MEC-E1060 - Machine Design

MBS Report - Meat Chopper

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Introduction

This week we decided on our final mechanism structure and joint location as well as proved that the mechanism is one degree of freedom using the Kutzbach criterion. We also built a skeleton model of our knife cutting mechanism and modeled the rods of the mechanism on top of the skeleton. Furthermore, we built dynamic and kinematic simulations in order to further verify the viability of our mechanism.

We had our first meeting of the week Monday 12.9 at Startup Sauna where we worked from 12-16. The second meeting took place on Tuesday 13.9 at Maarintie 8 where we started to extensively write the report and model the mechanism. This week Elias Puolakka Worked as the head report secretary. Next week San Vo will work as the head report secretary.

Selection of joints and Kutzbach kriterion

The Kutzbach criterion is also known as the mobility formula since it calculates the number of factors that characterize the configuration of a linkage from the number of links and joints and the degree of freedom at each joint.

We decided to continue the project with a dimensionally refined but functionally same mechanism as in the first week. So the joints and the rods are in the same positions but scaled in a more optimized way.

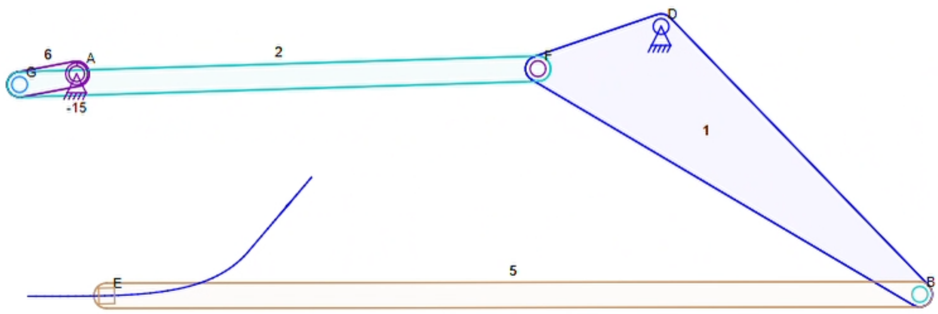

Image 1 The mechanism and its link positions.

The mechanism and its joints are as presented in Image 1. The Kutzbach criterion also known as the Chebychev–Grübler–Kutzbach criterion is presented in equation (1) and the resulting calculation for our mechanism, where n = 4, $j_1 = 2$, $j_2 = 2$, $j_3 = 1$, $j_4 = 1$ and $j_5 = 0$, is presented in equation (2).

$$M = 6 * (n - 1) - 5 * j1 - 4 * j2 - 3 * j3 - 2 * j4 - 1 * j5 \quad (1)$$

$$M = 6 * (5 - 1) - 5 * 2 - 4 * 2 - 3 * 1 - 2 * 1 - 1 * 0 = 1 \quad (2)$$

Thus we have proven that the mechanism has one degree of freedom according to the Chebychev–Grübler–Kutzbach criterion. Now let's for a second assume that a perfectly rigid position shaft of an electric motor is connected to the point A of image 1. In this case, in image 1 we would then, hypothetically, have a 0 degrees of freedom system of joints and beams.

Skeleton models

Skeletal modeling is a method for facilitating centralized design requirements and producing components that correspond to those criteria (it is a sort of top-down design). A streamlined interface between components in an assembly is offered by skeleton models. Engineers can now start with a concept, deconstruct the design into skeleton models, and then piece together components in accordance with those skeletons.

We decided that the length of the mechanism would be roughly 30 cm and designed the rod lengths of our models accordingly. In table 1 we display the measurements of individual members' names, which are based on the points as they are displayed in picture 1. Images 2-5 display the wireframe of our skeleton model.

Table 1 Lengths of mechanism members.

Part points (Image 1)	A-G	G-F	F-D-B	B-E	E
Length (mm)	13	119	101	187	-

Results of kinematic simulations

By computing the position, speed, and acceleration of points (such as joint positions) and bodies, kinematics analyses the motion of the mechanism. It is necessary to have a mechanism of mobility of zero in order to conduct a kinematic analysis. Practically speaking, this implies that the user must specify the proper joint types and make sure that all necessary degrees of freedom are addressed. The kinematic simulations displayed the motion and position of our model more accurately than the previous phases of our project which helps to further verify the motional soundness of our model. Images 2-5 present the skeleton model at different positions.

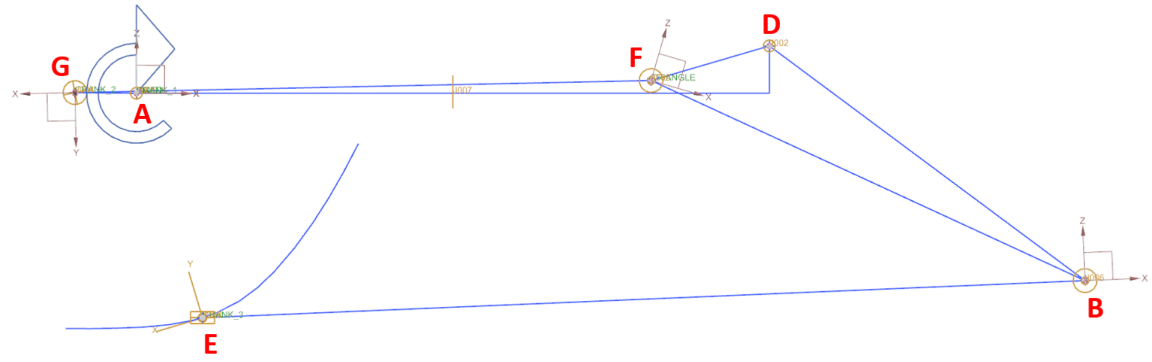

Image 2 The mechanism and its link positions.

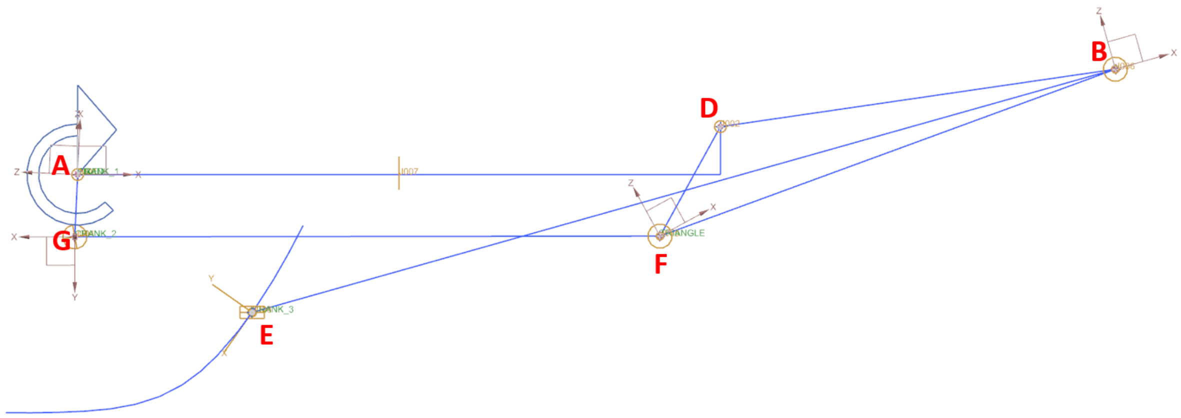

Image 3 The mechanism and its link positions.

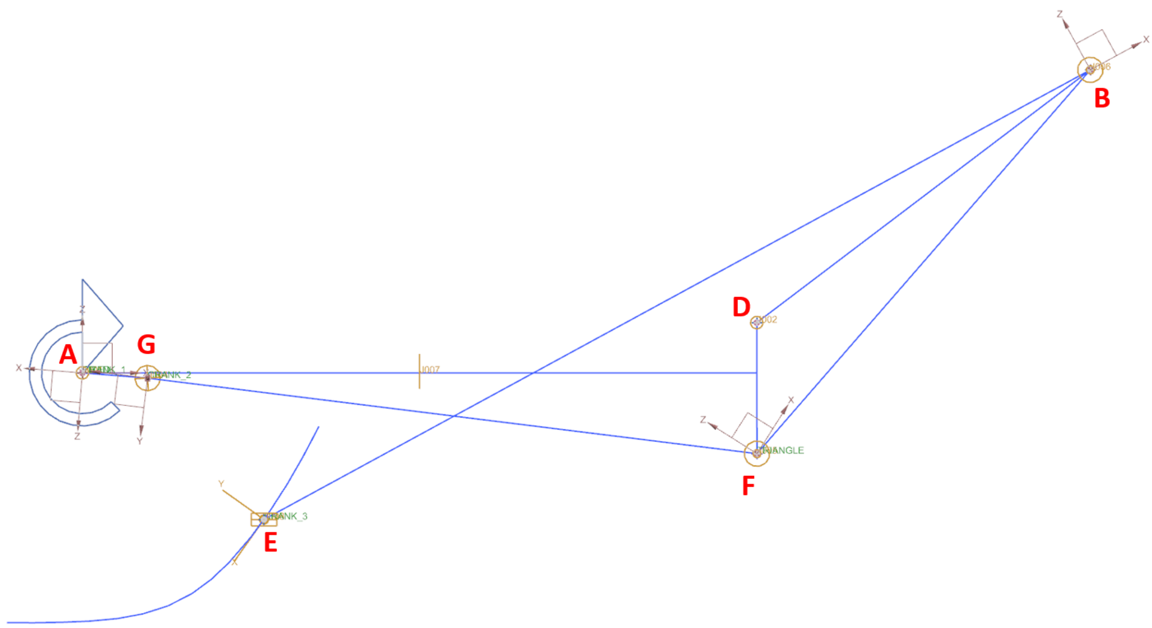

Image 4 The mechanism and its link positions.

