Design and Optimization of Magnetic Stimulation System for Peripheral Nerves

Kumar Rishav
Indraprastha Institute of Information Technology
rishav21159@iiitd.ac.in

***Abstract*—** This research project focuses on the design optimization and validation of a neural stimulation system using magnetic coils for sciatic nerve stimulation. The principal aims of this study are to optimize stimulation parameters stimulated by new coil designs, and stimulate the stimulation system more effectively and efficiently. The distribution of magnetic fields and the Neurostimulationctricbeer within nerve tissue are simulated using computational modeling approaches. The results of this study enhance the field of brain stimulation. neurostimulation may find used in the treatment of pain and the restoration of function. The study emphasizes how crucial it is to establish dependable and effective neuro stimulation systems via methodical design optimization and experimental validation.

Keywords*—Neural Stimulation, Magnetic Coil, Sciatic Nerve, Design Optimization, Computational Modeling, Electric Field Distribution, Stimulator Circuitry, Experimental Validation*

I. Introduction

Neural Stimulation systems play a crucial role in various medical applications, serving diverse purposes ranging from alleviating neurological disorders to augmenting sensory perception. These systems deliver controlled electrical impulses to the nerve (sciatic nerve specifically in this context), promoting desired physiological responses. Despite their transformative potential, optimizing neural stimulation systems for that latency poses a formidable challenge due to the intricate interplay of biological, electrical, and computational factors.

I propose a design optimization approach encompassing several critical dimensions to address these. We aim to refine the physical design of stimulation coils and electrodes to optimize the spatial distribution and intensity of the induced electric field.

In parallel, our approach emphasizes the enhancement of stimulator circuitry to achieve precise control over stimulation parameters. This includes developing programmable stimulator circuits capable of delivering tailored waveforms and adapting Stimulation patterns based on real-time feedback. By integrating feedback mechanisms, such as impedance Sensing, into the stimulator design, we aim to optimize stimulation efficiency.

II. Method

The magnetic stimulation system is designed using a single-turn circular coil with an inner diameter of 5 mm, constructed using 22 AWG wires. The coil's geometry is selected to be a simple circle for its ability to generate focused magnetic fields suitable for nerve stimulation applications. The coil was positioned with specific offsets along the y-axis and z-axis relative to the nerve target site, optimizing its proximity for efficient stimulation.

A DC voltage source delivering 400 V for the stimulator circuit was coupled with a 5 mF capacitor to create an RC (Resistor-Capacitor) circuit. This circuit configuration allows controlled capacitor discharge through the coil, generating precise current pulses essential for nerve stimulation experiments.

The computational modeling approach involved solving differential equations that describe the dynamics of the stimulator circuit. Specifically, the equations governing capacitor voltage (V_C) and inductor current ($i(t)$) were solved numerically using the 'odeint' function in Python. Initial conditions are set to $V_C(0) = 0$ and $dV_C(0) = 0$ to simulate the circuit's transient response.

For simulating the induced electric field (E) in the nerve and its gradient (dE/dx), a homogeneous simulation domain was assumed with a model of a Myelinated nerve fiber provided to us. Analytical equations based on electromagnetic theory were used to compute the magnetic field generated by the stimulation coil. The induced electric field (E) was then calculated using Faraday's law of electromagnetic induction. Additionally, numerical methods were employed to compute the gradient of the electric field (dE/dx), assessing field variations along specific axes passing through the nerve center.

III. Results

The proposed magnetic stimulation system and computational modeling approach are expected to yield several vital outcomes and results.

- Coil Design Optimization:
  The optimized single-turn circular coil design, with specific dimensions and placement relative to the nerve target site, is anticipated to enhance the efficiency and effectiveness of magnetic field generation for nerve stimulation.

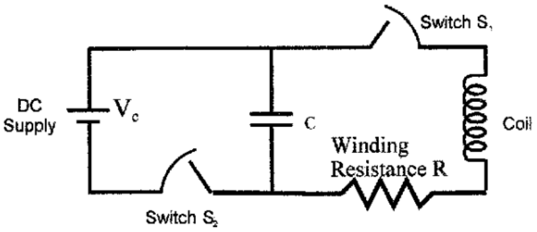

Figure 1:
circuit diagram used for the implementation of the coil design

- Stimulator Circuit Performance:
  The RC stimulator circuit, comprising a 400 V DC voltage source and 5 mF capacitor, is predicted to produce Controlled current pulses that are suitable for nerve stimulation experiments.
- Simulation Results:
  The computational modeling of the stimulator circuit dynamics, including the calculation of coil current ($i(t)$) and its time derivative (di/dt) [as represented in Figure 2], is expected to provide insights into the transient behavior of the circuit during stimulation.
- Electric Field Simulation in Nerve Tissue:
  The simulation of induced electric fields (E) [as represented in Figure 3] within a model of myelinated nerve fibers, along with the computation of field gradients (dE/dx) [as represented in Figure 4], will offer predictions on the spatial distribution and intensity of electric fields around the nerve target site.

