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KOREA UNIVERSITY

Design Options of a 3-T 900-mm Whole Body MRI Magnet with Selected Commercial MgB_2 Wires

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Abstract

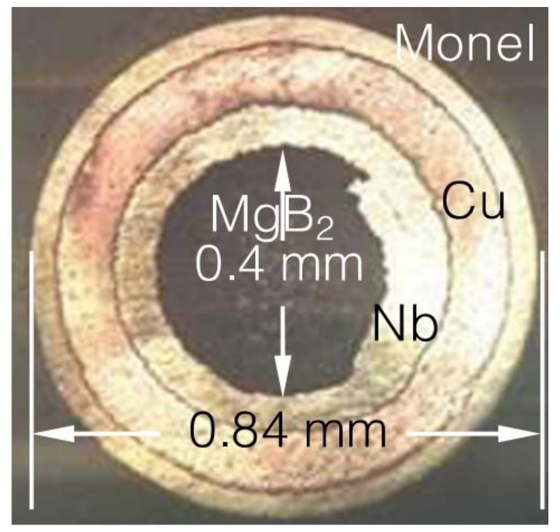
As the global helium crisis continues, the need for liquid-helium-free superconducting magnets continuously increases in the commercial sector of magnetic resonance imaging (MRI) systems. However, the conventional low temperature superconductor (LTS) magnets frequently experience unpredictable premature quenches, resulting in the extra usage of liquid helium before an MRI machine is delivered to its user site. The MgB_2 technology is expected to play an increasingly prominent role in the "next generation", mainly because of a greater thermal stability of the wires than that of their LTS counterparts, making them essentially immune to the premature quench, as well as with their liquid helium (LHe)-free feature. To date, MgB_2 wires have been routinely produced by a few companies, such as Kiswire Advanced Technology that recently embarked on a collaborative R&D project with Korea University to design, construct, and operate an MgB_2 MRI magnet. This study presents the design options of a 3-T/900 mm MRI magnet employing selected commercial MgB_2 wires with a focus on: (1) conductor design and in-field performance; (2) coil volume and stray field; (3) mechanical stress and its tolerance; (4) cryogenic stability in various conductor options; (5) post-quench behavior and protection; and (6) field inhomogeneity due to manufacturing uncertainties of conductors.

Results & discussion

★ MgB_2 wire

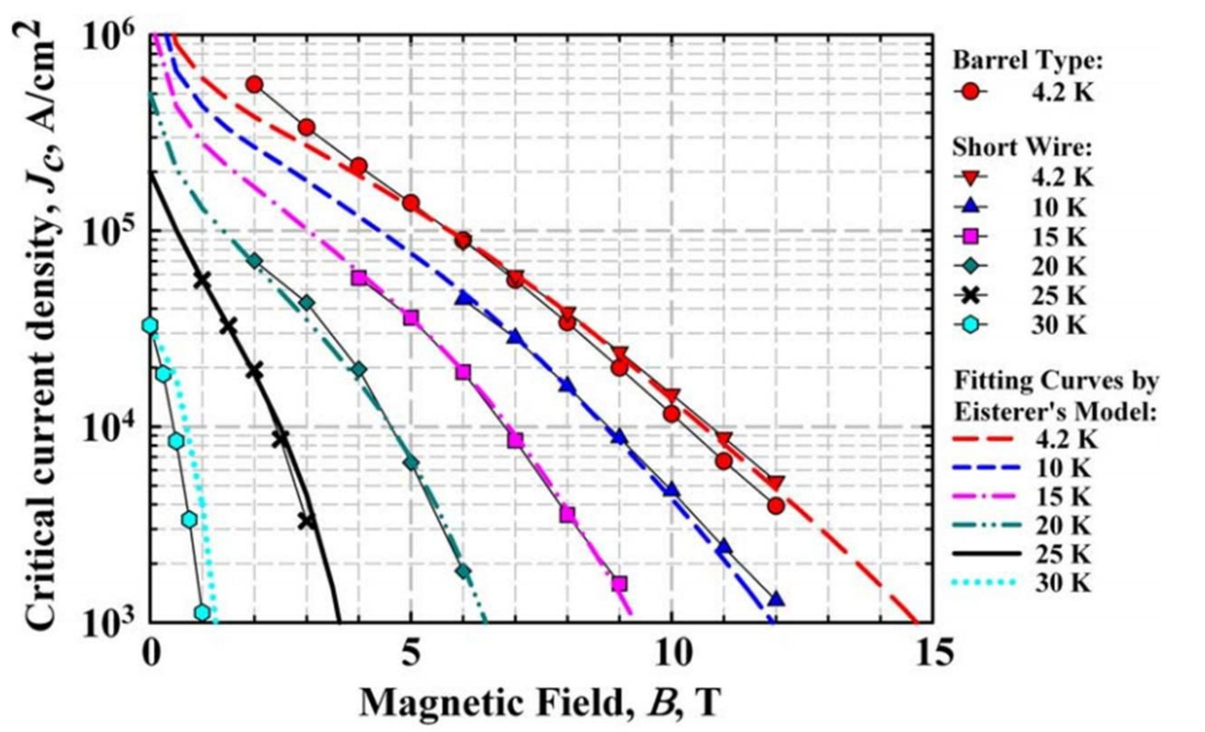
< Specifications of the MgB_2 wire used in this study >