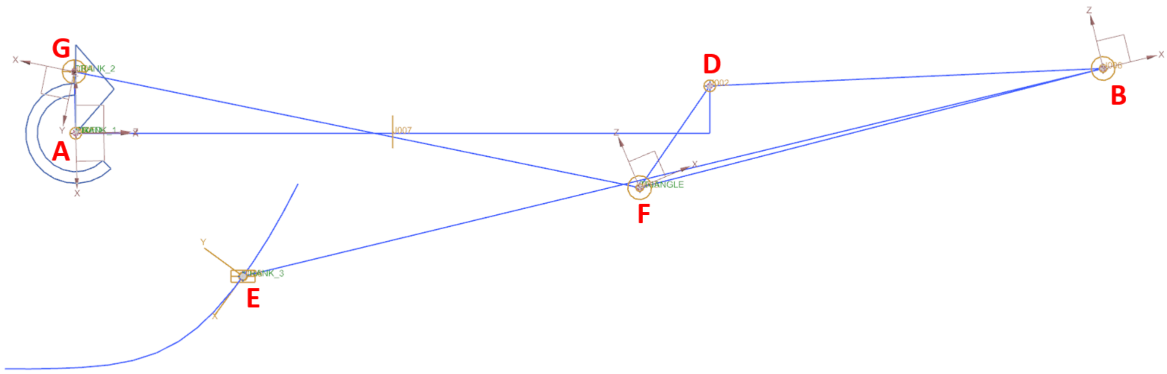

Image 5 The mechanism and its link positions.

Simplified models and results from dynamic simulations

Dynamics, in contrast to kinematics, incorporates forces into simulations. This makes it possible to calculate forces within the mechanism in addition to location solving. Friction models may also be added to the simulations. When the modality level of the mechanism is taken into account, the dynamic solution is significantly more forgiving. For instance, if no forces are affecting "within" the canvas, the same four-bar mechanism with cylindrical joints can be solved and a reasonable result can be reached. Pictures 6-9 are used to display our skeleton model with the motion bodies' beams (CAD-models of parts) included.

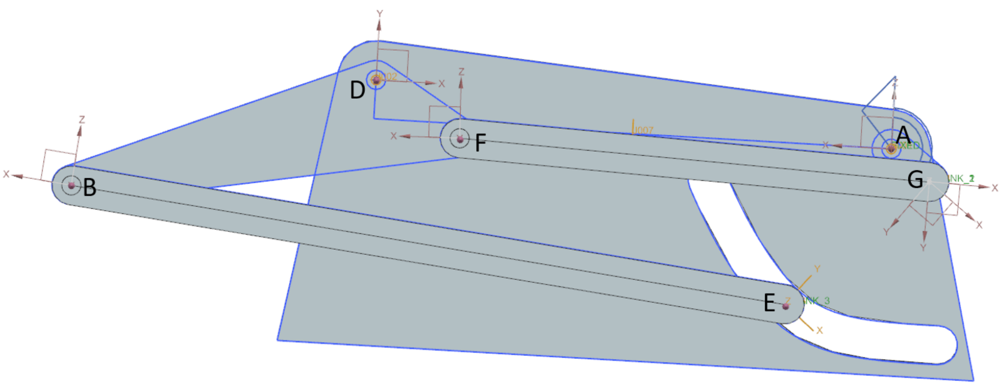

Image 6 The mechanism and its link positions.

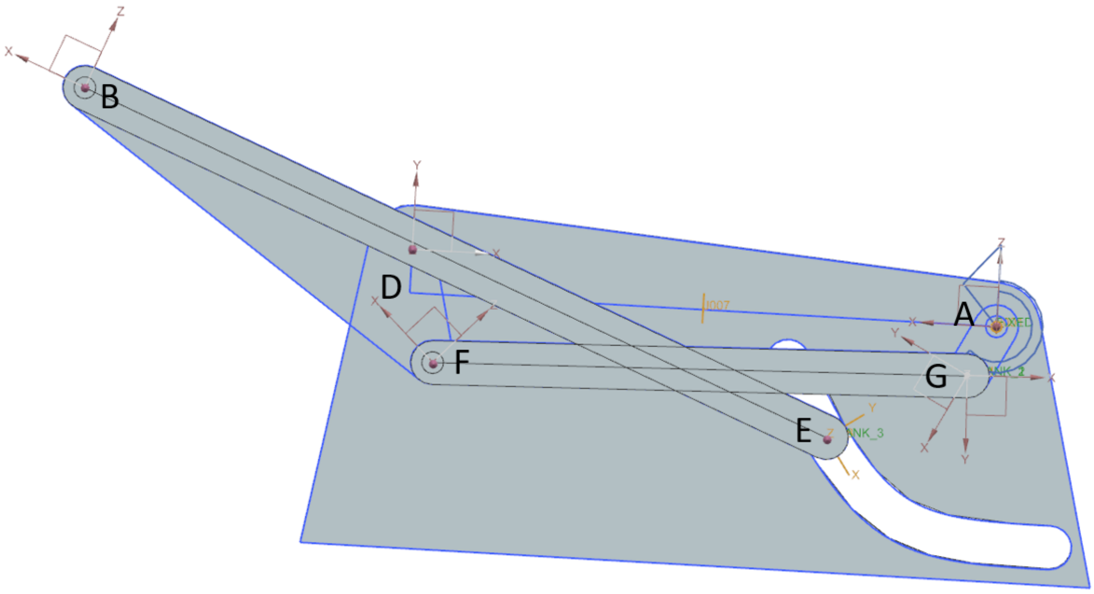

Image 7 The mechanism and its link positions.

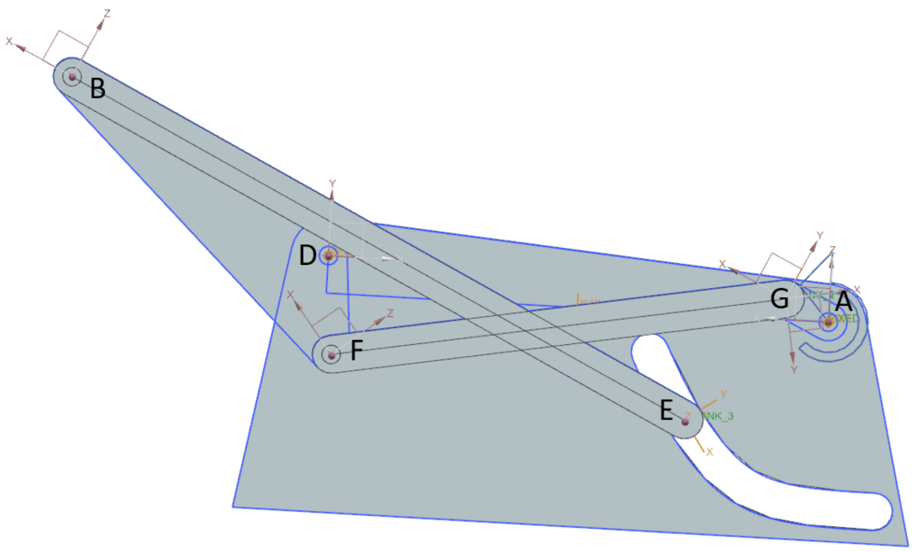

Image 8 The mechanism and its link positions.

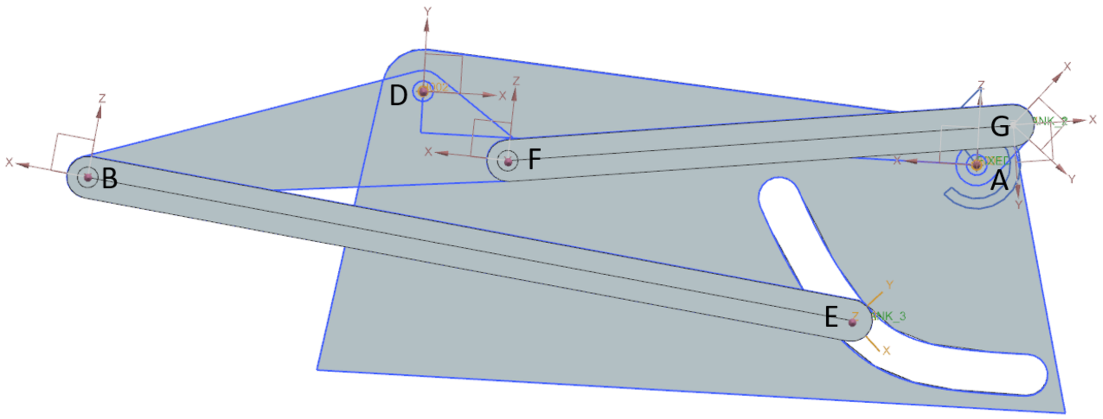

Image 9 The mechanism and its link positions.

Requirements

Table 3 Lengths of mechanism members.

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

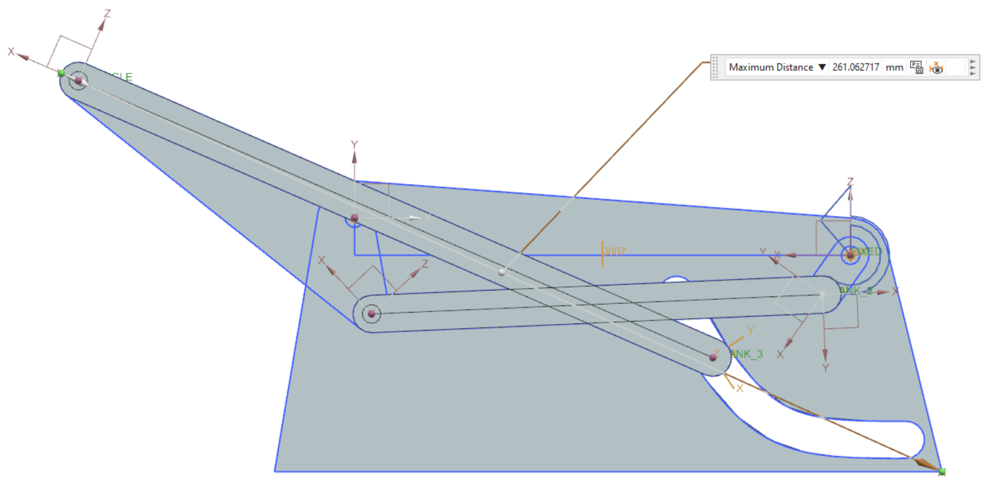

Image 10 Highest distance within the mechanism.

