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Non-Contact Torque Transfer Using Ferrofluid

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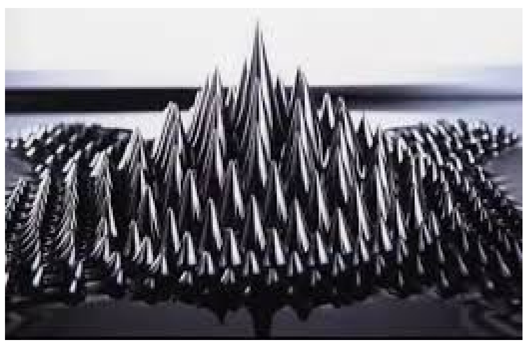
Non-Contact Torque Transfer Using Ferrofluid



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Sponsor: Dr. Nassersharif
Faculty Advisors: Dr. Nassersharif
Submission Date: May 6, 2019

Abstract

Gearing systems are a mechanical based systems that allow an input shaft torque to increase or decrease when it is transferred as an output shaft. Although the gearing system is an old creation that holds little mysteries in the current day, the complexities used to adapt it to new applications continues to grow. The invention discussed and researched in this paper goes in depth on how the gearing system was redesigned to accommodate new uses along with making the system more efficient.

A gearing system uses a solid surface to surface contact to transfer the torque from input to output. Overtime, the solid contact surfaces deteriorate due to friction and inefficiencies causing the destruction of the system. In order to produce longer lasting gearing system that require less maintenance and reduce the wear within the system, a more efficient and durable process must be implemented.

This paper discusses the redesign of the common gearing system referred to as the non-contact torque transfer using ferrofluid. The ferrofluid gearing system was created within the bounds specified by the sponsor, Dr. Nassersharif. It has been designed to outlast other gearing systems, making it appeal to the customer demand through implementing magnets and ferrofluid. Through calculations and physical observations, the ferrofluid gearing system proved to work and the design concept is able to be patented.

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List of Acronyms

CVT: Continuously Variable Transmission

IVT: Infinitely Variable Transmission

DMV: Department of Motor Vehicles

PLA: Polylactic acid

DOT: Department of Transportation

Nomenclature

A Area (m^2)

F Force (N)

h_i Film thickness at the inlet (m)

h_0 Film thickness at the outlet (m)

L_1 Land 1 Length (m)

L_2 Land 2 Length (m)

P Pressure (Pa)

U Velocity (m/s)

v Velocity (m/s)

y Depth (m)

η Absolute Viscosity (Pa * s)

ϱ Density (kg/m^3)

ν Kinematic Viscosity (m^2/s)

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Introduction

An invention is defined as a device, contrivance, or process originated after a study or experiment [1]. The task for this capstone design project was to produce a sophisticated mechanical based invention that solves a problem of interest to a large population of people with an end goal of a patent or publication. The invention design had to be approved by the team's sponsor Dr. Nassersharif, and the total prototyping and redesign process needs to fit a budget of three hundred dollars. Through much analysis and deliberation the team decided the invention project would be the a method of non-contact torque transfer using ferrofluid as a medium.

There are many mechanical applications in which this invention can be implemented, however the most practical one and the one where this would have the most impact is the automotive industry. Specifically looking at normal transmissions and continuously variable transmissions.

A continuously-variable transmission (CVT) unlike a conventional automatic transmission has uses no gears to send the power produced by the engine to the wheels of a car. It instead uses variable-width pulleys connected by a belt. The shape of a CVT also differs. Held together by the variable width pulleys are two cone shaped pieces as shown in the figure below.

Figure 1: Continuously Variable Transmission [2]

The advantages of a CVT in an automobile include obtaining maximum power from a small engine for a faster acceleration, smooth acceleration without interruption for gear shifts and because CVT's are typically lighter than automatic transmissions they deliver better power efficiency. A disadvantage however is that CVT's are expensive to repair and replace when they do malfunction. The CVT belt is subjected to a lot of wear/tear and can often stretch beyond its allowable tolerance or in some cases even break completely. The invention of a ferrofluid transmission would greatly reduce the wear and tear on a typical CVT, thus reduces the need for expensive repairs and replacement for a lot of people because CVT's are very common in cars today.

Ferrofluid was discovered at a NASA research center in the year 1960. It's unique trait is that it has the fluid properties of a liquid along with the magnetic properties of a solid. This is because it contains tiny solid magnetic particles contained in a liquid medium, usually some type of oil-like substance [3]. When exposed to a magnetic field ferrofluid takes the shape of the field, often producing an array of spikes as shown in the figure below.

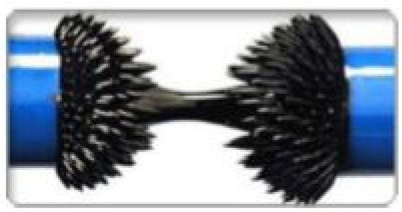


Figure 2: Ferrofluid in a Magnetic Field [4]

Because of its magnetic properties ferrofluid has been found to aid in many applications. For example, ferrofluid has the ability to behave as a liquid O-ring. Held in place by permanent magnets, ferrofluid can form an extremely tight seal while producing producing a fraction of the amount of mechanical friction usually produced because of it's liquid properties [5]. Because ferrofluid can form such a tight seal when it's exposed to a strong enough magnetic field, it has also been found that it can substitute as a valve for controlling flow of certain liquids. Using external magnets to actuate the ferrofluid, it can be used to seal of a section of pipe or other material to regulate flow. In a study conducted by Schwerdt, Bau and Thompson at John Hopkins University it was found that ferrofluid could withstand pressures up to 12 kPa and could be open or closed against pressures up to 5 kPa [6] in polycarbonate devices. Even though the material is not applicable, the team was encouraged by the results of this study because an original concern of this invention project was whether or not the ferrofluid would be able to withstand the forces felt in a continuously variable transmission.

The goal of this application of the invention is to produce a more efficient version of an transmission to reduce the maintenance and repairs required for many people. The overall objective of the capstone project is to obtain a utility patent for the teams idea of non-contact torque transfer through ferrofluid.

Patent Searches

US5007513A-Electroactive fluid torque transmission apparatus with ferrofluid seal [7]
This patent was used to understand how fluid transmission torque works so that the ferrofluid transmission can apply a maximum amount of torque and thus a maximum amount of rotational motion from the input shaft to the output shaft.

US4502700A-Ferrofluid linear seal apparatus [7]
This patent was used to understand how ferrofluid can be used to seal something using its magnetic properties for use in the ferrofluid transmission as a seal between the two transmission cones. By creating a temporary seal between the two cones, it would be possible for the ferrofluid to act as a third gear between the cones, thus allowing for a maximum amount of rotational energy to be transmitted.

US3917538A-Ferrofluid compositions and process of making same [7]
This patent was used to understand how ferrofluid is made and how to keep the iron particles in suspension in the fluid used. For the ferrofluid transmission, different viscosity ferrofluids were used and it was determined that the more viscous the fluid, the better the transmission of rotational motion between the two transmission cones. However, the more viscous the ferrofluid, the harder it was to move the ferrofluid from one location on the input transmission cone to another and the more likely it was for the iron particles to come out of suspension.

US7288860-Magnetic transducer with ferrofluid end bearings [7]
This patent was used to understand how a magnet interacts with the ferrofluid and how the ferrofluid can be controlled by magnetism. This patent also discussed magnetic configurations, which will be useful in Spring 2019 as electromagnets are implemented into the design.

US2199095-Automatic transmission [7]
This patent was used to understand the automatic transmission, which it the most widespread transmission product on the market today and thus the biggest competition for the ferrofluid transmission. This patent also helped to explain the most important considerations for a transmission to be effective and efficient, such as gear ratios and torque.

US3451283A-Infinitely variable cone pulley transmission [7]
This patent was used as a basis to develop the improved cone structure of the ferrofluid transmission in which the cones would have grooves for improved functionality. This patent also helped to understand a competitive product since it is also for an infinitely-variable transmission.

US4484493-Cone pulley V-belt continuously variable transmission [7]

This patent was used as a basis to develop the improved cone structure of the ferrofluid transmission in which the cones would have grooves for improved functionality. This patent also helped to understand a potentially competitive product since it is for a continuously-variable transmission.

Evaluation of the Competition

Because the invention of this capstone project was the idea to use ferrofluid as a non-contact method of transferring torque, the specific application of using this in a transmission was analyzed as this is the most marketable use.

Upon conducting a market analysis of the transmission market, and specifically the continuously-variable transmission market, it's been found that North America has both the highest value market and also the highest growth rate, making the USA the perfect place to start marketing the ferrofluid transmission product, as shown in the figure below:

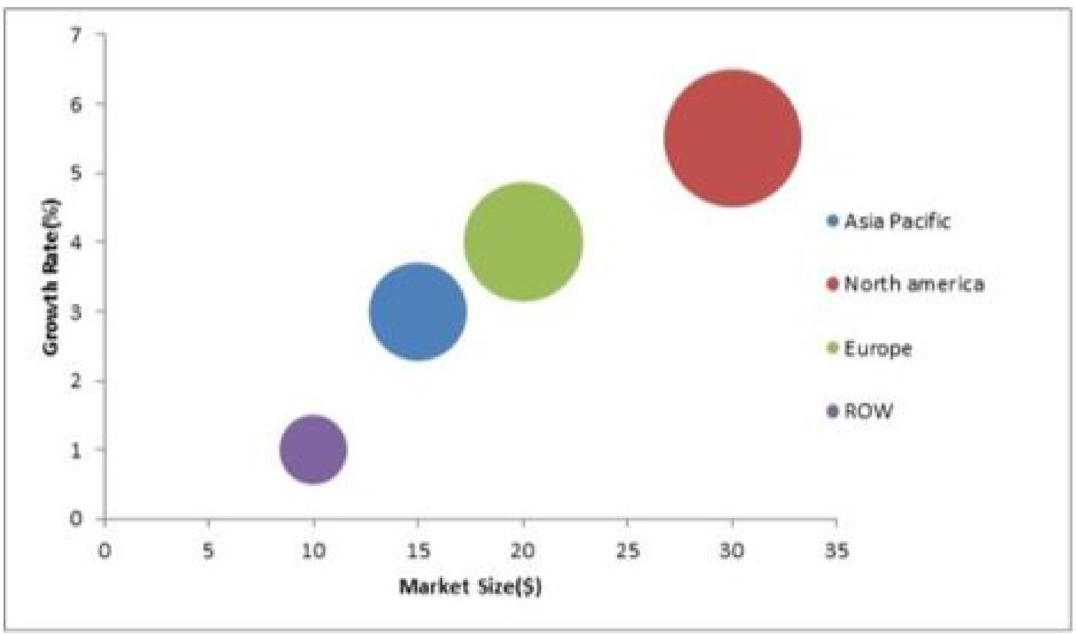


Figure 3: CVT Market Growth Rate by Region

The key companies of the CVT market that the ferrofluid transmission product would be competing against include BorgWarner, Jatco, Punch Powertrain, Toyota Motors, ZF Friedrichshafen AG, Aisin Seiki, Efficient Drivetrains, Folsom Technologies International, Hunan Jianglu & Rongda, and Hyundai Motor [12]. The advantage the ferrofluid transmission product has over the CVT's produced by these companies, however, is that it will require significantly less maintenance which will make it more appealing for consumers looking for efficiency and to save money.

Specifications Definition

Table 1: Design Specifications

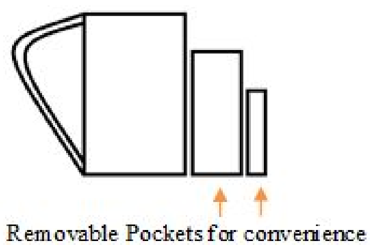
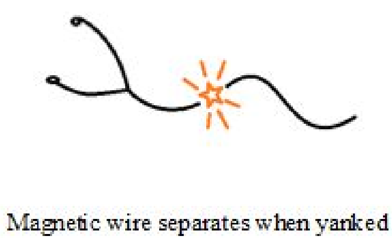
Category	**Design Specifications**
Product Identification	Name: ● Magnetic Transmission Function: ● As a transmission with infinitely variable input to output ratios Special features: ● Infinitely variable input to output ratios ● Fuel efficiency Key performance targets: ● Power output, Efficiency, Durability, Fuel economy Service environment: ● Transportation
Market Identification	Description of target market: ● Transmission manufacturers, very large market (global size) ● Anticipated market demand (units per year) depends on efficiency/cost-effectiveness (mpg rating) Competing products: ● Continuously variable transmission designs ● Standard automatic car transmissions Branding strategy: ● Trademark, logo, brand name Reasons for designing/building: ● To improve fuel efficiency/reduce pollution (improve mpg rating) ● Many other designs exist already, but most use complicated gear systems and ratios or parts that would easily wear out
Design Variables	What is known (general): ● Use of magnetic fluid to transmit rotational motion from input to output in a transmission Known design variable values: ● Dimensions of car transmission ● Properties of ferrofluid (viscosity depends on oil mixture) ● Frictional coefficients of tested materials [8]: ○ Plastic on plastic: 0.3-0.4 ○ Plastic on metal: 0.25-0.4 Dimensional Constraints [9]: ● Size (no larger than standard car transmission, approximately 24” x 24”) ● Weight (no greater than standard car transmission: approximately 100 - 400lbs)
Financial Requirement	What are the assumptions: ● Will create a large market by making transmission more efficient and durable (lower maintenance costs, higher power output, better fuel economy etc.) What are the criteria on profitability: ● To be determined based on the price to manufacture a singular ferrofluid transmission unit. Design not finalized.

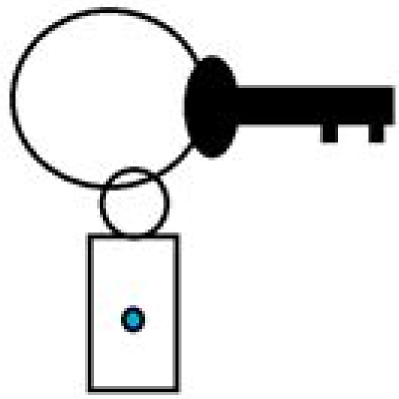
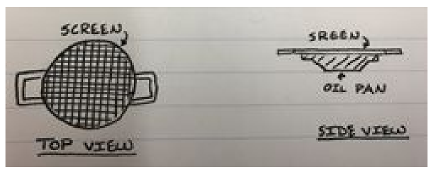
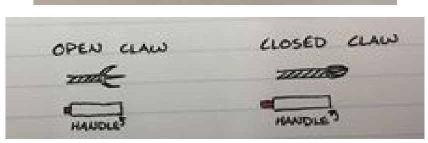
	Pricing policy over life cycle: ● As part of a whole car, the price of the transmission would be discounted to grab consumers attention. The spare parts would be sold at regular cost to prevent bankruptcy or negative profit. Overall would try to mimic other companies and their plans to help prevent customer confusion. Warranty policy: ● To be determined based on experimental results. In general, the transmission should last the life of the car. Expected financial performance: ● The rate of return would be slow during the production and selling as part of a whole car but will increase as people begin to buy spare parts. Level of capital investment required: ● To be determined by further research
Life Cycle Targets	What targets should be set for the performance of the product over time? ● Same life expectancy and continuous high quality performance as standard vehicle Applicable end-of-life policies: ● US metal recycling policies Cost of installation and operation (energy costs, crew size, etc.) ● To be determined by further research Maintenance schedule and location (user-performed or service centered) ● To be determined by further research Reliability (mean time to failure): ● To be determined by further research (May be important to consider effects of frictional wear on rotating parts, effects of heat on ferrofluid viscosity) End-of-life strategy: ● 100% recyclable components that can be reused/remanufactured
Social, Political, and Legal Requirements	Legal Requirements: ● US DOT controls and regulates car/car parts allowed on the roads. ● Product is patentable. ○ The idea of a magnetic transmission has not been patented ○ Ferrofluid and previously used transmission parts are patented and would not be included in the patent. Social Requirements: ● Environmentally Friendly: The design incorporates a safe way to ensure no ferrofluid escapes from the transmission No Political Requirements relevant at this time however will be addressed later on as design is finalized if one arises.
Manufacturing Specifications	Which parts or systems will be manufactured by the team: ● The team manufactures a prototype transmission and acquires ferrofluid and magnetic particles from an outside source (Amazon) Manufacturing requirements: ● $300 budget ● The team utilizes the 3D printer to manufacture transmission prototypes Suppliers: ● Ferrofluid/iron particles: Amazon ● 3D printing material: URI ● Waterproofing/Sealant/Magnets: Home Depot

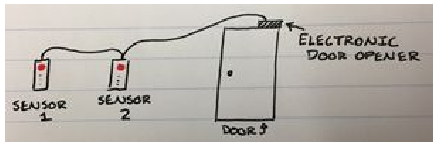
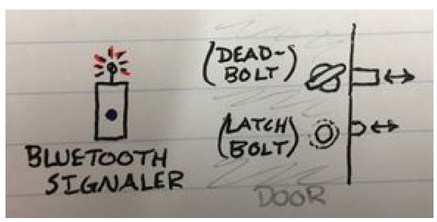
Conceptual Design

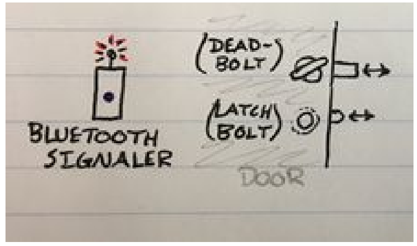
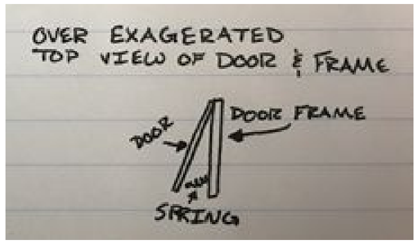
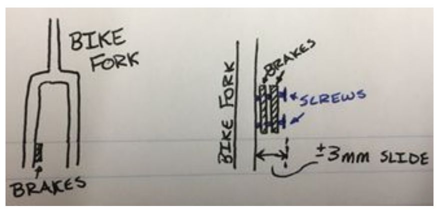
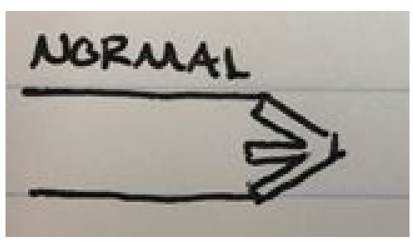
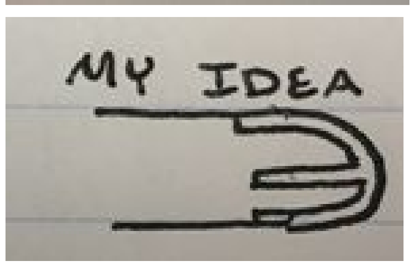
It should be noted that the concept generation was completed as one of the first assignments of the semester in which a multitude of possible inventions were generated instead of designs of the final invention. This was used to decide on the final invention project: the ferrofluid transmission.

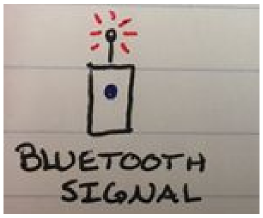
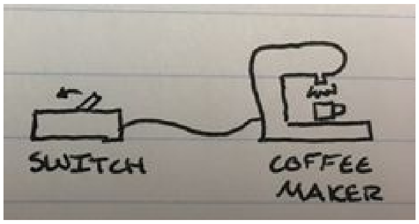
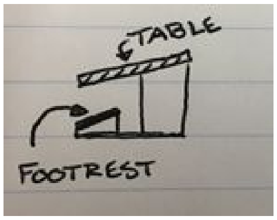
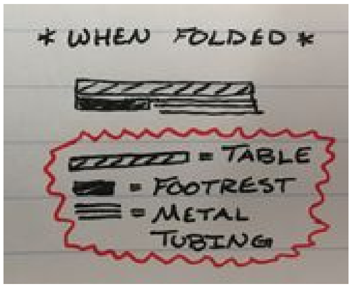
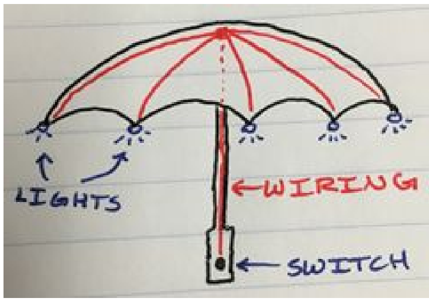
Table 2: Concept Generation & Analysis

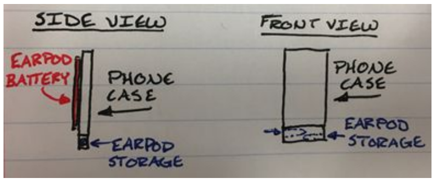
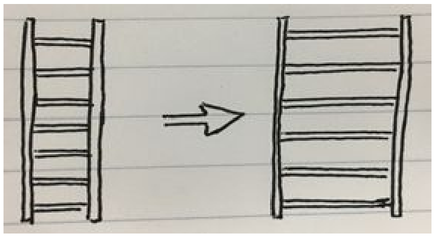
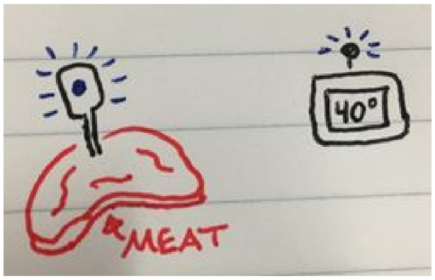
Concept Name	Concept Rendering	Concept Evaluation
1. Pull Apart Backpack		The pull apart backpack allows one to add on pockets and take pockets off. This would reduce excess weight when pockets are not used. Having less weight to carry makes the backpack more comfortable and ergonomic. The pockets would attach to the backpack through zippers and would remain water resistant.
2. Magnetic Earphones		The magnetic earphones are able to detach when the cord is yanked. This prevents the earbuds from tugging at your ears whenever the cord is pulled taught. The cord will have two parts; the first being the bottom half that connects to the music device and the second being the top half that has the earbuds that go in the ear. These two halves would be held together by a magnet that would be able to break apart when a large enough dynamic force is applied.

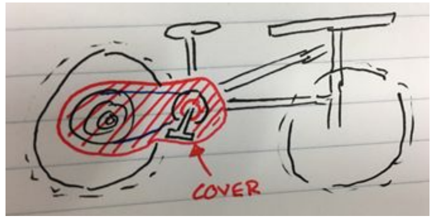
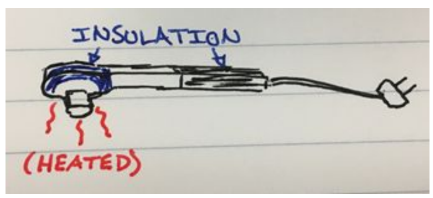
3. Keys Tracker		The key tracker allows a person to track their keys to a 3 foot radius. A Bluetooth box that would be small enough to fit onto a keychain would connect wirelessly to a smartphone. Using this Bluetooth signal, the phone would be able to locate and track the whereabouts of the keys at any point in time. The Bluetooth box would run on a small battery and always stay connected to the smartphone.
4. Magnetic Screen		The magnetic screen would be a device used when changing the oil in a car. The screen would easily fit over the oil pan and catch the screw/bolt from being dropped into the oil pan. It will also allow the oil to flow through the screen without a lot of disruption.
5. Snake with Claw		The snake with claw is a device used to retrieve objects in hard to reach places. The device has a handle at one end and a retractable claw at the other. The main body of said device would resemble the plumbers cleaning "snake" which could also be described as an extremely flexible rod. The handle would have a button that allows the claws to open and fit over an object. Once the button is released, the claws would close on the object allowing for it to be retrieved from the place it

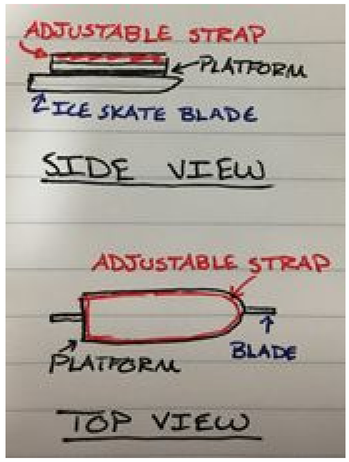
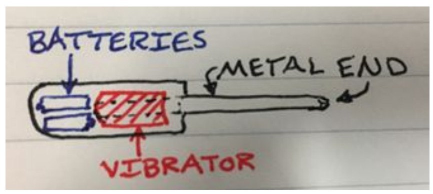
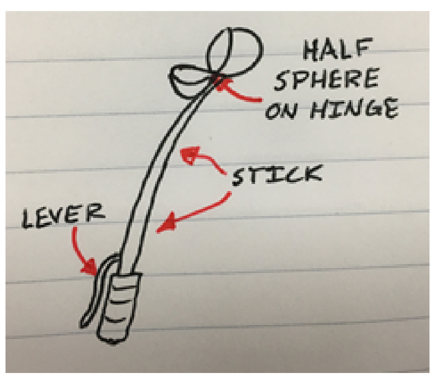
		fell.
6. Bathroom Sensor		The bathroom sensor is a simple design that uses two sensors to open a door. Currently, most bathroom doors require the person to open the door after using the bathroom. The door handle is covered with germs and reverses the effects of washing your hands. The bathroom sensor would automatically open the door to prevent the spread of germs. The two sensors would detect a person approaching the door by tracking the movement; if the movement is towards the door then the door will open, if it is away from the door then it will not open the door.
7. Electronic house Door Opener (inner unlocking mechanism)		The electronic door house opener is a way for a person to enter their house hands free. Similar to electronic deadbolts, the latch bolt would also be electronic allowing all bolts to be free of the doorway. The electronic deadbolt and latch bolt would be connected to a wireless device operating by a Bluetooth signal. At the push of a button both bolts would slide into the door and out of the door frame allowing one to enter their home with a simple push.

