MEC-E1060 - Machine Design

Detailed Design Report - Meat Chopper

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1. Introduction

This week we started working on the final design. After finishing our MBS and FEM simulations and making final design changes to our mechanism, our group members started working on the suitable final selection bearings, an actuator and materials. These results are presented in chapters 2. and 3. After this we estimate the lifetime of one critical bearing using state of the art engineering tools from SKF and other vendors. The main body of this report details the team's chosen machine design and includes the following sections: the selected components and materials, rendering procedures, summary of the previous reports, consideration of original requirements and a cost analysis. The discussion section of this report demonstrates what we have learnt in this course and the overall steps taken to finish this project.

The "Meat Chopper" is a straightforward knife cutting device created for a machine design course. By simulating a chef's knife cutting mechanism, the Meat Chopper is designed to be a straightforward, hands-free, and pleasant way to cook a variety of meat. The design is primarily designed to be a novel item for households with medium or large kitchens and is anticipated to be reasonably small. For cooks who must meet consumer requests, kitchens are stressful environments. To boost chefs' efficiency, it is crucial to automate various cooking processes. By instantly cutting materials with the stroke of a button, this automated knife mechanism promises to satisfy this demand. The mechanism is intriguing since it is capable of achieving quite sophisticated planar motion for a naturally practical application despite having a minimal part count. The seemingly ordinary process of cutting is mechanized in a creative way, making it a perfect way for individuals to get started with robotics.

2. Selected components

According to MBS simulation, we have composed the required specification of bearing and the motor as seen in table 1 below.

Table 1. Required specification

Required motor torque	875.45	Nmm
Required motor power	63	W
Max joint force (joint F)	151.2	N
Max joint angular velocity (joint G)	79.7	degree/s
Motor speed	72	degree/s

On the bearing type, the team decided to use the oil free bushings for the following reasons:

- We want to keep the whole mechanism as light as possible, so with bushings, we can make the bearing bore smaller, which keeps the size of shafts and ultimately, their weights as much smaller.

- We refrain from the use of lubricant and prefer bushing to ball bearing, which has multiple individual components, to minimize the chance that nothing will leak or fall off from our machine that could do harm to the kitchen environment.

Table 2. The technical properties of the Oil free bushing bearing MPBPU5-8 [1]

Feature	Value	Unit	Comment (**pass** or fail)
Inner diameter	5	mm	-
Outer diameter	7	mm	-
Length	8	mm	-
Max. Allowable Surface Pressure	29	N/mm2	Surface area: 125.6 mm^2 (used inner surface area for larger pressure) Max joint force: 151.2 N -> Actual surface pressure: **1.2 N/mm^2**
Max allowed velocity	0.5	m/s	Max joint angular velocity: 79.7 degree/s Actual velocity in inner surface of bushing (outer surface of bushing is fixed to bore): **0.0035** m/s
Operating Temperature Range	between -40 and 150	degree C	**Suitable** for kitchen environment.
RoHS	10	-	

Along with bushings, external retaining rings are used to secure the bushing in place.

Table 3. The technical properties of the Retaining Rings NETWS3. [2]

Feature	Value	Unit	Comment (**pass** or fail)
Type	External	-	-
Nominal	3	mm	-
Shaft used	4-5	mm	Shafts are designed **accordingly**.
Applicable shaft	3	mm	
Groove width	0.7	mm	
Material	Stainless steel	-	**Suitable** for kitchen environment.

Table 4. The technical properties of the DC-Motor 397172. [3]

Feature	Value	Unit	Comment (**pass** or fail)

Power rating	70	W	Required motor power: **63 W**
Max speed	10 000	rpm	Required speed: 72 degree/s = **12 rpm** PWM and Hall sensor are used to control motor speed accordingly.
Hall sensors	yes	-	
Maximum Output Torque	1460	Nmm	Required motor torque: **875.45 Nmm** (see below explanation)
Nominal torque	128	Nmm	

As can be seen, the required motor torque is much bigger than nominal torque but smaller than maximum output torque (stall torque), which means that the motor will occasionally work in high load, high temperature zones. This is not concerning thanks to the following reasons:

- The motor operates at slow speed with the position monitored by the Hall sensor, so the load is not expected to affect the speed of the motor.
- The device cover is designed to assure air ventilation around motor position.
- Overcurrent circuit breaker will be installed.
- The benefit of using a DC-motor is that we generally get more power compared to size than with conventional AC-motors. Indeed the smallest electric motors are usually DC-motors.
- Furthermore, a brushless DC-motor ensures that we have a long life span for the motor and then for the product.

3. Selected materials

Choosing the right materials for each application serves a great importance to our mechanism solution by enabling us to maximize the most desired properties of the different components of the mechanism like strength and rigidity as well as durability and user friendliness while minimizing characteristics that reduce the longevity, durability, safety of our solution for the users. For the main body of the mechanism, we will be using AISI 316 Stainless Steel which has the material properties as shown in **Table 5**.

Table 5 The material characteristics of AISI 316 Stainless Steel.

Property	Value
Elastic Modulus (MPa)	193,000
Poisson’s Ratio	0,27
Mass Density (kg/m^3)	8000
Tensile Strength (MPa)	580
Thermal Conductivity (W/(m*K))	1.6e-05

The bearings contained in this device are made with High Tensile Brass Alloy. The manufacturers often don’t provide specific data on the composition of their proprietary materials to protect their Intellectual Property rights. However, we can have a brief look at comparable materials to provide a rough estimate of the likely expected material characteristics. The table 6 below thus serves only as a rough reference rather than precise detail. One such material is the CW713R High Tensile Brass. We present the characteristics of the material below.

Table 6 The material characteristics of CW713R High Tensile Brass.

Property	Value
Elastic Modulus (MPa)	92000
Poisson’s Ratio	-
Mass Density (kg/m^3)	8200
Tensile Strength (MPa)	470
Thermal Conductivity (W/(m*K))	64

4. Lifetime of select component

In our report we will consider the lifetime of the mentioned Oil free bushing bearing MPBPU5-8, since it is the component which will experience wear and tear the fastest out of all the components in the mechanism. The actual lifetime of the product would be dependent on the rate at which the mechanism turns and how many times it is used, but the device should ideally be able to last about **5 years** with efficient functionality [5] as predicted from that an oil-impregnated bronze bearing can easily reach a lifespan of more than 50,000 hours under appropriate load and speed circumstances, ambient temperature, and working lubrication.

5. Mechanism renderings

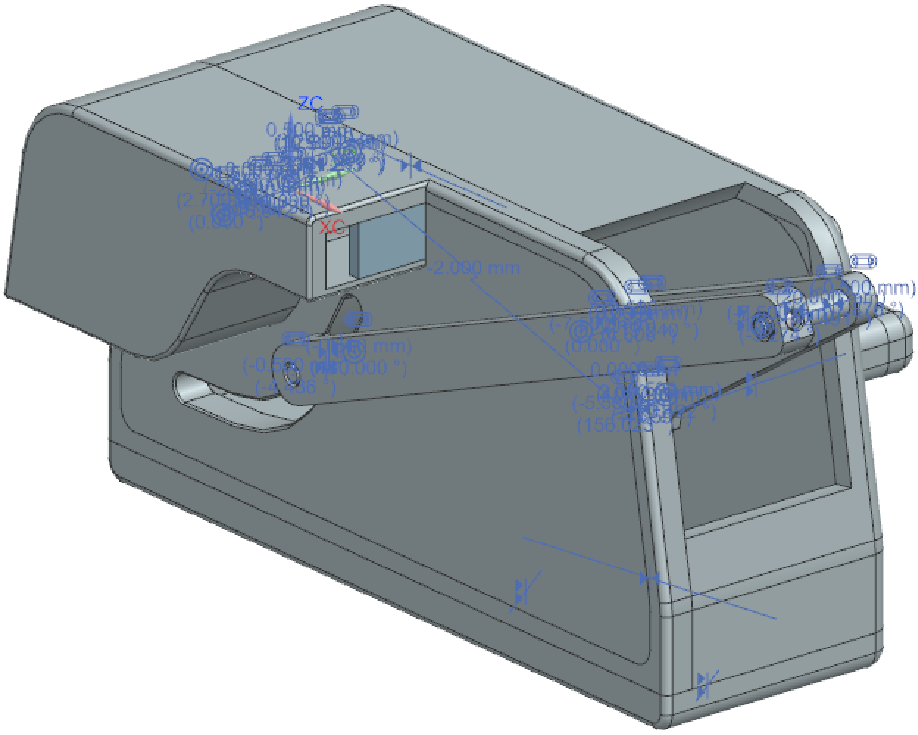


Image 1: Final Mechanism Design

The mechanism design is now updated as shown in Image 1. The motor is now added to the mechanism with the bearings and the shafts connecting the parts. Moreover, the body covers and cover plate are now enclosing the inner mechanism for more durability of the device and for protection for the user from being harmed by the inner moving parts. The mechanism is now ready to be rendered.

Visualization and rendering are crucial components of product development. The design must be as aesthetically pleasant as feasible in order to catch customers' attention and increase sales compared to products with similar features but less appealing appearances.

Additionally, product development goes beyond only the actual product design. Marketing and selling the finished product are steps in the process. Due to the improved quality of these photos and the simplicity of production, more marketers are using photorealistic rendered graphics to advertise items.

Rendering is the process of using software to produce a picture from a model. Although this article will concentrate on its usage in design visualization, it is used in architecture, simulators, video games and visual effects. These product visualizations can be utilized at any stage of the design process, from outlining early concepts to gauging consumer interest in potential new ideas to aiding in the selling of finished items via the internet. Models containing visual effects like shading, texture mapping, shadows, reflections, and motion blurs are given their final appearance during rendering.

Now, we will include the design rendering of our mechanism in this section. Since the main body is mainly composed of AISI 316 Stainless Steel Sheet, the closest material we can use in “System Material” is AISI 310 to give the rendering the shiny metallic glow for better aesthetics. The shadow effects will also be included.

Below image X presents the original mechanism functionality sketches from the Preliminary Design Report. The key takeaway is the knife is shown on the side where it can be accessed easily. Furthermore, we see a foldable cutting board under the mechanism.

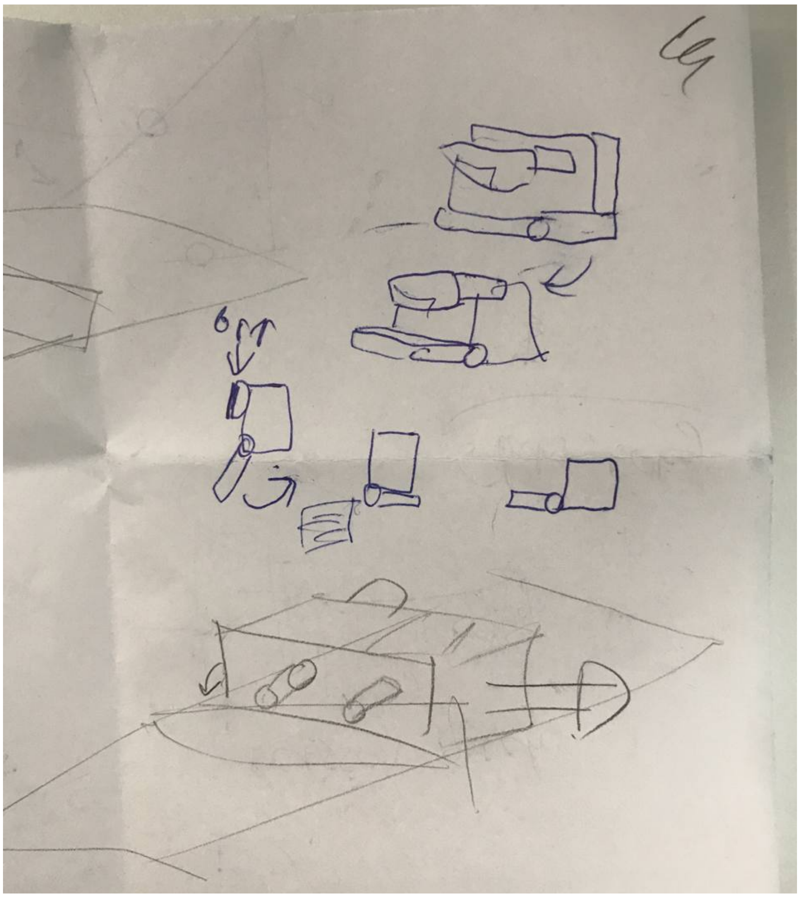


Image 2: Original sketches

Then in image 2 we show some concept art regarding the final external design of the mechanism. Hre we the knife is attached with a movement locking pin and a sturdy plastic compliant mechanism hinges that prevent rotation. The knife is attached under the hinges which means loading is only applied to the sturdy direction thus making the solution durable.

Furthermore, we see that the mechanism has a clear plastic cover which enables the users to see the mechanism in action while protecting the mechanism from food contaminants. The cover also serves a secondary clear purpose in which it prevents the user's hands from being caught between the rods of the mechanism.

The mechanism also has a cover for the motor housing. The electric motor is located right next to the motor start button to minimize waste in accordance with the principles of lean thinking and Toichi Ohno's principles. Under this motor housing is also the release mechanism for the plastic cover. The sketch in the bottom left corner also shows how the mechanism can be displayed in the kitchen so visitors can easily see the mechanism even if the machine is not in use. The overall design follows the concepts introduced in the Bauhaus movement and takes great inspiration from the minimalist clean design of Braun products like their well known world-famous mixers, coffee machines and toothbrushes.

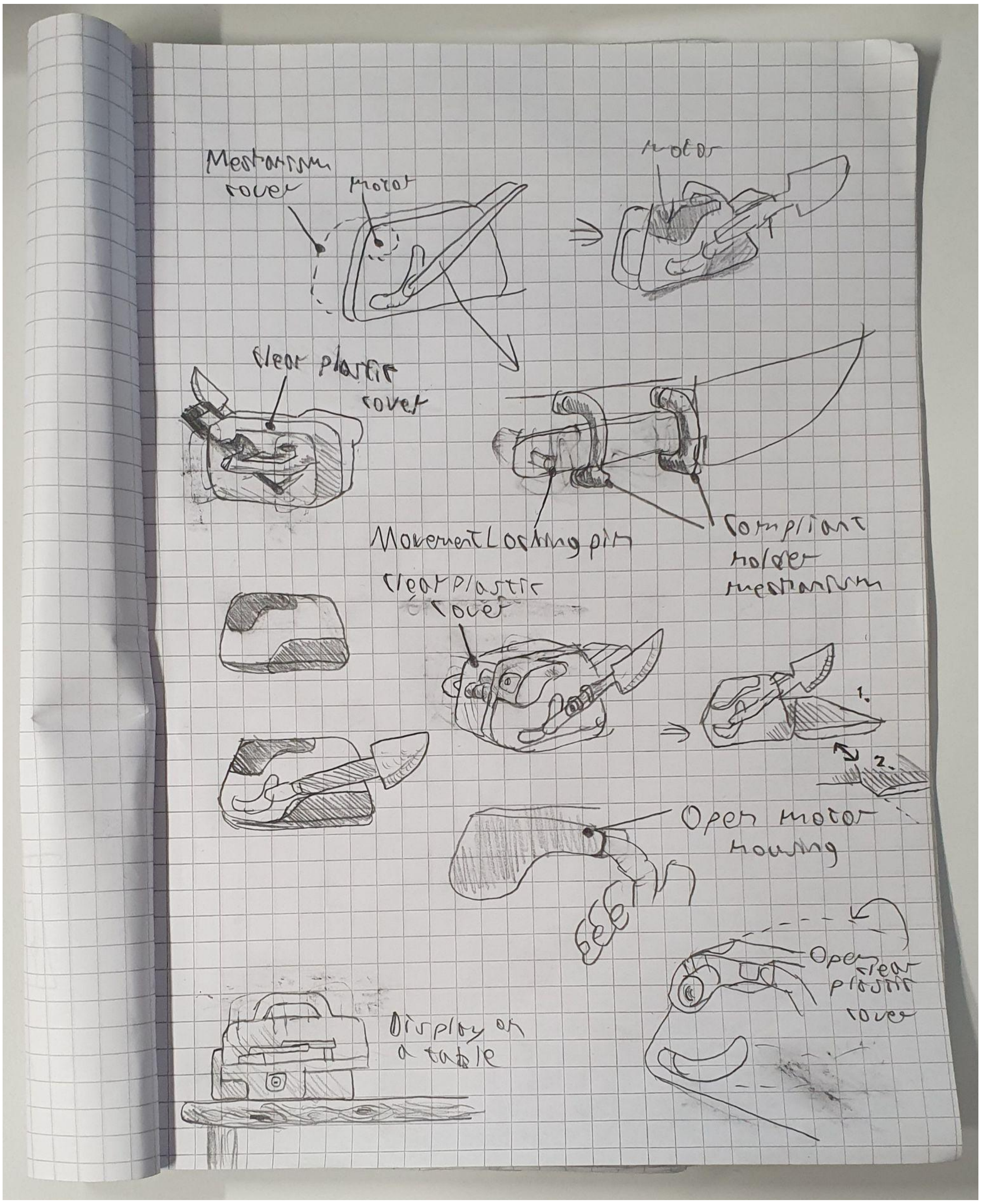


Image 3: Updated final design sketches

The final design sketches for the mechanism including the bearing and the display format are shown in Image 3. This mechanism will be rendered for aesthetic purposes. The images 4 - 5 below show the rendered images of the mechanism, one with the enclosure and one without. The moving parts, bearing and shafts have the system materials of AISI 310 Steel assigned, as AISI 316 is not available and the closest metal is chosen. The plastic part is polypropylene opaque as the enclosure cover. Moreover, we faced a problem with rendering a final mechanism since one part keeps jumping to the other side when we play the motion simulation. We could not fix this bug even with the help of tutors on Thursday and spending the weekends on this problem. However, we have tried our hardest to provide the best rendering solution for our problem.

