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Depth detection capability of handheld magnetic particle imaging under multiple excitation waveforms

Bo Zhang[a,b] · Haoran Zhang[a,b] · Hui Hui[c] · Jie Tian[a,b,*]

[a]School of Engineering Medicine & School of Biological Science and Medical Engineering, Beihang University, Beijing, 100191, People's Republic of China
[b]Key Laboratory of Big Data-Based Precision Medicine (Beihang University), Ministry of Industry and Information Technology of the People's Republic of China, Beijing, 100191, People's Republic of China
[c]CAS Key Laboratory of Molecular Imaging, Institute of Automation, Chinese Academy of Sciences, Beijing, China
[*]Corresponding author, email: jie.tian@ia.ac.cn

Abstract

Handheld magnetic particle imaging (Hand-held MPI) has broad application prospects in clinical medicine due to its unique portability. In the handheld MPI system, the excitation magnetic field will directly act on the magnetic particles and obtain the corresponding magnetization signal through the receiving coil. Therefore, different excitation waveforms will have a direct impact on the signal. In order to explore the performance of different excitation waveforms on handheld MPI devices, this study uses three excitation waveforms at both 0 mm and 10 mm detection depths. The results show that the trapezoidal wave is better than the triangular wave, and the signal difference corresponding to different excitation waveforms can be seen when the detection depth changes. This research has certain significance to promote the application of handheld MPI.

I. Introduction

Magnetic particle imaging (MPI) is a new biomedical imaging mode [1]. Compared with the existing imaging methods, MPI has the advantages of high sensitivity, deeper imaging depth and harmless to human body [2]. At present, MPI is developing rapidly towards multiple clinical applications, and has broad application prospects in many medical fields such as angiography, cell tracking, oncology [3-5].

Before the full body size MPI device has been successfully developed, handheld MPI is expected to be the first to be used in clinical applications due to its unique portability. At present, many researchers have made great efforts in the field of handheld MPI. Mason et al. proposed the concept of edge analysis in breast conserving surgery using handheld MPI and closed cell MPI [6]. The concept of portable unilateral MPI proposed by Choi et al. can realize imaging in one-dimensional depth direction [7]. The existing hand-held MPI uses the sine wave as the excitation mode, uses the receiving coil to receive the nonlinear magnetization response of magnetic particles to obtain signals, and can achieve 1-dimensional imaging through special structural design. However, when the hand-held MPI is excited by other waveforms other than the sine wave, the response characteristics of the received signal are still unknown. At the same time, the performance of these waveforms in different detection

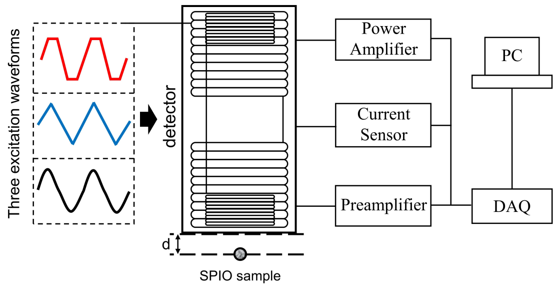

Figure 1: Schematic diagram of multi excitation handheld MPI system

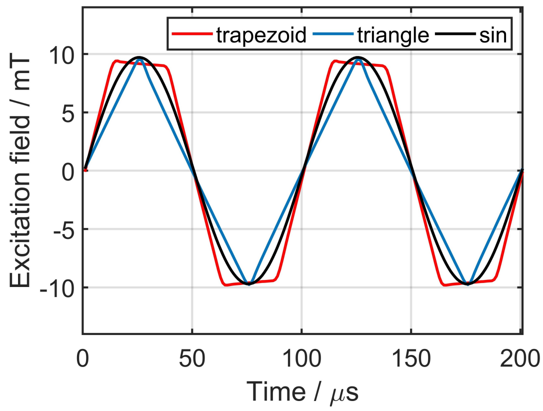

Figure 2: Three types of excitation waveforms used in this research

depths has certain research significance.

Here, we show the signal characteristics of magnetic particles at different detection depths when different excitation waveforms are applied to hand-held MPI. This research first designed and built a set of hand-held MPI equipment, which is tested in a unilateral form. Trapezoidal wave, triangle wave and sine wave are selected as excitation wave respectively, and experiments are carried out at two detection depths of 0 mm and 10 mm. The amplitude of harmonic signal in frequency domain is compared.