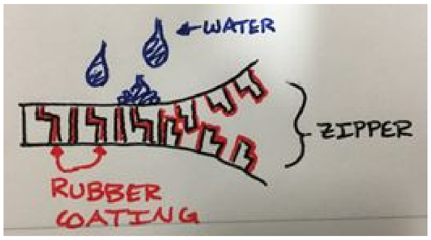
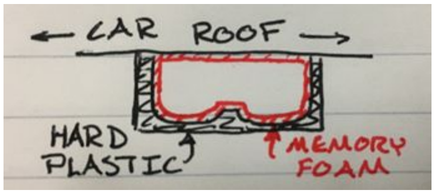
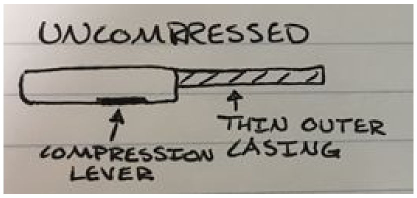
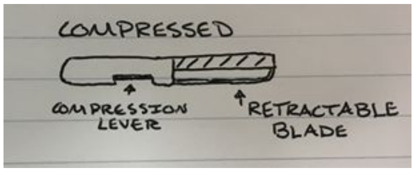
8. Electronic House Door Opener (door propping mechanism)	 	The electronic door opener would be extremely similar to the one stated above however, instead of the person pushing the door open, the door would crack open allowing for less of a force to open it. Everything would remain the same in terms of electronic bolt action, but now there would be an additional device attached to the door that would spring open when signaled and ideally open the door an inch to three inches.
9. Flexible Brake Pads		The flexible brake pads are able to adapt to warped rotors on mountain bikes. These rotors easily bend during the regular mountain bike ride. Having flexible brake pads allows a longer life for both the brakes and rotor by moving the brake pads to the pitch of the rotor.
10. Anti-strip Screwdriver Head	 	The anti-strip screwdriver head is a way of preventing stripping the head of a screw. Instead of the current tapered head, this screwdriver would have a fillet or more rounded head. The rounded tip would allow the screwdriver to be able to turn the screw at a wider range of angles and still fit tightly into the screwhead slots.

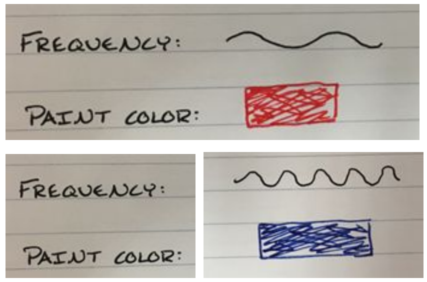
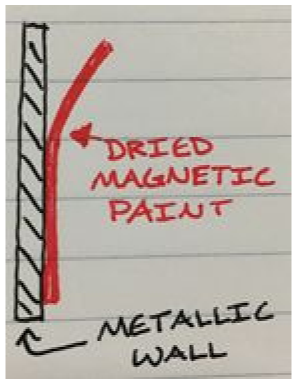
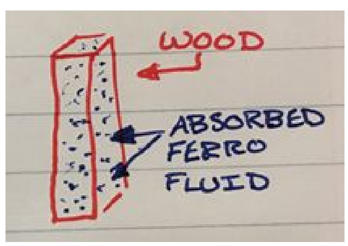
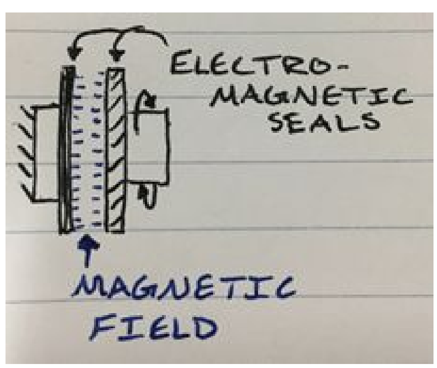
11. Remote Control Coffee Maker	 	The remote control coffee maker would be able to turn on and start brewing at the push of a button. Unlike modern coffee makers that have a timer to turn on, this coffee maker would be able to turn on at any given moment without human interaction. The coffee maker would be connected to a Bluetooth switch that flips on when activated.
12. Toilet Table	 	The toilet table is a foldable work station when on the go. It has an adjustable table height along with a footrest for a more ergonomic bathroom visit. The table and footrest would be a plastic material while the rest of the setup would be hollow metal tubing that pivots on its joints so that the whole system is collapsible.
13. Light Up Umbrella		The light up umbrella would have small LED lights in each tip of the umbrella. The lights would be connected to a small switch on the umbrella handle. The lights would allow the person to see where they are walking and for others to notice where the person is. More specifically this would help pedestrians from walking into hazards normally not seen in the rain and alert drivers where these pedestrians are walking as to not drive into them.

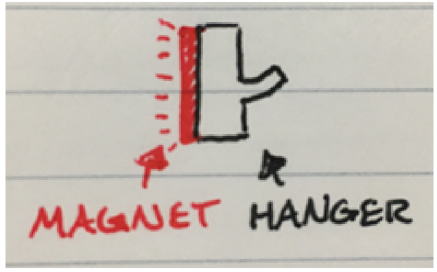
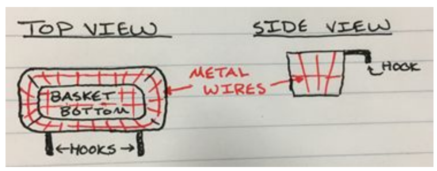
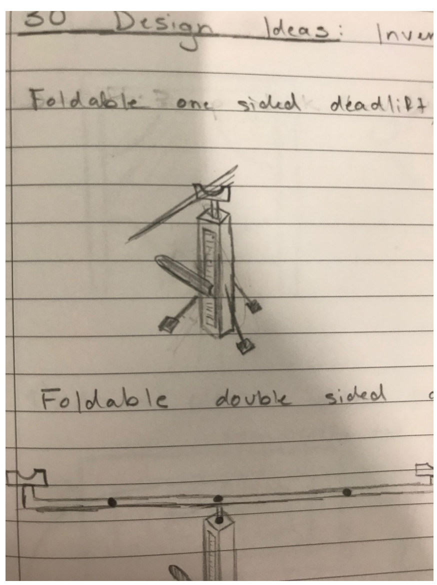
14. Phone Case with Earpods Holder		The phone case with earpods holder is a normal iPhone case that has a small extension at the bottom to place the Bluetooth earpods into. There would be a thin rechargeable battery imbedded into the case that would automatically charge the earpods. The material of the phone case would be a hard plastic outside with a rubber cushion on the inside to absorb impact while still being durable.
15. Sideways Extending Ladder		The sideways extending ladder would be able to ex tend the ladder to 1.5 to 2 times the original width. The ladder will not only still extend vertically as intended, but it will be able to extend horizontally as well. This allows a wider area for both the base and top of the ladder to push against creating a more stable environment.
16. Wireless Meat Gage		The wireless meat gage displays the temperature of the meat safely outside the oven. The gage that is placed in the meat would have a temperature protected circuit board that gives off an electronic signal to a separate display unit. The circuit board will have to be encased in a material that is insulating and prevents heat from penetrating through the material.

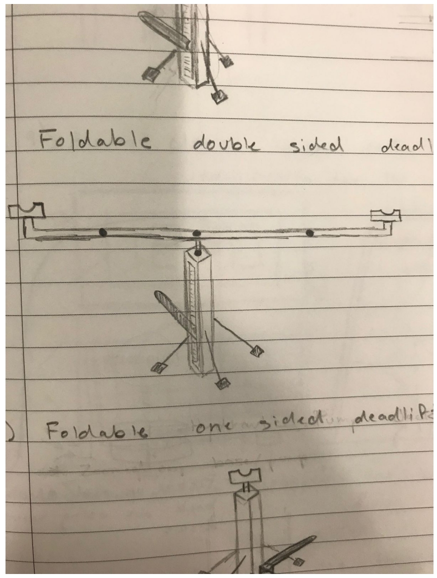
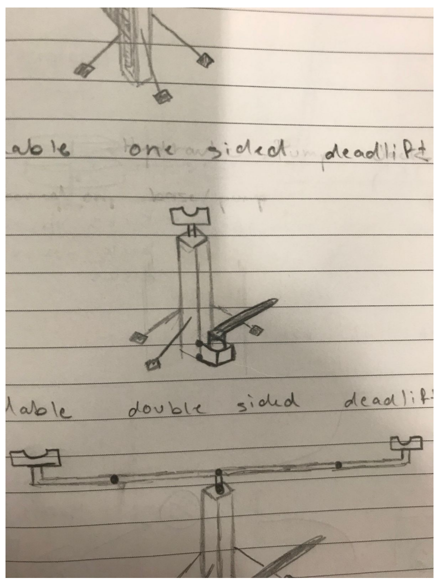
17. Bike Crank and Cassette Cover		The bike crank and cassette cover is stretchable cloth that covers the crank and cassette of a bike during storage. This cover has the sole purpose of keeping the chain and cassette grease from getting on clothes and other objects. The design would be a durable nylon material with an elastic around the edges that allows the cover to stretch over the cassette and wrap around it snug. The cover will also have a hole large enough to fit the pedal through.
18. Heated Torque Wrench		The heated torque wrench would have an electric coil surrounding the head of the wrench. The handle would be insulated and have a power cord extending out of it. The wrench head would be insulated as well and only allow the heat to escape through the side facing the bolt. The purpose would be to easily loosen the bolt and require less force to free a stuck bolt.

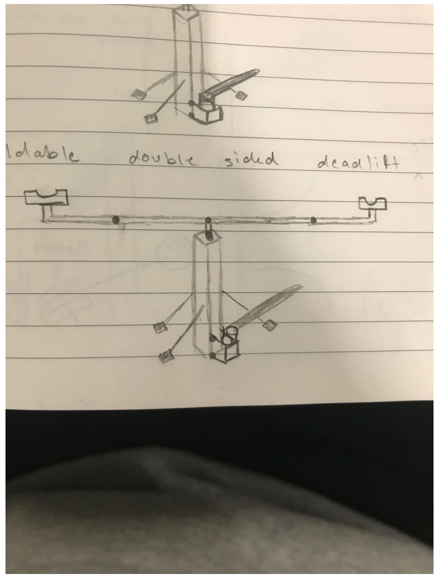
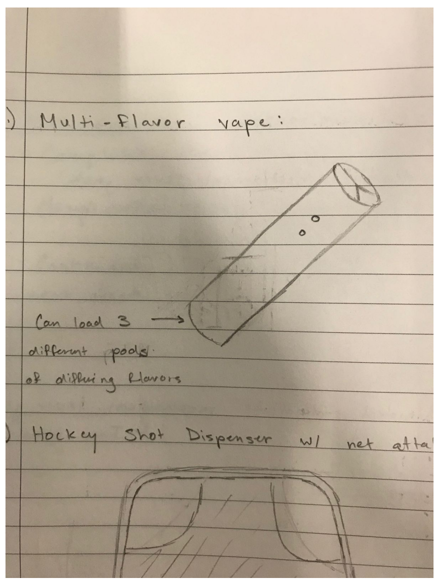
19. Slap-on Skates		The slap-on skates are ice skating blades that attach to the bottom of any shoe. The design would have a platform that the shoe fits onto and held in by adjustable straps. Under the platform would be the ice skating blade. This design would allow people to skate in more comfortable shoes and make the process from land to ice more efficient.
20. Vibrating Electric Screwdriver		The vibrating electric screwdriver uses small vibrations to help loosen stuck screws. There would be a small vibrator inserted into the handle of a screwdriver and attach to the metal end. The vibrator would run on batteries and not alter the exterior shape of a normal screwdriver.
21. Snowball Stick		The snowball stick is a long handled stick that most resembles the dog-tennis ball thrower. The handle end would have a small lever that allows a child to compress snow into the shape of a ball. The other end would have two hollow half spheres that shape the snow into a ball form when the lever is pulled. When the lever is released, the hinged half sphere flips down and out of the way. The child can then launch the snowball through the arc of his arm holding the stick.

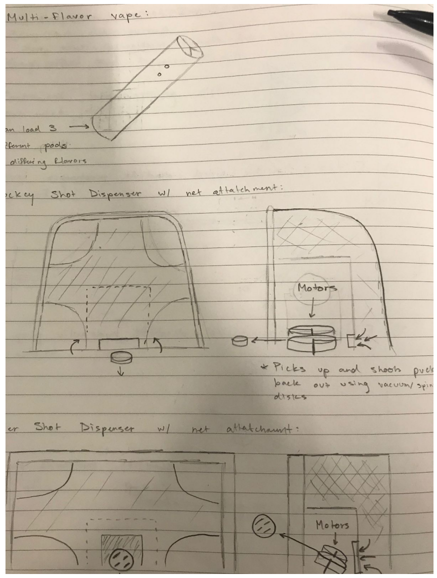
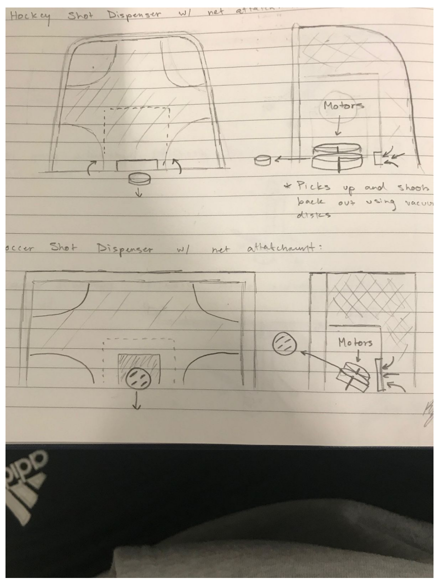
22. Waterproof Zipper		The waterproof zipper would use a rubber coating to prevent water from passing through. The metal zipper components would be dipped in a rubber finish so that when they are joined together, the rubber coating squishes together creating a seal similar to the way rubber insulation prevents the escape of heat.
23. Car Sunglasses Holder		The car sunglasses holder would be wear and tear free when storing a pair of glasses. Personally, in my car my glasses frames are rubbing against the hard plastic which in turn has left scrape marks. This new holder would be layered in memory foam to mold to the shape of each pair of glasses while remaining soft enough to leave no mark on the glasses.
24. Safety Knife		The safety knife is a regular household knife that prevents people from accidentally cutting themselves. The design would be a regular knife that only exposes the blade when the handle is compressed. The blade would be retracted into a thin outer casing when the handle receives no compression. When the handle is compressed, the blade will be exposed and allow a person to safely use the knife.

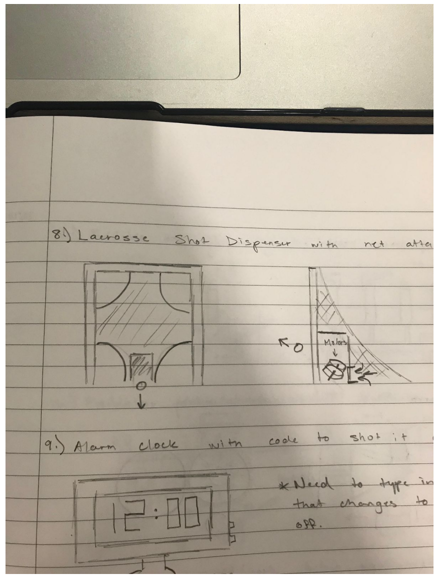
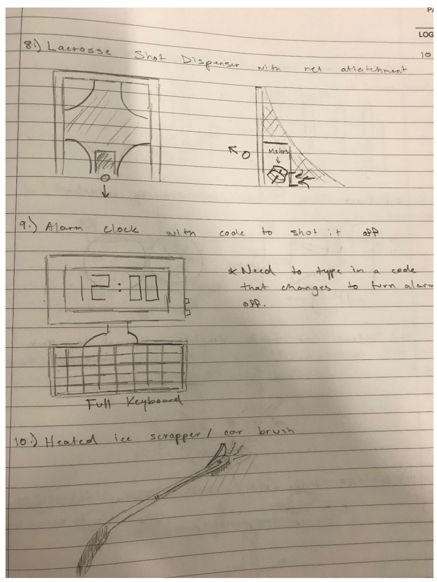
25. Electric Paint		The electric paint is a type of paint where electrodes are imbedded in the paint molecules. When a certain frequency of electricity runs through the paint, the paint is able to change colors.
26. Magnetic Paint		The magnetic paint uses miniscule particles of magnetic material that are dyed a certain color and have the properties of a liquid. The paint would be able to stick and to multiple metal surfaces and be able to be reused. The paint could also be peeled off and stuck to another metallic wall.
27. Magnetic Wood		The magnetic wood would be logs of wood submerged in ferro fluid (magnetic fluid). The wood would absorb the microscopic magnetic flakes. Once the magnetic flakes are absorbed into the wood, the wood would have magnetic properties that could be used in numerous industrial fields.
28. Electromagnetic Seal		The electromagnetic seal would ultimately be a frictionless seal that could have a changeable distance between both surfaces. The electromagnetic seals would use the same magnetic pull to repulse on another creating a frictionless surface. The seals could also be magnified more or less, creating a larger or smaller gap between the

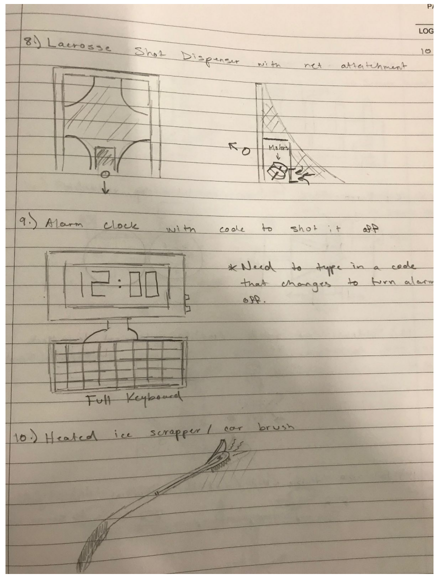
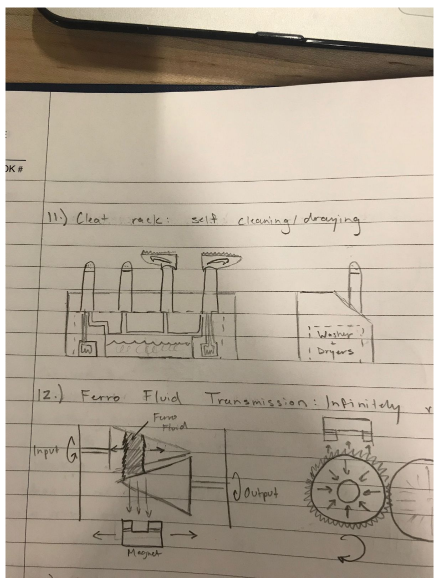
		surfaces.
29. Magnetic Coat Hanger		The magnetic coat hanger would stick to any metallic surface and be able to hold a coat or jacket. More importantly this coat hanger can be brought almost anywhere and is easy to carry around in a backpack. One side would have the super strong magnet and the other would have a hook for a jacket to latch on to.
30. Toilet Basket		The toilet basket attaches to the side of a toilet bowl and can hold books, bags, and briefcases. I will hang off the side of the bowl for easy reach and keeps the items stored inside from touching the dirty bathroom floor. It will be made of strong metal wire to prevent from bending under heavy loads.
31. Foldable one sided deadlift mechanical lever jack with free head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.

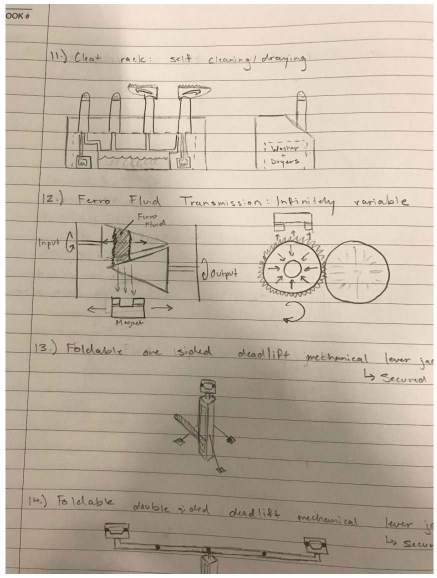
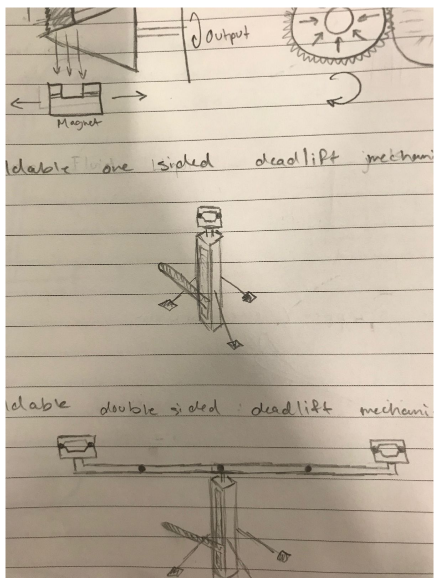
32. Foldable double sided deadlift mechanical lever jack with free heads		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.
33. Foldable one sided deadlift hydraulic pump jack with free head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.

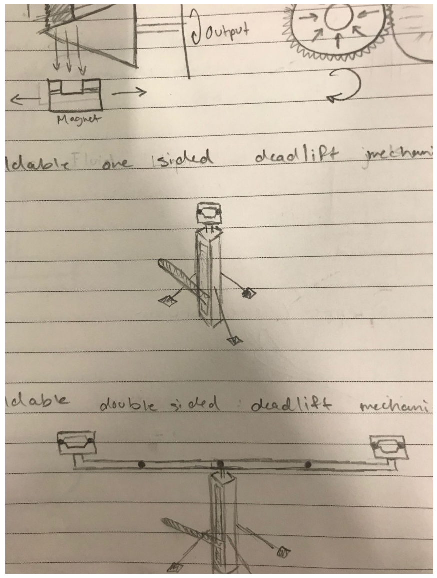
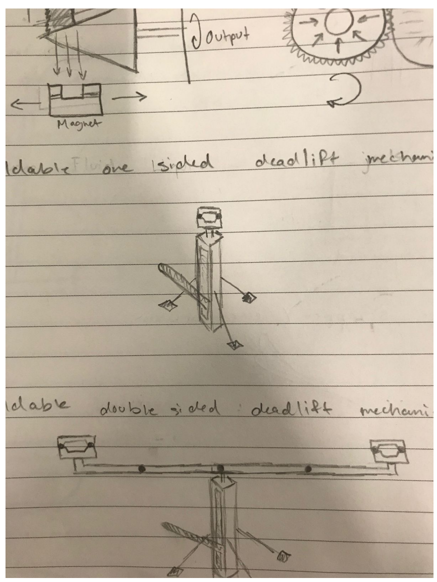
34. Foldable double sided deadlift hydraulic pump jack with free heads		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.
35. Multi-Flavor Vape		Through engineering analysis it was determined that this invention idea was more electrical based than mechanical based.

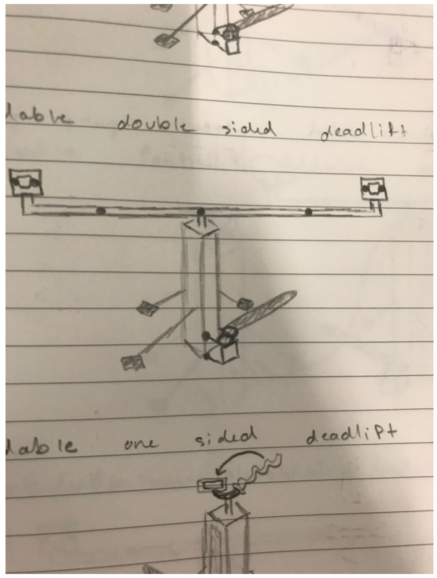
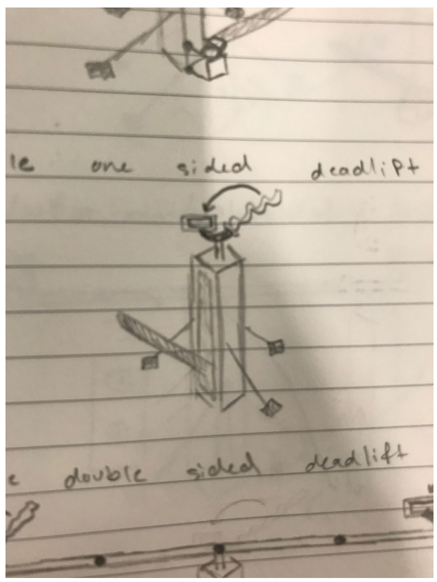
36. Hockey Shot Dispenser with net attachment		Through the patent analysis it was determined this was too similar to an existing patent, thus not fulfilling the design specifications.
37. Soccer Shot Dispenser with		Through the patent analysis it was determined this was too similar to an existing patent, thus not fulfilling the design specifications.