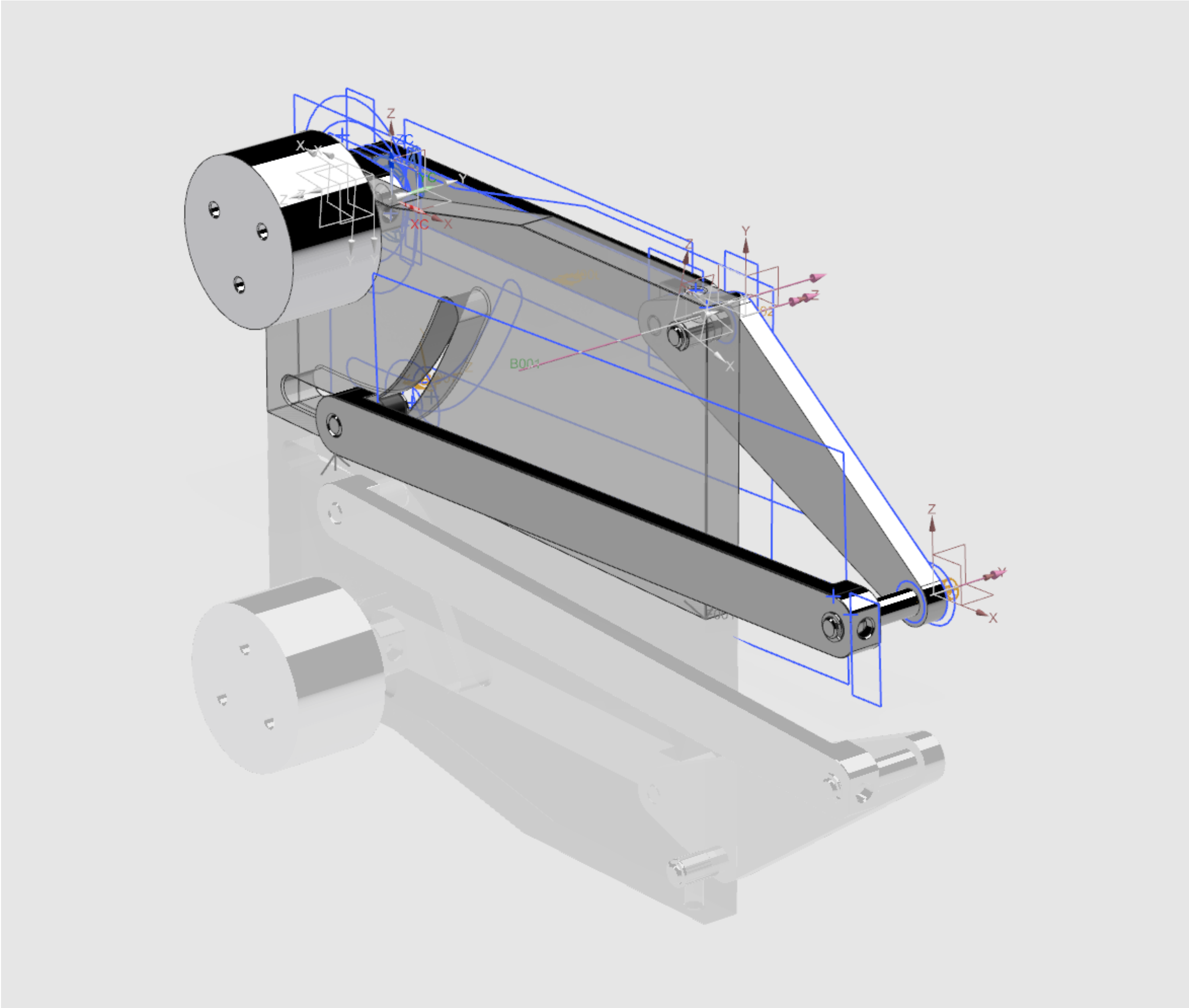


Image 4: Rendered image of the updated mechanism

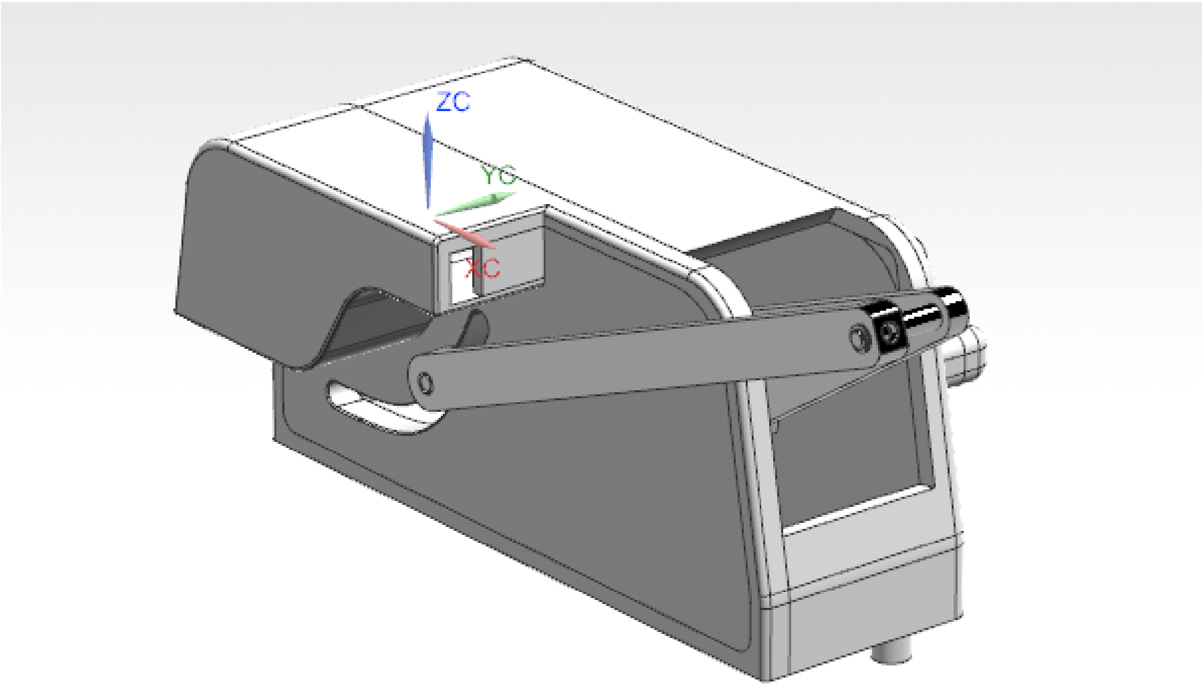


Image 5: Rendered image of the updated mechanism

6. Consideration of original requirements

After the MBS and FEM analysis, it is important to refer back to the original design requirements to see if the results can meet the initial requirements initiated. The requirement lists for the mechanism are given in **Table 7** as seen below. Our mechanism achieves the original requirements. We use a small but powerful brushless DC-motor with three phase current. Indeed such motors often outperform the other motors of similar size. We achieve the minimum cutting force with margin to spare. Maximum output torque of 1460 Nmm and a 20 mm arm means we achieve force of upto 73 N more than double our requirement for tougher cutting.

Our cycle time is 1.8 seconds so we also achieve our cycle time requirement with margin to spare. By using plastic moldings in the final product covers and thanks to our decision to make the parts our solution comes to just over half of the requirement at around 6 kg and this is not even a Demand requirement but rather a non-demand requirement.

Throughout our design process we also ensured the device stays small. During the previous weeks we took a corner to corner measurement and saw length way under our requirements at around: 261 mm. Our mechanism cover makes the box larger as our mechanism assumes height of roughly 100 mm and width of 50 mm will be under 30 cm from corner to corner. This is actually even smaller because one of the covers is removable. Thus we achieve all the requirements really well.

Table 7 Requirements list for the mechanism

Req	Level	Measure
Cutting force ≥ 30 N	Demand	MBS Software
Cutting Cycle < 2 s	Demand	MBS Software
Weight of product < 10 kg	Non-Demand	FEM Software
Maximum Length < 30 cm	Demand	FEM Software

7. Design process and application computer tools

Preliminary Report

The design process initiated with discussing and voting among the team members on the best mechanism to do for the machine design task. After much debate, we decided on moving forward with the knife cutting mechanism due to its fulfilling all the requirements of the project and the interesting nature of the mechanism. Firstly, we sketched how the mechanism should work and performed a simple free-body diagram analysis to understand which force and torque are acting on each part of the mechanism. In this initial round of the research, we learned how to model the mechanism using the Linkage software to make it easier to understand and determine if the suggested mechanism is likely to function or not, as a means to check the feasibility of the mechanism for later weeks.

MBS

Then, the first part of the main task started: multi-body simulation or MBS. Multibody simulation is a technique for numerical simulation in which multiple stiff or flexible bodies are combined to create multibody systems. Kinematic constraints like joints or force elements like spring dampers can be used to model connections between the bodies. It is frequently used in product development to assess comfort, safety, and performance attributes.

Firstly, we perform the kinematic simulation. Kinematics examines the motion of the mechanism by calculating the position, speed, and acceleration of points (such as joint locations) and bodies. A zero-mobility mechanism is required in order to perform a kinematic analysis. In terms of application, this means that the user must specify the appropriate joint types and ensure that all required degrees of freedom are taken into account. The kinematic simulations showed our model's motion and location more precisely than the earlier stages of our project. In contrast to kinematics, dynamics includes simulations of forces. In addition to location solving, this makes it possible to calculate forces inside the mechanism. The simulations may also incorporate friction models. The dynamic solution is far more forgiving when the mechanism's modality level is taken into account.

From the MBS simulation, it is possible to plot the displacement, angular velocity, force and torque plots for each joint in the mechanism. This step is important since it will be used to perform FEM simulation in a later section, and finding the torque and angular velocity allow one to calculate the minimum power needed to run the mechanism. The plots and all the necessary results obtained from MBS simulation are shown in the Appendix section, since the images are quite numerous to present in the main report. The MBS simulations are done by the Motion function of the Siemens NX Application tab.

FEM

The finite element method is a widely used approach for numerically solving differential equations that emerge in engineering and mathematical modeling (FEM). Common issue areas of interest include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. [4] The geometry of the mechanism was also updated since the previous mechanism has problems in the joints and the motion bodies, and the new mechanism had shafts which alleviated that problem. We consider the intended limitations after revising the mechanism geometries, eliminating any overlapping connections, and selecting the materials. We want one pinpoint to always be free to deflect under loads in order to mimic displacement. One such location is always free in our FEM simulations, and the highest possible loading is applied to it in accordance with the force and torque findings in our MBS report. A model with two pinpoints, for instance, will get two simulations, whereas a model with three pinpoints, gets three simulations. The other point or points in the case of the triangle member will be locked in place using the fixed constraint option of Siemens NX. Using the above-mentioned method, we will make mesh models for each body part and plot the contour plots for displacement and stress to find their maximum values. The plots and all the necessary results obtained from MBS simulation are shown in the Appendix section. The FEM simulations are done by the Design function of the Siemens NX Application tab.

After the plots,the machine designer may also calculate, subject to some limitations, the dynamic and thermal characteristics of a machine design using the finite element method. Our triangular bar was optimized. Because it has the most connecting links, it's the most crucial portion of the system. We optimized the shape for stress reduction. Two different shapes for the triangle shapes are also tested to check the maximum displacement and stress and compare with the original mechanism design. After this process, the mechanism is thought to have completed the FEM analysis and the rendering and the bill of materials can start.

We experienced a bug with our final animation where a rod jumps to a different position and even the most talented course assistants during the course of hours were unable to help us. When even the most talented assistants cannot find the cause of a bug we believe this should not be a reason for any point deductions and will happily elaborate further on the matter.

8. Cost estimate

In order to determine the cost of the design, a complete cost analysis and bill of materials were needed. Furthermore we will briefly give a rough estimate of the labor cost based on likely production measures. There were no cost ceilings because there were no clear budgetary restrictions. There was a desire to create a design that is cost-effective and satisfies all of the established objectives, even if a maximum cost was not mentioned.

The original design has metallic link members or beams and a 3D-printed outer shell. The 3D-model of the outer cover shown above is just a 3D-printed model and thus has much thicker walls. The final production ready machine will utilize a cheap plastic molding like the ones used in home appliances produced by Braun like mixers, toothbrushes and coffee machines.

Now, let us start with the cost of the known components. The cost of the bearing we use is 5.35 € when purchased individually. However, the manufacturer promises a scale discount. Thus we may expect a price around 4.00 € per component. Now let us consider the number of components used!!! thus our cost for one mechanism bearings is 4.0€*

The motor we use is Maxon Brushless DC Motor which can provide 70 W. There are seven retaining rings and seven plain bearing brushes for the mechanism for each device. We would need to buy the AISI 316 steel plates and the plastic mould for injection molding process to make the inner mechanism and the enclosure respectively. Last but not least, the labour cost is projected to be about 50% of the material cost, which also acts as a correction factor to make sure the estimated cost is at the upper bound. The detailed cost analysis is shown in Table 8.

Several vendors were asked for their component costs, but most have not yet responded. Due to the lack of precise cost estimates, an estimation of the costs of the individual component costs was established using prior information and experience. The ultimate cost estimated will be at the higher end of the anticipated cost scale because conservative cost values were chosen.

Table 8: Detailed Cost Analysis For Design

Item	Quantity	Cost/Unit (**€**)	Total Item Cost (**€**)
Material Cost			
Motor	1	150	150
Plain bearing bushes	7	4.10	28.7
Retaining Rings	7	0.18	1.26
AISI 316 Steel plates	10	20	200
Plastic Resins Bag for Injection Molding	25	1.48	37
Total Material Cost			416.96
Labour Cost			
Labour	50% of manufacturing cost		208.48
Total Cost			
Total Projected Cost			625.44

From the current projection for the cost, the total cost for manufacturing and labor is predicted to be about **€625.44**. This cost can change according to the cheaper vendor available or the third-party manufacturers being changed. For commercial kitchens this price makes sense and it pays itself back very fast in the end.

9. Bill of Materials

A bill of materials, often known as a BOM, is an exhaustive inventory of the raw materials, assemblies, subassemblies, parts, and components that are required for the manufacture of a product, as well as the quantities of each of these items. To put it succinctly, it is the exhaustive list of everything that must be present in order to manufacture a product. The production process is facilitated by an accurate and effective bill of materials (BOM). It outlines a specific strategy that is straightforward and easy to implement.

The following are the BOMs for our mechanism: one for the whole mechanism with enclosure and two for the inner moving mechanism, as shown in Appendix.

10. Discussion

This week, we conclude Machine Design by adding final design considerations to the mechanism, writing down the bill of materials and cost estimate, and summarizing what we have done in the past 5 weeks.

In the first stage of the project, we voted on the knife mechanism as the machine to work on after using Linkage to see how the mechanism would work. In the second stage, we used Siemens NX to run an MBS simulation to check that the mechanism operated as anticipated and to plot the necessary displacement, force, and torque plots for further study. In this third stage, we learned how to perform FEM analysis using the Siemens NX software to examine how much displacement and stress are acting on the parts and determine whether the device can be further optimized to increase product lifetime.

After performing the FEM simulation, we learnt how to use the rendering function of Siemens NX in order to add texture and shadows to the mechanism for asethetic effects, since the product should be pleasing to look at for attracting customers. The mechanism of the device is also updated again, by adding the motors and bearings to the mechanism as well as adding the body and the cover plates. This will act as a protective covering for the inner mechanism and prevent the user from being harmed by the moving parts. We also learnt how to draw Bill of Materials and assign the balloon notes to each part for clear notice. For this week, we discussed among ourselves and delegated the tasks needed to complete the detailed report.

We believe we have learnt the fundamentals of how to properly design a moving mechanism using the modeling software Siemens NX. We have not used this software before taking course, and it was a difficult journey learning how to use this software to perform FEM and MBS simulations, but we are glad to say we have learnt the basics of how to use this software and basic knowledge of machine design, which will be useful in later projects such as Machine Design Project. Moreover, we also learnt how to start the design process from the ground up by initiating the skeletal model, so if we need to change the design at any process, it would be much easier. The seminars offered on Monday each week were also quite informative and gave a general perspective on the machine design and the softwares associated with this in real-life context.

Because we completed the preliminary design, multi-body simulation and FEM analysis tasks efficiently and submitted the required tasks on time with great report documents, effectively discussed the cost estimate and bill of materials, and uploaded the rendered animation of the mechanism while trying our hardest to fix the problem with a motion part, we anticipate achieving a commendable grade of 5 for this report and commendable grade of 5 for this course.

11. References and Sources

[1] *Plain bearing bushes / brass / tolerance F7 from MISUMI | MISUMI*. (n.d.). Retrieved October 16, 2022, from https://uk.misumi-ec.com/vona2/detail/110302578920/?searchFlow=results2products

[2] *(NETWS3) Retaining Rings / External / E-Type from MISUMI | MISUMI*. (n.d.). Retrieved October 16, 2022, from https://uk.misumi-ec.com/vona2/detail/110300258420/?HissuCode=NETWS3

[3] *397172 | Maxon Brushless DC Motor, 70 W, 24 V, 128 mNm, 1460 mNm, 10000 rpm, 4mm Shaft Diameter | RS*. (n.d.). Retrieved October 16, 2022, from https://uk.rs-online.com/web/p/dc-motors/1817546

[4] Control automation. (n.d.). Validation and Verification in Finite Element Analysis (FEA). Retrieved October 9, 2022, from:

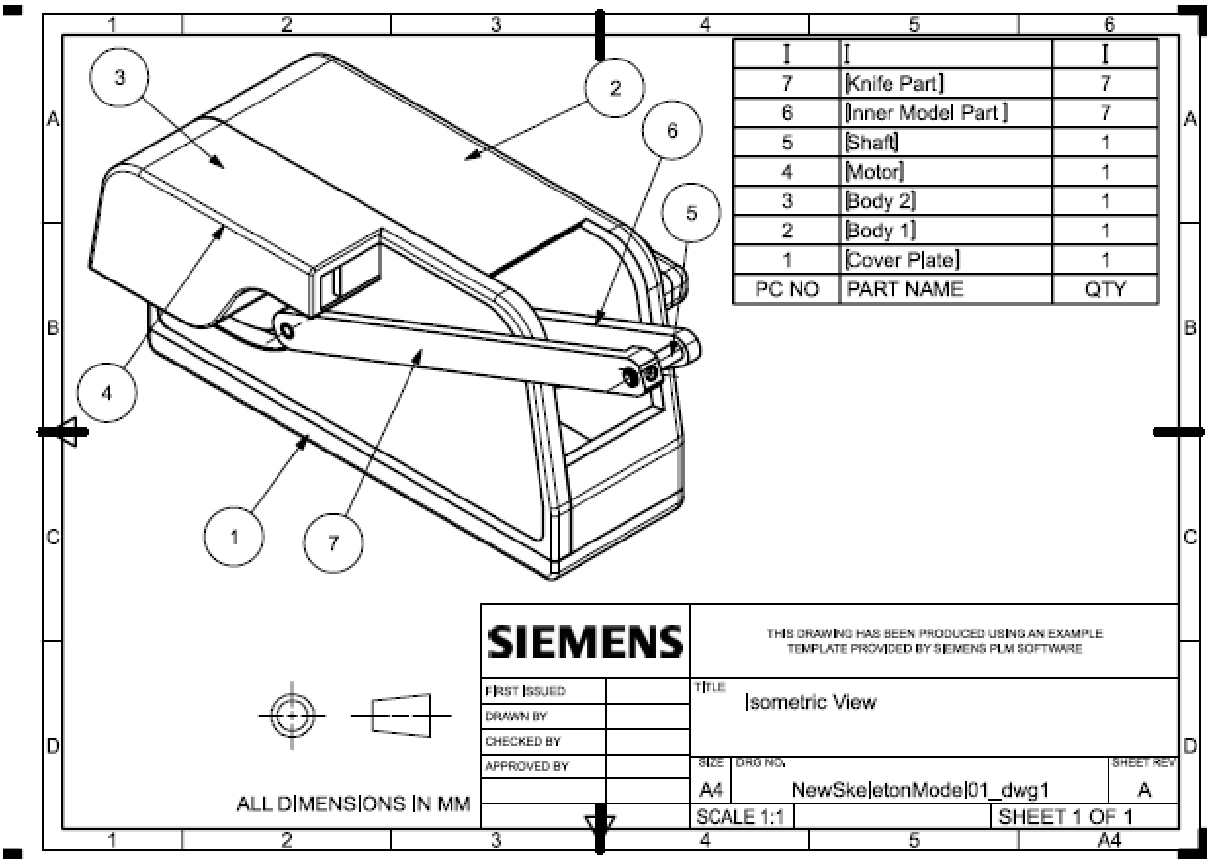
https://control.com/technical-articles/validation-and-verification-in-finite-element-analysis-fea

