Topology Optimization Based Method for Coil Arrangement for homogeneous Magnetic Field

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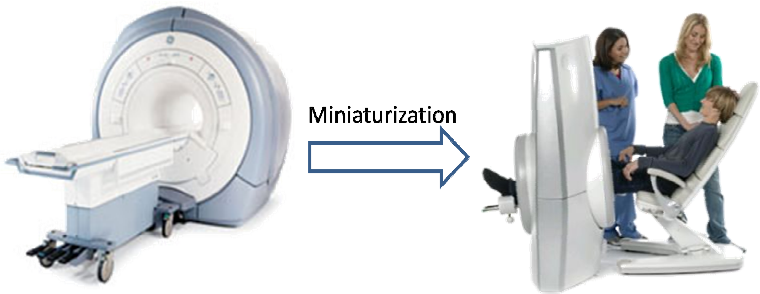
Summary MRI technology is a high-tech developing in the last ten years, which has been widely used in today's medical field and been essential for treatment of the medical profession. A typical MRI instrument consists of five major components: the main magnetic field system, the gradient magnetic field system, imaging spectroscopy systems, computer control systems, image reconstruction and processing system. Among them, the main magnetic field system is an important component part of the instrument, which needs to generate a uniform magnetic field. Superconducting magnetic systems can achieve high strength of uniform magnetic field, and be used in the medical field commonly. This paper introduces the topology optimization to the design of superconducting magnetic systems in the main field NMR instrumentation system, and the results obtained have a guiding significance to the designing of this area.

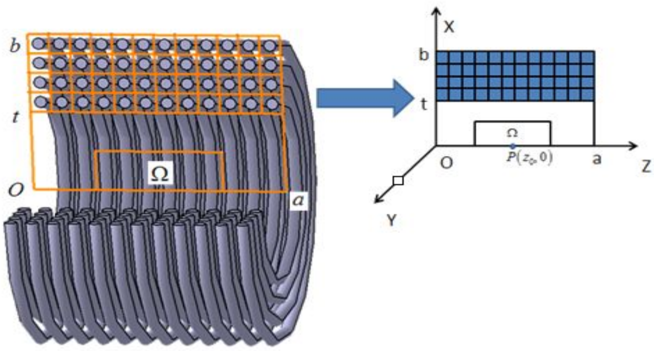
Introduction

In the NMR instrument, if the main magnetic field system can receive higher quality uniform magnetic field, the performance of MRI can be significantly improved. Using the excitation coil to generate the required uniform magnetic field, the volume of the instrument is inevitable too large, this is the major factor to restrict the miniaturization of NMR instrument. As shown below, the miniaturization of nuclear magnetic resonance apparatus is not only more convenient to use, but also to make the patient more comfort during treatment.



Simulations

The design problem can be simplified to the following model.



As shown below, analysis of any point P in the magnetic field under a single power coil, taking into account the magnetic field of axial symmetry, we select P-point in the XOZ plane, so the magnetic flux density of P-point is:

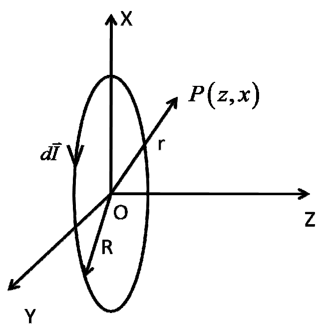
$$B = \frac{\mu_0}{4\pi}\int \frac{Id\vec{l} \times \vec{r}}{r^3} = B_x(z,x)\vec{i} + B_z(z,x)\vec{k}$$

$$B_X(z,x) = \frac{\mu_0 I}{4\pi R}\left[\frac{z}{R}\Phi\left(\frac{z}{R},\frac{x}{R}\right)\right]$$

$$B_Z(z,x) = \frac{\mu_0 I}{4\pi R}\left[\Psi\left(\frac{z}{R},\frac{x}{R}\right) - \frac{x}{R}\Phi\left(\frac{z}{R},\frac{x}{R}\right)\right]$$

$$\Psi(z,x) = \int_0^{2\pi} \frac{1}{\left(1+z^2+x^2-2x\cos\varphi\right)^{3/2}} d\varphi$$

$$\Phi(z,x) = \int_0^{2\pi} \frac{\cos\varphi}{\left(1+z^2+x^2-2x\cos\varphi\right)^{3/2}} d\varphi$$



