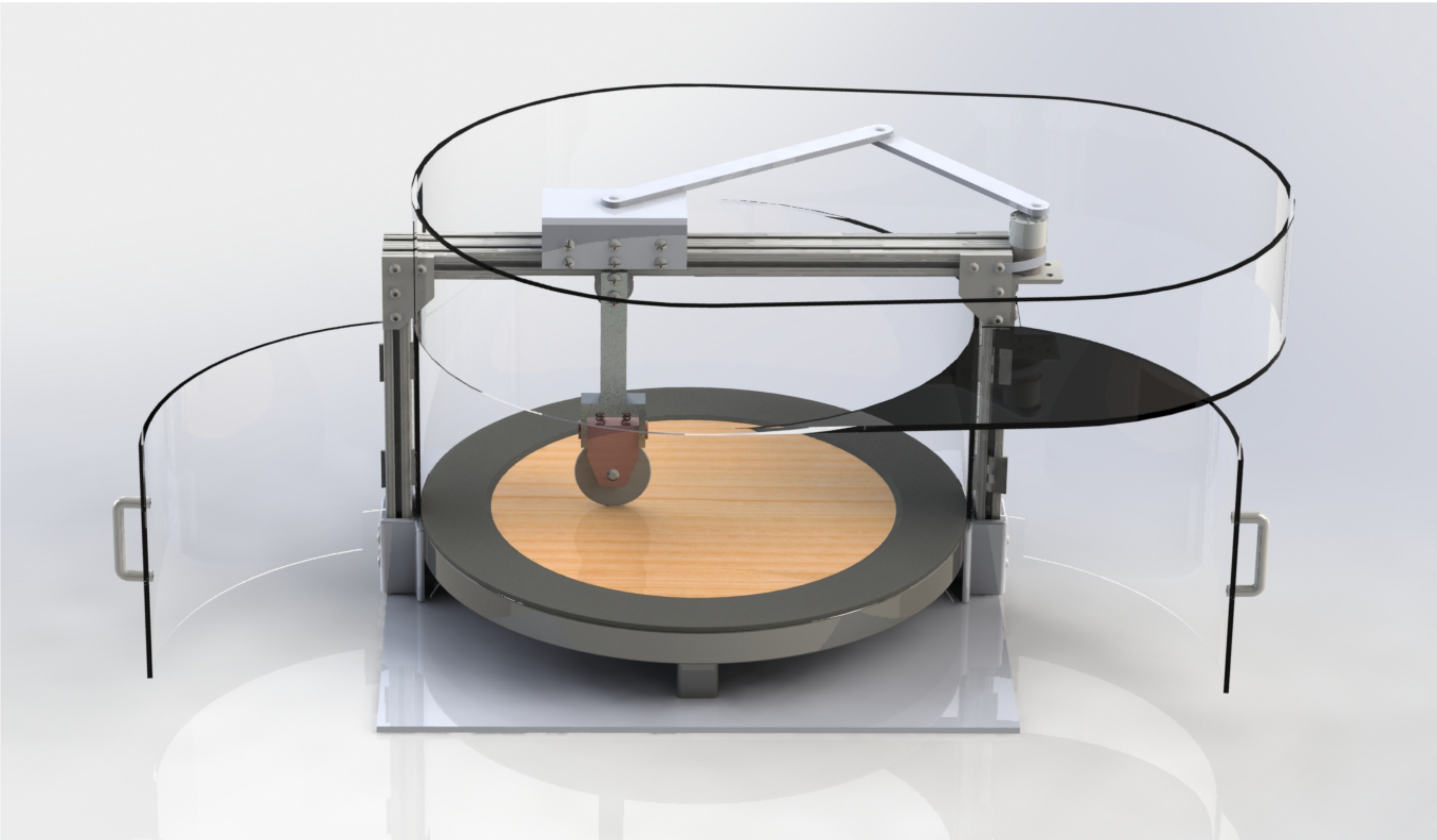
ME 130: Design of Planar Machinery



ZA Engineering Design Documentation

December 11, 2020

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Introduction

One of the most beloved foods for college students is pizza. I mean, who doesn't love the stuff? Hot cheese, crispy crust, zesty sauce… You almost want to dig right into it. But, oh no! The pizza isn't cut! Well, let's just get out the pizza roller and… OUCH! The pan is hot! And this cutter is so dull! Woe is me who is left with a tiny mangled slice due to my inability to cut perfectly even slices of pizza! Clearly, cutting the pie is the most monotonous process in the art that is pizza making. With pizza professionals taking years on the job to perfect their slicing technique, we might as well make a machine to do it!

Background

Our goal is to design an automatic pizza cutter that is capable of cutting any size or thickness of pizza into an adjustable number of slices, improving the pizza cutting experience in all aspects. Although there are other products that advertise mechanized pizza cutting, they are either ineffective or too expensive to be worth considering for any pizza chain or home cook. As mechanical engineers, but more importantly, pizza lovers, we hope to create a fast, automated pizza cutter that advertises safety, efficiency, and sleek form factor as a novelty item. Through our innovative replaceable mechanism, we will create perfectly cut slices for pizzas of any size, inspiring home pizzaiolos the world over. We hope that such a product can spread our love of pizzas into more households, and make serving our fellow pizza lovers more exciting.

Though there exist some current market solutions, we found that they all fall short in some aspects. An existing industrial design was a large conveyor-belt based machine that fed pizzas into a cutting chamber to be sliced one by one. Although this machine was fast and effective, it was extremely large and likely expensive. Furthermore, it seemed to only be able to cut pizzas into 8 slices. The machine would only be practical for a large and wealthy pizza chain but not for smaller restaurants or for homes. We also found a design for a smaller, table-top pizza cutter that cut pizzas one at a time. However, it required a significant amount of muscle power to operate and also could only cut pizzas into a fixed number of slices. It also seemed like the effectiveness of the press-based design was inconsistent, and it was easy to make incomplete cuts in the pizza if not enough pressure was applied. Through our research, we found that there was no ideal pizza cutting machine that allowed for variable slices while also being safe, affordable, and sleek in its design.

Need for Mechanism & Application

Pizza consumption has steadily increased in the US and as the beloved food item has grown to be more popular, more and more people have found themselves adventuring into the world of pizza, trying new recipes from their home kitchen. This lockdown-influenced surge in home pizza chefs along with the continually rising number of pizza restaurants in the US (per Statista) has birthed millions more pizzas that need to be cut! As a safe, effective, and elegant solution for adjustable pizza cutting does not exist, there is a significant enough market need for a reliable, yet also extravagant pizza cutter for restaurants, home cooks, and celebrities alike.

In addition, investing in R&D for such a mechanism may also open doors to future products. The adjustable, timed design can be modified to cut other food items such as cakes and pies, opening doors to even more possible applications and potential market share for the combined mechanism.

Conceptualization

The following figures are our early conceptualizations of what the mechanism would look like. We knew we wanted to use the interesting indexing motion of a geneva mechanism to move the pizza, however, we were uncertain of how we would produce the cutting motion or what the frame of the mechanism would look like.

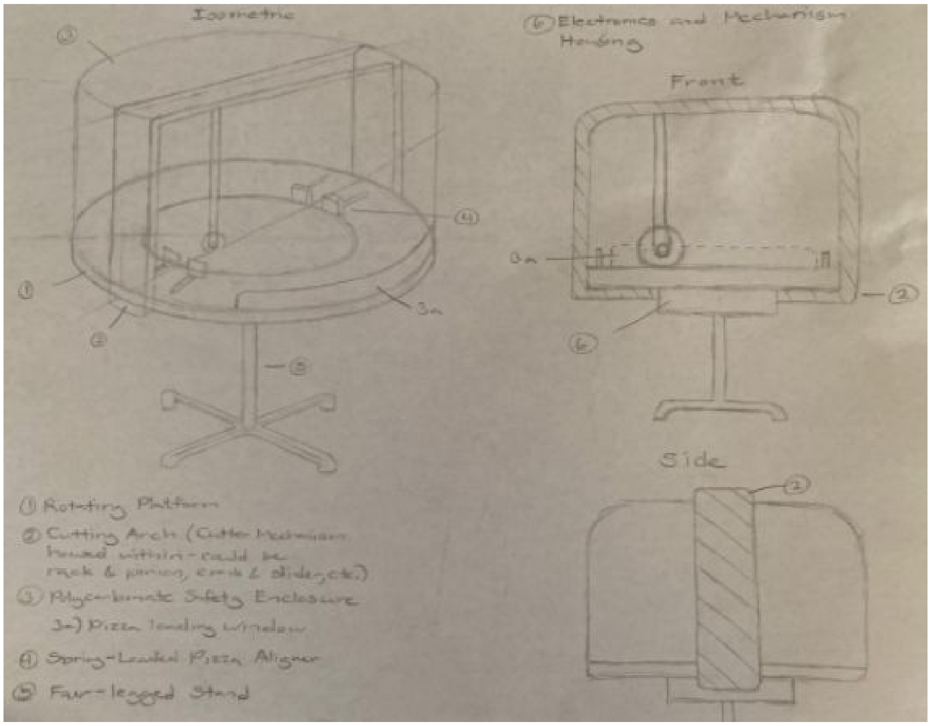

Fig. 1: Concept 1

In *Fig. 1* we experimented with a slider that would cut across the pizza using a circular pizza cutter. This approach was relatively simple since it only required a slider-crank to move the cutter. We also considered ways to keep the pizza in place, one of which was using spring-loaded stoppers to hold the pizza by applying a radial force. It was important to us that the housing for the mechanism was clear since watching the pizza get cut would be one of the best selling features of the device.

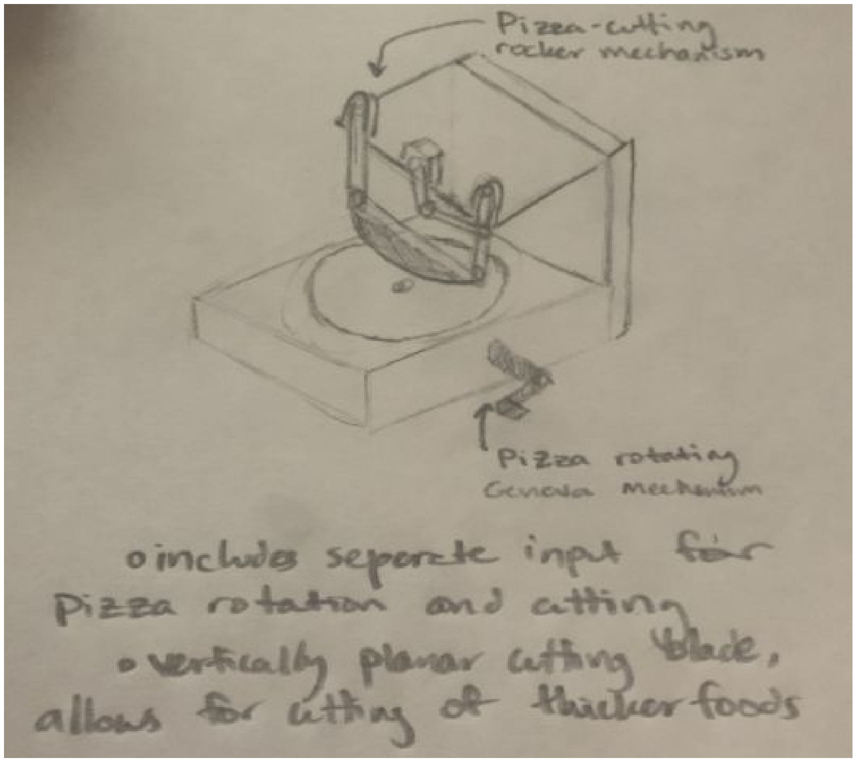

Fig. 2: Concept 2

Fig. 2 shows the second design for our mechanism. In this concept, the geneva wheel would be run by a hand crank instead of a motor to give the user more agency when using the product. We also considered using a rocker mechanism that would follow an arc when cutting subsequently allowing us to cut other foods besides pizza like cake. There were a few issues with this concept. Firstly, the rocker would be a complicated 6-bar mechanism and only be able to get good contact with the pizza at a point. Secondly, the hand crank was a bad idea since if a user had to put in the effort to turn a crank to cut a pizza, they might as well just have cut it with a regular cutter - the automatic function of the mechanism was paramount.

