MT 26
International Conference on Magnet Technology
Vancouver, Canada
Sept 22-27, 2019

Ultra-High Field Superconducting Magnets for Magnetic Resonance Imaging (MRI)

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imagination at work

TRIUMF

CENTENNIAL CONFERENCES

IEEE CSC Council on Superconductivity

MRI market

- The largest application of superconductivity
- Annual production: about 4,000 scanners
- Superconducting MRI: >85% of the installed base
  - 1.5 tesla magnet: 75% production
  - 3 tesla magnets: 25% production
  - 7+ tesla scanners: ~75 units delivered since 1998
  - No shift to higher-field commercial MRI is expected
- Commercial data:
  - Price-driven industry
  - Annual revenue: $5B to $10B (scanners, service)
  - Max sales price: $3M for the scanner installed (not magnet!)
- Annual conductor use by MRI industry:
  - 3,000 to 5,000 tons (including copper)
  - 65%-75% of all NbTi conductor (by weight)
  - More than 50% of NbTi alloy
  - Conductor: single most expensive component

Technical data

Special requirements to commercial whole-body MRI magnets

- Persistence
- Tight dimensional tolerances

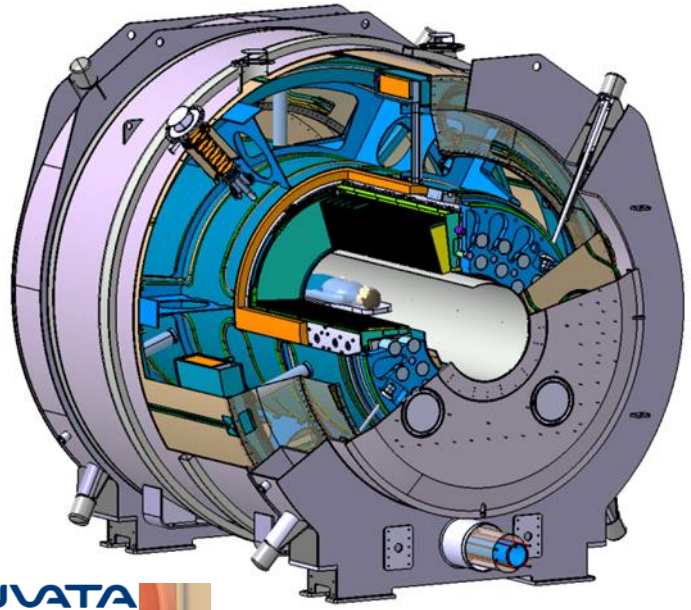
	1.5 tesla	3 tesla
Stored energy, MJ	3 – 4	8 – 12
Current, Amp	<1,000	<1,000
Peak field, tesla	4 – 5.5	5 - 6
Conductor length, kAmp-km	15 – 20	40 – 60
Conductor weight, kg	400 - 800	1,000 – 3,000
N-value guaranteed	>30	>30
Superconducting joints	Yes	Yes

M. Parizh, Yu. Lvovsky, M. Sumption
'Conductors for commercial MRI magnets beyond NbTi: requirements and challenges', SuST **30** (2017) 014007

- NbTi is the conductor of choice
- NbTi fully meets the present MRI requirements
- No need in a new high field conductor … for **commercial scanners**

Ultra-high field magnets

18 July, 2019 – Iseult at 11.72 tesla
Congratulations to Iseult team !!!



ALSTOM
GE Power

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Special session "*Magnet Technology and Conductor for future High-Field Applications*"

