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Fundamental imaging performance of magnetic particle imaging system using high-Tc superconducting coils

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Abstract

In this work, the fundamental imaging performance of the developed high temperature superconductor (HTS) MPI system with 120 mm bore diameter was investigated. The full width at half maximum, which is related to the spatial resolution of the image, was 30 mm under the gradient field of 0.34 T/m. Note that the gradient field can be easily increased by increasing the number of turns of the HTS selection field coils since the power consumption and the mass of the HTS coils are very low. The reasonable limit of detection of 48 µg(Fe) was also obtained. Since the power consumption and the mass of MPI scanner can be dramatically reduced by using HTS tape compared with those made of Cu wire, a HTS MPI scanner is one of the promising candidates for the realization of human-body-sized MPI scanner.

I. Introduction

Magnetic particle imaging (MPI) is a new modality for the imaging of the spatial distribution of magnetic nanoparticles (MNPs) [1]. To extend the application of MPI to clinical applications, large scale (head-sized) MPI scanners have been intensively developed recently [2]-[10]. One of the challenges to overcome for large scale MPI scanner is to develop a low power consumption and lightweight selection field coil. One of the solutions is to utilize superconductors as a selection field coil, and Le et al. developed a brain-sized MPI system using low temperature superconductor (LTS) [6] and Yoshida et al. developed a MPI scanner with 12 cm bore diameter using high temperature superconductor (HTS) tape [10]. The advantage of using HTS compared with LTS, for which expensive liquid hydrogen is required, is that liquid nitrogen (LN) can be used as a refrigerant.

In this work, the fundamental imaging performance of the MPI system using HTS coil as a selection field coil developed in [10] was investigated.

II. Material and method

II.I. HTS MPI

Figure 1 shows the schematic and photo of the developed MPI system, which is composed of a drive field coil made of Cu Litz-wire, the selection field coils made of yttrium barium copper oxide HTS tape (SCS4050-APi, Super Power), and the detection coil. Detailed specifications of the coils are found in [10].

II.II. Imaging Performance Experiments

150 ml of Resovist® (PDRadiopharma Inc.) sample, which contains 4.18 mg(Fe), was used as a MNPs sam-

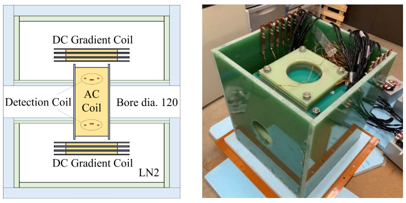

Figure 1: Schematic and photo of a developed MPI scanner.

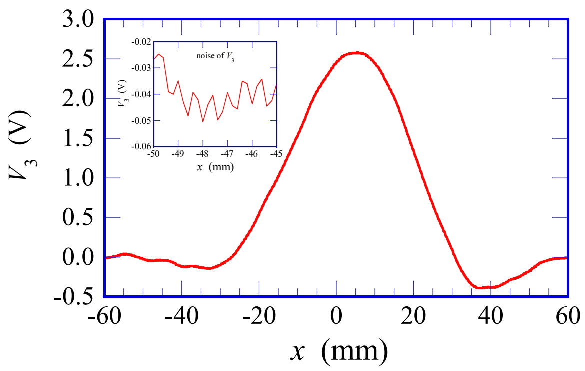

Figure 2: The third harmonic magnetization signal V_3 when the MNPs sample is mechanically scanned in x-direction.

ple. Since a shift coil is not installed in the HTS MPI system, the MNPs sample was mechanically scanned in x-direction, and the third harmonic magnetization signal, V_3, from the MNPs sample was recorded to investigate the full width at half maximum (FWHM) and the limit of detection (LOD). Note that V_3 was extracted from the voltage across the detection coil using a Lock-in amplifier (NF Corporation, LI5640) and its gain was set to 10000. Here, the FWHM is defined from V_3 when the MNPs sample was scanned in x-direction and the LOD is defined as the amount of iron content when the signal to noise ratio becomes 3. The amplitude and the frequency of the AC excitation field were set to 12 mT and 15 kHz, respectively. The gradient field, which is generated by the HTS selection field coils, was set to 0.34 T/m in x-direction (0.63 T/m in z-direction).

III. Results and discussion

Figure 1 shows the third harmonic magnetization when the MNPS sample was mechanically scanned. It was found that the FWHM is approximately 30 mm under the above mentioned field conditions. Note that the gradient field was 0.34 T/m in x-direction, however, the total power consumption of the HTS selection field coil was only 408 mW and the mass of the HTS selection field coil is only 3.6 kg, which indicates that higher gradient field can be easily obtained by increasing the number of turns of the HTS selection field coil. Regarding the signal strength, the third harmonic magnetization signal from 4.18 mg(Fe) MNPs sample was 2.6 V and the noise voltage was 10 mV. Therefore, the LOD is estimated as 48 mg(Fe). The noise voltage will be theoretically reduced by a factor 1 order by adjusting the power circuit to suppress the noise voltage caused by the power amplifier for AC drive field coil.

IV. Conclusions

In this work, the fundamental imaging performance of the HTS MPI system with 120 mm bore diameter was investigated. The reasonable FWHM which is related to the spatial resolution of the image and the LOD could be obtained. Since the power consumption and the mass of MPI scanner can be dramatically reduced by using HTS tape compared with those made of Cu wire, a HTS MPI scanner is one of the promising candidates for the realization of human-body-sized MPI scanner.

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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.

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