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A design of a low-power open-side MPI scanner Using inverted spliced permanent magnets

Tao Zhu[a,b,c] · Jie He[d] · Zechen Wei[a,b,c] · Hui Hui[a,b,c,*] · Xin Yang[a,b,c] · Jie Tian[a,b,d,e,f]

[a]CAS Key Laboratory of Molecular Imaging, Institution of Automation, Beijing, China
[b]Beijing Key Laboratory of Molecular Imaging, Beijing, China
[c]University of Chinese Academy of Sciences, Beijing, China
[d]School of Biological Science and Medical Engineering, Beihang University, Beijing, China
[e]Key Laboratory of Big Data-Based Precision Medicine (Beihang University), Ministry of Industry and Information Technology of the People's Republic of China, Beijing, People's Republic of China
[f]Zhuhai Precision Medical Center, Zhuhai People's Hospital, affiliated with Jinan University, Zhuhai, China
[*]Corresponding author, email: hui.hui@ia.ac.cn

Abstract

Magnetic particle imaging (MPI) is a promising imaging modality with high sensitivity, high resolution, and no depth limitation. Scaled MPI scanners are developed to satisfy the demand for imaging larger objects. Considering the ultimate goal of whole-body scanning, an open-side MPI scanner is more suitable than a traditional closed-bore MPI scanner. A fully electrically driven open-side MPI scanner has been built, enabling rotating and translating field free line (FFL) in three dimensions previously. However, the high power required to run the system may become a challenge when trying to scale it up. Here, we present a design of an open-side MPI device using inverted spliced permanent magnets. The design eliminates the need for power suppliers to generate and move the FFL, reducing the cooling requirements of the system. Compared to the conventional solution based on permanent magnets, our solution can generate a more uniform FFL.

I. Introduction

Magnetic particle imaging is a novel medical imaging technique utilizing the non-linear magnetization response to localize magnetic nanoparticles quickly and accurately. A series of experiments were conducted on mouse-scale[1], rat-scale[2], and rabbit-scale[3] using closed-bore MPI scanners. Further, to explore the potential of MPI technology, specialized MPI scanners for the brain and legs were designed, and promising results were achieved[4, 5]. However, since the sensitivity of MPI scanners decreases with increasing bore size, whole-body scanning, such as non-cylindrical trunks whose width is much larger than the thickness, would be a challenge for conventional close-bore scanners. To address this challenge, an open-side MPI scanner was proposed, where the object is restricted in only one direction and can well match the relatively flat shape of the human trunk[6].

In [6], two sets of eight solenoid coils that need to be powered by 1.5kW and 10kW power amplifiers are used to generate, maintain, translate and rotate the FFL. However, when considering scaling it to human size, the high power requirements and the cooling demands of

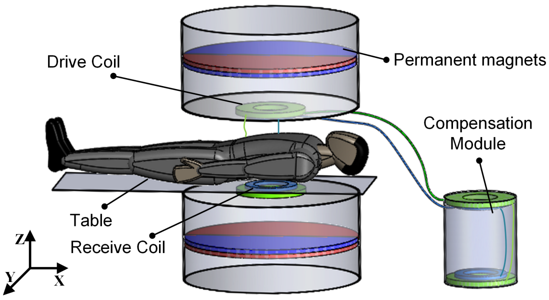

Figure 1: The main structure of the permanent magnets based open-side MPI scanner, mainly includes a pair of movable, rotating permanent magnets, receive coils, drive coils, and a compensation module.

the system under long-term high current drive will make the system hard to power and cool.

In this abstract, we present a design of a low power open-side MPI scanner based on inverted spliced permanent magnets. Simulation results and comparisons are given in the abstract.

