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Study on duty ratio of handheld Magnetic Particle Imaging system

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Abstract

This paper investigates the effect of duty ratio on the background signal of handheld magnetic particle imaging (MPI) system. The background signal is the most influential noise signal in MPI system. Hand-held MPI systems need to be used continuously for long periods of time, so they are susceptible to interference from background signals. By adjusting the duty ratio and single detection time used by the system, a set of parameters with minimal background signal variation is determined. During the experiment, we summarized testing procedures to determine the most appropriate duty ratio for the MPI system, which can be tried on other MPI systems.

I. Introduction

Magnetic particle imaging (MPI) is a promising tomography method [1].One of the challenges of applying this technique to the clinic is to generate a human-sized high gradient magnetic field. Cylindrical MPI devices require prohibitively high power consumption. One way to make such a practical MPI device is to use a single-sided geometry[2]. The coil size of single-side MPI systems is reduced, allowing for more accurate imaging and easy hand-holding. A small-size single-side MPI system was used to detect changes in cerebral blood volume (CBV) in rodents, and the results demonstrated the high temporal resolution of the MPI system[3]. A handheld MPI system was used to analyze incisor margins in breast conserving surgery, confirming the possibility of accurate detection by handheld MPI system[4]. Handheld and portable MPI systems are one of the current research directions.

Existing handheld MPI systems need to continuously detect the signal of magnetic nanoparticles (MNPs), which inevitably requires the study of noise and backgrond signals in the process. Signal interference in MPI systems can be divided into various types, of which the background signal is the most influential[5]. Strong background signal contributions are caused by the excitation fields generated by the MPI system[6]. In addition, the background signal will gradually increase with the use of the system time, which includes the instability of the coil and circuit. The removal of background signals is critical to imaging quality. The background signal can be subtracted during image reconstruction, but the background signal should be kept constant[7]. A common way to avoid background signal enlargement is to use the system intermittently. The duty ratio parameter is noteworthy, especially for handheld MPI devices.

In this paper, background signal changes of handheld MPI devices were studied and reduced by adjusting the duty ratio. Experiments with different duty ratio parameters were studied, and the suitable duty ratio for the system was finally determined in the experiment. An experimental procedure for determining the optimal duty ratio for MPI systems was summarized.

II. Material and methods

The signals detected by the MPI system include MNP signals and additional signals, which can be expressed as:

$$u = u_M + u_N + u_B + u_D. \qquad (1)$$

Where u is the detected signal. u_M is the signals generated by MNPs. u_N is random noise generated by the characteristics of the system. u_B is an internal or external background signal of the system. u_D is a sudden deviation or distortion of the signal relative to the original signal. The influence of u_B on system stability is the most prominent.

Background signals usually increase with the amount of time the system is powered on, so an effective way to avoid this increase is to use an MPI system intermittently. Thus, the duty cycle D is introduced, which indicates the frequency at which the system is energized. Accordingly, D is computed as follows:

$$D = \frac{t_1}{T}. \qquad (2)$$

Where t_1 is the single power-on time, and T is the interval time between starts of power-on. In theory, the smaller the value of D, the less heat energy is generated by the coil and part of the circuit, resulting in a smaller relative change in the background signal. The change in the background signal is also weak when D is constant and t_1 and T are reduced.

All experiments were performed using a homemade handheld MPI system. The overall diameter of the system is 55 mm, which can be easily used with one hand. The transmit coils are wound with 2 mm Litz wire, and the receive coil and compensation coil are wound with 1 mm Litz wire. The receive coil and compensation coil are located inside the transmit coils and aligned with both sides of the transmit coils to ensure detection depth. The structure and size of the coils of the system are shown in Figure 1.

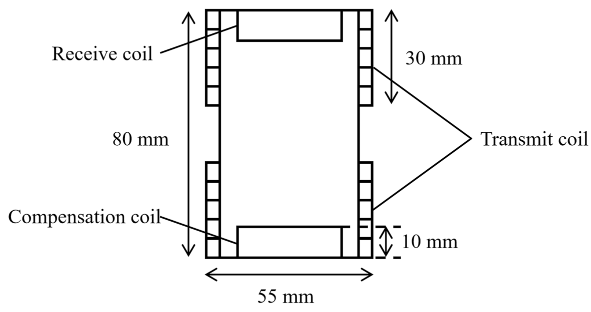

Figure 1: The structure and size of the coils of the system.

Table 1: Parameters set in six experiments.

Parameters	t_1	T	D
Parameter 1	0.05 s	1 s	5 %
Parameter 2	0.03 s	1 s	3 %
Parameter 3	0.01 s	1 s	1 %
Parameter 4	0.025 s	0.5 s	5 %
Parameter 5	0.015 s	0.5 s	3 %
Parameter 6	0.005 s	0.5 s	1 %

III. Results and discussion

We used a handheld MPI system to study the effect of the duty ratio. This system does not have an imaging function at present, and can only continuously detect MNPs signals. Under the same condition of T, experiments of different D are first carried out to verify the theory. Under the same condition of D, the experimental results of changing T ae also compared, which is used to study how to improve the detection speed. A total of six experiments with different parameters were conducted, and the parameters were shown in Table 1.

