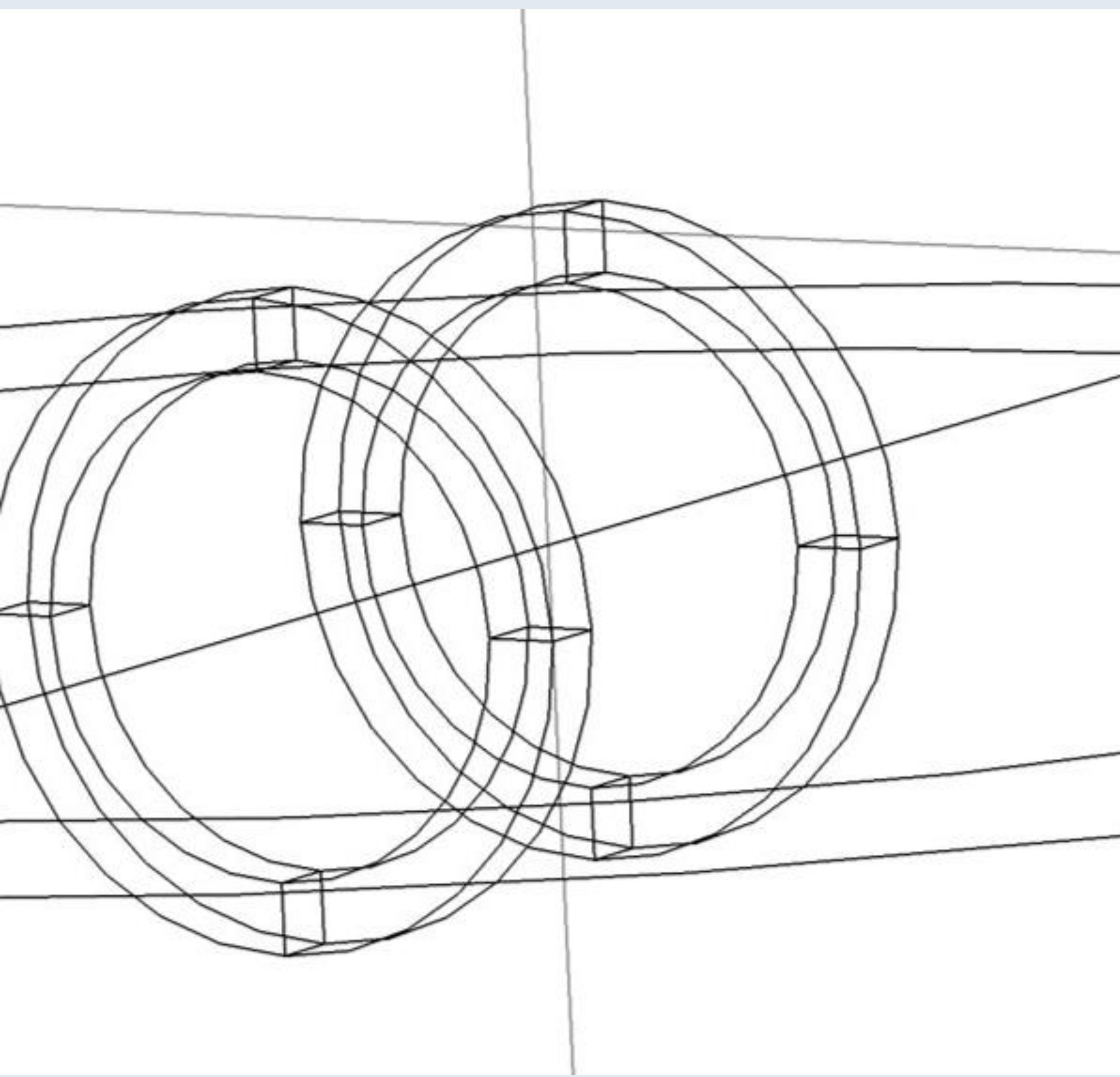




Electromagnetic Field Simulation of Helmholtz Coils for Biological Applications

A coil design is developed to produce magnetic flux densities of ~ 2 mT, comparable to those in therapeutic magnetic stimulators. The simulation environment is modeled to examine the magnetic field's distribution, uniformity, and decay with distance in free space.