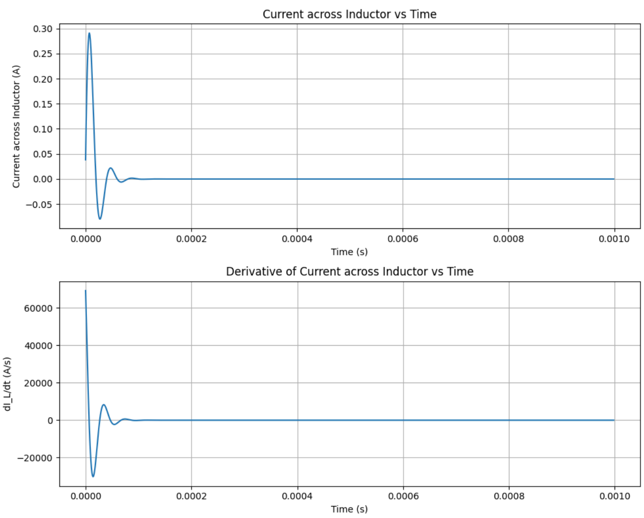

Figure 2:
(a) current through the inductor (i(t)) with respect to time.
(b) time derivative (di/dt) of current (i(t)) through the inductor with respect to time.

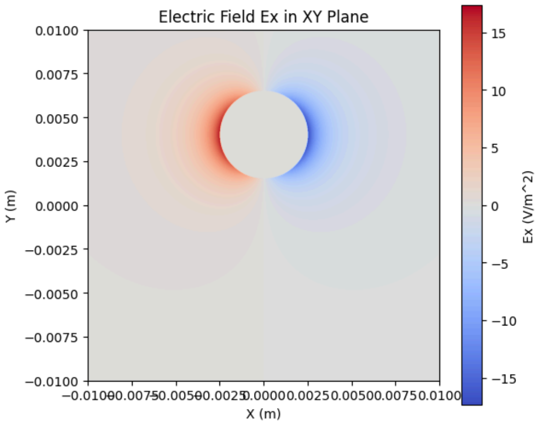

Figure 3:
electric fields (E) within a model of myelinated nerve fibers

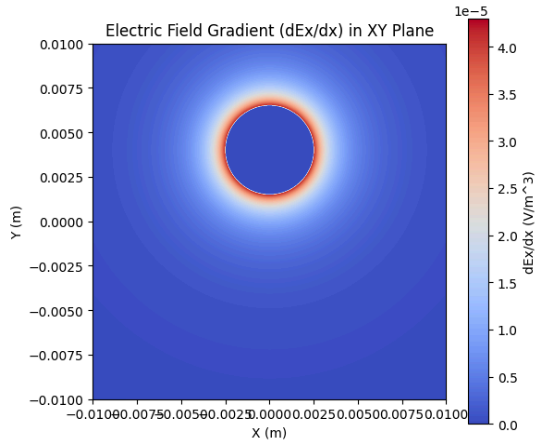

Figure 4:
Electric field gradient ((dE/dx) within a model of myelinated nerve fibers

IV. Discussion

Findings highlight the importance of coil design and positioning in optimizing neural stimulation efficacy. The study contributes to advancing non-invasive neural stimulation techniques for potential clinical applications in neuromodulation therapies.

V. Conclusion

In conclusion, this research demonstrates the feasibility of using computational modeling to design and optimize magnetic stimulation systems for peripheral nerves. Future work can further refine the stimulation system and could lead to many applications in neural rehabilitation and therapeutic interventions.

VI. Units and Acronyms

- Current (I):

  Primary Unit: Ampere (A)

  Secondary Unit (English): Ampere (A)
- Current Gradient (*dI*/*dt*):

  Primary Unit: Ampere/second (A/s)

  Secondary Unit (English): Ampere/second (A/s)
- Electric Field (E):

  Primary Unit: Volts per meter (V/m)

  Secondary Unit (English): millivolts per millimeter (mV/mm)
- Electric Field Gradient (*dE*/*dx*):

  Primary Unit: Volts per meter square (V/m^2)

  Secondary Unit (English): millivolts per millimeter squared (mV/mm^2)
- US standard measure for the diameter of electrical conductors.

  Primary Unit: AWG American Wire Gauge

VII. Acknowledgment

While this project was completed independently, I would like to express my gratitude to Ms. Pragya Kosta for their guidance and support throughout the process. Despite the challenges faced, their insights have been invaluable in navigating the complexities of this research endeavor.

VIII. Reference

- Chu XL, Song XZ, Li Q, Li YR, He F, Gu XS, Ming D. Basic mechanisms of peripheral nerve injury and treatment via electrical stimulation. Neural Regen Res. 2022 Oct;17(10):2185-2193. doi: 10.4103/1673-5374.335823. PMID: 35259827; PMCID: PMC9083151.
- Davey, K.R., & Epstein, C.M. (2000). Magnetic stimulation coil and circuit design. *IEEE Transactions on Biomedical Engineering, 47*, 1493-1499.
- Boshuo Wang, Warren M. Grill, Angel V. Peterchev,
- Coupling Magnetically Induced Electric Fields to Neurons: Longitudinal and Transverse Activation, Biophysical Journal, Volume 115, Issue 1,2018,
- Ms. Pragya Kosta of professor, “Lecture 17.” class lecture, Neural Engineering, and Implant Devices”, Indraprastha Institute of Information Technology, New Delhi.