Specifications

<u>Functional Requirements:</u>

After some consideration, we came up with a list of the functional requirements of our mechanism. First of all, the mechanism should be able to cut pizzas of various sizes including an extra-large (16in). The thickness of the crust of the pizza also shouldn't matter so we required our cutting blade to have at least a 2in diameter to function with all pizza thicknesses. Secondly, cutting a pizza with this automated cutter should be faster than cutting by hand. As such, we determined that it should take 15 seconds or less to cut a pizza using our device. The pizza cutter should also be able to cut the pizza in a single motion without needing to be reset by the user. As such, there must always be a constant contact force with the pizza and the pizza should be held in place to ensure clean cuts. In conjunction with this, the user should be able to choose how many slices of pizza they want by easily switching certain parts. In general, all materials that come into contact with the pizza should be food-safe and easy to remove for cleaning purposes. The combination of these requirements resulted in a large portion of the mechanism to be easy to remove. Finally, to add to the visual appeal of this product, we wanted it to come in an aesthetically pleasing color scheme and a clear housing so that users are entranced by the machine during operation.

Constraints:

When designing our product we had to impose constraints to make sure the product could be feasibly operated. We wanted to make sure it could fit on a standard countertop or table, so the footprint of the device is less than 24”x24” with some added space for the mechanism to operate. The device should also be less than 25lbs so it is easy to carry around and should be able to run off a standard 500W wall outlet. Safety was also a large concern so every moving part had to be fully enclosed during operation.

Task Assignments

Group Member	Tasks
Roshan Jagani	Design/CAD of turntable, base, housing. Additional CAD, FEA of crank, final renders and animations
Matthew Lee	Base CAD, manuscript writing, 2D Assembly Drawing
Dixun Cui	Design of cutter and slicing arm subassembly
John John Huddleston	Design of crank-slider and design of arm subassembly. Housing design to encompass crank-slider. Additional CAD and render work. Final report writing.
Shaan Jagani	Graphical synthesis of Geneva mechanisms, CAD of baseplate assembly, project presentation animations, exploded views, torque and angular velocity plot generation
Felix Lin	Motor specification, torque and velocity analysis

Final design

Our final design (all exploded views in Appendix A) maximizes the aesthetics of the machine while still meeting our functional requirements and specifications. We decided to use the reciprocating motion of a crank-slider to drive a conventional rolling pizza cutter blade through the pizza. While the blade travels back and forth along a fixed linear path, the pizza itself periodically rotates a specified angle to line up the next cut. Intermittent pizza rotation is achieved by driving the turntable/cutting board with a geneva drive. Synchronizing the timing of the two mechanisms is critical to ensure the blade does not interfere with the motion of the pizza and turntable. We used off the shelf parts when possible, which are listed in appendix B. The remaining parts are designed to be fabricated in the student machine shop and Jacobs Hall Makerspace.

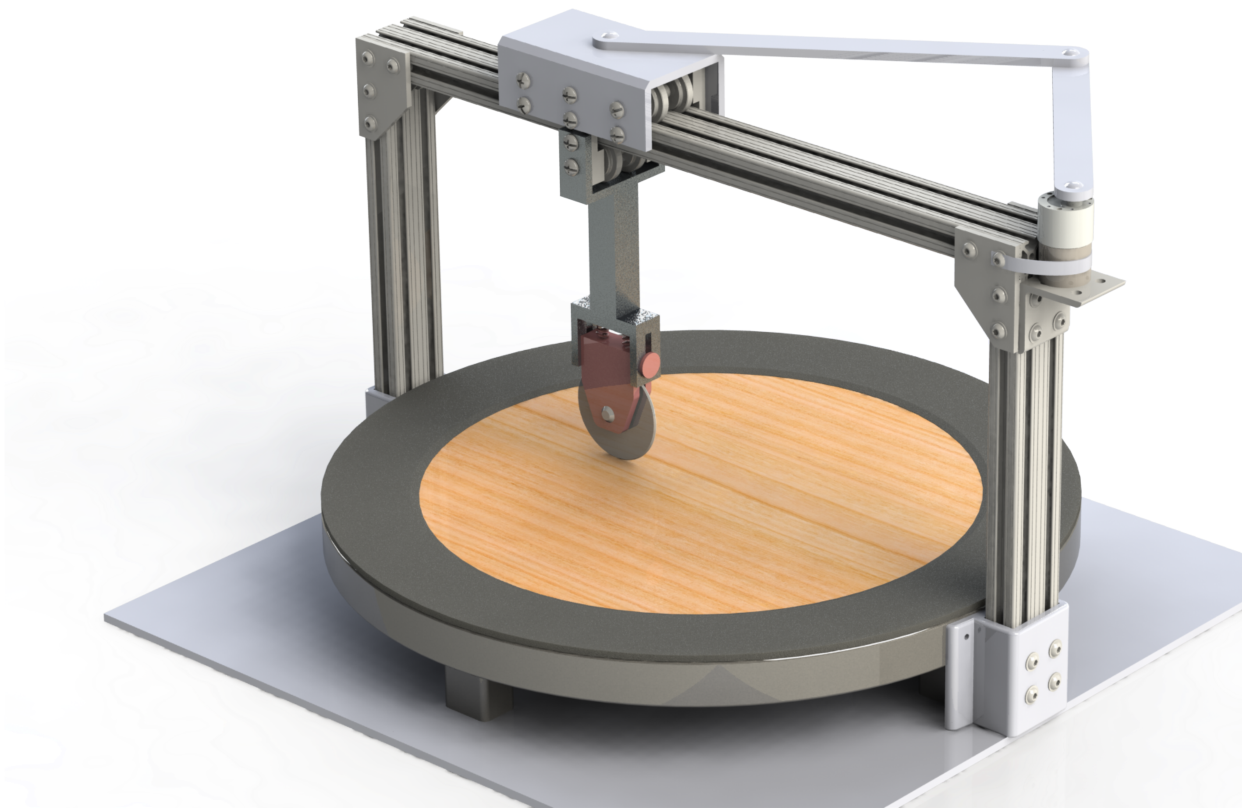

Fig. 3: Device without housing

The crank slider mechanism is designed to move the slider across the full diameter of the turntable with every half rotation of the crank. The crank is driven by a 12V DC motor. The entire assembly is mounted on an extruded aluminum frame to elevate it above the pizza. All metal components other than the 4 in diameter blade (made from stainless steel) are made from aluminum for ease of machining and to keep the inertial effects of the mechanism low. The cutter head assembly is spring-loaded to apply a constant downward force on the pizza and turntable, using two springs with a spring constant of 450 N/m each. At top dead center and bottom dead center the cutter clears the pizza crust and rolls off of the turntable onto a non-rotating lip allowing the turntable to rotate. The rubberized rim prevents the blade from dulling and also constrains the pizza to the turntable.

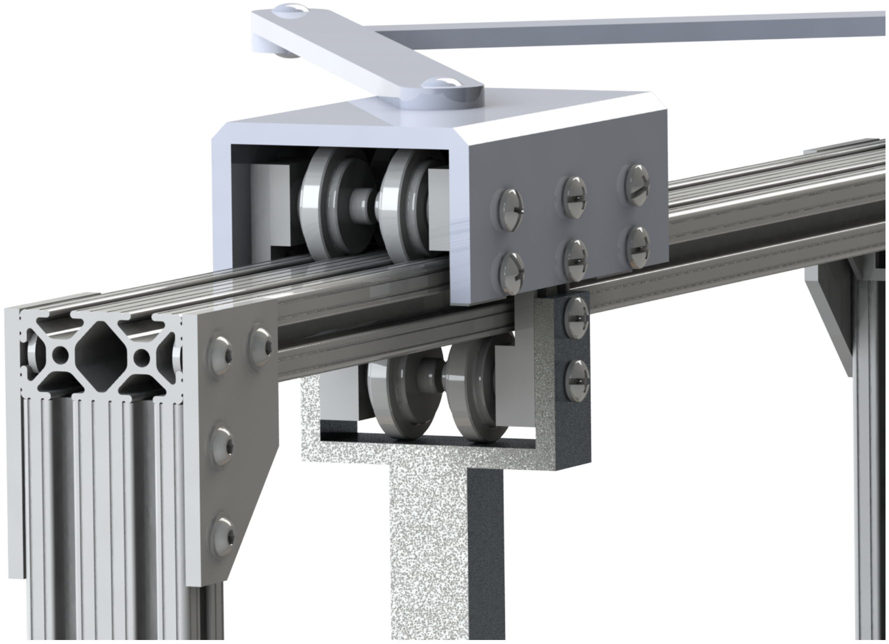

Fig. 4: Close up of the slider assembly

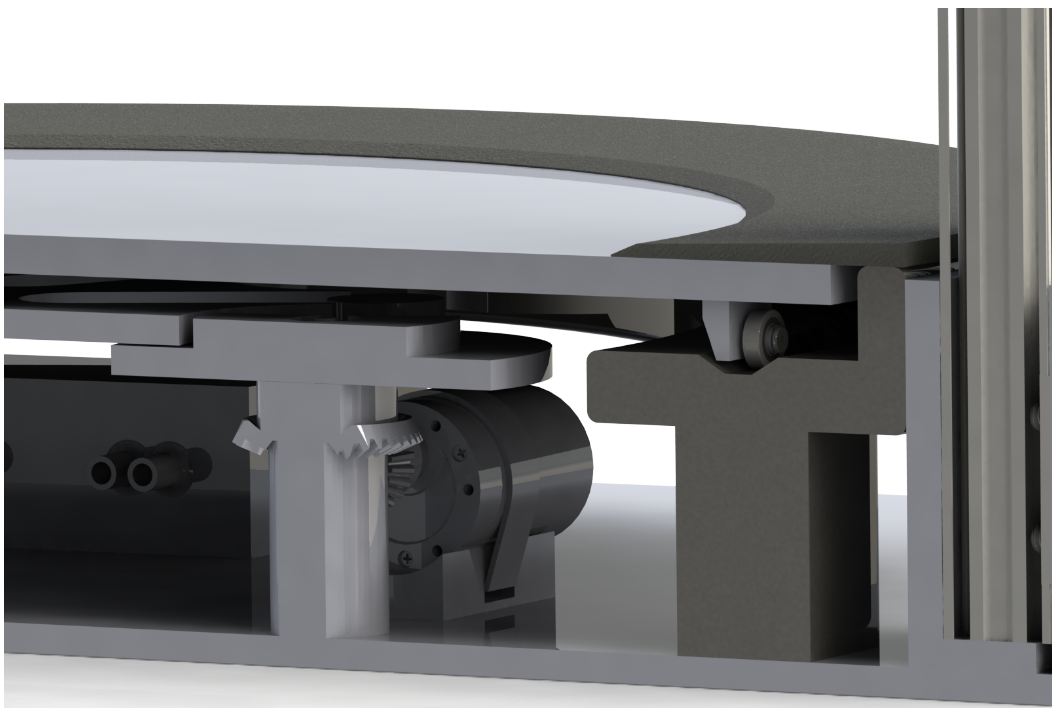

Fig. 5: Cross section of base and turntable, showing track and bearing assembly

The turntable is made from food-grade, polished wood (typical for cutting boards) and rests on roller bearings around its circumference. These roller bearings run around a recessed track built into the base, to ensure it turns in a perfect circle. Because the circular base has complex geometry, it is designed to be 3D printed in multiple interlocking parts and fixed to the bottom plate. The table itself is driven by a square shaft in its center which interfaces with the geneva drive mechanism in the base. This layout allows the entire turntable to be lifted out of the machine for easy cleaning. The geneva drive converts the constant rotation of the 12V DC motor in the base into intermittent rotary motion. Two bevel gears in the base allow a horizontally mounted motor to drive the geneva mechanism. The gears use a 2:1 ratio to double the motor's torque while halving its speed. This allows a lower-spec motor to be used in driving the turntable. The design of the slotted wheel determines the number of slices that the mechanism cuts. This component is easily interchangeable and is accessed by removing the turntable.

