Mechanical Design for Virtual Quality Control Robot

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Abstract

A virtual quality control robot is developed. The robot consists of parts designed in SolidWorks and off-the-shelf parts. It is controlled by an Arduino Leonardo and driven by a PCB. The PCB is designed and tested in MultiSim and Ultiboard. The robot is virtually simulated using Simulink and SimulationX.

In this paper Section 1 is a brief system overview of the design of the robot. Section 2 describes the custom parts that were designed and the stress analysis of the parts. Section 3 describes the off-the-shelf parts that were selected. Section 4 describes the SimulationX model that was used.

Nomenclature

Φ: Diameter

PCB: Printed Circuit Board

YS: Yield Strength

1. System Overview

Our quality control robot consists of a base, two arms and a gripper system (Figure 1). The base and the arm are connected using a pinion, gear, and a ball bearing (Figure 2). For further details on the pinion, gear, and ball bearing see sections 3.4, 3.5, and 3.6. Arm 1 and Arm 2 are connected in similar fashion. The gripper system consists of the gripper base, two gear arms and two grippers (Figure 3 and 4).

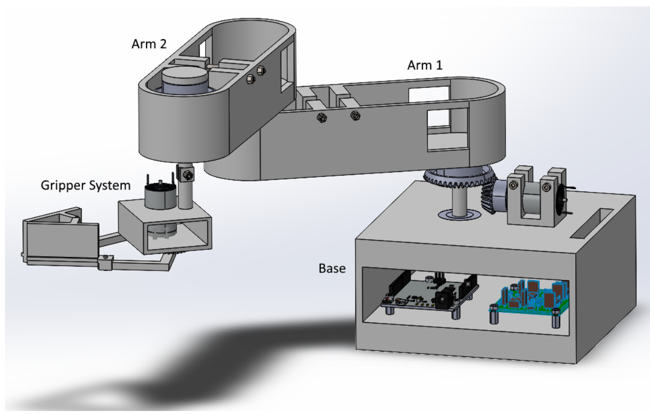


Figure 1: Overview of the quality control robot.

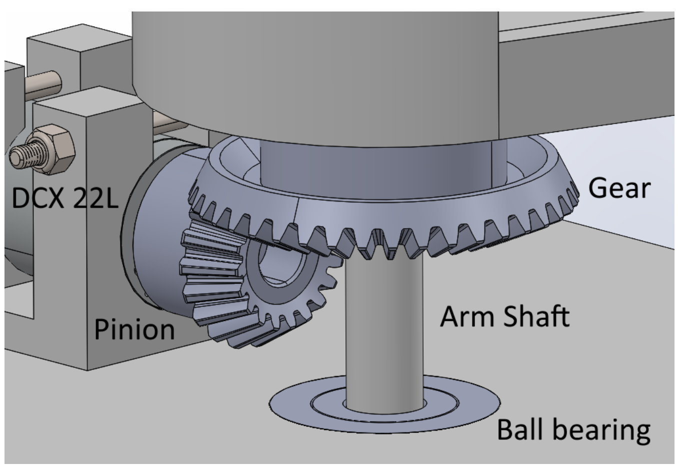


Figure 2: Connection between Arm and Base

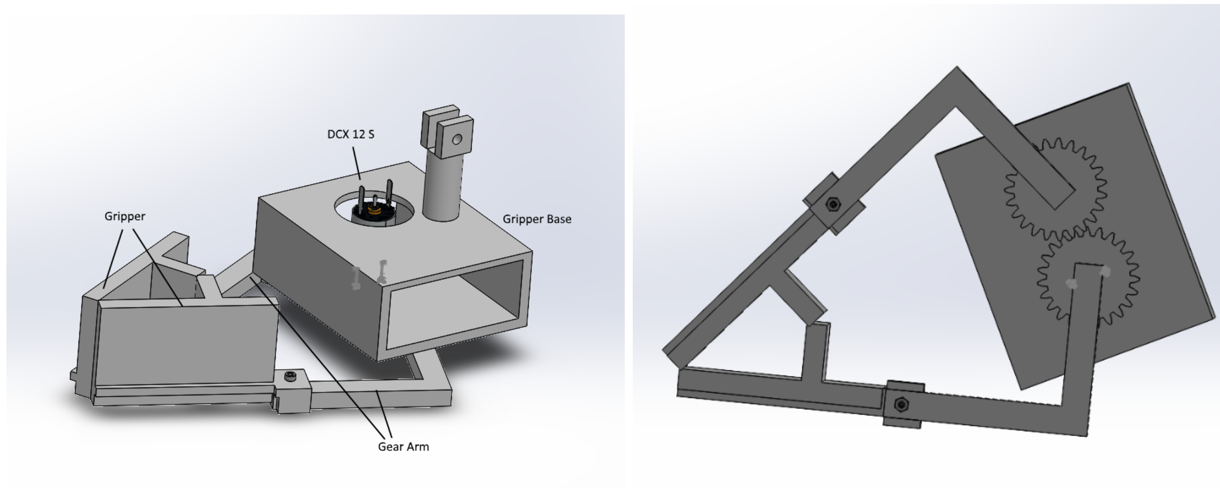


Figure 3 and 4: 3D views of the gripper system

2. Custom Parts and Stress Analysis

The following custom parts are designed in SolidWorks and made of ABS plastic. ABS plastic has a mass density of 1020 kg/m^3 and a YS of 64.91 MPa. The parts are designed to be 3D printed. 3D printing may lower the YS of the material during construction but the stress analysis results show that the parts are receiving stress at least 10x lower than the YS.