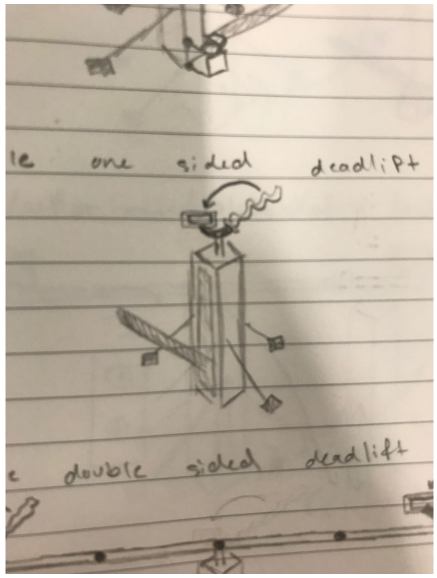
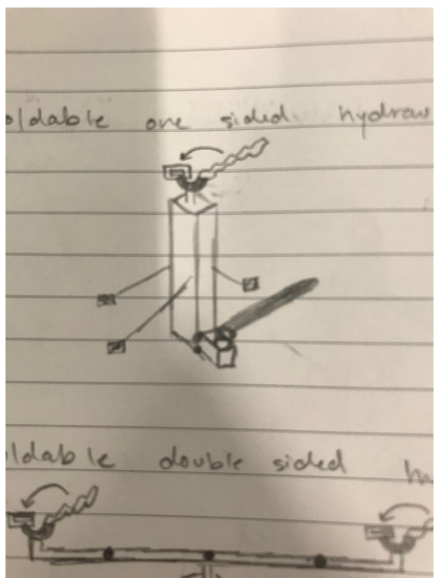
<table>
<tr>
<td>38. Lacrosse Shot Dispenser with net attachment</td>
<td>
</td>
<td>Through the patent analysis it was determined this was too similar to an existing patent, thus not fulfilling the design specifications.</td>
</tr>
<tr>
<td>39. Alarm Clock with code to shut it off</td>
<td>
</td>
<td>Through the patent analysis it was determined this already patented, thus not fulfilling the design specifications.</td>
</tr>
</table>

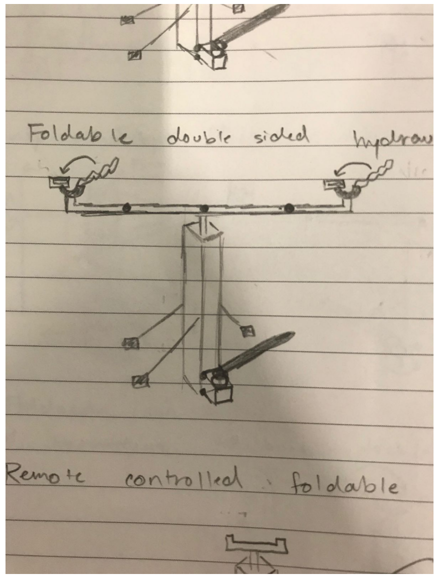
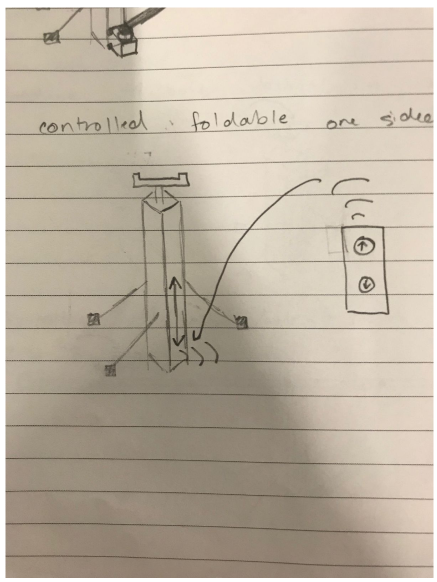
40. Heated Ice Scraper/Car Brush		It was found through the patent analysis that this was already patented. Thus it wouldn't fulfill the design specifications.
41. Self Cleaning/Drying Cleat Rack		Through engineering analysis it was decided that this would be too difficult and electrical dependent to make work.

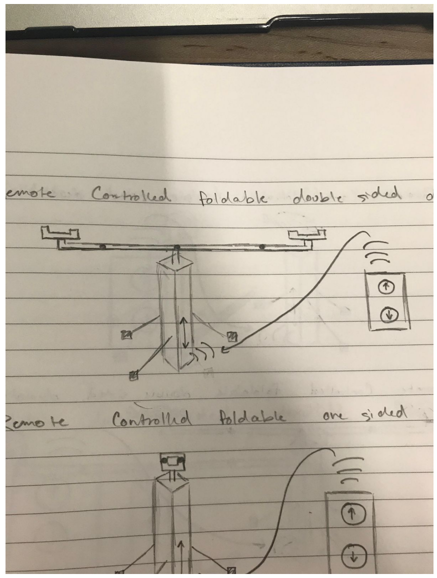
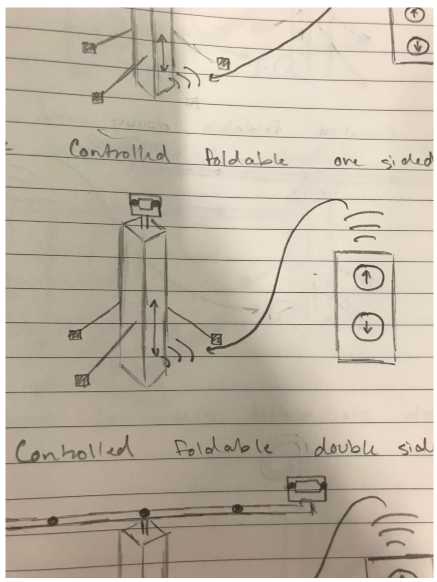
42. Ferrofluid Transmission	 	This concept was a good idea as it was chosen as the final invention.
43. Foldable one sided deadlift mechanical lever jack with secure head	 	The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.

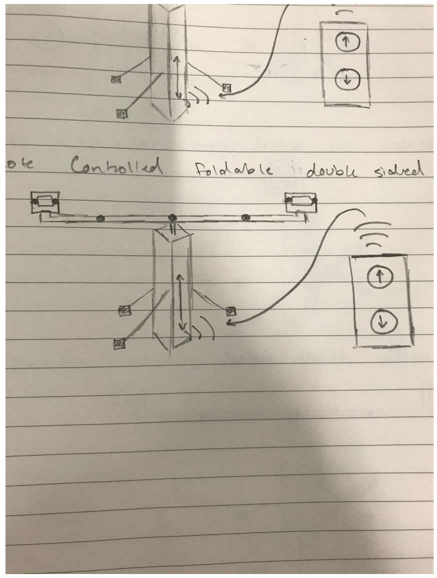
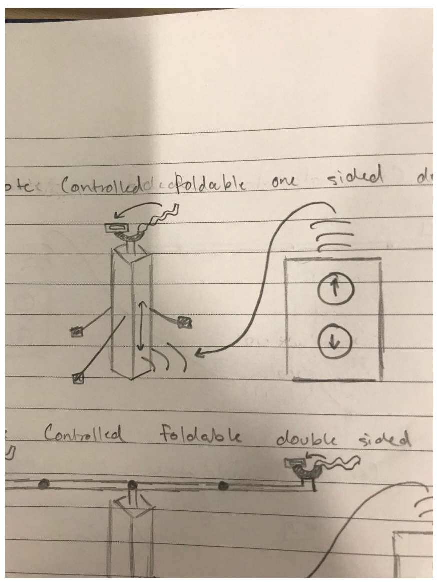
44. Foldable double sided deadlift mechanical lever jack with secure head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.
45. Foldable one sided deadlift hydraulic pump jack with secure head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.

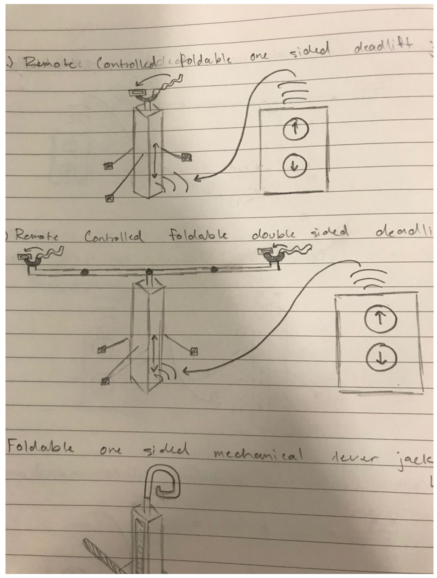
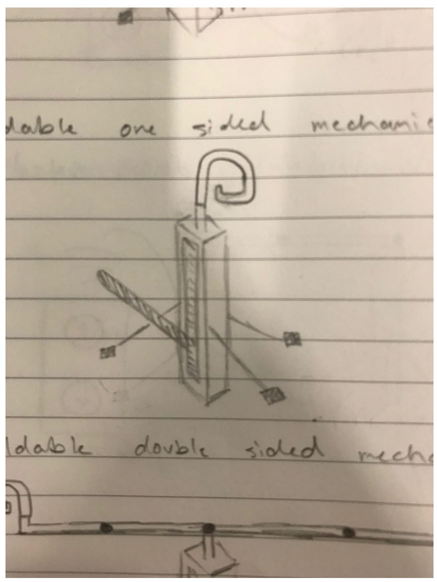
46. Foldable double sided deadlift hydraulic pump jack with secure head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.
47. Foldable one sided deadlift mechanical lever jack with strap head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.

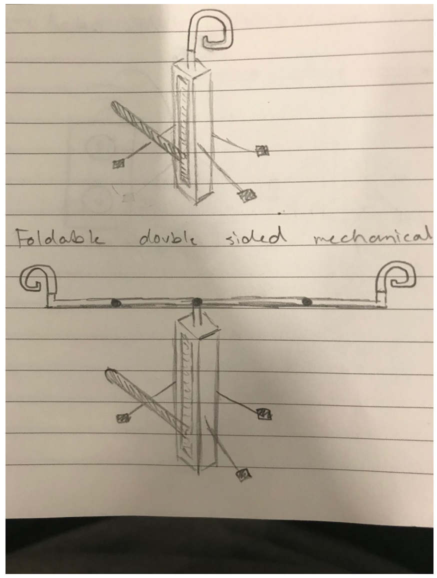
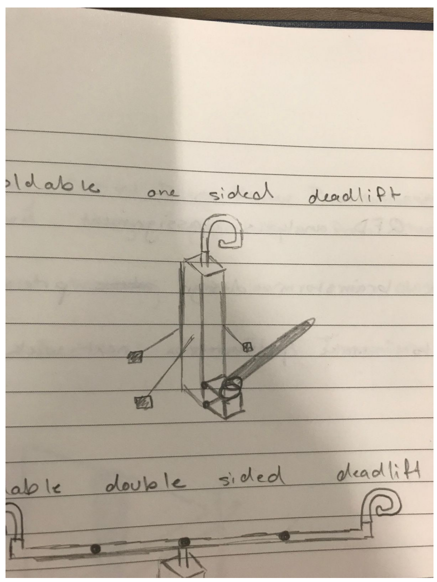
48. Foldable double sided deadlift mechanical lever jack with strap head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.
49. Foldable one sided deadlift hydraulic pump jack with strap head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.

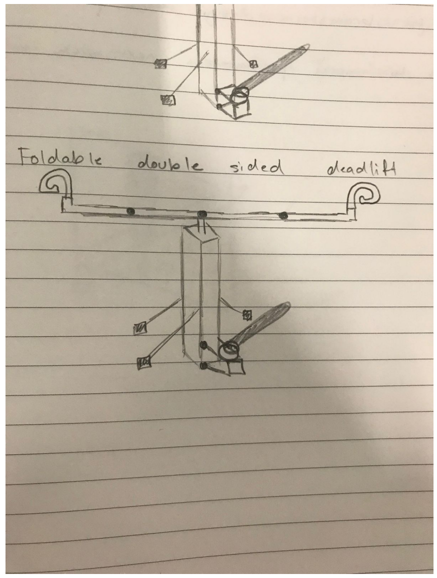
50. Foldable double sided deadlift hydraulic pump jack with strap head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.
51. Remote controlled foldable one sided deadlift jack with free head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.

52. Remote controlled foldable double sided deadlift jack with free head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.
53. Remote controlled foldable one sided deadlift jack with secure head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.

54. Remote controlled foldable double sided deadlift jack with secure head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.
55. Remote controlled foldable one sided deadlift jack with strap head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.

56. Remote controlled foldable double sided deadlift jack with strap head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.
57. Foldable one sided mechanical lever jack with hook head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.

<table>
<tr>
<td>58. Foldable double sided mechanical lever jack with hook head</td>
<td>
</td>
<td>The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it’s not patentable it wouldn’t fulfill the design specifications.</td>
</tr>
<tr>
<td>59. Foldable one sided hydraulic pump jack with hook head</td>
<td>
</td>
<td>The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it’s not patentable it wouldn’t fulfill the design specifications.</td>
</tr>
</table>

60. Foldable double sided deadlift hydraulic pump jack with hook head		The design of this idea would be too similar and serve the same purpose as the tire jack of a car. Since it's not patentable it wouldn't fulfill the design specifications.
61. Mechanical Pencil Improvement		An improvement to prevent mechanical pencil lead from snapping. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
62. Car Bumper Improvement		An improvement to the compressive force resistance. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
63. Water Bottle Shape		An improvement to the shape of a water bottle to reduce plastic use. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
64. Parking Lot Counter		A device to count how many cars are in a parking lot and report spot availability through a mobile application.

		This invention was not chosen because it was an inefficient method and did not meet the design specifications as required by MCE 401H.
65. Air Conditioner Improvement		Reduce sound and improve efficiency of air conditioner system. This invention was not chosen because it was too complicated given external factors and did not meet the design specifications as required by MCE 401H.
66. Luggage Improvement		An improvement to the shape and wheels of luggage. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
67. Cooler Improvement		An improvement to heat capacity of cooler. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
68. Shoe Covers for Ice		A detachable shoe cover for walking in icy conditions. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
69. Headphone Holder		A small, portable device for containing headphones when not in use to prevent tangling. This invention was not chosen because it was too

		simple and did not meet the design specifications as required by MCE 401H.
70. Beach Umbrella Shape		An improvement to the shape of a beach umbrella to prevent it from blowing away in the wind. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
71. Parallel Parking Assistance		A detachable sensor for any car to assist with parallel parking. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
72. Car Tire Improvement		An improvement to the tire treads for better friction in snow and ice. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
73. Windshield Wipers Improvement		An improvement to windshield wipers to reach and clear a greater percentage of the windshield. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
74. Garbage Can Shape		An improvement to garbage can shape to increase stability and containment ability. This invention was not chosen

		because it was too simple and did not meet the design specifications as required by MCE 401H.
75. Classroom Desk Shape		An improvement to classroom desks to improve angle, shape and size of desk. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
76. Baseball Cap Shape		An improvement to the shape to increase sun protection area. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
77. Clothing Folder		A machine to fold clothing for you. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
78. Multipurpose Hot Plate		A hot plate that can also convert into a baking oven. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
79. Car Headlight Glare		An improvement to reduce glare from car headlights. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.

80. Surfboard Shape		An improvement to the shape of a surfboard using biomimicry. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
81. Fishing Pole Shape		An improvement to the shape of a fishing pole to increase strength and reduce force. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
82. Purse Theft Prevention Device		A detachable alarm system for purses to prevent theft. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
83. Bicycle Gear Improvement		An improvement to bicycle gears to reduce grease and increase the number of gear ratios. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
84. Computer Station Heat Dissipation		A system to dissipate heat from a computer for use on any surface. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
85. Mask/Goggles		An improvement to masks

Improvement		and goggles to improve peripheral vision. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
86. Swim Fins Shape Improvement		An improvement to the shape of swim fins for better propulsion, using biomimicry. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
87. SCUBA Gear Improvement		An improvement to SCUBA gear to reduce size and weight. This invention was not chosen because it was too complicated and did not meet the design specifications as required by MCE 401H.
88. Sneaker Scales		Sneakers that can measure force and weigh to measure and improve walking/running performance. This invention was not chosen because it was too simple and did not meet the design specifications as required by MCE 401H.
89. Magnet Transmission		A transmission that uses ferrofluid to transfer input to output torque.
90. Ferrofluid Pump		A pump using ferrofluid as a means of controlling pump flow.

QFD

The ferrofluid gearing system falls under the market that consists of all automatic transmissions and gearing systems. To specify an ideal market, the gearing system was analyzed using a ferrofluid transmission market. This market has been established in 1921 with the first automatic transmission and has only grown exponentially since the beginning [10]. In today's society, North America holds the largest market for continuously-variable transmissions (CVT) and would be the ideal place to launch the ferrofluid transmission. There are plenty of automotive and transmission companies that already have their product out in the market. The ferrofluid transmission would be able to stand its ground in this market through efficiency and durability. While other companies require regular maintenance, the ferrofluid transmission will be made so that it will span the life of the car before needing to be worked on. The QFD Chart shown below shows where the window of opportunity is; the competition cannot outlast ferrofluid transmission.

The ferrofluid transmission has many advantages and disadvantages, similar to most transmissions, in order to compete in the competitive market, the transmission needed to have a step up on the other designs, and in doing so, there had to be a few critical trade offs. As shown in the QFD analysis, the simplicity was a large trade off because there are easier ways to make the CVT work, such as a metal band that is not dependent on the strength of magnets. The reliability of the transmission was an extremely critical trade off because the design is based off of magnets, rotational momentum, and friction. The prototype used for the Proof of Concept Presentation was showing poor output results when the input shaft was spun at a low angular velocity. If the engine is not inputting enough revolutions per minute, the transmission may stall. The team hopes to relinquish these trade-offs for future versions of the ferrofluid transmission.

When looking at the QFD Chart, it is clear that above all else, the ferrofluid transmission is mostly stuck in the middle of all the competition. The budget would cost about as much as the other transmissions to make, along with how easily it can be manufactured. It is estimated that when made in a assembly line, it can be mass produced on a timely schedule of two days. The first day would be creating the cones and metal box, the second day would be reserved for assembling each component before being shipped out to distributors. The transmission is also just as safe as the competition. Safety is a huge concern and closely governed by the Department of Motor Vehicles (DMV), the ferrofluid does not violate any safety laws and cannot harm any person as long as it is not tempered with, giving it a full safety rating on the chart. Lastly, the ferrofluid transmission was made to replace other transmissions and therefore needed to be small enough to take the competitions spot in the car. Despite being amongst the competition, the ferrofluid will still stand above and go above the competitors.

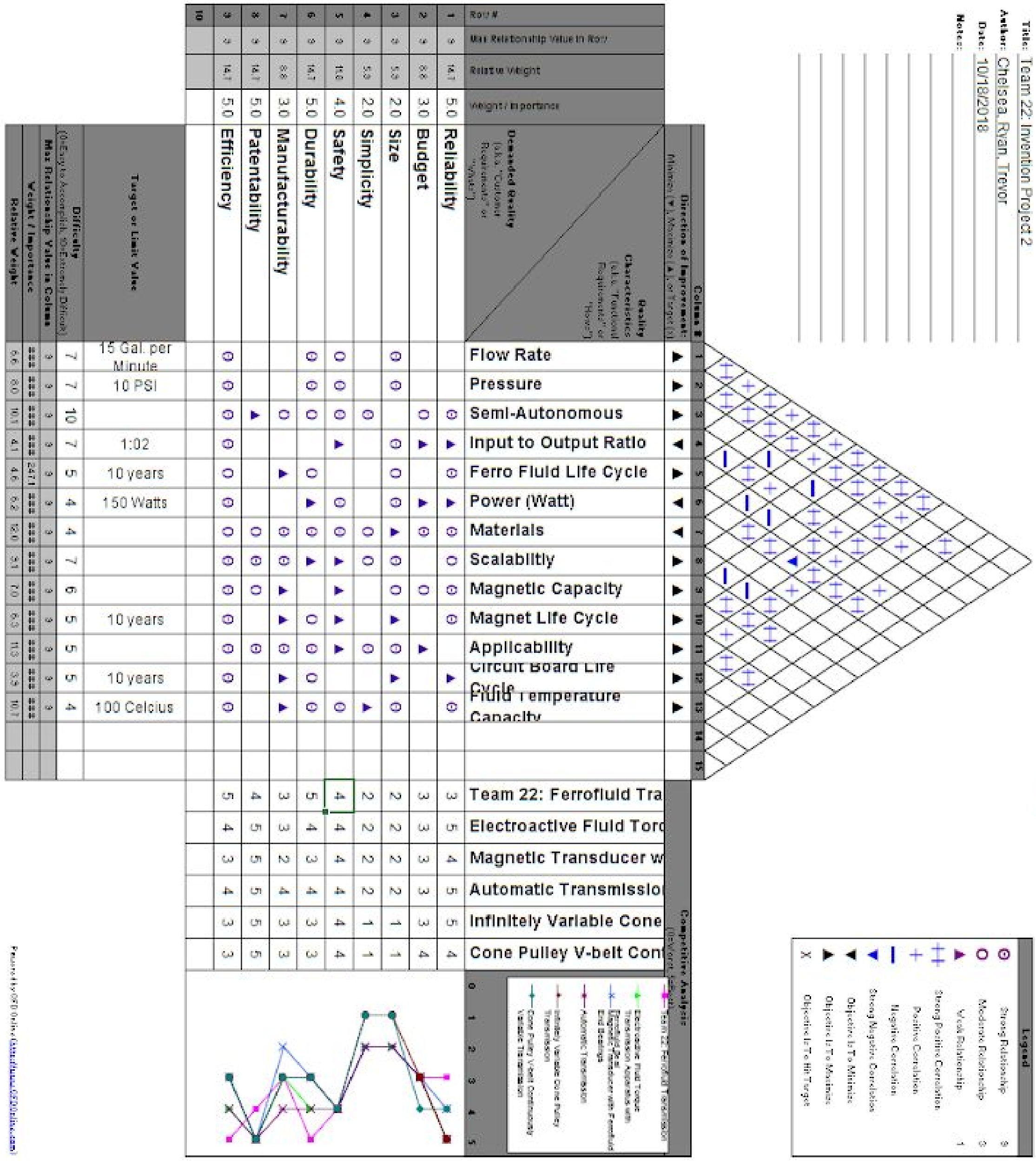


Figure 4: QFD Chart

Design for X

The team began the design process with a very general concept of developing a product to be patented. In order to narrow down the team's ideas, design specifications were developed, such as how the product needed to meet the $300 budget, how it needed to solve a problem for a large population, how it needed to be simple and effective, how it needed to be manufacturable on both a large and small scale. From there, the team brainstormed thirty concepts each and then considered each idea in terms of how it met the design specifications. Finally, the idea of the ferrofluid non-contact transmission was chosen because of its potential as a patentable product, because it met all of the design specifications and because it was something that could be completed in the duration of the Capstone course.

Once the product was chosen, the team began to consider how to develop a prototype and used a combination of engineering analysis and Solidworks to design the first prototype. During the engineering analysis and Solidworks drawings, the team considered the cost, manufacturability and ergonomics of the product. In order to meet the budget and to ultimately develop an inexpensive product, the team decided to use 3D printers to make the first two prototypes. In order to meet the manufacturability requirement, the team developed a tribological and magnetic analysis that could be scaled up or down to suit the mechanical system. In order to meet the ergonomics of the product, the team used Solidworks to design and test the product virtually before printing a physical model on the 3D printers in order to remain cost-effective.

Once the initial prototype had been printed, the team began testing for effectiveness and safety through torque and magnetic testing. Meanwhile, the team completed research looking into the recyclability and lifespan of certain materials such as ferrofluid to ensure that the final product would be environmentally friendly and ideally more sustainable than current transmission models.

Finally, in order to prove the concept, the team designed a simplified version of the cones by replacing them with a 2D version in the form of gears. Through this prototype, the team was able to prove that the concept functioned as an effective torque transfer device, which could be improved through additional testing and redesign and ultimately implemented in any mechanical system.