The upper housing is made of clear plastic to provide a 360-degree view of the pizza and cutter mechanism. For safety reasons, we enclosed all moving parts in the machine and implemented electronic checks to prevent misuse. Electrical switches check to ensure that the doors to the housing are closed before the motors can be powered on. Exploded views of all sub-assemblies are shown in Appendix A. The planar mechanisms were designed so that they could be driven with two standard DC motors running at a constant RPM. The clockwork-like synchronization of the crank slider and geneva wheel can therefore be powered by simple analog circuitry or a simple PCB. This allows us to maintain the minimalist mechanical and analog nature of this mechanical sculpture. The final product is both an eye-catching conversation piece and a functional tool.

Mechanism Synthesis

The Crank-Slider:

From our specifications, it was determined that the slider of our cutting mechanism must travel 18" in a reciprocating motion. It also must be able to fit within our frame in order to not interfere with the housing of the product.

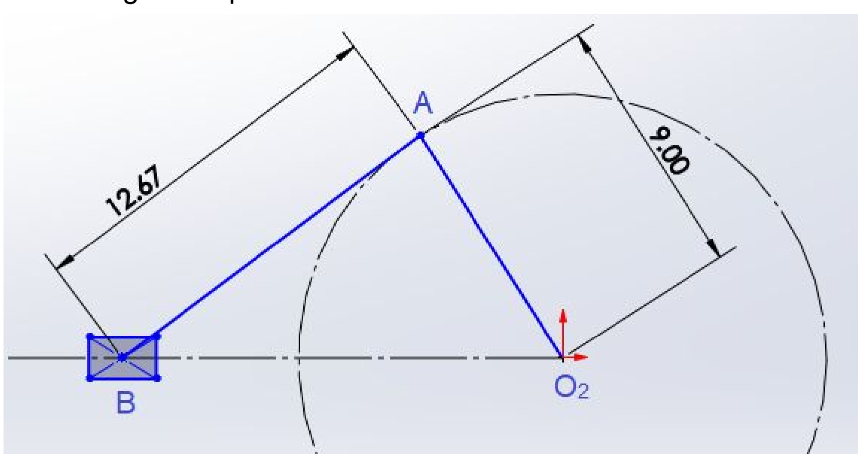

Fig. 6: Graphical synthesis of the crank-slider mechanism

Given these requirements, the synthesis of our crank-slider mechanism was fairly simple. The crank was chosen to be 9" to ensure the slider would travel 18" in a full rotation while the connecting link was chosen to be 12 ⅔" to fit within our housing. Once the path and design of the mechanism were determined, motor rpm was chosen to ensure the proper slider speed and the timing which would coincide with the geneva mechanism.

Geneva Mechanism:

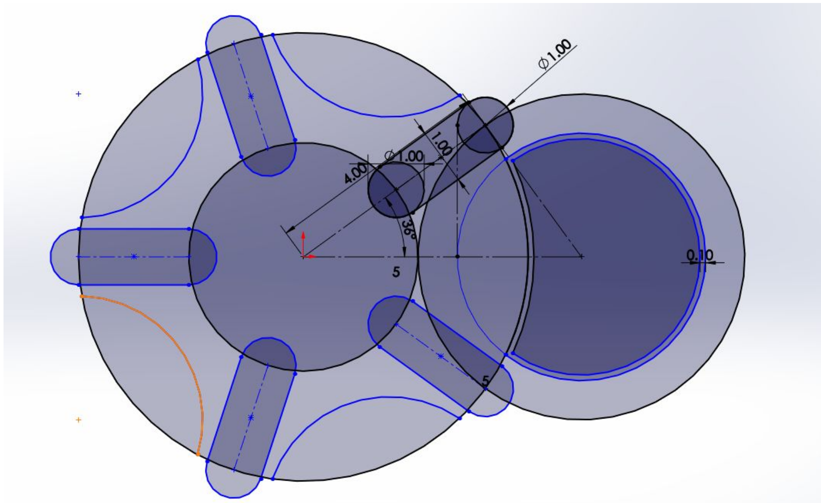

Fig. 7: Graphical synthesis of the geneva mechanism

The geneva mechanism was synthesized using graphical methods, where the primary design parameter was the center-to-center distance between the two components and the number of pizza slices desired. The construction triangle used to define the geneva mechanism is defined by the most acute angle of the triangle, which is 180 degrees divided by the number of indexes in the mechanisms. For 10 slices, only 5 slots are required because each cut is mutually exclusive, whereas the 8 slice mechanism requires 8 slots,to create the distinct angles. The driving component of the mechanism is defined by a peg and a crescent, which allows for it to turn the geneva mechanism while also arresting any unwanted motion when the peg is not in the slot.

Stress/Deflection Analysis

Crank Arm:

One of the primary linkages on the device which warrants stress analysis is the crank arm, as it experiences a significant bending moment as it drives the cutter head back and forth across the pizza. FEA was conducted in Solidworks to determine the maximum bending stress and deflection of the crank arm during operation. The stall torque of the chosen motor (470 oz-in or 28.375 lbf-in) was taken as an upper limit to the torque applied to the linkage, applied at the left bolt-hole in the below diagrams. This would be the experience load if for some reason the cutting mechanism was stuck or jammed, and the motor stalled.

Comparing the maximum Von-Mises stress calculated to the yield strength of the aluminum, we arrive at a safety factor of >3.1, which is more than sufficient, given that actual operational loads are far less than what was simulated here. The maximum deflection in this condition is also a fraction of a millimeter, which is certainly acceptable to ensure the functionality of the mechanism.

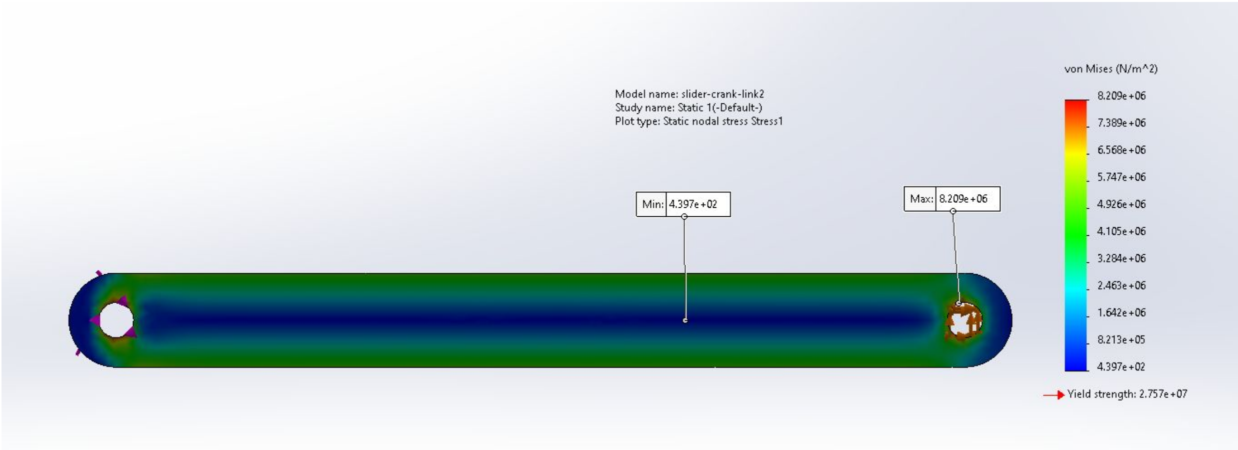

Fig. 8: Crank arm stress analysis results

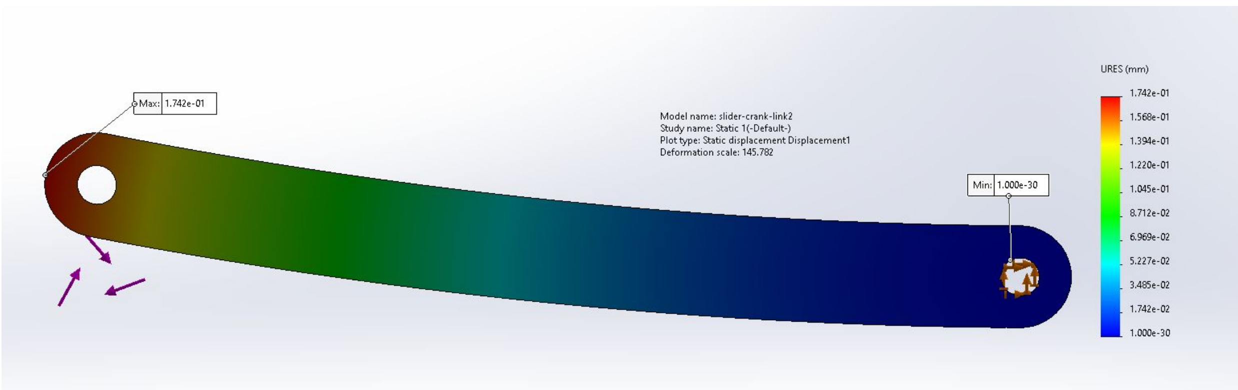

Fig. 9: Crank arm deflection analysis results

<u>Cutter:</u>

Another major part that requires stress analysis is the vertical cutter arm, as it must resist forces resulting from being driven by the slider-crank mechanism. FEA was conducted in Solidworks to determine the maximum stress and deflection experienced. The linear force resulting from the stall torque of the motor and the crank arm of the slider-crank was taken as the upper bound of the force and was applied horizontally to the bottom of the cutter. This would be the case if the cutting head was stuck in the worst possible position in terms of force transmission, and the motor stalled.

When comparing the maximum von Mises stress experienced in the aluminum arm to the yield strength of the material, the safety factor can be calculated to be >3.6, which is more than sufficient, given we are simulating the maximum force situation that is far below normal operational loads. The deflection is also shown using a 217:1 scale, with the maximum simulated deflection being 0.1267 mm, which will not hinder the function of the mechanism.