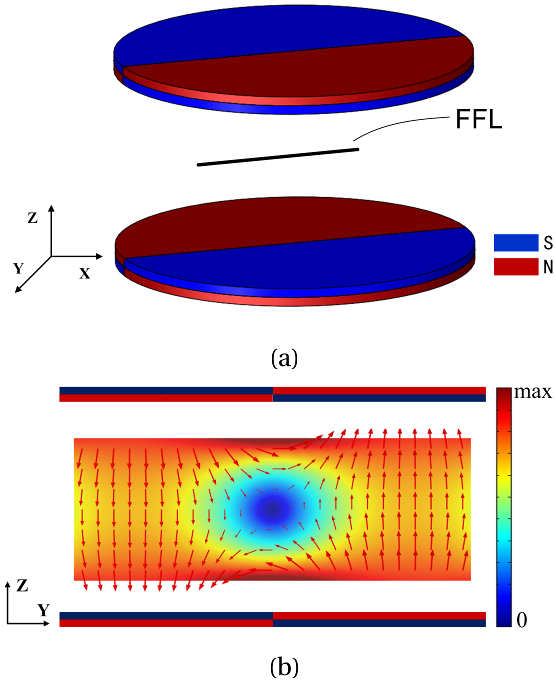

Figure 2: The inverted spliced permanent magnets. (a) Arrangement of magnets and the generation of FFL. (b) Magnetic flux density distribution of permanent magnets in YZ-plane. In simulation, the diameter of the magnets is 40 cm and the thickness is 5.5mm. The gap distance is set to 100mm.

II. Material and methods

II.I. Main Structure

The designed open-side MPI scanner is encoded by FFL and is able to perform 3D tomography (see Fig. 1). Instead of using solenoid coils, we use a pair of inverted spliced permanent magnets to generate stable FFL, as shown in Fig. 1. To compensate for the direct feedthrough, an external compensation module is used and an identical pair of excitation receiver coils are placed outside the imaging area[7]. The translation table is capable of moving the target object into the imaging area for scanning. The drive coils and receive coils are placed similarly to the device in [6]. In the following sections, the permanent magnets will be focused on.

II.II. Inverted spliced permanent magnets

Each permanent magnet we use is spliced by two identical and opposite polarized permanent magnets. With this arrangement, a stable FFL is produced in the central area, which is distributed along the magnet splicing direction. In addition, the magnetic field distribution in space is similar to the field generated by the solenoid coil set, so there is no need to make much adjustment to the other components of the open MPI system (see Fig. 2).

To achieve 3D tomographic scanning, we move the FFL in a mechanical way. First, since FFL is always distributed along the splice line, it is possible to rotate the FFL in the XY-plane by synchronously rotating the permanent magnet pair. With the excitation/drive magnetic field, the magnetic nanoparticles can be encoded in the XY-plane and 2D imaging can be realized. Then, by synchronous translation of the permanent magnet along the Z-axis, the imaging region can be extended along the Z-axis, so as to achieve three-dimensional tomography. The process of FFL movement in space driven by the mechanical displacement of the permanent magnet team is shown in Fig. 3. In practice, the translation and rotation of permanent magnets can be achieved by the combination of a lifting table and a rotating table. And the synchronous rotation or translation of the upper and lower permanent magnets can be achieved by program control.

III. Simulations and results

To demonstrate the advantages of inverted spliced permanent magnets clearly, we designed two simulation experiments. First, we compare our inverted spliced permanent magnets with solenoid coils through simulations. The data for the solenoid coil based MPI device come from [6], and correspondingly, the simulation parameters are set up aiming to match the 100mm vertical gap size mentioned in [6]. The results in Table 1 show that the

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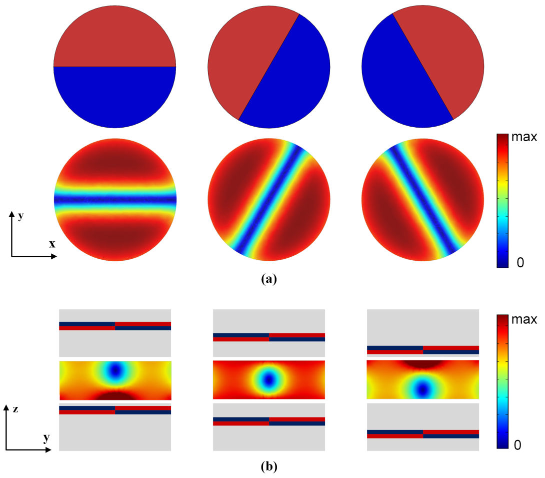


