A WHOLE BODY CONDUCTION COOLED MRI MAGNET DESIGN FOR ULTRA-HIGH FIELD STRENGTH OF 7T

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Introduction: In a magnetic resonance imaging (MRI) system, the superconducting main magnet generates a large static magnetic field that is very uniform over the imaging volume. These magnets are predominantly constructed with niobium-titanium (NbTi) wire cooled below 4.2K using liquid helium for operation in persistent current mode. Any full-body MRI system in a range of medium (1.5T) to ultra-high field (7.0T) would require 1500 to 3000 liters of liquid helium in a reservoir to keep it cool during operation. A naturally limited reserve of helium on earth and its constantly increasing demand continues to drive ups its price. In the last decade the cost of helium has tripled and the forecast is that the price will increase three-fold in the next five years. A conduction cooled superconducting magnet for MRI could address the helium crisis by using as little as 5 liters of helium per system. A cost-effective way of designing a conduction cooled magnet is to use high-temperature superconducting wire operating at a temperature higher than 4.2K. Present research is in progress to develop such magnet [1-4]. Most of these designs deal with low-field (generally 0.5T or less) to medium field magnet design due to the limitations of wire/tape performance of such superconductors. At the ultra-high field strength of 7T most conductors are limited by maximum critical field considerations,, but Nb_3Sn is a high temperature superconductor that shows superior current carrying quality at a higher peak field on wire compared to other available superconducting wires including NbTi. In the present study an optimized design is presented for 7T conduction cooled whole body magnet using latest Nb_3Sn wire developed by Hyper Tech research.

Theory and Method: An improved functional approach previously presented by the CWRU computational physics group is used to optimize main magnet designs [5]. A continuous current density distribution is obtained by minimizing a function that requires nulling certain external and internal moments. The continuous solution is then discretized into separate bundles of wire with the same cross section and each carrying the same amount of current. The bundle positions and aspect ratios are then further optimized to get a final solution that would provide desired uniformity in the imaging field of view (FOV) and shielding outside magnet structure. In this ultra-high-field magnet design, particular emphasis has been given to improving the shielding to attain a practical five gauss (5G) line.

Result and Discussion: Table 1 shows the parameters for the new 7T Nb_3Sn design compared with a guideline for a NbTi 7T magnet. The Nb_3Sn wire cross-section for the design is chosen to be 1 mm^2. The maximum allowable current density is 314A/mm^2 at a peak field of 12T and operating at a temperature of 8K. The proposed design meets all the present day guidelines set for NbTi magnet design at the field strength of 7T. The magnet is more compact in length and has a significantly smaller 5G footprint. Due to higher peak field allowed on the wire, the current density of 179.95 A/mm^2 in this design is much larger than previously presented designs using NbTi wire [6]. This in turn reduces the total volume of wire required for such magnet. The energy and amp-length of this new design are at the lower end of the proposed guideline.

Table 1: Parameters of Nb_3Sn design

Superconductor	NbTi	Nb_3Sn
Length (m)	~3	1.7
Inner Diameter (m)	1	1
Outer Diameter (m)	> 2.5	2.35
Radial FOV 1ppm (m)		0.36
Axial FOV 1ppm (m)		0.40
Radial 5 G (m)	5	4
Axial 5 G (m)	7	5.5
Inductance (H)		3556.26
Stored Energy (MJ)	50-90	57.58
Max. Hoop Stress (MPa)		296.63
Peak Magnetic Field (T)	≤ 9T	11.59
Current Density(A/mm^2)	<250	179.95
Amp-length (kA-km)	<180	79.46

Conclusion: The price of manufacturing Nb_3Sn wire is currently higher than NbTi by a significant margin. However, a Nb_3Sn design with a reduced volume of wire, coupled with a significantly reduced Helium usage, demonstrates the promise for developing conduction cooled dry magnets that reduce the dependence on naturally limited Helium resources.

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References : [1] Alessandrini, M., et al, IEEE Trans. Appl. Supercond., 17, 2, pp 2252-57, 2007, [2] Park, K., et al, IEEE Trans. Appl. Supercond., 22, 3, p 4400305, 2012, [3] Urayama, Shin-ichi, et al., Complex Med. Eng. (CME), 2012 ICME Int. Conf., IEEE, 2012., [4] Parkinson, Benjamin J., et al., Applied Superconductivity, IEEE Trans., 23.3 (2013): 4400405, [5] Cheng N., MAGMA, 16, pp 57-67, 2003, [6] Vegh, Viktor., et al, Concepts in MR Part B, 35.3 (2009): 180-189.

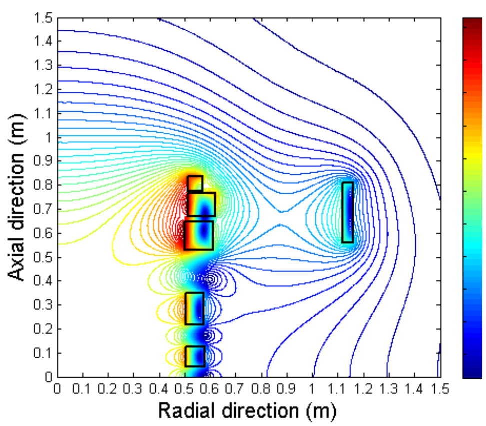

Figure 1

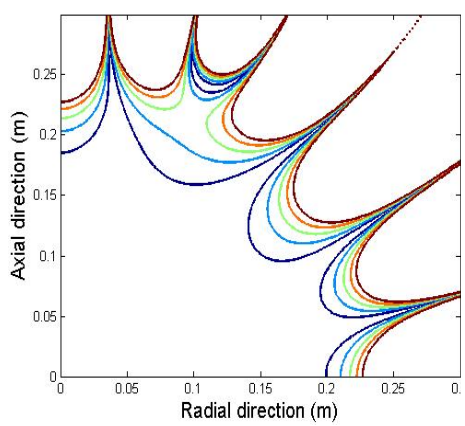

Figure 2

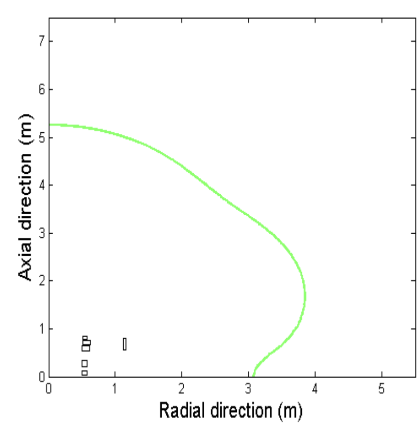

Figure 3