Summer Research Report/Log

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1. Introduction

As a research assistant, my tasks varied day to day. These tasks included: building and taking linear field measurements from a linear magnetic gear, building and taking torque measurements from a circular magnetic gear, reading about magnets, and learning software such as LaTex and SignalCalc.

2. Linear Magnetic Gear

The first task of my summer research experience was to help with the construction of a linear magnetic gearing system. The purpose of designing the linear gear was for Ismail to take magnetic field measurements and gain knowledge before going into the construction of the circular gearing system. The major parts of the linear gearing system include: the flux modulator, the base, the inner and outer magnetic rotors, the mechanics, and the lid. I, personally, helped with the flux modulator, the lid, and the mechanics of the rig. After the construction of the gear, I helped with the data acquisition and analysis.

The Flux Modulator

The flux modulator was to be made of 3D printed material (PLA), for structure, as well as low carbon steel, to enable the flux from the outer magnets to pass through to each other and create magneto-mechanical coupling. The modulator allowed for 18 steel pieces and was limited by the size of the 3D printer.

In the construction of the linear gear, Ismail designed two iterations. The first had no side walls as seen in Figure 1. This design worked as a flux modulator, but proved to be unstable structurally; the team decided that walls were to be added for support and more structural integrity.

After walls were added in the second iteration, the modulator proved to be much more stable. Its design is shown in Figure 2. With its redesign, the base structure of the linear magnetic gearing system also needed a redesign. The next iteration of the base would enable the whole rig to be assembled and disassembled.

The Lid

The lid was an acrylic protector that was to be placed on top of the linear gearing rig after its completion. The construction of the lid was quick, but through it, I learned a lot. The first thought for constructing the lid was to drill through the acrylic where the screws would go and sand the edges to the base size. This idea could have worked, but I decided that laser cutting the lid was much more precise and allowed for a lower error margin.

After creating a model of the lid in SolidWorks, a .dxf file was exported and sent to a laser cutter. The laser cutter quickly cut the lid to the exact dimensions assigned.

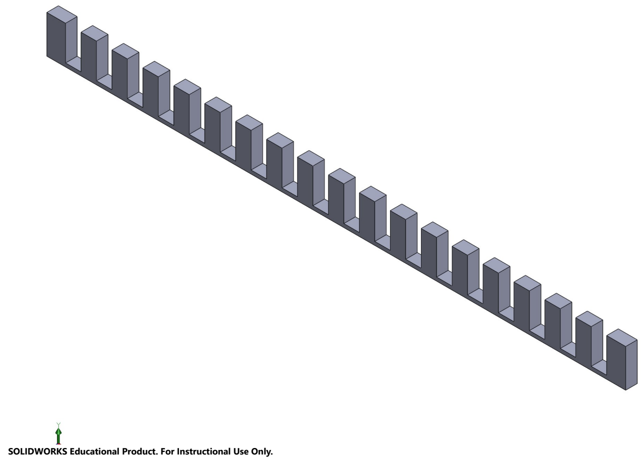

Figure 1. Rendering of first flux modulator tested.

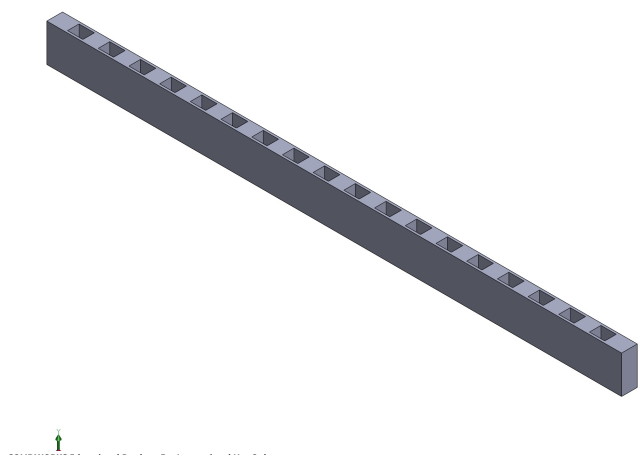

Figure 2. Rendering of second flux modulator (modulator_rotor.SLDPRT).

The dxf file is a 2D file and can be opened in the laser cutting software and be used as a guide to cut the acrylic.

One thing that I would have done differently if I could construct the lid again would be to add more support at the corners. As seen in Figure 3, the corners of the lid are very thin and easily allow the acrylic to crumble. In the redesign of the lid, I would have cut it to the shape shown in Figure 4. This would strengthen up the corners of the acrylic lid.

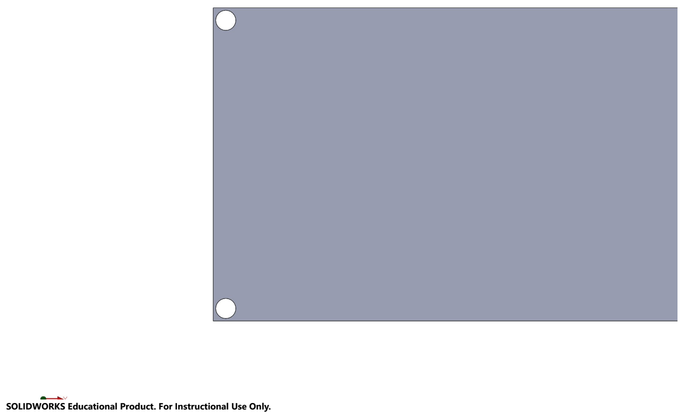

Figure 3. The left edge of the lid is shown. Notice the holes at the corners are very close to the edge and allow for a weak spot between the hole and the edge.

