Computational Models for Creating Homogeneous Magnetic Field Generation Systems

Modelos Computacionales para Crear Sistemas de Generación de Campo Magnético Homogéneo

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Abstract

It is increasingly common to use magnetic fields at the cellular level to assess their interaction with biological tissues. The stimulation is usually done with Helmholtz coils which generate a uniform magnetic field in the center of the system. However, assessing cellular behavior with different magnetic field characteristics can be a long and expensive process. For this, it can be used computational models to previously estimate the cellular behavior due to variety of field characteristics prior to in-vitro stimulation in a laboratory. In this paper, we present a methodology for the development of three computational models of homogeneous magnetic field generation systems for possible application in cell stimulation. The models were developed in the Ansys Workbench environment and it was evaluated the magnetic flux density behavior at different configurations. The results were validated with theoretical calculations from the Biot-Savart law. Validated models will be coupled to Ansys APDL environment in order to assess the harmonic response of the system.

Keywords

Computational model; magnetic flux density; magnetic field stimulation; square Helmholtz coil.

Resumen

Cada vez es más común el uso de campos magnéticos a nivel celular para evaluar su interacción con los tejidos biológicos. La estimulación se hace generalmente con bobinas Helmholtz que generan un campo magnético uniforme en el centro del sistema. Sin embargo, evaluar el comportamiento celular con diferentes características del campo magnético puede ser un proceso largo y costoso. Para esto, se pueden utilizar modelos computacionales para estimar previamente el comportamiento celular debido a la variedad de características de campo antes de la estimulación in vitro en un laboratorio. En este artículo se presenta una metodología para el desarrollo de tres modelos computacionales de sistemas de generación de campos magnéticos homogéneos para su posible aplicación en la estimulación de células. Los modelos fueron desarrollados en el entorno de ANSYS Workbench y se evaluó el comportamiento de la densidad de campo magnético en diferentes configuraciones. Los resultados fueron validados con los cálculos teóricos a partir de la ley de Biot-Savart. Los modelos validados serán acoplados al ambiente Ansys APDL con el fin de evaluar la respuesta del sistema en estado armónico.

Palabras clave

Modelo computacional; densidad de campo magnético; estimulación con campo magnético; bobina Helmholtz cuadrada.

1. INTRODUCTION

Given the more frequent exposure to electromagnetic fields of various frequencies and intensities, there is great interest in understanding the effects of interactions between these fields and biological systems. Some studies (Adey, 1980; Macrì et al., 2002) have demonstrated the influence of magnetic fields in living tissue, and for years it has be used the electromagnetic field stimulation as an alternative to pharmacological treatments without side effects (Kloth, 2005) or for tissue regeneration treatments (Goodman & Shirley-Henderson, 1991; Poltawski & Watson, 2009). However, the relationship between magnetic field characteristics (intensity, frequency, waveform, etc.) and its effects on various cellular structures is still the subject of study. For this, it is necessary to have homogeneous magnetic field generation systems that allow experimental studies at the cellular level. The generation of uniform magnetic field is based on the well-known Helmholtz coils, which are composed by circular or square coils that produce maximum magnetic field uniformity near the center of the system.

There are several systems which can be used in the generation of uniform magnetic fields, such systems vary in complexity and field uniformity. Some authors (Bronaugh, 1990; Frix et al., 1994) have reviewed four different systems. These four systems were: the single round loop, the round Helmholtz coil, the single square loop, and the square Helmholtz coil. By comparing and contrasting uniform field regions of the four systems, it was found that the round loop has the greatest deviation as a function of the lateral position while the square Helmholtz coil has the least deviation as a function of the lateral position.

The magnetic field of the square Helmholtz coil is more uniform than any other comparably magnetic field generation system. Additionally, the design and construction of the square Helmholtz system are not much more difficult than that of a single square loop. Due to these advantages, it was decided to dimension and model a square Helmholtz coil system as a magnetic field generation system. However, there have been numerous improvements in the design of these coils to produce larger volumes of space with

homogeneous magnetic fields. In this work, we report the development methodology of several computational models to evaluate uniform magnetic field generation systems to simulate the cell behavior stimulated by fields.

2. METHODOLOGY

The models were developed in Ansys Workbench environment. First, we built the geometry of three homogeneous magnetic field generation systems. Depending on the number of axes in which the magnetic field is generated, the system can be classified as one, two or three axes (Fig. 1).
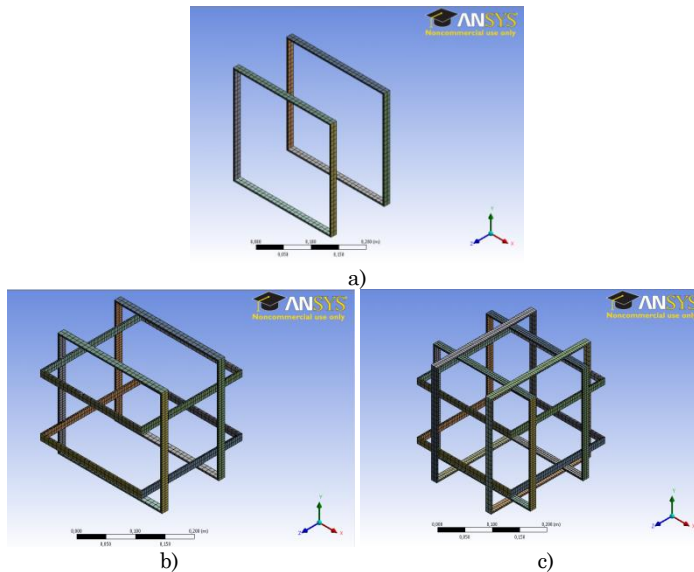