Parameters		Values
Manufacturer		Hyper Tech Research Inc.
No. of filament		24
Barrier material		Nb
Sheath material		Monel
Dopant material		C
Insulation material		S-glass
Diameter of wire	[mm]	0.83 (w/o insulation) 1 (with insulation)
SC/non-SC ratio	[%]	11.7



< Photograph of the cross-section of the MgB_2 wire >

REF: Li et. al., Transport Critical Current Densities and n-Values of Multifilamentary MgB_2 Wires at Various Temperatures and Magnetic Fields, *IEEE Trans. Appl. Supercond.*, Vol. 24, No. 3, 6200105 (2014).



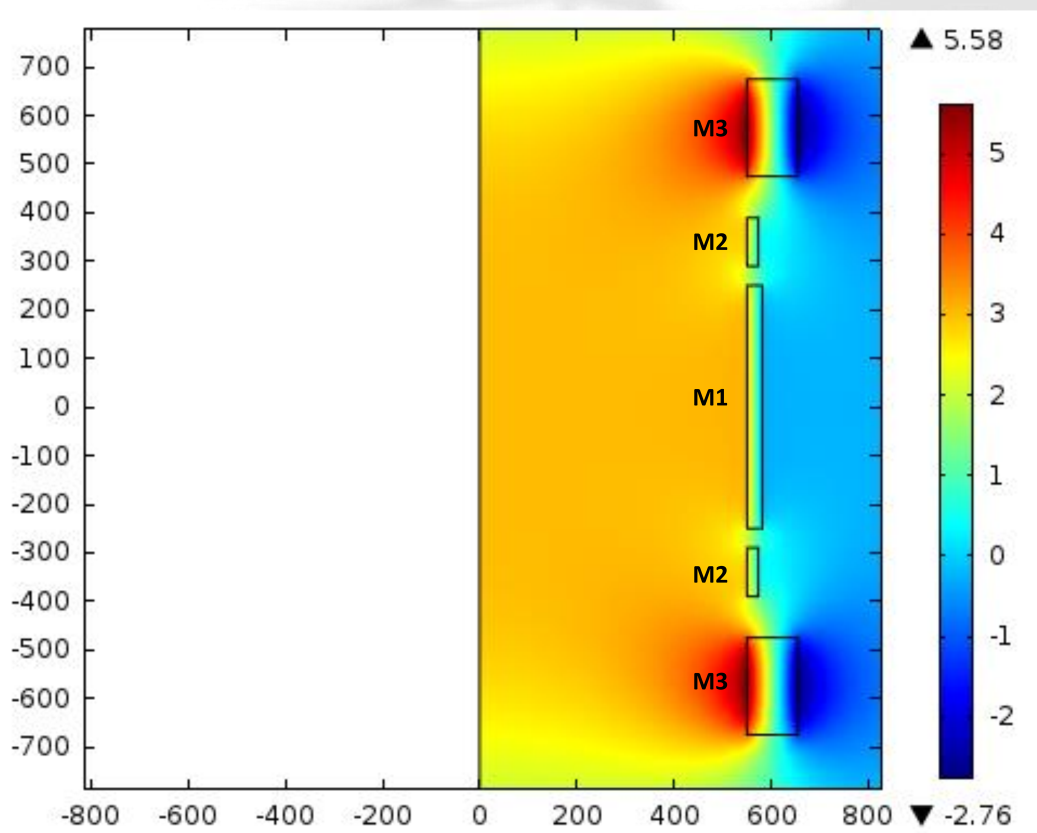
< Critical current density of the MgB_2 wire with respect to the magnetic field obtained at various temperatures >

REF: Li et. al., Transport Critical Current Densities and n-Values of Multifilamentary MgB_2 Wires at Various Temperatures and Magnetic Fields, *IEEE Trans. Appl. Supercond.*, Vol. 24, No. 3, 6200105 (2014).