Project Specific Details & Analysis

Upon conducting a market analysis of the transmission market, and specifically the continuously-variable transmission market, it's been found that North America has both the highest value market and also the highest growth rate, making the USA the perfect place to start marketing the ferrofluid transmission product, as shown in the figure below:

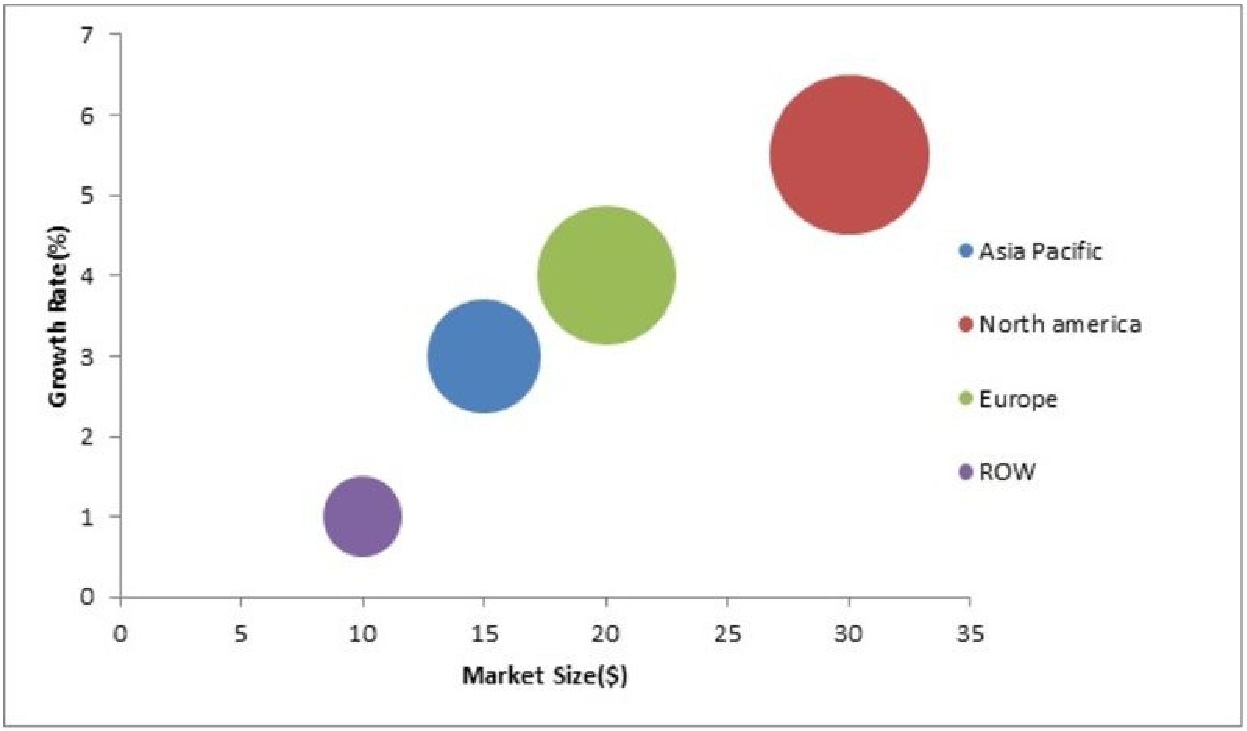


Figure 5: CVT Market Growth Rate by Region [11]

The key companies of the CVT market that the ferrofluid transmission product would be competing against include BorgWarner, Jatco, Punch Powertrain, Toyota Motors, ZF Friedrichshafen AG, Aisin Seiki, Efficient Drivetrains, Folsom Technologies International, Hunan Jianglu & Rongda, and Hyundai Motor [12]. The advantage the ferrofluid transmission product has over the CVT's produced by these companies, however, is that it will require significantly less maintenance which will make it more appealing for consumers looking for efficiency and to save money.

If the product does successfully execute the goal of performing the job of a continuously variable transmission while significantly reducing the maintenance required by a normal CVT, the demand for the ferrofluid transmission would be very high. With said high demand the potential profit of this product would be very high as well because it would only cost slightly more to manufacture than a normal CVT. The only added the costs would be the ferrofluid itself, magnetic coils, and whatever electronic controlling mechanism the team decides to use next semester, all of which are relatively inexpensive. The team would be able to charge more than a normal CVT in price because the product will require less maintenance (which for a CVT typically is very expensive) so in the long run consumers would be saving money by paying slightly more for the ferrofluid transmission instead of a normal CVT.

Detailed Product Design

The ferrofluid gearing system started off using the basic design of a transmission; two cones facing opposite ways within an outer box. The original design also featured magnets within the cones, ferrofluid on the bottom of the outer box, and a motor attached to the input independent cone. It was discovered that the motor was too powerful and too fast at the time and was saved for future concepts. The team agreed to lessen the cost of the final design and magnets were only implemented into the independent cone which acts as the engine input to the transmission. The design was created using the Solidworks software and 3D printed using the Raise3D N2 Plus machine. For the preliminary design, it was agreed to use the provided polylactic acid (PLA) material to save more of the budget for future redesigns. Sponsor Dr. Nassersharif suggested using a flexible sealant to cover the PLA parts because the ferrofluid can seep into the pores. The first prototype was completed and tested for proof of concept. A second, simpler prototype was created as a backup to the first prototype, but was not used. After showing proof of concept, a third prototype was made with a simpler design to focus on the overall goal of the invention; find an effective replacement for torque transfer. Thus, two gears of the same shape and size were made. The independent gear, or input gear, housed the magnets that would pick up and hold ferrofluid to turn the dependent gear, or output gear. To maximize the torque transfer, the gear teeth were made according to tribology gear calculations. The figures shown below feature the bills of materials used and the three working prototypes.

Quantity	Part Number	Description	Unit $	Subtotal
1	B004KICAVU	Black Iron Oxide - Fe3O4 - Natural - 5 Pounds	$18.99	$18.99
1	B07K4VZYNN	CMS MAGNETICS 12 oz Iron Powder for Magnet Education Iron Filing (2 Pieces)	$14.86	$14.86
1	B073Q2Y3RC	Topoox 6 Pack DC 1.5-6 V Mini Electric Motor	$6.49	$6.49
1	B077BV6J7F	Balpha 12pcs/1 Donzen 2X 1.5V AA Battery Holder Case	$8.99	$8.99
1	B00GTYF1ZU	Duracell AA 1.5V Battery	$12.99	$12.99
2	B008H40LG4	2 oz. Packed with Gloves, Petri Dish, and Dropper	$17.49	$34.98
1	B076H5YHQ7	Magnetic Holders Multi-Use Square Cube Magnets Toy Puzzle Magnet Block Magic Cube Education Toys Metal 3x3x3mm (216 Pack)	$8.99	$8.99
1	8873K36	Multipurpose Copper Wire, 1/4 lb spool, 0.005" diameter (3200 ft)	$7.96	$7.96
4	1001597837	3/4 in. Dia Neodymium Rare-Earth Magnet Discs with Foam Adhesive (5-Pack)	$8.98	$35.92
1	B072V3RLCM	GARTT ML 5008 330KV Brushless Motor for Multicopter Hexacopter T960 T810 RC Drone	$32.99	$32.99
4	GFM-1012-05	iglide G300, flange bushing	$1.22	$4.88
4	JFM-1012-05	iglide J, flange bushing	$1.63	$6.52
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
			Total	$194.56
			Left in Budget	$105.44

