International Journal on Magnetic Particle Imaging
Vol 8, No 1, Suppl 1, Article ID 2203030, 3 Pages

Infinite Science Publishing

Proceedings Article

Improvement study of field-free-line generator for mechanically scanned-type MPI system

T. Y. Kim[a] · J. C. Jeong[a] · H. B. Hong[a,*] · S. B. Seo[a]

[a]SW Contents Research Lab., Electronics Telecommunications Research Institute (ETRI), 218 Gajeong-Ro, Yuseong-Gu, Daejeon 34129, Republic of Korea
[*]Corresponding author, email: hb8868@etri.re.kr

© 2022 Kim *et al.*; licensee Infinite Science Publishing GmbH

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Abstract

We proposed hybrid field free line(H-FFL) generator that is composed of permanent magnet and coil, it was compact and had low power consumption in 2020. In this paper, we summarize the development process and advantages of new type of FFL generator that outperform the previous H-FFL generator. The FFL generator not only shows 1.83 times higher the magnetic gradient field but also decrease the total volume and weight to be 1/3. In addition, it is designed to be easier and cheaper to manufacture.

I. Introduction

In the development of Magnetic particle imaging (MPI) system, the selection field generation is an essential element. By sensing the nonlinear magnetic response only generated in the field free area (FFA) while moving FFA in three dimensionally in desired sample volume, three-dimensional image of magnetic nanoparticles (NMP) can be obtained non-invasively [1, 2].

Field free line (FFL), one of selection fields, can be composed of an electromagnetic coil or a permanent magnet, or a combination of both. The move of FFL can be achieved by exerting the drive field or the travelling the FFL generator part mechanically [1, 3]. The method of moving FFL with drive field by electromagnet has the advantage of being able to move FFL quickly, but it requires high power consumption and bulky cooling system. On the other hand, mechanically-moving FFL way has the advantage that it does not require high power consumption and enables compact equipment configuration, but it is slower relatively.

In 2020, we presented compact MPI system that does not need high power source and cooling system, and hybrid field free line generator [3]. This year, we improved FFL performance with development of new type of FFL generator composed only with permanent magnets [4]. In this article, the process of development and characteristic of the FFL generator are summarized, and the FFL generator is compared with former one.

II. Material and methods

The schematic design and real photo of FFL generator of previous hybrid field free line (H-FFL) generator of 2020 are shown in Fig 2(a). It consists of a current-driven electromagnet and permanent magnet. The open aperture of electromagnet part was adopted to make open structure to z direction where the sensor and sample insert.

While this configuration of H-MPI does not need high power source and cooling part, it is still using DC power supply for FFL generation. In addition, this H-FFL generator has the disadvantage of requiring too large magnet when trying to widen the MPI's FOV. These shortcomings of the existing FFL generator were solved by developing open-aperture type FFL generator with a small permanent magnet array.

Fig 1(a) is composed of two ring magnets, each of

10.18416/ijmpi.2022.2203030

© 2022 Infinite Science Publishing

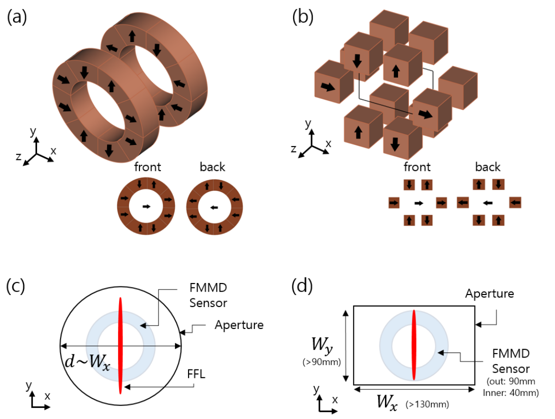

Figure 1: (a) Cylinder-type of FFL generator (b) Rectangular-type of FFL generator

which is a simplified form of a Halbach ring (k=1) [5]. If the magnetization directions of the front and rear rings are reversed, and the two are overlapped as shown in Fig 1(a), an FFL is formed at the center of the structure. This ring-structured FFL generator provides a circular aperture through which the sensor and sample can freely move in the z-direction.

Our research team modified this ring-type FFL generator into a rectangular-type structure as illustrated in Fig1 (b) with following reasons. First, the rectangular-type FFL generator is more efficient in terms of space utilization than the ring-type FFL generator. In our MPI system, which moves the FFL by mechanical motion, the x-axis width of aperture (W_x) should be wide so that the FFL perpendicular to the y-axis covers the FOV in the x-axis. Detailed scanning mechanism is described in previous paper [3]. When the aperture has circular type, the unnecessary spare distance of y-axis exists as shown in Fig1 (c). On the contrary, the magnets in rectangular-type aperture configuration can be positioned more tightly in y-axis. Secondly, the rectangular-type FFL generator has several practical advantages in the manufacturing process. In the case of a ring-type magnet as shown in Fig1 (a), it is difficult to obtain those type of magnet component as desired size than a square-type magnet. Also, it is difficult to assemble. Other side, rectangular magnets are easily available in the market, and they are convenient to use by overlapping several sheets. Thus, rectangular-type FFL generator was developed instead of ring-type configuration. Also, those rectangular-type FFL generator was inspired by a paper that used rectangular permanent magnet array. [6] The FFL generator was designed that the size of the rectangular window to be 140 mm × 90 mm. Each component magnet size in Fig 2 (b) is 50 cc (cubic centimeter). The size of magnet was chosen because that is easily available in the market, and it was suitable for the size of the window of FFL generator.