2.1 Base

The base is in the shape 160 mm x 160 mm x 80 mm hollow cuboid (Figure 5). On the top surface, multiple holes with Φs of 22 mm, 28 mm and 30 mm are cut with depths of 11 mm 9 mm and 2 mm respectively. A ball bearing will be inserted into this slot. Also on the top surface is a motor mount, designed for the Maxon DCX22L. It has an area of 32 mm x 34 mm and a height of 34 mm. A 22 mm Φ hole is cut through the middle to make room for the body of the motor. At the top two holes with 3 mm Φ are cut to allow for screws. Slightly behind the motor mount, an 80 mm x 10 mm window is cut to allow access to the inside of the base. The window is to allow for wiring from the PCB to reach the motor. The cuboid has a 150 mm x 40 mm cut through the side to allow an Arduino Leonardo and a PCB to be mounted inside it. Eight holes of 3 mm Φ are cut through the bottom to allow for coupling nuts and screws. Refer to Figure 6 for more details and dimensions.

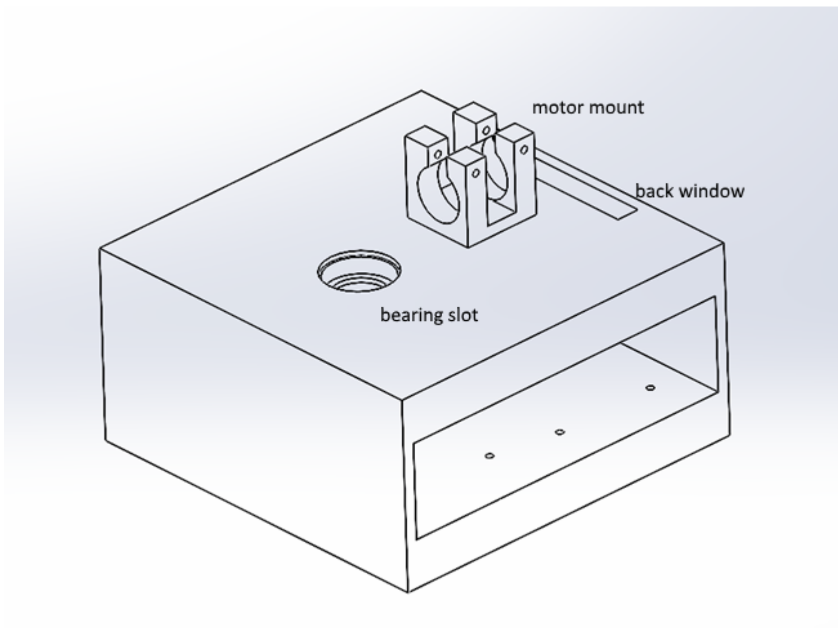


Figure 5: 3D view of the base

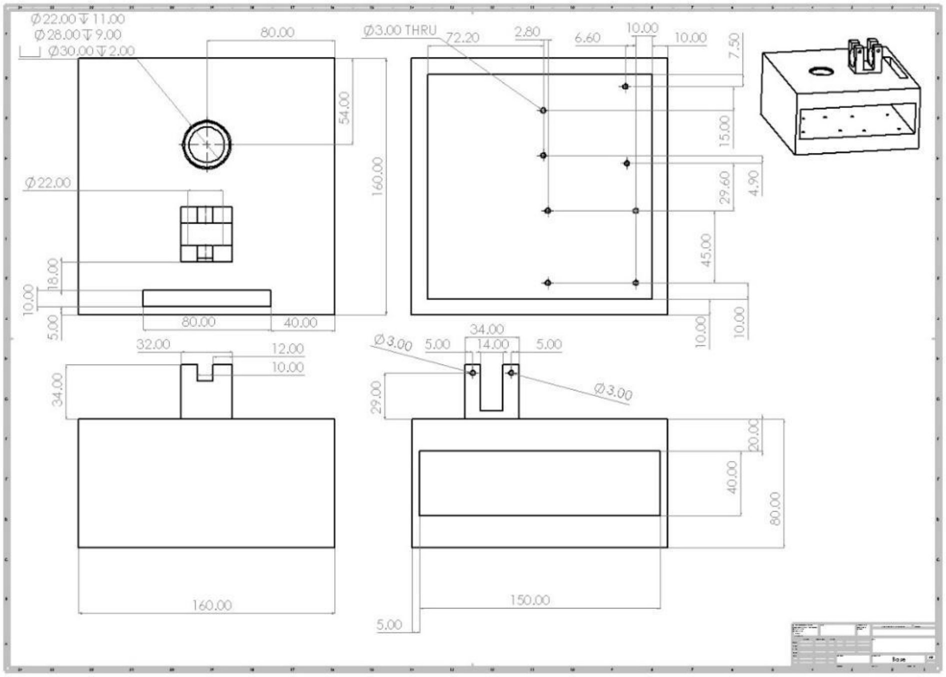


Figure 6: Schematic for the base

In the static study in Figure 7, a weight of 740g is applied to the body. The 740g includes the weight of two DCX22L motors, two DCX12S motors, two arms, the base of the gripper, the gripper, and miscellaneous parts. The bottom side of the body is fixed as it is under the assumption that it will be bolted down. The maximum stress is approximately 1000x less than the YS.