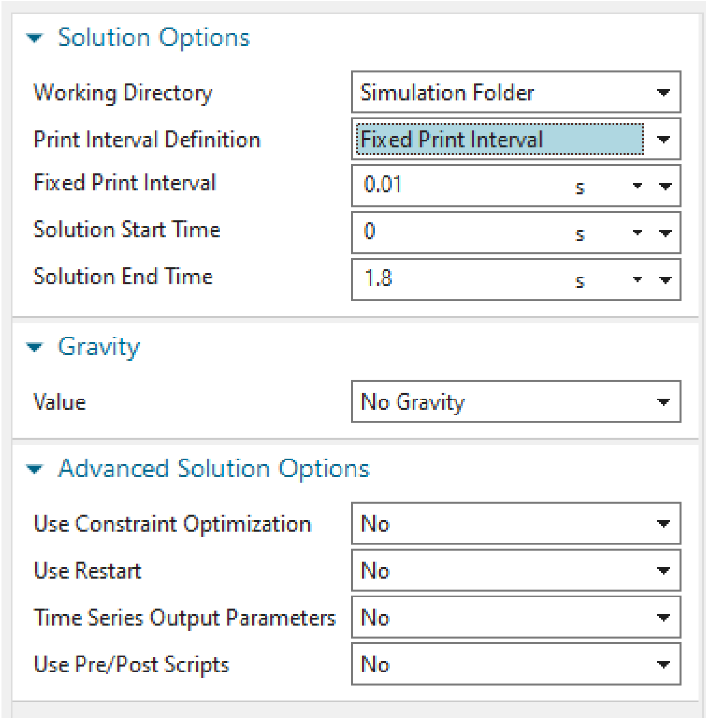

Image 11 Simulation time settings.

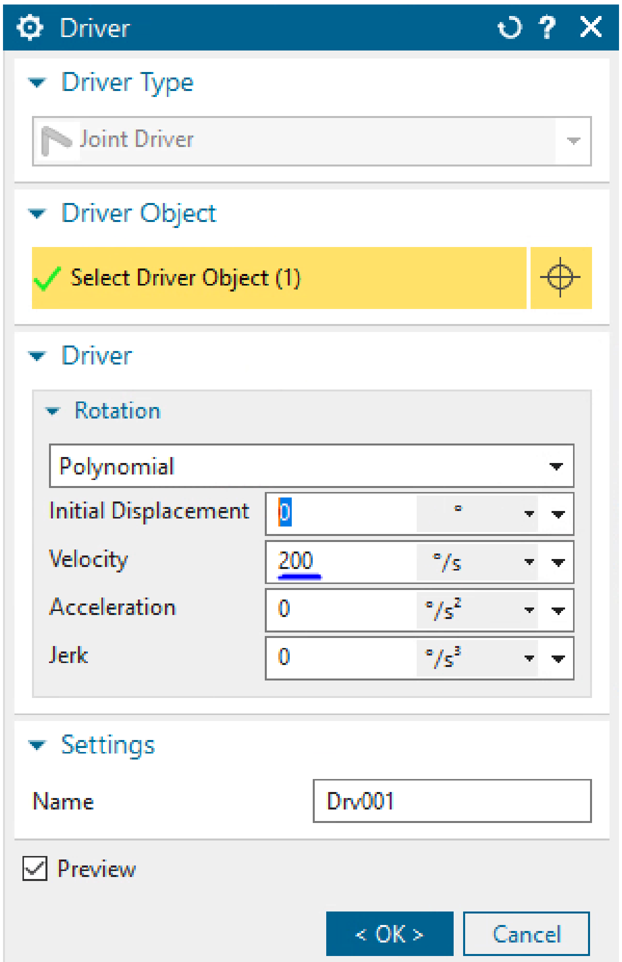

Image 12 Actuator speed settings.

Table 3 presents the requirements our group developed during week one. Our requirement was that the mechanism is under 30 cm in maximum length. According to our CAD model the maximum possible distance for the device is 26.1 cm, which is below the maximum length allowed by the requirements and thus fits the criteria. Next we decreased the simulation time to 1.8 seconds and capped the sample time to 0.1 seconds to ensure stable time in simulation and to meet the time requirement as seen in image 11. Furthermore our team increased the motor speed to 200 degrees/s as seen on image 12. Thus now our model fills all the requirements.

Displacement Plots

The displacement plots for each and every joint are shown in the images 13-18 below. The values should not be different for both kinematic and dynamic simulations.