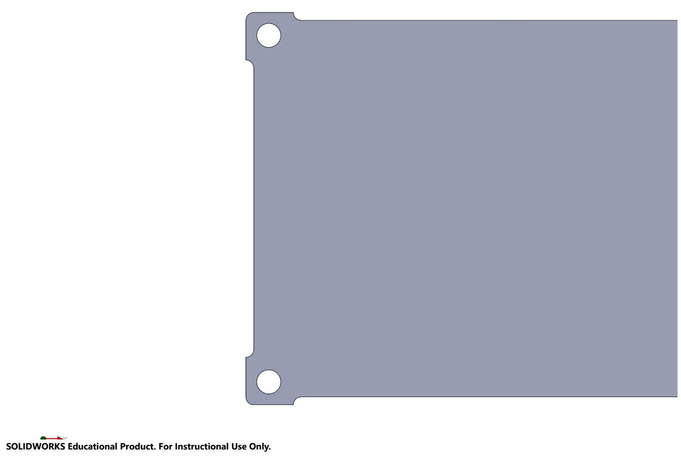

Figure 4. The left edge of the redesigned lid is shown. Notice the holes at the corners are given extra room at the edges for added strength.

The Mechanics

After designing the final iteration of the linear model, the parts were 3D printed or ordered to be assembled. The base was 3D printed to hold the rest of the structure. The 2 rotors were 3D printed to confine the magnet arrays. The modulator was 3D printed to confine steel pole pieces. Bearings, threaded rods, turning dials, and nuts were ordered to establish a linear advancement mechanism for the rotors.

The threaded rod and 10 nuts needed to be machined further in order to fit into the assembly as designed. The threaded rod was cut to size and turned on the ends to fit into the bearings as well as allow a dial to attach on one side. The threaded rod ordered was long enough to be cut in half to put a dial on each rotor. Each of the 10 nuts was cut so that after attaching 5 of them to the rotors, the rotors would slide smoothly into their slots.

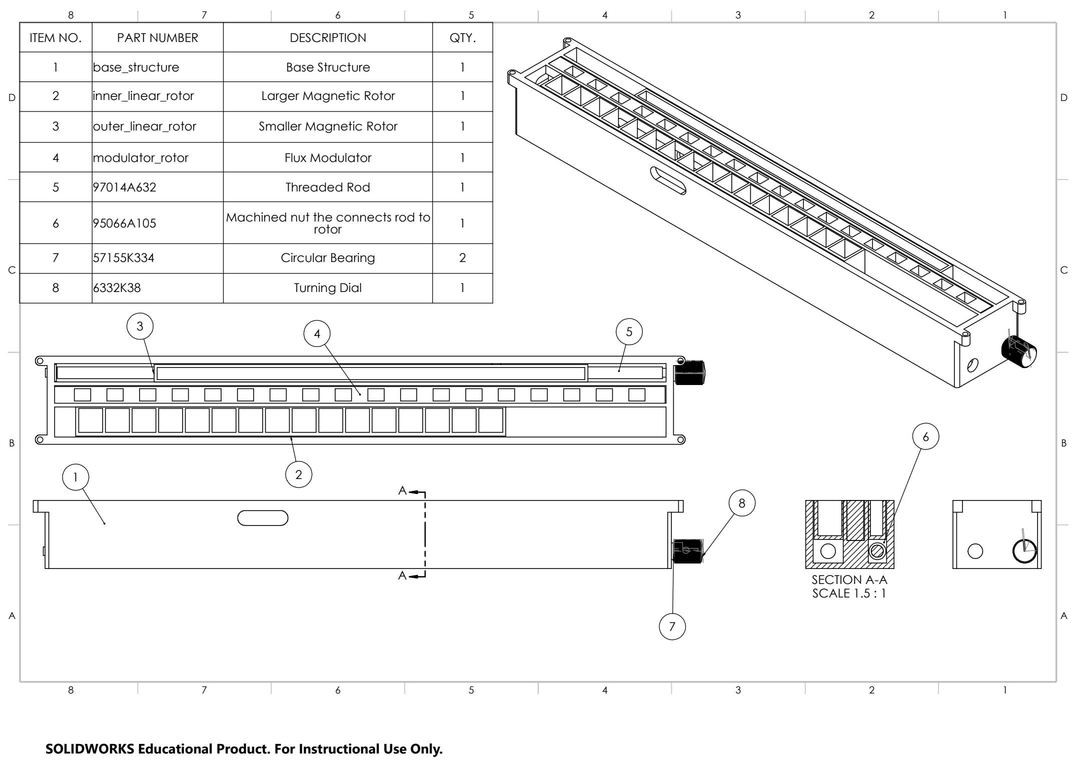

Figure 5. The design of the linear gear is shown. Parts have been removed for clarity.

Data Collection and Analysis of the Linear Gear

To collect data from the linear gear, we used a Quattro paired with SignalCalc 240 software, both made by DataPhysics. A Keyence positioning laser was used for measuring distance of the moving rotor, while a Walker Scientific Gaussmeter was used to collect magnetic field data at a predefined location. These magnetic field versus distance measurements, one of which is shown in Figure 6, are to be compared with magnetic field predicted by FE simulations.

At first, Ismail and I had the laser reading the distance straight from the inner rotor. This proved to be difficult since we cranked the rotor by hand; the crank could only be turned a little at a time or else the laser would hit our finger and throw off the readings. This setup can be seen in Figure 7.