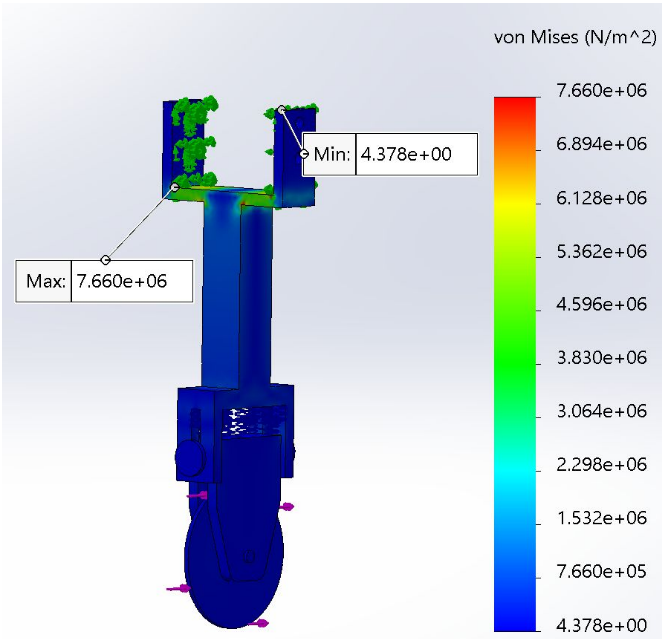

Fig. 10: Cutter arm Stress analysis

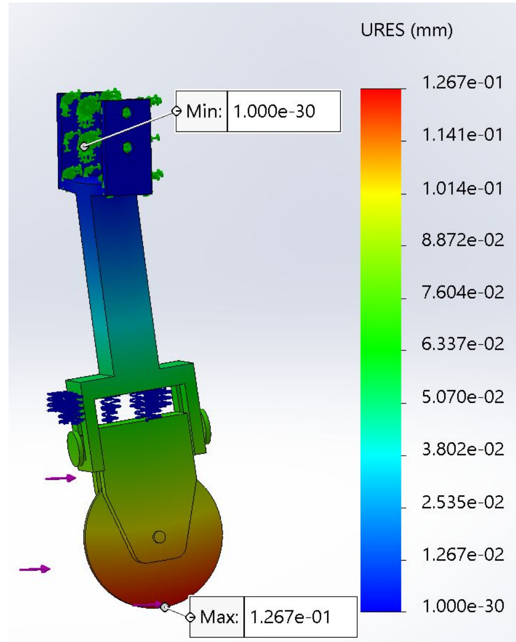

Fig. 11: Cutter Arm deflection (217:1 scale)

Velocity and Torque Analytical Analysis:

<u>Velocity Requirements:</u>

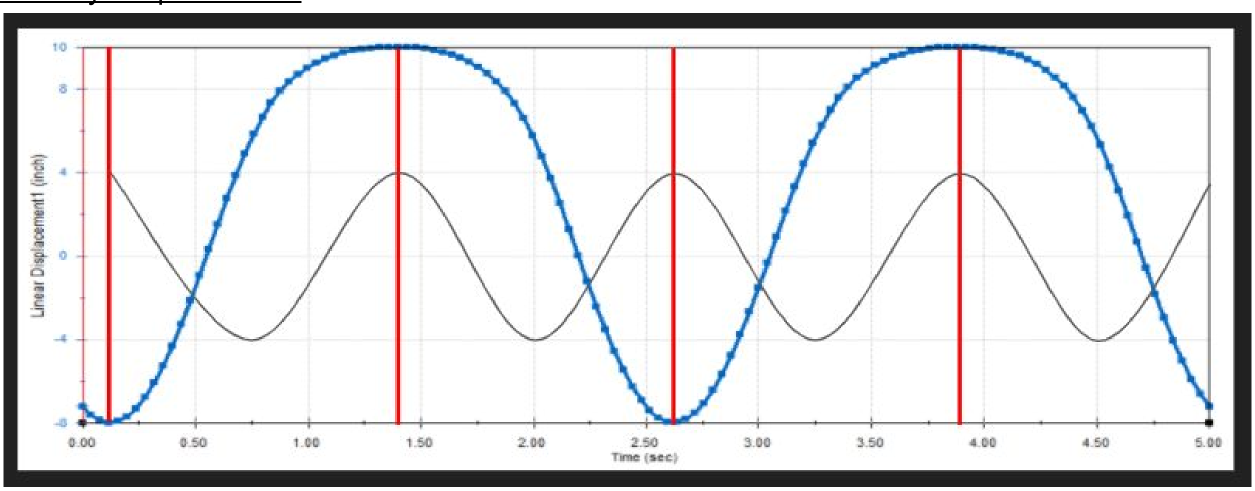

Fig. 12: Superposition of Motor X Displacements
Blue: Crank Slider, Black: Geneva Driver

First, to determine the motor speeds we wanted to drive the pizza cutter assembly at, we used our stated specification of approximately 15 seconds to cut a whole pizza. Therefore, if each stroke of the crank slider mechanism was to create one cut across the pizza, then each rotation of the crank slider would create 2 cuts. For the designed maximum 16 number of slices (8 cuts), the crank slider would need to complete 4 cycles. If we selected 15 rpm for the rank slider motor (4 seconds/revolution), then we would be able to achieve these 8 cuts in 16 seconds, which satisfactorily met our specifications. Then to match this 15 rpm motor for the crank slider with the geneva mechanism, we would need to double the geneva mechanism driver speed to index the turntable with each stroke of the crank slider, requiring a driver speed of 30 rpm. Because we used a 2:1 bevel gear for our geneva mechanism driver-motor interface, the required motor speed would be 60 rpm. Both 15rpm and 60rpm are speeds that are achievable by common DC motors.

To ensure that the timing of our whole mechanism could function properly without the use of any microcontrollers, we used Solidworks to do some positional analysis. The key aspect we had to evaluate was to make sure that the crank slider would be at its extreme positions on the step while the turntable spun to make sure that the cutter wouldn't shift the pizza or damage the components. To guarantee this, we plotted the displacement of the crank slider cutter and matched the geneva mechanism to it so that every time the pizza cutter traversed the table from one end to the other, the turntable would rotate to the next position. We designed the size of our lip to accommodate our worst-case condition of the shortest time the crank slider spends at its extreme positions (extended position of crank slider) and the longest time spent rotating the turntable (5 index geneva mechanism). The crank slider spends much less time at its extended position as can be seen in *Fig. 12*, with -8 inches being the extended position displacement value. The worst-case for the geneva wheel was determined by taking the approximation that the approximate time in the geneva mechanism spent rotating is the inverse of the number of indices of the geneva mechanism, resulting in the worst case of the 5 index geneva system. Using these assumptions, we can see that the approximate time in the cycle spent rotating the geneva wheel is 20% of the 2 s/revolution (30rpm) of the geneva driver, or 0.4 seconds. Accordingly, the time the crank slider spends on the raised lip must be greater than 0.4 seconds at its worst case extended position to allow for the turntable to completely rotate before the cutter returns to the table. Looking again at the displacement plot of the crank slider shown in *Fig. 12*, it can be concluded that to accommodate this transitionary period, a lip thickness of ~2 inches is necessary.

<u>Torque Requirements</u>

To determine our motor torque requirements for both mechanisms, we conducted rough calculations based on very conservative assumptions. In the following 2 sections, the assumptions used to determine the motor requirements are detailed along with their corresponding reasoning. For conciseness and clarity of the report, the full analysis for both motors can be found in Appendix C.

1. Geneva Motor
   Required Motor Torque: 210 oz in

- Assumptions:

Wp = Pizza Weight = 2.5 lbf

- A large pizza is typically around 1.6 lbf

Wt = Turntable Assembly Weight = 5 lbf

- True turntable assembly weight as defined in Solidworks is 2.39 lbf

D = Table Diameter - 2’

- True Table Diameter is 20”

us = Static Friction Coefficient = 0.4

- True Static Friction Coefficient of Plastic (Roller Track) on Metal (Roller Wheels) is in the range of 0.25~0.4

Note: Because the angular velocity and angular acceleration of the geneva wheel's rotation is difficult to characterize analytically, we decided to take the very conservative route of calculating for a motor that will be able to rotate the turntable in the case that the turntable rollers seize (resulting in sliding friction). The static friction coefficient is used for all calculations, as static friction will always be higher than kinetic friction.

2. Crank-Slider Motor
   Required Motor Torque: 455 oz in

- Assumptions:

Wc = Cutting Arm Assembly (Cutter and roller assy) - 2.5 lbf

- True Cutting Arm Assembly is also 2.5 lbf

Fc = Vertical Pizza Cutting Force - 5 lbf

- Circular pizza cutters primarily exert vertical cutting forces, an overestimate of 5 lbf is used for this value as no rigorous studies can be referenced regarding this topic

Fch = Horizontal Pizza Cutting Force is in the order of Fc/2

- Estimate horizontal resistance (<<Fc in reality) of pizza to cutting to be half of the vertical cutting force
- Static friction is negligible to due implementation of rollers and low-friction bearings (us = 0)

Simulations:

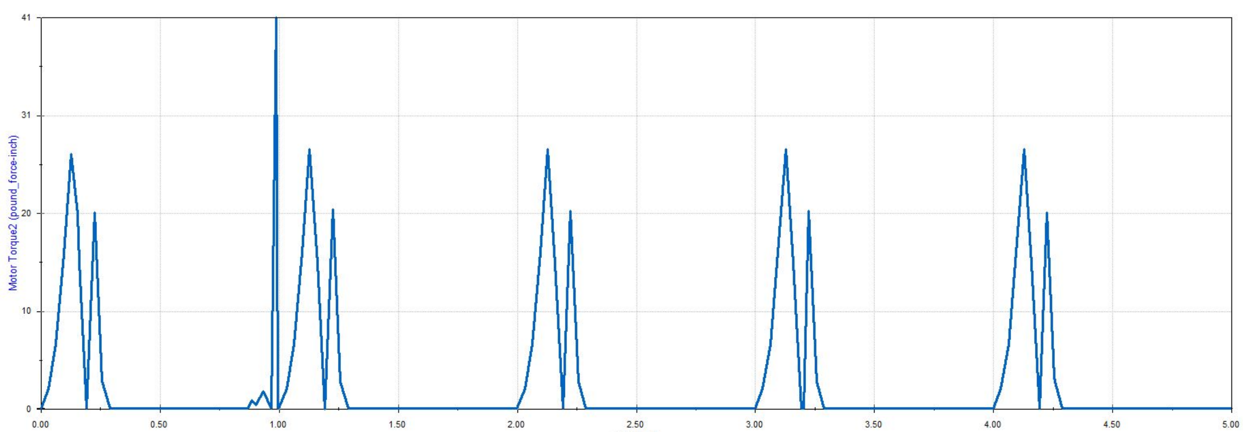

Fig. 13: Simulated torque requirements to drive the 10 slice turntable. Spike to above 41 lb-in at around 1 second is an erroneous value from the inherent inaccuracy of the simulation, and actual max torque is around 26 lb-in.

