学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

A Study on the Design Optimization of the Bipolar Permanent Magnet Type Low-field MRI Device
（バイポーラ永久磁石型低磁場 MRI 装置の設計最適化に関する研究）

In recent years, portable low-field Magnetic resonance imaging (MRI) devices have been developed to complement high-field superconducting MRI. Portable low-field MRI devices offer advantages such as being lightweight, movable, and providing low-cost diagnostic services compared to the commonly used high-field MRI devices. However, there are still some challenges to be addressed, particularly concerning the electromagnetic (EM) structure. Based on how the main magnetic field is generated, there are different types of low-field MRI devices. Among these, the bipolar permanent magnet type low-field MRI device is commonly used due to its advantages, such as good magnetic field homogeneity, structural compactness, and an open imaging area. However, some problems remain to be studied, especially about the EM structure including gradient coil design and permanent magnets design.

In this paper, we focus on the design optimization of the bipolar permanent magnet type low-field MRI device, the main content of the thesis is as follows:

In Chapter 1, the research background and motivations are introduced, and the contributions of this study are also summarized.

In Chapter 2, a novel method for designing gradient coils for low-field MRI devices is proposed. The proposed method considers the effect of magnetic materials, particularly anti-eddy plates, by introducing image dipole currents. In the optimal design of gradient coils, the effect of ferromagnetic materials is minimized to obtain highly linear fields. The magnetic field measurement results and phantom images reveal the validity of the proposed method.

In Chapter 3, a design method for Z-gradient coils in low-field MRI systems is proposed, focusing on enhancing anti-eddy performance. The newly introduced design procedure significantly improves the anti-eddy performance of the coils. Measurement and imaging results demonstrate that the optimal coil exhibited superior anti-eddy performance compared to conventional coils.

In Chapter 4, a multi-fidelity topology optimization method has been proposed to alleviate the local optima problem. This method simplifies the design difficulty by dividing the optimization into sub-problems at the physical level. The proposed method shows a better performance than the conventional method in the design of low-field MRI devices.

In Chapter 5, a passive shimming method is proposed for fine-tuning the static magnetic field in a low-field MRI device. Initially, we created a straightforward evaluation model for the shimming magnet by combining a FEM model with a theoretical model. Subsequently, LP was employed to swiftly design the distribution of shimming magnets. A test case validated the effectiveness of this approach, reducing non-uniformity from 10,000 ppm to 125 ppm after three iterations.

In Chapter 6, conclusions and future works are discussed.