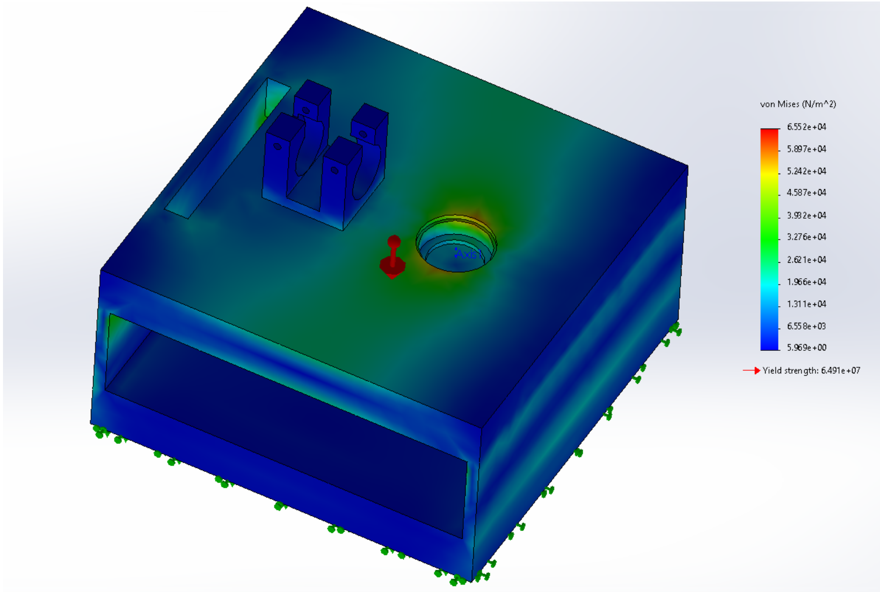


Figure 7: Static study of a mass applied to the base

2.2 Arm

The arm is a stadium with length of 150 mm, a radius of 65 mm raised to a height of 48 mm (Figure 8). The inside is hollow aside from a motor mount that consists of two brackets with a hole of 22 mm Φ cut through the center of the brackets. The top of the brackets also have 3 mm Φ holes cut through them for screws. On the front end on the inside of the arm, two holes of 28 mm and 32 mm Φ are cut for a ball bearing to be inserted. On the side of the arm located near the back, two windows of 30 mm x 30 mm are cut through the wall of the arm to allow for easier access to the motor for wiring. On the bottom side the arm a 10 mm Φ shaft of 52 mm length is placed. This shaft will connect to a gear. For further details refer to Figure 9.

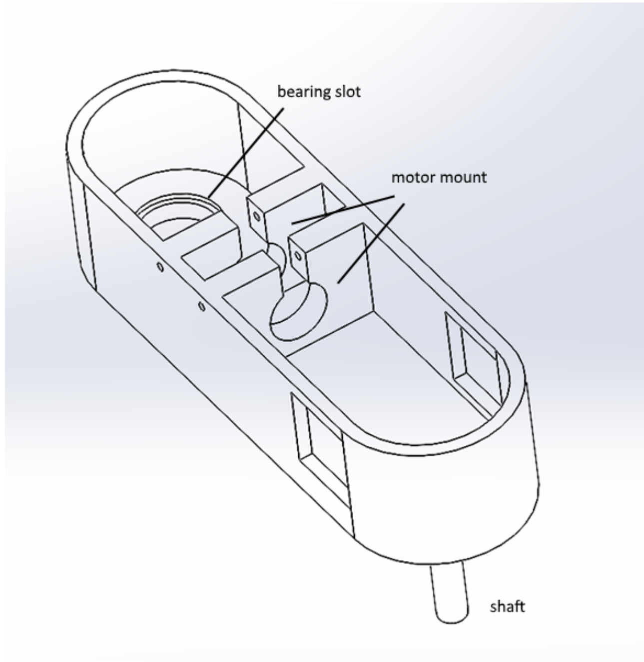


Figure 8: 3D view of the arm

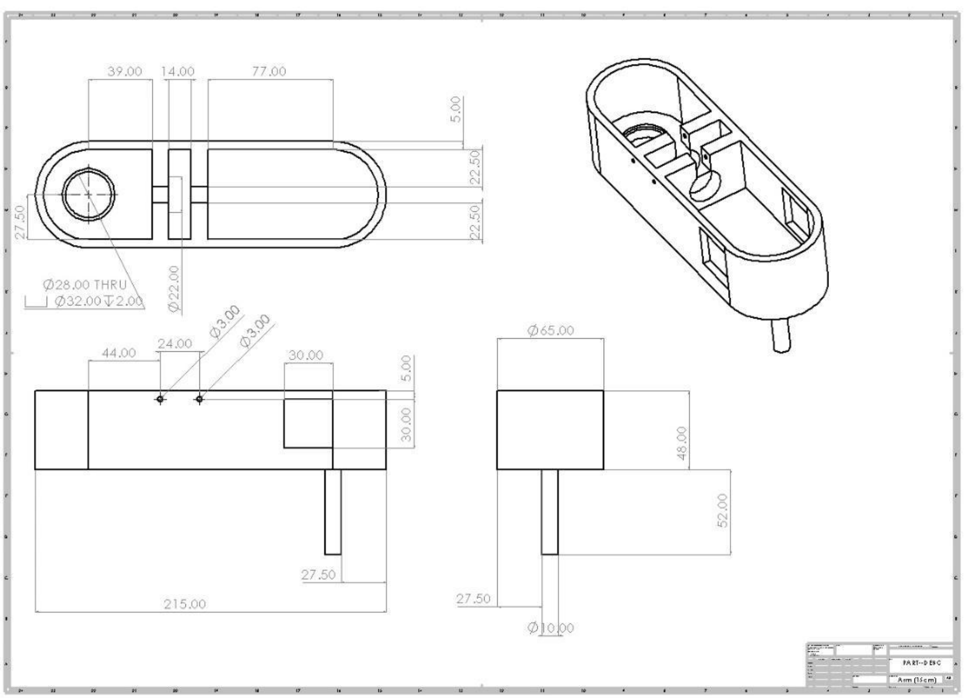


Figure 9: Schematic of the arm

In the static study in Figure 10, a torque of 59 mNm was applied to the shaft around Axis 1. 59.5 mNm was applied as it is double of the nominal torque of the DCX22L and the torque is being transferred through a gearset with a gear ratio of 2. The connection between the main body and the shaft is fixed as that is the connection point. The maximum stress is 200x less than that of the YS of 64MPa.