II. Material and methods

II.I. Construction of handheld MPI system

In order to study the detection capability of handheld MPI at different depths under different excitation waveforms, we designed and built a handheld MPI system. The hand-held MPI device detects in a unilateral form and can change the excitation waveform and frequency. The overall schematic diagram of the system is shown in Figure 1. The diameter of the equipment is 55 mm, which is convenient for single handed inspection. The excitation magnetic field is generated by solenoid coil. The excitation coil is wound by Litz wire with a diameter of 2 mm The receiving coil is on the single edge of the excitation coil. It is wound with 1 mm Litz wire. Both the excitation coil and the receiving coil are wound in the same two parts. The upper part is used to detect the magnetization response signal of MNPs, and the lower part is used to offset and eliminate irrelevant signals other than particles (direct feed through signal and background noise).

II.II. Experimental method

We used the stock solution of Perimag (Micromod Partikelt technology GmbH, Germany) as the experimental sample. The particle concentration of this solution is 25 mg/mL, and the iron particle concentration is 8 mg/mL. 20 µL liquid is obtained for each experiment and put into the plastic sample tube for testing.

In this study, three different waveforms are applied to the excitation coil, namely trapezoidal wave, triangular wave and widely used sine wave. The excitation frequency of all experiments is 10 kHz, and the magnetic field intensity is set as 10 mT. The magnetic field changes generated by the three excitation waveforms are shown in Figure 2. Under the conditions of different excitation waveforms, two positions, 0 mm and 10 mm from the test surface of the hand-held MPI device, were tested respectively. The purpose is to compare the different depth detection effects of the handheld MPI device under different excitation waveforms. The received signal is amplified by 20 times and a 300 k low-pass filter. Each test lasts for 100 ms. Before particle signal detection, empty measurement shall be conducted and background noise signal shall be subtracted. Each experiment shall be conducted 5 times and the average value shall be taken as the final data.

III. Results and discussion

Through the experiment, we obtained the time domain signals of magnetic particles under different excitation waveforms. The experiment is divided into two positions: 0 mm and 10 mm from the hand-held MPI device. The time-domain signal is converted into frequency-domain information through Fourier transform for analysis. As shown in Figure 3, we have extracted the amplitude of the harmonic signal of the 1st to 10th order in the frequency domain signal, and compared the signals at two distances.

First, the signal performance under each excitation waveform is analyzed separately: under the trapezoidal wave excitation, except for the 10th harmonic, the harmonic signal amplitude measured at 0 mm of the particle

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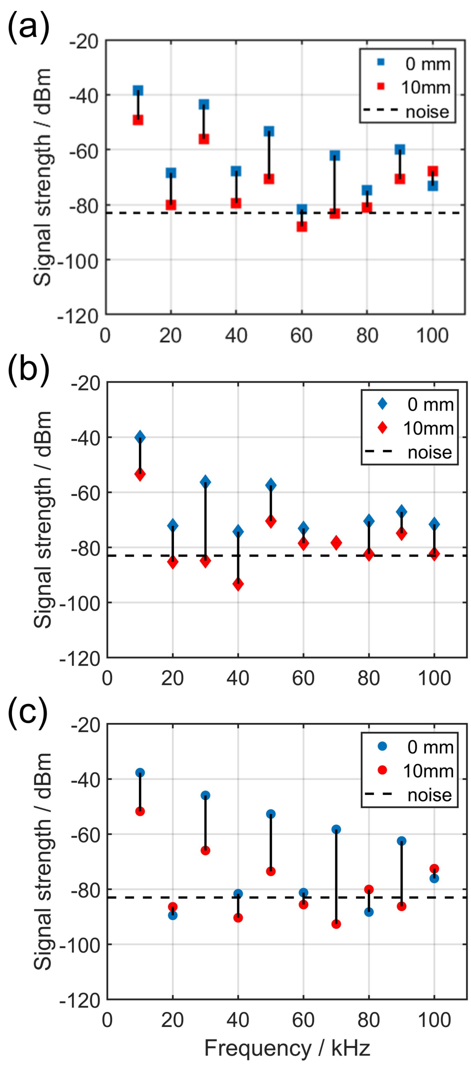