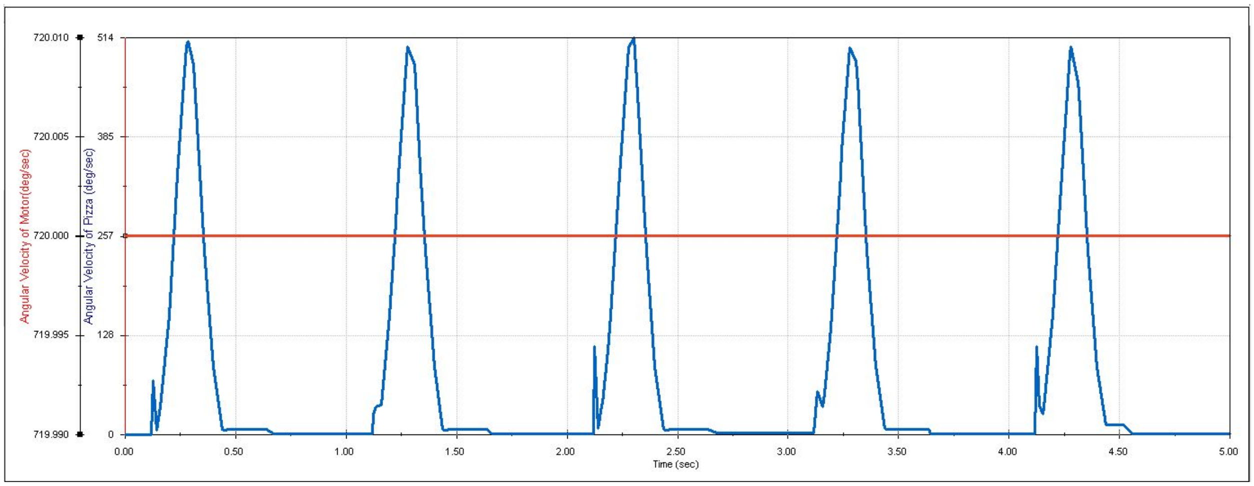

Fig. 14: Angular velocity plot for the 10 slice geneva mechanism

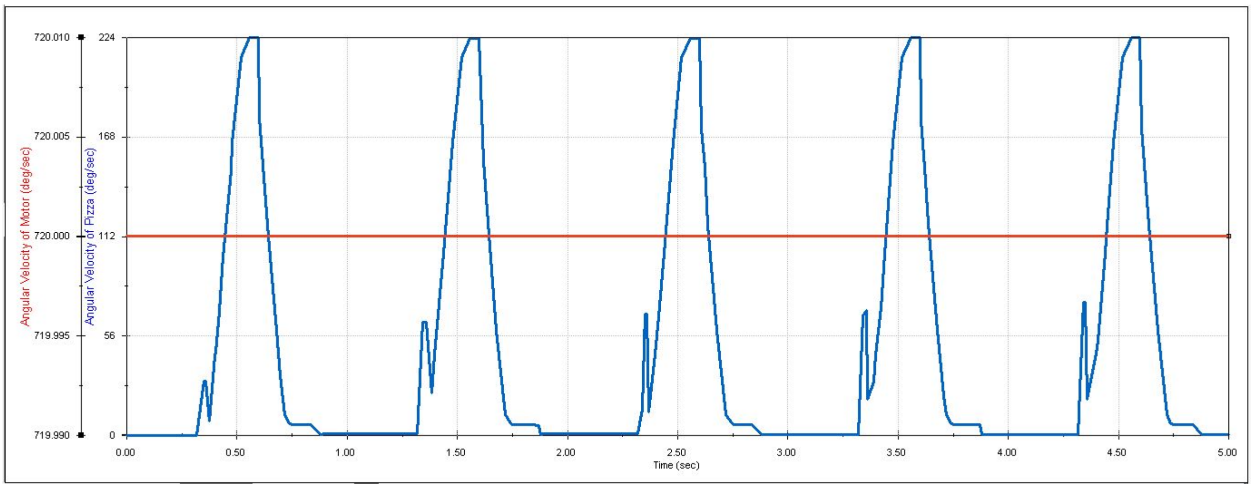

Fig. 15: Angular velocity for the 8 slice geneva mechanism

As evident in SolidWorks torque analysis, the maximum torque required to turn the turntable at the provisioned rate is approximately 26 lb-in, or 416 oz-in. Given our 2:1 speed reduction with our bevel gear mechanism, the torque provided by our motor should be more than sufficient. This was calculated using the 10 slice variant, since it necessitates the greatest angular displacement between slices per cycle, and therefore the most angular acceleration and torque.

The required motor timings are also wholly the same between the two variants of the mechanism. This is consistent with our design since each index cycle takes the same amount of time regardless of the number of indices on the mechanism.

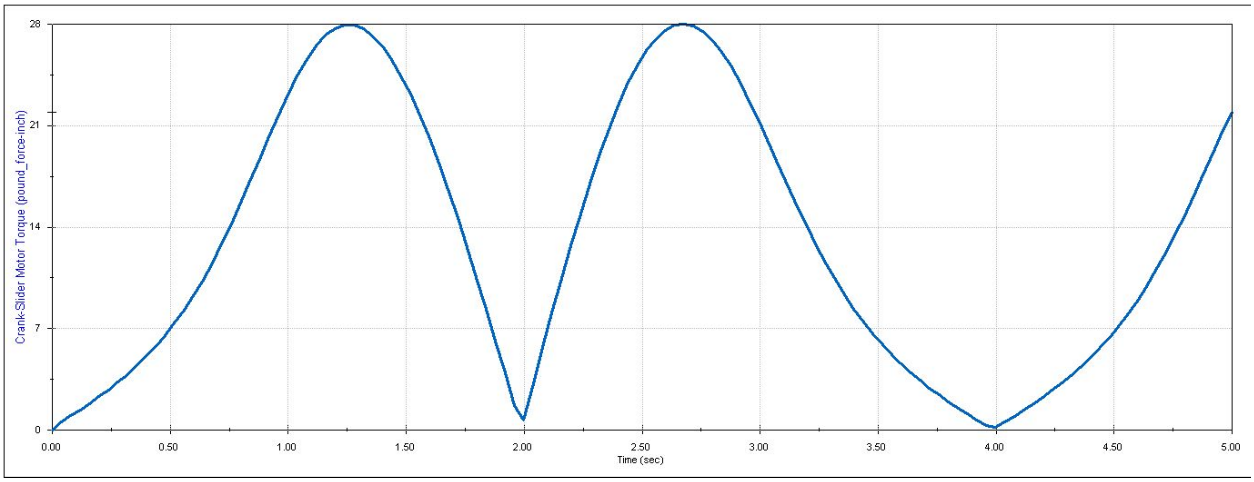

Fig. 16: Simulated motor torque requirements a full cycle of the crank-slider mechanism

Presuming a 2.5 lbs maximum possible horizontal cutting force, the crank-slider motor needs to produce a maximum of 28 lb-in, or 448 oz-in, of torque. This is in line with our specifications for the driving motor.

2D Project Drawing (base footprint and overall volume)

Standard Views of Project Assembly (dimensions in inches)

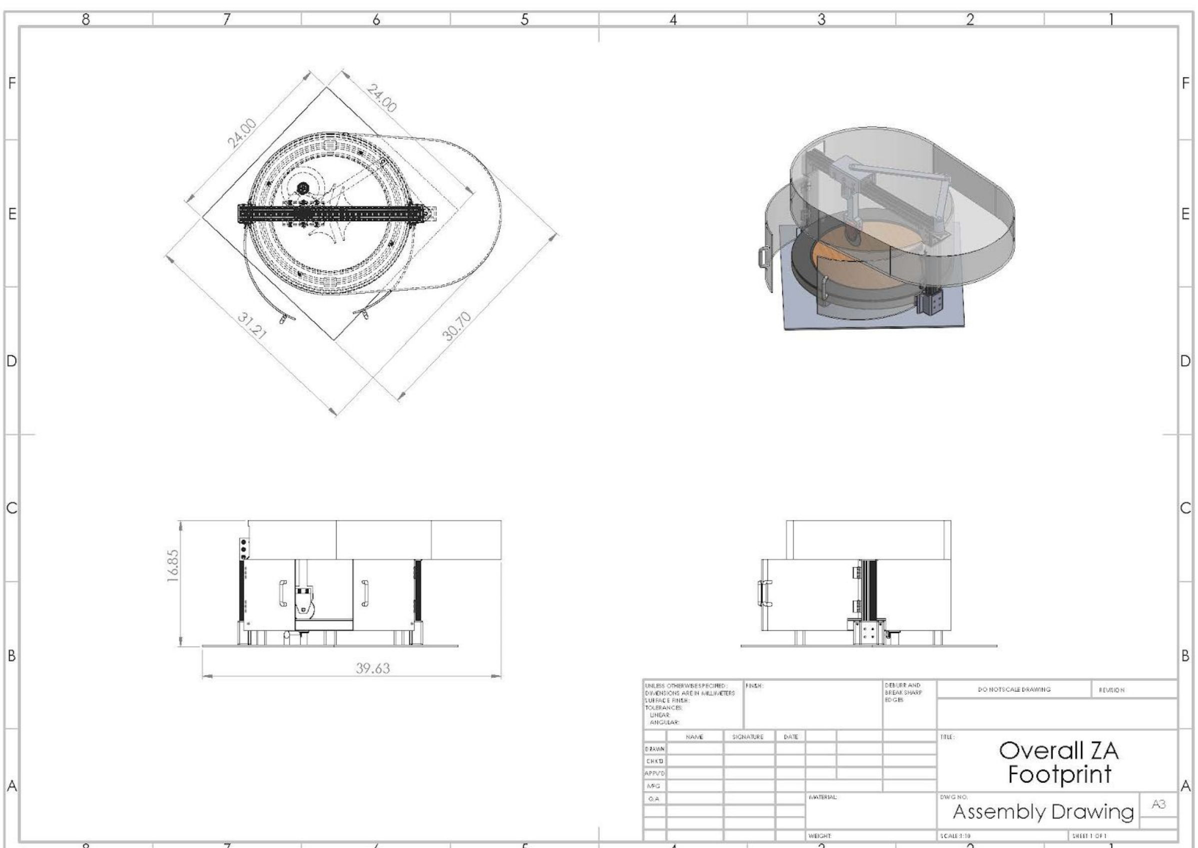

Fig. 17: Overall dimensions and product footprint

Discussion

One of the greatest challenges we faced while working on this project was designing the machine to meet our vision of creating a convenient and affordable pizza showpiece. Many of our main design decisions, from the aluminum extrusions used to construct the crank slider assembly to even the geneva mechanism of the turntable itself, were chosen after great consideration for the main users that this product would appeal to, namely mechanical enthusiasts with a great love for pizza. The material selection and manufacturing considerations for the whole project assembly were a delicate balancing act between maintaining the aesthetic show quality of the piece, while still conveying the impression of a purely mechanical design, the very same one that draws many individuals towards mechanical rather than digital watches even in this age of microchip fueled technological advancement.

For the crank slider mechanism design, rather crude aluminum extrusions were used as the foundation for the whole design, as a nod towards this mechanical sense that we wanted our piece to convey, instead of some custom-designed parts. The aluminum rails also allow us as engineers to modify the machine to cut taller food items without needing to redesign the base. In addition, while the aluminum extrusions themselves can be seen as unrefined, when juxtaposed against the clean and modern lines of the enclosure, the complete assembly is rather visually striking. These extrusions allow observers to immediately grasp the function of the device even when it isn't in motion, while still contributing to its visual allure.

The choice of a geneva mechanism rather than the use of a simple stepper motor or even a motor with a separate microcontroller was driven by much the same intentions to create not just a pizza cutter, but a mechanical showpiece. We believe that basing our design around the interaction and harmony of two purely mechanical mechanisms is more in-line with the aesthetic of a novel, elegant mechanical sculpture than the use of perhaps a mechanically simpler, but less aesthetic microcontroller and stepper motor based system. Even for passing observers oblivious to the inner workings of the device, the clacking of the geneva mechanism emits a noise evocative of mechanical watches or old movie projectors, imparting the mechanical quality of the device through the alternative avenue of sound.

Future Work

To address the critique given by Professor Youssefi regarding the potential issue users may have with correctly timing the geneva mechanism to align with the crank slider mechanism cycle, our team is exploring a few different options:

1. Create aligning markers on the device for users to reference
2. Write a detailed setup manual for users to reference
3. Use limit switches to automatically bring the mechanisms to the correct positions

We believe that these 3 options each have their own merits and downfalls in addressing this user pain point while also maintaining our vision for the device. To ensure that the best experience is created for our users, we intend to prototype and test each of these options to decide on the final solution.