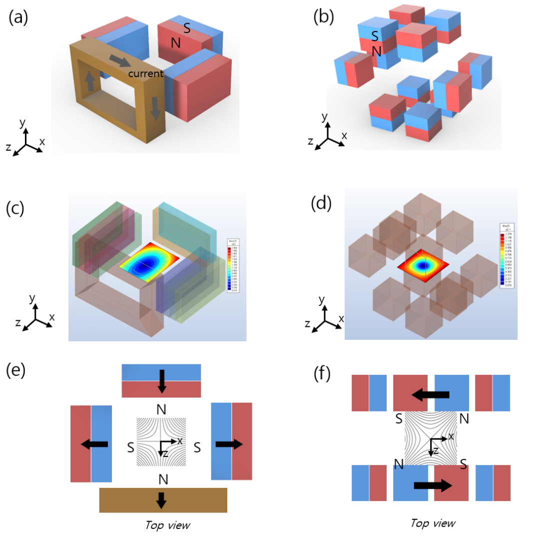

Figure 2: (a) Schematic sketch of previous H-FFL generator (b) new version of FFL generator (c) Faraday simulation results of H-FFL generator (d) and of the FFL device (e) magnetic field of H-FFL generator (f) and of the FFL generator

III. Results and discussion

Simulation study of magnetic field generation were made with FARADAY software (Integrated Engineering Software, Winnipeg, Manitoba), and the magnet material used in the simulations was NdFeB.

Fig 2 (c) shows magnetic contour map of XZ-plane of H-FFL generator, the magnetic gradients in the x-axis and y-axis are asymmetrically configured. The field free point (FFP) in XZ-plane is from the quadrupole magnet characteristic illustrated in Fig 2 (e), and as the quadrupole magnet has a length in the y direction, FFL is generated. Fig 2 (d) shows magnetic contour map of XZ-plane of the FFL generator, the generated magnetic gradient field was steeper than in the case of H-FFL generator. That is because each of the component magnets are placed closer to the FFL location than the H-FFL configuration. The magnetic field in Fig 2 (f) shows characteristic as if the magnetic field in Fig 2 (e) rotated with 45 degrees about the y-axis direction.

The table 1 compares the performance of the newly designed FFL generator and former H-FFL generator. Both FFL generators are designed to cover 40 mm diameter sample, and the FFL generator can measure samples longer in z-axis than H-FFL generator since it has open structure in z-axis. Comparing the magnetic field gradient with previous H-FFL generator, it was improved by 1.22 times in the x-axis and 1.83 times in the y-axis. Surprisingly, while achieving this performance improvement, the weight and overall volume of the FFL generator were reduced by 1/3.

Table 1: Comparison table of H-FFL generator and new FFL generator

	H-FFL generator (Fig2.(a))	**FFL generator** (Fig2.(b))
FOV	40×40×60 mm^3	40×40×inf mm^3
G_x	3 T/m	3.66 T/m
G_z	1.5 & 2 T/m	3.66 T/m
Weight	33 kg (magnet & coil)	11 kg (magnet)
Size	330×450×200 mm^3	260×210×150 mm^3

IV. Conclusions

We designed an FFL generator based on the principle of the Halbach ring configuration. It is much lighter and easier to fabricate than the H-FFL generator of the past, while it shows a stronger magnetic gradient. The experimental results of the MPI equipped with this new type of FFL generator are described in the reference [4].

Acknowledgments

This work was supported by Electronics and Telecommunication Research Institute, Rep. of Korea (Grant No. 21-YS-1910).

Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

References

[1] B. GLEICH AND J. WEIZENECKER, "TOMOGRAPHIC IMAGING USING THE NONLINEAR RESPONSE OF MAGNETIC PARTICLES," NATURE, VOL. 435, PP. 1214–1217, JUN 2005.

[2] N. PANAGIOTOPOULOS, R. L. DUSCHKA, M. AHLBORG, G. BRINGOUT, C. DEBBELER, M. GRAESER, C. KAETHNER, K. LÜDTKE-BUZUG, H. MEDIMAGH, J. STELZNER, T. M. BUZUG, J. BARKHAUSEN, F. M. VOGT, AND J. HAEGELE, "MAGNETIC PARTICLE IMAGING: CURRENT DEVELOPMENTS AND FUTURE DIRECTIONS," INT. J. NANOMED., VOL. 10, PP. 3097–3114, 2015.

[3] S. M. CHOI, J. C. JEONG, J. KIM, E. G. LIM, C.-B. KIM, S. J. PARK, D. Y. SONG, H. J. KRAUSE, H. HONG, AND I. S. KWEON, "A NOVEL THREE-DIMENSIONAL MAGNETIC PARTICLE IMAGING SYSTEM BASED ON THE FREQUENCY MIXING FOR THE POINT-OF-CARE DIAGNOSTICS," Sci. Rep., vol. 10, no. 1, 11833, Jul. 2020.

[4] J. C. JEONG, J. KIM, B. SEO, H. J. KRAUSE, AND H. HONG, "MAGNETIC PARTICLE IMAGING USING MOVING HALBACH CUBOID AND FREQUENCY MIXING MAGNETIC DETECTION", RESEARCH SQUARE, Dec 2020.

[5] LARS GJESTEBY, Y. XI, M. K. KALRA, Q. YANG, AND G. WANG, "HYBRID IMAGING SYSTEM FOR SIMULTANEOUS SPIRAL MR AND X-RAY (MRX) SCANS", IEEE ACCESS., VOL. 5, PP. 1050-1061, 2017

[6] VOGEL, P., MARKERT, J., RÜCKERT, M.A. ET AL., "MAGNETIC PARTICLE IMAGING MEETS COMPUTED TOMOGRAPHY: FIRST SIMULTANEOUS IMAGING", SCI REP 9, 12627, 2019.