1.5 M

M

Abstract—**In this paper, an effective method to design the superconducting magnet for 1.5 T dedicated extremity MRI is proposed. The feasible current carrying zones of superconducting magnet are subdivided by an array of grid elements. The size of each grid element is determined by the actual superconducting wire. The initial current distribution of superconducting magnet is optimized using 0–1 integer programming by a comprehensive consideration of superconductivity wire consumption, central magnetic field intensity, imaging region homogeneity, and the range of leakage file. The final rectangular section of magnet is obtained using the genetic algorithm optimization with artificial limitation of the coil position and section size considering the initial current distribution of superconducting magnet. The method based on the actual superconducting wire makes the MRI magnet design more feasible. A superconducting magnet for 1.5 T dedicated extremity MRI system is designed using this method. This magnet can offer 1.5 T central field with high homogeneity in diameter sphere volume (DSV), with total length of 430 mm, inner diameter of 350 mm. This method can also be used for short whole-body MRI superconducting magnet design.**

Index Terms—**Magnetic resonance imaging (MRI), optimization methods, superconducting magnet.**

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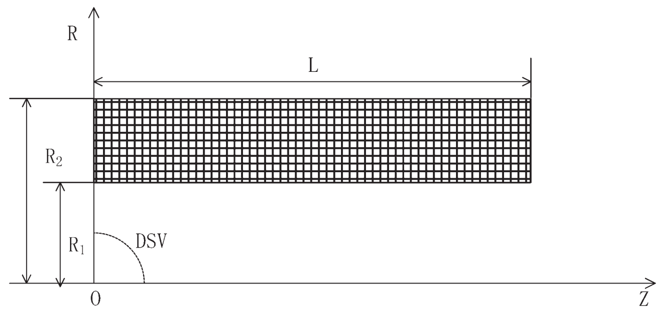


. 1.

H 1999 7 . H , . , 0 1 . 1.5 M 1.5 ( ), 430 , 350 .

. M M M H

A. Grid of the Feasible Current Carrying Zone

(r, z, φ) M z . , (N) . 1. , , , (-) , . r_i, z

z_i, I_i, B_{ri} B_{zi} j (r_j, z_j) 8

$$B_{zi,j} = \frac{\mu_0 I_i}{2\pi} \frac{1}{[(r_i + r_j)^2 + (z_j - z_i)^2]^{\frac{1}{2}}} \times \left\{ K(k) - \left[\frac{r_j^2 - r_i^2 + (z_j - z_i)^2}{(r_j - r_i)^2 + (z_j - z_i)^2} \right] E(k) \right\} \quad (1)$$

$$B_{ri,j} = -\frac{\mu_0 I_i}{2\pi} \frac{z_j - z_i}{r_j [(r_j + r_i)^2 + (z_j - z_i)^2]^{\frac{1}{2}}} \times \left\{ K(k) - \left[\frac{r_j^2 + r_i^2 + (z_j - z_i)^2}{(r_j - r_i)^2 + (z_j - z_i)^2} \right] E(k) \right\} \quad (2)$$

$$k = \left[\frac{4 r_i r_j}{(r_i + r_j)^2 + (z_j - z_i)^2} \right]^{\frac{1}{2}}. \quad (3)$$

$$K(k) = \int_0^{\frac{\pi}{2}} \frac{d\alpha}{\sqrt{1 - k^2 \sin^2 \alpha}} \quad (4)$$

$$E(k) = \int_0^{\frac{\pi}{2}} \sqrt{1 - k^2 \sin^2 \alpha}\, d\alpha. \quad (5)$$

B. Magnetic Field at Target Point

(,)

$$B_{zj} = \sum_{i=1}^{N} e_i a_{ij} I_i \quad (6)$$

$$B_{rj} = \sum_{i=1}^{N} e_i b_{ij} I_i \quad (7)$$

$$a_{ij} = \frac{\mu_0}{2\pi} \frac{1}{[(r_i + r_j)^2 + (z_j - z_i)^2]^{\frac{1}{2}}} \times \left\{ K(k) - \left[\frac{r_j^2 - r_i^2 + (z_j - z_i)^2}{(r_j - r_i)^2 + (z_j - z_i)^2} \right] E(k) \right\} \quad (8)$$

$$b_{ij} = -\frac{\mu_0}{2\pi} \frac{z_j - z_i}{r_j [(r_j + r_i)^2 + (z_j - z_i)^2]^{\frac{1}{2}}} \times \left\{ K(k) - \left[\frac{r_j^2 + r_i^2 + (z_j - z_i)^2}{(r_j - r_i)^2 + (z_j - z_i)^2} \right] E(k) \right\}. \quad (9)$$

e_i : 0 1, 0 1

C. 0–1 Integer Programming

B_z 7.

$$L = 2\pi \sum_{i=1}^{N} e_i r_i. \quad (10)$$

0 1

$$\text{M}: \sum_{i=1}^{N} e_i r_i \quad (11)$$

$$: |B_{zj} - B_0| \le \varepsilon B_0 \quad (12)$$

ε (12)

$$: \begin{cases} |B_{zj} - B_0| \le \varepsilon B_0 \\ |B_{zj}| \le B_{z,shield} \\ |B_{rj}| \le B_{r,shield}. \end{cases} \quad (13)$$