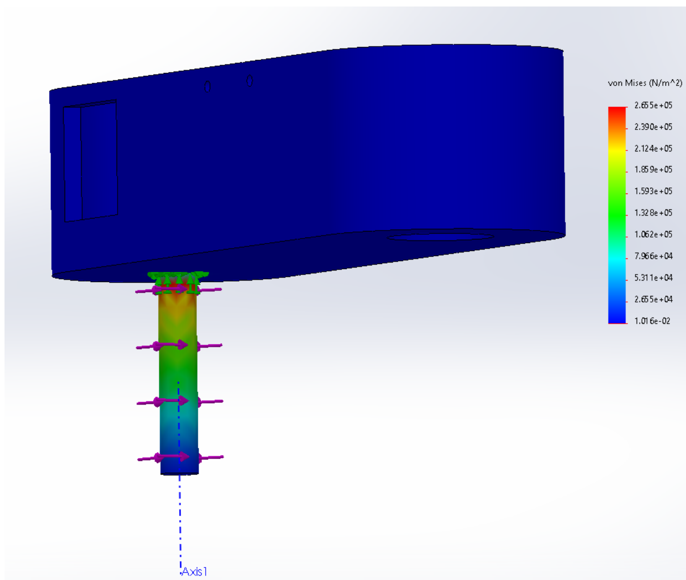


Figure 10: Static study of a torque applied to the shaft of the arm

In the static study in Figure 11, a weight of 411g is applied to the body. The 411g includes the weight of one DCX22L motor, two DCX12S motors, the second arm, the base of the gripper, the gripper, and miscellaneous parts. The shaft is fixed as that is the part that is held firm by the base. The maximum stress is 20x less than the YS.

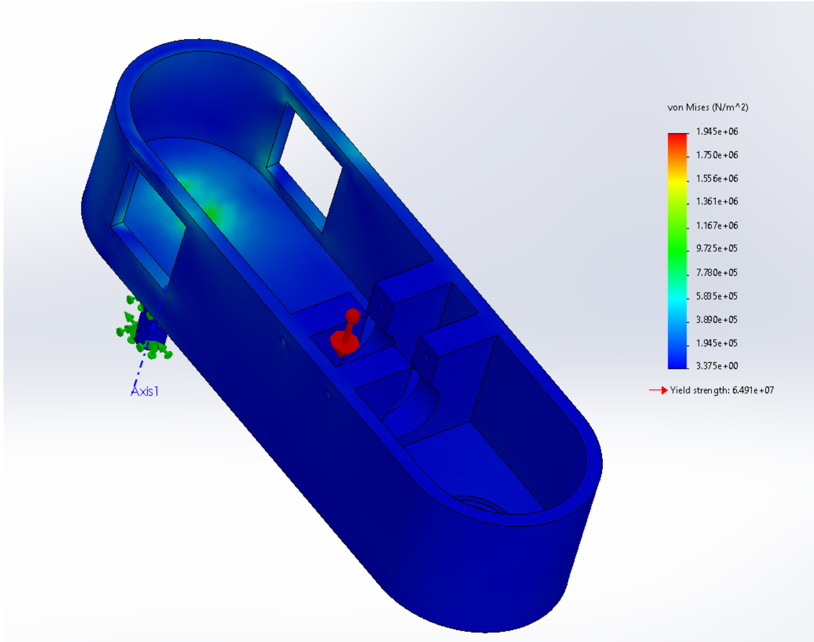


Figure 11: Static study of a mass applied to the arm

2.3 Gripper Base

The gripper base consists of the connector, connector shaft, body and motor mount (Figure 12). The connector is designed to fit with the gripper base connector shaft. The body is a 50 mm x 61 mm x 23 mm hollow cuboid. On the top surface is a 22 mm Φ hole to allow for easy access to the motor. The motor mount consists of a 12 mm Φ hole with 1 mm depth, a 6 mm Φ hole with 0.70 mm depth and a 2 mm through hole for the shaft to go through. Also included is two through holes of 1 mm Φ to bolt the motor to the body of the gripper base. On the bottom of the gripper base is a 1.5 mm Φ shaft of 3 mm length to attach a gear arm. For further details refer to Figure 13.