[5] *Oil bronze bearings*. (n.d.). https://www.johnson-metall.com/. Retrieved October 16, 2022, from

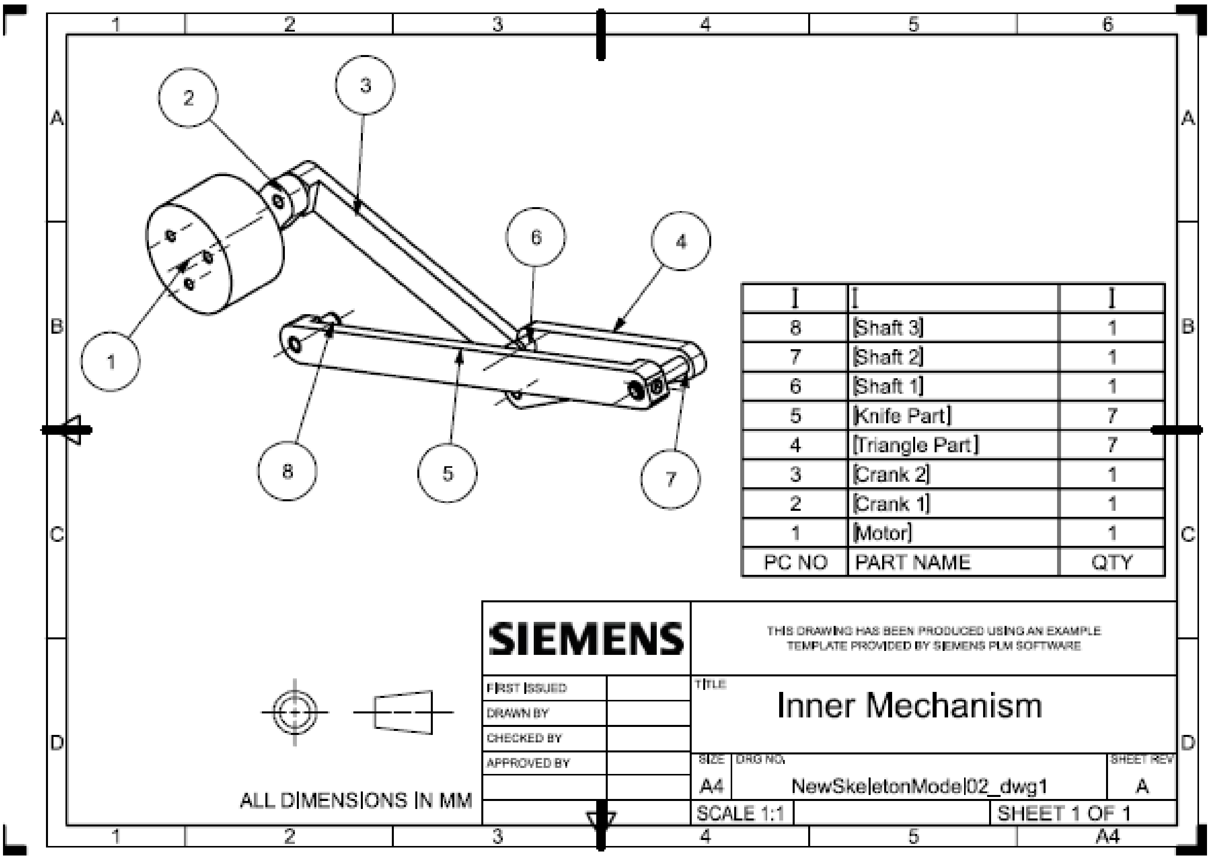
https://www.johnson-metall.com/wp-content/uploads/2021/10/JM-Katalog-Oljebronslager-8191-Folder_enGB_v4.pdf

Appendix

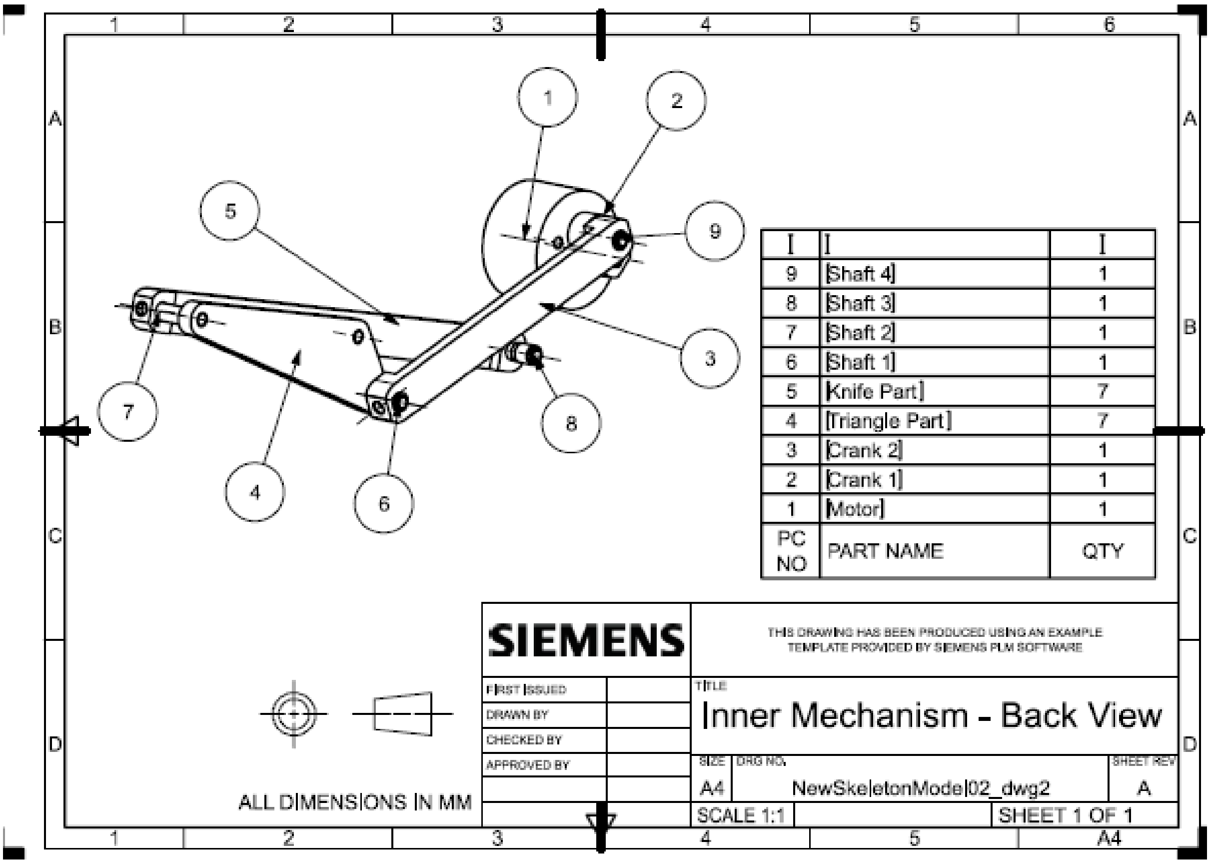
Bill of Materials



Isometric View

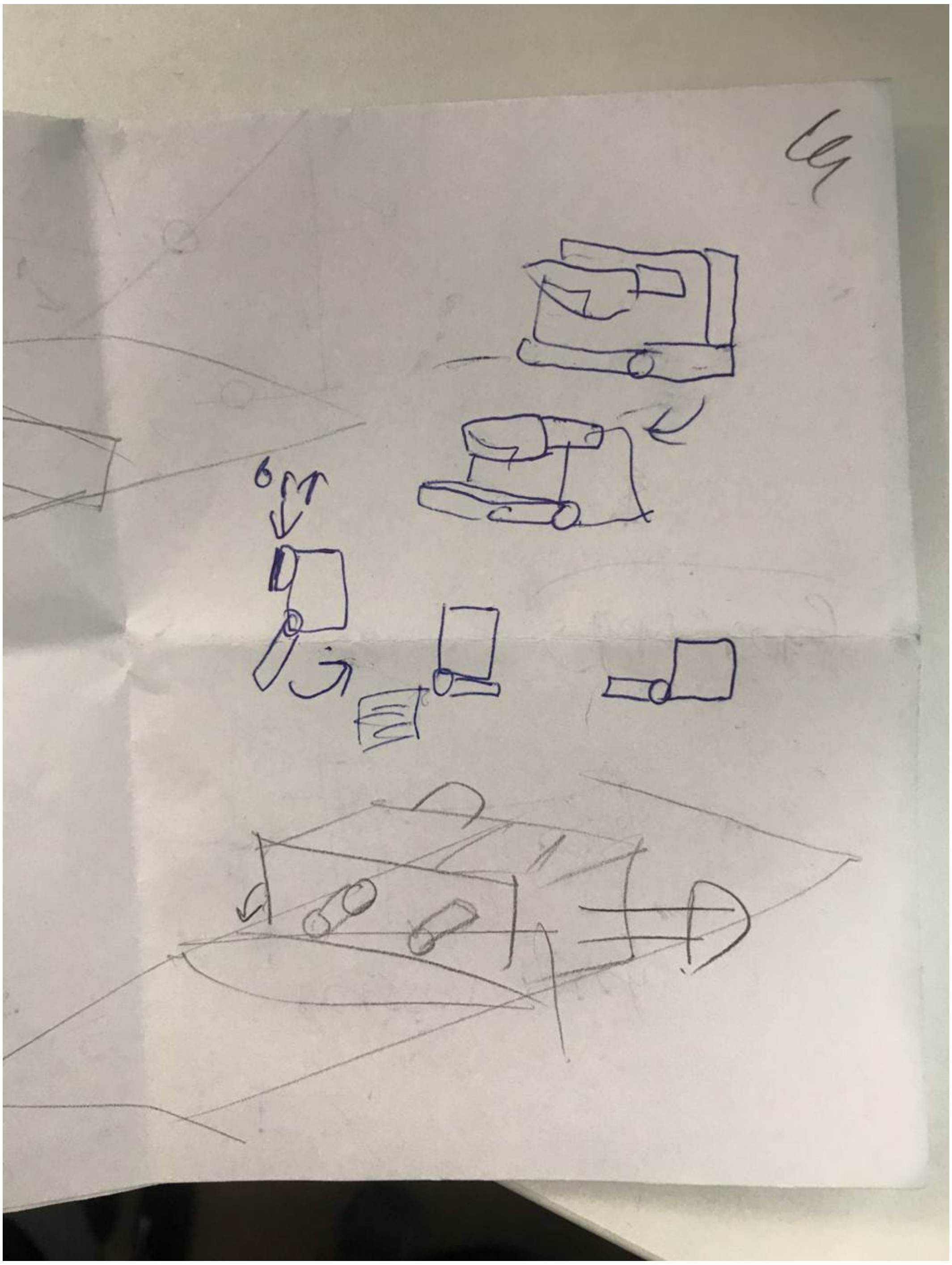


Inner Mechanism - Front View

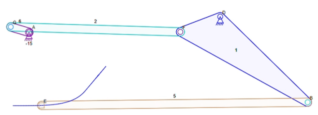
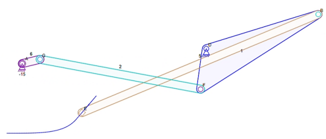
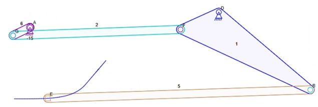