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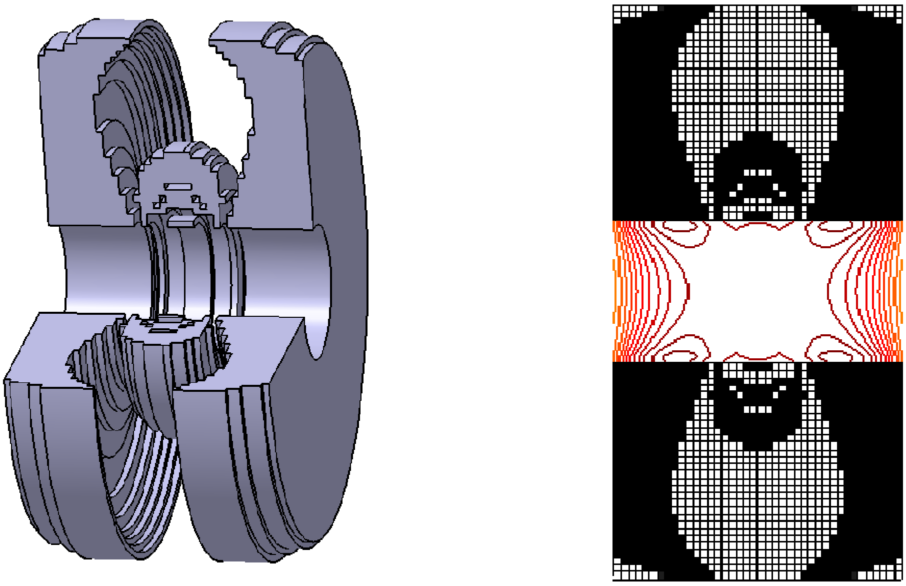
Optimization Formulations

The optimization formula is as follows:

$$\begin{cases} find \quad \rho_i \quad i=1,\dots,NE \\ \min \quad obj=\left\{par\cdot\dfrac{U}{U_0}-(1-par)\cdot\dfrac{S}{S_0}\right\}+\alpha\cdot\sum_{i=1}^{NE}\rho_i\cdot(1-\rho_i) \\ s.t. \quad \sum_{i=1}^{NE}\rho_i\cdot V_i=volfrac\cdot\sum_{i=1}^{NE}V_i \\ \qquad 0<I_{\min}\le I_i\le 1 \end{cases}$$

Uniformity index: $U=\int_{\Omega}\left[B_Z(z,x)-B_Z(z_0,0)\right]^2 d\Omega$, Strength index: $S=B_Z(z_0,0)$, U_0, S_0 are the initial value, par Weight parameters, $volfrac$ is volume ratio parameter, V_i is the volume of the i-th current loop. $I_{\min}$ is the Lower limit for the design variables, Z_0 is the location of the center.

The initial parameters taken as a = 1m, b = 1m, t = 0.25m. Assuming that each grid contains 20-turn excitation coils, and a single-turn coil excitation current is 200A. The target area Z coordinate in the range of 0.25m to 0.75m, X coordinates range from 0 to 0.125 m. The volume ratio parameter volfrac = 0.5, the weight parameter par = 0.8, a = 1. Optimization results are shown as below.



(a) (b)

(a) Distribution of the coil, (b) Simulation diagram

	Our results	Uniform coil	Helmholtz coil
S (T)	2.0702	1.5926	1.4615
U (T^2)	0.0063	0.3742	0.0196

Compared with uniform coil and Helmholtz coil, our result has the highest strength index and the smallest uniform index, indicating that our result not only improve the center strength of the magnetic field, but also improves its uniformity, the result illustrate the effectiveness of the optimization model proposed.

Conclusion

Based on the main system magnetic field of NMR instrumentation, using the topology optimization technology, we have designed the arrangement of excitation, and the designated field meet the actual needs which the magnetic flux density at the center is 2.05 T, and the uniformity index is less than 2%, this also prove the validity of the proposed optimization model.

References

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