NEID PROJECT

Submitted by
Harshvardhan Chourasia 2021151
Ramit Nag 2021188
Parveen Kumar 2021177

24 April 2024

Contents

1 Abstract

The aim of this project is to develop a nerve stimulation system for the peripheral nervous system, focusing on the sciatic nerve using computer modeling. The system consists of three main components: (1) excitation coil design, (2) circuitry to deliver the desired excitation current, (3) optimizing coil placement with respect to excitation target site We aim to develop a flying magnetic stimulation system effective and efficient for induction of peripheral nerve stimulation.

2 Introduction

In neuroscience and neurophysiology, magnetic stimulation has emerged as a favored approach over electric stimulation. This choice is largely due to the non-invasive nature of magnetic stimulation and its potential to successfully modulate neuronal activity. Magnetic stimulation is based on primary standards: Faraday's law and Biot-Savert's regulation.

Faraday's law states that a time varient magnetic field induces a electric field, mathematically expressed as:

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \tag{1}$$

The Biot-Savart law describes the magnetic field generated by a current-carrying wire, given by:-

$$\vec{B} = \frac{\mu_0}{4\pi} \frac{I\vec{dl} \times \hat{r}}{r^2} \tag{2}$$

3 Method

The equation describing the simulation of a coil with both inductance and resistance is as follows:

$$R = \frac{\rho \cdot l}{A}$$

where:

$$\begin{aligned} \rho &= \text{resistivity of copper} \\ l &= \text{length of the coil} \\ l &= 2\pi r \\ A &= \pi d^2 \end{aligned}$$

Here, d is taken from the American Wire Gauge (AWG) to meter conversion, and C is specified in the question.

The formula for the inductance of the coil, derived using Kirchhoff's law, is:

$$0 = L\frac{d^2 i}{dt^2} + R\frac{di}{dt} + \frac{I}{C}$$

Solving this equation using Python's inbuilt module provides $\frac{di}{dt}$ and I, from which respective graphs are plotted. We then normalize $\frac{di}{dt}$ and save the values in a text file.

To calculate the electric field (E), we consider the maximum value of $\frac{di}{dt}$. Since $B = \mu \times A$, $\mu \times E = -\frac{dB}{dt}$, and $\mu \times E = -\mu \times \frac{dA}{dt}$, we have $E = -\frac{dA}{dt}$.

For dl (an infinitesimally small element), $dA = \frac{\mu}{4\pi r} \cdot dl \cdot I$. The electric field due to this element becomes:

$$\vec{E} = -\frac{\mu}{4\pi r} \cdot \mathbf{dl} \cdot \left(\frac{d\vec{i}}{dt}\right)$$

where $\frac{di}{dt}$ is the maximum value, and r is the distance between the point on the plane and the element on the coil.

To calculate E due to the coil, we consider a 2D plane in specified dimensions. The coil is placed at some height, and we construct the coil using discrete points in 3D space. We then calculate E at each point on the plane due to this small element.

For this, the coordinates of the element are x_0, y_0, z_0. To calculate E at point r, we use the formula:

$$r = \sqrt{(x_0 - x_1)^2 + (y_0 - y_1)^2 + (z_0 - 0)^2}$$

where x_0 and y_0 are the points on the plane. This process is repeated for dl sized elements along the coil. We sum up the force (F) due to all points on the plane. We use the `gradient()` function to calculate the derivative of E with respect to x.

Suppose the nerve is situated at $x = 0.001$ m. We calculate $\frac{dF}{dx}$ along this line for the particular value of x. We repeat the same process along the y-axis. We save the values of $\frac{di}{dt}$ and $\frac{dE}{dx}$ in a text file and run `init.hoc` file to see the stimulation spike. We set different values of the scaling factor to find the threshold stimulation.

4 Results

Results for the current i(t) that is passing through the coil and its $\frac{di}{dt}$.