A sinusoidal current of 10 A is intermittently passed through the excitation coil. This generates a magnetic field of 6.2 mT at a distance of 10 mm from the detection coil. Each experiment continued to detect 200 periods. The detected signal is obtained by magnifying the original signal 50 times. The frequency spectrum of the detected signal in each period is analyzed to extract the amplitude of the 3rd harmonic. Since the detected signal includes random noise and background signal, the influence of random noise is removed by using the five-point average method. The 3rd harmonic signals of the six experiments after processing are shown in Figure 2. The absolute slope values of the background signals of the parameters 1-3 are 0.1264 uV/s, 0.0537 uV/s and 0.0030 uV/s, which are lower than those of the parameters 4-6, which are 0.2114 uV/s, 0.0903 uV/s and 0.0672 uV/s, respectively. This indicates that the background signals of the three parameters on the left in Figure 2 are more stable.

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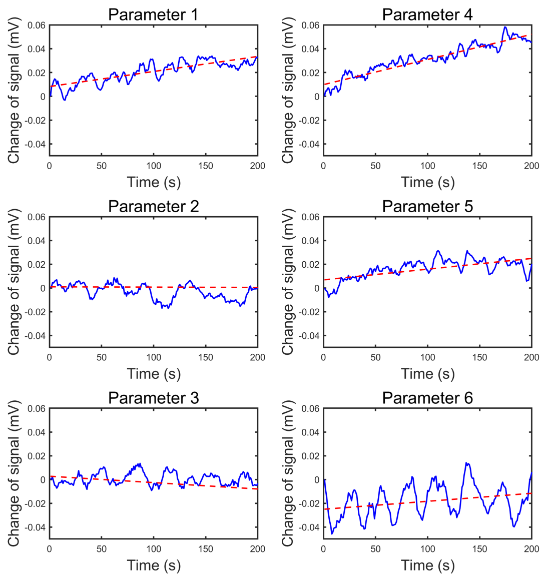

Figure 2: The background signal changes in six experiments with different parameters. The blue curves are the detection data, and the red lines are the fitting curves.

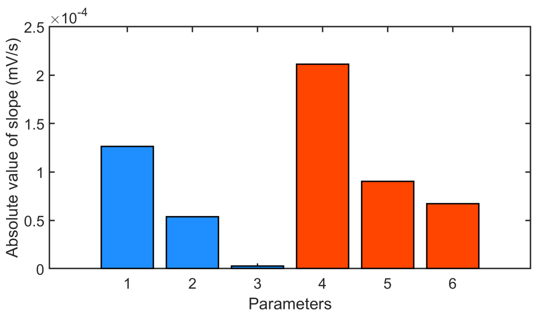

Figure 3: Slope comparison of background signal changes with six different parameters.

The changing slopes of the signals with the six parameters are calculated, and the absolute values of the slopes are shown in Figure 3. By separately analyzing the first three groups and the last three groups, it can be concluded that when T is the same, the change speed of the background signal decreases with the decrease of D. This result is consistent with the theory. Through the experimental results of parameters 1 and 4, 2 and 5, and 3 and 6, it is clear that when D is fixed, the change of background signal is positively correlated with T.

The experimental results show that the influence of background signal can be reduced by adjusting duty ratio D and interval time T. A procedure for determining the optimal duty ratio parameters of MPI devices can be summarized through experiments. At the beginning of the experiment, D and T were determined as small values according to the characteristics of the system, and T should be less than 1s. The value of D is gradually increased and T is fixed until a significant change in the background signal is observed. Finally, the value of T and t_1 is increased in equal proportion until the background signal can be kept stable for a long time. At this time, the values are the most appropriate duty ratio parameters for the system.

IV. Conclusions

This paper proves the influence of duty ratio parameters on handheld MPI system through experiments, which is mainly manifested in the background signal changes. According to the experimental results, a process for determining the optimal duty ratio parameters of the MPI system is summarized, which can make the detection signal of the MPI system be more accurate.

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Author's statement

Conflict of interest: Authors state no conflict of interest.

References

[1] B. Gleich and J. Weizenecker. Tomographic imaging using the nonlinear response of magnetic particles. *Nature*, 435(7046):1214–1217, 2005.

[2] A. Tonyushkin. Single-sided field-free line generator magnet for multi-dimensional magnetic particle imaging. *IEEE Transactions on Magnetics*, 53(9):1–6, 2017.

[3] C. Z. Cooley, J. B. Mandeville, E. E. Mason, E. T. Mandeville, and L. L. Wald. Rodent cerebral blood volume (cbv) changes during hypercapnia observed using magnetic particle imaging (mpi) detection. *NeuroImage*, 178:713–720, 2018.

[4] E. E. Mason, E. Mattingly, K. Herb, M. Śliwiak, S. Franconi, C. Z. Cooley, P. J. Slanetz, and L. L. Wald. Concept for using magnetic particle imaging for intraoperative margin analysis in breast-conserving surgery. *Scientific Reports*, 11(1):1–16, 2021.

10.18416/ijmpi.2023.2303049

[5] H. Paysen, O. Kosch, J. Wells, N. Loewa, and F. Wiekhorst. Characterization of noise and background signals in a magnetic particle imaging system. *Physics in Medicine & Biology*, 65(23):235031, 2020.

[6] M. Graeser, T. Knopp, M. Grüttner, T. F. Sattel, and T. M. Buzug. Analog receive signal processing for magnetic particle imaging. *Medical physics*, 40(4):042303, 2013.

[7] K. Them, M. G. Kaul, C. Jung, M. Hofmann, T. Mummert, F. Werner, and T. Knopp. Sensitivity enhancement in magnetic particle imaging by background subtraction. *IEEE transactions on medical imaging*, 35(3):893–900, 2015.

10.18416/ijmpi.2023.2303049