The redesigned setup we used worked much better. We moved the laser away from the crank and added a Plexiglas wall for it to measure distance. This enabled us to

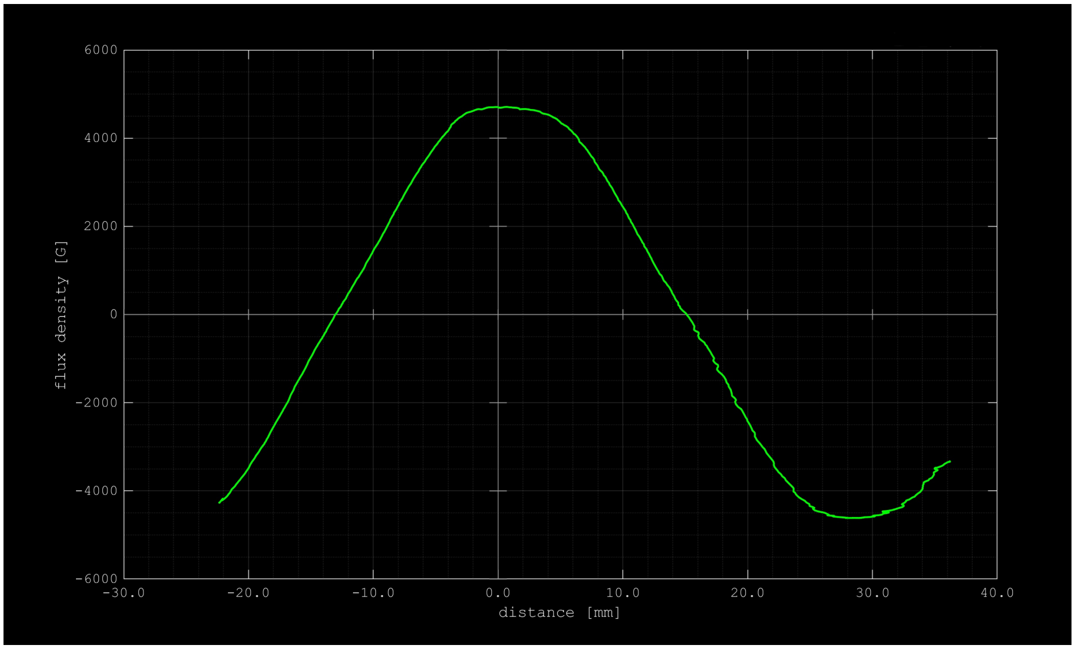

Figure 6. Sample measurement taken from linear data collection setup.

crank the inner rotor smoother, allowing for less noise in our data. The second setup can be seen in Figure 8.

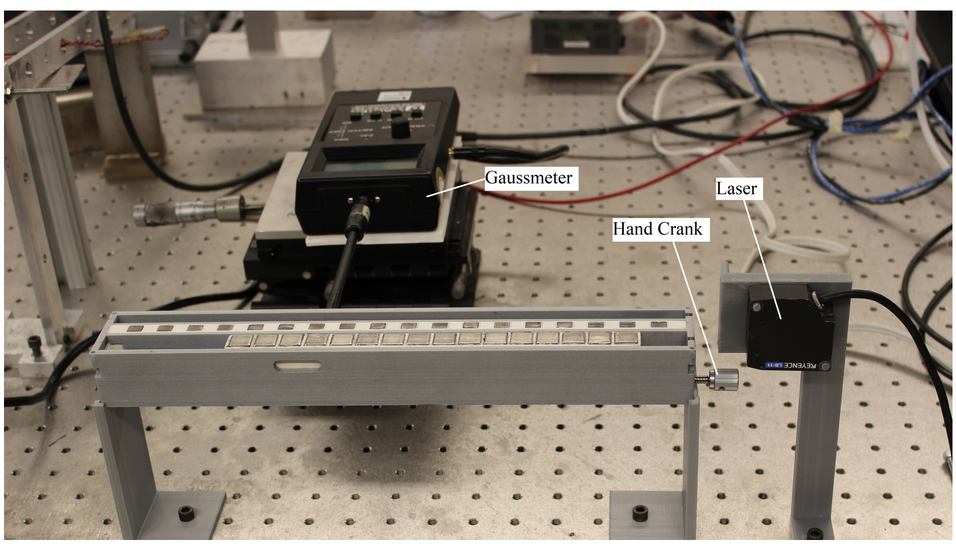

Figure 7. The first linear data collection setup.