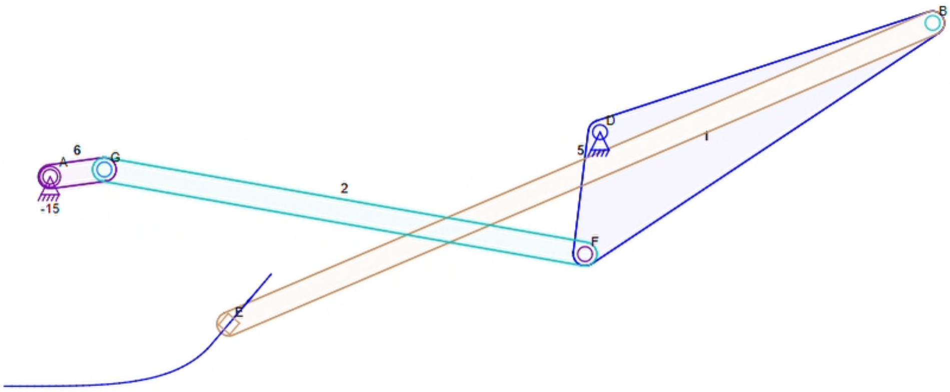
Inner Mechanism - Back View

Preliminary Report
Sketches

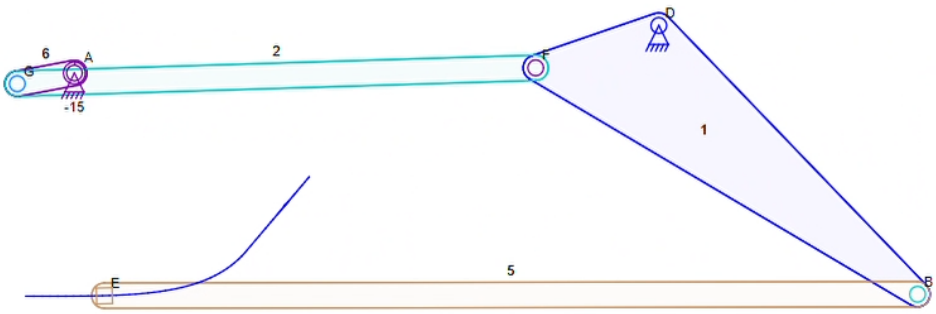


Improved model of the mechanism at various cycle time points

T = 0 s	T = 1 s	T = 2 s
		

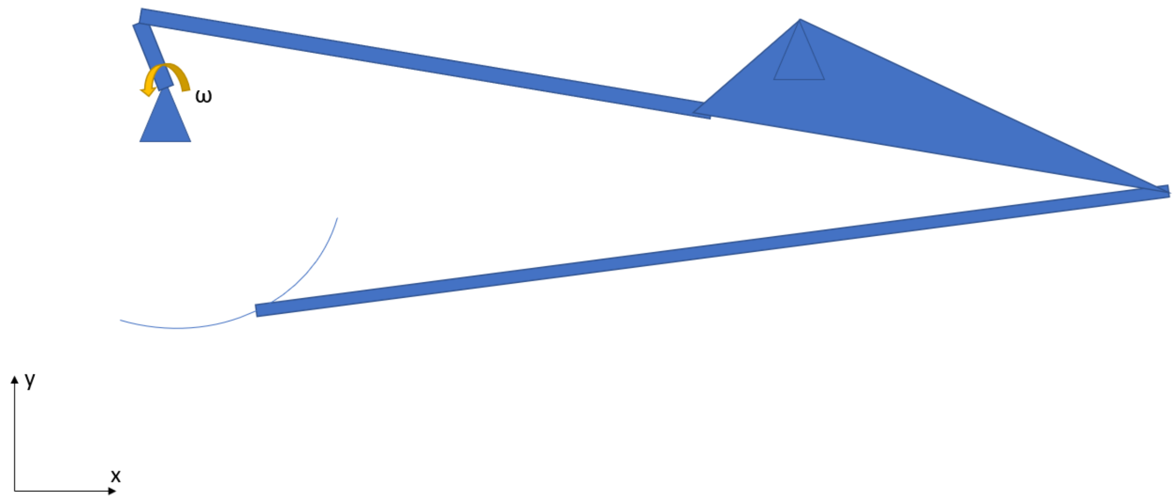


Linkage Mechanism in Upwards Swing

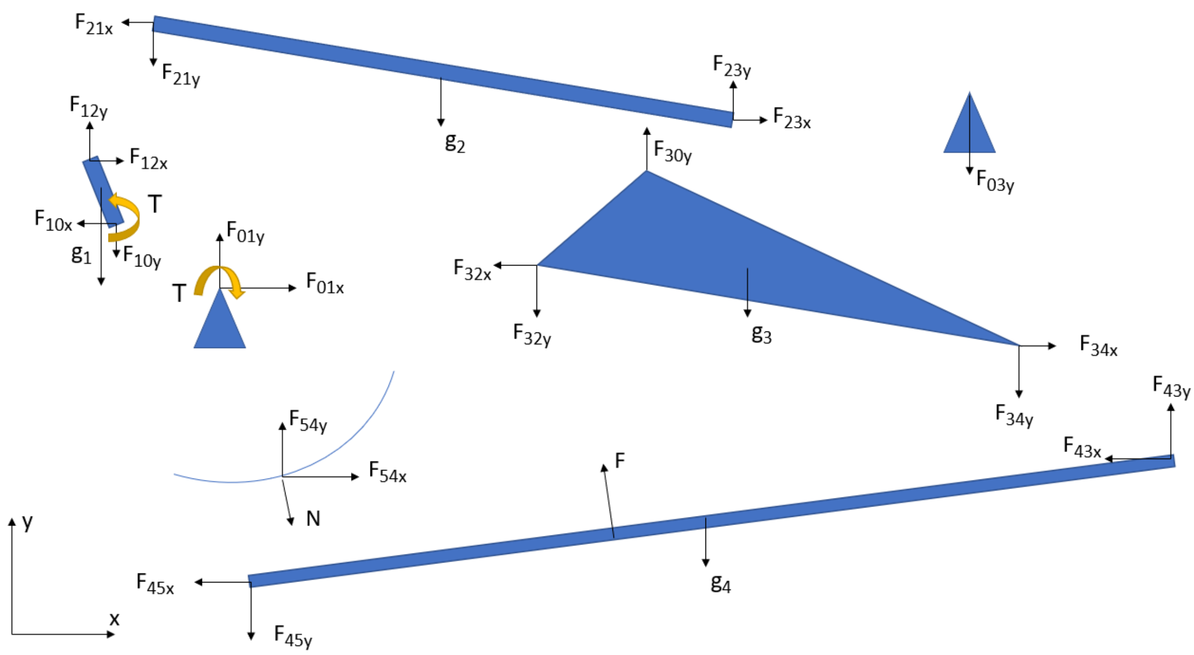


Linkage Mechanism in Downwards Swing

Free-body diagrams



Structural diagram



Free-body diagram without friction

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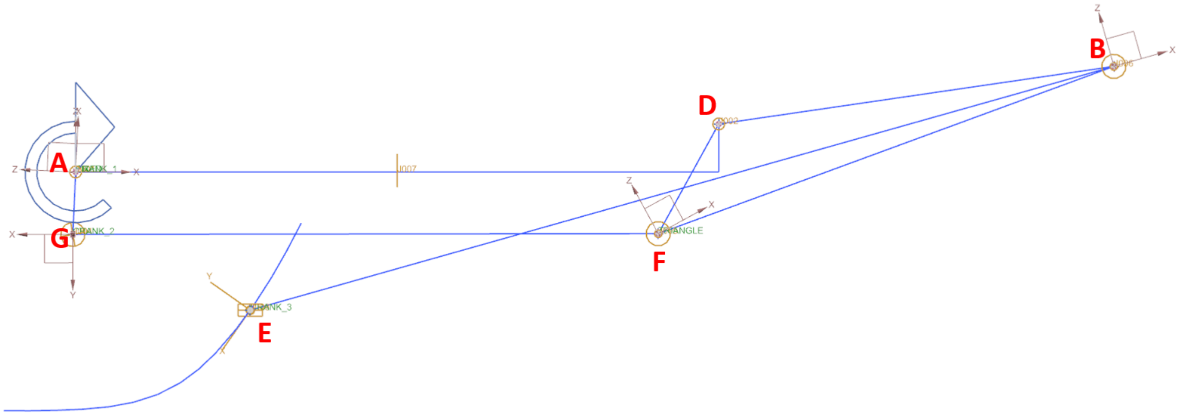
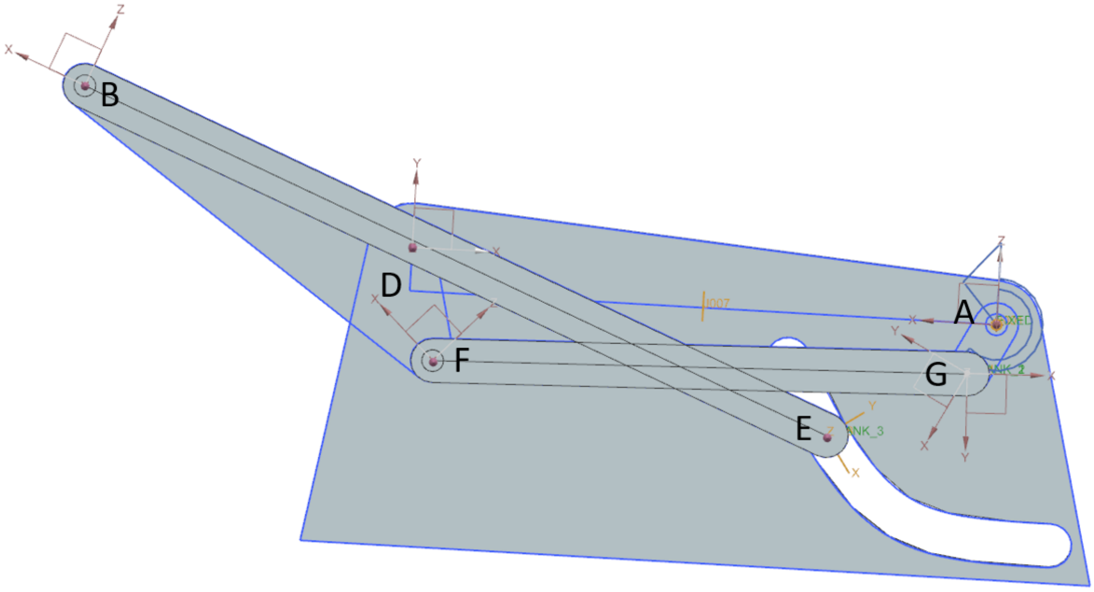
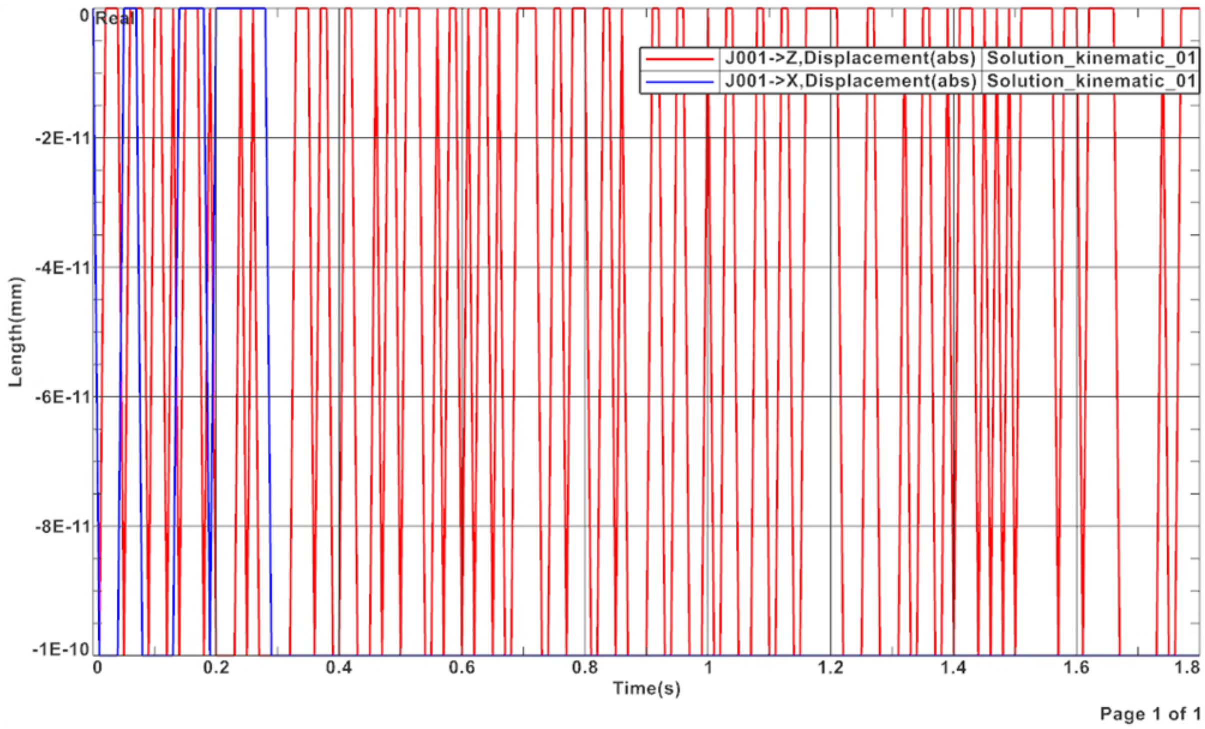


The mechanism and its link positions.

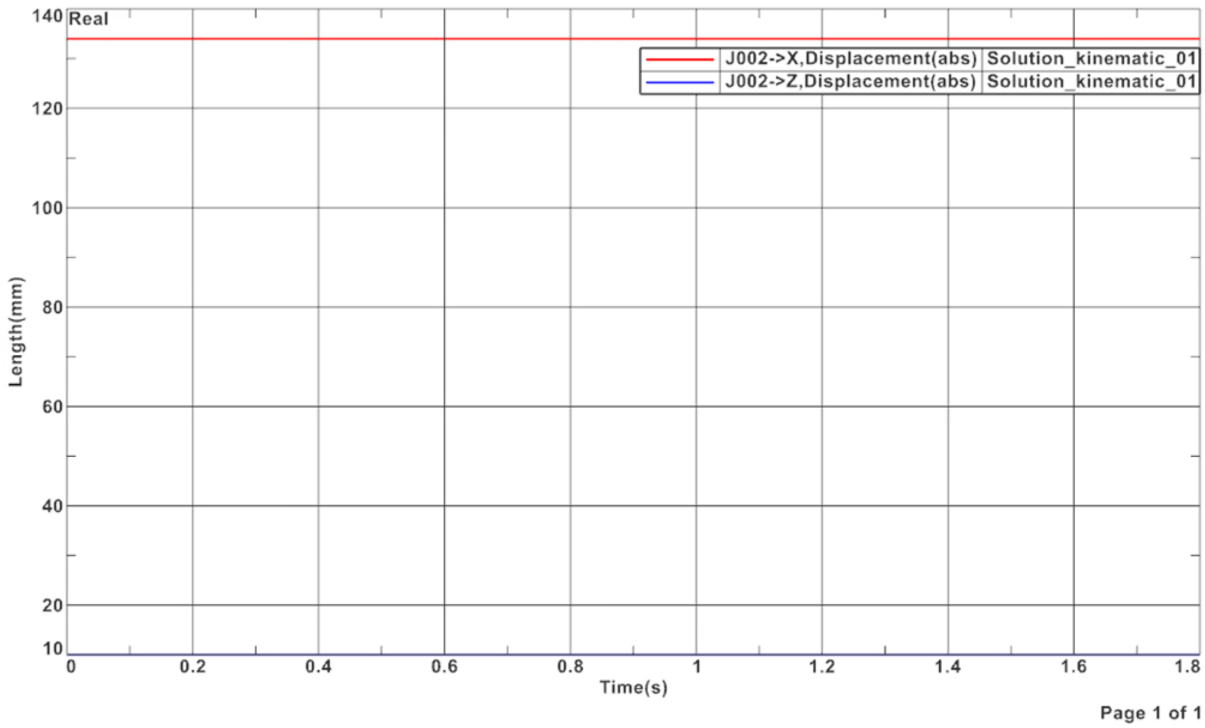


The mechanism and its link positions.