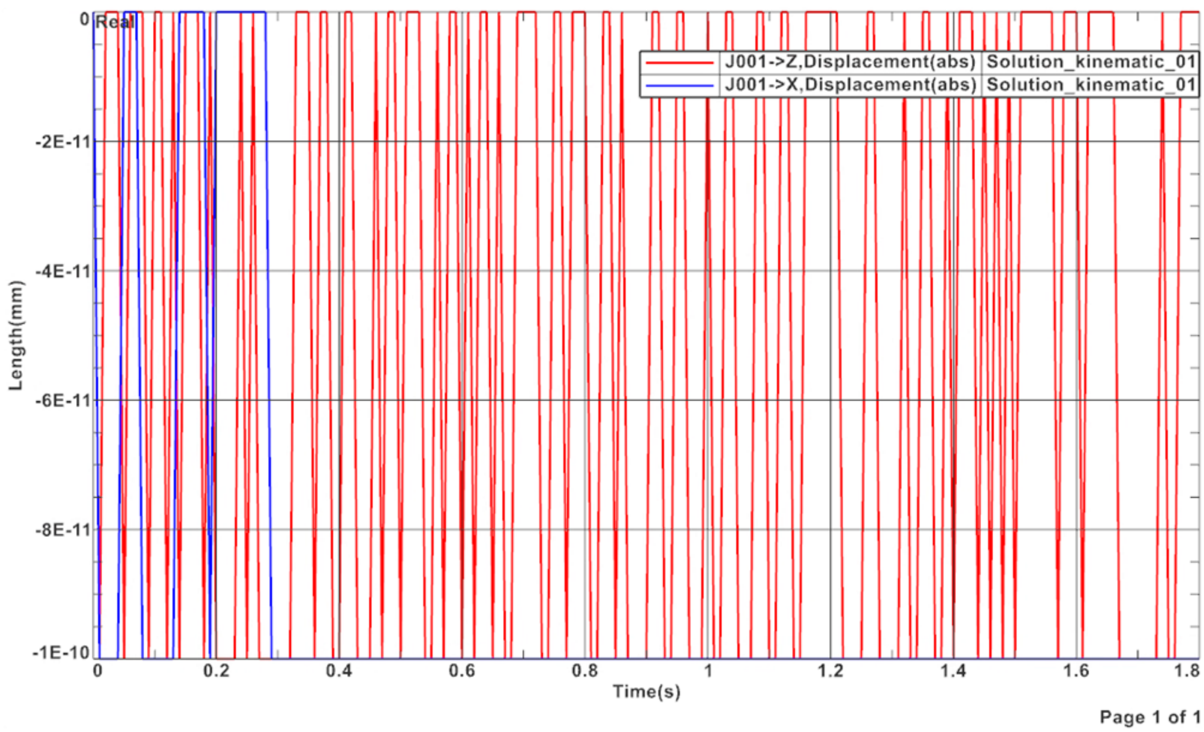

Image 13: Displacement Plot for Joint A

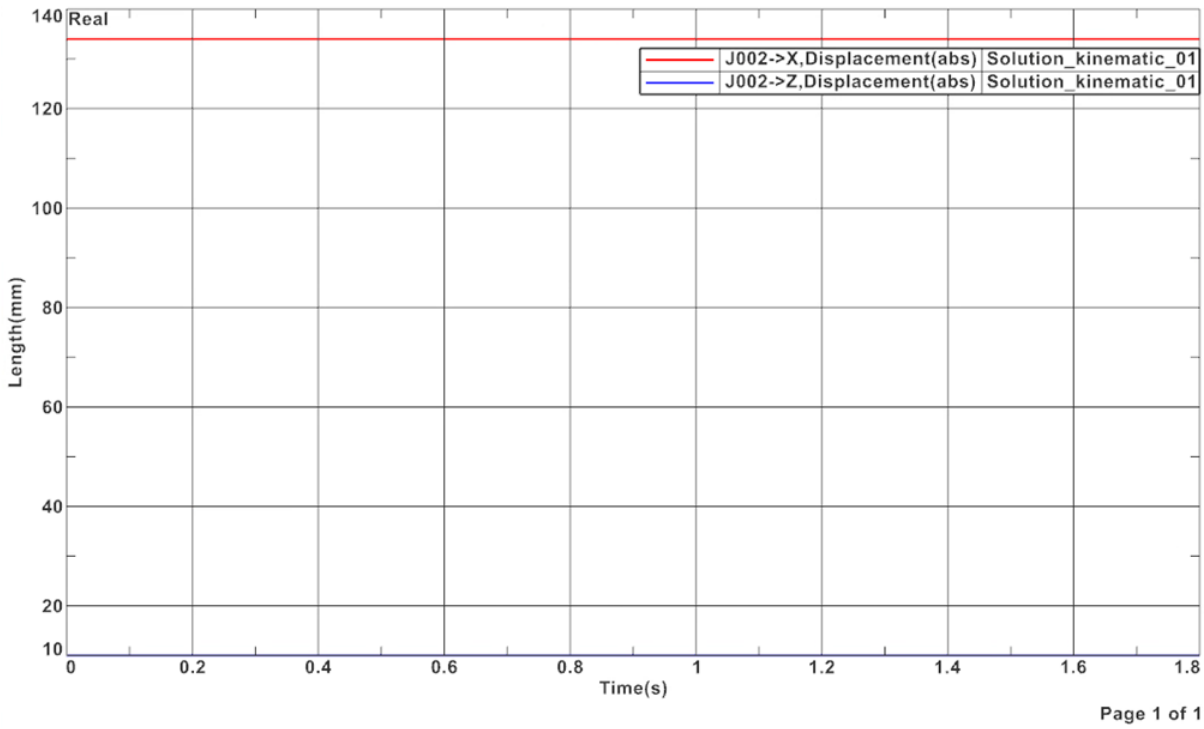

Image 14: Displacement Plot for Joint D

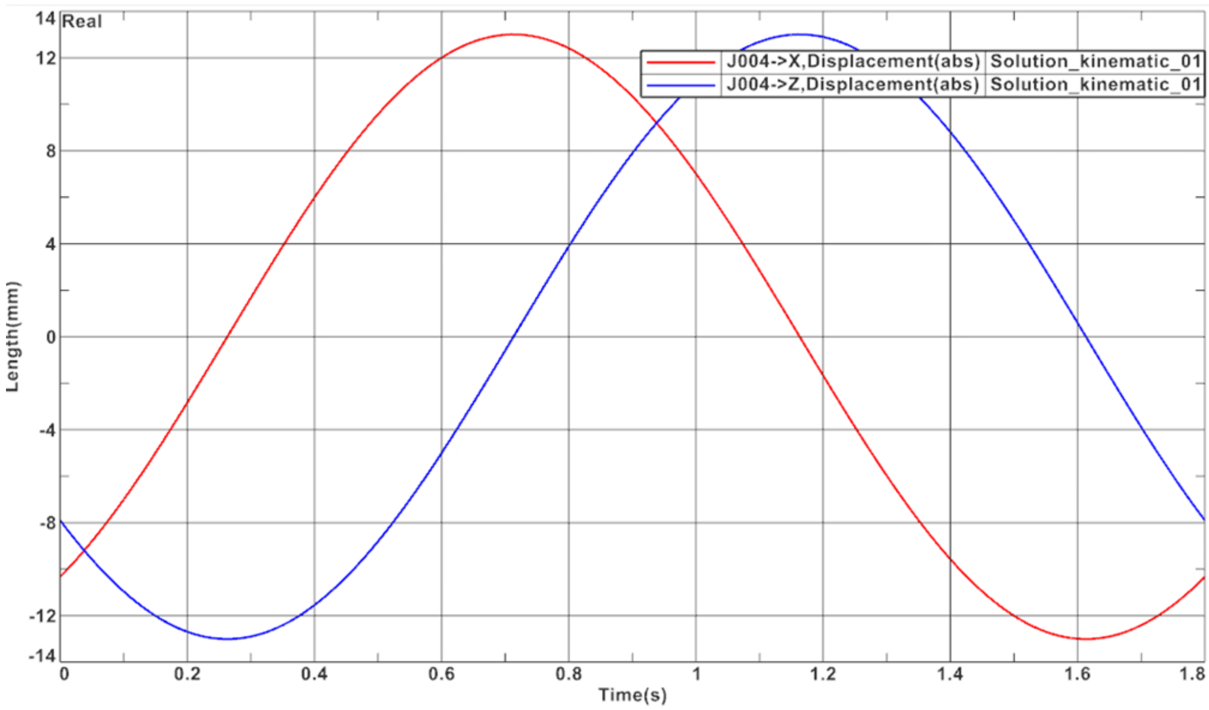

Image 15: Displacement Plot for Joint G

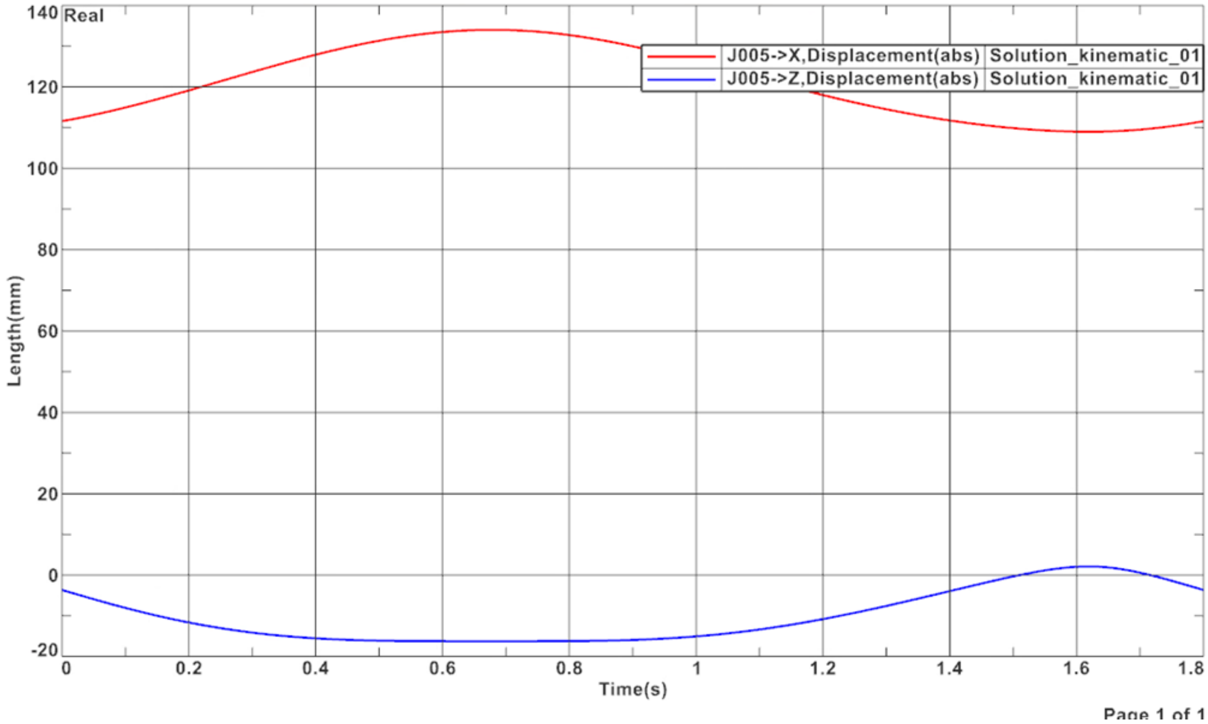

Image 16: Displacement Plot for Joint F

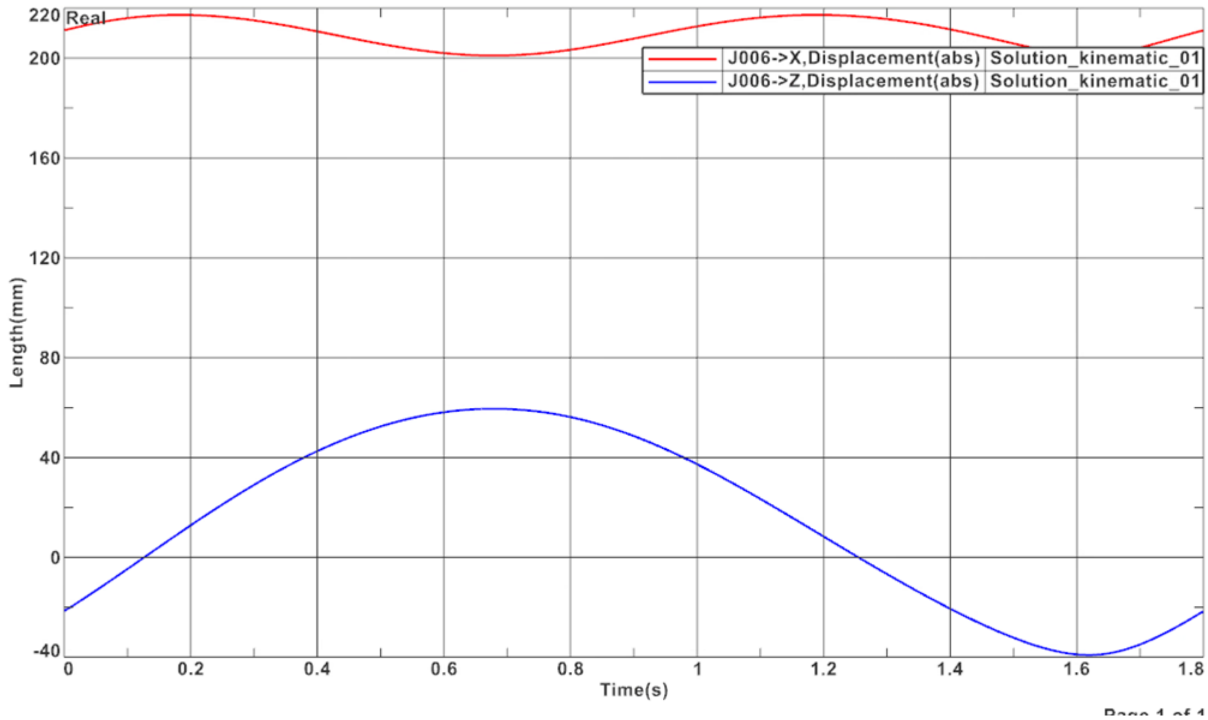

Image 17: Displacement Plot for Joint B

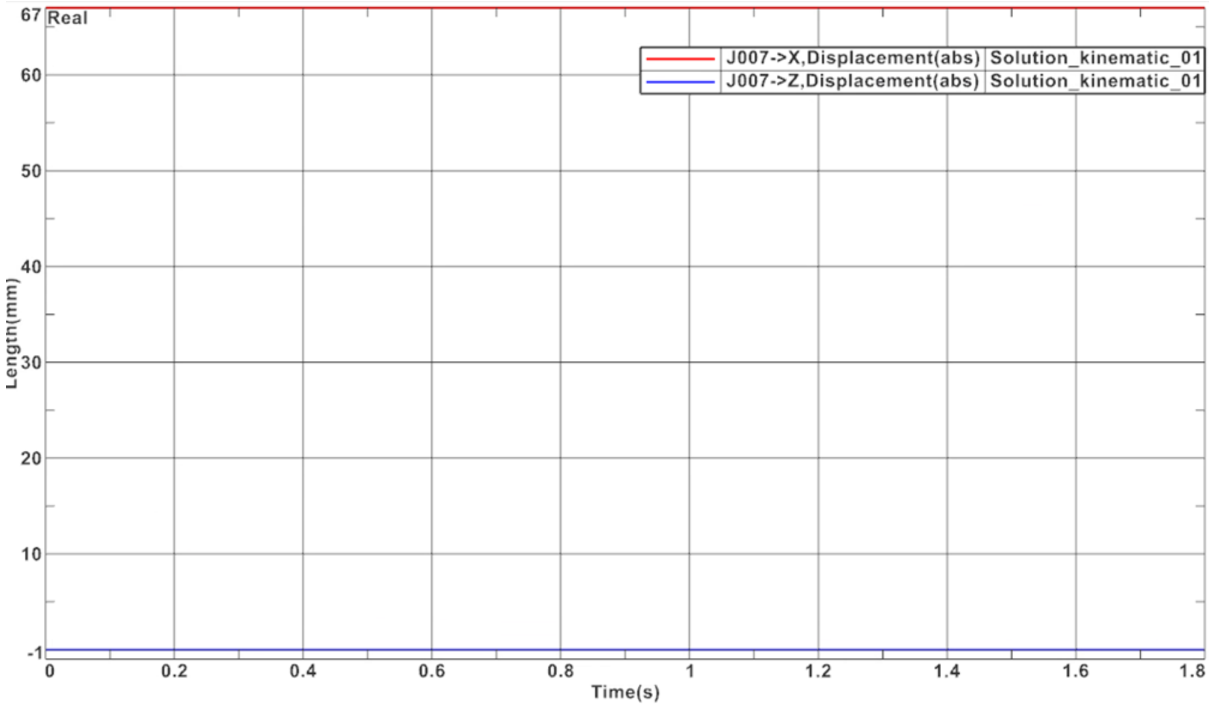

Image 18: Displacement Plot for Mechanism Holder Attached To The Ground

Velocity Plots

The velocity plots for each and every joint are shown in the images 19-24 below. 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.