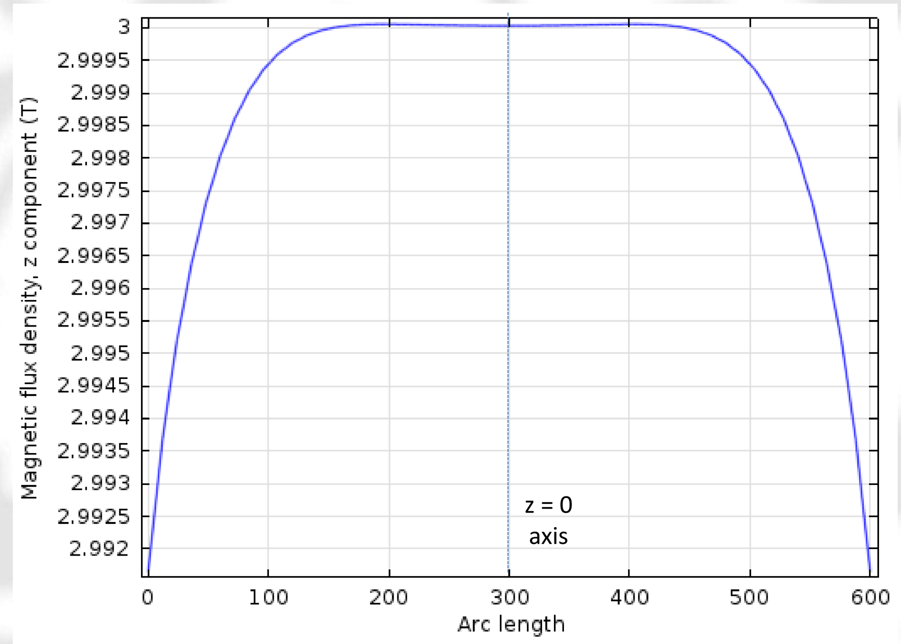
★ Electromagnetic design

< 1st-cut design parameters of the 3.0-T whole-body MgB_2 MRI magnet >

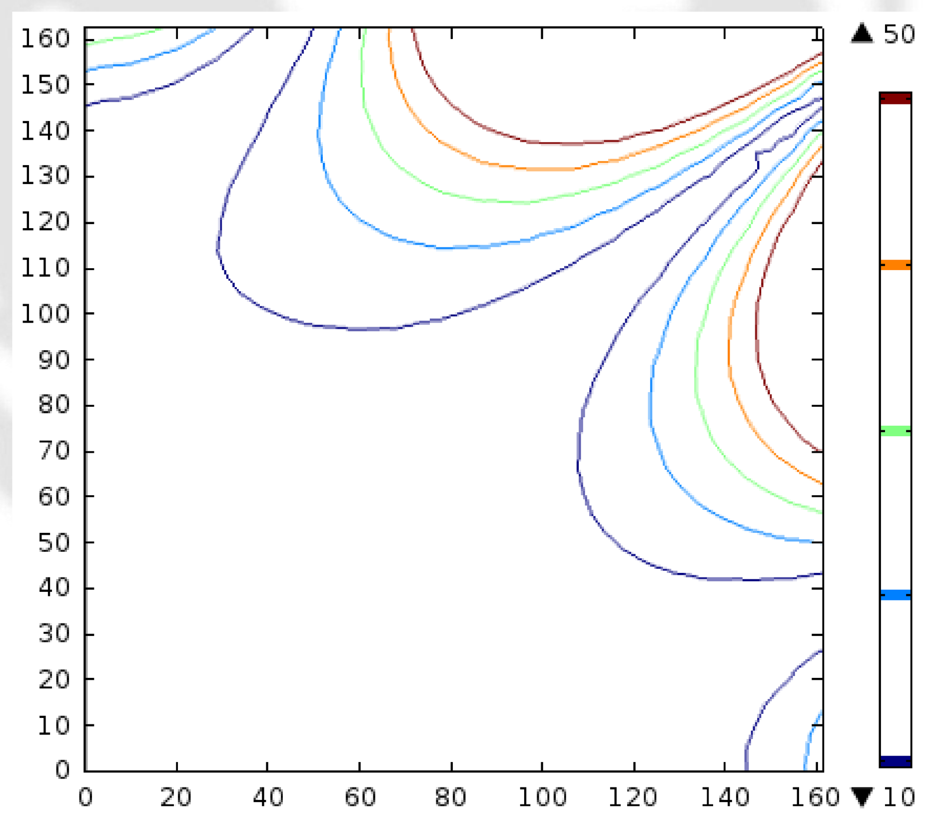
Parameters		M1	M2	M3
Magnet				
Inner diameter	[mm]		1100	
Outer diameter	[mm]	1162.62	1147.03	1309.85
Height	[mm]	500	100	200
Total height	[mm]		1349	
Number of coil	[mm]	1	2	2
Turns/layer		500	100	200
Layers		36	27	121
Conductor length per coil	[km]	63.97	9.53	91.61
Operation				
Center field	[T]		3.0000	
Operating current	[A]		67.442	
Operating temperature	[K]		10	
Stored energy	[MJ]		9.41	
Field error at 30-cm DSV	[ppm]		< 20 (before shimming)	



