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MPI system using the mechanically movement of a three-dimensionally arranged permanent magnets

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Abstract

We present a magnetic particle imaging (MPI) system arranging permanent magnets three dimensionally to form a Field Free Line (FFL) and then moving the FFL mechanically. FFL was formed in the center of the magnet structure and the FFL was moved in the sample volume translationally and rotationally. Securing the signal due to the nonlinear magnetic properties of Nano Magnetic Particle (NMP) was obtained by applying electromagnetic waves with two different frequencies. The performance of the system was tested using the silicone tube with a spiral structure filled with NMP, and it was shown that 3D images can be obtained using the system proposed.

I. Introduction

In relation to the instrumentation of Magnetic Particle Imaging (MPI), fabrication can be largely divided into two parts. The first concerns how to obtain the signal from the magnetic nanoparticles. The second is to find out where the signal is generated. The signal of MPI developed so far is based on the nonlinear magnetic properties of Superparamagnetic Iron Oxide (SPIO) particles [1, 2]. In all MPIs proposed so far, information on the location and concentration of SPIOs in space is obtained using a Field Free Line (FFL) or a Field Free Point (FFP). FFL or FFP refers to the region or to the point where the field strength becomes zero. In this region, the SPIOs respond to the sinusoidal excitation field. In contrast, in the remaining region where SPIOs are saturated due to the strong magnetic field, they do not respond to the sinusoidal field. In addition, whether the created FFL or FFP is effectively moved in the sample volume is another important factor. As for the method of generating and moving FFL or FFP, various methods have been proposed and used by different research teams. In a paper published by Gleich and Weizenecker in 2005 [3], For FFP generation, a solenoid coil was mainly used. And, in the study, two types of movement of the FFP were presented and discussed: an electromagnetic method and a mechanical movement using a robot. Another method is to use a combination of solenoid coils and permanent magnets. This method has been proposed by Goodwill et al. The selection field is made by a permanent magnet and the drive field by a solenoid coil [4]. As a method of using a permanent magnet, there are a method of using a large magnet and a method of forming an FFL or FFP by arranging relatively small magnets three-dimensionally [5-7]. In the case of large magnets, there is an advantage that the amount of calculation required when designing MPI is very small and can be made in an intuitive form. However, in order to increase the size, it is very difficult to obtain a large magnet with a constant magnetic force on the surface, and safety issues arise during manufacture. In a previous study, we presented a study on a device that can image the spatial distribution of SPIOs by permanent

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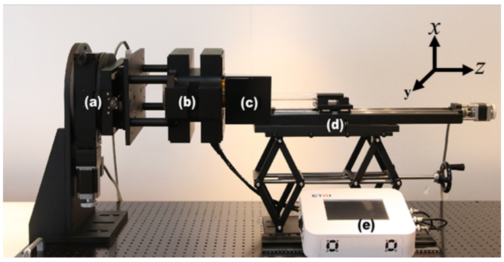

Figure 1: Photo of the MPI system used. (a) stage for the translational and rotational movement (b)the permanent magnet structure (c)the measurement coil system (d)linear stage for z-axis movement (e)control box

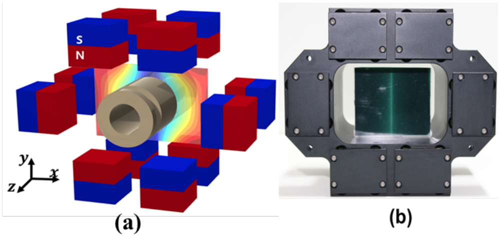

Figure 2: An illustration showing the magnet array and measurement coil (a) and a photo of the fabricated structure and generation of FFL (b)

magnets and solenoid coil [6]. In this research, instead of using large plate magnets, the MPI system using the FFL generation system in which relatively small magnets are arranged three-dimensionally was fabricated. FFL generating system proposed in this paper can be fabricated by arranging magnets only vertically or horizontally. The adoption of the FFL generation system of this structure made it easier to manufacture and replace the magnets. As a result, by using this FFL generating system and mechanical movement, it was possible to manufacture and operate the MPI system, which can be another alternative in addition to existing ones.

II. Material and methods

Fig. 1 shows the MPI system used in this study. For the integrated control of the system, the MFC-based software developed was used. The S/W is registered with the following number with the Korean Copyright Association (C-2019-027032). Fig. 1 (a) is the mechanical stages (Namil Optical Instruments Co. Incheon, Korea) performing translational and rotational movements simultaneously. The linear stage moves the specimen into the measurement coil constantly in the Z-axis.

The magnet used is NdFeB (N35 grade), and the size is 50.0 × 50.0 × 10.0 mm. Two magnets stacked together are used as one magnet. The magnetic field gradient strength of the magnet stack is 3.66 T/m for X & Z axis.

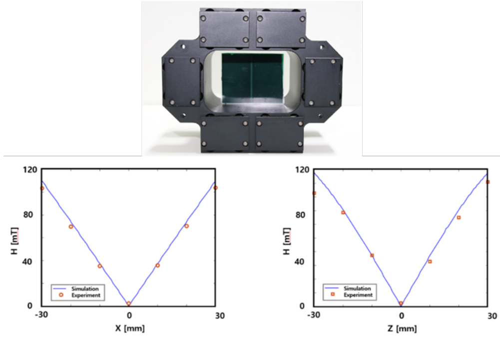

Figure 3: Magnetic strength of inside of PMS

The measurement coils are composed of three coils each, two excitation coils and one detection coil consisting of two oppositely wound compartments. The excitation coils are wound clockwise (if seen from the top) in both measurement heads. They consist of a set of inner and outer coil generating a high and a low frequency magnetic field, respectively [6]. The detection coils are located at the innermost part, and wound clockwise in one half and counter-clockwise in the other half of each measurement head. For the 3D image acquisition experiment, a silicone tube (inner diameter 1.0 mm, outer diameter 2.0 mm) filled with SPIOs on an acryl rod at intervals of about 10.0 mm was prepared. The generated volume data was imaged using a volumeviewer function of Matlab® (Mathworks, Natick, MA, USA). The parameters of the rendering editor were set to the maximum intensity projection, the alpha power was set to Mri-Mpi, and the color power was set to hot.