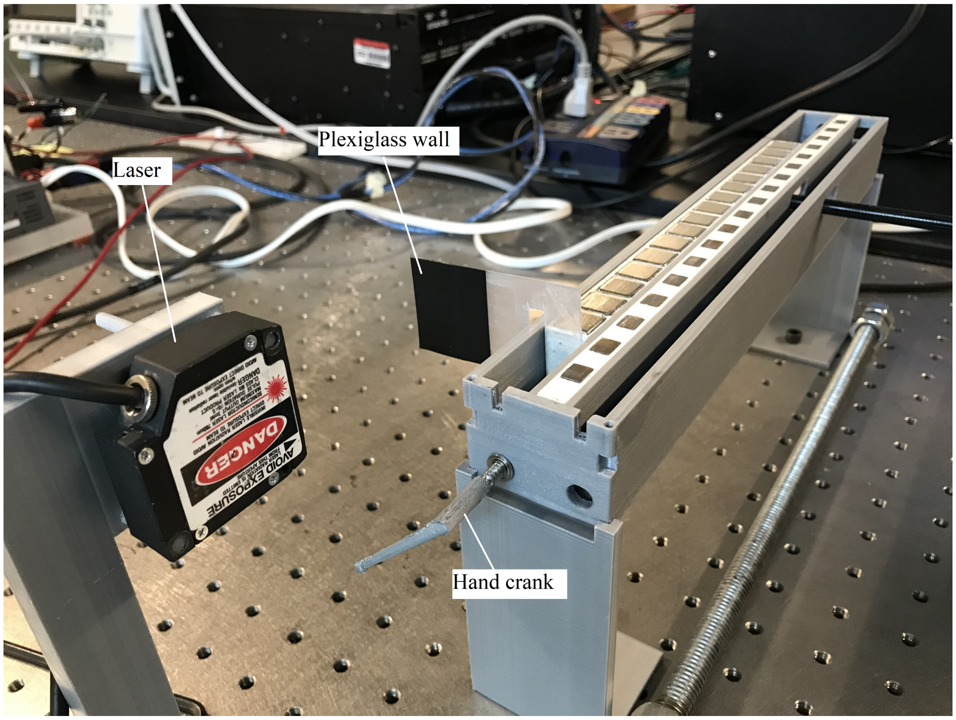

Figure 8. The laser, moved to the outside of the setup measuring the distance from the wall.

3. Circular Magnetic Gear

Based on a prototype designed by Ismail last year, I started constructing a circular magnetic gear. The iteration we built can be seen in Figures 9 and 10.

Inner Rotor

The inner rotor has 16 magnets arranged in a Halbach Array, which forces the flux to prefer the outside of the rotor. The Halbach Array used 4 magnets per pole pair; the rotor had a total of 4 pole pairs.

Outer Rotor

The outer rotor has 52 magnets also assembled in a Halbach Array. There are 13 pole pairs in this rotor.

Flux Modulator

Since the inner rotor to outer rotor magnet ratio in this setup is 4:13, there are 17 steel pieces in the flux modulator, evenly spaced. To maximize the volume of each steel piece, Ismail designed the modulator to fit curved steel pieces. We had the pieces fabricated in a workshop.

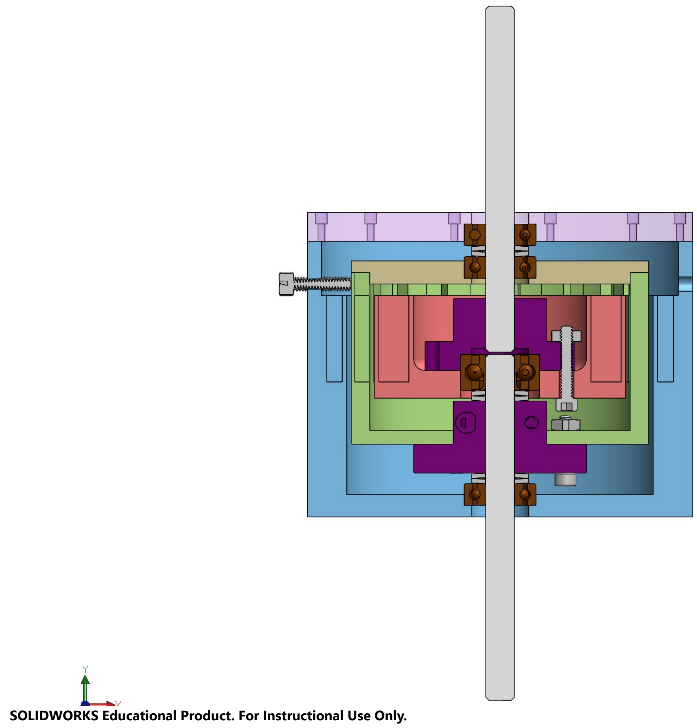

Figure 9. The circular gear as seen from the axial view. The inner rotor is pink, the flux modulator is green, and the outer rotor is blue. Bearings are brown and the input and output shafts are grey(Assembly.SLDASM).

Data Collection and Analysis of Circular Gear

To collect the static, or pullout, torque reading, the base of the circular gear was fixed by a vice while the input shaft was turned with a hand crank and the output shaft turned a moment arm. This moment arm that extended out from the output shaft rested on a scale one foot away from the center of the shaft. The setup can be seen in Figure 11. The scale reading would numerically be the same as the torque in foot-pounds units the scale was set up horizontally from the output shaft. The reading can be repeated with a scale of better resolution and accuracy as the one used here is normally used for rather crude measurements.

As the input shaft was turned, the spot where the maximum torque is transferred was recorded. This was the reading recorded. The static output torque measured was around 2.06 Newton-meters.

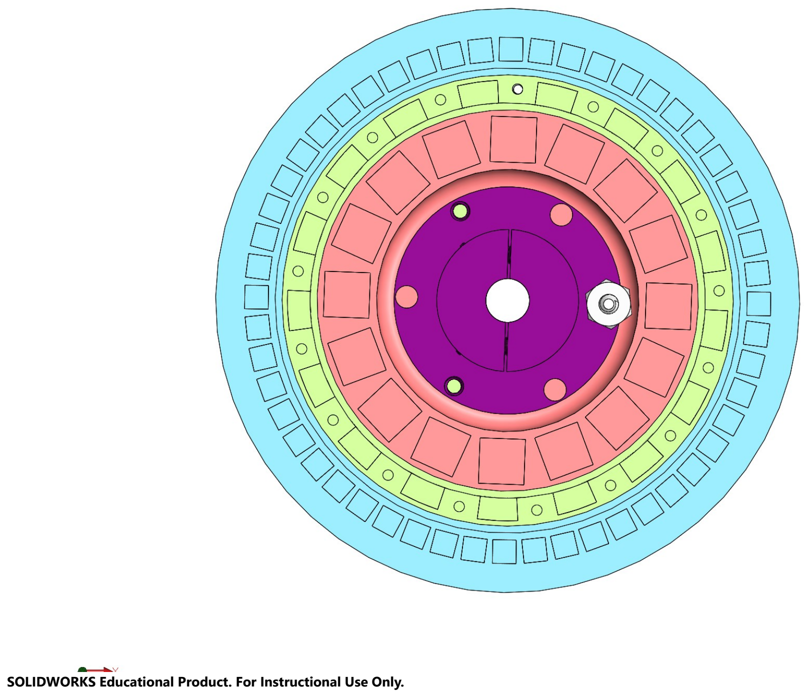

Figure 10. The circular gear as seen from the radial view (Assembly.SLDASM).

