International Journal on Magnetic Particle Imaging
Vol 6, No 2, Suppl 1, Article ID 2009016, 3 Pages

Proceedings Article

Selection field generation for an open aperture field free line magnetic particle imaging scanner

C. B. Top[1,*]

[1]ASELSAN Research Center, Aselsan A.Ş., Ankara, Turkey
[*]Corresponding author, email: cbtop@aselsan.com.tr

Abstract

We present the design and measurement results for the selection field generation of an open scanner configuration for field free line (FFL) Magnetic Particle Imaging. The FFL can be rotated electronically using the designed coils. The selection of the imaging plane is possible by asymmetrical excitation of the upper and lower coil groups. The magnetic field is orthogonal to its gradient, allowing 2D scan using a single drive field coil channel. The mechanical housing of the coils are manually adjustable to provide the highest gradient level for the imaged object size. In the current configuration, a magnetic field gradient between 0.5 T/m - 0.74 T/m can be generated in a 60 mm diameter field of view.

I Introduction

In Magnetic Particle Imaging (MPI), field free line (FFL) scanning has increased sensitivity advantage over field free point (FFP) scanning [1]. Closed-bore and single-sided MPI scanners have been proposed for FFL imaging [2-4]. Although the selection field coil efficiency is high for closed bore scanners, access to the imaged subject is limited. Although single-sided scanners do not have this restriction, their imaging depth is limited as the FFL gradient decrease with distance to the SF coils [4]. An open aperture configuration can provide a good trade-off between closed and single sided configurations. Recently, we proposed an open coil topology for FFL scanning and analyzed its feasibility on a human scale design [5]. Based on this coil topology, we built a prototype scanner. In this study, we present the design and measurement results of the selection field for our prototype scanner.

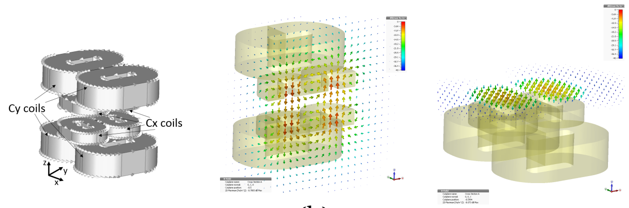
II Material and methods

FFL scanning open coil topology is shown in Fig. 1. SF coils rotate the FFL in any desired direction on the imaging plane, while the FFL can be translated using drive field and/or focus field coils. Imaging plane can be selected by properly adjusting the excitation of the upper and lower SF coil groups [5].

SF coils are formed by using two bi-planar gradient coils in the x- and y-direction. An FFL in the x-direction can be generated using the Cx coils, while a y-directed FFL can be generated by using the Cy coils (Fig. 1). FFL can be rotated to any direction (θ) on the xy-plane by exciting Cy and Cy coils with currents:

$$\begin{aligned} I_x(\theta) &= I_{x0}\cos(\theta) \\ I_y(\theta) &= I_{y0}\sin(\theta) \end{aligned} \qquad (1)$$

Where, I_{x0} and I_{x0} are the currents required to generate the desired magnetic field gradient level for the FFL in the x- and y-directions, respectively. θ is the angle between the FFL axis and the x-axis.



(a) (b) (c)

Figure 1: (a) 3D Model of the designed SF coils. Simulation result of the magnetic field distribution (b) at the yz-plane, (c) at the xy-plane showing the FFL for $\theta = 0°$.

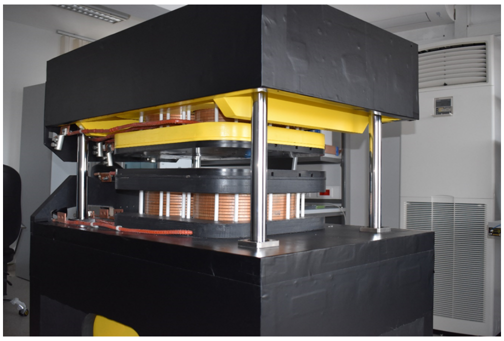


Figure 2: Produced SF coils and mechanical support structure with adjustable height. The Cy coils are visible in the picture.

In this configuration, magnetic field vector is mainly in the z-direction. Therefore, the FFL can be translated on the xy- plane using z-directed drive/focus coils. It should be noted that the translation direction is inherently perpendicular to the FFL axis. Therefore, 2D imaging is possible with single axis drive/focus coils.

II.I Selection Field Coil Design

We designed the selection field coils to achieve minimum 0.5 T/m gradient in a 30 mm x× 30 mm x 30 mm FOV. We used pancake type coils with 7 x 9 turns (6 mm x 6 mm coil cross section) for the Cx coils and 12 x 12 turns (7 mm x 7 mm cross section) for the Cy coils. All coils were built from hollow copper tubing for water cooling. The design was firstly done using an in-house developed Matlab (Mathworks, CA, USA) tool. For the detailed analyses, CST EM Studio (Dassault Sytemes, France) was used. The coils were produced by Danfysik A/S (Denmark). The mechanical support structure for the coils were designed and produced by ANOVA R&D Technologies (Turkey). The structure was designed such that the aperture height between the upper and lower coils can be manually adjusted (Fig. 2). This allows flexibility for adjusting the size of the imaging volume for maximum achievable gradient.