Appendix

A. 3D CAD Assemblies

Cutter and Slider Crank

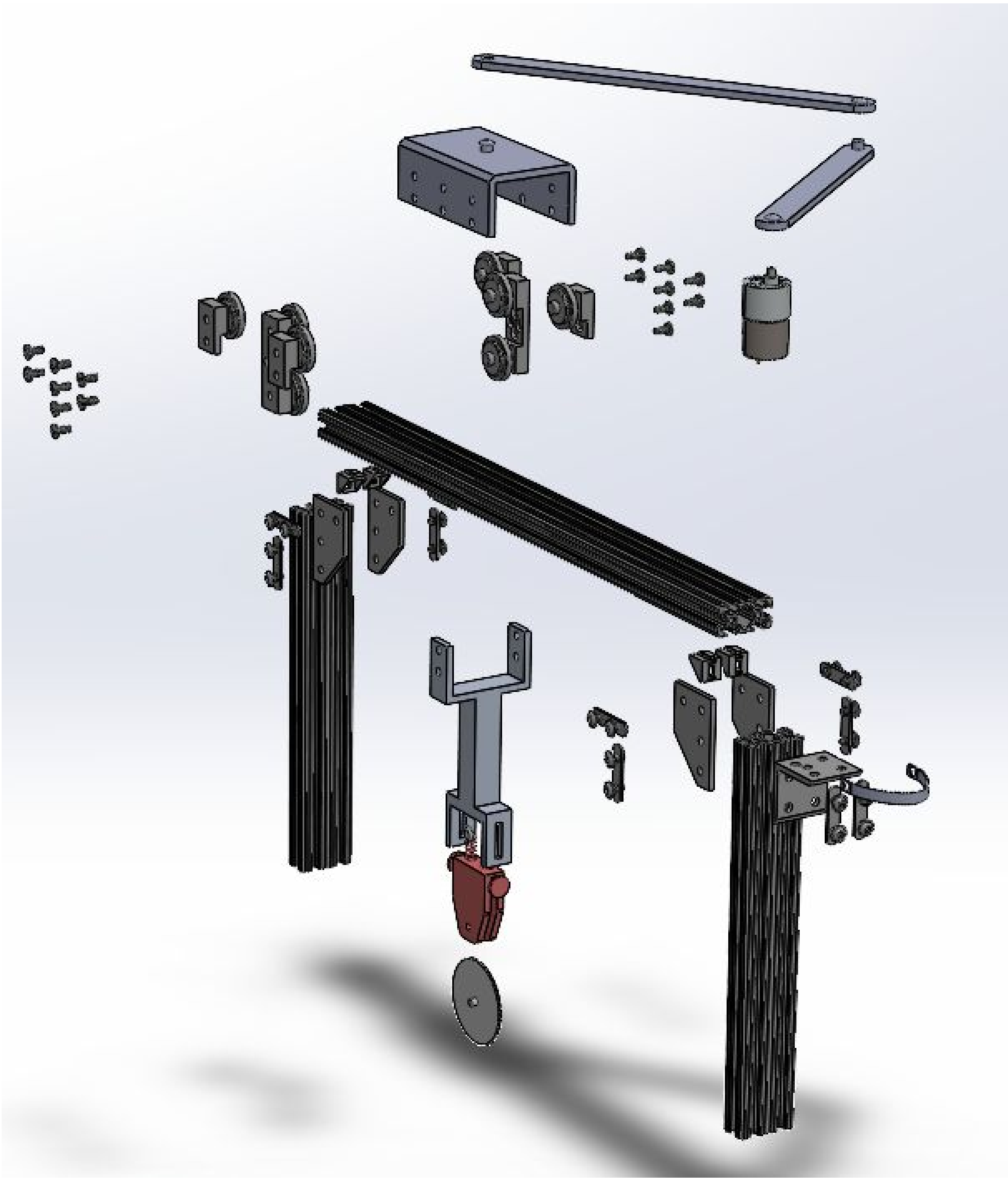

Fig. 18: Exploded view of arm subassembly. Motor mounted on lower right, slider-crank and cutter arm attached to roller carriage.

