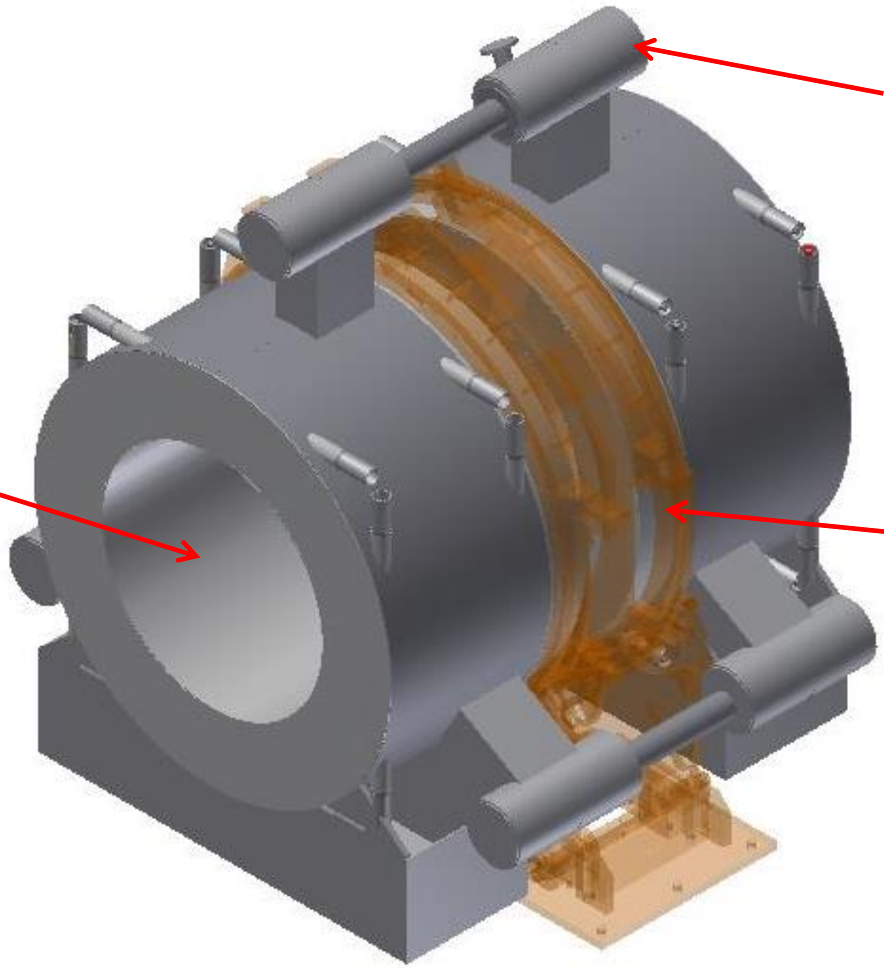
Problems Facing Major Full-Body MRI Producers

$3 billion MRI market at risk

- All current MRIs use liquid helium bath cooling (NbTi SC)
- Rising liquid helium cost - effects felt worldwide
- Tripled in price in US the last 5 years
- Predicted to increase further over the next 5 years
- Liquid helium in the field can be as much as $100K over the life cycle of the MRI system (depending on number of quenches)
- Helium is currently unavailable in some locations in the world
- MRI initial cost and maintenance fees destined to be prohibitive

The only solution to this problem is to develop helium-free conduction-cooled MRIs and MgB2 is the best conductor to do so.

IGRT Background Magnet



Magnet structural supports (3)