Figure 6: Bills of Materials List

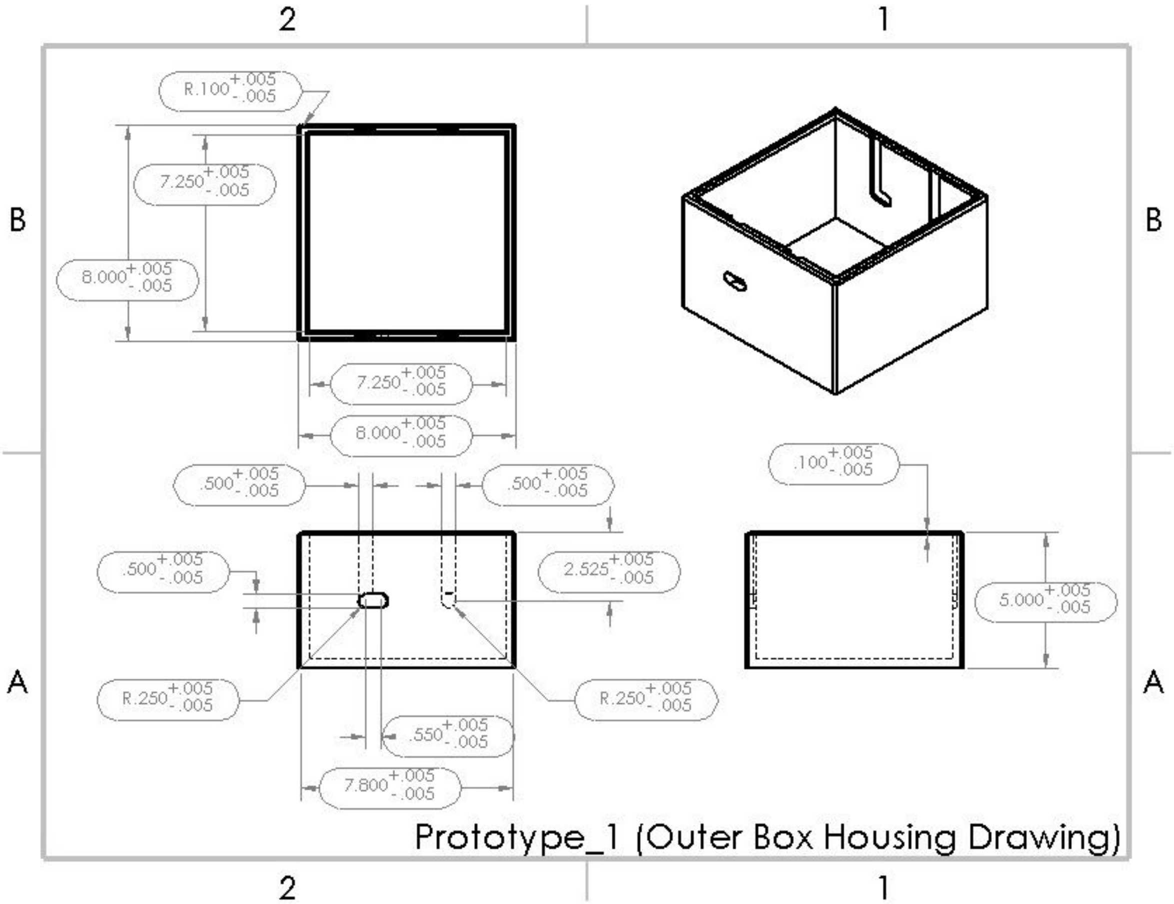


Figure 7: Solidworks Outer Box Housing Drawing

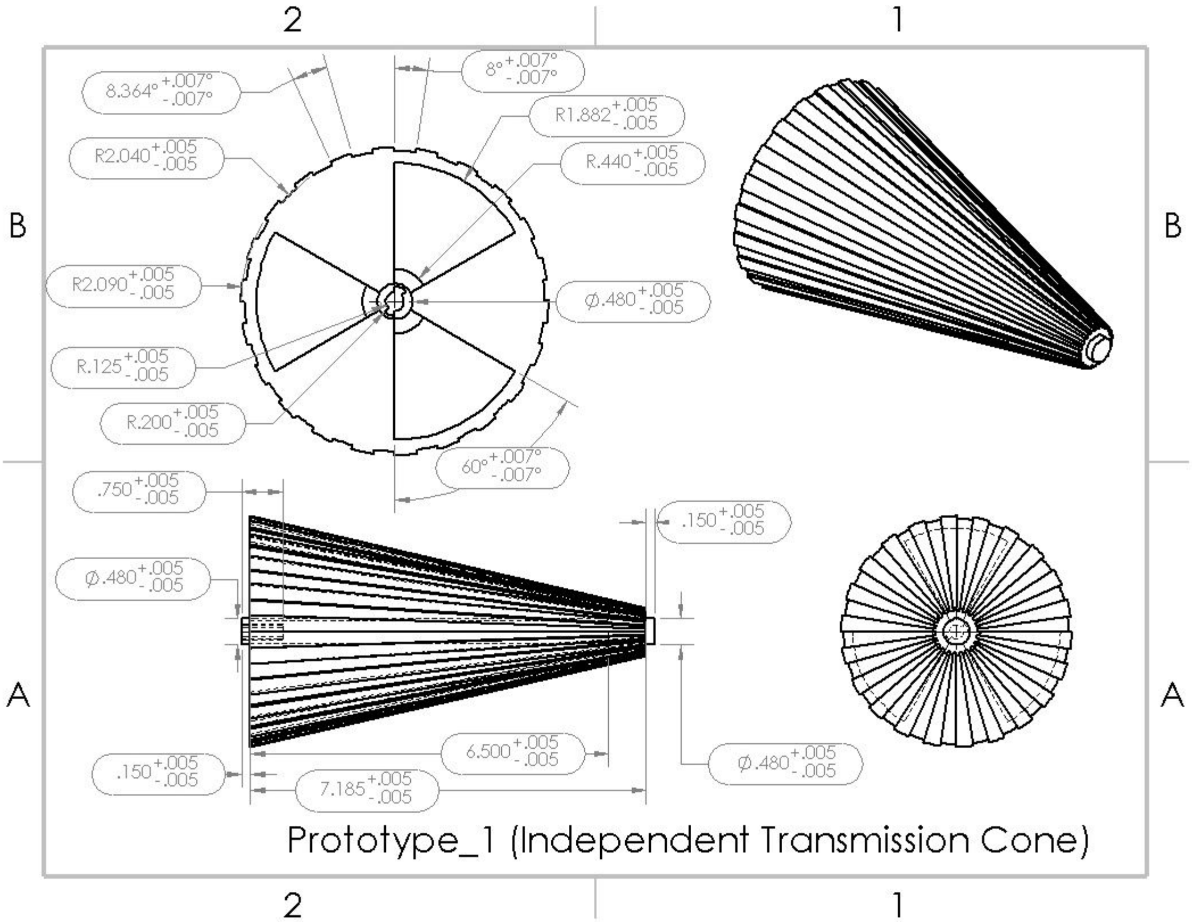


Figure 8: Solidworks Independent Transmission Cone Drawing

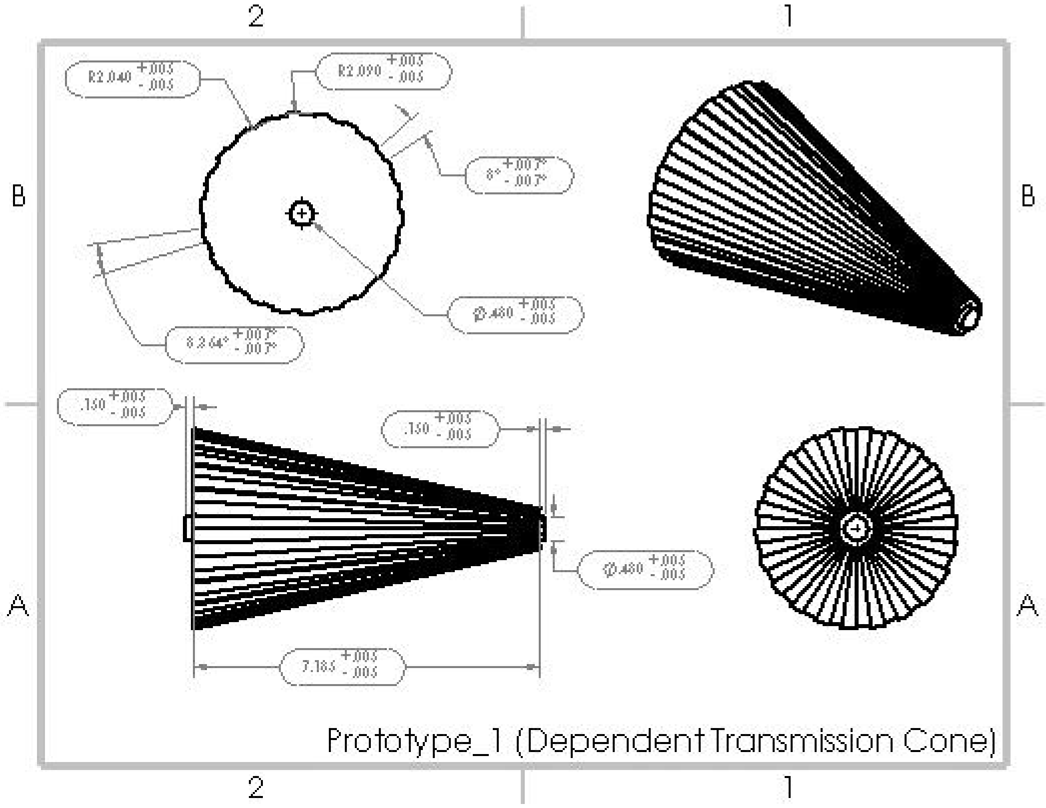


Figure 9: Solidworks Dependent Transmission Cone Drawing

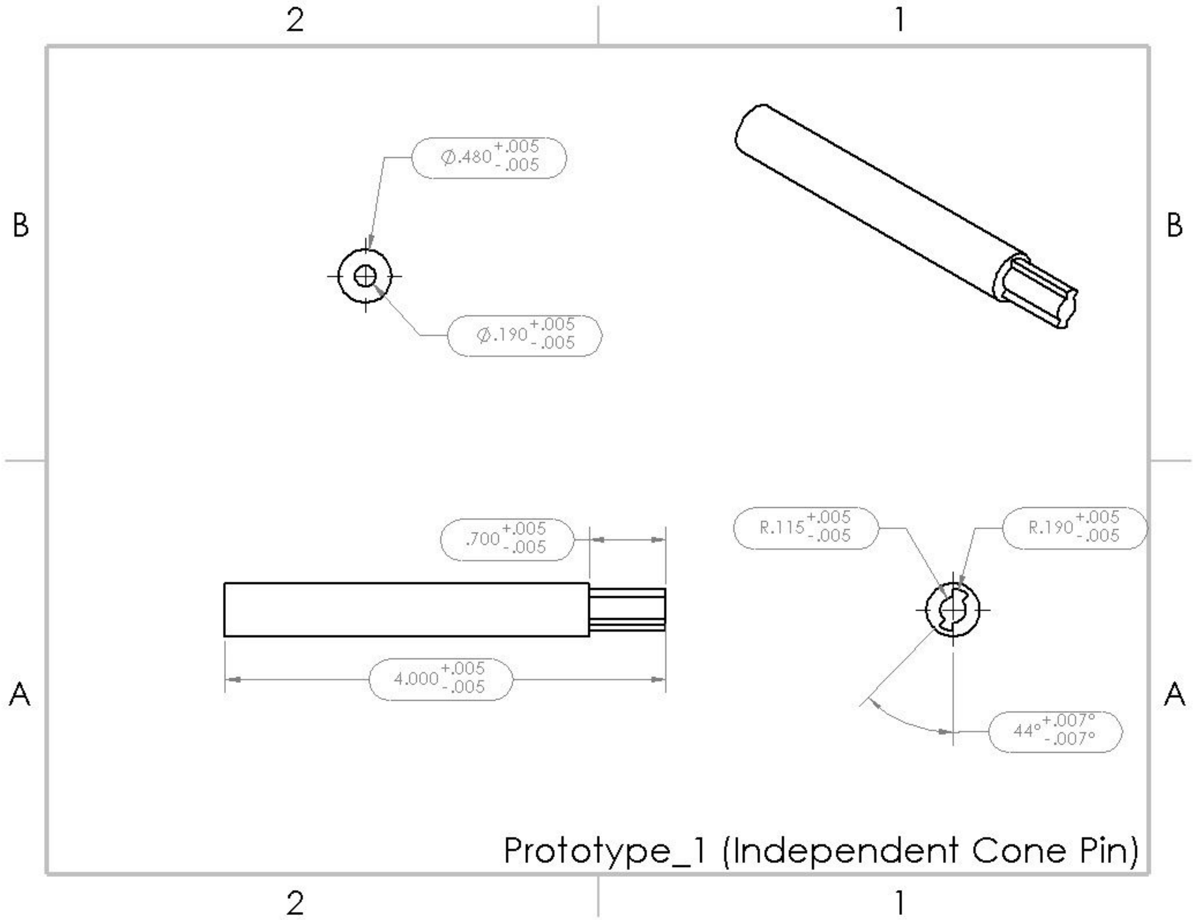


Figure 10: Solidworks Independent Transmission Cone Pin Drawing

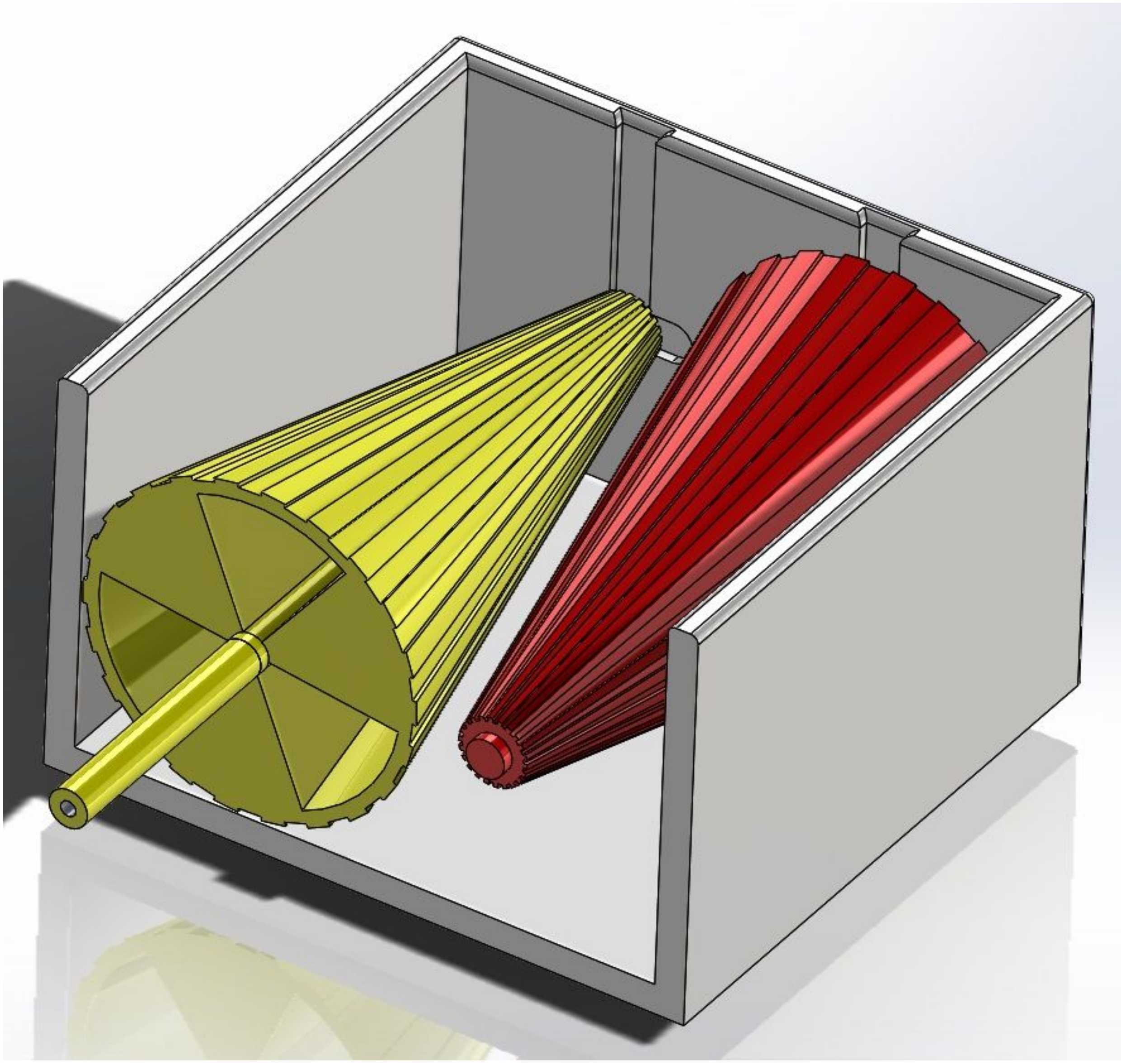


Figure 11: Solidworks Assembly of First Prototype

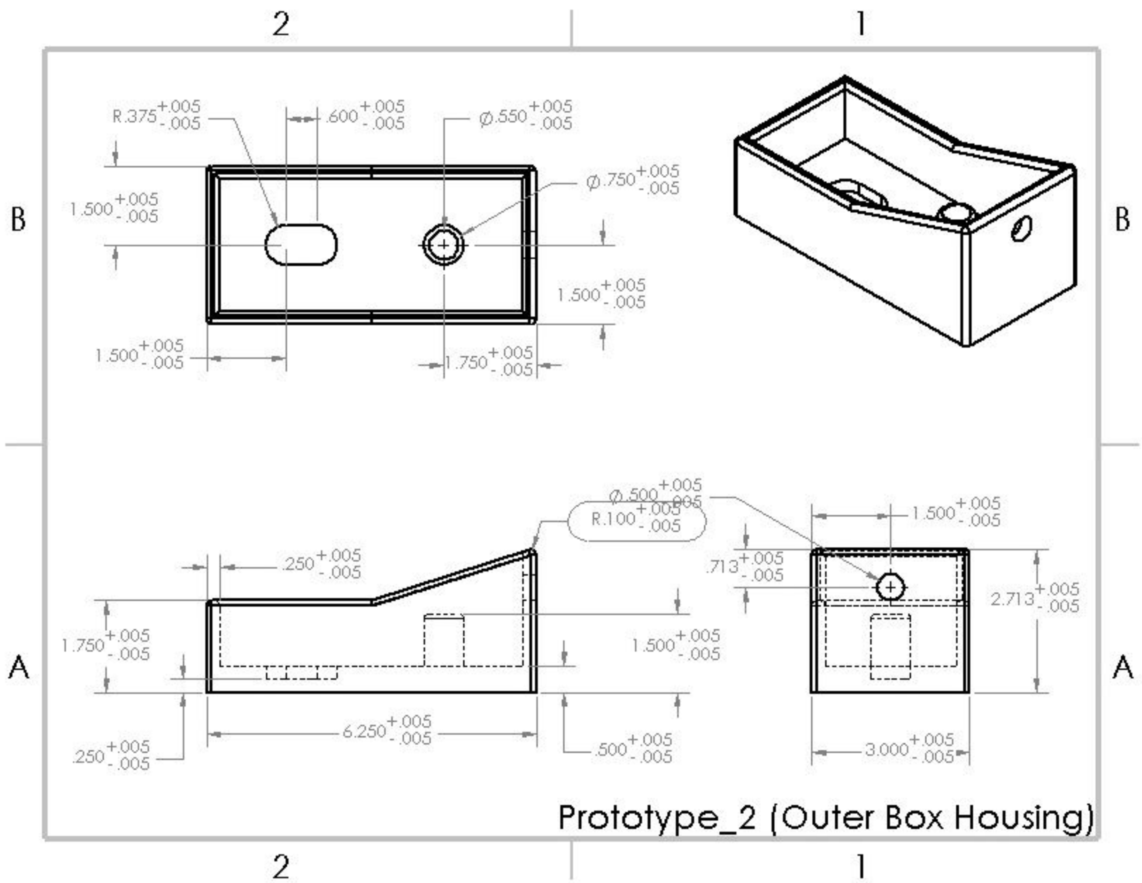


Figure 12: Solidworks 2D Prototype Outer Box Housing Drawing

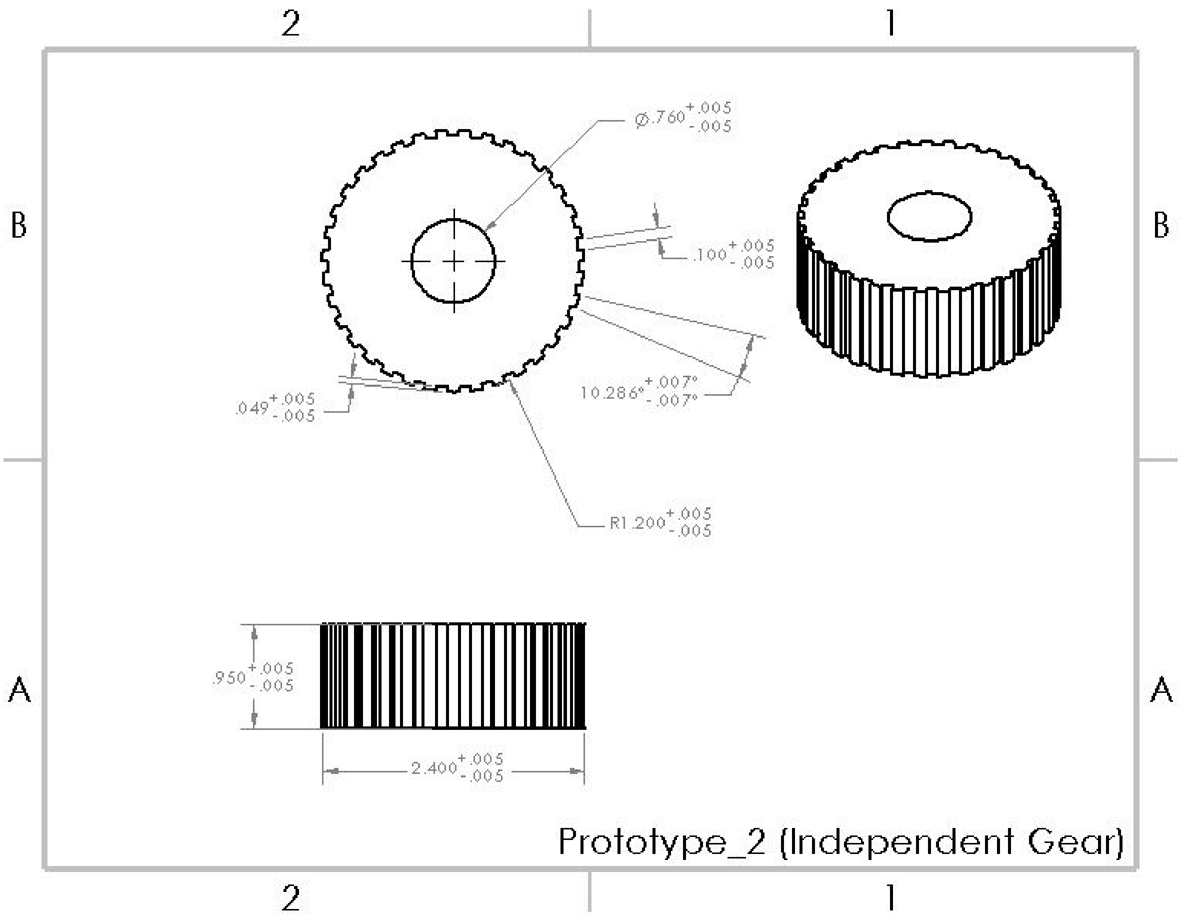


Figure 13: Solidworks 2D Prototype Independent Gear Drawing

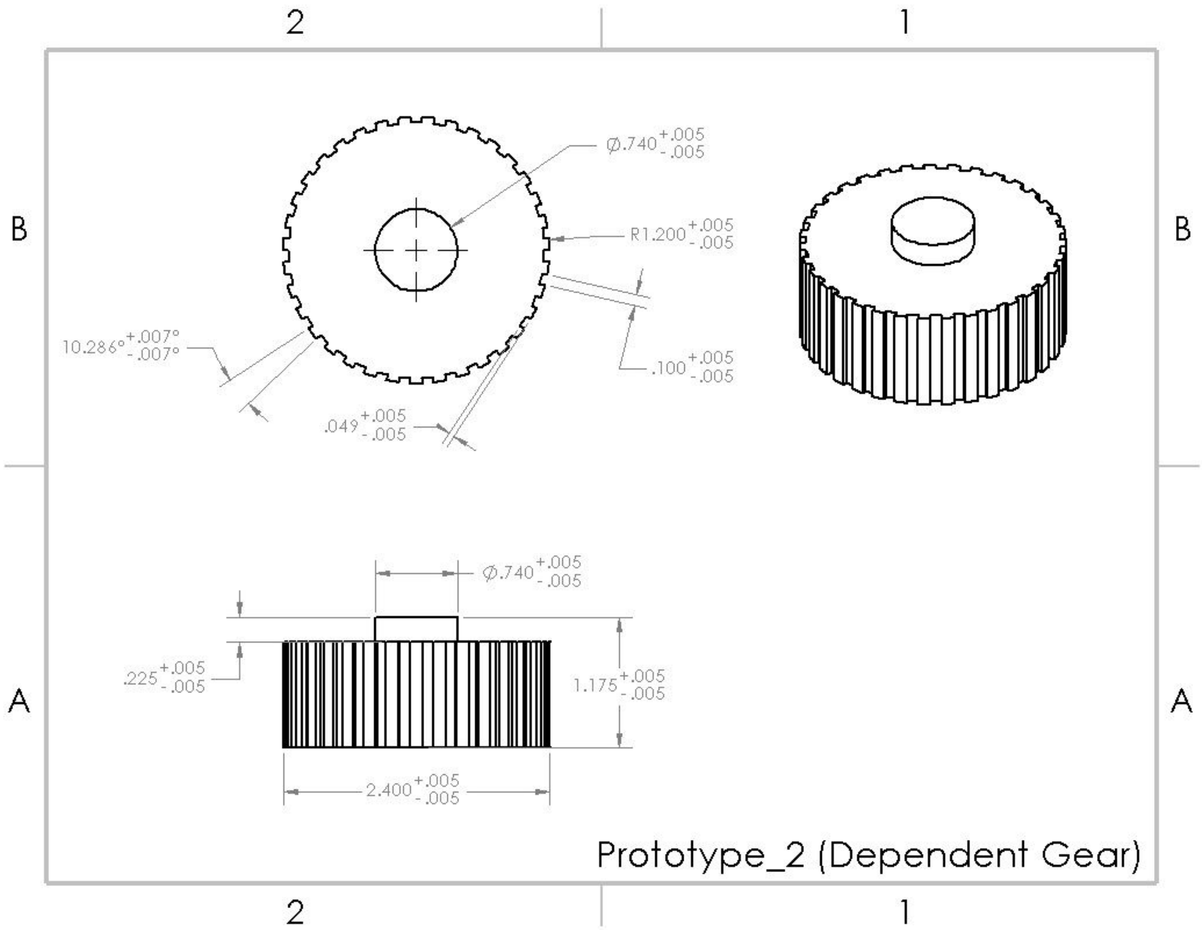


Figure 14: Solidworks 2D Prototype Dependent Gear Drawing

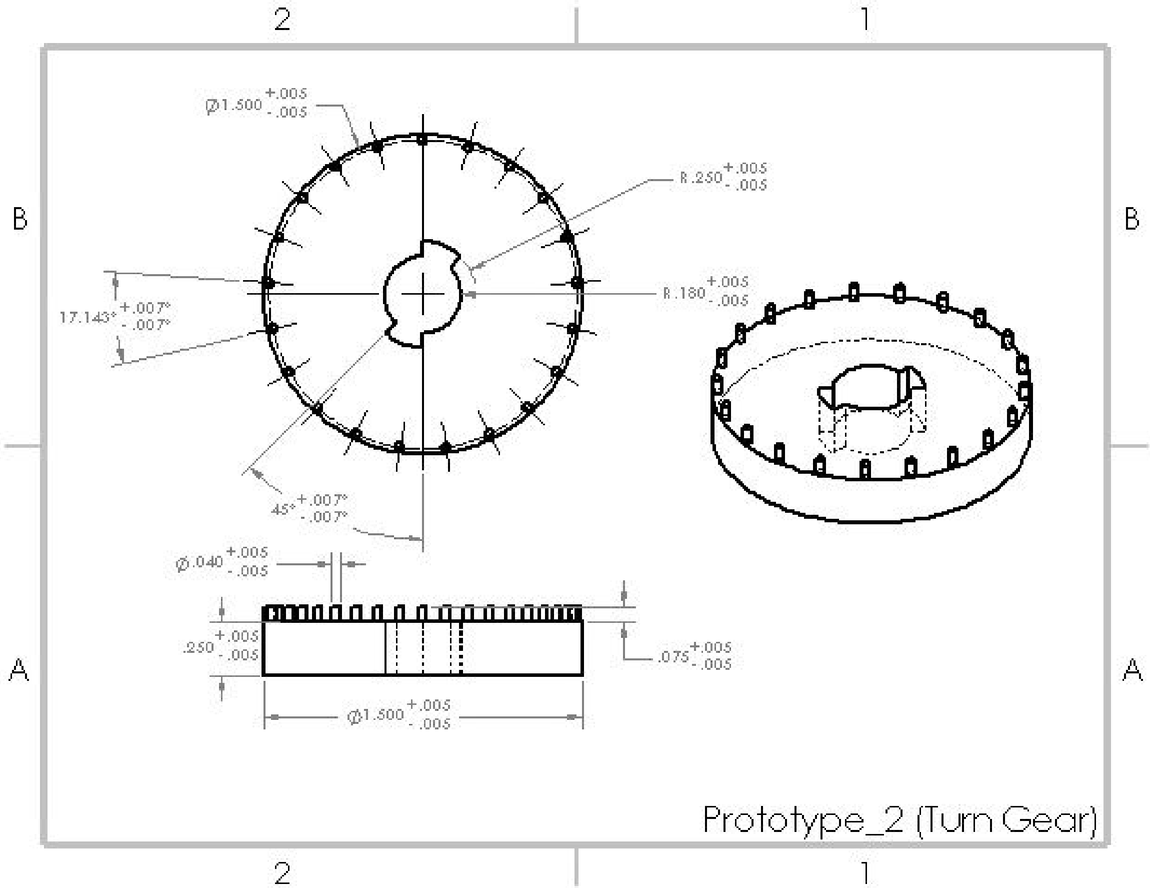


Figure 15: Solidworks 2D Prototype Dependent Gear Drawing with Cross-Section

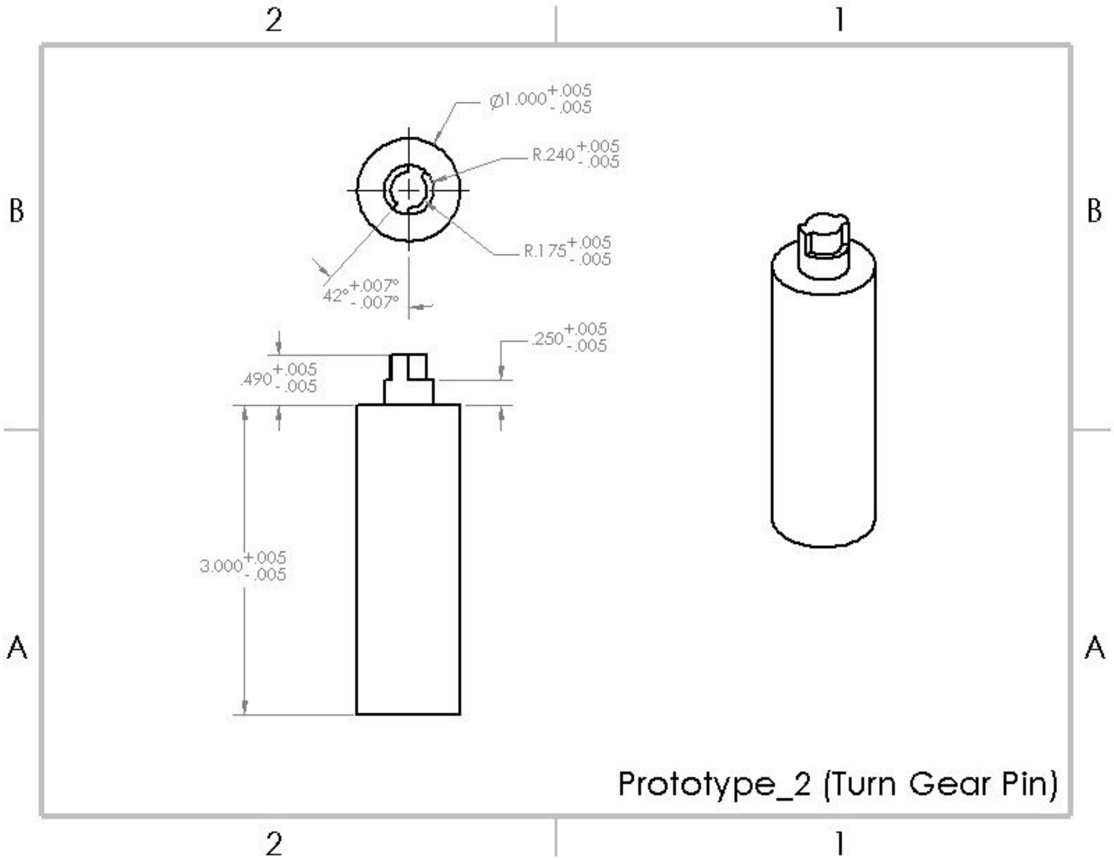


Figure 16: Solidworks 2D Prototype Gear Pin

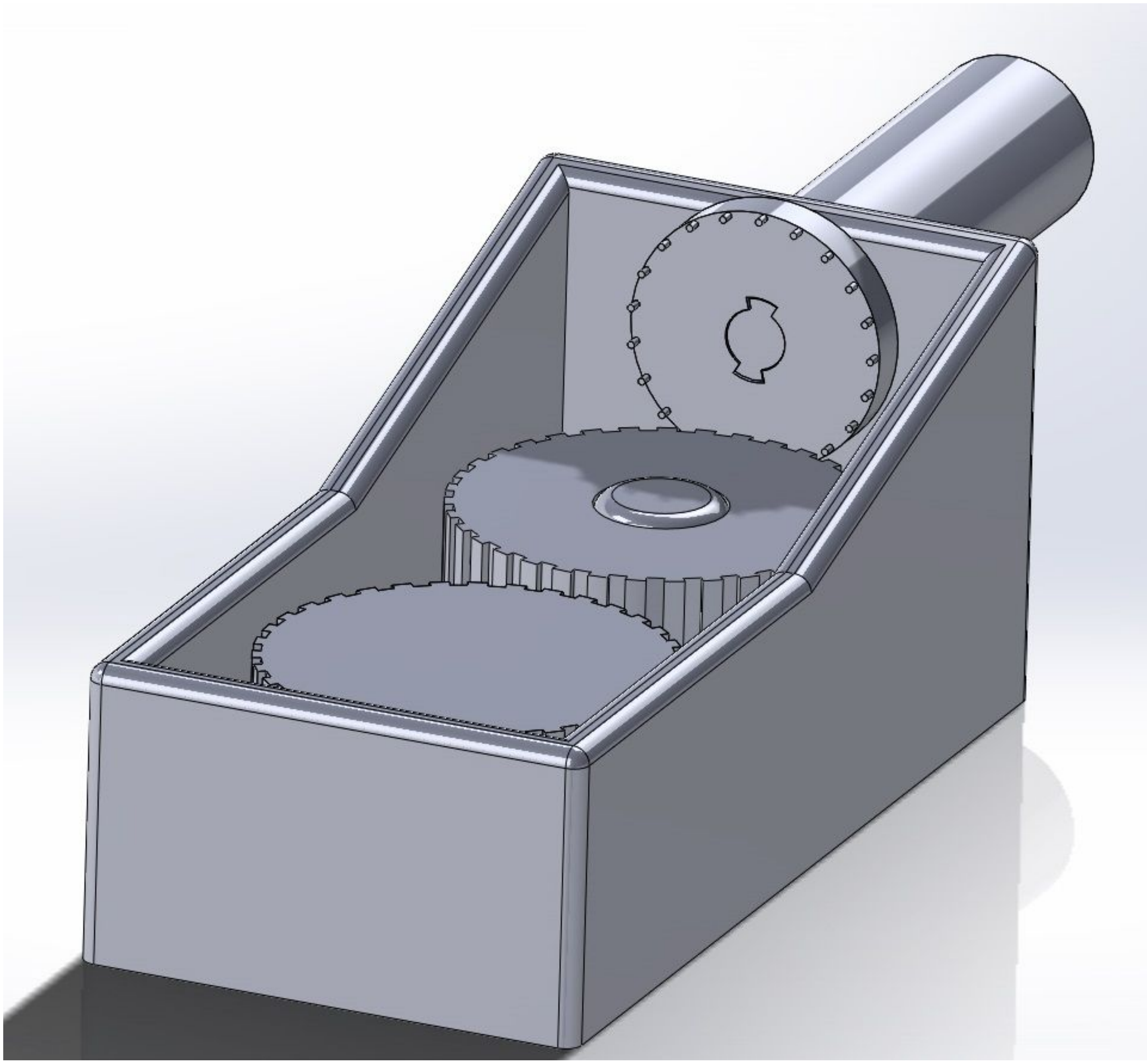


Figure 17: Solidworks Assembly of Second Prototype

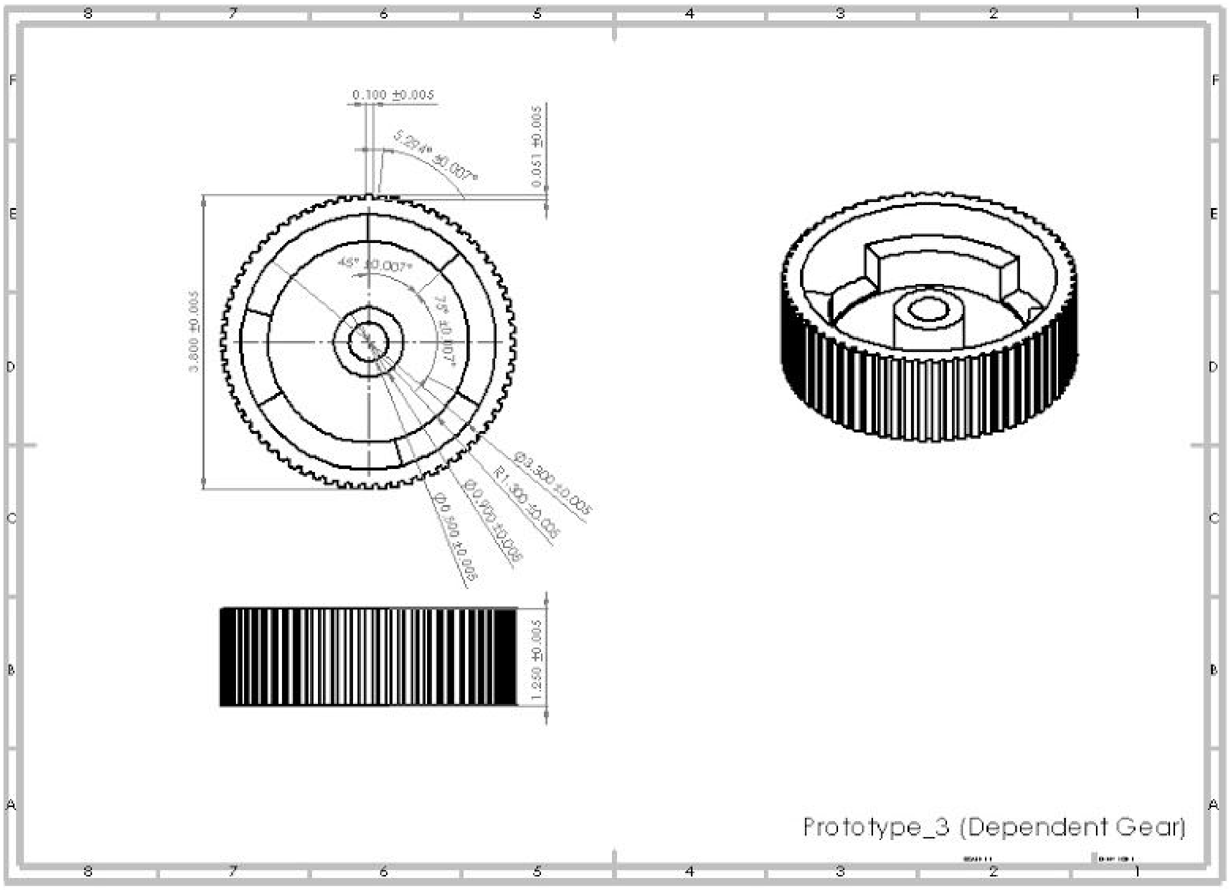


Figure 18: Solidworks 2D Prototype Dependent Gear

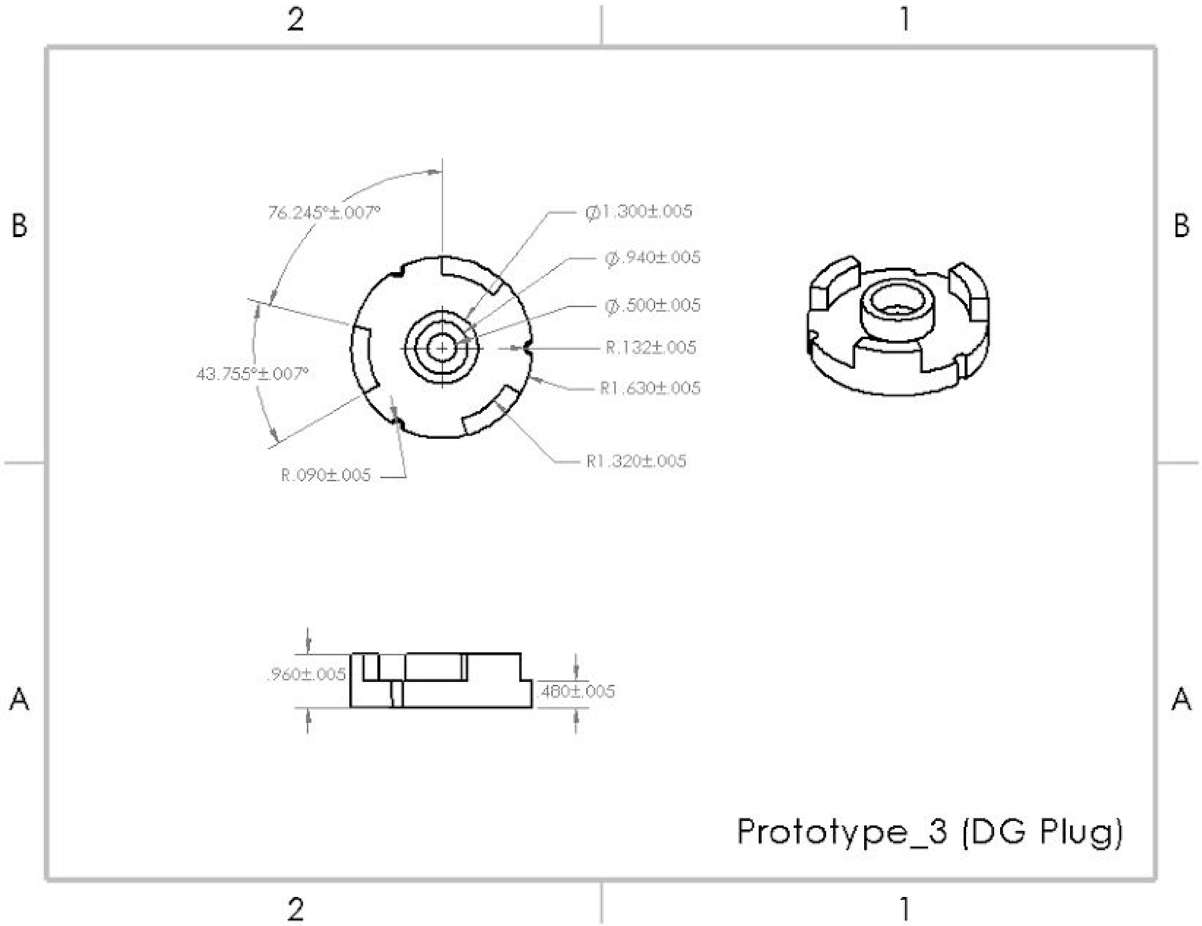


Figure 19: Solidworks 2D Prototype Dependent Gear Plug

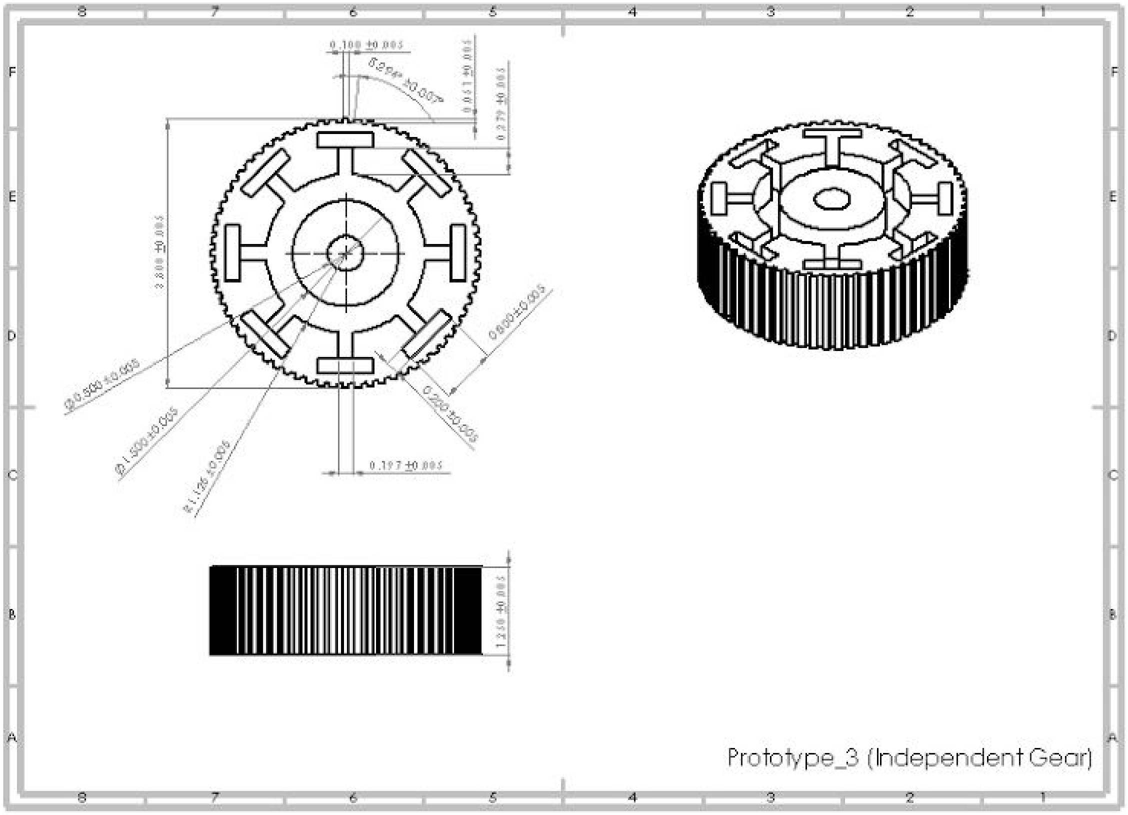


Figure 20: Solidworks 2D Prototype Independent Gear

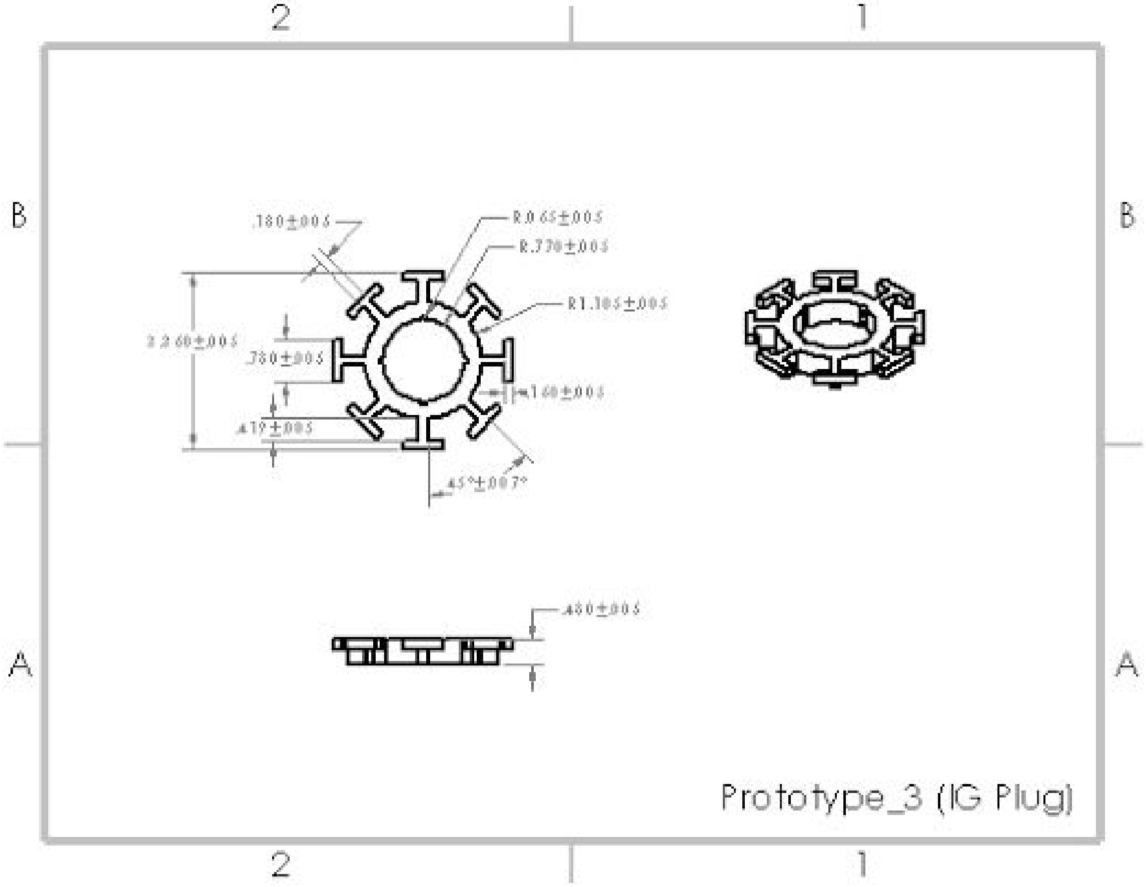


Figure 21: Solidworks 2D Prototype Independent Gear Plug

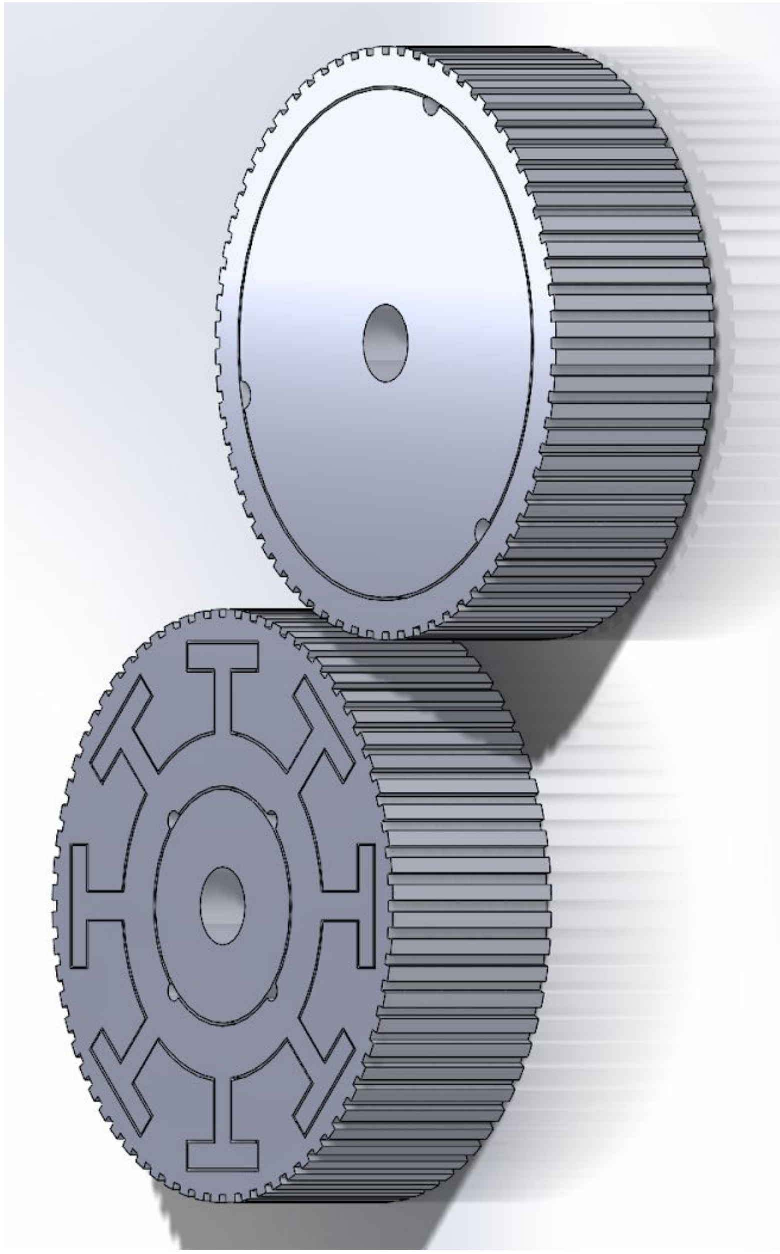


Figure 22: Solidworks Assembly of Third Prototype

Engineering Analysis

Pressure (Load) Capacity/Transmission Cone Dimension Analysis [13]:

To determine the distance between the transmission cones and the amount of ferrofluid that would be needed to transmit the rotational motion from the input to the output, tribological analysis was conducted by zooming in on one element of the transmission cone, as illustrated below.

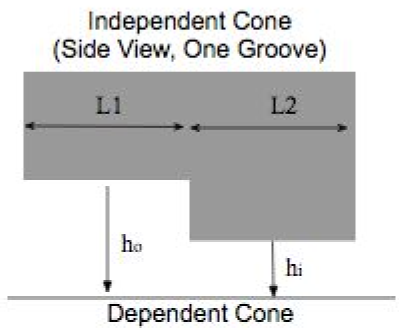


Figure 23: Transmission Cone Design Analysis

In order to determine the ideal design for the transmission cones, the cones were simplified to Rayleigh step bearings. Thus, starting with Reynolds Equation for hydrodynamic pressure and integrating with respect to x:

$$\frac{\partial}{\partial x}\left(h^3 \frac{\partial P}{\partial x}\right) = 6\eta U \frac{\partial h}{\partial x}$$

$$\int_{h_i}^{h_o} \frac{\partial}{\partial x}\left(h^3 \frac{\partial P}{\partial x}\right) dx = \int_{h_i}^{h_o} 6\eta U \frac{\partial h}{\partial x} dx$$

$$h_o^3 \frac{\partial P}{\partial x} - h_i^3 \frac{\partial P}{\partial x} = 6\eta U \; h_o - 6\eta U \; h_i$$

The pressure profile for a Rayleigh Step bearing is linear, therefore, for the first land, $\frac{\partial P}{\partial x}$ can be rewritten as $\frac{P}{L_1}$, and for the step, $\frac{\partial P}{\partial x}$ can be rewritten as - $\frac{P}{L_2}$. Replacing $\frac{\partial P}{\partial x}$ in the pressure profile, the equation simplifies to:

$$h_o^3 (- \frac{P}{L_2}) - h_i^3 (\frac{P}{L_1}) = 6\eta U \ h_o - 6\eta U \ h_i$$

Rearranging to solve for P:

$$P = \frac{6\eta U(h_o - h_i)}{(-\frac{h_o^3}{L_2} - \frac{h_i^3}{L_1})} \quad \textbf{(1)}$$

Thus, the pressure profile, and therefore load capacity, of the transmission cones has been established. In order to determine the maximum load capacity and thus the maximum amount of rotational motion transfer possible, equation (1) was simplified into a ratio relating the ferrofluid film thicknesses, h_o and h_i , to the land lengths (the width of the grooves on the transmission cones), L_1 and L_2 . This ratio equation was then differentiated to find the maximum values for pressure, which were determined to be when the inlet film thickness was one and a half times the outlet film thickness and when the first land was three times the second land length. Thus, the ferrofluid film between cones needed to be one and a half times as deep as the grooves in the cones and the grooves in the transmission cones needed to be three times as wide as the ridges in the cones for maximum rotational motion transmission.

Viscous Shear Fluid Force Analysis [13]:

In order to determine how much shear force the ferrofluid could withstand and thus how much rotational motion it could transmit, viscous shear forces for drag were also considered:

$$F_{\text{viscous}} = \eta A \frac{\Delta v}{\Delta y} \quad \textbf{(2)}$$

In which the force of the ferrofluid can be considered a shear fluid force, $F_{viscous}$, and thus it depends on the viscosity of the ferrofluid, η , the area of the transmission cone in contact with the ferrofluid, *A*, the rotational velocity, *v*, and the depth of the ferrofluid, *y*, which is also the distance between the two cones. From this equation, it is clear that the higher the viscosity and the closer the cones, the higher the force and the higher the amount of rotational motion transmitted. However, equation (2) does not consider all the factors and thus the ideal distance between cones was already determined from equation (1). Additionally, the ferrofluid must be able to flow completely from one position on the cone to another, therefore, a highly viscous ferrofluid would be ineffective and thus a moderately viscous ferrofluid was chosen for testing trials to ensure safe and effective design and functionality.