<u>Housing and Turntable</u>

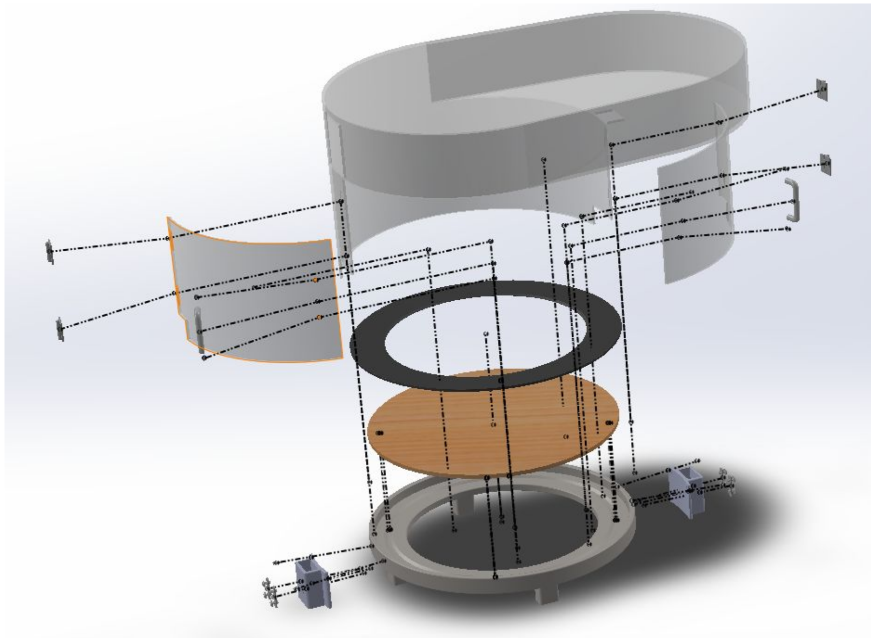

Fig. 19: Exploded view of housing subassembly

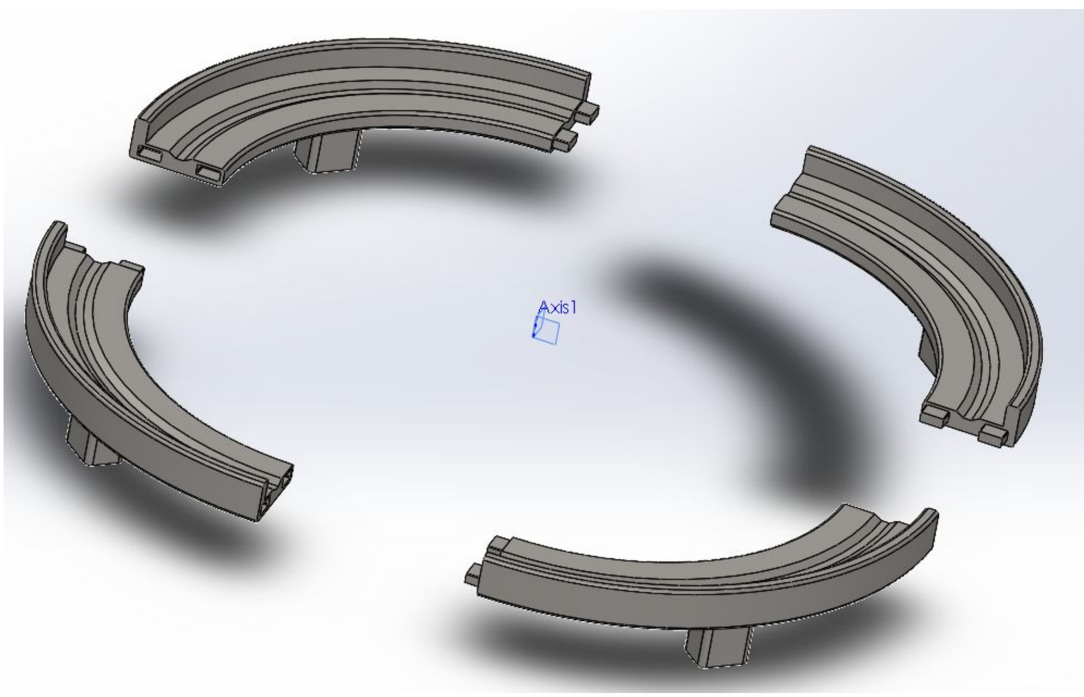

Fig. 20: Exploded view of 3-D printed frame

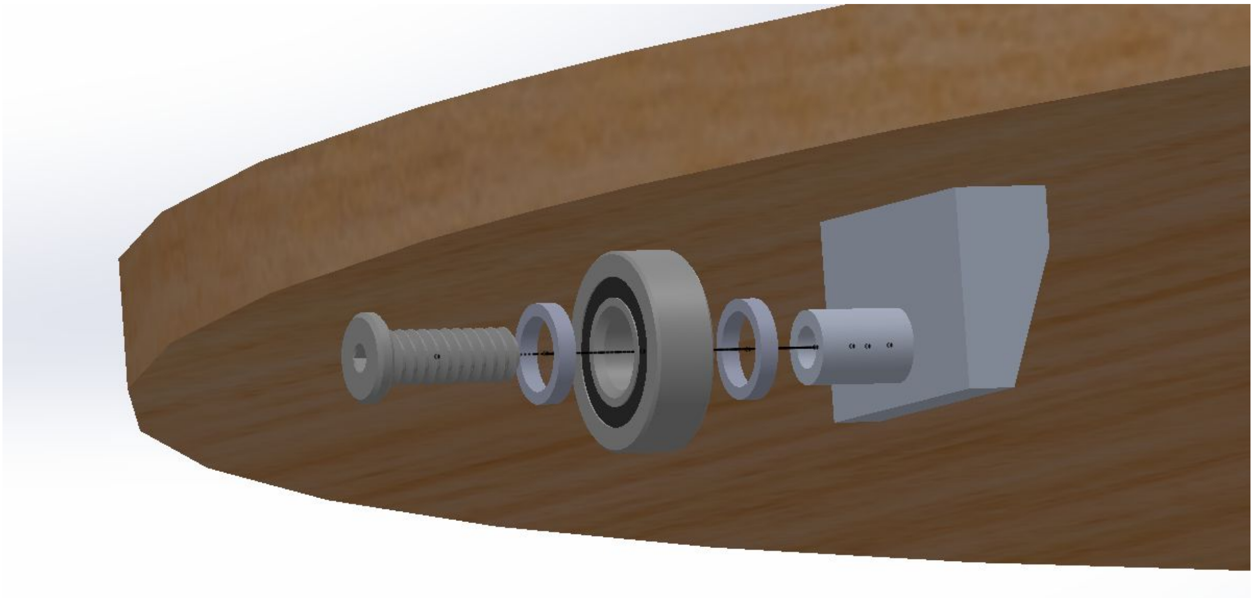

Fig. 21, Exploded view of roller subassembly

<u>Base and Geneva Mechanism</u>

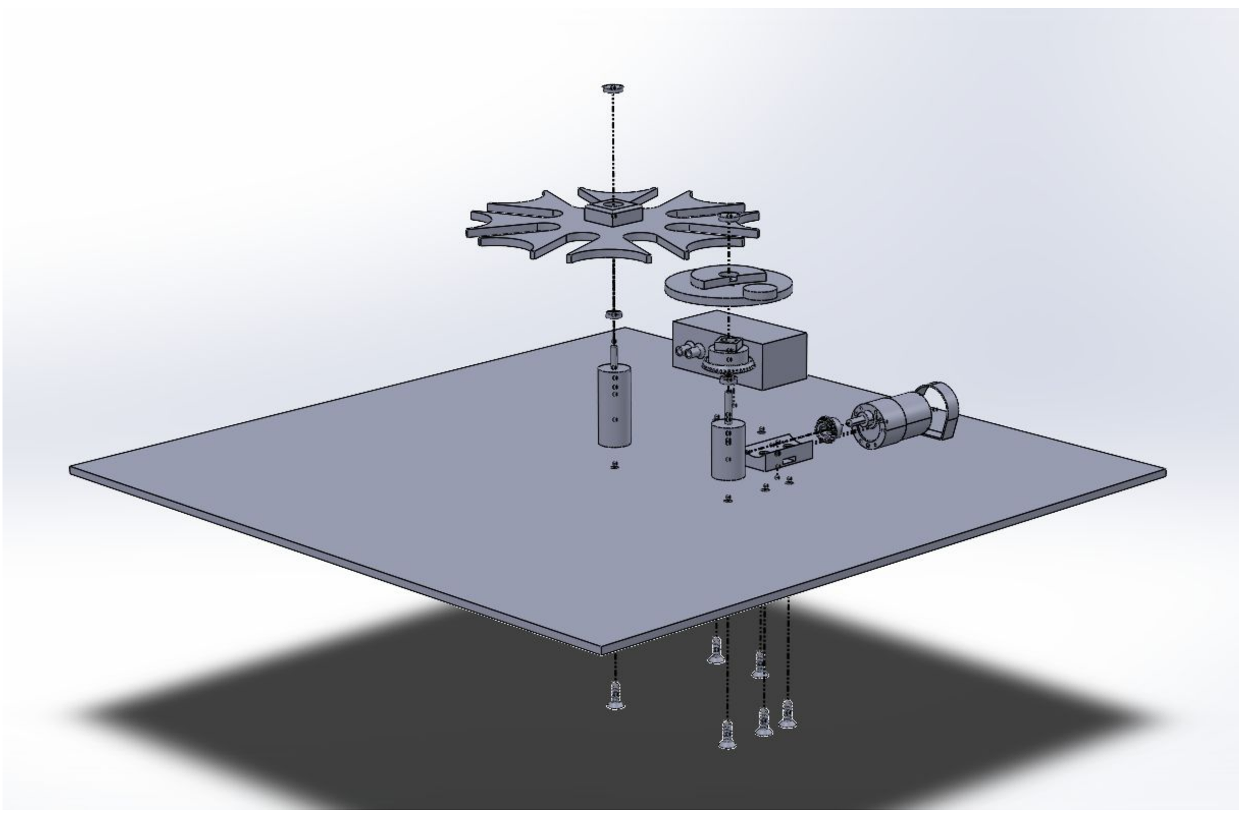

Fig. 22: Exploded view of base subassembly. All vertically oriented rotating components rest on bearings and are retained with an easy to remove plastic cap. The motor and driving bevel gear are constrained to the motor mount with a metal strap. The motor mount and standoffs are mounted on the plate with screws. A compact power supply to supply the motors with power is also mounted to the plate.

B. COTS Part Table:

Function	**Part**	**Source**	**Link**
Turntable Motor	70:1 Metal Gearmotor 37Dx54L mm 12V (Helical Pinion) (380 oz · in)	70:1 37D Metal Gearmotor	https://www.pololu.com/product/4744
Crank-Slider Motor	100:1 Metal Gearmotor 37Dx57L mm 12V (Helical Pinion) (470 oz · in)	100:1 37D Metal Gearmotor	https://www.pololu.com/product/4745
Aluminum Rail Extrusion	T-Slotted Framing, Double Six Slot Rail, Silver, 2" High x 1" Wide, Solid	McMaster-Carr	https://www.mcmaster.com/47065T107/
20-80 Extrusion Framing	T-Slotted Framing, Silver Corner Surface Bracket	McMaster-Carr	https://www.mcmaster.com/47065T267/
20-80 Extrusion Framing	T-Slotted Framing, Silver Corner Bracket	McMaster-Carr	https://www.mcmaster.com/47065T253/
20-80 Extrusion Framing	Corner Brace for Rail T-Slotted	McMaster-Carr	https://www.mcmaster.com/47065T216/
Slider-Crank Rollers	T-slotted Framing Track Roller for 2” High Double Rail	McMaster-Carr	https://www.mcmaster.com/47065T975/
Cutter Springs	Steel 0.5’’ Compression Spring, 3.3 lbs/in	McMaster-Carr	https://www.mcmaster.com/9657K627/
Turntable Roller Bearings	Permanently Lubricated Ball Bearings	McMaster-Carr	https://www.mcmaster.com/2342K62/
Turntable Bearing assembly bolt	Alloy Steel Ultra-Low-Profile Socket Head Screws	McMaster-Carr	https://www.mcmaster.com/90357A001/
Bevel Gears	40 Tooth Plastic Bevel Gear	McMaster-Carr	https://www.mcmaster.com/3856N121/
	20 Tooth Plastic Bevel Gear	McMaster-Carr	https://www.mcmaster.com/3856N119/

Geneva Wheel Bearings	R3 for 3/16” shaft	McMaster-Carr	https://www.mcmaster.com/60355K502/
Fastener	¼-20 Flathead screw	McMaster-Carr	https://www.mcmaster.com/91253A540/
Fastener	T-Slotted Framing, End-Feed Double Nut, Flanged-Button Head 1/4"-20 Thread	McMaster-Carr	https://www.mcmaster.com/47065T147/
Fastener	Phillips/Slotted Screw, 1/4"-20, 1/2" Long	McMaster-Carr	https://www.mcmaster.com/90604A537/
Fastener	Phillips Head Screw, 8-32 Thread, 1/2" Long	McMaster-Carr	https://www.mcmaster.com/91772A194/
Limit Switch	Miniature Snap-Acting Switch	McMaster-Carr	https://www.mcmaster .com/7779K22/

C. Analytical Analysis
1. Geneva Motor
Assumptions

Wp = Pizza Weight = 2.5 lbf
- A large pizza is typically around 1.6 lbf

Wt = Turntable Assembly Weight = 5 lbf
- True turntable assembly weight as defined in Solidworks is 2.39 lbf

D = Table Diameter - 2’
- True Table Diameter is 20”

us = Static Friction Coefficient = 0.4
- True Static Friction Coefficient of Plastic (Roller Track) on Metal (Roller Wheels) is in the range of 0.25~0.4

Note: Because the angular velocity and angular acceleration of the geneva wheel’s rotation is difficult to characterize analytically, we decided to take the very conservative route of calculating for a motor that will be able to rotate the turntable in the case that the turntable rollers seize (resulting in sliding friction). The static friction coefficient is used for all calculations, as static friction will always be higher than kinetic friction.

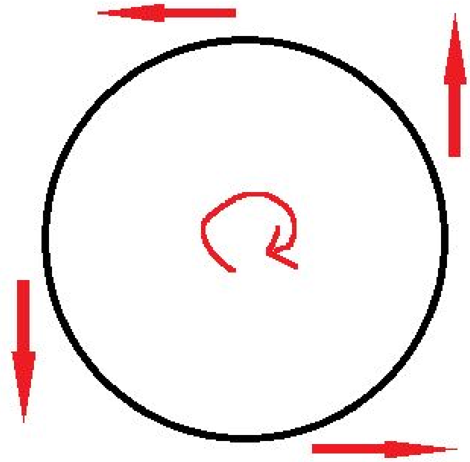

Fig 23: Red Arrows indicate Static Friction of roller wheels acting against turntable rotation

$$T_g = \text{ Geneva Wheel Torque}$$
$$f_s = \text{Turntable Roller Wheel Static Friction Force } = u_s * N$$
$$N = \text{Normal Force Exerted on Roller Wheels } = W_t + W_p$$
$$T_g = f_s * D/2 = \text{Torque to overcome Static Friction of Turntable Rollers}$$

$$=> T_g = \text{Approximately } 3 \ lbf * ft$$

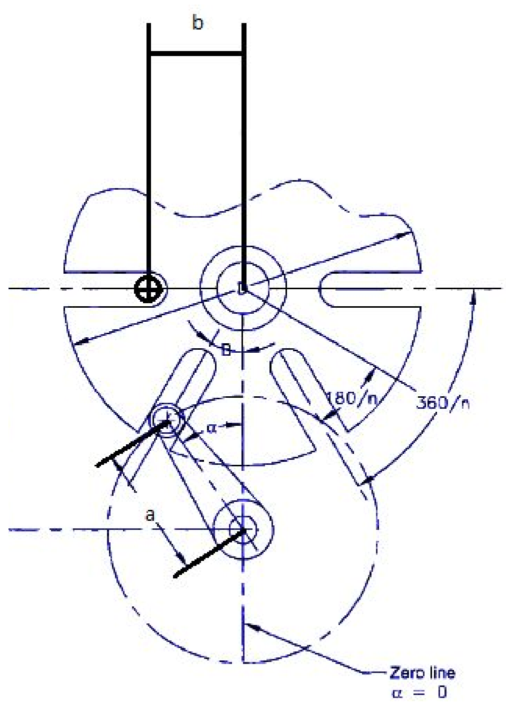

Fig. 24: Geneva Mechanism

$$T_d = \text{ Geneva Mechanism Driver Torque}$$
$$\text{Torque Equation} : T = F * d$$
$$=> T_g/b = T_d/a \ => \ T_d = T_g * a/b$$

5 Index Geneva Mechanism
a = 2.91”, b = 4”
a/b = 0.7275
8 Index Geneva Mechanism
a = 1.89”, b = 4.56”
a/b = 0.41447

5 Slot b/a > 8 Slot b/a => Worst case Torque is on 5 Slot Geneva Mechanism

$$=> T_d = \text{Approximately } 2.18 \ lbf * ft$$

Bevel Gear Ratio 2:1

$$=> \text{Motor Torque Required} = T_d/2 = \text{Approximately } 1.09 \ lbf * ft$$
$$= \text{Approximately } 210 \ oz * in$$

2. Crank-Slider Motor
Assumptions
Wc = Cutting Arm Assembly (Cutter and roller assy) - 2.5 lbf
- True Cutting Arm Assembly is also 2.5 lbf

Fc = Vertical Pizza Cutting Force - 5 lbf
- Circular pizza cutters primarily exert vertical cutting forces, an overestimate of 5 lbf is used for this value as no rigorous studies can be referenced regarding this topic

Fch = Horizontal Pizza Cutting Force is in the order of Fc/2
- Estimate horizontal resistance (<<Fc in reality) of pizza to cutting to be half of the vertical cutting force

us = 0
- Static friction is negligible to due implementation of rollers and low-friction bearings