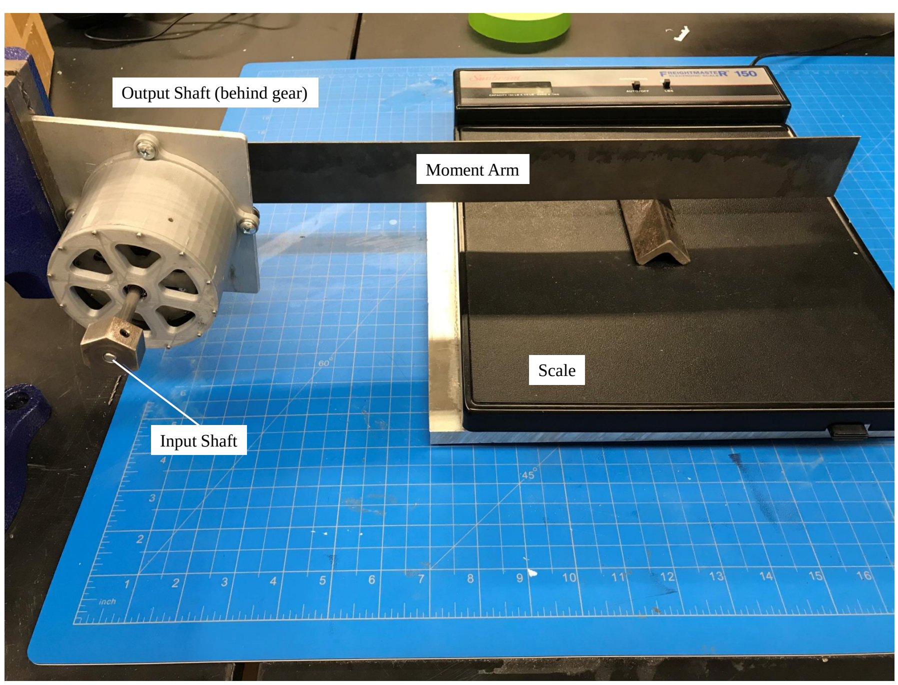

Figure 11. Setup used for collecting static torque outputs.

4. Reading Log

- 5-17-19
  Normal magnetization curve and hysteresis loop as well as the critical points on each curve [1, 4]. Magnetic theory [3]. History of magnetic gears [5].
- 5-20-19
  Lenz's Law, Faraday's Law, and practiced examples through Khan Academy.
- 5-28-19
  Gauss's Law and its derivation [2].
- 5-29-19
  Ampere-Maxwell Equation [2].
  NASA's interest in magnetic gears, its applications, and the beginning stages of their research [6].
- 5-30-19
  DC motors, AC motors, AC current, Induction motors.
- 6-12-19
  The application for magnetic gears in vehicles [7].
- 7-17-19
  Magnetostriction and applications.

5. LaTeX

- 5-15-19
  Installed TexMaker and MikTex onto laptop, started experimenting with the LaTeXlanguage.
- 5-16-19
  Learned how to write math equations by reproducing one of Ismail's report, practiced writing math with equation sheet Ismail sent.
- 5-17-19
  Learned how to include figures into LaTeXthrough reproduction of Ismail's report.

6. Miscellaneous

- 5-22-19
  Started lab report/summer log in LaTeX.
- 5-23-19
  Revised lab report/summer log in LaTeX.
  Machined threaded rod ends for linear build.
- 5-24-19
  Revised lab report/summer log in LaTeX.
  Machined nuts to hold rotors to threaded rod.

- 6-4-19
  Revised lab report/summer log in LaTeX.
- 6-11-19
  Completed lab training modules.
- 6-25-19
  Revised lab report/summer log in LaTeX.
- 7-1-19
  Creation of Linear Data Collection Video (v1).

7. Major Build Days

- 5-15-19
  Started Linear Gear.
- 5-28-19
  Finished Linear Gear.
- 5-31-19
  Started Circular Gear.
- 6-18-19
  Setup linear gear data collection setup.
- 6-24-19
  Finished Circular Gear.
- 7-11-19
  Circular gear housing slippage discovered - gear taken apart.
- 7-17-19
  Circular gear fully assembled - no slippage.

8. To Do

- ~~Write linear mechanics section.~~ -completed 5-29-19
- ~~Fix .dxf image to make clearer.~~ -completed 5-29-18
- ~~Complete circular gear section.~~ -completed 6-5-19
- ~~Construct circular magnetic gear.~~ - completed 6-24-19
- ~~Construct second linear measuring setup.~~ - completed 6-24-19
- Collect all necessary data from linear setup. - in progress
- Look through/learn notes shared by MD and Arun regarding instrumentation.
- ~~Create video of linear data collection.~~ - completed 7-9-19
- ~~PowerPoint of pictures as to edit later.~~ - completed 7-3-19
- ~~Complete circular gear and collect data.~~ - completed 7-17-19
- Create circular gear demo.