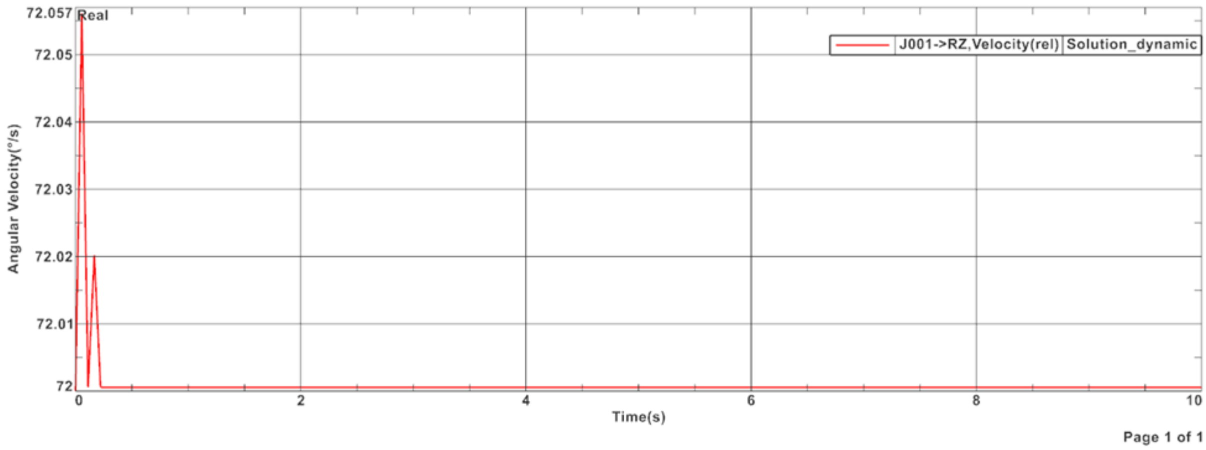

Image 19: Angular Velocity Plot for Joint A

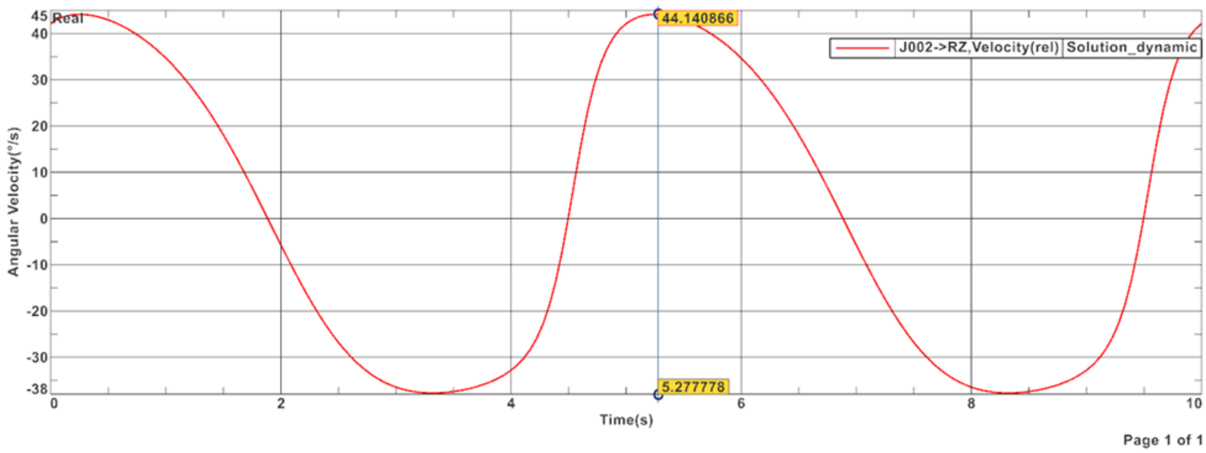

Image 20: Angular Velocity Plot for Joint D

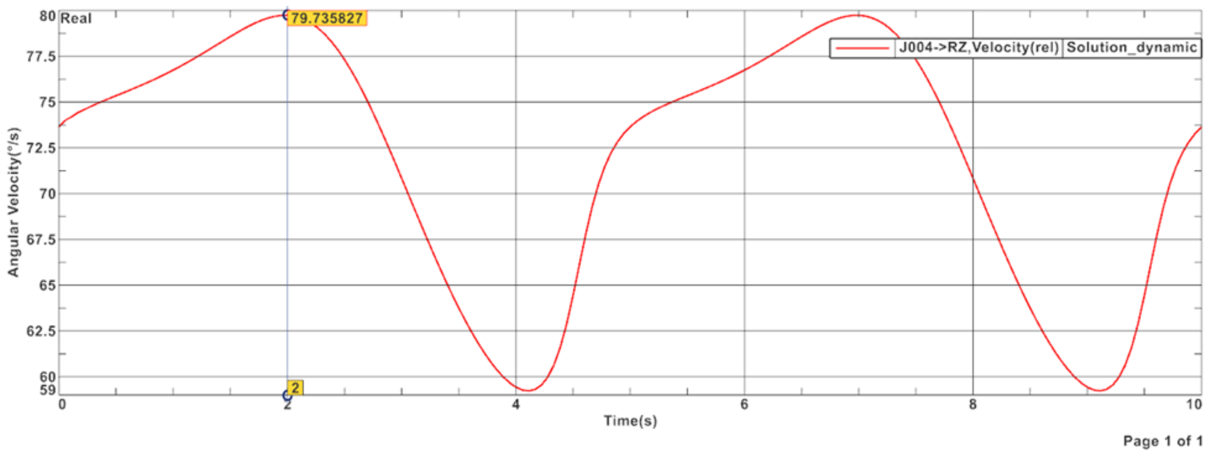

Image 21: Angular Velocity Plot for Joint G

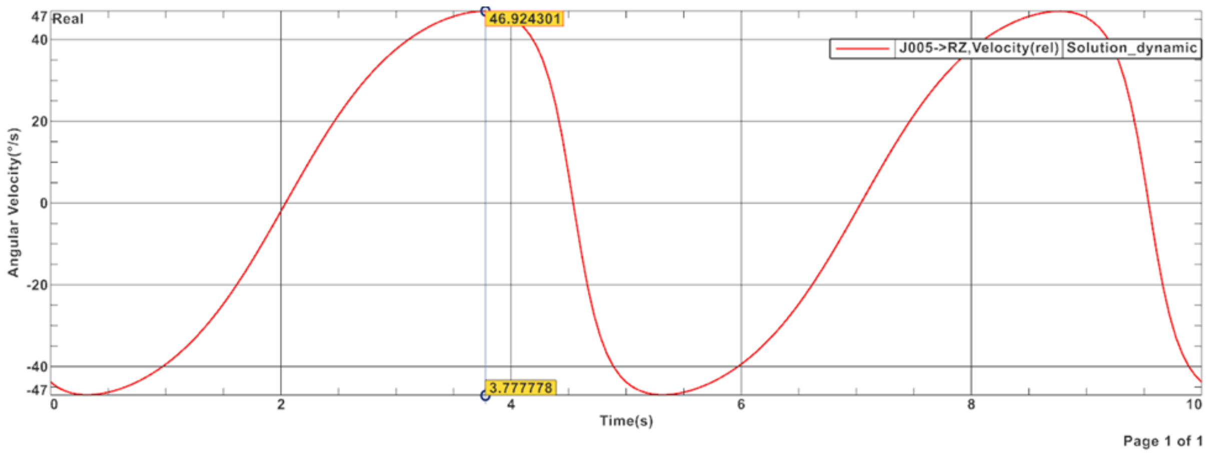

Image 22: Angular Velocity Plot for Joint F

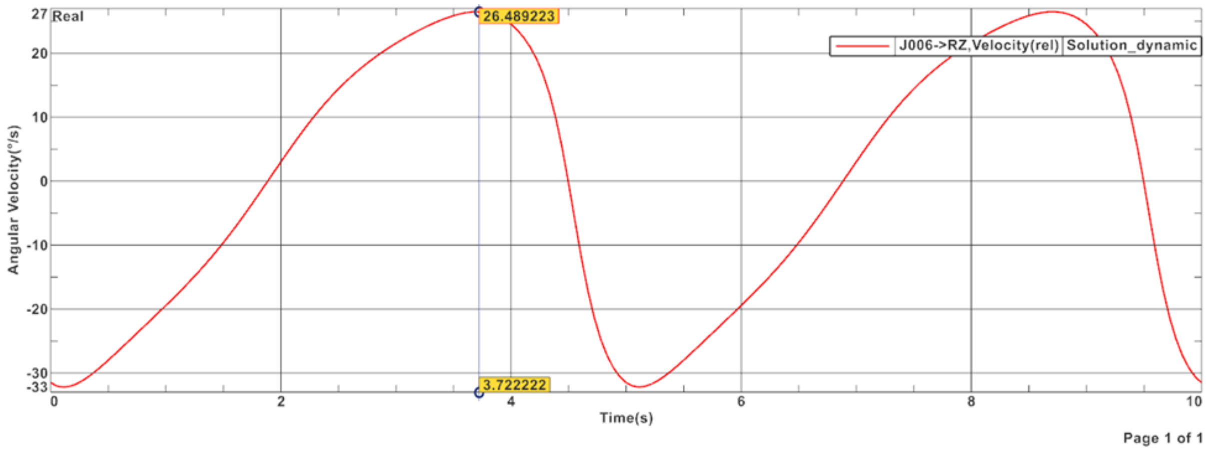

Image 23: Angular Velocity Plot for Joint B

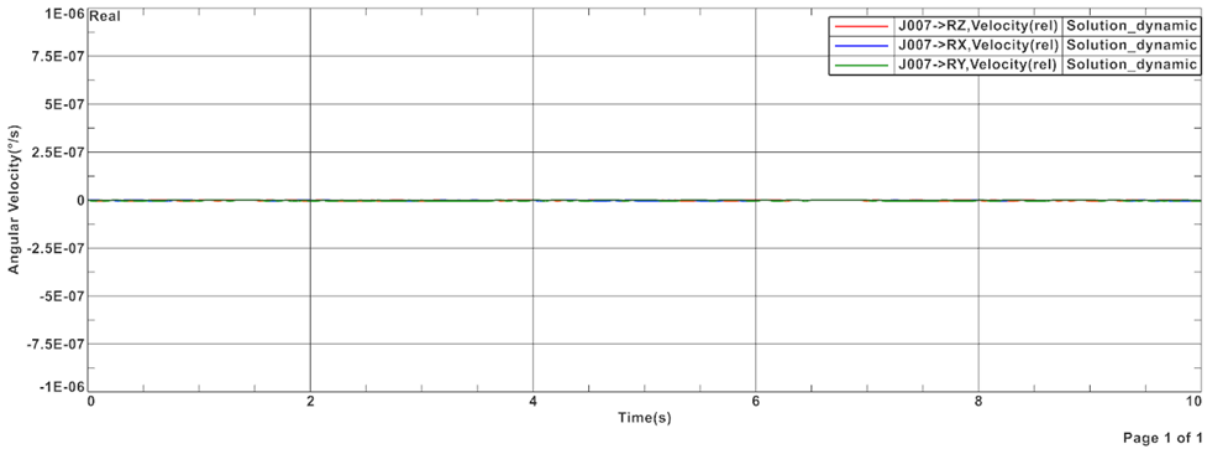

Image 24: Angular Velocity Plot for Mechanism Holder Attached To The Ground

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. The force plots are shown in images 25-30 below.