Magnetic Analysis

The strength of the magnets used to move the ferrofluid was also considered and tested empirically, using various shapes and strength magnets. It was determined that the stronger the magnet, the better for holding and moving the ferrofluid, although the original idea of using electromagnetic coils that can be controlled through mechatronic programming was not implemented since the electromagnets within budget were not as strong as the neodymium magnets. However, it must also be noted that the stronger the magnetic force, the more likely that other components of the transmission or computer system (i.e. in a vehicle) will be affected and thus further testing must be completed to ensure that the magnetic forces do not impede the functionality and safety of the operating system. The following diagram shows the different magnets tested and their resulting effectiveness and how the conclusion was reached that the circular neodymium magnets were the most effective.

Table 3: Magnet Effectiveness Testing

Magnet Height Testing Ranking		
Magnet Type	**Ferrofluid Height (in.)**	**Magnetic Field Ranking (Effectiveness 1-5)**
Electromagnet - Small washer	0.1	1
Electromagnet - Large washer	0.1	1
Electromagnet - Stator	0.2	2
Electromagnet - Iron rod	0.2	2
Permanent Magnet - Square	0.25	2
Electromagnet - Circular 100N	0.25	2

Electromagnet - Circular 200N	0.3	3
Permanent Magnet - Rectangle	0.35	3
Permanent Magnet - 2 Rectangles	0.4	3
Permanent Magnet - Circle	0.35	3
Permanent Magnet - 2 Circles	0.45	4
Permanent Magnet - 4 Circles	0.65	5

Torque Analysis

In order to determine the effectiveness of the design and its potential as a transmission, the torque transferred from the input to the output was measured using a fishing scale. The following equation was used to determine torque using the radius and force measured off the gear rod.

$$\tau = F \cdot r\sin\Theta \quad \textbf{(3)}$$

The following schematic shows the testing setup. It was determined that the design had an average ratio of 0.55, meaning that 55% of the input torque was transferred to the output. Although this value is not as effective as a standard gear system, there were significant losses that occurred during testing, including frictional losses, that could be improved through more redesign and testing.

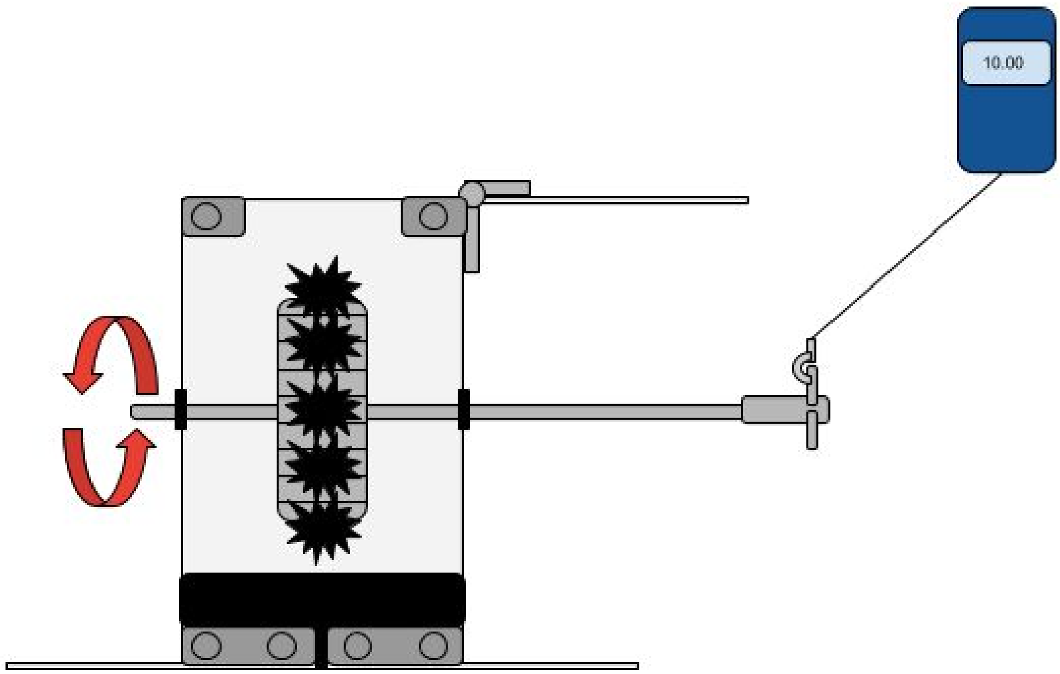


Figure 24: Torque Testing Design Setup Schematic with Fishing Scale

Table 4: Torque Analysis of Final Design

Trial	Input Torque (lbs•in)	Output Torque (lbs•in)	Ratio
1	0.41	0.23	0.56
2	0.41	0.22	0.54
3	0.41	0.25	0.61
4	0.41	0.19	0.46
5	0.41	0.23	0.56
Average	0.41	0.22	0.55

Build/Manufacture

The production of the third and final prototype was made in a way that could be easily replicated in other manufacturing plants with ease. The first step in creating the final design was making the gears on SolidWorks and 3D printing them on the Objet 30 printer. Once those were made, the magnets could be inserted into the input gear and sealed off with the plug. The output gear does not house anything and therefore could have the plug inserted immediately after printing. Once the gears were all set up, the outer box casing could be made to ensure the gears are close, but do not touch. After the housing is built, the gears can be placed inside and finally epoxied to a rod that is connected to the input torque and output torque. Lastly, ferrofluid is added to the box for the system to work properly and efficiently.

Since the ferrofluid gearing system can be accommodated to almost any mechanical system that has moving parts, every different system will have its own specific manufacturing steps. However, despite all the different applications, they are predicted to use a similar overall manufacturing process. The gearing system is expected to be mass produced no matter the application. Ideally, a manufacturing plant would run all day and night using machine-based production lines. This would cut down on labor costs and maximize production outputs.

As previously specified, one application of the ferrofluid gearing system would be a continuously variable transmission. In the automotive industry alone, it is projected that around 75 million transmissions would be manufactured annually. In order to meet this demand, it would have to mimic the automotive manufacturing style by using process lines. Skilled laborers would watch over the production of the transmission, but machines would do most of the work to meet the high demand. Additionally, the transmission as a whole would be made in the same plant; this reduces shipping costs and lack of supervision when being moved. The following diagram shows a manufacturing model for the ferrofluid transmission application:

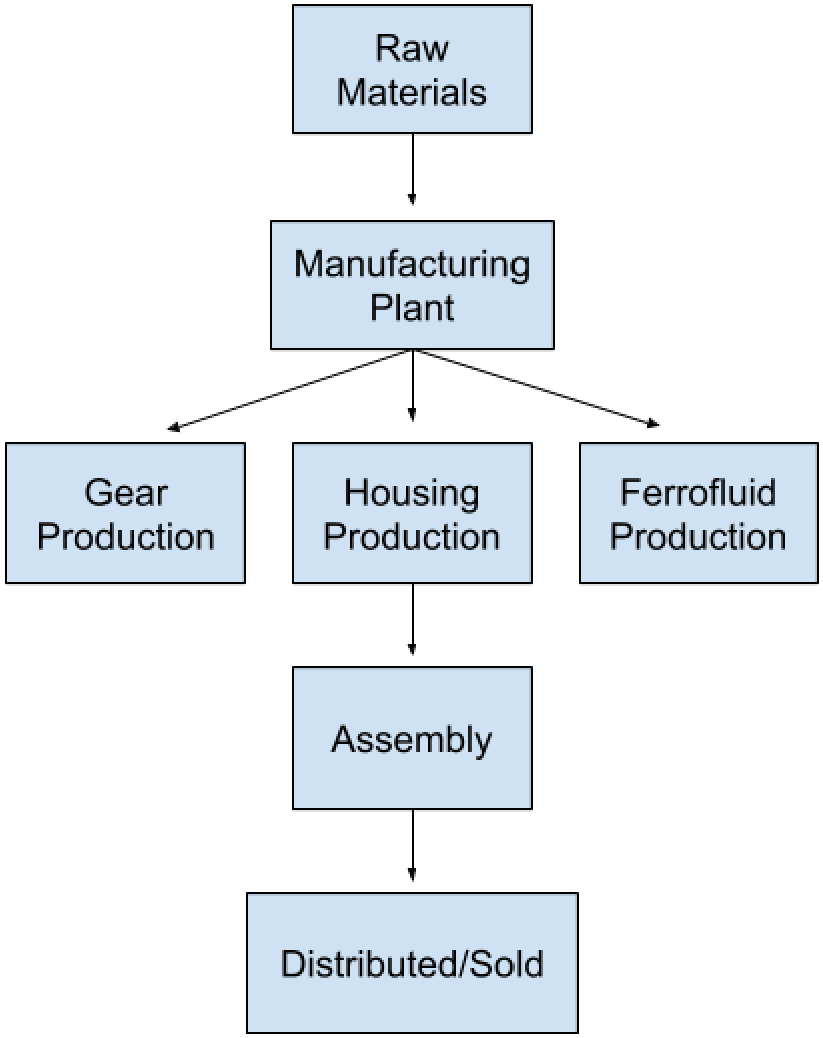


Figure 25: Diagram of Manufacturing Model

Testing

The adequacy of our design was tested in a variety of ways, which are discussed in the following test matrix and individual tests.