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Introduction

As people age, their risk of developing bone and joint issues increases significantly. Osteoporosis is a common degenerative disease that weakens bones by increasing their brittleness and thereby increasing the risk of fractures. It is characterized by structural deterioration and a decrease in bone mineral density. About 60% inorganic minerals, mostly hydroxyapatite, 30% organic matrix, mostly type I collagen, and 10% water make up bone tissue. The organic matrix is crucial for maintaining the strength and flexibility of the bone, providing a framework for the deposition of minerals. Osteoblasts, which generate collagen and enzymes such as osteocalcin (OCN) and alkaline

phosphatase (ALP), are primarily responsible for the regeneration process. These materials are necessary for bone remodeling and mineralization. According to several studies, electromagnetic stimulation may promote osteoblast activity, thereby enhancing bone development and increasing levels of osteogenic markers [1]. This study focuses on modeling low-frequency electromagnetic fields generated by circular air-core coils at 10 Hz. COMSOL simulations and Biot-Savart calculations, are employed to assess magnetic flux density and uniformity for various coil geometries in Pulsed Electromagnetic Field (PEMF) therapy.

Methodology

A pair of identical circular coils was modeled in the Helmholtz configuration. Each coil had a radius of 0.05 m, and the separation between the coils was 0.1 m. The coil cross-section was approximated as a square region of $0.0125 \text{ m} \times 0.0125 \text{ m}$ (1.25 cm^2), representing bundled copper windings. The number of turns N varied between 50 and 200 in different simulations. The coils were excited with a sinusoidal current of 20 A at 10 Hz. Copper material was applied to the coil domain ($\sigma = 6e7 \text{ S/m}$) and $\mu_r = 1$. The surrounding air domain was modeled as a sphere with a radius of 0.325 m to avoid boundary interference. The mesh was refined near the coil and tissue region, and the study was solved in the frequency domain.

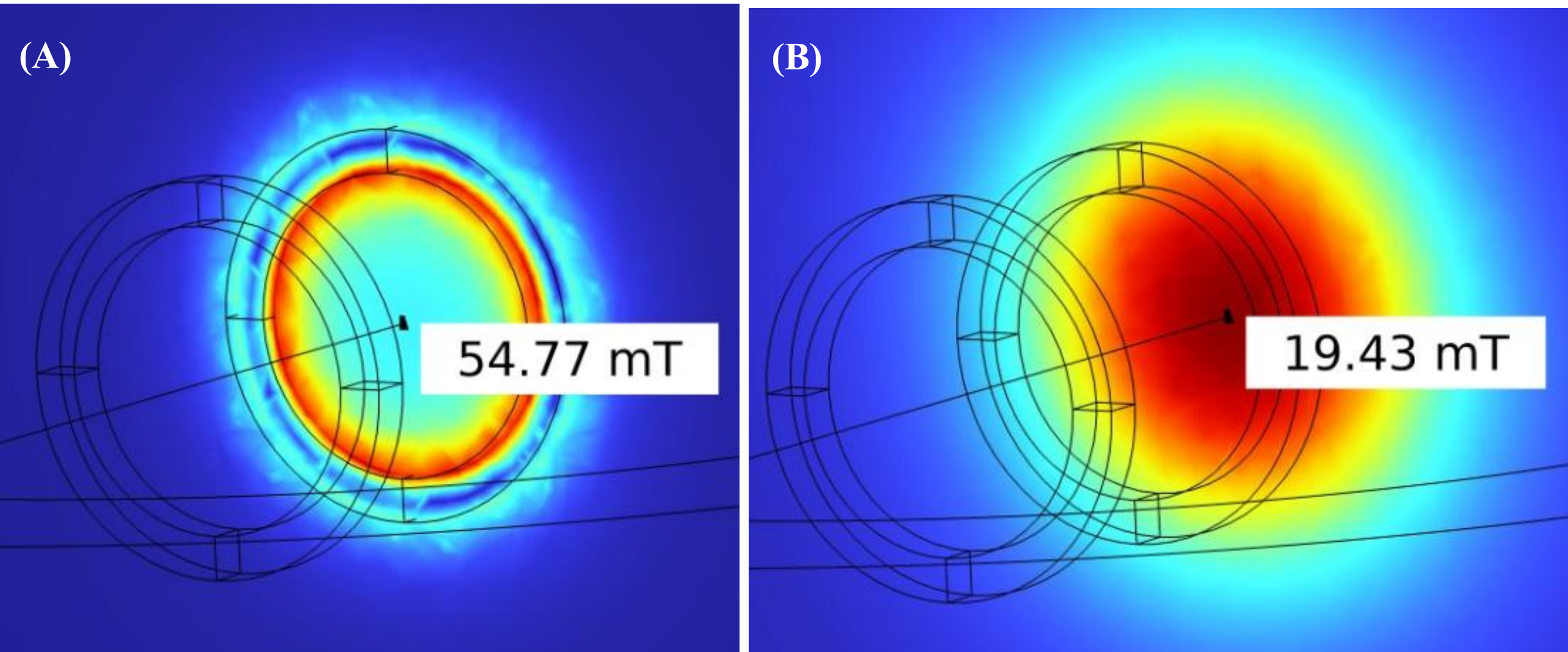


FIGURE 1. : (A-B) Magnetic field intensity (mT) in XZ plane with 200 turns at (B) at center; (C) at 0.05 m; (D) at 0.1 m.