Unique ultra-high field MRI magnets after 11.7 T Iseult

Next step

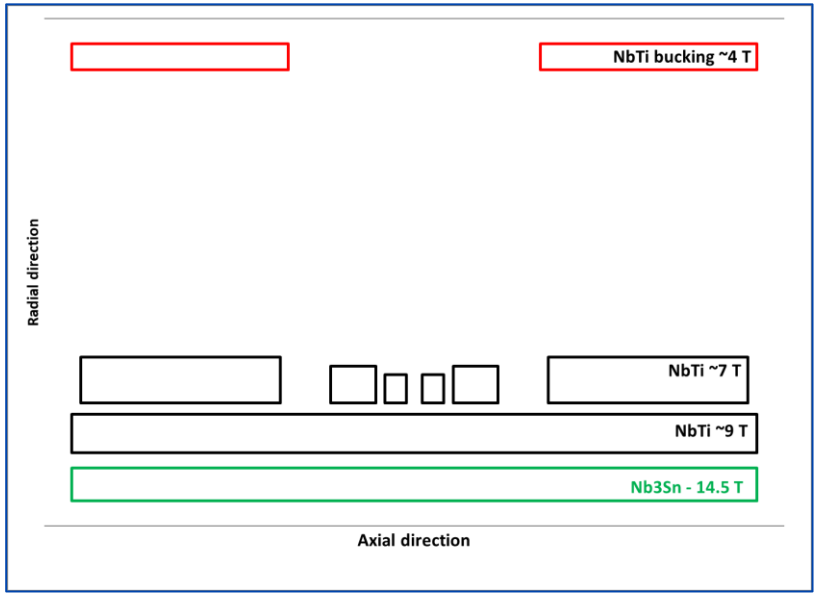
Boost MRI magnet technology,
and magnet technology in general
to
14+ tesla, 600+ MHz

600 MHz, 14.1 tesla MRI example

	500 MHz Iseult	600 MHz
Center field, tesla	11.7	14.1
Uniformity	0.5 ppm @ 22 cm DSV – brain imaging	
Warm bore	90 cm	60 – 70 cm
Magnet length	5.2 m	3 – 3.5 m
Peak field	11.8 T	14.5 T
Operating temperature	1.8 K	4.2 K
Persistent operation	Driven	TBD
Stored energy	338 MJ	120 – 180 MJ
Current	1.5 kAmp	TBD
Current density	25 to 39 Amp/mm^2	50 – 70 Amp/mm^2
Magnet technology	Double-pancakes, shielded	Compensated solenoid, shielded
Conductor type	NbTi	NbTi and Nb_3Sn
Conductor weight total Nb_3Sn and/or HTS	84 tons -	12 to 25 tons 1 to 2.5 tons

600 MHz, 14.1 tesla MRI

	500 MHz Iseult	600 MHz
Peak field, tesla	11.8	14.5
Stored energy, MJ	338	120 - 200
Current, kAmp	1.5	???
Current density, Amp/mm^2	25 to 39	50 - 80
Conductor weight, ton	84	12 - 25



Issues / Challenges

- Magnet Technology/SC community collaboration
- System / magnet trade-offs: bore size, dimensions, uniformity, persistence, etc.
- Select high-field conductor: “HTS insert”?
- Operating current ➔ Wire vs cable, Long conductor lengths
- Persistence: SC joints, high current switch vs driven operation
- Quench protection
- High forces/stresses
  - Structural approach
  - Jc degradation at high strain – trade-off
- And much more

Possible programmatic approaches

1. **"Fast track", schedule-driven approach**
   - Use known technologies and components if possible
   - Conservative design
   - Budget: TBD
   - Delivery: 6-8 years

2. **Innovation approach, breakthrough technologies**
   - Develop new, disruptive technologies, materials
   - Aggressive design
   - Budget: TBD **x 2**
   - Delivery: 12-15 years

Need interdisciplinary exploratory committee

Conclusion

- Commercial MRI
  - NbTi remains conductor of choice
  - Cost-driven
  - No need for higher-field conductor
  - Competitive conductor: must meet or exceed NbTi in performance, availability and price
- Ultra-high field, 14+ tesla research MRI scanner
  - Create community-wide exploratory committee
  - Technology challenges
  - New MRI system, magnet technology and conductor approaches