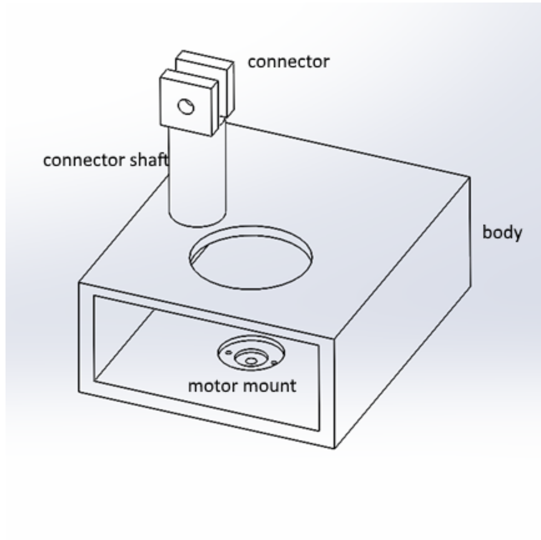


Figure 12: 3D view of the gripper base

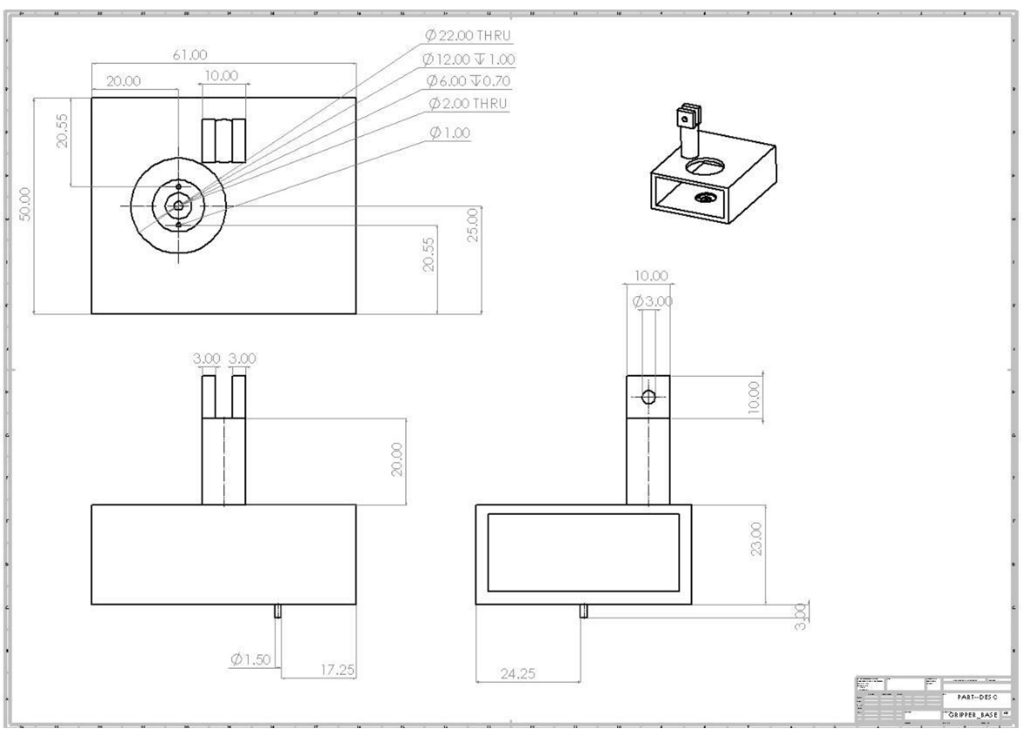


Figure 13: Schematic of the gripper base

In the static study in Figure 14, a torque of 3.76 mNm is applied to the connector at the top. The 3.76 mNm is double the nominal torque that comes from the DCX12S motor. The bottom of the connector shaft is fixed as that is the connection point between the shaft and the base. The maximum stress is 300x lower than that of the YS.

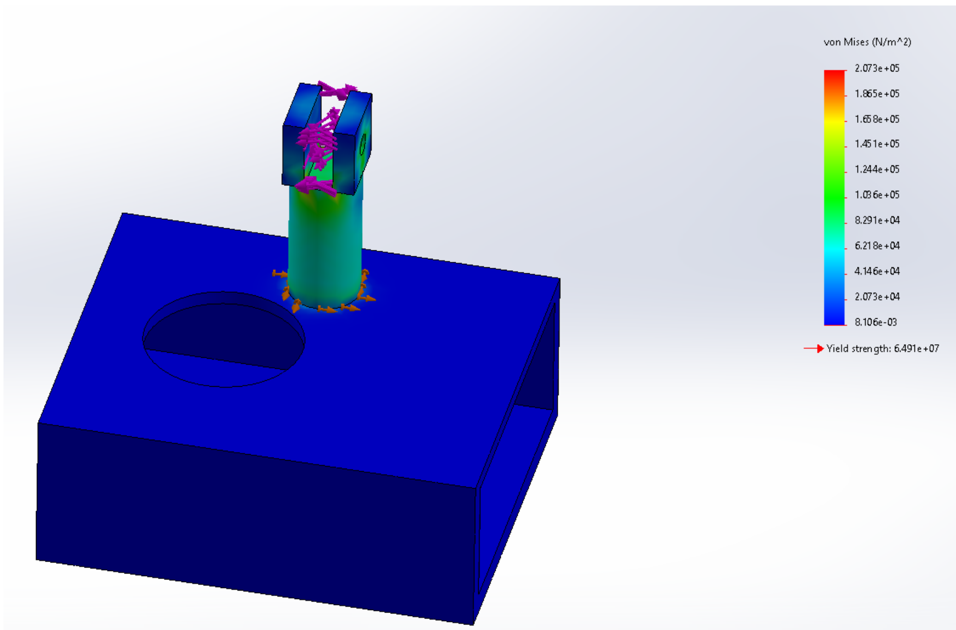


Figure 14: Static study of applied torque on the gripper base.

In the static study in Figure 15, a weight of 60g is applied to the body. The 60g includes the weight of one DCX12S motor, two arms, the gripper, and miscellaneous parts. The screw hole at the top of the connector is fixed as that is what is supporting the body. The maximum stress is approximately 100x less than the YS.

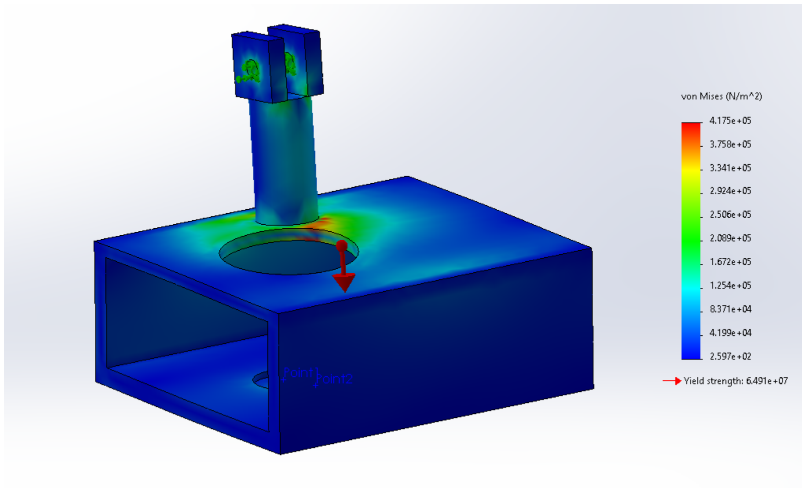


Figure 15: Static study of a load applied to the gripper base.

2.4 Gear Arm

The gear arm is shown in Figure 16 with a gear with 23 teeth, a face width of 2.5 mm and a bore Φ of 1.5 mm. Attached to the back is a 90 degree arm with a height of 41.86 mm and length of 50 m. A 1.6 mm Φ hole for screws is cut into the end of the arm. This part was mirrored to produce one for the opposite side as seen in Figure X. For further details see Figure 17.

