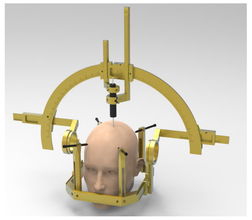
Discovering the 6th Degree of Freedom: How to Incorporate the Electrode Lead in the DBS Automatic Leksell Frame Adjuster Device

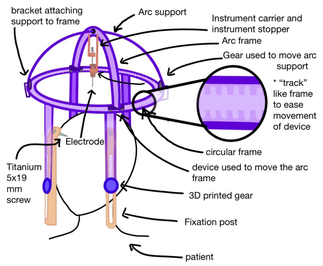
Isabelle Yacoub[1], Jitendran Muthuswamy, Ph.D[1], Dr. Balthazar Zavala[2]

School of Biological and Health Systems Engineering, Arizona State University, Tempe, AZ, USA[1]
Barrow Neurological Institute, Phoenix, AZ[2]

Introduction

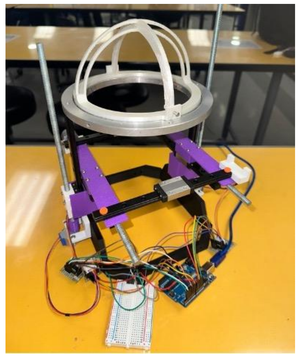
- Deep brain stimulation (DBS) is a stereotactic procedure in which electrode(s) are implanted in the patient's brain through an invasive procedure into the skull.
- The electrode(s) send out electrical impulses to the brain, which effects brain activity, to treat certain neurological disorders (i.e. Parkinson's disease, epilepsy, OCD, obesity, Tourette's, etc.). [1][2]
- The current Leksell Frame was invented in 1949 and is still used in Deep Brain Stimulation (DBS) surgery today. The frame requires soft tapping of the frame with a screwdriver which is time consuming and increases human error.
- The aim is to motorize and make the LFA automatic, while discovering the 6th DOF and incorporating the component that holds the electrode lead into the device.





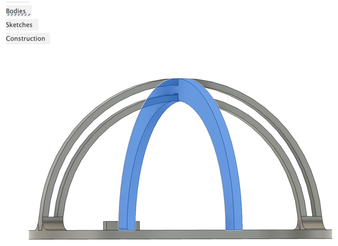
Background Information

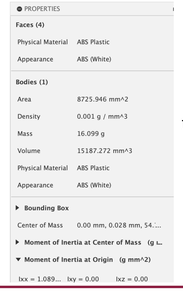
- My team last semester worked with Barrow Neurological Institute (BNI) to completely motorize the original LFA device, essentially making it automatic.
- The purpose of motorizing was so that the neurosurgeon performing the procedure wouldn't have to manually adjust the coordinates on the frame, which would ultimately lead to a minimal amount of potential human error, and higher precision.
- Unlike the original version of the LFA device, this version incorporates 5 degrees of freedom (DOF) (x, y, z, phi, theta) due to switching from cartesian to spherical coordinate for optimal precision.



Methods

Estimation of moment of inertia using Fusion360 modeling software



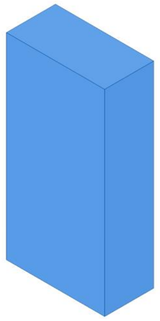


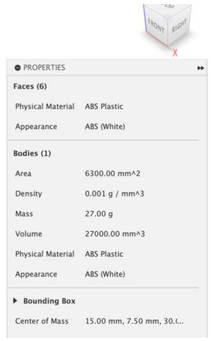
The moment of inertia for the arc frame, calculated as:

$I = 1.089 \times 10^5$ g mm^2

Results

Rectangular block to represent and approximate STar Drive





- The STar Drive represented as a rectangular block for simplification and experimental purposes, was also assigned ABS plastic and sized based on estimated dimensions to approximate the weight of the actual component.
- This estimation enabled the creation of a theoretically sufficient load that the arc frame would support, allowing us to analyze whether the frame could withstand the additional mass.