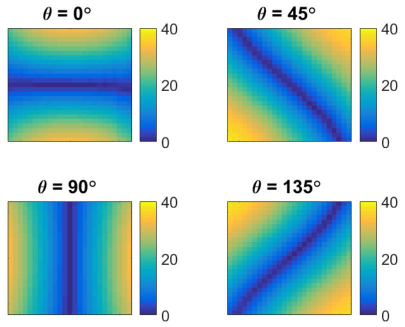
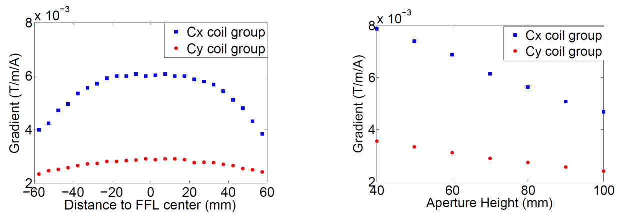


Figure 3: Absolute magnetic field in "mT" showing FFL rotation at 0°, 45°, 90°, and 135° rotation angles. The axes span -60 mm to 60 mm in x and y axes.



(a) (b)

Figure 4: (a) Magnetic field gradient efficiency along the FFL for the Cx and Cy coil groups. (b) Magnetic field gradient efficiency at the FFL center as a function of aperture height.

II.II Field Measurements

SF coils were excited in pairs. The Cx and Cy coil pairs were driven by FAST-PS-1K5 and NGPS power supplies (CAEN ELS S.R.L., Italy), respectively. The magnetic field generated by the SF coils were measured using a Model 460 gaussmeter (Lakeshore Cryotronics Inc., OH, USA) mounted on a three-axis mechanical scanner (Velmex Inc., NY, USA). A 120 mm by 120 mm area was scanned with 5 mm steps on the xy-plane. The field gradient was calculated for several aperture height values.

III Results and discussion

Magnetic field distributions for 0°, 45°, 90°, and 135° angles are shown in Fig. 3. The measurements show that the FFL can be directed electronically.

Magnetic field gradient efficiencies along the FFL are shown in Fig. 4(a) for the Cx and Cy coil groups at 70 mm aperture height. Maximum gradient efficiency is 6 mT/m/A and 3 mT/m/A for the Cx and Cy coils, respectively. The degradation of the gradient is smaller than 10 % in 60 mm range for the Cx coils, and 80 mm range for the Cy coils. Using the developed SF coils, minimum 60 mm diameter FOV can be covered in the xy-plane.

10.18416/ijmpi.2020.2009016

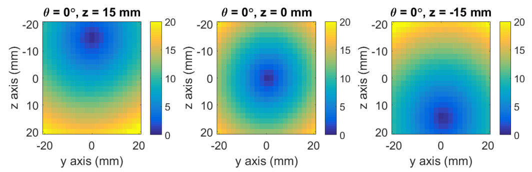


Figure 5: Absolute magnetic field in “mT” showing FFL translation in the z-axis using asymmetrical excitation of upper and lower SF coils.

Gradient efficiency at the center is plotted as a function of aperture height in Fig. 4(b). Cx coil group gradient efficiency decreases from 8 mT/m/A to 5 mT/m/A, whereas the Cy coil group efficiency decreases from 3.7 mT/m/A to 2.5 mT/m/A as the aperture height is increased from 40 mm to 100 mm. With the current DC supply configuration (4.4 kW mean power consumption), the magnetic field gradient of the system is 0.5 T/m at 100 mm aperture height, and 0.74 T/m at 40 mm aperture height.

The proposed SF coil topology allows selection of the imaging plane in the z-axis. If the upper and lower coil groups are symmetrically excited, the imaging plane is on the mid-plane between these coil groups. The imaging plane can be translated by asymmetrical excitation of the upper and lower coil groups. To demonstrate this, we measured the magnetic field at the yz-plane, when the imaging plane was translated to z positions: -15 mm, 0 mm, and 15 mm (Fig. 5).

IV Conclusions

In this study, we presented the magnetic field properties of our open aperture FFL MPI scanner. A 60 mm diameter 2D field of view (FOV) can be scanned with 0.5 T/m to 0.74 T/m gradient. Aperture height is adjustable between 40 mm to 100 mm. The main advantages of the proposed coil system are: Open aperture with no restriction in penetration depth, adjustable aperture height, and 3D imaging capability with single axis drive/focus field channel. We have shown that the FFL can be rotated on the imaging plane, and the imaging plane can be translated electronically.

Author’s Statement

Research funding: This work is partly supported by the Technological and Scientific Research Council of Turkey (9050103). Conflict of interest: Authors state no conflict of interest.

References

[1] J. Weizenecker, B. Gleich, and J. Borgert. Magnetic particle imag-ing using a field free line.J. Phys. D: Appl. Phys., 41(10):105009,2008

[2] Bente K, Weber M, Graeser M, Sattel TF, Erbe M, Buzug TM. Electronic field free line rotation and relaxation deconvolution in magnetic particle imaging. IEEE Trans Med Imaging. 2015; 34: 644– 651.

[3] J. Konkle, P. Goodwill, O. Carrasco-Zevallos, S. Conolly, "Projection reconstruction magnetic particle imaging", IEEE Trans. Med. Imag., vol. 32, no. 2, pp. 338-347, Feb. 2013.

[4] A. Tonyushkin, "Single-Sided Field-Free Line Generator Magnet for Multi-Dimensional Magnetic Particle Imaging," in IEEE Transactions on Magnetics, vol. 53, no. 9, pp. 1-6, Sept. 2017, Art no. 5300506.

[5] Top, C. B., Ilbey, S. and Güven, H. E. (2017), Electronically rotated and translated field-free line generation for open bore magnetic particle imaging. Med. Phys., 44: 6225-6238.

10.18416/ijmpi.2020.2009016