Design and Optimization of a Permanent Magnet for Small-sized MRI Based on Particle Swarm Optimization Algorithm

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Introduction: The magnet is crucial part of an MRI system. In a permanent MRI system, the well-known widespread end-effect of permanent magnets usually causes a non-uniform magnetic field distribution and therefore affects the imaging quality [1]. By adding pole pieces of pure iron, one can improve the field uniformity within the imaging area. Previously, the design of the permanent magnets has been discussed, mostly focusing on the optimization of these used pole pieces [2]. However, the optimized pole piece shapes are usually complicated and difficult to produce. In this work, we consider an alternative approach to improve the magnetic field quality. Here a shimming ring is used directly outside the pole piece, the size and position of which is numerically obtained through a nonlinear optimization procedure. To illustrate the effectiveness of the proposed method, a small H-type permanent magnet was designed with an optimized ring structure.

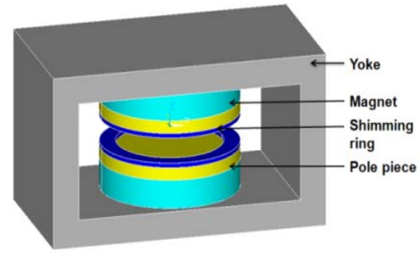

Figure 1. Construction of the H-type MRI magnet.

Method: As shown in figure 1, a small H-type permanent magnet for animal MRI is considered here. The construction of the permanent magnet consists of magnets, pole pieces, shimming rings and the yoke. For details, see Table 1. The pole piece is made of pure iron on the magnet surface and can smooth the magnetization characteristics of the Nd-Fe-B blocks [3]. However, if the surface of the pole piece is flat, the magnetic flux in the air gap can then be uneven, with a drum shape (see Fig.2 (a)). This effect is so-called end effect. One effective way to avoid this effect is through adding a flange outside the pole piece. As shown in Fig.2 (b), by a proper adjustment of the pole pieces, the flux in the air gap becomes more uniform [1]. In practice, a further improvement of the uniformity of the magnetic field in the imaging area is required and therefore, an additional shimming ring is added into the system, as shown in Fig.2(c). Manufacturers usually determine the size of the shimming ring based on experience, which is sub optimal in a number of respects. In this analysis, we optimize the structure of the shimming ring (inner radius R_{in} and height H) using the particle swarm optimization (PSO) algorithm [4], moreover the outer radius R_{out} is fixed and the value is same as the radius of the magnets. The flow of the optimization procedure is explained as follows [5]: 1) initialize each particle with a random setting; 2) evaluate the fitness function for each particle; 3) for each individual particle, compare the particle's fitness value with its p_{best}(particle's best). If the current value is better than the p_{best} value, then set this value as the p_{best} and the current particle's position, x_i, as p_i ; 4) identify the particle that has the best fitness value. The value of its fitness function is identified as g_{best}(global best) and its position as p_g; 5) update the velocities and positions of all particles; 6) repeat steps 2–5 until a stopping criterion is met. The field uniformity in a 60 mm diameter of spherical volume (DSV) is chosen as the fitness function, which is defined as: $Per = (B_{max} - B_{min}) / B_{avg}$ (Eq.(1)), where B_{min} , B_{max} and B_{avg} are the maximum, the minimum and averaged magnetic field intensities over the DSV, respectively.

Table 1. Function, Material and Attributes of Permanent Magnet Components

Component	Function	Material	Attributes
Magnet	Provide the magnetic energy to generate the static magnetic field	Nd-Fe-B (N40)	Br=1.28T Hcb=939.0142(kA/m) (BH)max=300(Kj/m^3)
Yoke	Support the magnet frame to compose the magnetic circuits	A3 Steel	μ_r=10000
Pole piece & Shimming ring	Smooth the surface of magnets to get the uniform magnetic field	Pure Iron DT4	μ_r=5730

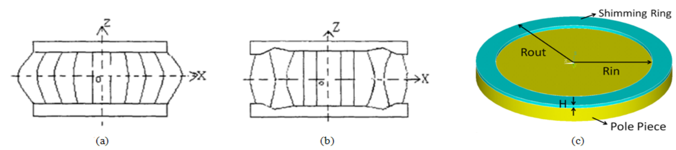

Figure 2. (a) Magnetic flux distribution due to the end effect; (b) Magnetic flux distribution with the optimization of the pole pieces; (c) The pole piece model with a shimming ring.

Table 2. Comparison of the magnetic fields over the DSV before and after the shimming ring optimization.

	Average field intensity of DSV(T)	Field Uniformity of DSV(ppm)
Without the shimming rings	0.5427	162.37
With the optimized shimming rings	0.5107	54.05

Results: In this work, the software ANSYS is used for field calculations and MATLAB program is used for optimization. For the 3D magnetic field computation using ANSYS, only half of the magnet was modeled by taking advantage of the system symmetry. In the simulations, the final geometry of the shimming ring and the resulting magnetic fields was obtained after 30 iterations of the PSO algorithm. The optimized shimming ring structure: height-6.02 mm; inner radius-127.54 mm. For comparison, the magnetic field intensity and uniformity before and after optimization are summarized in Table 2. Clearly, the shimming rings can significantly improve the magnetic field uniformity. Over a 60mm- DSV, 66% enhancement of the field homogeneity was achieved compared the magnet structure without the shimming rings. From Fig.3, it can be seen that use of the shimming rings provides a large useable DSV and the field errors inside the DSV can be easily shimmed by an additional passive shimming step.

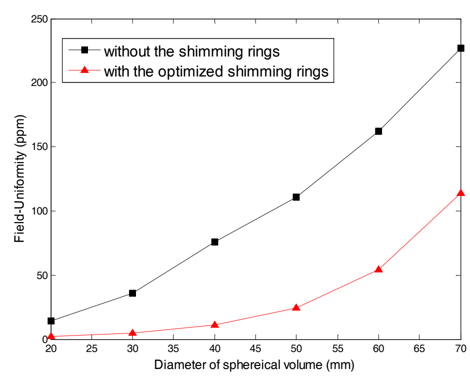

Figure 3. Behavior of the field uniformity variations over the DSV.

Conclusion: In this work, a shimming ring has been successfully used to improve the magnetic field quality of the permanent magnet system. Compared with conventional pole piece optimization techniques, this solution can be easily implemented and is of low cost.

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