9. Outcomes

- Linear Gear Constructed
- Circular Gear Constructed
- Video Created ('linear_demo_v4')

10. Takeaways

This summer has been a great experience because I learned more about the engineering process and what research is. I learned a lot about magnets and I am excited to learn more in the upcoming semesters. Besides magnets, I learned about smart-materials and a few of their applications. I practiced SolidWorks and Adobe Premiere and learned how to write in LaTeX. I became more familiar with machining custom parts and assembling linear and circular magnetic gears with these parts. I have gained interest in simulations and hope that I have the opportunity to learn more about them in the future.

Appendix A - Linear Model

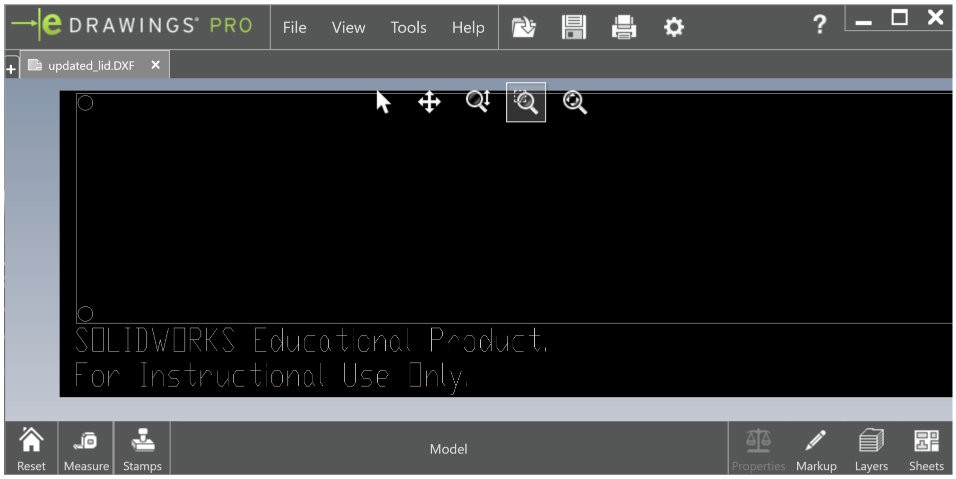

Figure A1. After exporting the .dxf file for laser-cutting the lid, the file opens to show this window.

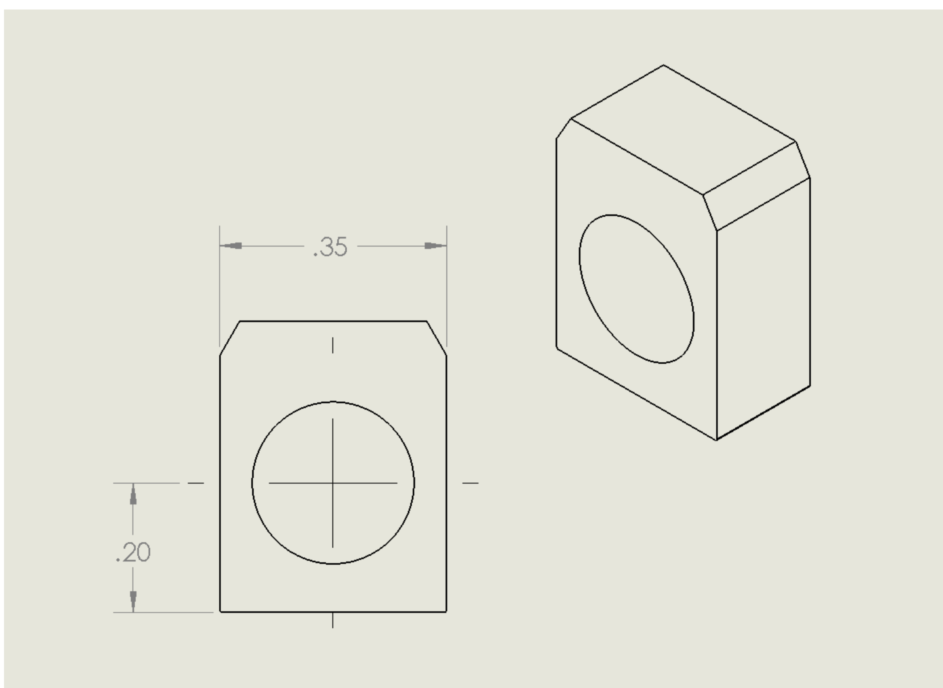

Figure A2. The dimensions of the machined nut are shown in inches (nut.SLDDRW).

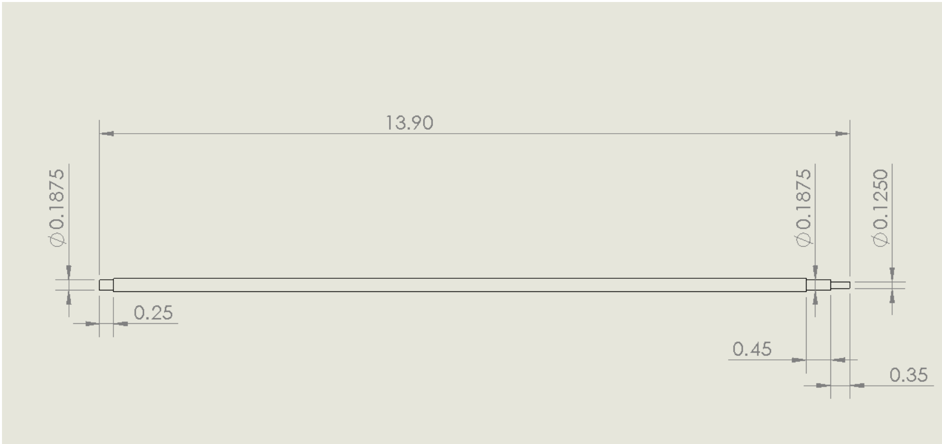

Figure A3. The dimensions of the machined shaft are shown in inches (shaft.SLDDRW).