< Magnetic flux density distributions of the 3.0-T whole-body MgB_2 MRI magnet >

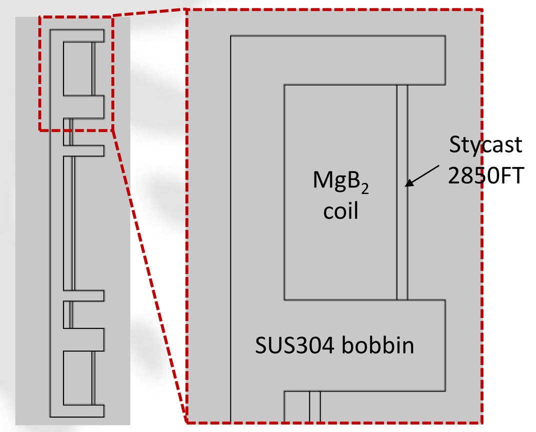


< Magnetic flux density distributions of the 3.0-T whole-body MgB_2 MRI magnet along the z-axis >

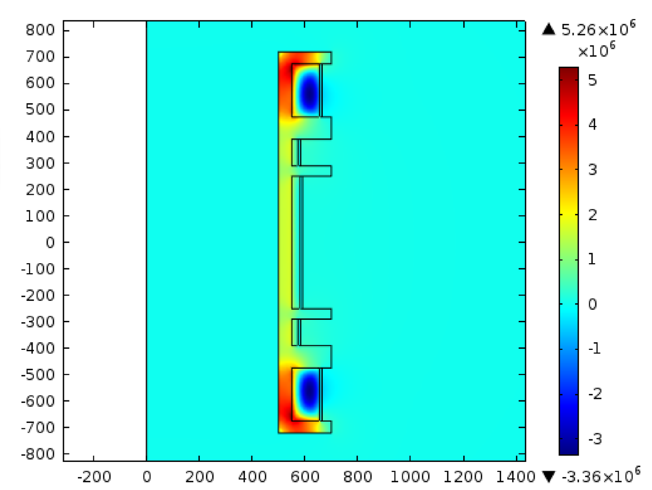


< Spatial field homogeneity distribution of the 3.0-T whole-body MgB_2 MRI magnet >