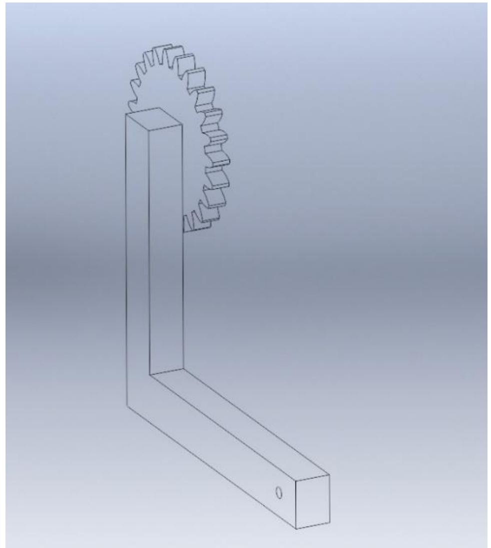


Figure 16: 3D view of the gear arm

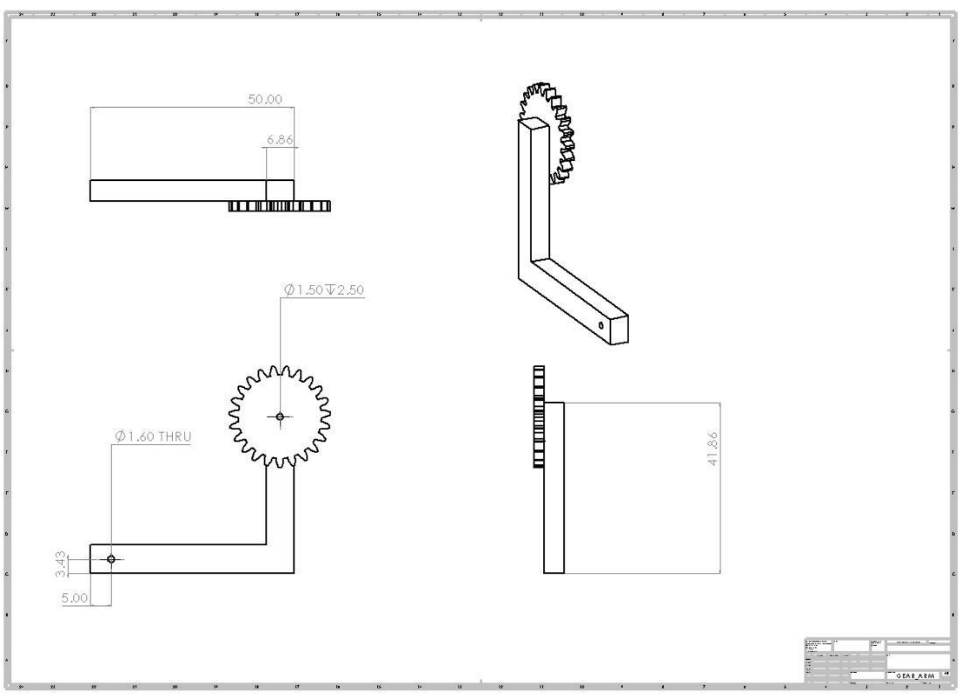


Figure 17: Schematic for the gear arm

In the static study in Figure 18, the nominal motor torque of 1.88mNm from the DCX12S was applied to the gear. The screw hole at the bottom has been fixed as that is the supporting area. The maximum stress is lower than the YS by a factor of 200x.

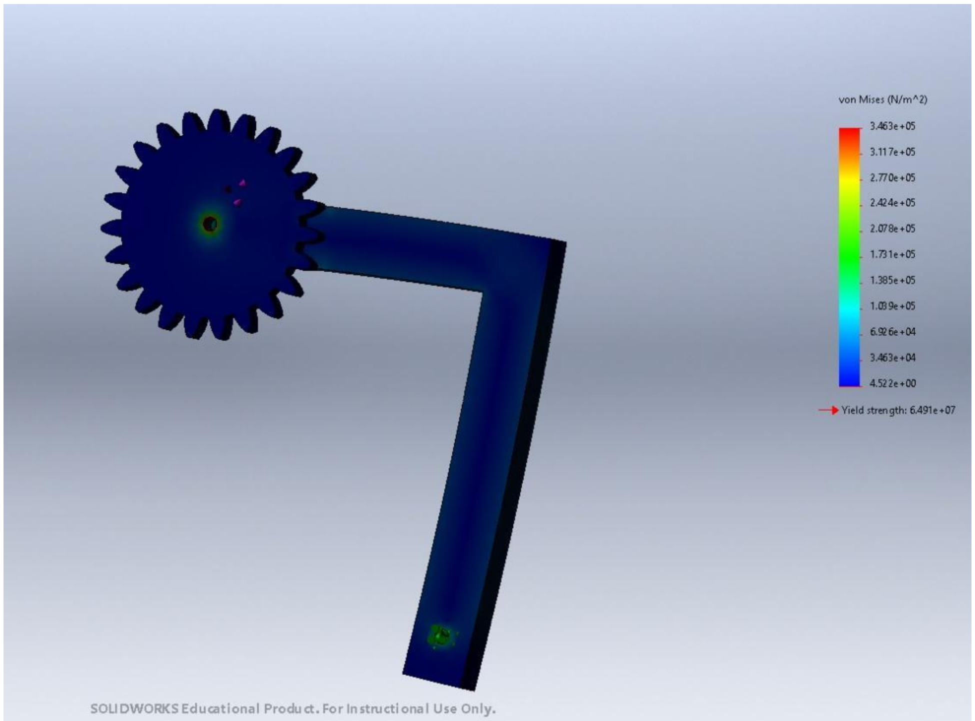


Figure 18: Static study with applied torque on gear arm

2.5 Gripper

The gripper consists of three parts, the connector, the catching arm and the closing arm (Figure 19). The connector is designed to connect with the gear arm and a 1.6 mm Φ hole is cut into the connector and the width of the slot is 6.86 mm. The catching arm is 14 mm long and is designed to meet with the mirrored part's catching arm when the gripper is closed. When the gripper is closed as seen in Figure 4, it creates a pocket that is able to grip on to the marshmallow tightly.

The part has been mirrored to create another part for the opposite side. For further details see Figure 20.