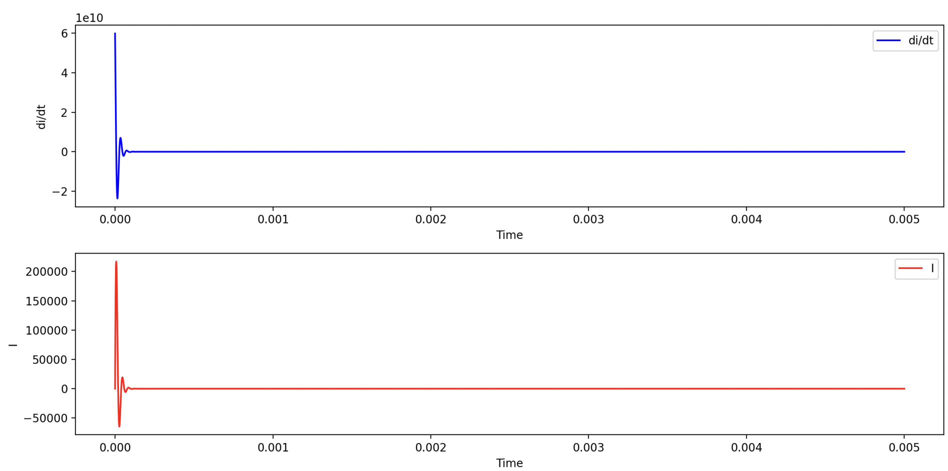

Figure 1: Plot of i(t) and $\frac{di}{dt}$

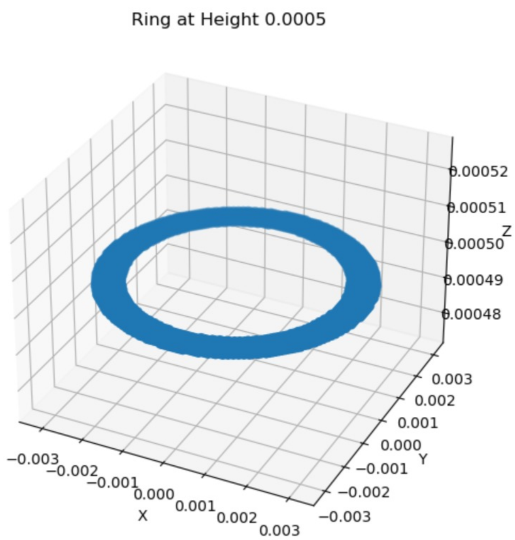

Figure 2: Plot for the coil

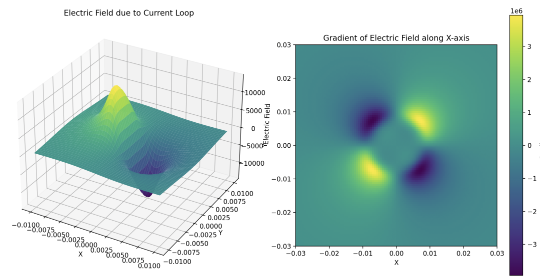

Figure 3: Electric field due to current loop

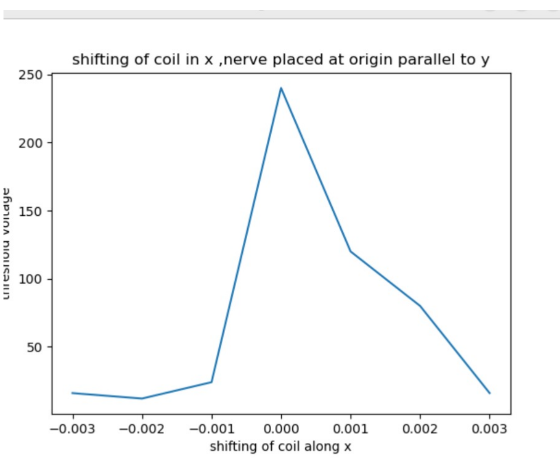

Figure 4: Shifting of coil in x-axis

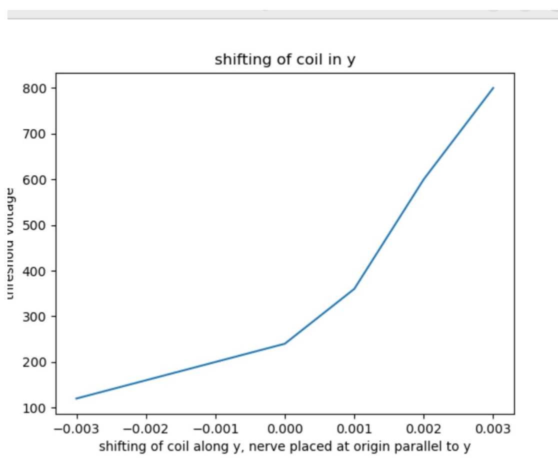

Figure 5: Shifting of coil in y-axis

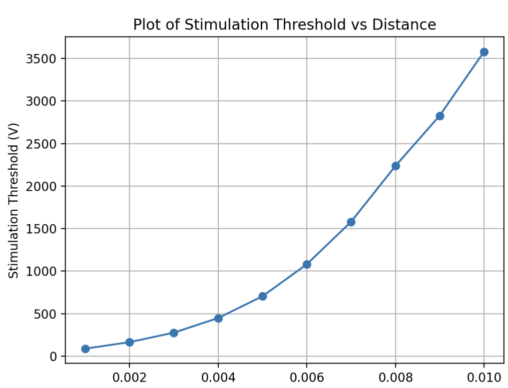

Figure 6: Shifting of coil in z-axis

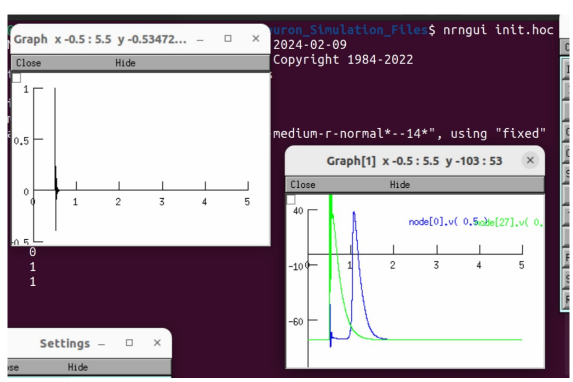

Figure 7: Verification of output

5 Discussion

The improvement of a neural stimulation system for peripheral nerves, focusing on the sciatic nerve, making use of computational modeling, represents a huge development within the subject of neuroscience and neurophysiology. This project aims to design an green and effective magnetic stimulation device by leveraging computational modelling and principles from electromagnetism.

Advantages of Magnetic Stimulation

Magnetic stimulation has emerged as a preferred technique over electric subject stimulation due to its non-invasive nature and its capacity to successfully modulate neural activity. Two laws, maminly biot-savart and faraday is used Faraday's Law: Faraday's law states that a changing magnetic field induces an electric field

- **Faraday's Law:** Faraday's law states that a changing magnetic field induces an electric field. This principle is mathematically expressed as $\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$.