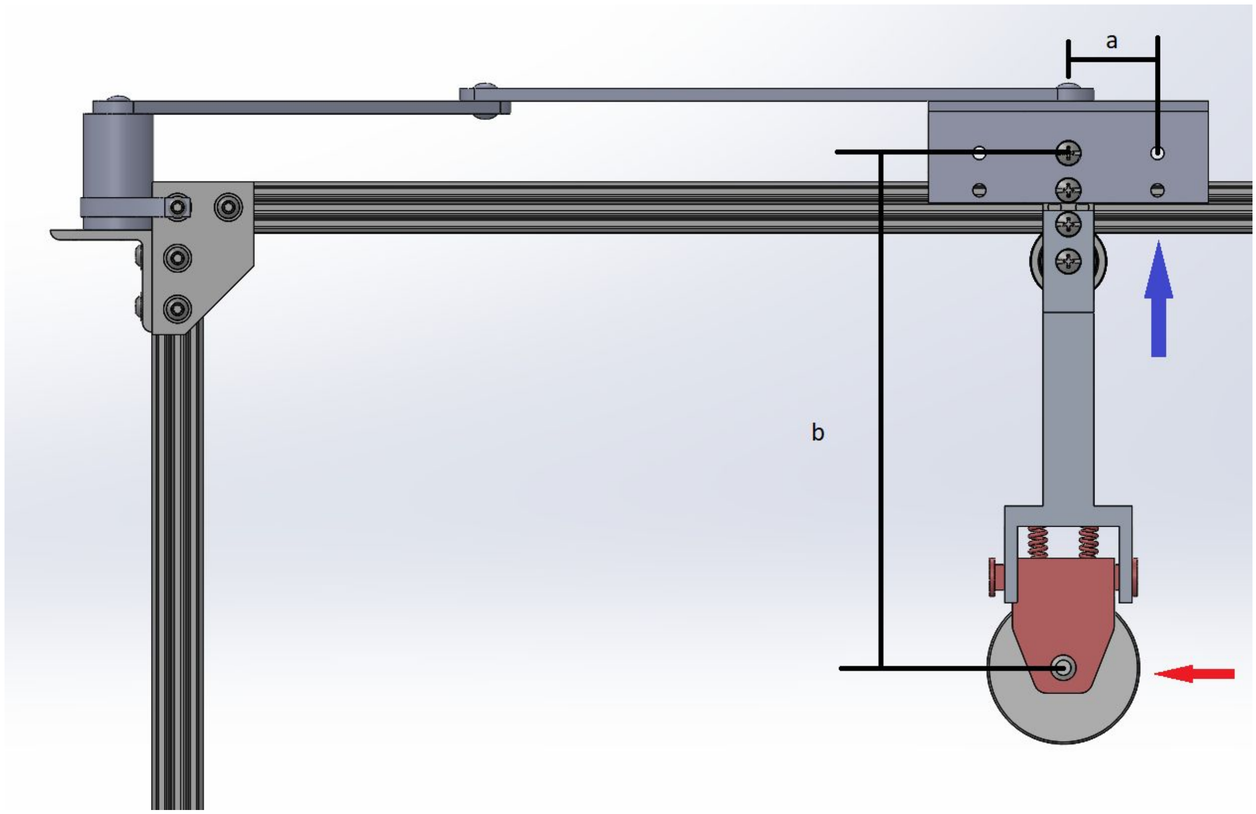

Fig. 25: Cutter Arm Force Diagram

Blue: R = Reaction Force, Red: Fch = Horizontal Pizza Cutting Force = 1 lbf
a = 1.75", b= 10.1"

$$Torque\ Equation : T = F * d$$
$$=> R * a = F_{ch} * b => R = 5.77\ lbf$$
$$N = Normal\ Force\ Exerted\ on\ Slider\ Assembly = W_c + R$$
$$f_s = Slider\ Assembly\ Static\ Friction\ Force = u_s * N = 0$$

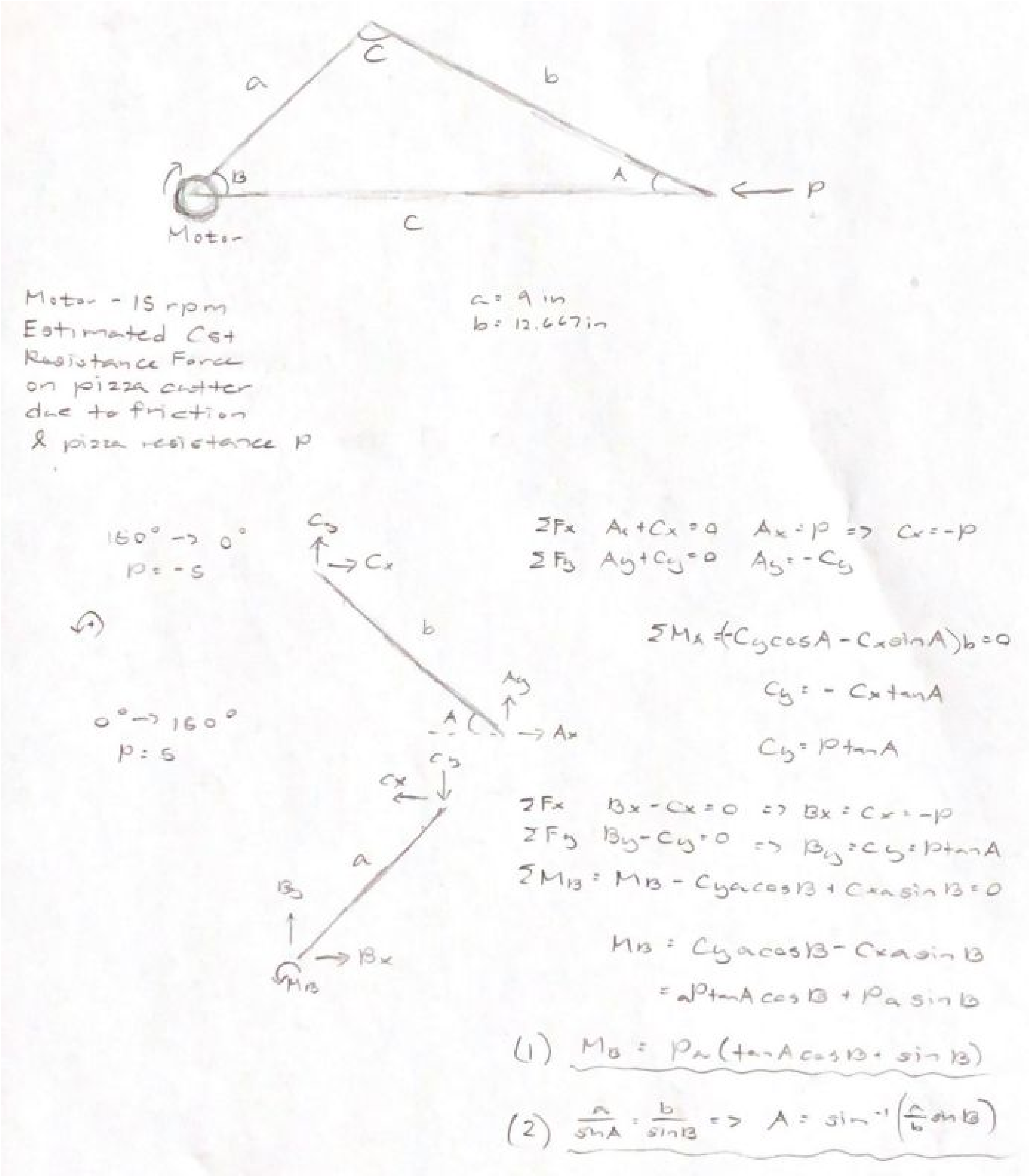

Fig. 26: Crank Slider Force Analysis

$$P = f_s + F_{ch} = F_{ch}$$

```
% Input Parameters
% Crank Slider Arm Dimensions (inches)
a = 9;
b = 12.6666;
% Applied Load
P = 40;

% t is time from 0-4 seconds
t = linspace(0, 4, 100);
% B is the crank angle from 180 degrees to 0 degrees
B = linspace(pi, 0, 100);

% Equation 2
A = asin(a/b*sin(B));
% Equation 1
T = P*a*(tan(A).*cos(B)+sin(B));


subplot(2,1,1)
plot(t, T)
title("Motor Torque Required vs. Time");
xlabel("Time (s)");
ylabel("Motor Torque Required (oz*in)");
subplot(2,1,2)
plot(B*180/pi, T)
title("Motor Torque Required vs. Motor Angle");
xlabel("Motor Angle (deg)");
ylabel("Motor Torque Required (oz*in)");
[val, i] = max(T);
display("Max Required Motor Torque: " + T(65) + " oz*in")
display("Motor Angle of Max Required Torque: " + B(65)*180/pi + " degrees")
```

Command Window

New to MATLAB? See resources for Getting Started.

```
>> CrankSliderAnalysis
    "Max Required Motor Torque: 454.5318 oz*in"

    "Motor Angle of Max Required Torque: 63.6364 degrees"
```

Fig. 27: Crank Slider Analytical Solver

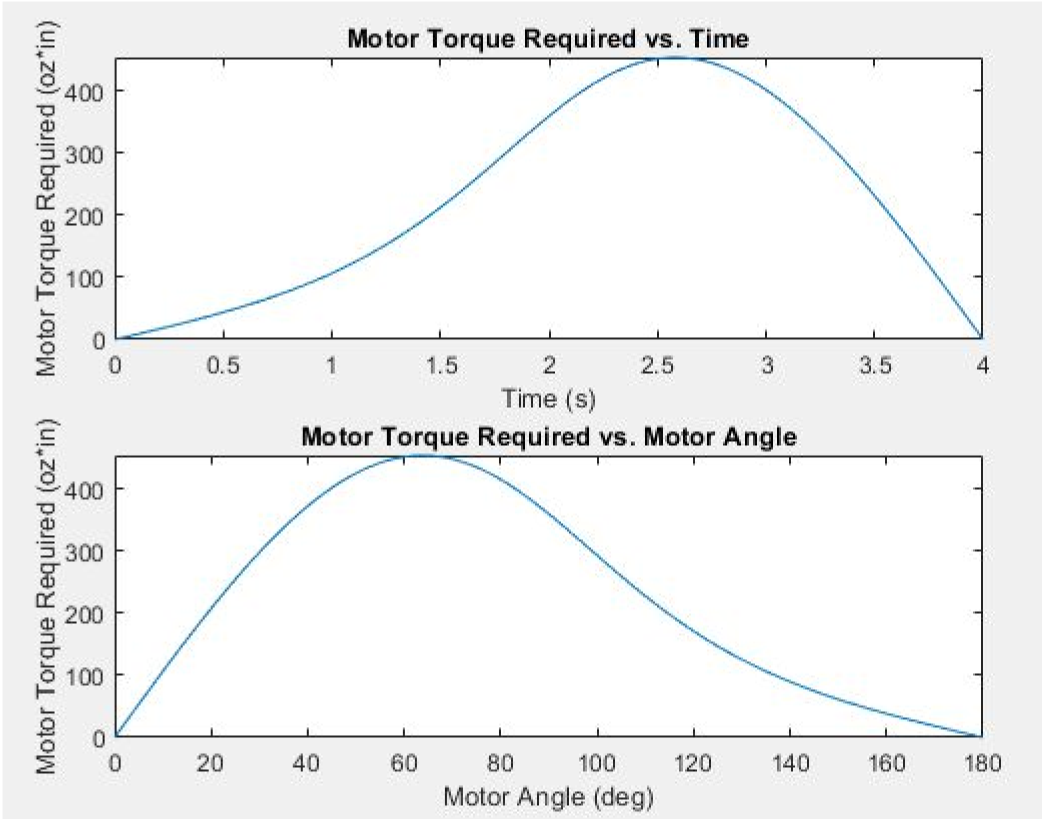

Fig. 28: Motor Torque Plots

$$=> Motor\ Torque\ Required = Approximately\ 455\ oz * in$$

3. Spring-Loaded Cutter
Assumptions

Fc = Vertical Pizza Cutting Force - 5 lbf

- Like the previous calculation, an overestimate of 5 lbf is used for this value as no rigorous studies can be referenced regarding this topic

uk = 0

- Slider Materials are built to minimize frictional forces. This also considers the maximum case of the springs absorbing all the vertical force

$$F = 2kx \text{ (for 2 springs)}$$

$$5\ lbf * 4.45\ N/lbf = 2k * 1\ in * 0.0254\ m/in$$

$$k = 438\ N/m$$

$$= \text{Approximately } 450\ N/m$$