Gradient and RF send/receive coils

Gantry supporting 3 Co-60 treatment sources

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

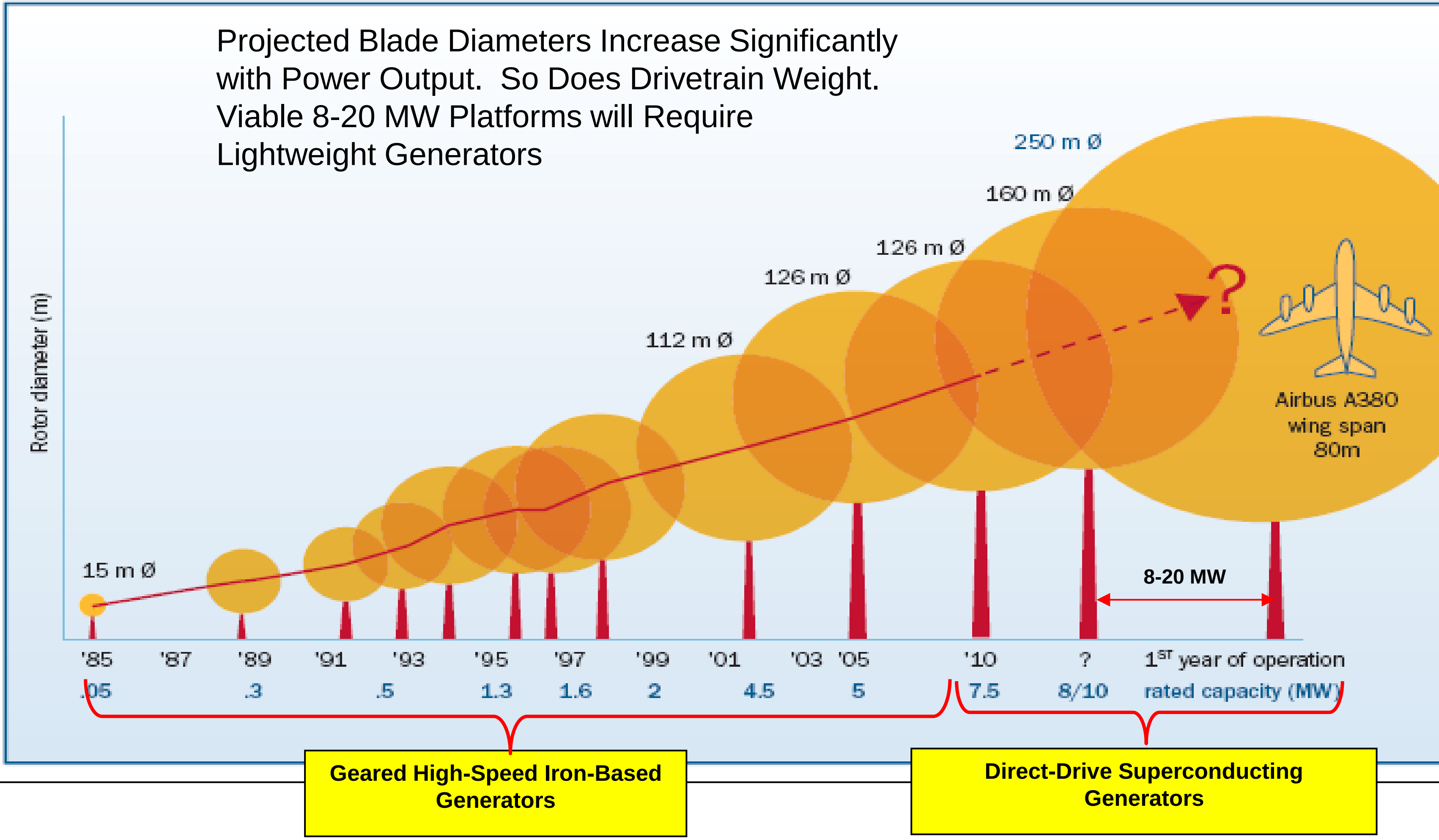
DOE's Goals and Objectives for Wind Power

Component	2010	2020	2030	2010 - Land
Installed Capital Cost ($/kW)	$ 4,259	$ 2,900	$ 2,600	$ 2,120
Discount Rate Factor (DRF)[6]	20%	14%	8%	12%
Turbine Rating (MW)	3.6	8.0	10.0	1.5
Rotor Diameter (m)	107	156	175	77
Annual Energy Production / Turbine (MWh)	12,276	31,040	39,381	4684
Capacity Factor	39%	44%	45%	36%
Array Losses	10%	7%	7%	15%
Availability	95%	97%	97%	98%
Rotor Coefficient of Power	0.45	0.49	0.49	.47
Drivetrain Efficiency	0.9	0.95	0.95	0.9
Rated Windspeed (m/s)	12.03	12.03	12.03	10.97
Average Wind Speed at Hub Heights (m/s)	8.8	9.09	9.17	7.75
Wind Shear	0.1	0.1	0.1	.143
Hub Height (m)	80	110	120	80
Cost of Energy ($/kWh)	**0.27**	**0.10**	**0.07**	**0.09**
Cost of Energy ($/kWh) at constant 7% DR	**0.12**	**0.08**	**0.07**	**0.08**