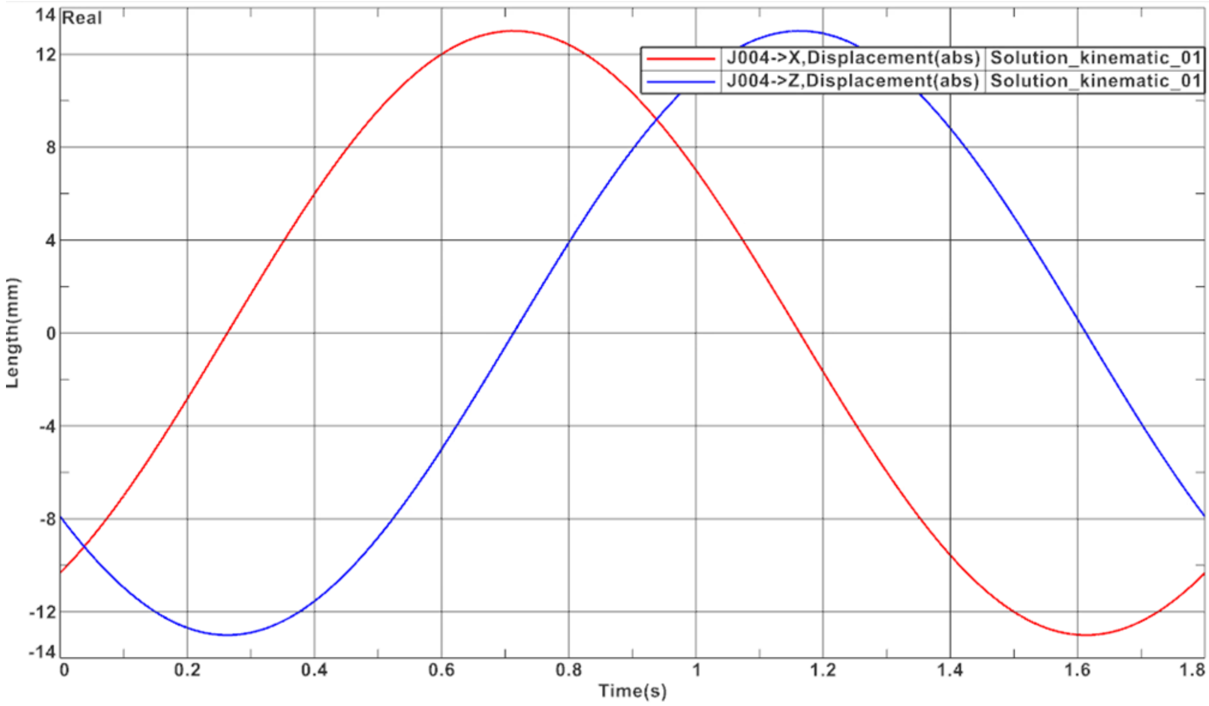
Displacement Plots



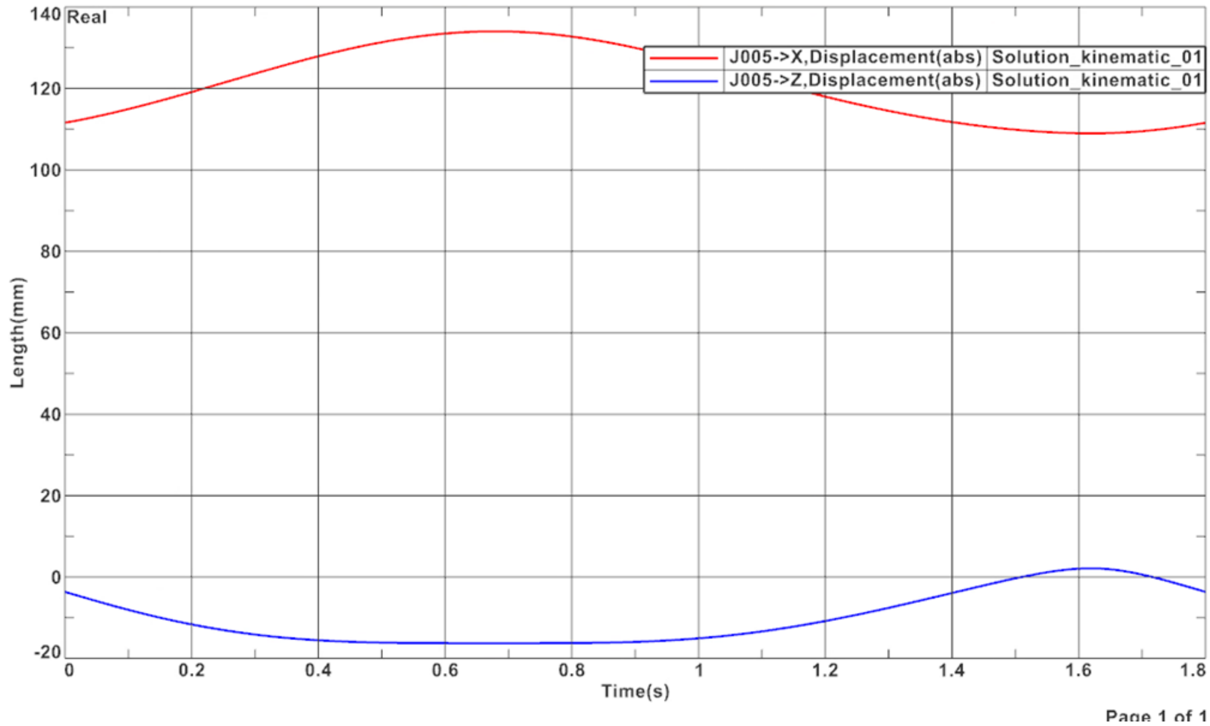
Displacement Plot for Joint A



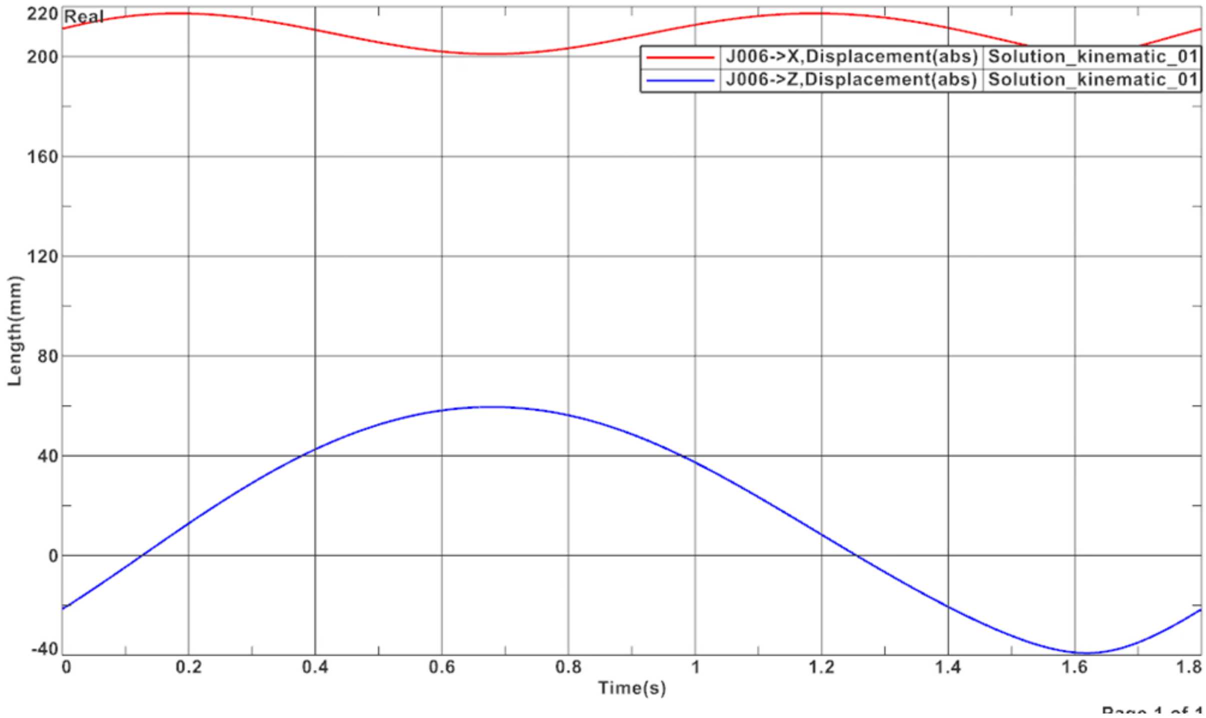
Displacement Plot for Joint D



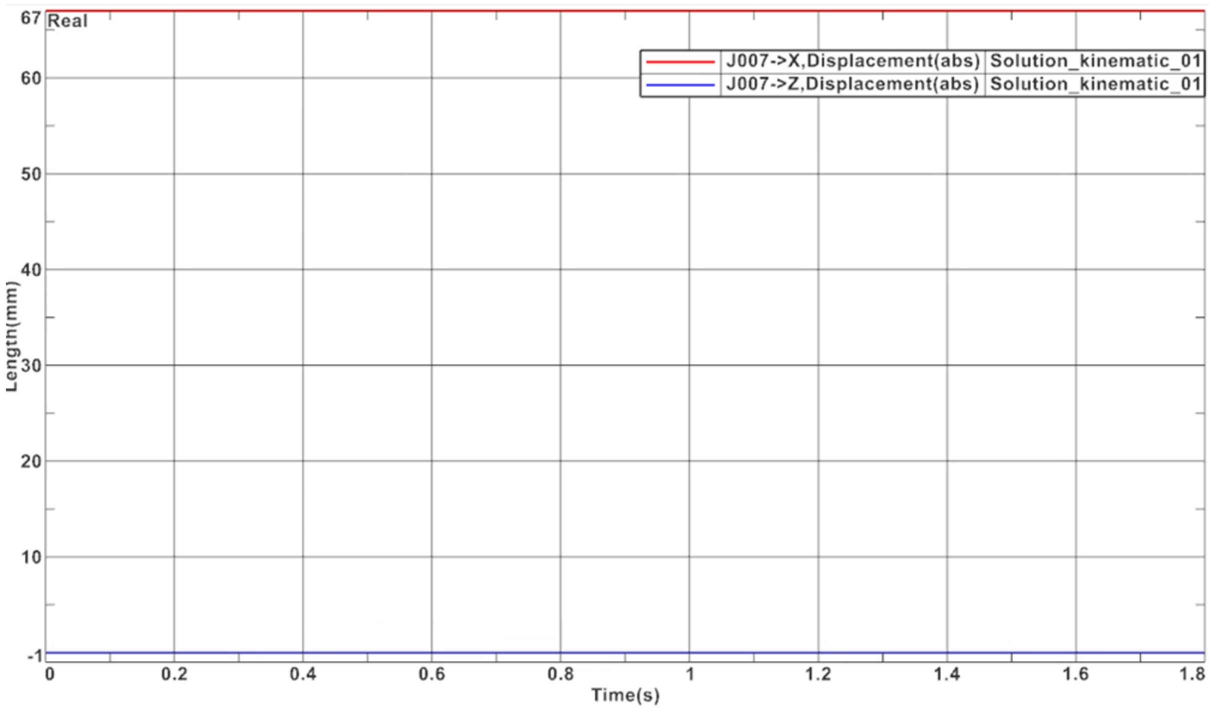
Displacement Plot for Joint G



Displacement Plot for Joint F



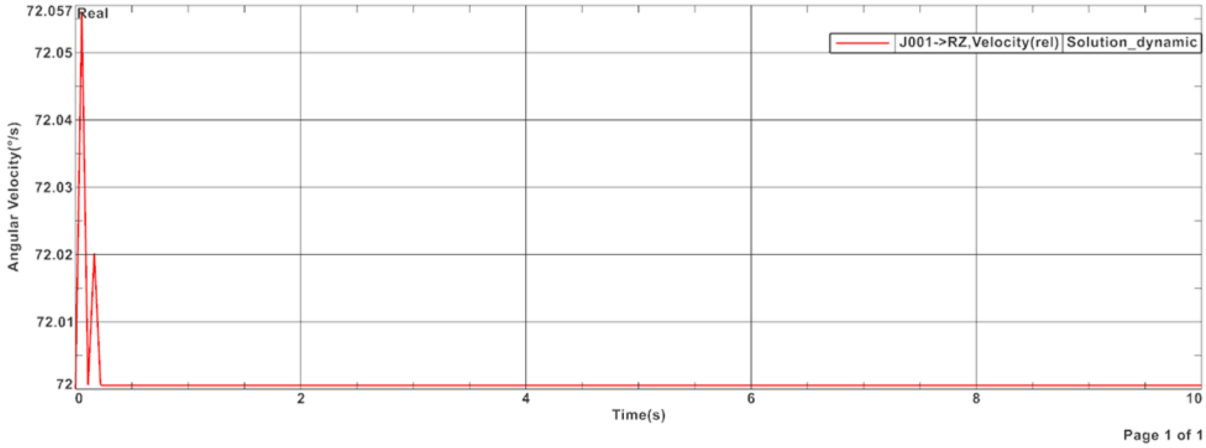
Displacement Plot for Joint B



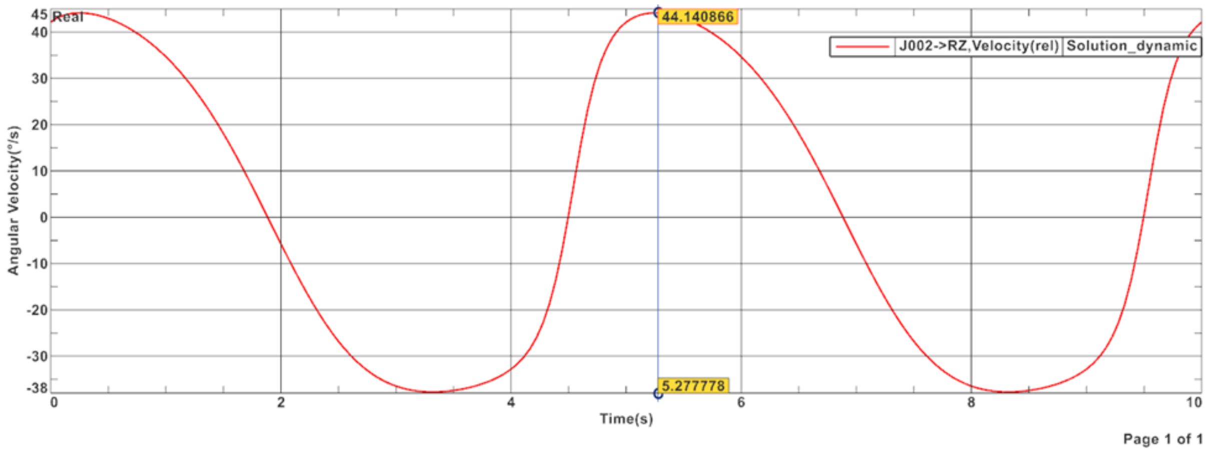
Displacement Plot for Mechanism Holder Attached To The Ground

Velocity Plots

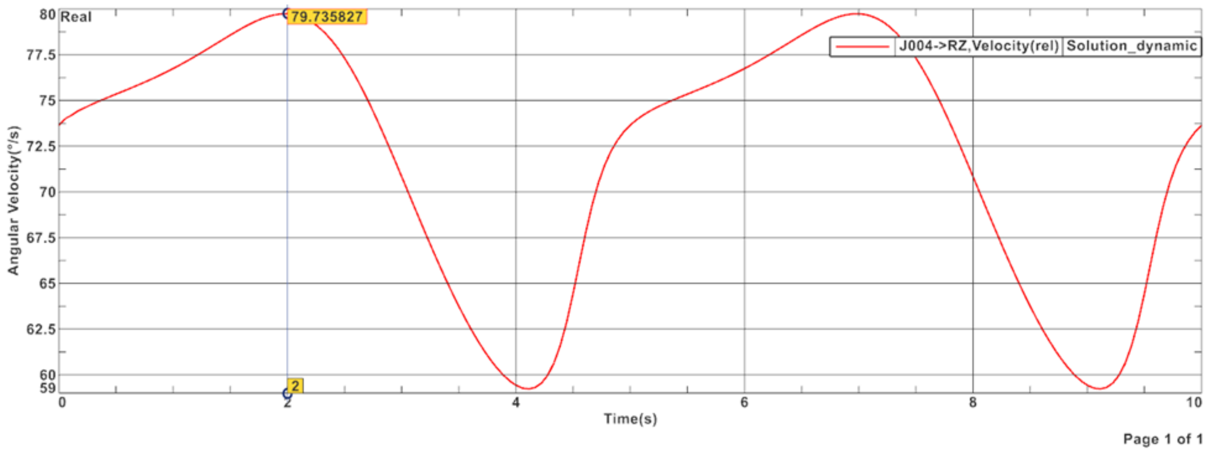
The values should not be different for both kinematic and dynamic simulations. The angular velocity is used in the following analysis since most of the motions are rotational in this mechanism. In particular, angular velocity RZ is most paramount in this plotting step. The cycle time is 1.8 seconds even though the plots below will show the scale of 0 to 10.



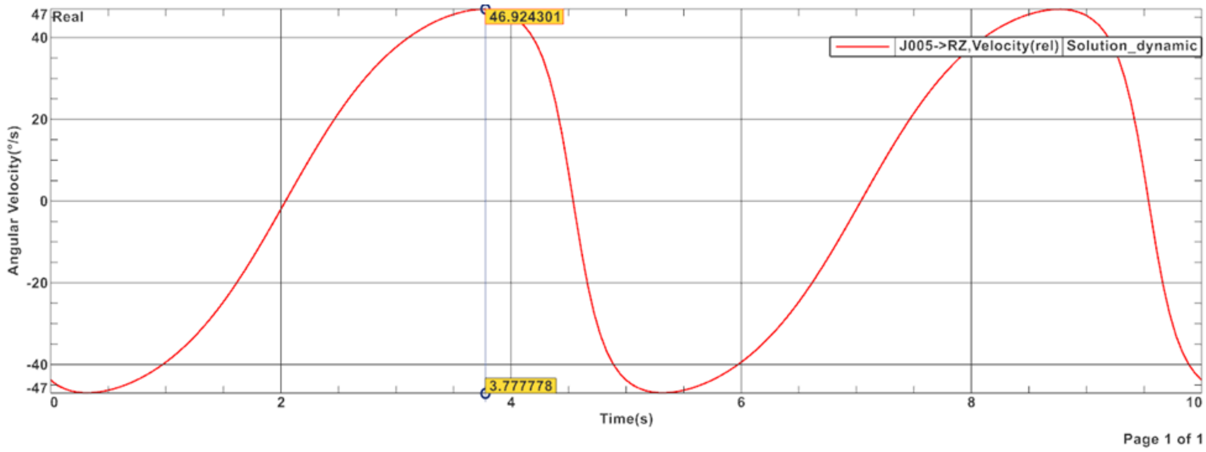
Angular Velocity Plot for Joint A



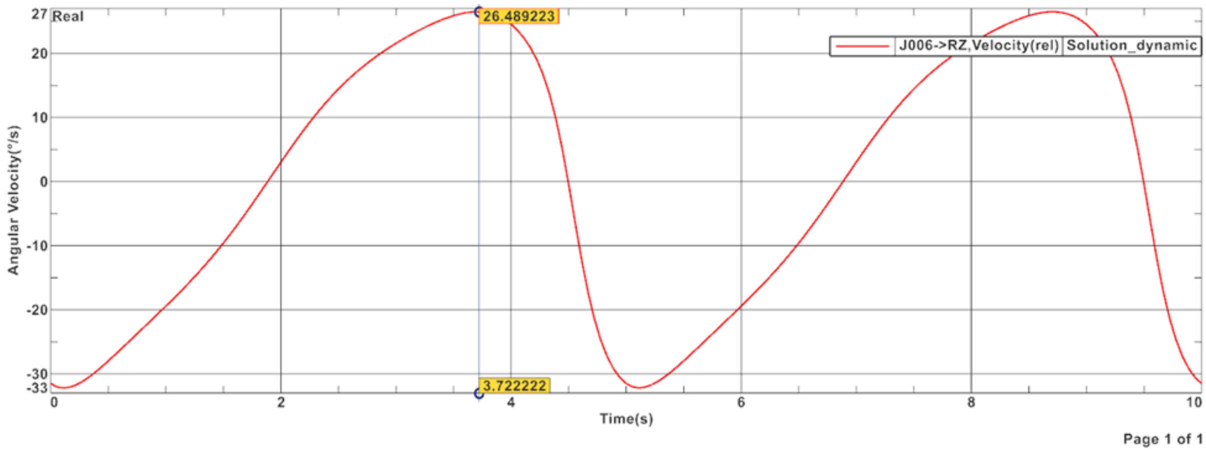
Angular Velocity Plot for Joint D



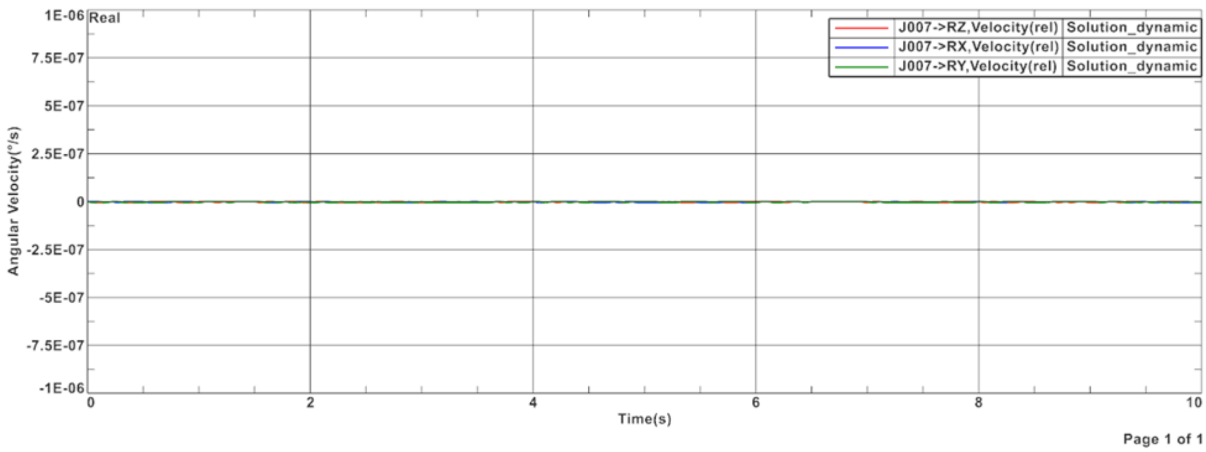
Angular Velocity Plot for Joint G



Angular Velocity Plot for Joint F



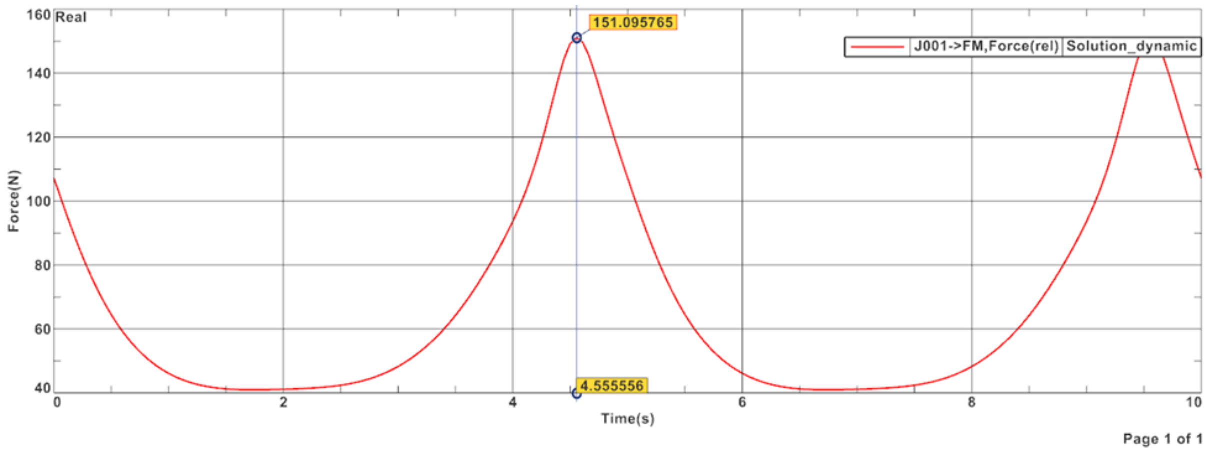
Angular Velocity Plot for Joint B



Angular Velocity Plot for Mechanism Holder Attached To The Ground

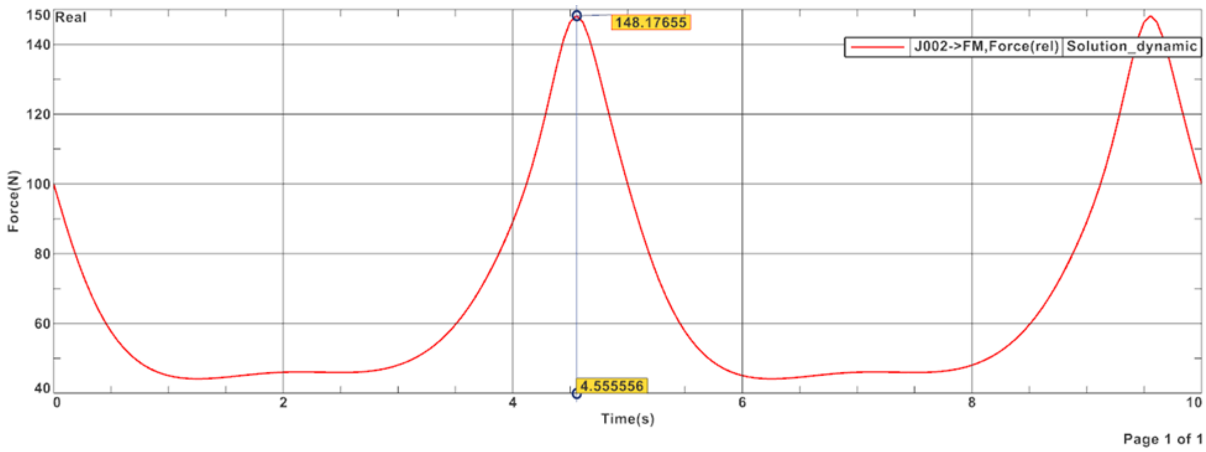
Force Plots

In order to find the maximum and minimum forces acting on the joints, the plots are taken from the dynamic simulations of the mechanism.