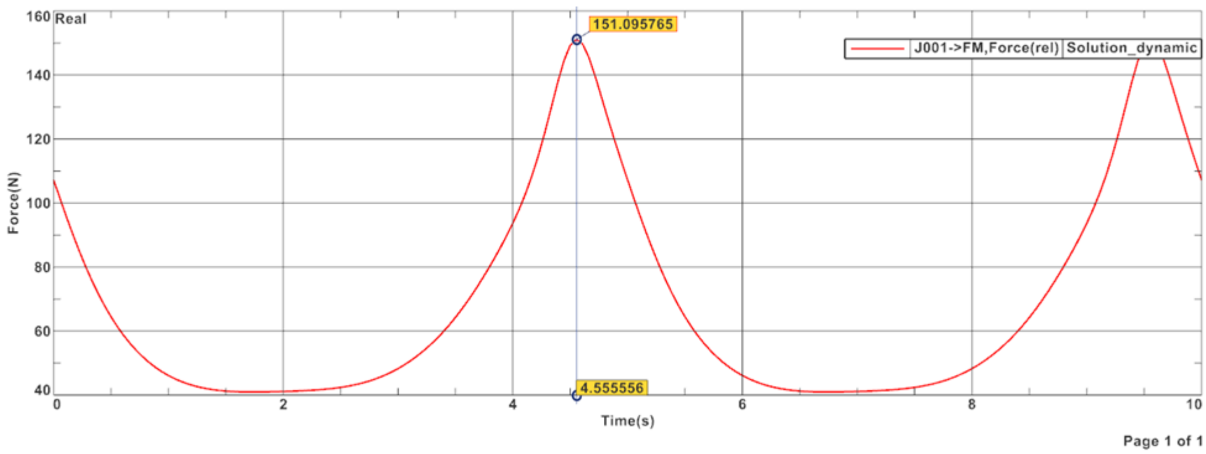

Image 25: Force Plot for Joint A

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

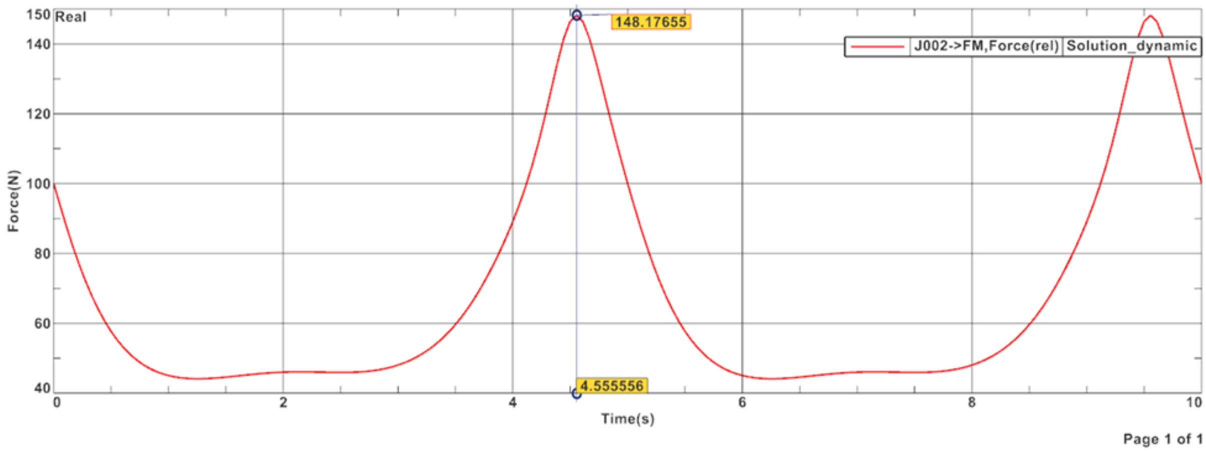

Image 26: Force Plot for Joint D

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

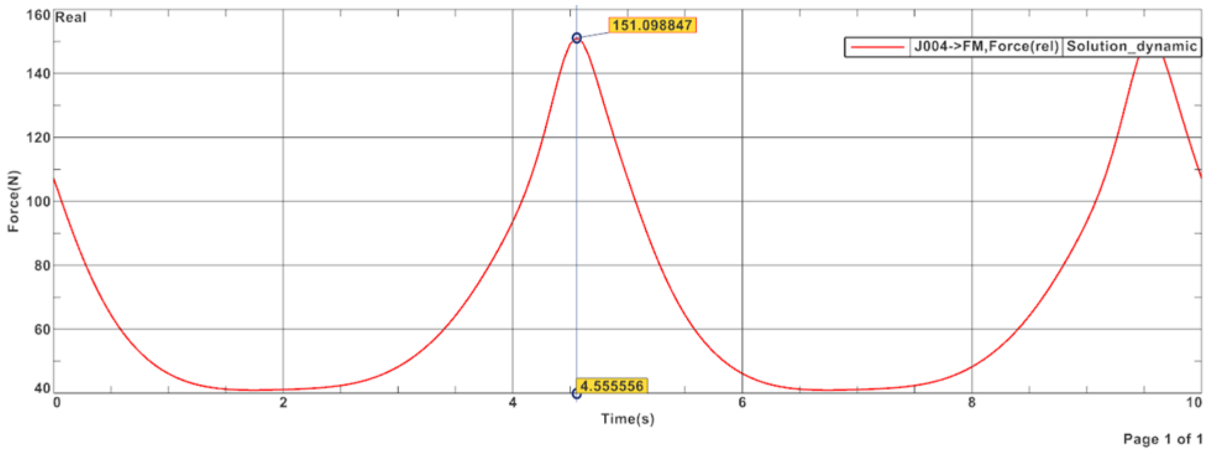

Image 27: Force Plot for Joint G

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.

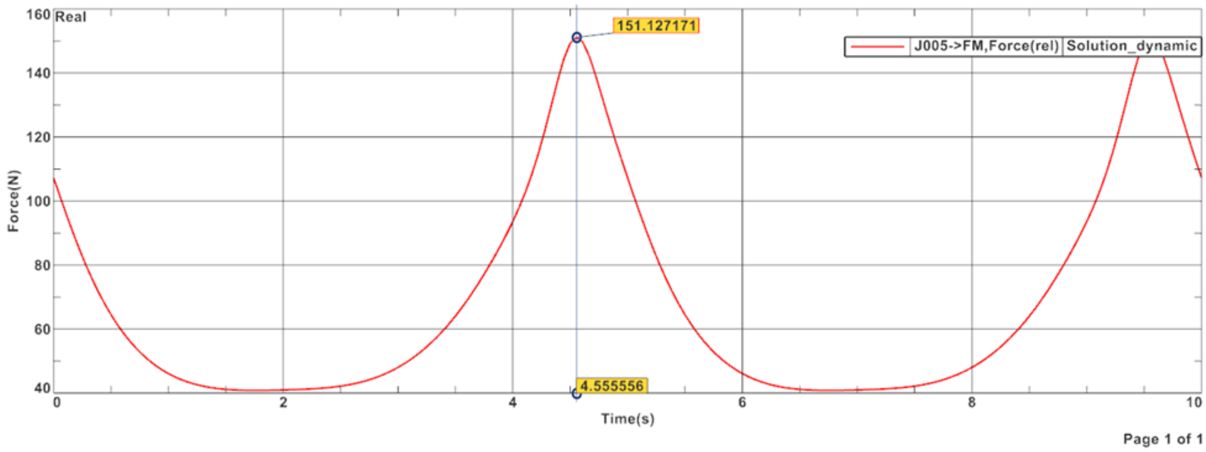

Image 28: Force Plot for Joint F

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

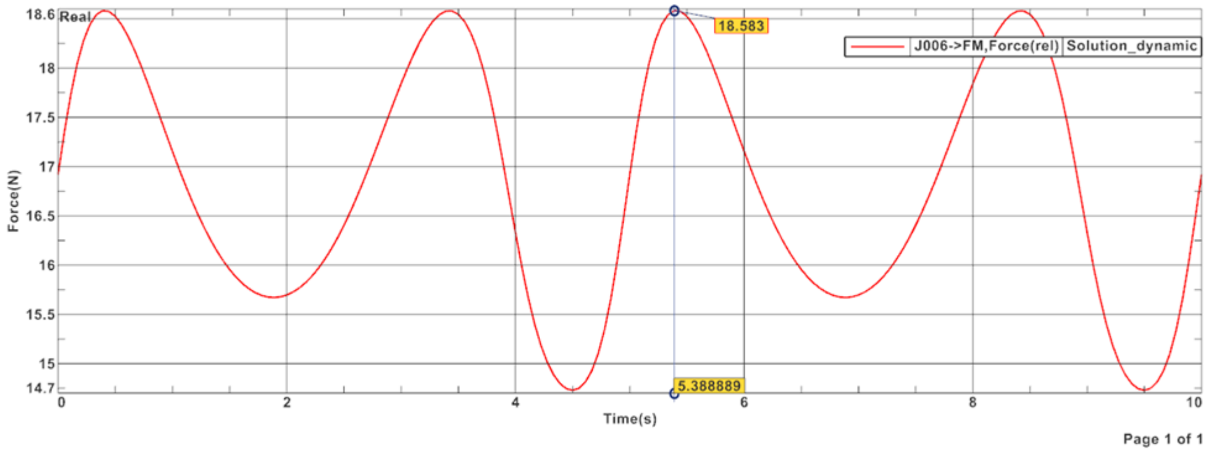

Image 29: Force Plot for Joint B

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.

