Short Main Magnet Cylindrical Coils: The Next Generation?

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Synopsis

A short main magnet has the attractive capability of openness but implies a more difficult shielding problem. We present a method for improvements in main magnet design, and we illustrate it with the stretch goal of attempting a 1.1 m length, 1.5 T design. The method incorporates a series of steps involving Lagrange multiplier techniques, discretization, and optimizing wire bundle positions. The attempted design leads to a competitive DSV and 5-Gauss footprint, at the cost of a large increase in the current density. We discuss the possibility that this high density can be accommodated with today’s technology.

Introduction

The design of a main magnet presents a challenge when the length of the main magnet becomes shorter. The average bare-coil length of a 1.5 T MRI machine is about 1.55 m at the present time. The shortest main magnet at 1.5 T available in the market has a bare coil length of 1.26 m. However, its 5-Gauss footprint area is larger than the 5-Gauss footprint area of the average 1.55 m unit. Previous work used a Lagrange multiplier technique and the target field method to design somewhat longer coils at the same field strength [1]. In this paper, we use a similar technique but impose the shielding constraints by nulling external moments. As a challenging test to our new procedure, we attempt to design a short 1.1 m, 1.5 T machine.

Theory and Methods

In a main magnet design, with cylindrical coordinates, we first assume that infinitesimal wires located at all grid points on the ρ-z plane fill out the profile of an MRI machine. The current distributions can be found through the functional method with constraints [2]. The functional is simply the sum of current squares. The constraints are the magnetic field at the center of the magnet and the first few nulled moments inside and outside the magnet.

After the continuous current distributions are obtained, we make bundles of wires based on these distributions. The idea is to use the fewest number of bundles of wires to reduce construction costs. On the other hand, the requisite field homogeneity inside the DSV and the desired 5-Gauss contour both have to be maintained.

Results

The result is the 1.5 T design shown in Fig. 1. The shielding coil and the second coil from the right on the primary carry current with the opposite sign to that of the other coils. We have assumed that the size of each wire is 1 mm² and the current in each wire is chosen to be 225 Amps. The peak to peak field inhomogeneity inside an elliptical DSV is 4 ppm, before shimming. The size of the DSV, or rather, DEV, is 50 cm along the ρ-direction and 38 cm along the z-direction. This size is similar to that of the Infinion design [3]. The total current is about 8.4 MAmp-turns. The 5-Gauss footprint size is roughly 9.5 m along the z-direction and 5.3 m along the p-direction. The highest field inside the coil bundles is close to 10 T. This high field appears at the edges of the two outer primary coils.

Discussion

We have attempted a main magnet design for a coil length that is 10% shorter than the Infinion [3]. In view of the constraints in such designs, this is a significant reduction. The field inhomogeneity inside the elliptical DSV of our design is similar to that of the Infinion design [3]. The 5-Gauss footprint area is estimated to be 25% smaller than the footprint of the Infinion. However, the high field at the edge of the primary coils leads to quenching issues. We may be able to handle 10 T by using NbTi wire at 1.8ºK. The remaining questions are whether NbTi wire can withstand the 800 MPa stress and whether the current density is high enough to cause damage during quenching. New advances in material technology appear to be needed. The total length of wire required, on the other hand, is at least 25% less, which may directly translates into a commensurate wire cost reduction.

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Fig. 1: The location of the six wire bundles in the primary and shielding main-magnet half-coils.

References