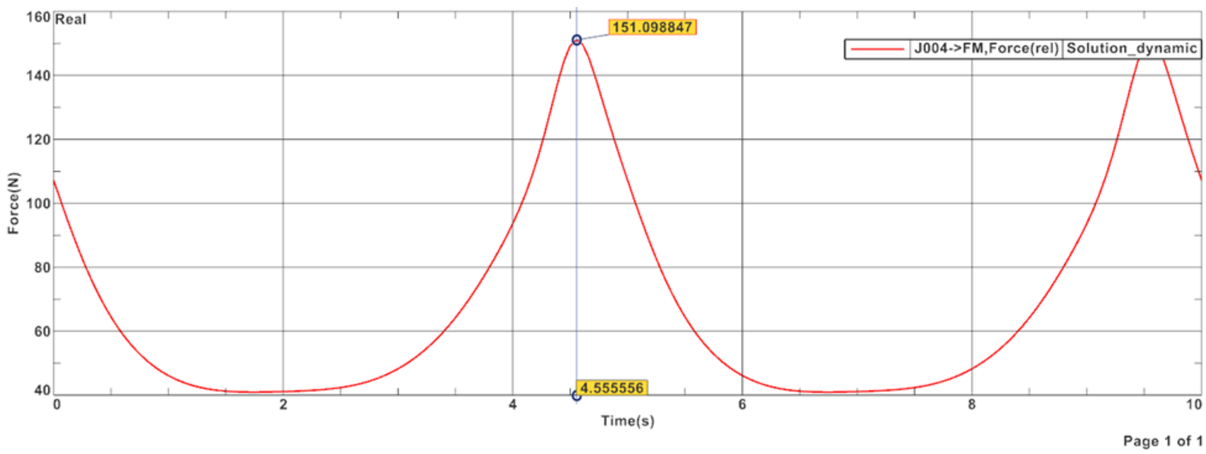
Force Plot for Joint A

The maximum and minimum force acting on Joint A are 151.1 N and 40 N respectively.



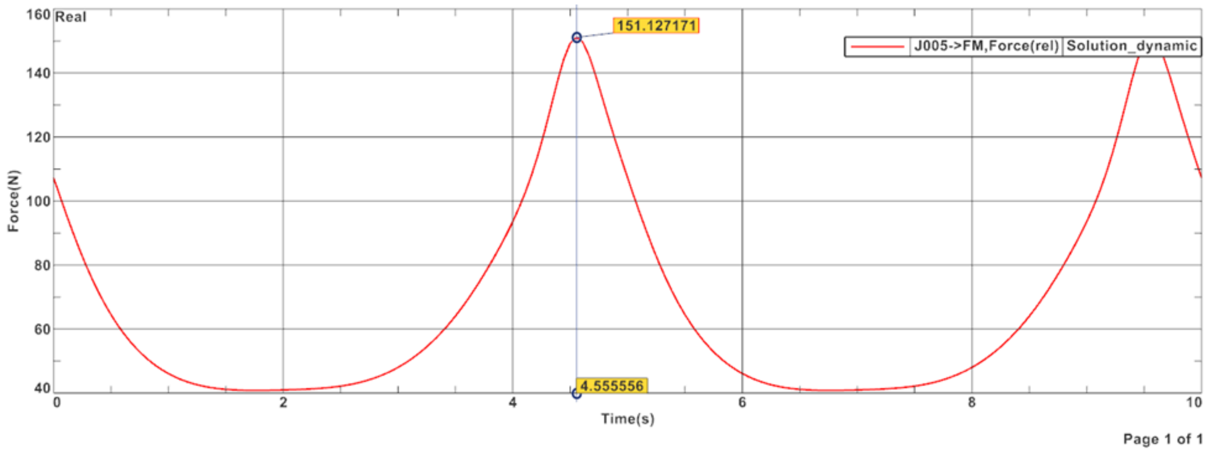
Force Plot for Joint D

The maximum and minimum force acting on Joint D are 148.2 N and 44.1 N, respectively.



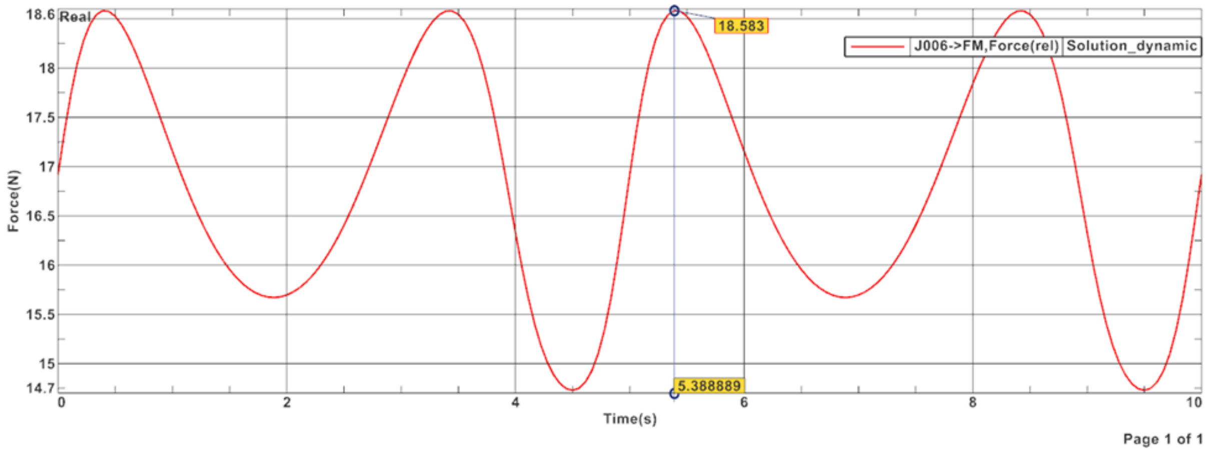
Force Plot for Joint G

The maximum and minimum force acting on Joint G are 151.1 N and 40 N respectively. There is about the same force magnitude acting on the joints as in the Joint A.



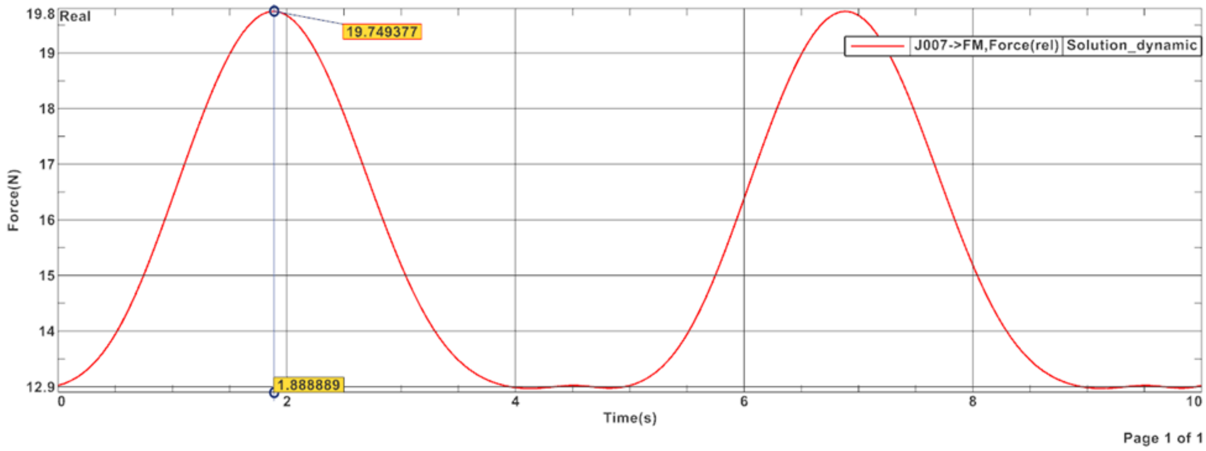
Force Plot for Joint F

The maximum and minimum force acting on Joint F are 151.13 N and 40 N respectively.



Force Plot for Joint B

The maximum and minimum force acting on Joint A are 18.6 N and 14.7 N respectively. The force values decrease compared to the previous joints.

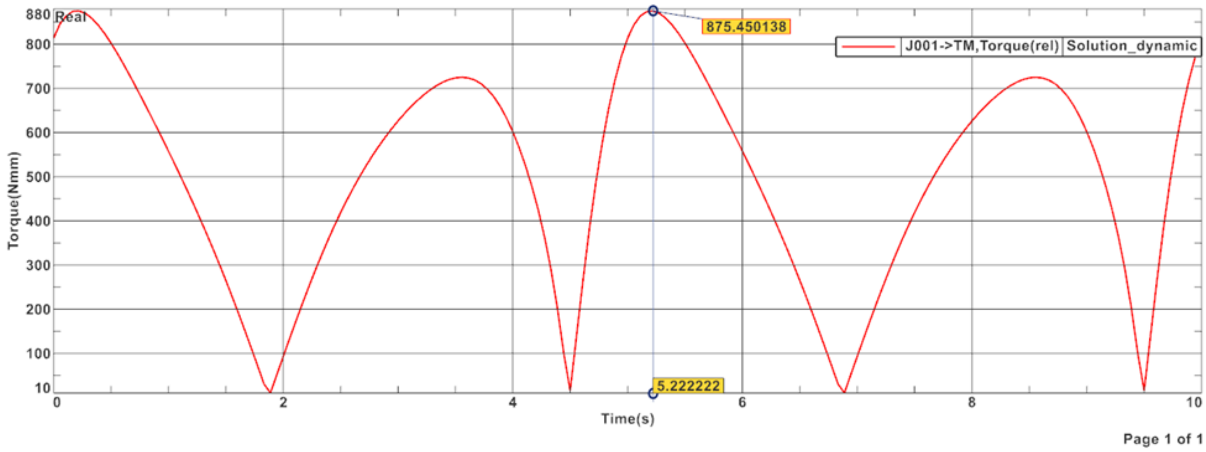


Force Plot for Mechanism Holder Attached To The Ground

The maximum and minimum force acting on Mechanism Holder Attached To The Ground are 19.75 N and 12.9 N respectively.

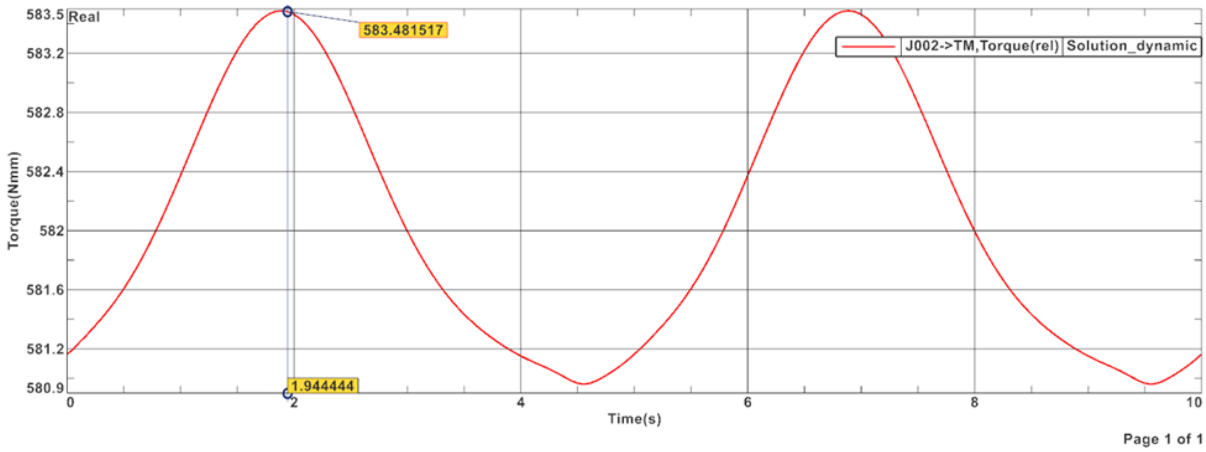
Torque Plots

In order to find the maximum and minimum torques acting on the joints, the plots are taken from the dynamic simulations of the mechanism.



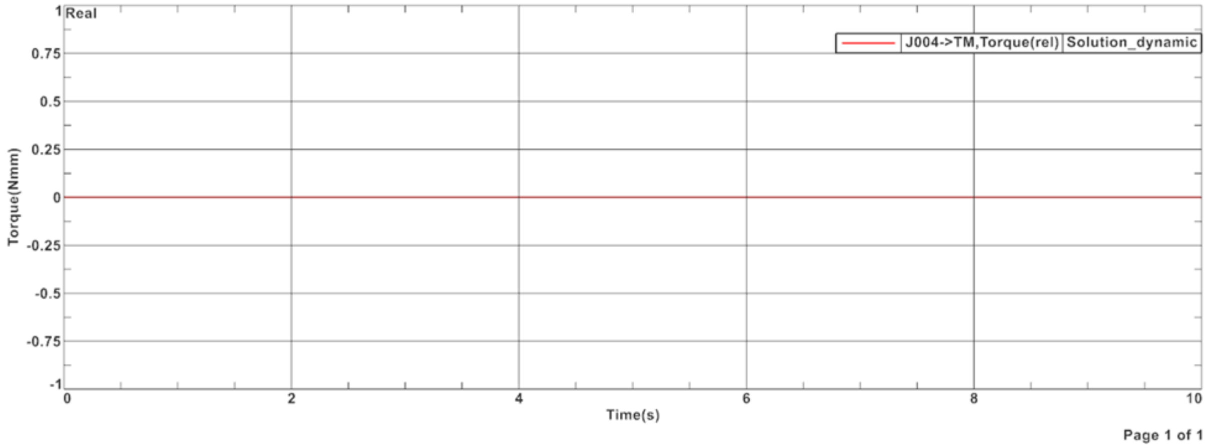
Torque Plot for Joint A

The maximum and minimum torque acting on Joint A are 875.45 Nmm and 10 Nmm respectively.



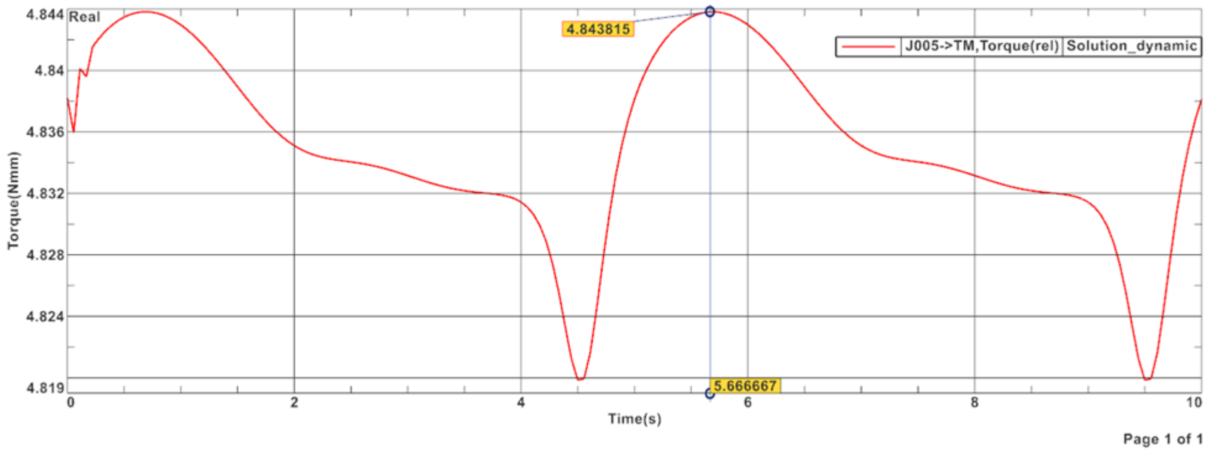
Torque Plot for Joint D

The maximum and minimum torque acting on Joint D are 583.48 Nmm and 580.9 Nmm respectively. There is a more or less same amount of torque acting on Joint D during the runtime.



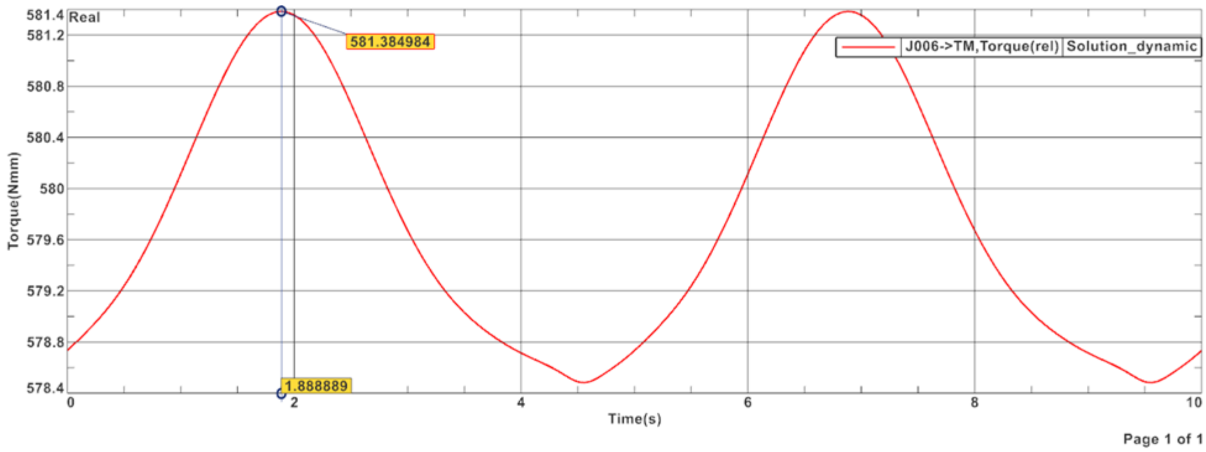
Torque Plot for Joint G

There are no torque acting on Joint G.



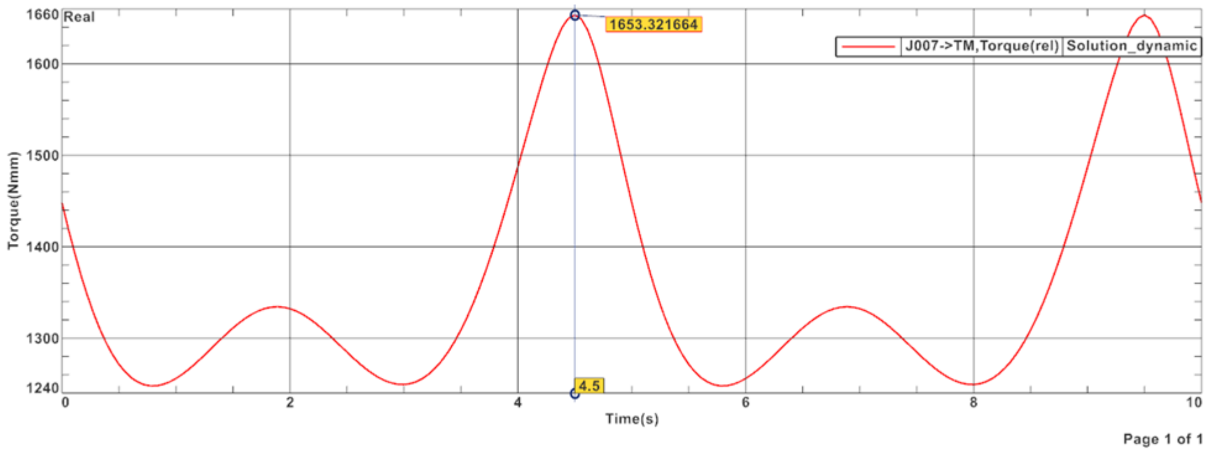
Torque Plot for Joint F

The maximum and minimum torque acting on Joint F are 4.844 Nmm and 4.82 Nmm respectively. Compared to the Joint A and Joint D, there is not much torque acting on this joint.