III. Results and discussion

To fabricate the permanent magnet structure (PMS), optimal magnet placement was conducted using electromagnetic field simulation software (Faraday V10.2 Integrated Engineering Software, MB, Canada) in advance. Fig. 2 (b) shows that a FFL (Field Free Line) is generated in the center of the structure and the magnetic field gradient within 1.0 mm from the center of the FFL is +/- 10 mT. All of the spherical objects surrounding the magnet were made of aluminum, and then anodizing treatment was performed. In this study, by using the PMS instead of the plate-shaped magnet used in the previous paper we published [6], the weight could be reduced to about 1/3 (33Kg to 10 kg). Nevertheless, the magnetic strength could be increased from 2.5mT on average to 3.6mT comparing with the previous one. Fig.3 shows the comparison of the simulated and actual measured values for the magnetic field strength in the PMS.

The strength of the magnetic field is 3.6 T/m and the aperture size of the PMS is 140.0 × 90.0 mm. Based on this result, the width of the area around the FFL in which

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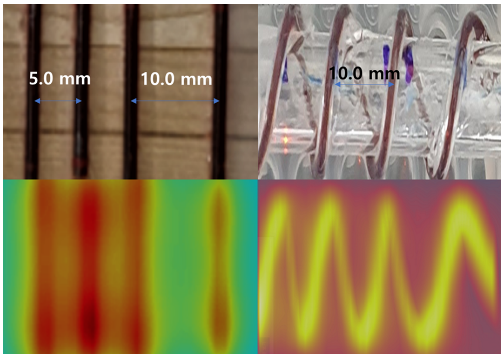

Figure 4: Imaging of capillary tubes placed at intervals of 5.0 mm and 10.0 mm (left) and Silicone tube filled with SPIOs wound on an acryl rod

the absolute magnetic field is less than 10 mT is 1.0 mm. Therefore, the limit of spatial resolution is calculated to be about 1.0 mm. Since only rotation can obtain information on angle change, which is one of two sets of information necessary (degree and moving distance), an additional drive coil is installed in most cases. In addition, the drive coil installation requires a separate design for the coil and ancillary equipment for power supply and cooling. Therefore, in the method proposed in this study, the function of the drive coil was replaced with a mechanical stage that moves in transnationally. The difference from the equipment we presented previously was that a coil was used on one side to provide an aperture for inserting the sample, while the two overlapping PMS were used to make even this unnecessary.

The left picture of Fig. 4 shows the imaging results of samples filled with SPIO solution placed side by side with a width of 5.0 to 10.0 mm. This result shows that at least 5.0 mm can be separated and imaged using the currently developed MPI system. The figure on the right is the test result of whether it is possible to image a sample of a spiral structure, which is a 3D sample. The results of this experiment show that it is possible to fully image the distribution of three-dimensional samples.

IV. Conclusions

Through this research, we have developed an FFL generation system that arranges permanent magnets three-dimensionally but only vertically and horizontally. And, the MPI image was obtained by mechanically moving the developed permanent magnet structure. This approach made the manufacture of the equipment relatively simple, and the high current power supply and cooling system required by commercially available MPI equipment. Therefore, this study showed a clear possibility for the MPI based on the permanent magnets and mechanical movement.

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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] A.V. Samrot, C.S. Sahithya, J. Selvarani A, S.K. Purayil, P. Ponnaiah, A review on synthesis, characterization and potential biological applications of superparamagnetic iron oxide nanoparticles, Current Research in Green and Sustainable Chemistry 4 (2021) 100042.

[2] S.A. Shah, D.B. Reeves, R.M. Ferguson, J.B. Weaver, K.M. Krishnan, Mixed Brownian alignment and Néel rotations in superparamagnetic iron oxide nanoparticle suspensions driven by an ac field, Physical Review B 92(9) (2015) 094438.

[3] B. Gleich, J. Weizenecker, Tomographic imaging using the nonlinear response of magnetic particles, Nature 435(7046) (2005) 1214-1217.

[4] P.W. Goodwill, J.J. Konkle, B. Zheng, E.U. Saritas, S.M. Conolly, Projection x-space magnetic particle imaging, IEEE Trans Med Imaging 31(5) (2012) 1076-1085.

[5] P. Vogel, J. Markert, M.A. Rückert, S. Herz, B. Keßler, K. Dremel, D. Althoff, M. Weber, T.M. Buzug, T.A. Bley, W.H. Kullmann, R. Hanke, S. Zabler, V.C. Behr, Magnetic Particle Imaging meets Computed Tomography: first simultaneous imaging, Scientific Reports 9(1) (2019) 12627.

[6] 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, I.S. Kweon, A novel three-dimensional magnetic particle imaging system based on the frequency mixing for the point-of-care diagnostics, Scientific Reports 10(1) (2020) 11833.

[7] Matthias Weber, Anselm von Gladiss, Ksenija Gräfe, Patrick Vogel, Volker C. Behr, Thorsten M. Buzug Novel Field Geometry Using Two Halbach Cylinders for FFL-MPI, International Journal on Magnetic Particle Imaging 4(2) (2018) 5.