Fig. 1. Computational models of three evaluated generation systems, a) 1-D Helmholtz coils, b) 2-D Helmholtz coils, and c) 3-D Helmholtz coils. Source: Authors

The one-axis system is a pair of square coils which generate a field along one direction (1-D Helmholtz coils). The two-axis system with two orthogonal pairs of square coils (four coils) generates a field along any of the two directions independently, or on a plane

by vector addition of the two axes (2-D Helmholtz coils). The three-axis system with three orthogonal pairs of square coils (six coils) generates a field along any of the three directions independently, or on a plane by vector addition of two axes, or on any spatial direction by vector addition of the three axes (3-D Helmholtz coils).

The geometric model was based on the creation of square Helmholtz coil with a length that would guarantee a homogeneous magnetic field region in the center of the system where would be located a cell culture plate. Fig. 2 shows the dimensions of one square coil. The cross sectional area of the coil was calculated from a distribution of 100 turns of copper wire with a nominal diameter of 0.574 mm (AWG 23). The coil was arranged in five layers with 20 turns per layer. The separation between the coils of a square Helmholtz configuration is 0.544505643 times the length of one side of a coil [6]. The material properties used in the models were the properties of Copper Alloy for the coils and Air for the enclosure. The materials were chosen from General Material data source.
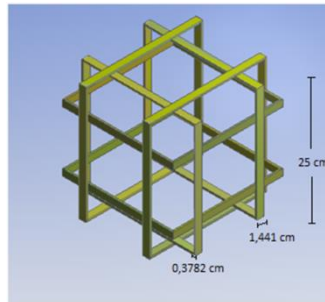

Fig. 2. Dimensions of the coil. Source: Authors

Later, in the magnetostatic analysis system, it was created four coordinate systems to define the direction of current flow in coils (Fig. 3). The coils were declared to be a source conductor. The conductor type was defined as stranded, the number of turns was set to 100 and the conducting area was established to 5.19e-5 m2. Thereafter, the current in the conductors was set to 3.12 Ampere

in magnitude (Fig. 4). This value was chosen to generate a 2 mT magnetic field at the center of the system.
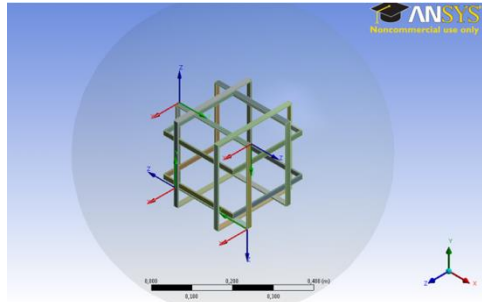

Fig. 3. Coordinate systems to define direction of current flow in 3-D Helmholtz coils. Source: Authors
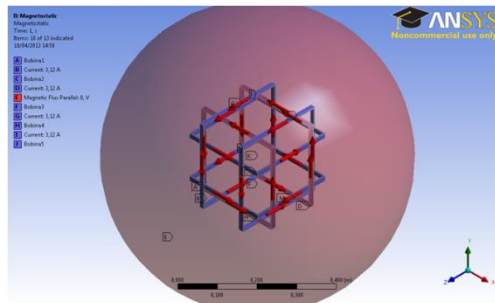

Fig. 4. Visualization of currents and magnetic flux parallel in 3-D Helmholtz coils. Source: Authors

3. RESULTS

During the analysis stage, we assessed the current density in the coils and the magnetic flux density along a path and in a plane on the basis of the center of the system. The Fig. 5 shows the contour maps on a plane in the center of the system for the three arrangements.