Testing with Python Simulation, modeling the motion of the device, calculating each variable through different conditions

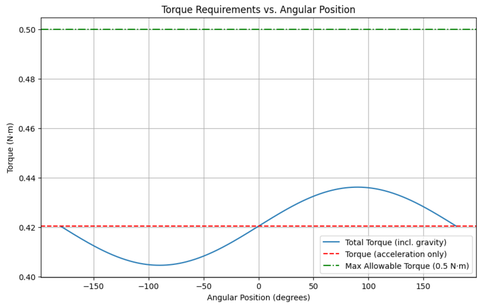
Key Variables to Test:

- Torque requirement (τ) : depends on the moment of inertia and the angular acceleration
- Angular displacement (θ): shows how well the device reaches each position along the arc, especially in the case of any slipping, binding, or resistance at certain angles that may be too extreme
- Angular velocity (ω): shows if the device can attain a uniform speed throughout its ±180 degrees movement
- Angular acceleration (α): ensures that the frame moves within the time constraints smoothly without surpassing structural limits

Results

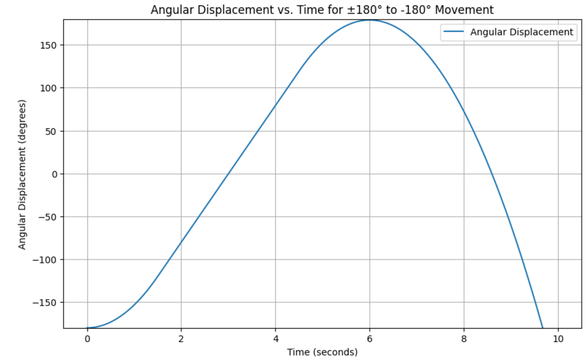
$$\text{alpha} = \frac{torque}{moment\ of\ inertia}$$

- NEMA 17 Stepper Motor with a torque requirement of 50 N cm was chosen so that all the calculated torque values are within the allowable limit.

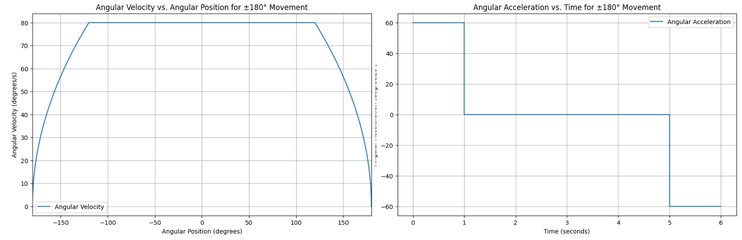


Results

Simulation showed it takes 10 seconds to complete a full cycle, starting at its origin -180, to +180° , then back to -180°



The capability of the device to achieve uniform motion and to decelerate gradually was further confirmed by analyses of angular velocity and angular acceleration



Summary, Conclusions and Future Directions

- This study established a theoretical framework to analyze the performance of an automatic Leksell Frame Adjuster with Elekta's STar™ Drive, using CAD modeling, simulations, and theoretical calculations.
- Torque requirements varied by position, peaking at ±90º, leading to the choice of a NEMA 17 stepper motor with 50 N·cm torque. Displacement simulations confirmed suitability for neurosurgery with smooth motion control.
- Analyses of velocity and acceleration showed stable, uniform motion, reducing mechanical wear and enhancing positioning accuracy.
- Results are promising, but for future steps, physical prototyping is needed to validate findings, laying groundwork for improving safety and reliability in deep brain stimulation procedures.

References & Acknowledgments

[1] Mayo Clinic. "Deep Brain Stimulation." *Mayoclinic.org*, 19 Sept. 2023, www.mayoclinic.org/tests-procedures/deep-brain-stimulation/about/pac-20384562.

[2 Elekta. *Leksell Stereotactic System® Instructions for Use, Leksell Stereotactic System® Instructions for Use*. May 2015. https://data2bids.greydongilmore.com/static/elekta_leksell_manual_v10 07063.4_2015.pdf

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