Results

Magnetic flux densities of 35.60 mT, 54.77 mT, and 19.43 mT were simulated at the center of the coils, at distances of 0.05 m and 0.1 m from the center of both coils, respectively as shown in Figure 1. The computed magnetic flux density (B-field) exhibits strong localization at the coil, which is placed at 0.05 m (represented by the orange dotted line in the plot), with a maximum amplitude of approximately 13.62 mT (50 turns), as illustrated in Figure 2(A). The field at 0.125 m (from the center of the Helmholtz coil (HC) configuration) is ~ 2.2 mT, which is comparable to a pulsed electromagnetic field (PEMF), i.e., required for therapy. Whereas, with an increasing number of turns, the magnetic field increases to ~ 8.4 mT for the same distance, i.e., 0.125 m, and with 200 turns. The magnetic field strength increases proportionally with turn count.

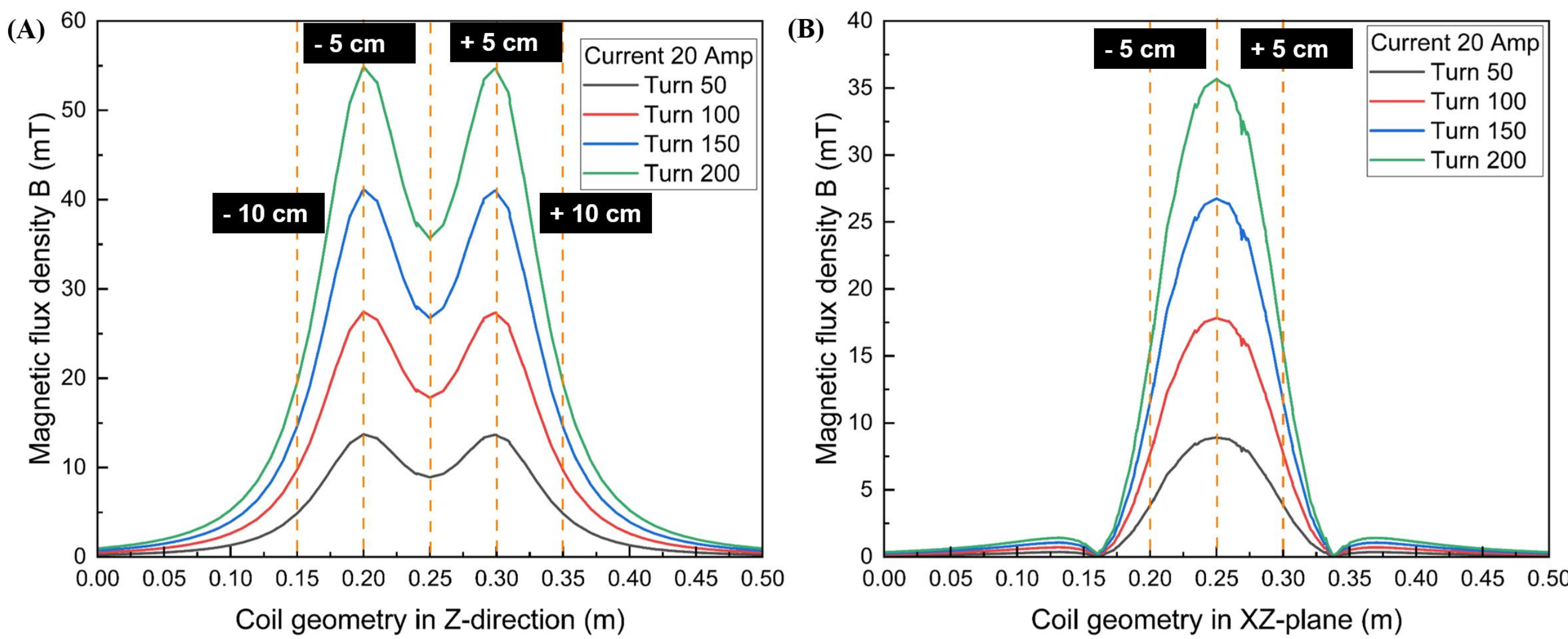


FIGURE 2. Magnetic Field along: (A) Y direction; (B) XZ plane. The dotted line represents the position of the coil.

REFERENCES

1. Gerdesmeyer, Lennart, Jutta Tübel, Andreas Obermeier, Norbert Harrasser, Claudio Glowalla, Rüdiger von Eisenhart-Rothe, and Rainer Burgkart, "Extracorporeal magnetotransduction therapy as a new form of electromagnetic wave therapy: from gene upregulation to accelerated matrix mineralization in bone healing," Biomedicines, vol. 12, pp.2269, 2024.