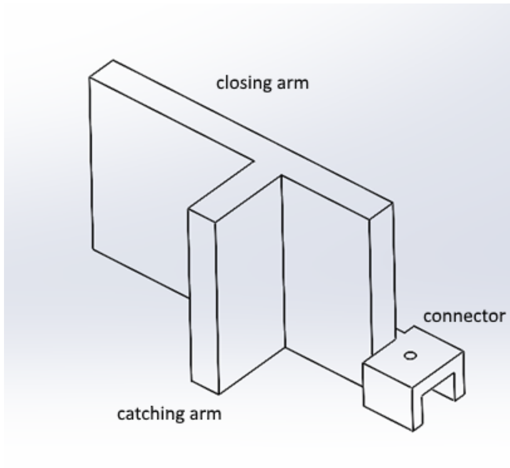


Figure 19: 3D view of the gripper

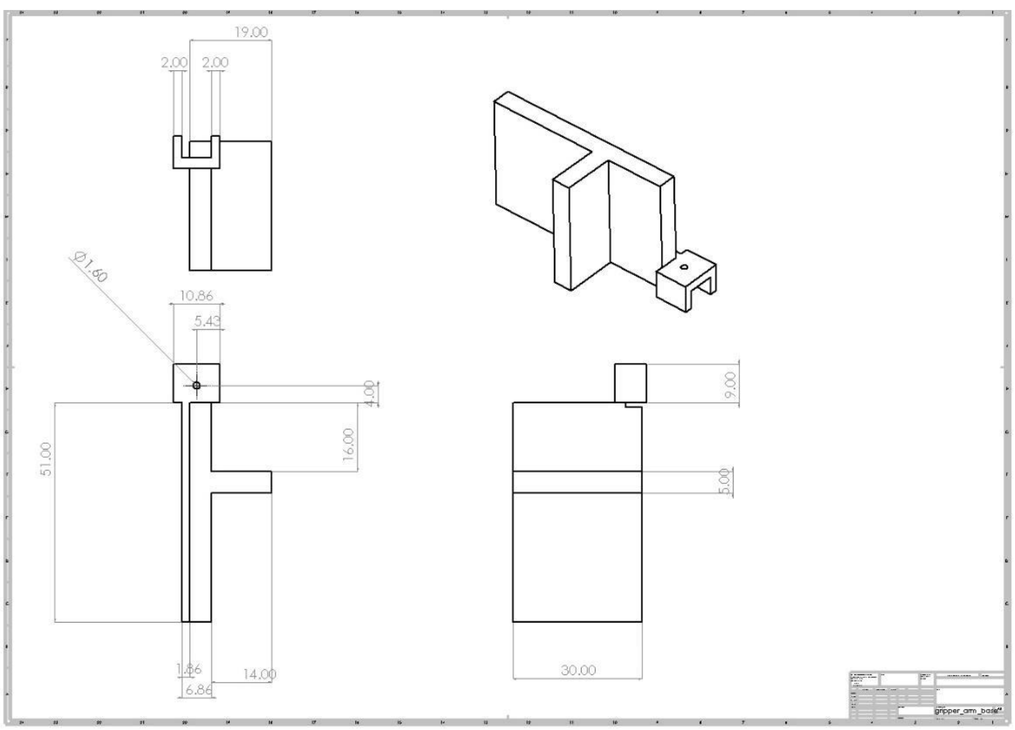


Figure 20: Schematic for the gripper

In the static study in Figure 21, a force of 5N is applied to the connector where the gear arm connects to the gripper. The force is calculated using the formula: torque = force x distance and the nominal torque and the radius of the motor shaft. The two edges where the gripper would collide with the other gripper has been fixed. The maximum stress is approximately 30x lower than the YS.

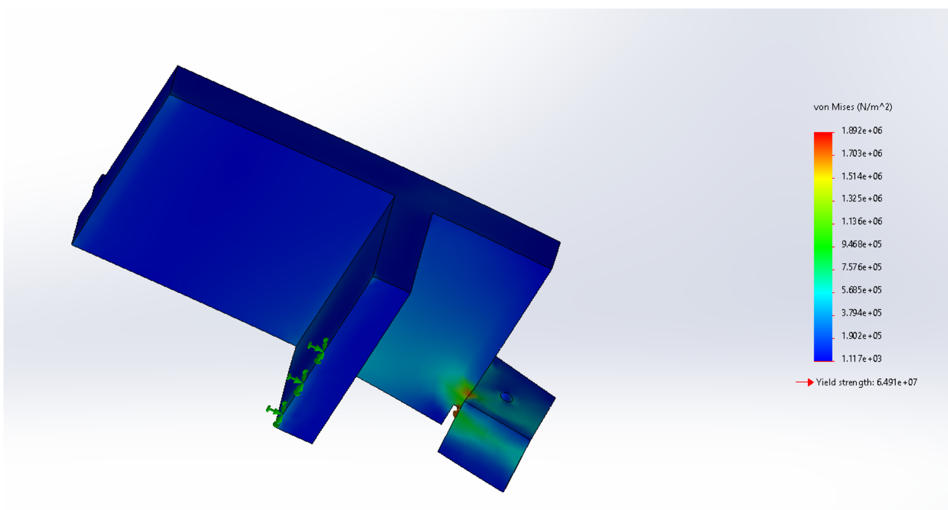


Figure 21: Static study with applied force on the gripper

2.6 Motor to Pinion Connector

The DCX22L motor shaft has a Φ of 3 mm while our pinion has a bore Φ of 8 mm. This part is designed to connect the shaft to the pinion (Figure 22).