Torque Plot for Joint B

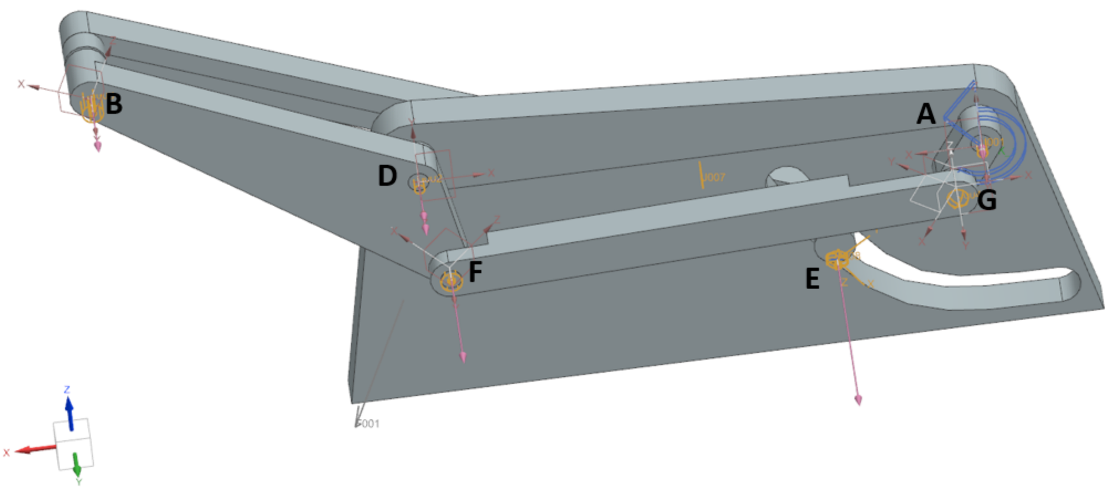
The maximum and minimum torque acting on Joint B are 581.38 Nmm and 578.5 Nmm respectively.



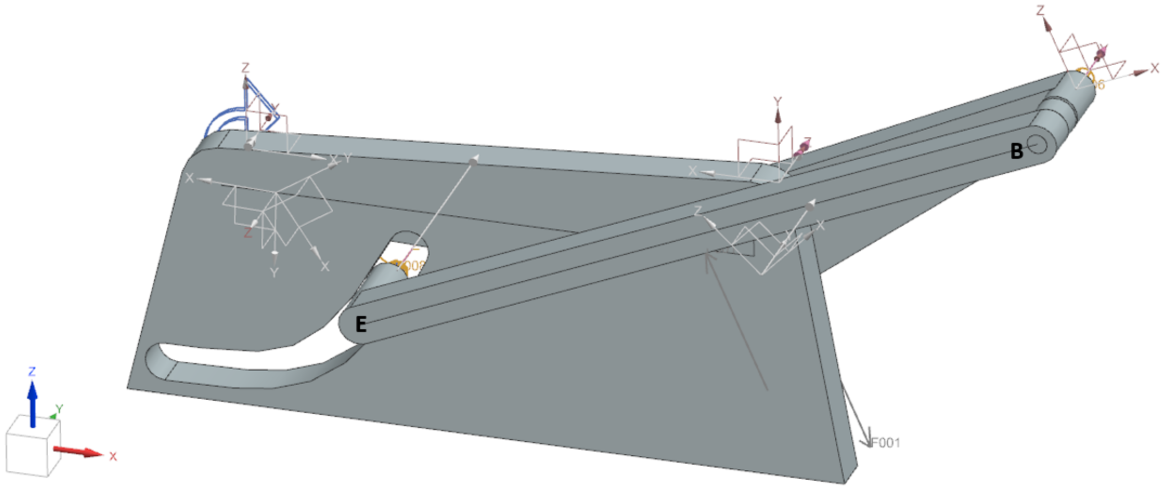
Torque Plot for Mechanism Holder Attached To The Ground

The maximum and minimum torque acting on Mechanism Holder Attached To The Ground are 1653.32 Nmm and 1250 Nmm respectively. Mechanism Holder Attached To The Ground experiences the greatest torque magnitude of all the joints in this mechanism.

FEM Report

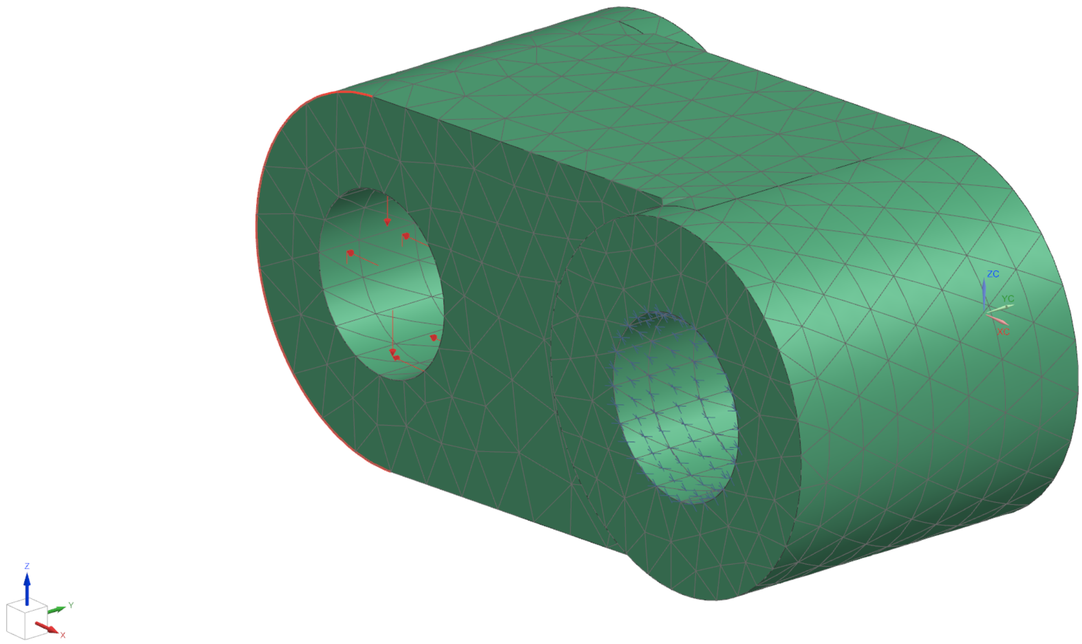


Updated mechanism design structure front-side.

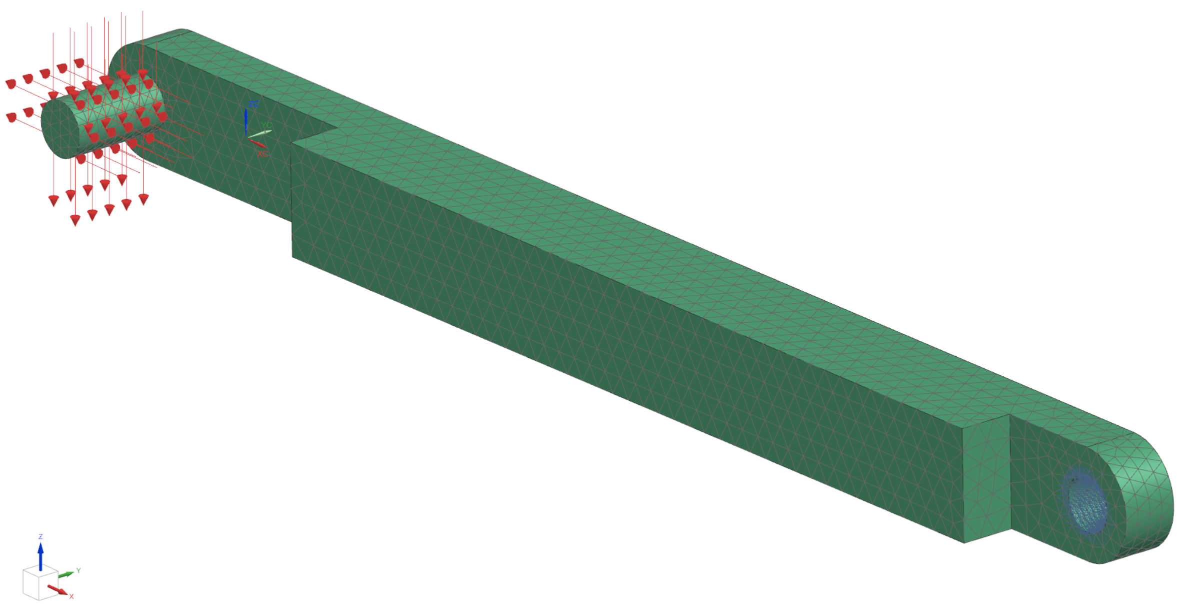


Updated mechanism design structure back-side

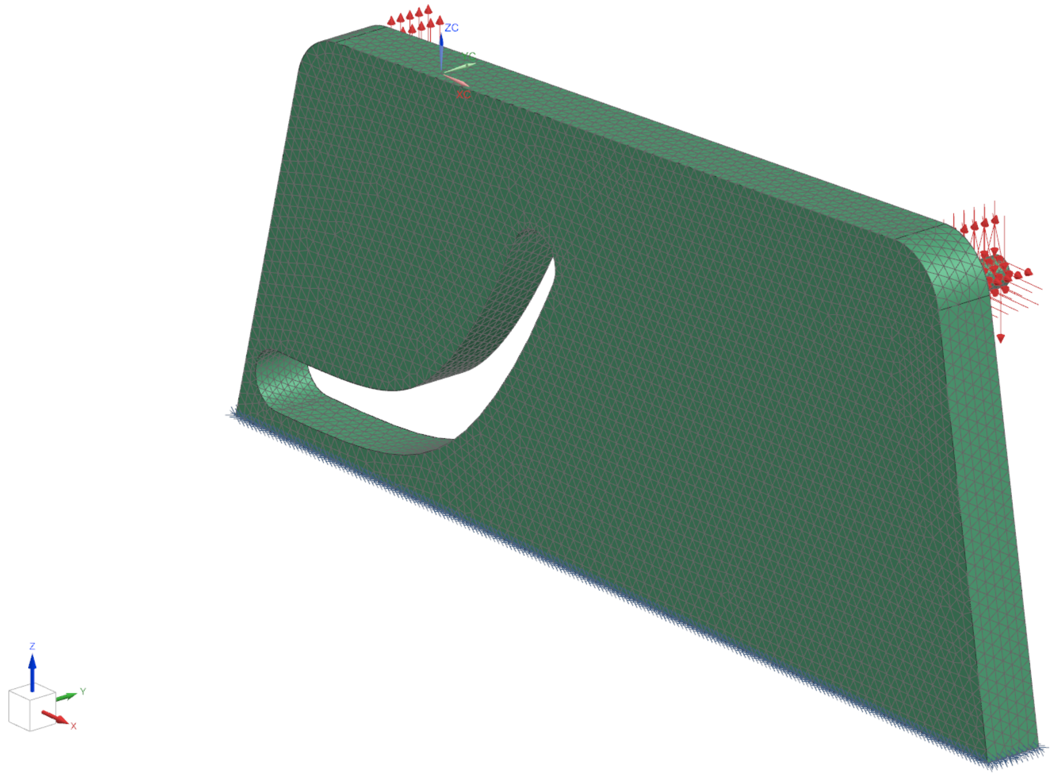
Materials and FEM models for all parts



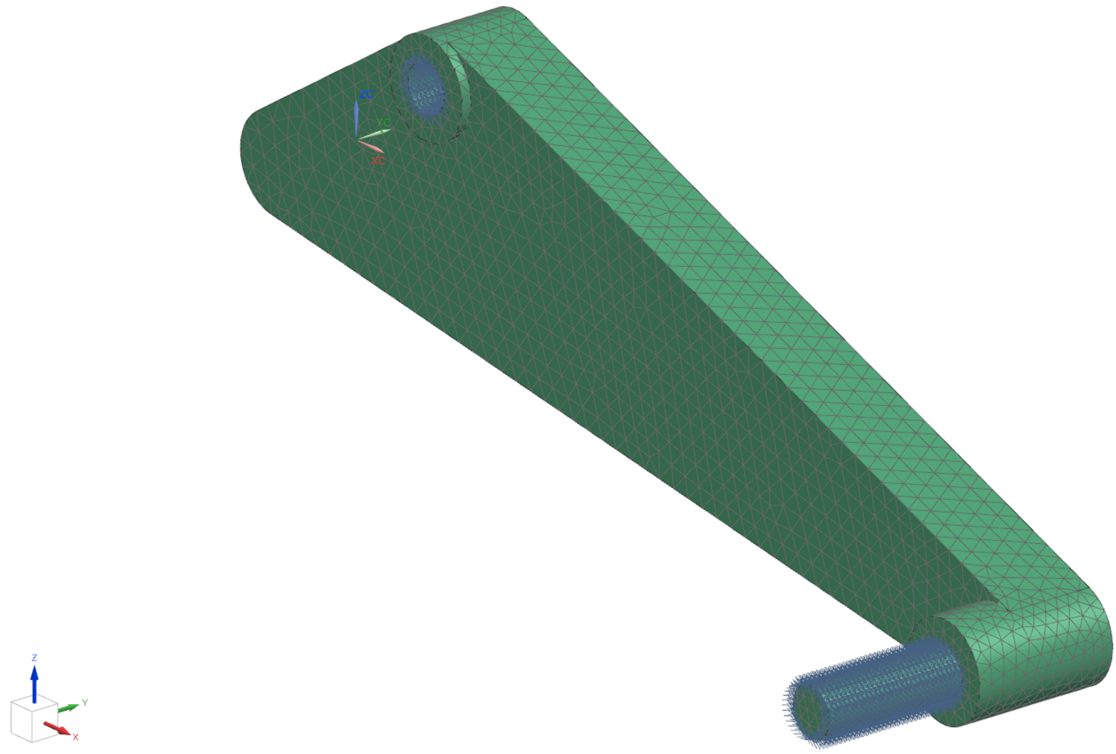
Short Crank FEM Model



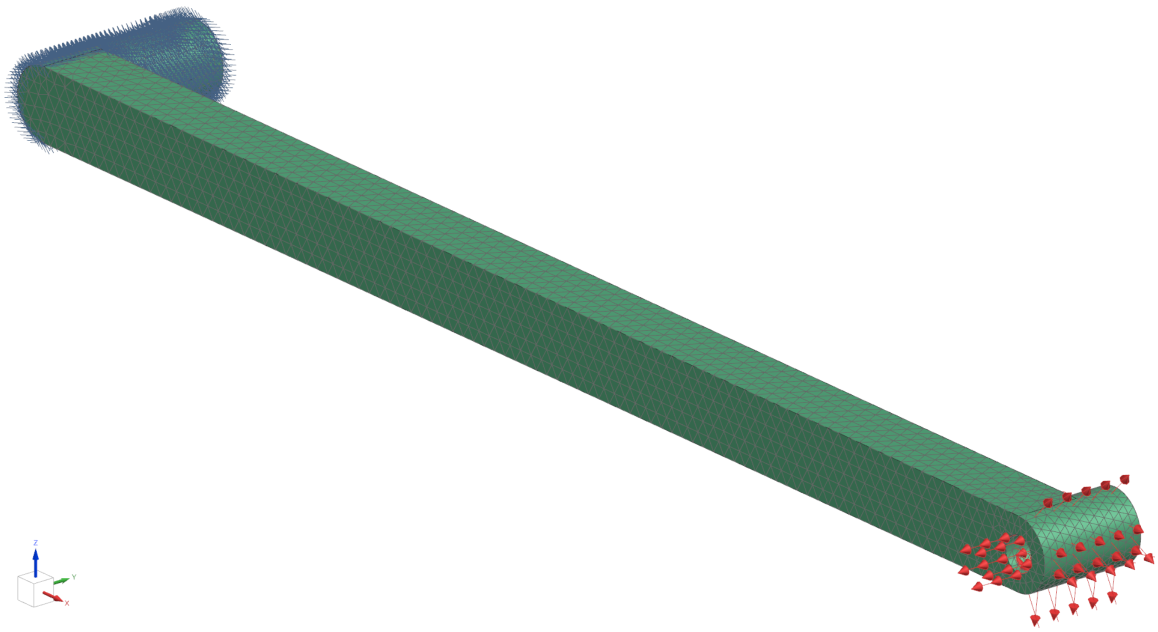
Long Crank FEM Model



Ground body FEM Model



Triangle Part FEM Model



Knife Part FEM Model

Mesh Sizes Used for the Parts

Part	Mesh Size (mm)
Short Crank	2
Long crank	2
Triangle	2
Knife Part	2
Ground Part	2