0 1

D. Rectangularity of Current Carrying Zones

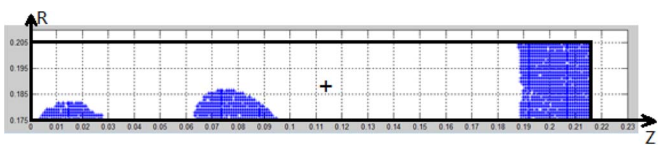
0 1

1.5

A. Requirement of Superconducting Magnet

Central magnetic field (T)	1.5
DSV (mm)	160
Inner diameter of Dewar (mm)	>280
Outer diameter of Dewar (mm)	<600
Total length of Dewar (mm)	<520
Inner diameter of coils (mm)	>350
Outer diameter of coils (mm)	<450
Total length of coils (mm)	<430

Cu/Sc ratio	Bare size (mm)	Ins size (mm)	RRR	Ic@4.2K,5T
1.3:1	0.5*0.8	0.55*0.85	>100	>335A



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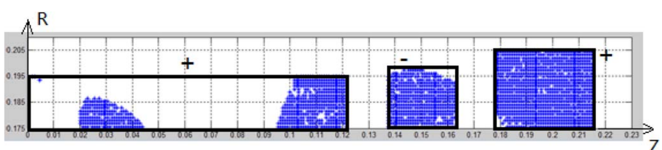


. 3.

B. Performance of Superconducting Wire

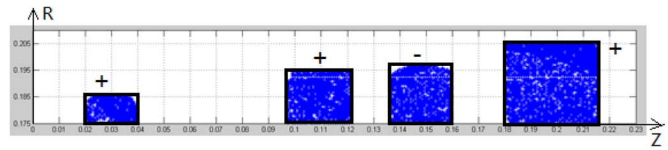
180 , 5 . 50, 1.3.

C. Result of the First Iteration

. 1, 0 1 . 2 H , 1.5 23.1 160 .

D. Creation of the Negative Current Zone

. 3. $-I_{op}$,



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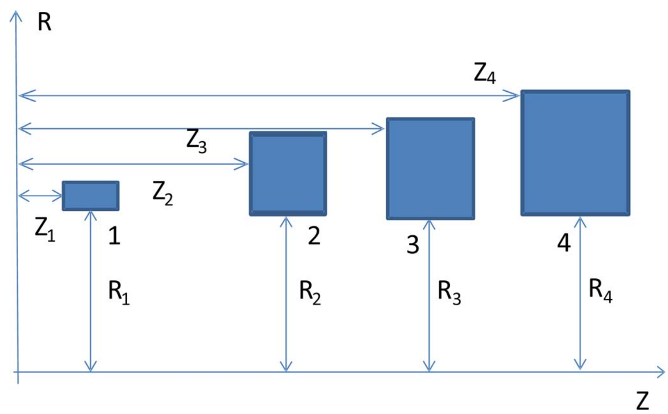
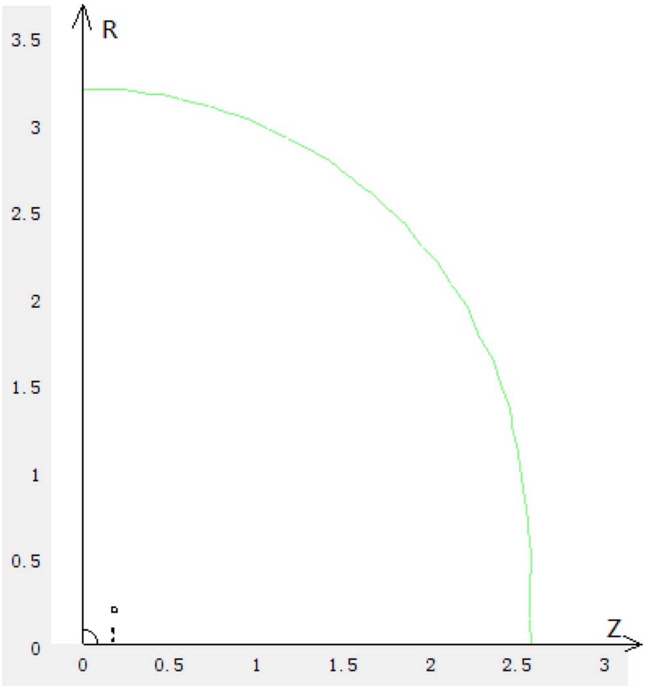


. 5.

Coil no.	Inner radius(m)	Layers in the radial direction	Zmin(m)	Turns in the axial direction	current
1	0.176	17	0.0187	23	+I
2	0.175	31	0.093	27	+I
3	0.1755	33	0.1348	25	-I
4	0.1765	50	0.1796	41	+I

. 6. H

0 1



. 7.

E. Rectangularity of Current Carrying Zones

H , ; . 4. , (. 5). , 5 , 0.215 .

F. Final Optimal Design of Magnet

. . 6 160 22 , 1.5 , 120 3.67 0.2 . 4.85 .

. 7, 5 3.2 2.6 .

0 1 , 1.5 , 1.5 ( ), 430 , 350 .

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