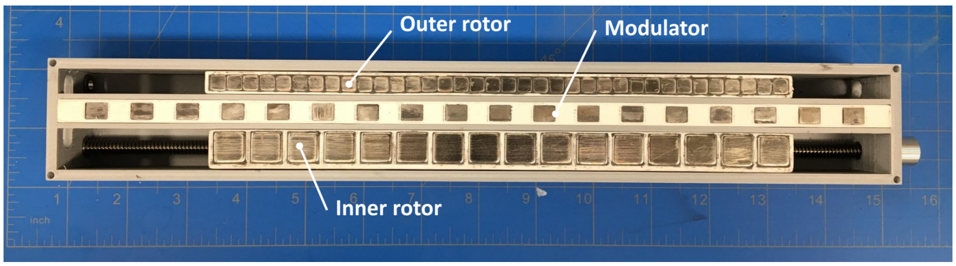

Figure A4. The completed linear magnetic gear: top view.

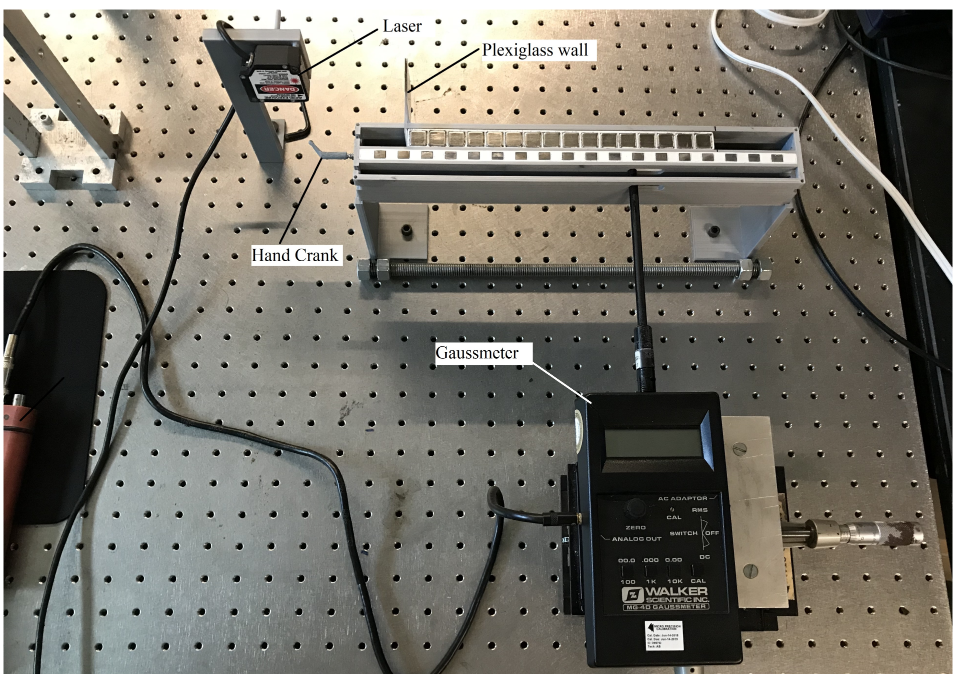

Figure A5. The final data collection setup from above.

Appendix B - Circular Model

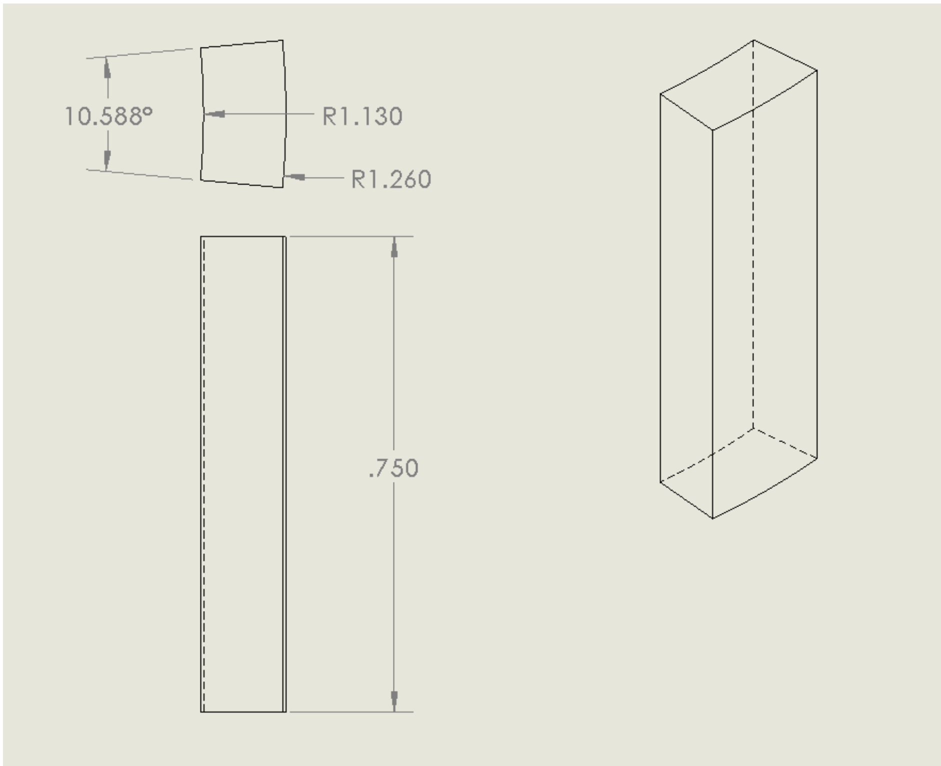

Figure B1. The design of the curved flux modulator piece (flux_modulator2.SLDDRW).