Maximum Displacement and Stress in Parts for Different Cases

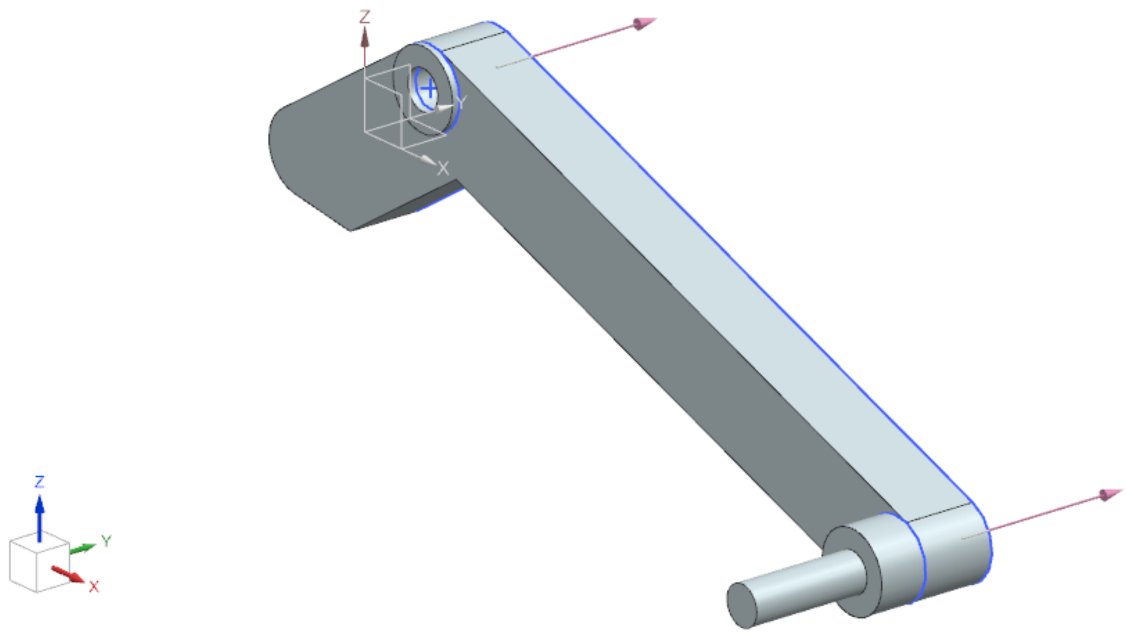
Part	Case	Maximum Displacement (mm)	Maximum Stress (MPa)
Short Crank	A free	1.726e-05	16.59
	G free	4.539e-06	7.544
Long crank	G free	7.241e-03	331.37
	F free	3.532e-04	71.29
Triangle	F free	5.715e-05	105.51
	D free	1.230e-04	41.42
	B free	9.744e-05	88.18
Knife Part	B free	1.171e-03	38.91

	E free	1.997e-03	28.35
Ground Part	A free	1.172e-04	126.20

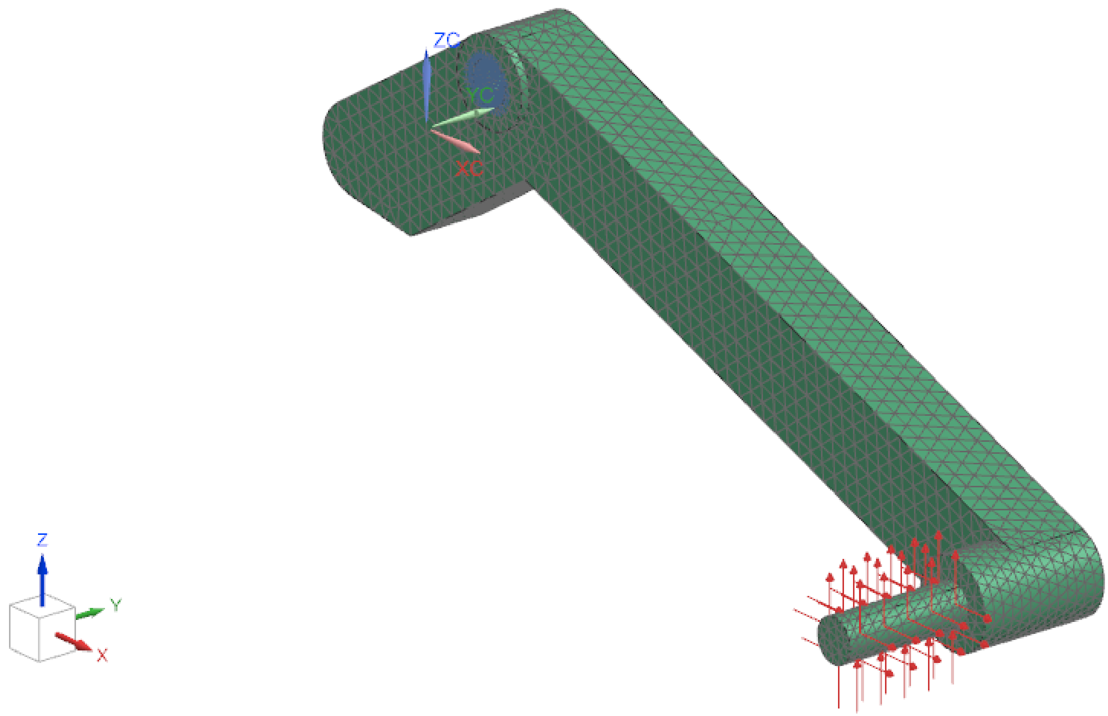
Simulation result comparison

Part	Criteria	NX	Solidworks
Short Crank (G free)	Maximum Displacement (mm)	4.539e-06	3.507 e-4
	Maximum Stress (MPa)	7.544	5.83
Long crank (F free)	Maximum Displacement (mm)	3.532e-04	2.216 e-2
	Maximum Stress (MPa)	71.29	20.03
Triangle (B free)	Maximum Displacement (mm)	9.744e-05	8.383 e-3
	Maximum Stress (MPa)	88.18	11.90
Knife Part (E free)	Maximum Displacement (mm)	1.997e-03	9.847 e-2
	Maximum Stress (MPa)	28.35	14.35
Ground Part (A free)	Maximum Displacement (mm)	1.172e-04	2.908 e-2
	Maximum Stress (MPa)	126.20	162.0.

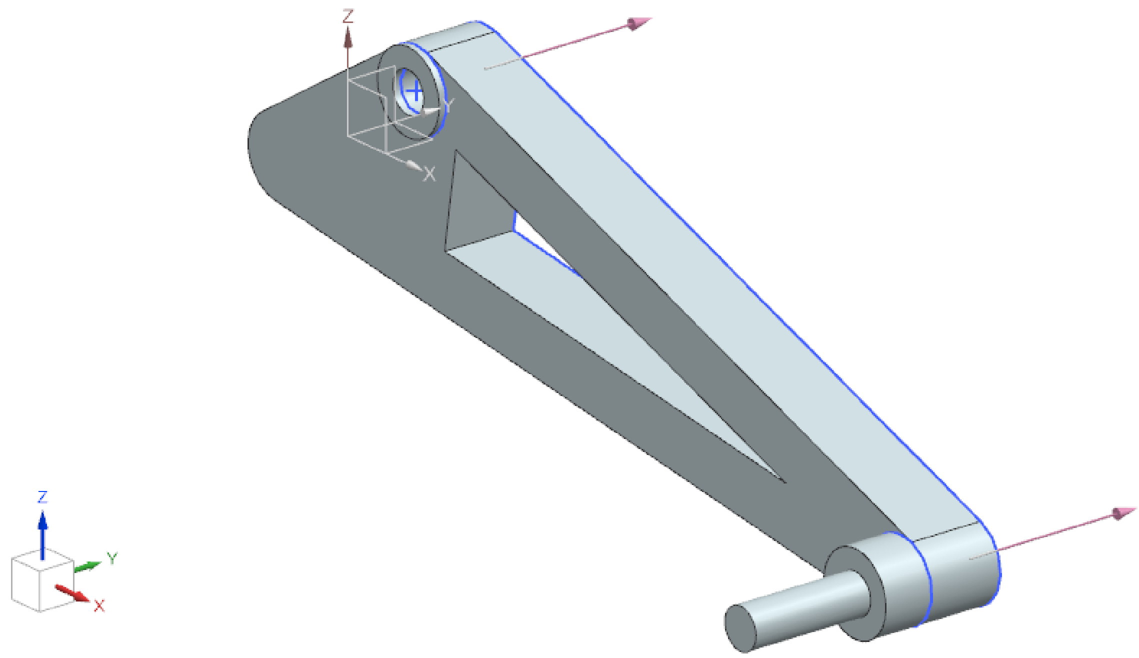
Different shape testing



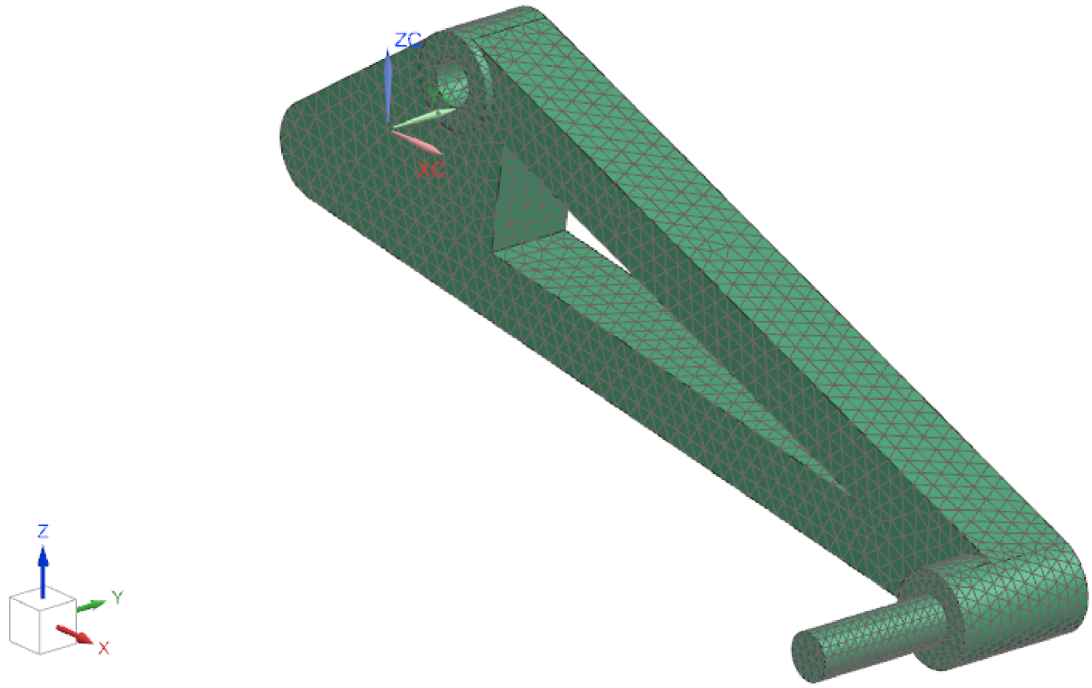
New Design for Triangle Model Part (1)



FEM Mesh model for Triangle Model Part (1)



New Design for Triangle Model Part (2)



FEM Mesh model for Triangle Model Part (2)

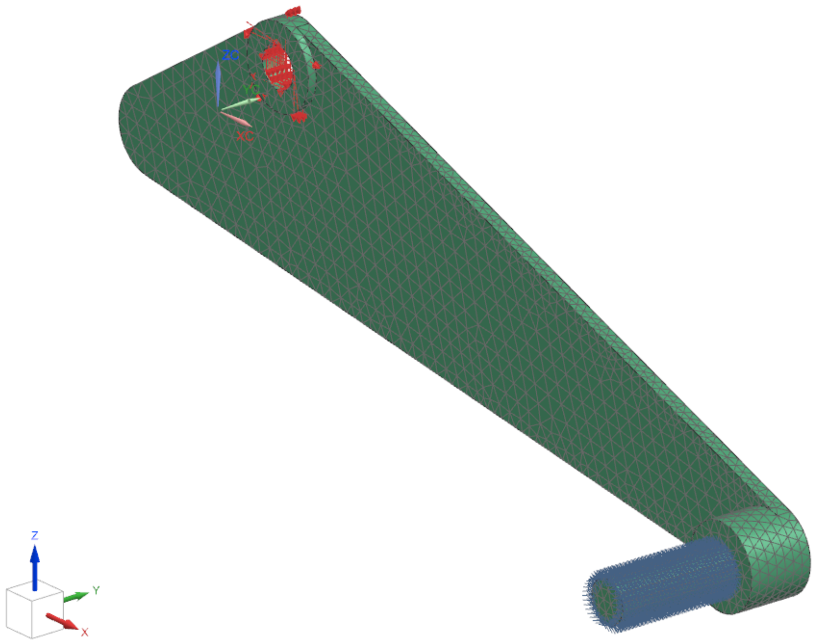
Maximum Displacement and Stress in Parts with new shapes

Constraint	Criteria	Shapes		
		Original Design	New model 1	New model 2
F free	Maximum Displacement (mm)	5.715e-05	6.365e-03	4.309e-03
	Maximum Stress (MPa)	105.51	54.91	55.84
D free	Maximum Displacement (mm)	1.230e-04	2.878e-03	2.573e-03
	Maximum Stress (MPa)	41.42	55.50	55.06
B free	Maximum Displacement (mm)	9.744e-05	0.0181	1.107e-02
	Maximum Stress (MPa)	88.18	16.66	16.51

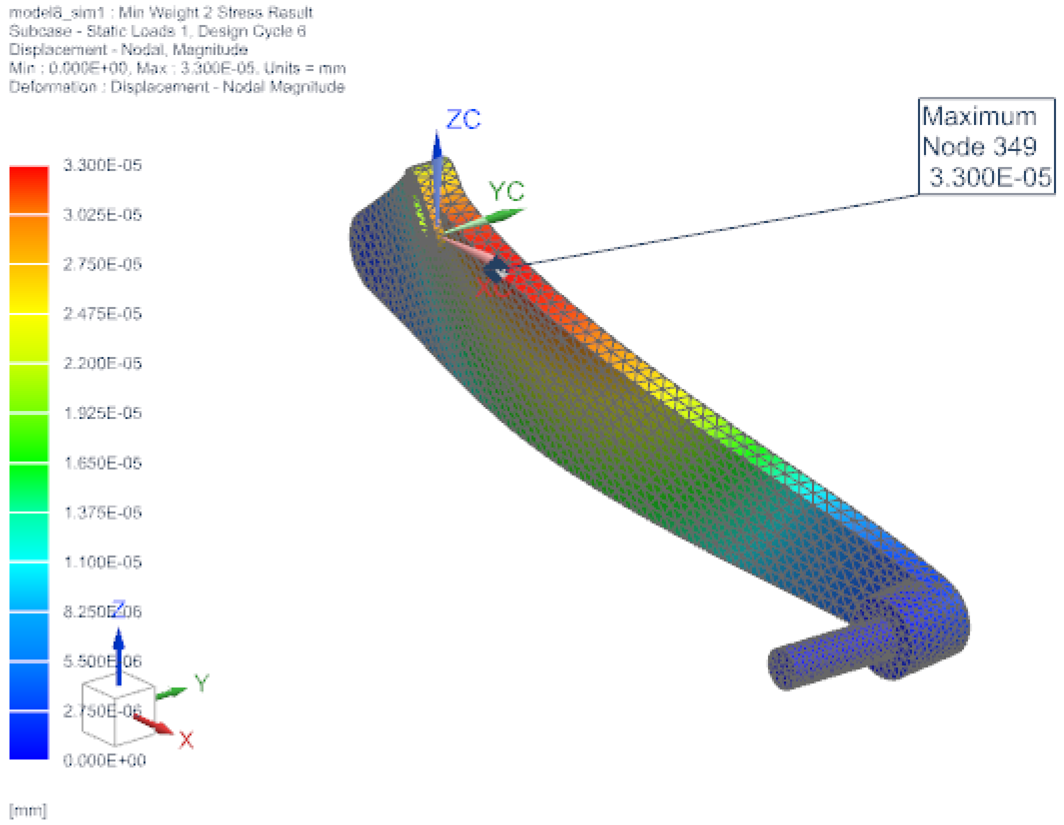
Design Objective Function Results

	0	1	2	…	12	13	14
Minimum Weight [N]	1.19E+09	9.54E+08	8.42E+08	-	3.4E+08	3.29E+08	3.22E+08
	Design Variable Results						
"model8"::p20=-1	-1	-2.7	-3.50421	-	-7.1068	-7.18374	-7.23967
	Design Constraint Results						
Upper Limit = 25.000000 [MPa]	22.477	24.243	20.114	-	21.494	22.389	22.848

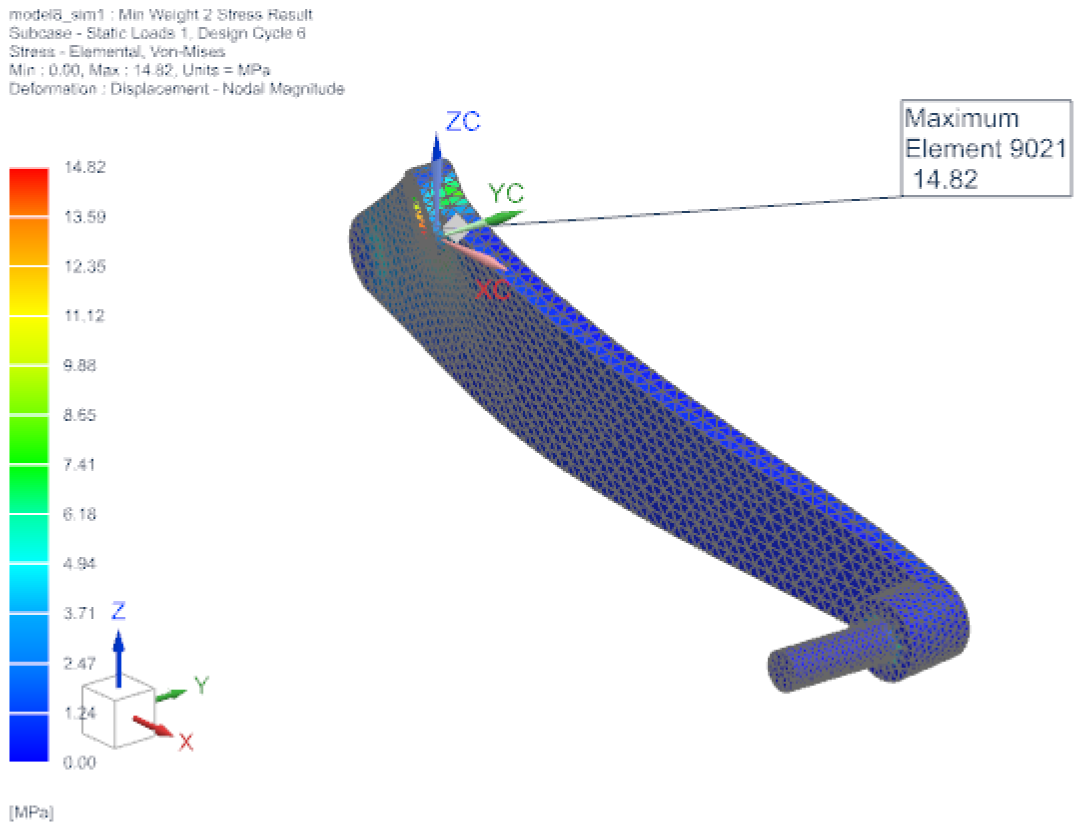
FEM Analysis on New Parts



Part file for the new FEM model



Maximum Displacement for Design Cycle 6



Maximum Stress for Design Cycle 6

Maximum Stress acting on optimized part

Case	Max Stress (MPa)
Original Configuration	41.42
Design Cycle 6	14.82
Difference	26.6
Percentage Difference	64%