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2D Image using 2nd Harmonic Response Improved by Application of System Function

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Abstract

In general, a third harmonic component of a magnetic response is used for magnetic nanoparticle imaging (MPI). However, when applying a high AC modulated magnetic field to magnetic nano-particles (MNPs), the size of the apparatus become large, and a high power source is required. Thus, we have been investigating an imaging method using a second harmonic with a signal intensity higher than that of the third harmonic. Since the signal of the second harmonic component has positive and negative peaks, signal processing is necessary to represent the position of the MNPs. Therefore, we investigated a method to quantitatively represent the position and the content of magnetic nanoparticles not using differentiation but applying a system function. Results showed that the identification of the amount and the position of MNPs was possible.

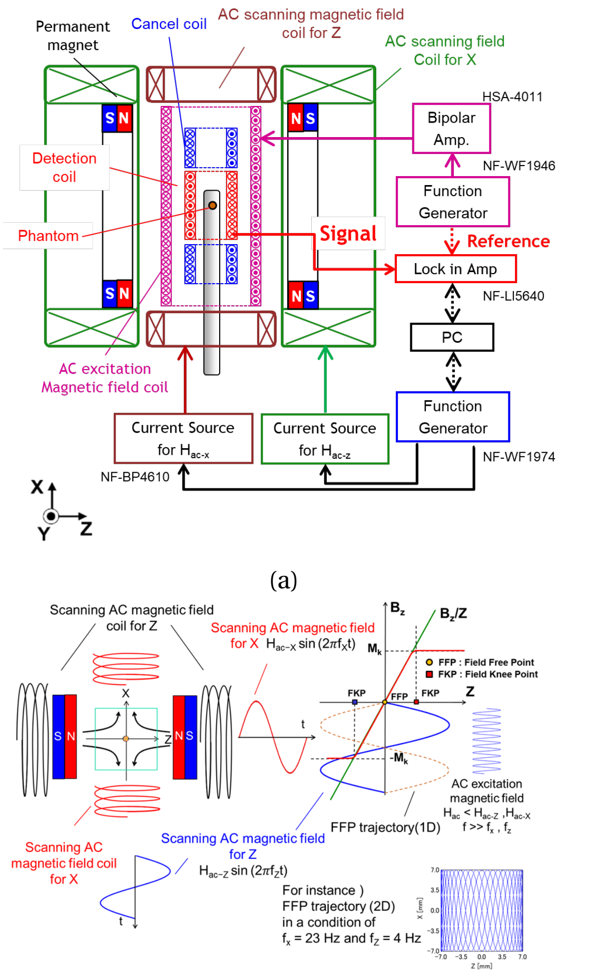
I Introduction

Magnetic nanoparticle imaging (MPI) is a method to detect superparamagnetic iron oxide nanoparticles (MNPs). It is based on detecting the non-linear magnetization response M of MNPs [1]. The response M contains not only the fundamental excitation frequency ω_0, but also its harmonics, by applying an ac excitation magnetic field, $H_{ac} = H_0 \sin(\omega_0 t)$). In the MPI, mostly the odd harmonics of the response M are detected [2]. We have proposed and constructed a MPI scanner besed on the detection of the second harmonic of the response [3]. The advantage of using the second harmonic response is that the response can be measured even with a small amplitude of H_{ac} [4]. However, the signal has both positive and negative peaks, and as a result it was necessary to differentiate the signal to identify the MNPs position. In this paper, we investigated a method to quantitatively represent the position and the amount of magnetic nanoparticles by applying a system function rather than differentiation.

II Experimental

II.I System

A 2D MPI system consisting of a solenoid type detection coil, a compensation coil, two set of scanning AC magnetic field coils in the X and Z directions, an excitation AC magnetic field coil and a NdFeB permanent magnets for a gradient magnetic field was built, as shown in Fig.1 [5]. For the characterization, the detection coil and compensation coil were connected electrically and placed under a scanning magnetic field of 44.5 $mT_{p\text{-}p}/\mu_0$ @ 23 Hz in X-direction and a magnetic field of 17.6 $mT_{p\text{-}p}/\mu_0$ @ 4 Hz in Z-direction. AC modulation field of 3.3 $mT_{p\text{-}p}/\mu_0$ @13.5 kHz was applied. A MNPs phantom (ϕ3 x L4 mm) was prepared and placed in the center of the imaging region. Resovist (γFe_2O_3, 27.8mg/ml), which are commercially available MNPs, was used as a MNPs. Second harmonic responses were detected by a lock-in amplifier and recorded by an A/D converter.



(a)

(b)

Figure 1: Experimental setup of magnetic particle imaging. (a) hardware; (b) principle of scanning.

II.II System function

The system function was obtained in the imaging area of 13 x 13 points. The position of the phantom was moved in the center of the imaging 5 x 5 pixels and the magnetization response taken for each pixel. The response was obtained using a $\phi 3$ x L4 mm phantom. The magnetization response measured at each pixel was stored into one data block (13 x 13 points x 25 pixels) as system functions after applying gritting and smoothing processes.

III Results and Discussions

III.I Dependence of Iron Content

In order to reconstruct an image by applying the system functions, the dependence of the signal amplitude and the separation of the two peaks on the iron content of the phantom of 278 μg (10 μl) was investigated, as shown in Fig. 2. Comparing the separation of the peaks and the peak amplitude for each phantom with different iron content, it was found that the signal amplitude was proportional to the iron content, and the peak separation was almost constant for all the iron contents. Even if the iron content changed, the spread of the signal did not.