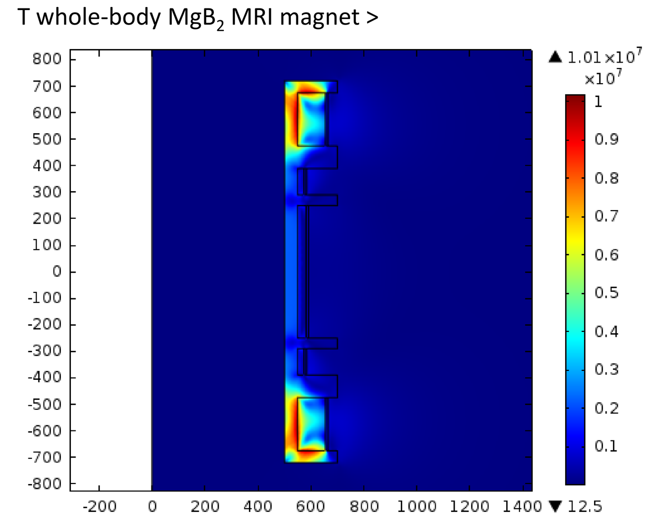
★ Stress-strain analysis



< Schematic drawing of a rigid body model for the stress-strain analysis of the 3.0-T whole-body MgB_2 MRI magnet >



< Stress tensor (phi component) distribution of the 3.0-T whole-body MgB_2 MRI magnet >



< Von Mises stress distribution of the 3.0-T whole-body MgB_2 MRI magnet >

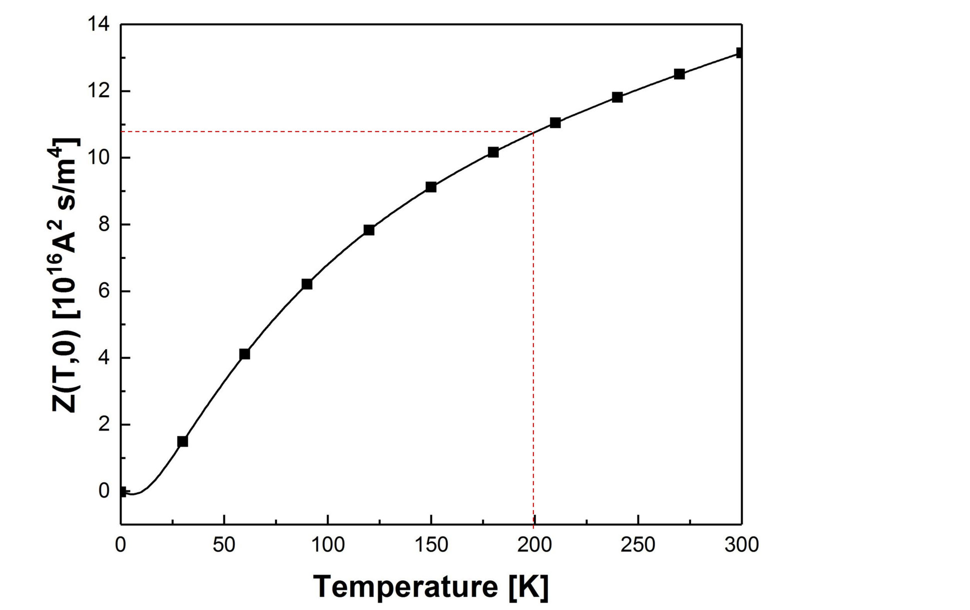
★ Z-function analysis

Assumptions

- Adiabatic heating
- Isolated magnet (no conduction heat input)
- No disturbance heat input (AC loss, flux jumping, wire motion, etc.)
- Constant current applied

$$Z(T_f, T_i) \equiv \int_{T_i}^{T_f} \frac{C_m(T)}{\rho_m(T)}\, dT$$

$C_m(T)$: heat capacity of materials
$\rho_m(T)$: electrical resistivity of copper



< Z-function of the winding pack including MgB_2 magnet, SUS304 bobbin, and Stycast 2850FT epoxy >

$$\int_{T_i}^{T_f} \frac{C_m(T)}{\rho_m(T)}\, dT = \left(\frac{A_m}{A_{cd}}\right) J_{m_o}^2 \tau_{ah}$$

A_m: cross-sectional area of matrix within the wire
A_{cd}: cross-sectional area of conductor within the wire
J_{m0}: current density within the copper matrix
τ_{ah}: time required to reach final temperature

τ_{ah} = 1.47 s → Reach 200 K within 1.47 s

Quench should be detected in ~ 0.5 s.

★ Future works

- Optimization of the design of the 3.0-T whole-body MgB_2 MRI magnet will be performed to minimize the conductor consumption.
- Cryogenics, stability, and protection for the 3.0-T whole-body MgB_2 MRI magnet will be investigated with respect to the commercialized conductor options.

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