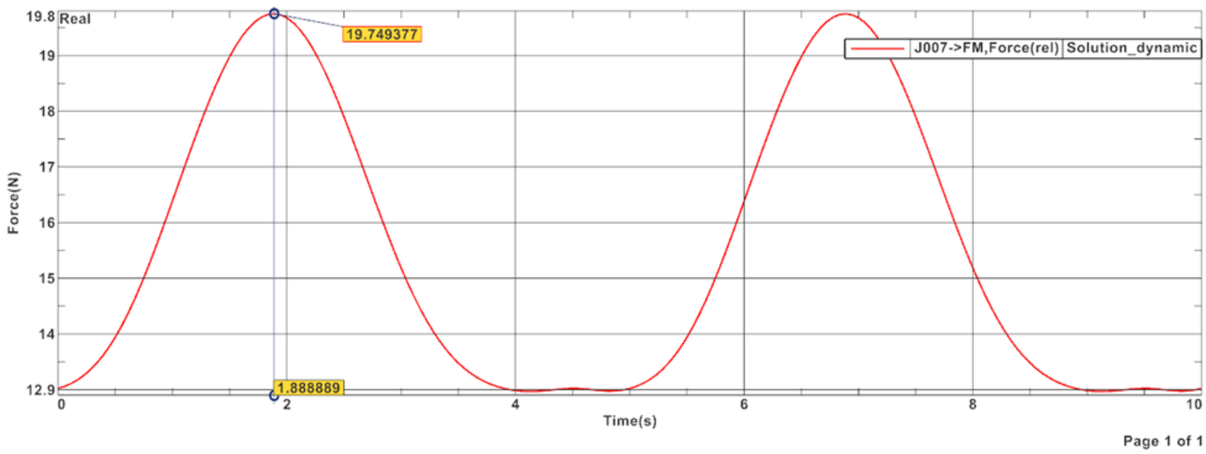

Image 30: Force Plot for Mechanism Holder Attached To The Ground

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. The torque plots are shown in images 31-36 below.

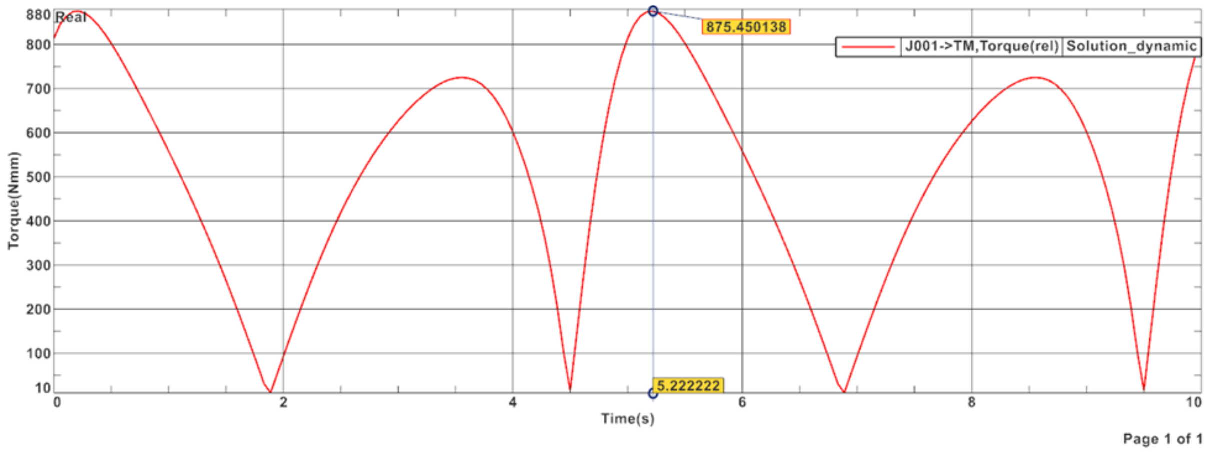

Image 31: Torque Plot for Joint A

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

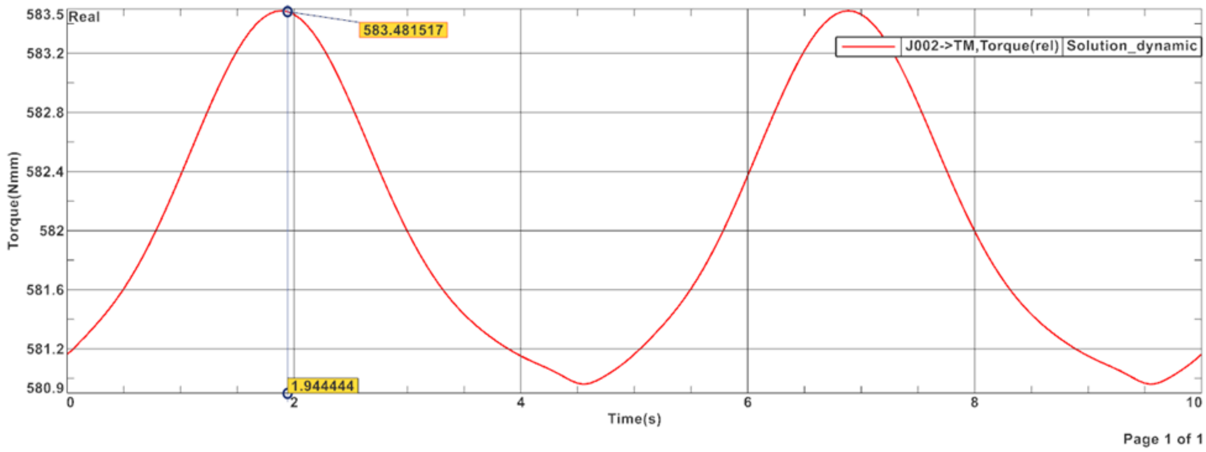

Image 32: Torque Plot for Joint D

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.

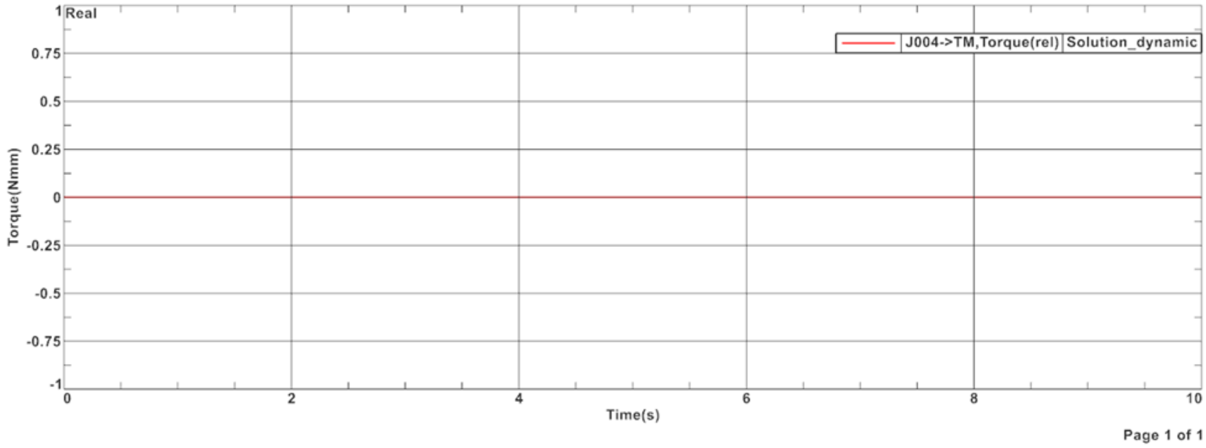

Image 33: Torque Plot for Joint G

There are no torque acting on Joint G.

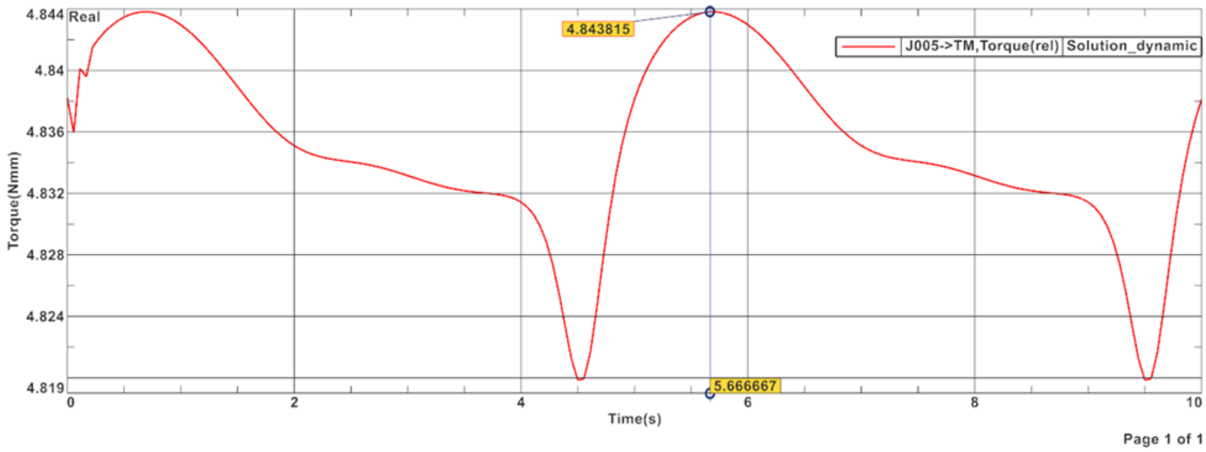

Image 34: Torque Plot for Joint F

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.