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

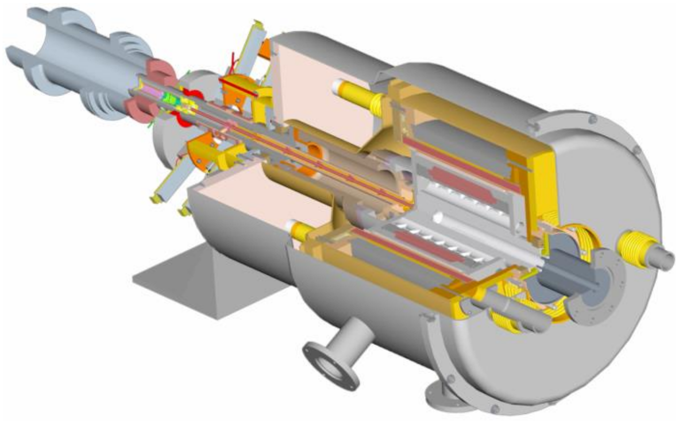
Evolution of Wind Generator Platforms



Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

Motors and generators



Emerging power systems:

- **Wind turbine generators (8-10 MW)**
- **Aircraft turbo-generators (8-10 MW)**
- **Offshore oil platform motors (5-10 MW)**
- **Marine propulsion and generation systems (4-20 MW)**
- **Portable emergency power systems (4–8 MW)**

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

Motors and generators

Advantages of MgB_2:

- **Reduction of size and weight of machine**
- **Significant reduction of cost**
- **No joints in rotor pole (long length conductor*)**
- **Faster normal zone propagation**
- **Meets current density requirements (< 4T)**
- **Made round to be easier to configure into complex coil geometries**
- **Persistent coils**

Compared with NbTi, YBCO, BSCCO and Nb3Sn, MgB2 conductor adds the least cost to the overall wind generator cost*.

* **Enabled by Technology Innovation Program, "High-Speed, Continuous Manufacturing of Nano-Doped Magnesium Diboride Superconductors for Next-Generation MRI Systems."**

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

10 MW Wind Generator Systems

Performance Parameter	Conventional with gear box	Permanent Magnetic Direct Drive	SC Generator (YBCO) Direct Drive	SC Generator (MgB_2) Direct Drive	SC Generator (Nb_3Sn) Direct Drive	SC generator (NbTi) Direct Drive
Gen. Power (MW)	10	10	10	10	10	10
RPM	8-15	8-15	8-15	8-15	8-15	8-15
Diameter m (ft)	High speed generator Plus large Gear box	10 (31)	4.9 (16)	4.5 (14.8)	4.0(12)	4.0(12)
Rotor Excitation	Copper	Rare earth Magnets	YBCO	MgB_2	Nb3Sn	NbTi
Operating Temp	130 C	Ambient	30- 35K	20K	10K	4K
Weight (tons)	250-300	250-300	120 - 150	100-120	90-110	100-120

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

MgB_2 Fault Current Limiter

Advantages of MgB_2 wire for Fault Current Limiters

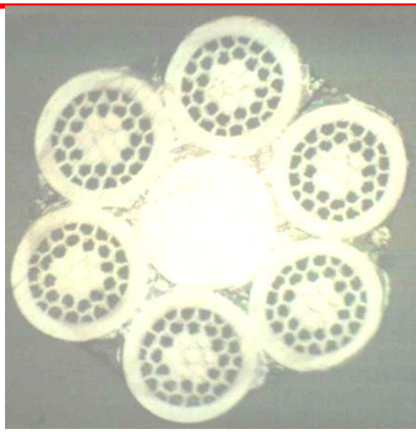
- Low cost especially as compared to ceramic superconductors
- Can be sized to carry a specified current level
- The sheath thermal properties and electrical resistivity can be varied to match operational requirements
- Can be twisted to reduce AC loss and braided for insulation.
- Low equipment costs to scale manufacturing to commercial production quantities
- Is readily available in quantity and lengths required to support SFCL demand