Table 5: Testing Matrix

Item	Test Category	What to Test?	Test Parameters	Results	Resolution
Manual Rod	Performance	Effective method of shifting gears	● Rod must easily slide the length of the cone ● Rod must remain level during testing and during spinning of the independent cone ● Rod must remain attached to spring and magnet mechanisms	The rod supported at both ends of the cone showed more stability and control when rotating and moving the magnets up and down. A larger tolerance at the nose (slimmer) end of the cone allowed for more movement of the rod without too much interference. Solder does not hold as well to the steel rod as hot glue, but the hot glue allows for too much motion when holding down the spring end.	The final design will have the independent cone supporting the rod at either end. The nose end of the cone was drilled out with a 27/64in drill bit. A rod-spring adapter was 3D printed to create a solid base to glue the spring end down and can be secured onto the rod.
Rod/Magnet Spring Connections	Performance	Connections remained while spinning	● The springs must remain attached to both the magnets and the rod as the rod moves up and down the length of the cone ● The independent cone must be spinning at normal transmission speeds during testing (60 RPM for scale)	Since the spring pulls the magnets at an angle and with a relatively large force, hot glue did not work as well as solder. The magnets have a strong enough hold on each other that only one magnet in each of the six groups needs to be soldered. It was also found that making a loop at the end of	The magnet closest to the cone center will be soldered to a circular end of a spring.

				the spring make a stronger connection compared to having a straight end of the spring.	
Magnet Strength	Performance	Picked up and held sufficient amount of ferrofluid	• Equivalent masses of ferrofluid particles (25g) for each test • Magnet(s) positioned at same distance from ferrofluid and 3D printed plastic for each test • Same 3D printed plastic disk must be used for each test to maintain thickness consistency • Measurements of ferrofluid height/magnet field are taken from the top of the plastic disk to the highest point in the ferrofluid form • All ferrofluid is removed from the disk after each test • For electromagnets, equal initial amounts of voltage and current are applied and then modified to try to improve/maximize magnetic field	The permanent circular magnets were the best at producing a strong and large magnetic field in the ferrofluid. The electromagnets were not able to produce enough height in the ferrofluid, although their field was wider than the permanent magnets.	The final design will incorporate permanent circular magnets in the design instead of electromagnets as initially determined.
Ferrofluid Layer	Performance	Dense enough to spin dependent cone at various speeds	• The ferrofluid must be strong enough to turn the dependent cone at various speeds • The ferrofluid cannot be too abrasive on the two cones • The ferrofluid should contain iron particles no larger than 50 microns	The more oil added to the iron particles, the less of a magnetic field was created. The iron particle purchased from Alpha Chemicals falls within the 50 microns parameter and provides very minimal abrasion.	Due to the limited strength of the magnets through the plastic cone, the iron particles will be mixed with oil in a 15:1 ratio.
Independent Cone	Performance	Measured Speed	• The input and output cones must be in contact with the ferrofluid • The input and output cones must be positioned at the same distance apart throughout the test • The speed of each cone will be measured with a tachometer for accurate results	The ferrofluid field was large enough to separate the two cones up to ½ in apart and still able to touch. Both cones feature the same angled surface and slots in the	The cones will be separated by ¼in at all points for an ideal transfer of torque.

				outer casing box that are equidistant at either end.	
Dependent Cone	Performance	Measured Speed	- The input and output cones must be in contact with the ferrofluid - The input and output cones must be positioned at the same distance apart throughout the test - The speed of each cone will be measured with a tachometer for accurate results	The ferrofluid field was large enough to separate the two cones up to ½ in apart and still able to touch. Both cones feature the same angled surface and slots in the outer casing box that are equidistant at either end.	The cones will be separated by ¼in at all points for an ideal transfer of torque.
Power Transmission	Design Spec	Calculation of Power transmitted from input to output cone	- The input and output cones must be in contact with the ferrofluid - The input and output cones must be positioned at the same distance apart throughout the test - The speed of each cone will be measured with a tachometer for accurate results	The ferrofluid field was large enough to separate the two cones up to ½ in apart and still able to touch. Both cones feature the same angled surface and slots in the outer casing box that are equidistant at either end.	The cones will be separated by ¼in at all points for an ideal transfer of torque.
Outer Casing Box	Safety	No leak of ferrofluid through 3D printed plastic	- The outer casing box must be waterproof to prevent ferrofluid from seeping through - The box must be able to hold a large amount of ferrofluid under the transmission cones - The box must prevent ferrofluid from going over the walls and spilling out	The PLA printed material has holes in its surface on a microscopic level that allow for oil and iron particles to leak through. The independent cone printed from the Object 360 printer is solid and does not leak any material out. The magnets can produce a ferrofluid field roughly 1 inch tall. Having 8in walls keeps the ferrofluid from reaching over	The outer casing box was large and therefore printed with the PLA (The cheaper option) and sprayed with a rubber coating to prevent leaks. A basin greater than 1 inch was made at the bottom to maximize the ferrofluid field. The box was printed with 8in walls to

				and out of the box.	keep ferrofluid inside.
Dependent Cone	Performance	Sufficient mass to function with heavier independent cone	• The dependent cone must have less mass than the independent cone • The dependent cone should still have a strong structural integrity	The Objet30 printer can only produce fully dense parts but is extremely accurate. The PLA printer can produce parts with varying densities and inner structures. The PLA leaks ferrofluid, but the Objet30 does not.	The dependent cone was produced using PLA and then coated with a rubber sealant. The inner structure was chosen as a honeycomb pattern to prevent structural weakness.
Independent Cone Magnet Slots	Performance	Magnet motion throughout the cone length	• The magnet slots must be able to accompany ¾in circular magnets • The slots must allow the magnets to move up and down the entire length of the cone • The slots must allow the magnets to be in contact with the metal rod	The nose (slimmer) end of the cone is too small to allow the magnets to travel throughout the entire length. The slots using a gap in the bottom allow for the spring to move and follow the motion of the rod. A small gap gets in the way of the springs, therefore a larger gap is ideal. Keeping a close tolerance on the slots allows for maximum motion up and down the cone.	The six slots have a tolerance that allow the magnets to move freely without jeopardizing how far it can move down the cone. For material and time reasons, the cones shall remain unchanged and the magnets can move roughly 4in down the cone. A large gap is added to the bottom of the slots to prevent inefficiency.
Permanent Magnets	Performance	No residue from tape side	• The magnets should be smooth on either side • To maximize magnetic field, the magnets should have no interference between them	The magnets come with one adhesive side that does reduce the magnetic field significantly. If not cleaned off, the adhesive acts	The adhesive was removed by fingers and wiped down to ensure no residue was left.

				as friction when sliding and reduces overall motion.	
Independent Cone	Performance	All 3D printed support material removed	- Support material must not interfere the movement and freedom of the rod's, spring's, and magnet's motion - The support material must not interfere with the magnetic field	Uncleaned support material halts the movement and freedom of the rod's, spring's, and magnet's motion The support material can dampen the magnetic field. The support material can be removed with the power washer with great amounts of effort.	The support material was meticulously removed using both power washer hoses to prevent any interference.
Spring Weld	Performance	Sufficient material	- The spring must be secured to both magnets and the steel rod - The spring cannot have motion at the direct point of contact on either magnets or rod	The magnets and springs are able to be held securely together with a solder weld with minimal magnetic motion interference. Using hot glue between the magnet and springs does not create a strong enough bond. The rod and springs cannot be welded with solder. Using hot glue for the weld allows for too much motion at the base of the spring.	The magnets and springs were soldered together. A rod adapter was created to secure the base of the springs with hot glue, but it does interfere minimally with the rod motion.
Magnet Weld	Performance	Sufficient material	- The magnets must be secured to the spring - The weld cannot interfere with the magnet motion	The magnets and springs are able to be held securely together with a solder weld with minimal magnetic motion interference. Using hot glue	The magnets and springs were soldered together.

				between the magnet and springs does not create a strong enough bond.	
Rod Weld	Performance	Sufficient material	• The rod must be secured to the spring • The weld should not interfere with the rod motion	The rod and springs cannot be welded with solder. Using hot glue for the weld allows for too much motion at the base of the spring.	A rod adapter was created to secure the base of the springs with hot glue, but it does interfere minimally with the rod motion.

Individual Performance Tests

Table 6: Record of Test #1 (Performance & Design Specification)

MCE 402 Team 22	**Record of Individual Test**
Name of Tester	Ryan Buglio, Trevor Chambers & Chelsea Fox
Date of Test	4/15
Test Description	● Input and output cone speed and power transferred from input cone to output cone determined by torque measured using fishing scale.
Test Parameters	● The input and output cones must both be in contact with the ferrofluid during the test ● The input and output cones must be positioned at the same distance apart throughout the test ● The force produced on the scale by the output cone must be measured at the same radius/position with the fishing scale
Test Results	Average torque ratio of 0.55 input to output

Table 7: Record of Test #2 (Performance)

MCE 402 Team 22	**Record of Individual Test**
Date of Test	2/25/19, 3/1/19, 3/18/19, 3/20/19
Test Description	Permanent magnets and electromagnets were tested with ferrofluid samples of equal mass to determine the magnetic field and ferrofluid height produced by the magnets.
Test Parameters	● Equivalent mass of ferrofluid particles (25g) for each test ● Magnet(s) positioned at same distance from ferrofluid and 3D printed plastic for each test ● Measurements of ferrofluid height/magnet field are taken from the top of the plastic disk to the highest point in the ferrofluid form ● All ferrofluid is removed from the disk after each test ● Equal initial amounts of voltage and current
Test Results	The permanent circular magnets were the best at producing a strong and large magnetic field in the ferrofluid.
Resolution	The final design will incorporate permanent circular neodymium magnets in the design instead of electromagnets as initially determined.

Table 8: Record of Test #3 (Performance & Design Specification)

MCE 402 Team 22	**Record of Individual Test**
Name of Tester	Ryan Buglio, Trevor Chambers & Chelsea Fox
Date of Test	4/15
Test Description	Input and output cone speed and power transferred from input cone to output cone determined by torque measured using fishing scale.
Test Parameters	● The input and output cones must both be in contact with the ferrofluid during the test ● The input and output cones must be positioned at the same distance apart throughout the test ● The force produced on the scale by the output cone must be measured at the same radius/position with the fishing scale
Test Results	Average torque ratio of 0.55 input to output
Resolution	Higher ratio needed (decrease friction, increase ridge depth, decrease gear distance)

Design Specification Compliance

As an invention team, there were only a few design specifications indicated at the beginning of the project, including the $300 budget, an objective of designing a product to solve a problem for a large population and the stipulation that the product must be mechanically-based and either patentable or publishable. The following summary of design specifications taken from the original design specifications in Table 1 were thus determined to be validated by the final design.

Table 9: Design Specification Validation

Design Specification	Validated?
Patentable	Yes
Meets $300 budget	Yes
Solves problem for large population	Yes
Efficient/Effective/Simple (Compared to current products on the market)	Yes
Manufacturable	Yes
Scalable (Up or down)	Yes
Inexpensive (<$1000-$2000)	Yes

Decommissioning and Disposal

In terms of decommissioning and disposal, since this transmission will be more efficient, durable, functional and environmentally-safe due to the simplicity of the design, its ability to be recycled and its long anticipated life due to infinitely-variable ratios and fluid lubrication means that the decommissioning and disposal process will consist primarily of a recycling and upcycling process. Furthermore, since the ferrofluid transmission will be cheaper to manufacture, since there are fewer parts than a standard transmission and the design is predicted to last longer than a standard transmission due to the simplicity and innate lubrication properties of the design, the product will last longer before decommissioning will need to occur. As part of life cycle pricing, warranty and financial return considerations, the ferrofluid transmission will also be cheaper and more durable, and thus a better return on investment since it is a simpler design instead of current designs that employ complex gear systems that may require maintenance or replacement. Furthermore, the product will be able to follow US metal recycling policies since the components are all non-hazardous materials that can easily be separated and sorted for reuse and manufacturing.

Safety Standards

In terms of social, political and legal requirements for the design, in the example of its use in the automotive industry, the ferrofluid transmission will be able to meet US DOT controls and regulations, such as safety factors, since the design can be scaled and improved through many controls (i.e. ferrofluid viscosity, transmission cone proximity, transmission cone dimensions). Finally, with regards to social issues, the ferrofluid transmission is environmentally-friendly since it improves miles-per-gallon ratings and since the design, manufacturing, and recycling processes will ensure that none of the components end up in the environment (i.e. none of the ferrofluid will be able to spill from the sealed transmission box).

Redesign

Redesign Accomplished

Based on the testing procedures, there was a need to redesign two different evolutions from the original design concept of the two cones in the transmission box, which was printed in PLA on the 3D printer. Due to frictional losses, tolerance issues and changes in the type of magnets used to control the ferrofluid, the independent cone was reprinted to fit in the original PLA box using the more precise Objet30 3D printer. As a result of the magnet testing and determination that the circular neodymium magnets were the most effective for the design, the independent cone was redesigned to accommodate the magnets in slots that ran the length of the cone in 360 degrees. This redesign allowed for the magnets to be moved up and down the length of the cone, allowing for infinitely variable ratios of ferrofluid gearing. The following Solidworks drawings and images show the redesign.

The second design evolution of the ferrofluid transmission simplified the original design and was created to prove the invention concept through a 2D gear system. A plexiglass box was constructed and waterproofed and an input and output gear of equal size, but scaled down from the original cones, were printed on the Objet30 printer. The circular neodymium magnets were then placed in the input gear in the slots in 360 degree positions. Both gears were then sealed and placed in the plexiglas box, where they were positioned on the input and output rods. Nylon bearings were used to reduced friction in the holes drilled in the plexiglas where the input and output rods were located. The following Solidworks drawings and images show the redesign.