Figure 3: The schematic diagram of FFL movement in 3D space. (a) Permanent magnet rotates (upper row) drive FFL rotation in XY-plane (lower row). (b) Permanent magnet to synchronous moving drive FFL along Z-axis.

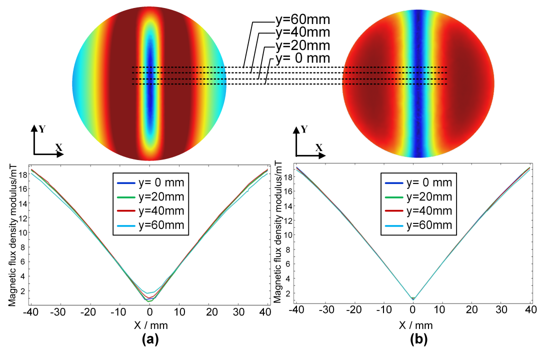
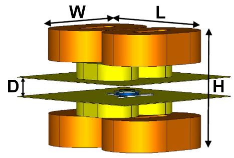
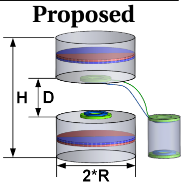


Figure 4: FFL uniformity comparison of inverted splicing magnets and conventional long magnets. (a) inverted splicing magnets. (b) conventional long magnets.

inverted spliced permanent magnet device could generate the same gradient magnetic field as the Solenoid coil, without increasing the overall size of the device.

Second, we compare the inverted spliced permanent magnets with the conventional long permanent magnets at the vertical gap size of 100mm[8]. The simulation results show that in order to generate an FFL of 0.5 T/m, a pair of 50×10×1.1cm (Length×Width×Height) is required, if using inverted splicing magnets, only a pair of 20×0.55cm (Radius×Height) magnets are required. Further, uniformity along the FFL extension direction is analyzed, and the results are shown in Fig. 4. The results demonstrate that inverted splicing magnets could provide a more uniform FFL gradient magnetic field. Also, compared to the solenoid coils based scanner mentioned in [6] that was able to achieve a field of view (FOV) of 60 mm with a gradient degradation of 10%, the gradient degradation of our design was less than 1%.

Table 1: Comparison of solenoid coils based and proposed scanner. (L, W, R and H represents the length, width, radius and height of the device. The gap size D is set to 100mm.)

	Solenoid coils based	Proposed
Main Structure		
Gradient-generation material	litz wire	NdFeB (N50)
Gradient (T/m)	0.5	0.5
Scanner size (cm)	50×34×34 (L×W×H)	40×30 (2×R)×H
Power supplier	2×1.5kW 2×10kW	Mechanical drive
Cooling demand	Yes	No

IV. Discussion and conclusions

We discussed a low-power open-side MPI scanner using inverted spliced permanent magnets in the abstract. The scanner based on inverted spliced permanent magnets enables 3D tomographic imaging without requiring multiple power suppliers to power the coils to generate and move the FFL. Compared to conventional long permanent magnets, our solution can provide a more homogeneous FFL with thinner magnets. With reduced system requirements for power and cooling, we believe our solution can be extended to larger devices, even human-sized devices, in future work. Currently, our work is only a brief design for the permanent magnet, the detailed design for the remaining components and verification of the imaging effect are still needed in the future. In particular, when the FOV increases, how to ensure the strength of the excitation field and the sensitivity of the receiving coil will be an important research problem.

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Author's statement

Conflict of interest: Authors state no conflict of interest.

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