Figure 3: Harmonic signal amplitude when particles are 0mm and 10mm away from equipment surface. (1) Trapezoidal wave excitation. (2) Triangular wave excitation. (3) Sine wave excitation.

is greater than the corresponding value of 10 mm. The odd harmonic signal is obvious, and the difference of signal amplitude at different distances increases gradually. It is worth noting that the amplitude of the 9th harmonic signal is higher than that of the 7th harmonic. Even harmonics under trapezoidal wave excitation also have a certain degree of signal amplitude, and the difference between the second harmonic and the third harmonic is not significant. Under the condition of triangular wave excitation, the overall signal amplitude is low except for the fundamental frequency. The amplitude difference of the third harmonic at different distances is obvious. Under the sine wave excitation, the odd harmonic signal has a very smooth downward trend, and the signal amplitude difference at different distances is also expanding, and there is basically no even harmonic signal.

Transverse comparison of the signal strength of three excitation waveforms at two detection distances: trapezoidal wave performs best, with multiple harmonics that can be used to characterize the magnetic particle signal, and different detection depths also have obvious differences. The triangle wave signal is poor, but the amplitude of the third harmonic signal seems to be more sensitive to distance. Although the sine wave has only odd harmonic signal, the overall change trend is stable, and the influence of different detection depths on the signal strength is also obvious. The root causes of the above signal differences need to be further studied.

IV. Conclusions

We have designed a handheld MPI that can generate multiple excitation waveforms. The device detects in a unilateral form. Based on this device, we have explored the signal characteristics of handheld MPI at different detection depths under multiple excitation waveforms. The results show that the particle signals detected by the three excitation waveforms have obvious differences under the excitation frequency of 10 kHz. Under trapezoidal wave excitation, the signal strength is generally good, the sine wave has a relatively stable odd harmonic signal, and the triangular wave has a poor overall performance, but the third harmonic is more sensitive to depth. In general, due to the advantages of trapezoidal wave, better harmonic signals can be obtained by replacing the excitation waveform of hand-held MPI with trapezoidal wave according to specific requirements. On the other hand, the different harmonic components of different excitation waveforms have obvious differences in different detection depths. Using this feature will hopefully enable handheld MPI to achieve a certain degree of one-dimensional imaging in the depth direction without using gradient field coding.

It should be noted that since this study requires the application of non-sinusoidal waveform on the excitation coil, no resonance circuit, band-pass circuit and band stop circuit matching the excitation frequency are added to the circuit, and the direct feed through signal can only be offset by the reverse wound receiving coil. This problem needs to be further optimized and solved by circuit and other hardware systems. On the other hand, this study only detected two depths of 0 mm and 10 mm at the frequency of 10 kHz, and more detailed detection depths at different excitation frequencies need to be further studied.

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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.

References

[1] B. Gleich, et al. *Tomographic imaging using the nonlinear response of magnetic particles*, Nature, vol. 435, pp. 1214–1217, Jun. 2005.

[2] T. Knopp, et al. *Magnetic particle imaging: From proof of principle to preclinical applications*, Phys. Med. Biol., vol. 62, pp. 124–178, Jun. 2017

[3] Franke, J. et al., *Hybrid MPI-MRI system for dual-modal in situ cardiovascular assessments of real-time 3D blood flow quantification-A pre-clinical in vivo feasibility investigation.*, IEEE Trans. Med. Imag., vol. 39, pp. 4335-4345, Aug. 2020.

[4] Zheng B. et al. Mason, et al, *Magnetic Particle Imaging tracks the long-term fate of in vivo neural cell implants with high image contrast.*, Sci. Rep, vol. 5, pp. 14055, Sep. 2015.

[5] Yu, E. Y. e, et al, *Magnetic particle imaging: A novel in vivo imaging platform for cancer detection*, Nano Lett, vol. 17, pp. 1648-1654, Feb. 2017.

[6] Erica E. Mason, et al, *Concept for using magnetic particle imaging for intraoperative margin analysis in breast-conserving surgery*, Scientific Reports, vol. 11, pp. 13456, Dec. 2021.

[7] S. H. Choi, et al, *A portable single-sided magnetic particle imaging concept using amplitude modulation for breast conserving surgery*, International Journal on Magnetic Particle Imaging, vol. 8, pp. 2203024, Mar. 2022.

10.18416/ijmpi.2023.2303050