Likewise, we compared the simulation results with theoretical values calculated from equations based on the Biot-Savart law and we found errors less than 4% (Fig. 6). Fig. 7 compares the magnet-

ic field profiles obtained with Ansys for two field generation systems: round Helmholtz coil and square Helmholtz coil. It can be seen that the area of the uniform magnetic field is higher for the system with square coils.
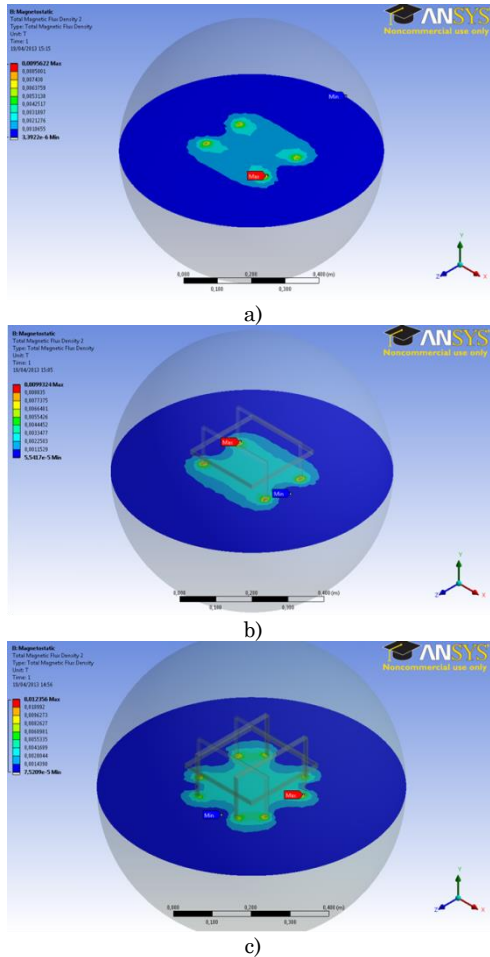

a)

b)

c)

Fig. 5. Magnetic flux density generated for the three evaluated systems, a) 1-D Helmholtz coils, b) 2-D Helmholtz coils, and c) 3-D Helmholtz coils.
Source: Authors

Fig. 8 shows the total magnetic flux density for the three magnetic field generation systems evaluated. It is observed as the level of magnetic flux increases with the inclusion of pairs of coils. Validation of computational models will allow the application of magnetic fields to study structural and physiological changes on cells when they are exposed to fields with different frequency and magnetic intensities. In other words, many experiments of stimulation on cell cultures can be performed.
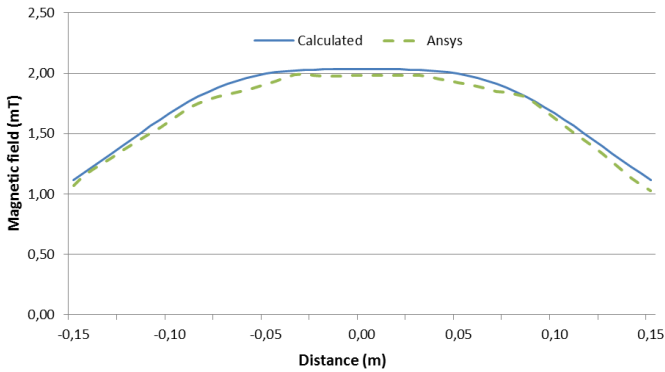
Fig. 6. Magnetic flux density along a path obtained with Ansys compared with values calculated from Biot-Savart law. Source: Authors
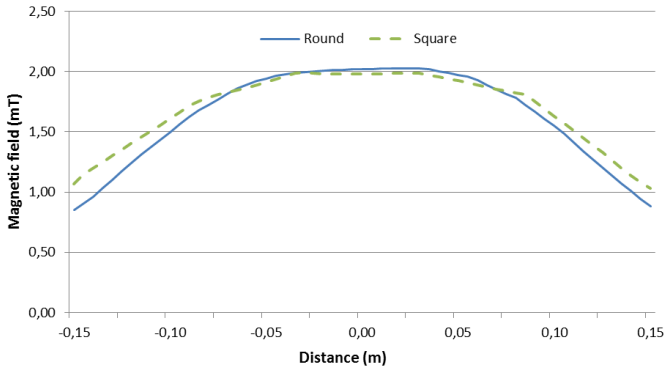
Fig. 7. Magnetic flux density along a path obtained with Ansys for two field generation systems. Source: Authors
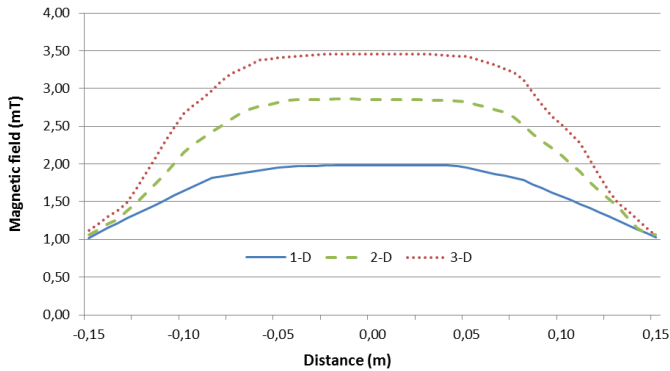
Fig. 8. Total magnetic flux density along a path obtained with Ansys for the three generation systems. Source: Authors

4. CONCLUSIONS

Computational models developed reproduce correctly magnetic field uniformity, allowing evaluate induced variables in stimulated cells with different characteristics magnetic fields. Computer models can be used as a predictive tool of the behavior of electromagnetic fields generated by a stimulation source, under ideal operating conditions.

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