- **Biot-Savart Law:** The Biot-Savart law describes the magnetic field generated by a current-carrying wire, given by $\mathbf{B} = \left(\frac{\mu_0}{4\pi}\right) \times \frac{(I\, d\mathbf{l} \times \mathbf{r})}{r^2}$.

Methodology Overview

The methodology employed in this project encompasses three main components:

1. **Design of the Stimulation Coil:**The parameters for the stimulation coil, such as resistance and inductance, are calculated using formulas that consider the variety of turns inside the coil, cord dimensions, and fabric properties.
2. **Circuit for Delivering Stimulation Current:** The circuit is designed to deliver the desired stimulation current primarily based at the calculated parameters for the stimulation coil.
3. **Optimizing Coil Placement:** The placement of the coil concerning the stimulation target site is optimized using computational modeling. This involves calculating the electric field ($\tilde{\mathbf{E}}$) at various points on a specified 2D plane due to the coil.

Computational Modeling

The simulation of the coil considers both inductance and resistance. The resistivity of copper and the length of the coil are used to calculate resistance, while the inductance of the coil is derived using Kirchhoff's law.

To calculate the electric field ($\tilde{\mathbf{E}}$), the maximum value of di (change in current) is considered. Using the formula $\tilde{\mathbf{E}} = -\frac{\mu \cdot dl \cdot d\mathbf{i}}{4\pi r\, dt}$, the electric field is calculated at each point on the specified 2D plane due to the coil.