Therefore, if the shape of the phantom was similar to that of the phantom when the system function was obtained, it is possible to specify the amount and the position of the unknown phantom.

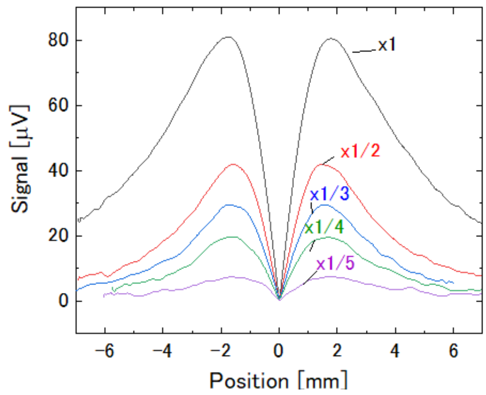


Figure 2: 1D image of phantom with different iron content.

III.II Application of System Function

Using a $\phi 3$ x L4 mm phantom placed at the center, the second harmonic responses were taken, as shown in Fig. 3 (a). Then the system function and the measured data were compared. The standard deviation of the ratio of the amplitude for each pixel was calculated, as shown in Fig. 3 (b), and the pixel number with the smallest standard deviation was selected. It was found that the system function when the phantom was placed at pixel #13 (X: 0, Z: 0) matched with the measured data. The averaged value of the ratio was used as a correlation factor to determine the iron content. Finally, the 2D image was reconstructed using the system function and the correlation factor. Figure 4 shows the reconstructed image of the phantom. The position and content of the phantom could be precisely imaged. In the experiment, the system function of the restricted 25 (5 x 5) pixels in the center of imaging area was used. In the future, we hope to realize the imaging of multiple objects in a wider range.

IV Conclusions

The method for quantitative representation of the position and amount of a phantom with magnetic nanoparticles that takes second harmonic responses was investigated by applying a system function rather than differentiation. The results of the experiment showed that the amplitude was proportional to the amount of iron and

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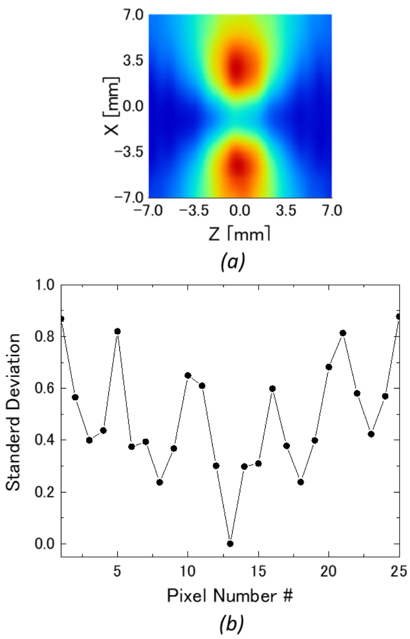

Figure 3: (a) Image of 2nd harmonic response. (b) Standard deviation of the ratio of the amplitude for each pixel.

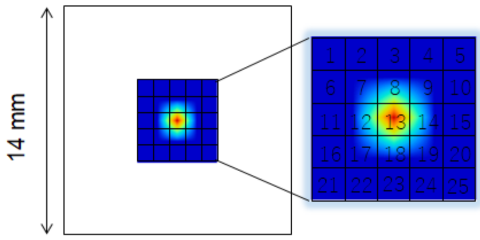

Figure 4: Reconstructed contour image of the phantom.

that the peak separation was constant. Taking account of these results, we demonstrated that the position and the iron content of a single phantom could be imaged using the second harmonic responses by applying the system function. In the future, we hope to realize the imaging of multiple objects in a wider range.

References

[1] B. Gleich and J. Weizenecker. Tomographic imaging using the nonlinear response of magnetic particles. Nature, 435(7046):1217-1217, 2005. doi: 10.1038/nature03808.

[2] T. Knopp and T. M. Buzug. Magnetic Particle Imaging: An Introduction to Imaging Principles and Scanner Instrumentation. Springer, Berlin/Heidelberg, 2012. doi: 10.1007/978-3-642-04199-0.

[3] S. Tanaka, T. Matsuo, K. Kobayashi, M. Kabasawa, T. Ohtani and S. Ariyoshi. Measurement of Magnetic Nanoparticles by Small HTS SQUID Array. IEEE Trans. Appl. Supercond., 2792405_1-6, 2018. doi: 10.1109/TASC.2018. 2792405.

[4] S. Tanaka, H. Murata, T. Oishi, Y. Hatsukade, Y. Zhang, H. Horng, S. Liao and H. Yang, "Imaging of Magnetic Nanoparticles using a Second Harmonic of Magnetization with DC Bias Field", IEEE Transactions on Magnetics, 51, 6502504, 2015.

[5] S. Tanaka, T. Oishi, T. Suzuki, T. Ohtani and S. Ariyoshi. Imaging of Magnetic Nanoparticles using second harmonic signals. IEEE Trans. on Magnetics, 55, 1-4, 2015. doi: 10.1109/TMAG.2015.2445411.

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