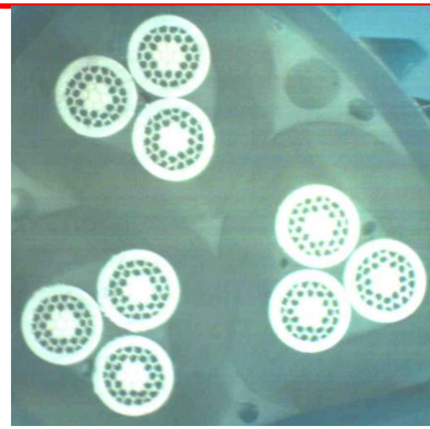
Hyper Tech working with two companies to match MgB_2 wire to meet their resistive and inductive SFCL design requirements.

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

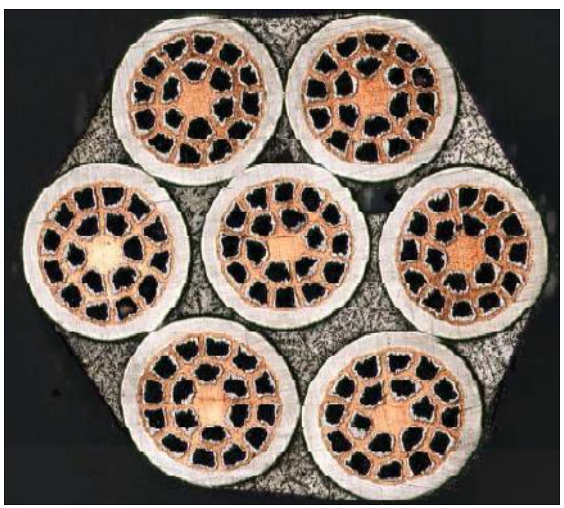
Multi-strand MgB_2 Cable Demonstration



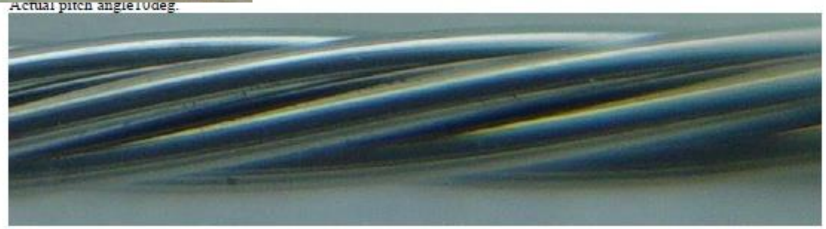


Other low field magnets or cables MgB_2 could be considered for:

- Novel circular superconducting quadrupole for linear accelerators
- Other DC cables
- ? Superconducting cyclotrons (peak fields on wire below 8T)
- ? Muon collider MICE experiments (large bore, peak fields on wire below 6T)

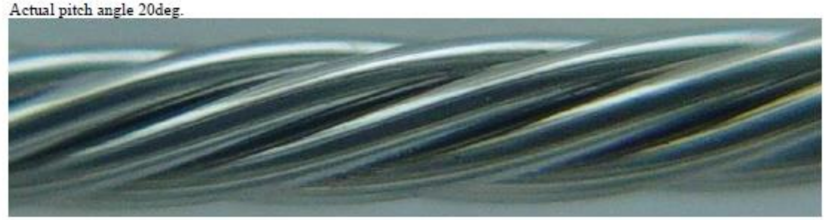


Actual pitch angle10deg.



10° pitch angle

Actual pitch angle 20deg.



20° pitch angle

Hyper Tech

Department of Materials Science & Engineering
Center for Superconducting & Magnetic Materials

Conclusions

- Hyper Tech has brought MgB_2 wire development to commercial readiness.
- We can customize MgB_2 wire to meet requirements for MRI background magnets, motors/generators and fault current limiters.
- We are poised to produce long lengths greater than 60 km.
- Wire properties have reached application relevant levels with potential improvements in foreseeable future.
- Design tools and manufacturing capability in place to produce MgB_2 coils for a range of applications.

---- thank you for your attention