The results obtained from the computational models allow for the visualization of the stimulation spike. By setting different values of the scaling factor, the threshold stimulation is determined.

The utilization of computational modeling in the design of a magnetic stimulation system for peripheral nerve stimulation, focusing on the sciatic nerve, holds great promise in the field of neuroscience and neurophysiology. The developed system has the potential to offer a non-invasive, efficient, and effective method for modulating neural activity, with wide-ranging applications in both research and clinical settings.

Novel design

In this design, I attempted to make the solenoid coil more efficient by reducing its length. However, upon observing the results, I found that the inductance actually increased. For this model to be efficient, it is crucial to reduce the inductance. This can be achieved by altering the permeability of the medium. Reducing the inductance results in a lower voltage requirement and less noise in the current signal. Moreover, the current signal remains within the normal safety values for the coil to operate.

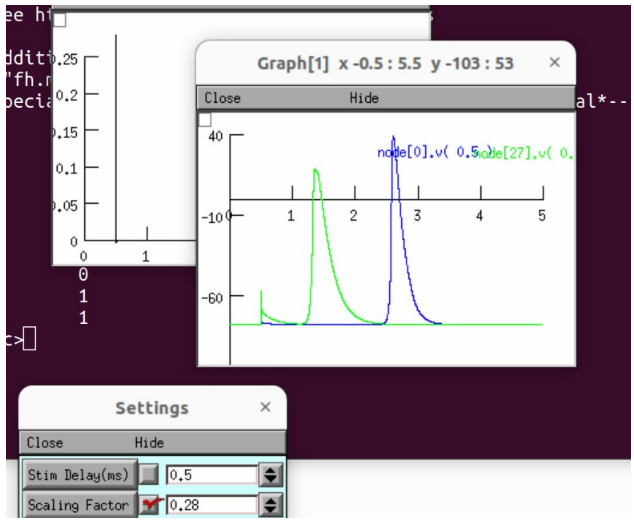

Figure 8: Verification of novel design

The voltage applied here is 4 DC, and the scaling factor is calculated to be 0.28. Therefore, the voltage requirement is significantly reduced, and noise is also minimized.

6 Conclusion

In this study, we developed a computational model for designing a magnetic stimulation system targeting peripheral nerves, particularly the sciatic nerve. By integrating principles from Faraday's and the Biot-Savart laws, we optimized the stimulation coil parameters for efficient neural stimulation.

Our computational model calculated the coil's resistance and inductance, considering factors such as wire dimensions and material properties. We also optimized the coil's placement for effective stimulation.

Using Python's modules, we simulated the coil and calculated the electric field (E) for threshold stimulation. Our model provides a non-invasive method for modulating neural activity, with potential applications in neuroscience research and clinical interventions.

7 Acknowlegement

We would love to express our sincere gratitude to our project supervisor, [Dr. Pragya kosta], for his or her invaluable steerage and guide in the course of this project. We additionally extend our thanks to our group individuals, Harshavardhan Chourasia (2021151), Parveen Kumar (2021177), and Ramit Nag (2021188), for their hard work and determination. Additionally, we acknowledge

the help of [INDRAPRASTHA INSTITUTE OF INFORMATION TECHNOLOGY] for providing us with the vital sources to complete this challenge efficiently.]

PART A :- Parveen Kumar founded the equation of RLC circuit and coded it , Ramit Nag has done the debugging part .
PART B : - Both Parveen Kumar and Ramit Nag has verified and tested the electric field through the coil.
PART C:-Harshvardhan Chourasia has done variation of coil along height and Parveen Kumar has done the variation of coil along x , y direction.
PART D : - Ramit Nag has founded the novel design and Harshvardhan Chourasia implemented the design and debugged it.
REPORT WRITTING : - Harshvardhan Chourasia has written the report and verified by Ramit Nag and Parveen Kumar.

8 References

Fields and Waves Lecture Notes (By Dr. Sayak Bhattacharya)
NEID classroom slides