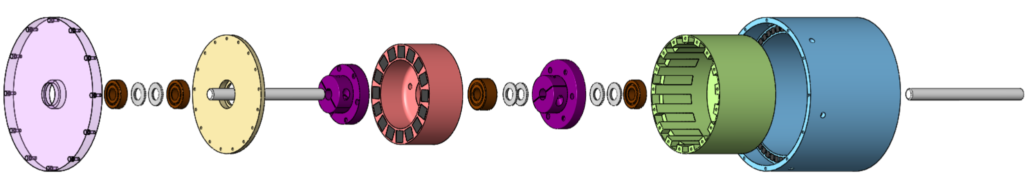

Figure B2. An exploded view of the circular gear (Assembly.SLDASM).

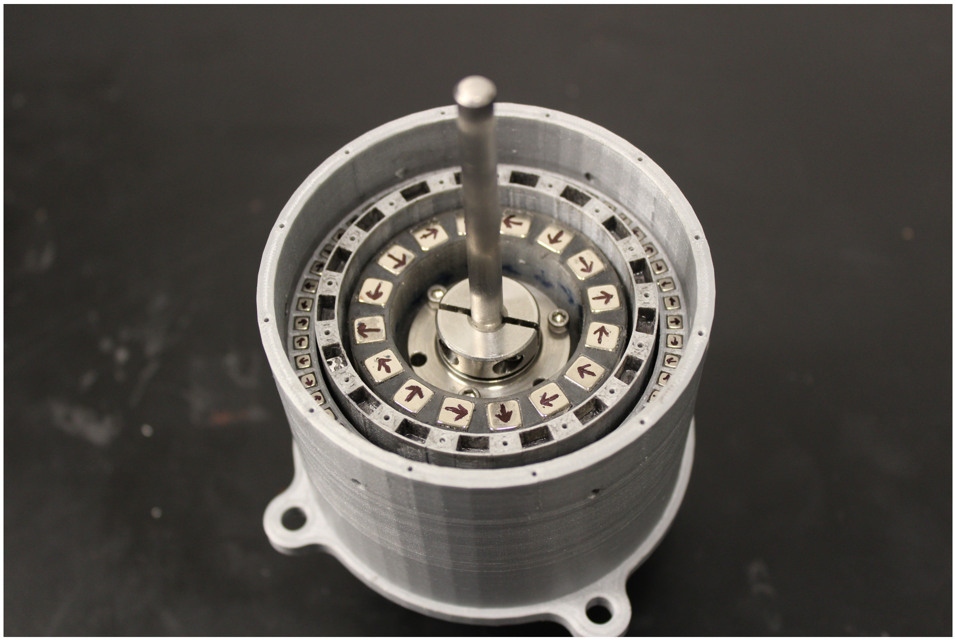

Figure B3. The circular gear assembled without the lids.

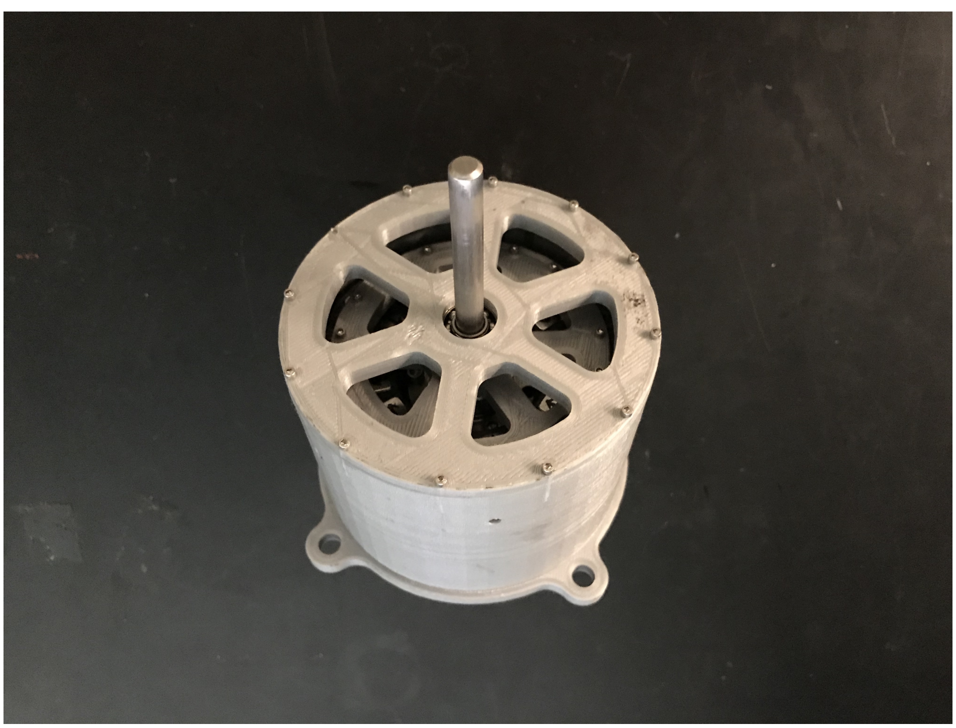

Figure B4. The circular gear fully assembled.

References

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