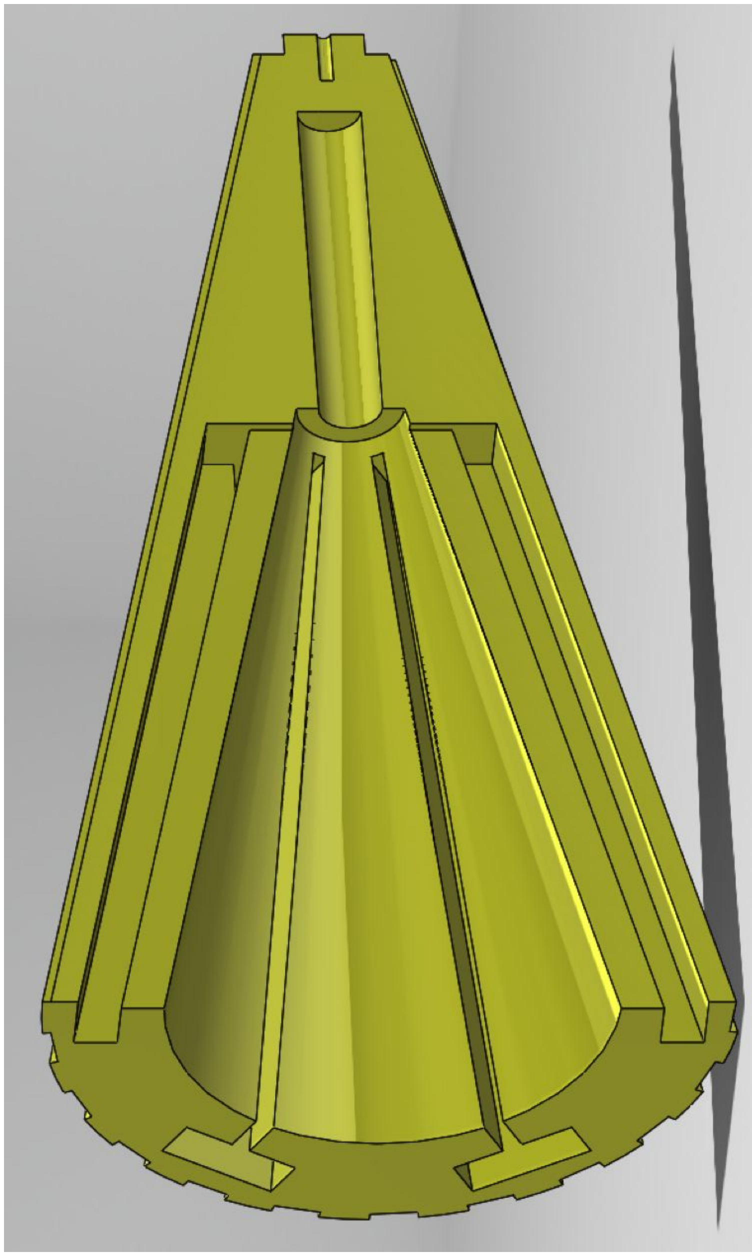


Figure 26: Independent Cone Cross Section Solidworks Drawing

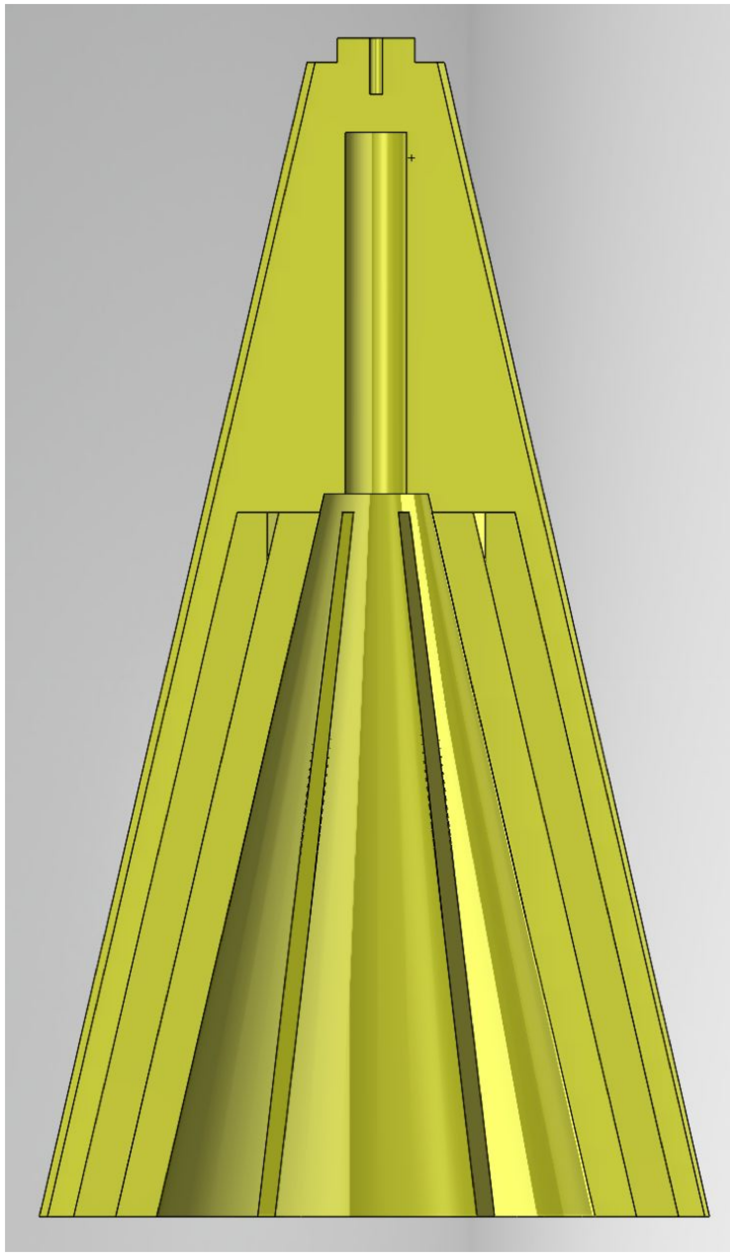


Figure 27: Independent Cone Cross Section Solidworks Drawing

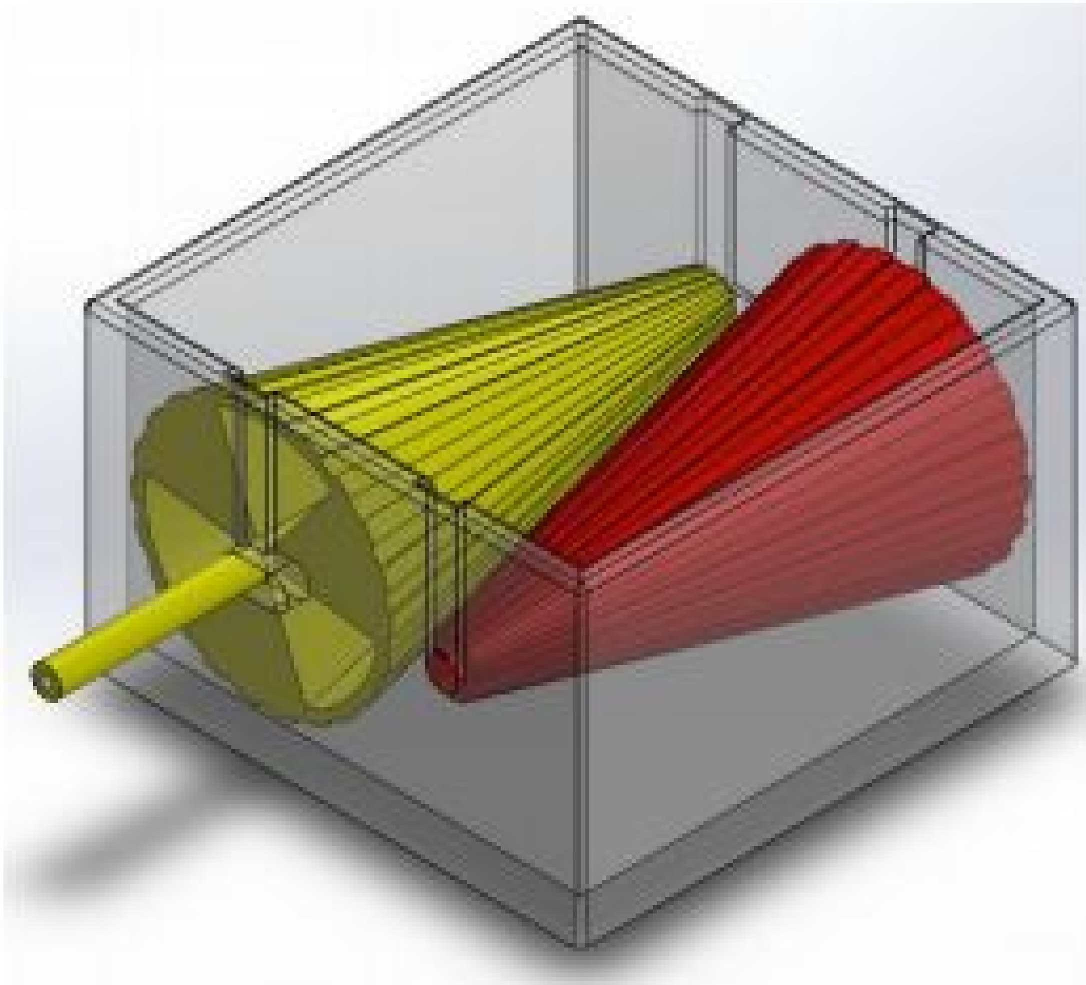


Figure 28: Independent and Dependent Cone Solidworks Drawing

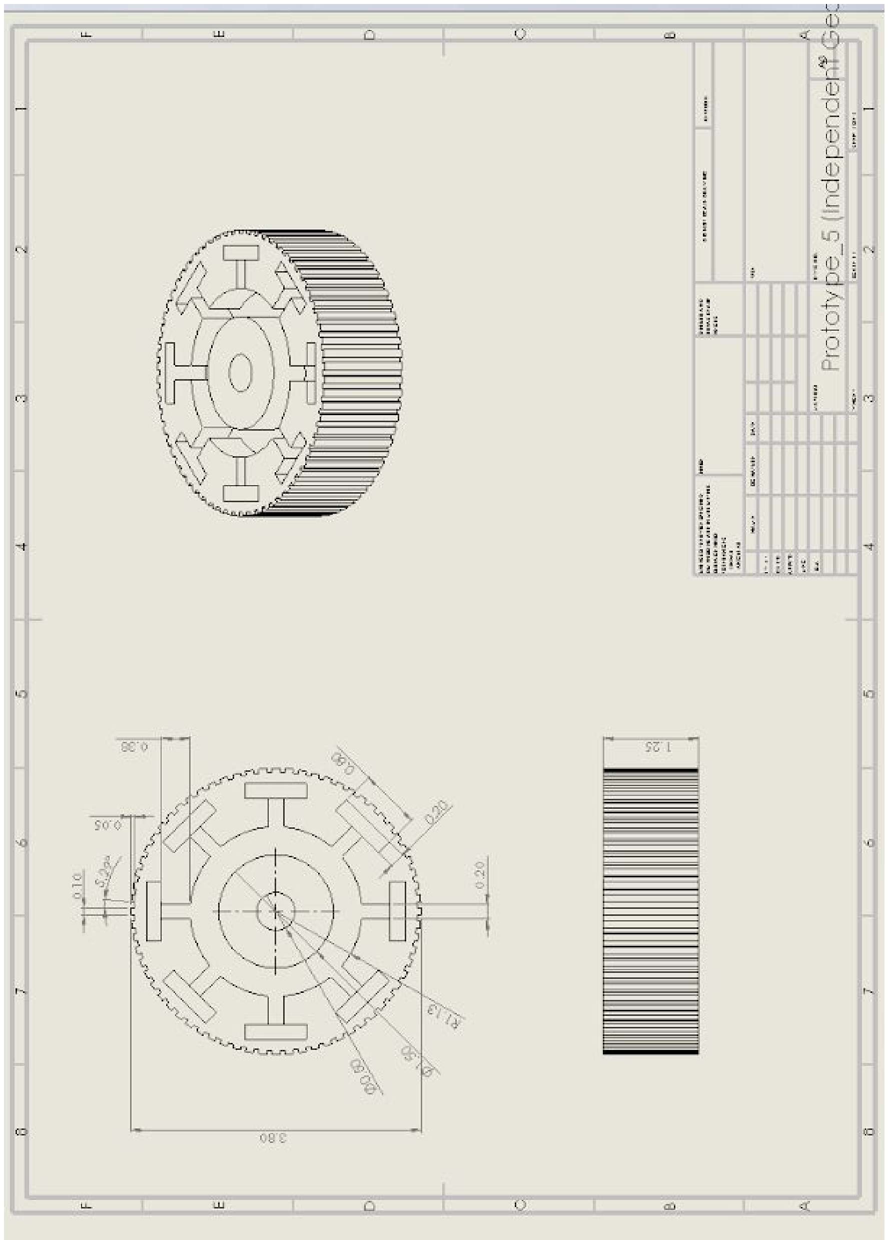


Figure 29: Independent Gear Solidworks Drawing

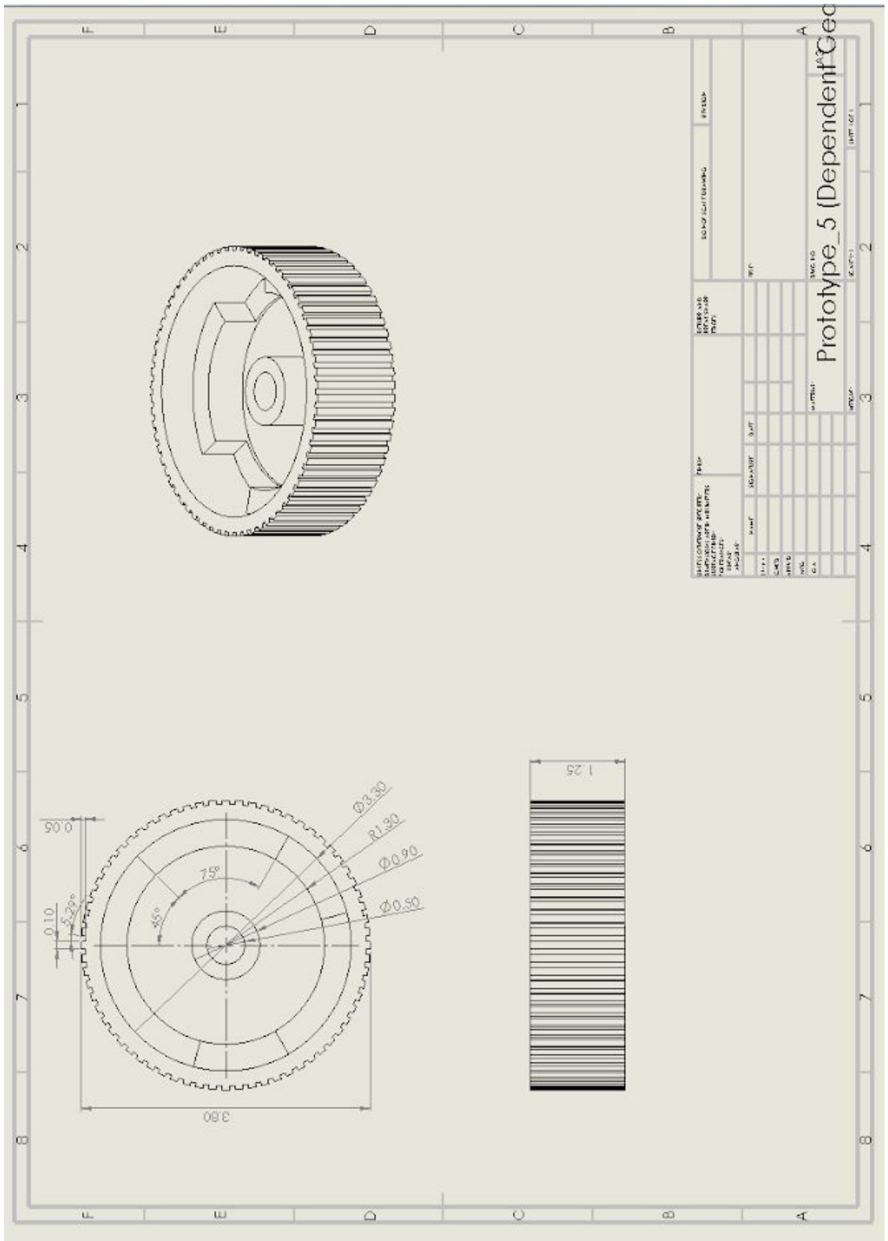


Figure 30: Dependent Gear Solidworks Drawing

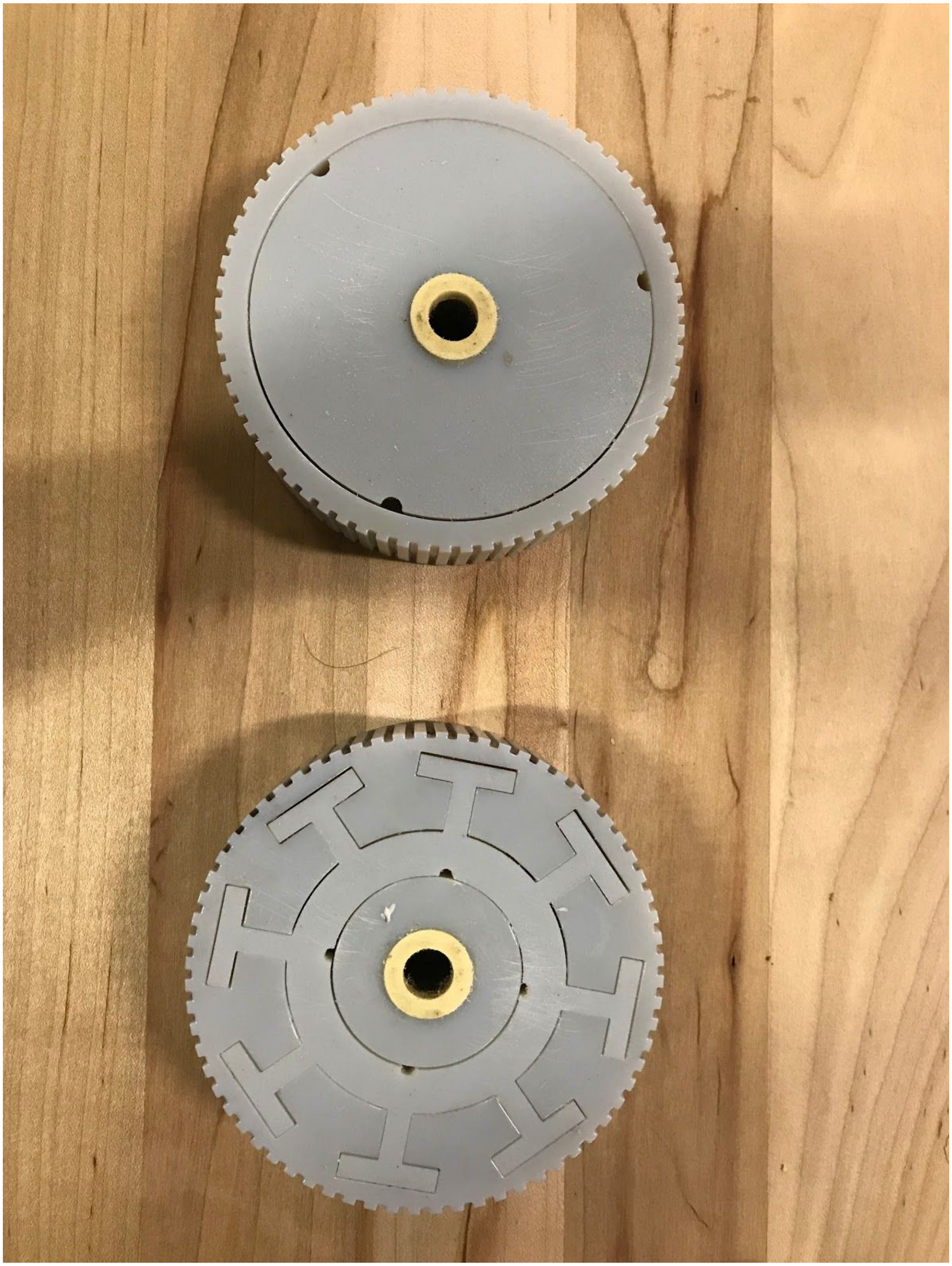


Figure 31: Independent and Dependent Gears (Sealed)

Figure 32: Independent Gear Side View

Figure 33: Final Design Setup without Ferrofluid

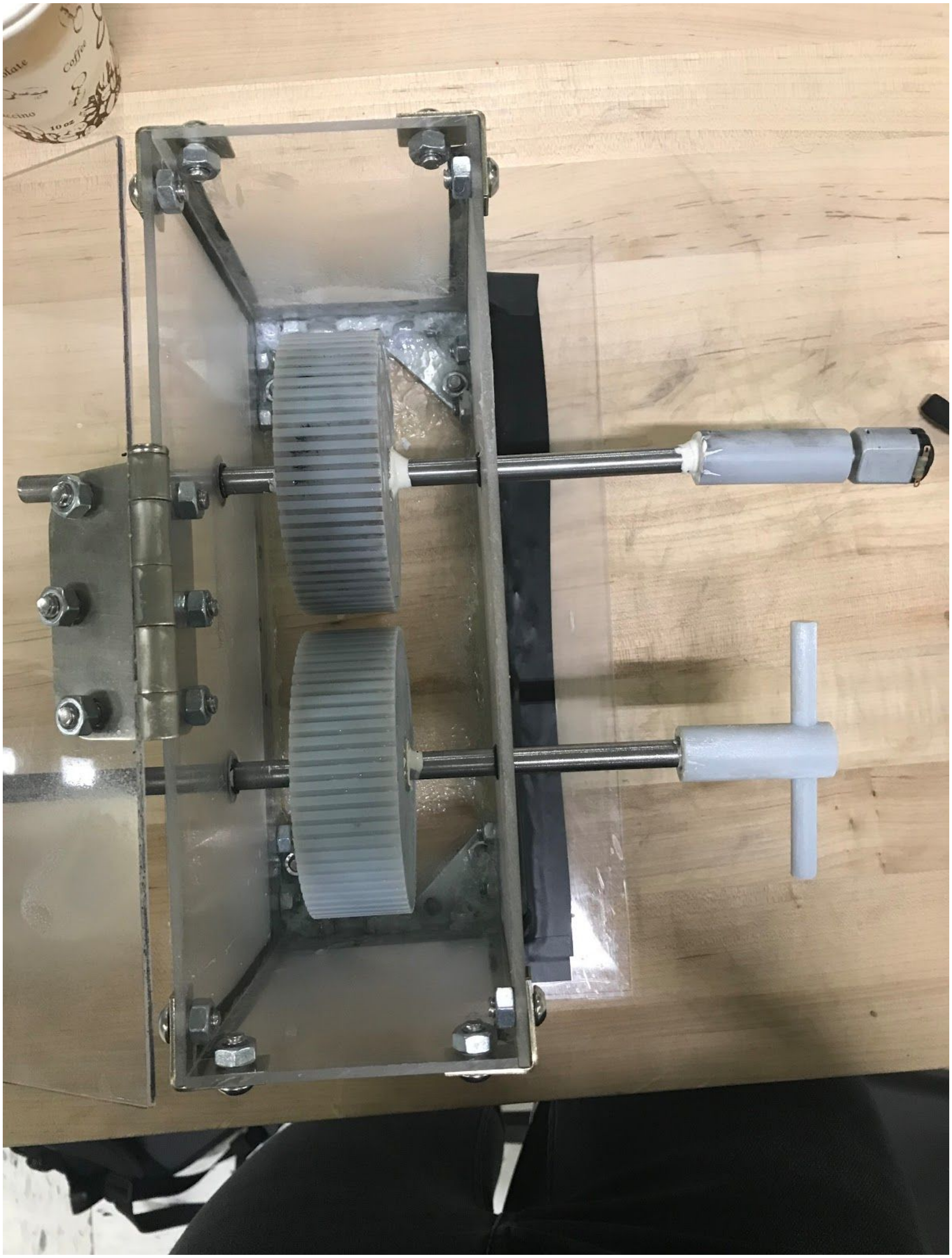


Figure 34: Final Design Setup without Ferrofluid

Future Recommendations

Future recommendations for another capstone group taking on this specific invention project would be to go forward with this idea of non-contact torque transfer and try to patent a design using it in an application.

A promising idea would be to design and incorporate a mechatronics or electrical system in order to control the location of ferrofluid along transmission cones in order to create an infinitely variable transmission. This was the original goal of this project however after the testing conducted and consulting with the project sponsor it was decided that a more appropriate direction for patenting this project would be trying to obtain a utility patent on the idea of non contact torque transfer with ferrofluid as a medium.

Project Planning

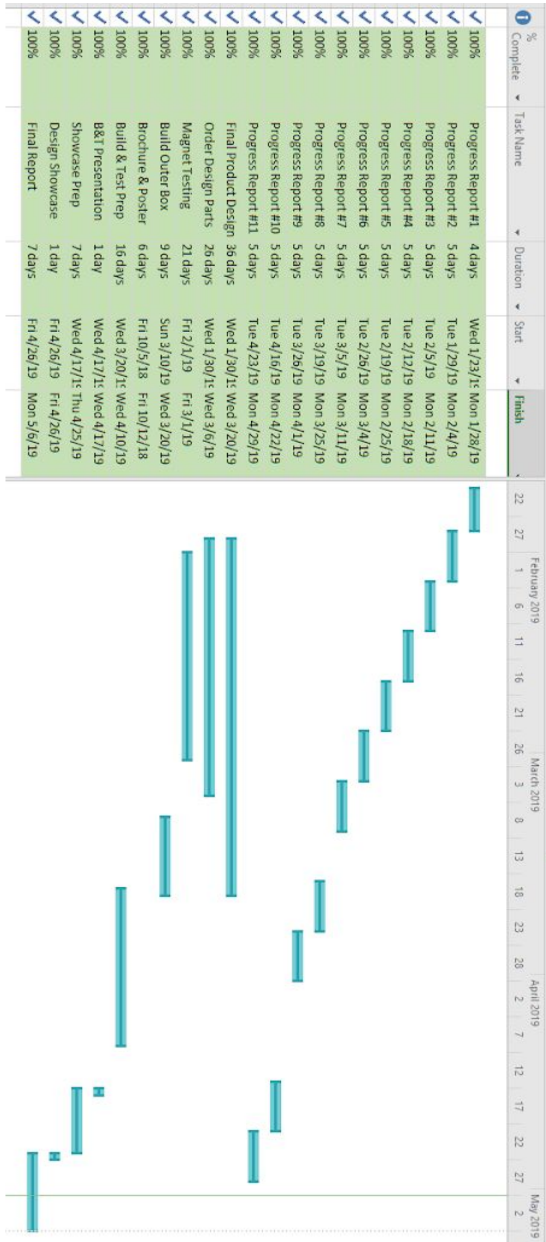


Figure 35: Gantt Chart

Over the course of the semester, Team 22 remained on task and on time for all the deadlines due to the Gantt chart featured above. The Gantt chart acted as a timely organizer that helped the team focus on each individual task in the correct order. It can be seen that all tasks have been fully completed when looking at the *% Complete* column. The chart was organized in a way that the top half portion was dedicated to keeping track of the reports and the bottom half portion of the chart was dedicated to the individual and team assignments.

A weekly progress report was submitted electronically along with an updated project plan to show the progress with the ferrofluid transmission. The report included a discussion of each team members accomplishments over the week, the overall progress on the ferrofluid transmission, any challenges faced, and the plan for the following week. Looking at the individual assignments, the Final Product Design was the newest gear system design that incorporated all the achievements and discoveries since the fall semester. The Magnet Testing helped focus on the pros and cons of using each type of magnet to ensure maximum efficiency. The permanent magnets were chosen due to their high magnetic pull and were also easiest to use. The Build and Test Presentation brought the team to the next step; presenting the final concept and design to the senior mechanical class for review and to update everyone on the team's progress. The Gantt chart was very resourceful on what to focus on leading up to and during the presentation. The Design Showcase was the next big task to complete. The final design was to be displayed to the public to show off the entire year's work and progress. Lastly, a summary of all the events and tasks completed during the semester needed to be put into the Final Report.

Financial Analysis

To perform an appropriate financial and market analysis of the invention product, the application of using ferrofluid in a transmission was analyzed for the impact it would have in the automotive industry.

For the design, prototyping, testing and redesign processes a budget of three hundred dollars was supplied by the project sponsor Dr. Nassersharif. A total of two hundred dollars was spent on ordered material, meaning the invention project came in under budget. When taking into consideration the theoretical cost of the resources Schneider Electric provides capstone groups for free, the financial cost analysis can be described as shown in the below figure:

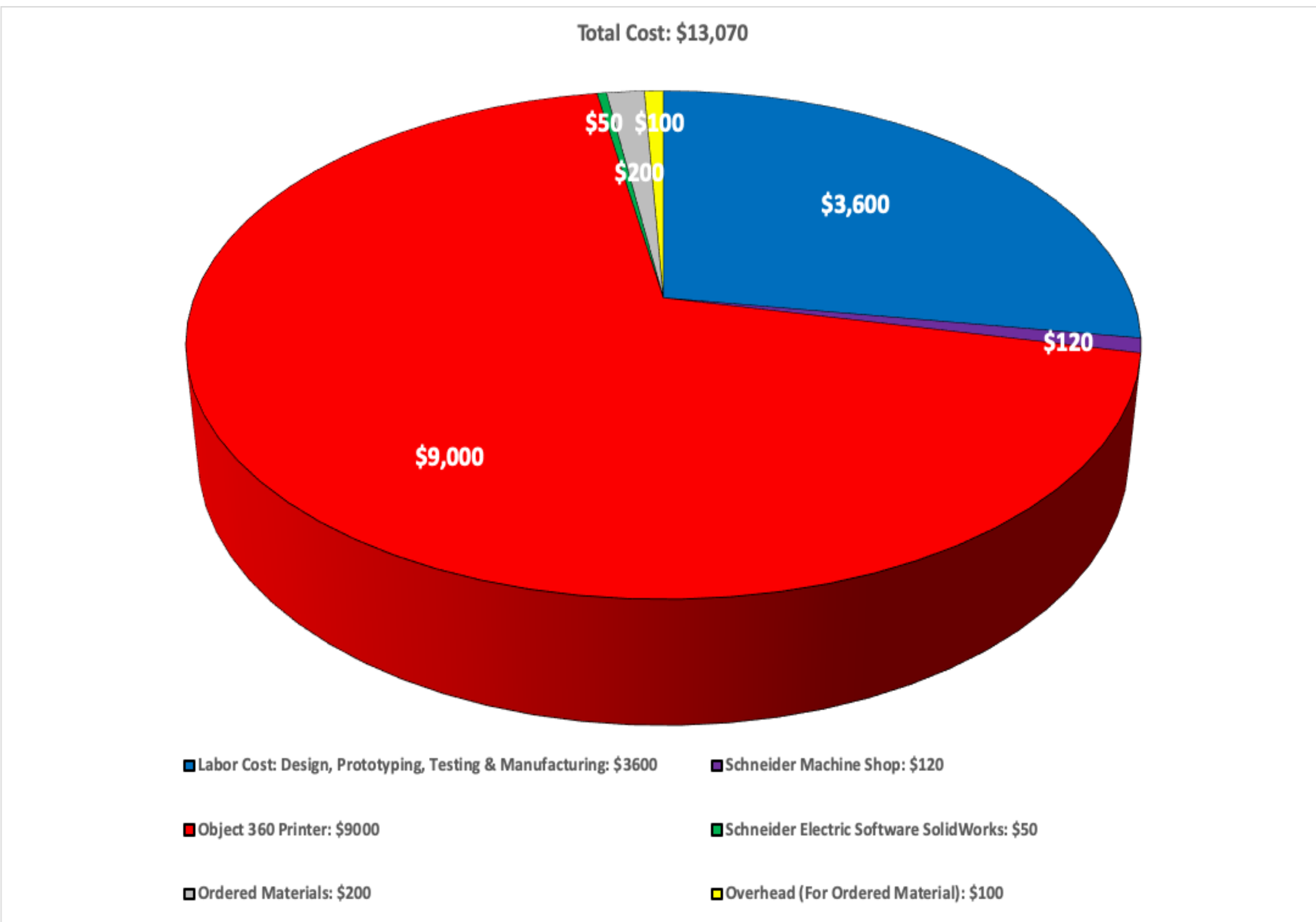


Figure 36: Financial Cost Analysis

Table 10: Design Cost Parameters

Person/Resource	Price/Hour
Undergraduate Students	$20
Graduate Students	$30
Faculty/Sponsor	$100
Schneider Electric Machine Shop	$40
Schneider Electric Software	$5
Objet30 Printer	$300
Ordered Materials	$200
Overhead	50% of Ordered Material Cost

Moving forward to manufacturing and possibly mass producing the ferrofluid transmission the cost to produce would be similar to that of a normal transmission. The only added costs would be for whatever electromagnet controlling mechanism the manufacturing company would use, additional hours by the machinist to hollow out the transmission gears/cones, the ferrofluid itself and electromagnets or permanent magnets which are relatively inexpensive. The only difference in the manufacturing process would be in hollowing out one of transmission gears/cones and also some electrical setup with the magnets/electrical system used to control the magnets. The following table represents rough estimate of manufacturing time and cost per transmission.

Table 11: Cost Analysis of Ferrofluid Transmission Manufacturing

Job	Role	Hours	Cost/Hour	Cost
Material	Ordering all mechanical materials, ferrofluid wiring and electrical pieces needed	N/A	N/A	$500
Machinist	Manufacture and assemble mechanical components	25	$25	$625
Electrical Tech	Wire electromagnetic components	10	$25	$250
Engineer	Check the product against engineering design	5	$35	$175
Test Man	Test the finished ferrofluid transmission	5	$20	$100
			Total	**$1650**

It should be noted that if this product is to be mass produced it will more than likely be done on an assembly line rather than hand made by a machinist and electrical tech, which would significantly cut down the cost of manufacturing. The demand for the ferrofluid transmission would be very high due to the increased efficiency and increased sustainability. If it costs a little less than $1650 when mass producing using machines in an assembly line instead of a mechanic for all the machining/manufacturing (around $1500 for simplicity) and charge the average cost of a new transmission which is $2,500 [11] than there would be a profit of around $1000 per ferrofluid transmission sold.

As previously mentioned, upon conducting a market analysis of the transmission market, and specifically the continuously-variable transmission market, it's been found that North America has both the highest value market and also the highest growth rate, making the USA the perfect place to start marketing the ferrofluid transmission product.

The key companies of the CVT market that the ferrofluid transmission product would be competing against include BorgWarner, Jatco, Punch Powertrain, Toyota Motors, ZF Friedrichshafen AG, Aisin Seiki, Efficient Drivetrains, Folsom Technologies International, Hunan Jianglu & Rongda, and Hyundai Motor [11]. The advantage the ferrofluid transmission product has over the CVT's produced by these companies, however, is that it will require significantly less maintenance which will make it more appealing for consumers looking for efficiency and to save money.

Operation

The invention operates by transferring torque from an input to an output using ferrofluid as a medium. Because ferrofluid contains magnetic particles, it takes the shape of a magnetic field when exposed to one. Utilizing electromagnets or permanent magnets, it's possible to create a permanent medium on the outside of a gear or transmission component for example. By using the ferrofluid as a point of contact between the input and output components, it's possible to transfer torque between the two with little to no mechanical friction; greatly increasing the life/decreasing the maintenance required of the input and output components.

As this capstone project was an invention with the ultimate goal of obtaining a patent, no manuals of any kind were produced as this invention be implemented in a variety of applications. If another capstone group were to take this invention a step further next year and try to patent a design utilizing this non-contact torque transfer method, then some operation and safety manuals may be produced.

Maintenance

Again as this capstone project was an invention with the ultimate goal of obtaining a patent, it’s difficult to describe possible maintenance as this can be applied to a variety of applications. The problem that this invention solves is increasing the life of input/output components of torque transfer due to ferrofluid being a medium instead of metal pieces themselves, virtually eliminating mechanical friction. This would hopefully yield less maintenance required of whatever machine/application this invention is used in. In terms of maintenance the same maintenance of the machine/application would probably be required but on a less frequent basis.

Possible maintenance of the invention itself (depending on the design and application) could be having to replenish ferrofluid supply being used as a medium and also having to change magnets if their magnetic field begins to deteriorate. If it is used in an application in which a mechatronics/electrical system is used to control the location of the ferrofluid, electrical maintenance could also be required from time to time.

As stated before ferrofluid contains many tiny solid magnetic particles suspended in a liquid medium which is usually an oil type substance. Because of this, proper disposal procedure would be similar to that of disposing of oil, however it is mixed so it shouldn't be recycled. It should be emptied from it’s application into some sort of storage container and then brought to a service station for disposal.

Additional Considerations

Economic Impact

Since the ferrofluid transmission could potentially replace all current mechanical transmission systems due to its simplified and cheaper design, it would have an economic impact on many industries by reducing machinery costs and increasing machinery lifespans. For example, in the automotive industry, the ferrofluid transmission could replace all current transmission gear systems, thus decreasing the initial and maintenance costs of the vehicle since the design is both cheaper to manufacture and has a longer lifespan due to its non-contact transfer.

Societal and Political Impact

This product would have a societal impact since it could potentially replace current mechanical transmissions with a cheaper and more durable product. For example, in the automotive industry, the product would reduce the cost of the vehicles in which it is implemented, thus inciting consumers to purchase those vehicles. The more consumers in society that purchase such a vehicle would then impact society by shifting from the current, more expensive and shorter lifespan gear transmission systems to favor the ferrofluid transmission.

Ethical Considerations

This product would have ethical considerations since it could potentially replace current mechanical transmissions with a cheaper and more durable product that can easily be recycled or upcycled. In a society concerned with the environmental impact and sustainability, such a product would pose an ethical consideration for consumers looking to reduce their impact by providing them with an option that meets their needs.

Health, Ergonomics and Safety Considerations

Since this product could potentially replace current mechanical transmissions, such as those found in the automotive industry, the health, safety and ergonomic must be considered. For a vehicle to meet safety standards set by the US DOT, all of the components of the vehicle must meet the requirements, and the ferrofluid transmission must thus be a reliable, efficient and effective product. This was proven to be the case through repeated prototype testing.

Environmental Impact and Sustainability Considerations

The ferrofluid transmission invention was designed to improve current transmission designs by developing a simpler and more effective product. Due to its non-contact nature and cost-effective materials that can be recycled, the product has implications for its environmental impact and sustainability since it provides a product with a longer lifespan that can be recycled during decommissioning rather than disposed of. Therefore, this product, if patented will reduce environmental impact and promote sustainability in many different industries that use mechanical transmissions.

Conclusions

In conclusion, the ferrofluid non-contact torque transfer system does in fact satisfy all the design requirements of the capstone project. As stated previously, the design requirements for the invention project were that it needed to be an invention that solves a problem for a large population of people, be patentable/publishable and be a mechanical-based design. The invention also reached its goal of successfully transferring torque between gears using permanent magnets.

The ferrofluid gear system solves a problem for a large population of people because it would save consumers of the auto industry a lot of money in repairs/maintenance compared to the usual gear system with input and output gears. Based on the patent search there are no existing patents or applications for a product anything like the ferrofluid gear system, satisfying the fact that the design needs to be patentable. Last but not least, the product would be used in various industries, such as the automotive industry, making it mechanical based. The applications for this gear system seems endless giving it the flexibility to adapt and intwine itself into most machines.

Moving forward the team will be patenting the non-contact torque transfer using ferrofluid design. There are no current patents that interfere with this design and therefore can be patented. The function of this patent will be for utility, making it applicable to most mechanical based systems.

Overall the first and second semester of the capstone design project can be considered a success. The team produced a functional final prototype and will be creating a patent to secure the future of this ferrofluid gear system.

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Appendices

No additional information.