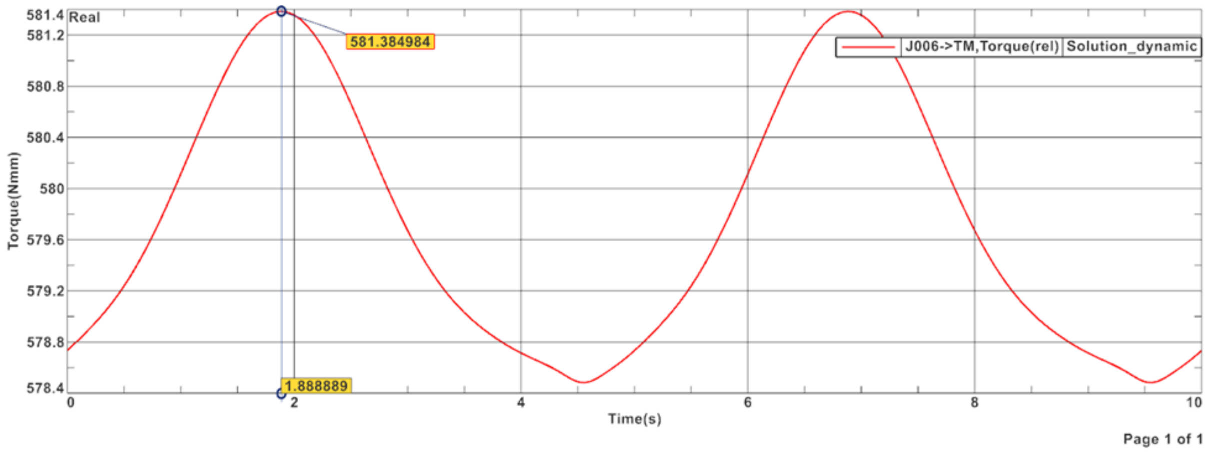

Image 35: Torque Plot for Joint B

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

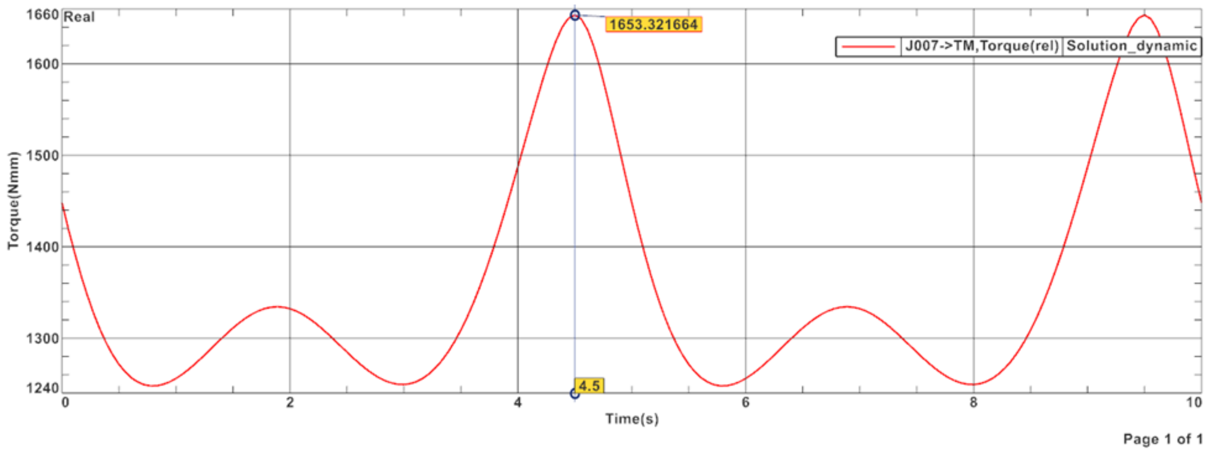

Image 36: Torque Plot for Mechanism Holder Attached To The Ground

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.

Needed Power to Run Mechanism

When discussing applications in engineering and physics, power is a constant topic of conversation. When the force is constant, power for rotational motion is just as significant as power for linear motion and can be determined similarly. The torque times the angular velocity, or $P = \tau \omega$, is the power applied to a system revolving about a fixed axis.

Thus, we obtain the graph object of the Angular Velocity and the Torque acting on Joint A, then export them into an excel spreadsheet. Then we multiply the two terms to obtain the power value needed for the mechanism. The plot of power vs time is shown in Image 37.

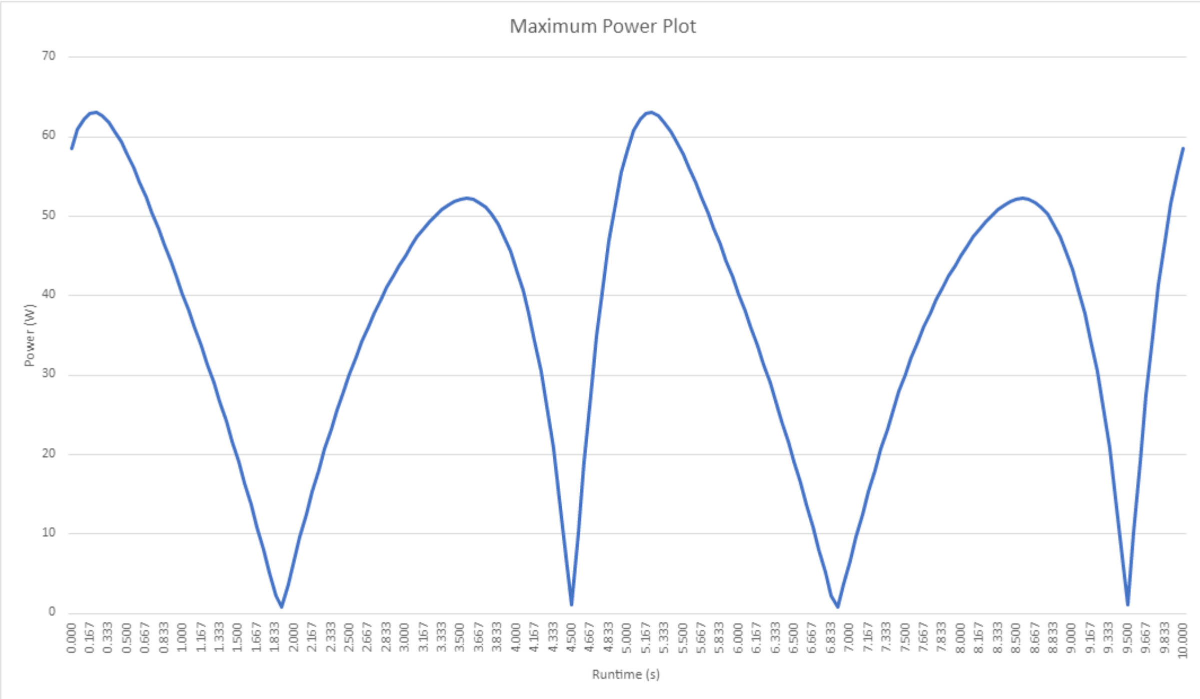

Image 37: Plot of needed power for the mechanism

From this graph, the minimum power needed to run the mechanism is about 63.03W or **63 W**.

Animation of dynamic simulation

The 10-second avi file of the dynamic simulation is uploaded along with this MBS report.

Validation of simulation results

The results could be verified in reality by first making blueprints with tolerances for the parts. For this we could simply use Siemens NX, Creo Parametric or Solid Edge. We would cast the part wireframes on to a measurement document and then we would add the necessary measurements, constraints and tolerances. Then these parts could be produced on a mill and a lathe at Aalto university campus or some machine shop outside of the campus. For parts with round symmetry we would use a lathe and the other parts would be milled. A multi axis (4 or 5 axis) machine could also be used however our parts are sufficiently simple that such a machine would not be necessary. We can find the Sandvik Coromant tool tips and drills based on inputting the material and shape properties on the Sandvik Coromant website calculator [1.]. For testing the machined parts could be attached to an electric motor. The test setup could be attached to a Siegmund table.

Furthermore, we could attach various speed, acceleration, angle and position sensors to the mechanism. These could then for an example be connected to

National Instruments measurement cards which are connected to a power source and to a laptop that runs LabVIEW or other similar programs (Method 1).

An alternative option would be to use a Norbar T-Box to easily obtain live measurement data (Method 2).

Both methods 1 and 2 would then output a .csv file that we can convert to an Excel spreadsheet. From the data we can then construct a chart that we compare to the charts produced by our simulation software Siemens NX in this case. This cycle can be repeated as many times as needed to produce an accurate simulation that accurately reflects on our newfound real life experience. Such a procedure would represent a repeating lean style Kaizen cycle which we can utilize to gather a high quality final product design.

Discussion

This week we conducted various simulations to verify the performance of our initial linkage concept model. Furthermore, we optimized our design to the size and performance that supports our intended purpose of serving as a kitchen meat cutting knife mechanism.

In this second stage of the project, we learnt how to use the Siemens NX software to produce the kinematic and dynamic simulations in order to understand how the mechanism works more clearly and produce the necessary plots for the report. At this stage, we are not familiar with using Siemens NX to utilize FEM functionalities to see how the mechanism acts under certain loads, but we hope to learn how to utilize them in later weeks.

In the previous week, we voted on the optimal mechanism to proceed with the project and learnt how to use Linkage to draw simple diagrams. In this week, we learnt the basics of joints and the kinematic and dynamic simulations. In order to facilitate the workload, we discussed among ourselves who would be the main input for each report, even though we would help each other on tasks which proved to be too difficult to be done. To improve the overall quality of the report, we can ask for even more input in the future weeks.

We started the week by first learning how to use the software from the tutorials uploaded to MyCourses and the computer sessions. Compared to the previous task, this report needs more time since the software was unfamiliar to use beforehand. However, we were able to successfully convert the simple diagram from the previous report into the full model of the mechanism ready for FEM simulations thanks to the assistance from tutors and teachers. Then we conducted the overall finishing touches of the report on the weekends. Just like in the first report, we will have a rotating role of main secretary for the report, who will be responsible for the report's layout. This week our report's main secretary was Elias Puolakka.

We anticipate receiving a noteworthy grade of 5 because we completed all the required descriptions, simulations, and prerequisite lists for this project and put forth a great deal of additional high-quality work, such as learning how to utilize the software to draw and simulate results for the plots.

References

1. *Sandvik Coromant; CoroPlus ToolGuide and Cutting speed calculator. (n.d.).* Retrieved September 13, 2022, from:

   CoroPlus® Tool Guide: Select cutting tools & cutting data online (coromant.com)