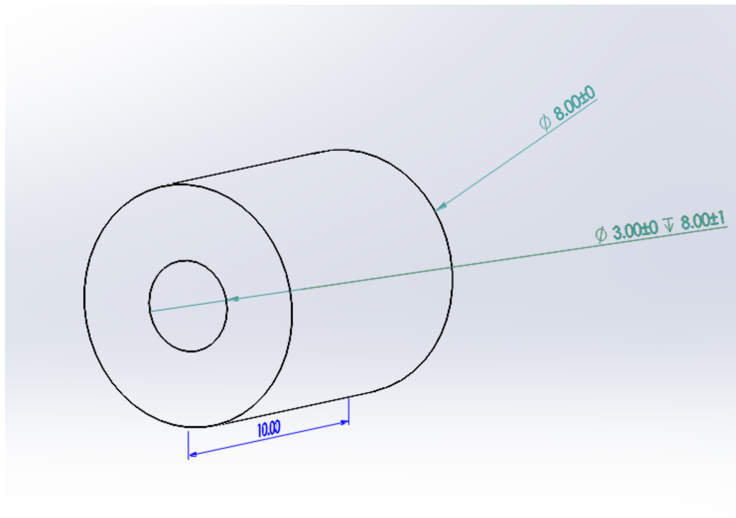


Figure 22: 3D view of motor to pinion connector

2.7 Gripper Base Connector Shaft

The gripper base connector shaft is used to connect the arm and the gear to the gripper base (Figure 23). The end of the shaft is cut into a square to allow for easier fit. A 3 mm Φ screw hole is cut into this square to allow for it to be screwed into the connector on the gripper base. For further details see Figure 24.

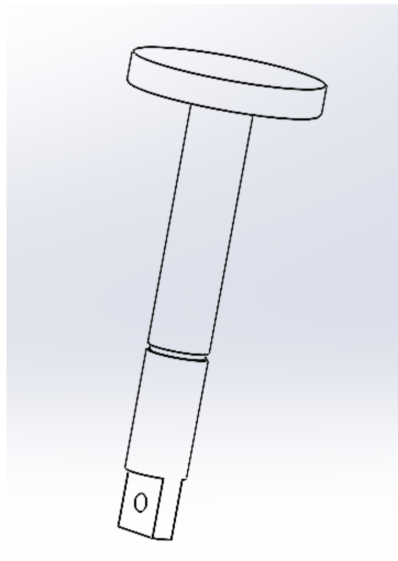


Figure 23: 3D view of gripper base connector shaft

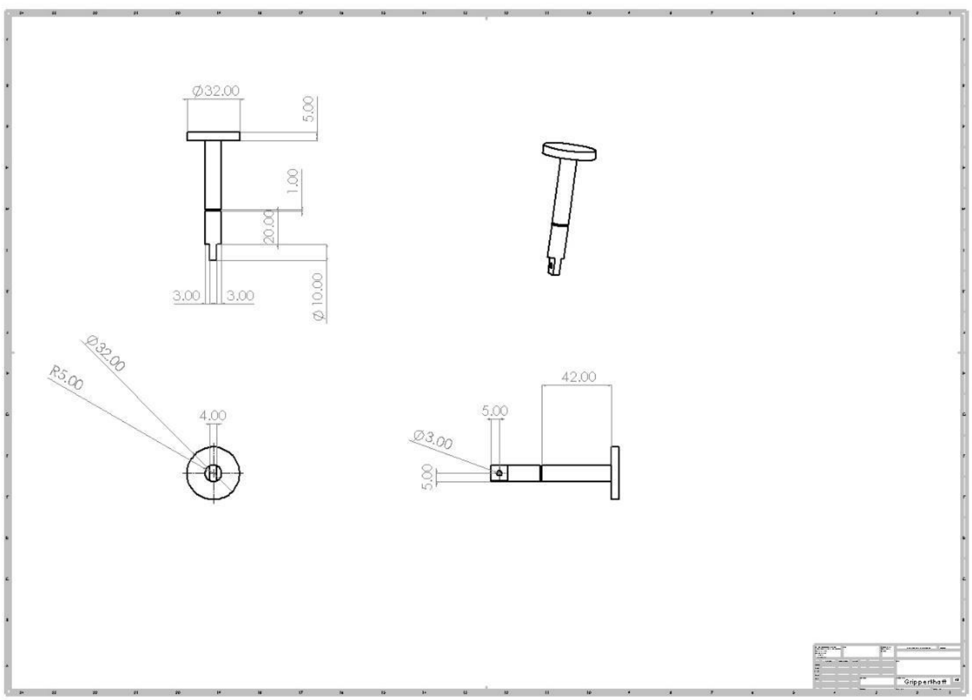


Figure 24: Schematic of the gripper base connector shaft

In the static study in Figure 25, a torque of 59 mNm is applied to the shaft. The screw hole and the connecting point of between the shaft and the top is fixed as those are the supports. The maximum stress is approximately 100x less than the YS of 64.9 MPa.

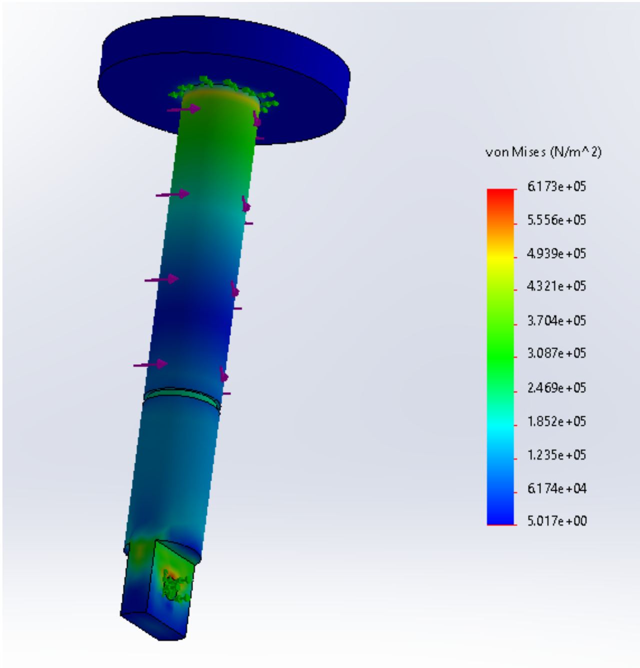


Figure 25: Static study of applied torque on the gripper base connector shaft.

3. OTS components

3.1 Maxon DCX 22L

The motor has a length of 47.2 mm x 22 mm diameter with a 3mm output shaft. Running this motor at 12 V draws a current of 1.30 A and provides a maximum speed of 4980 rpm, a stall torque of 150 mNm and a nominal torque of 29.5 mNm [1]. The motor can be seen in Figure 26

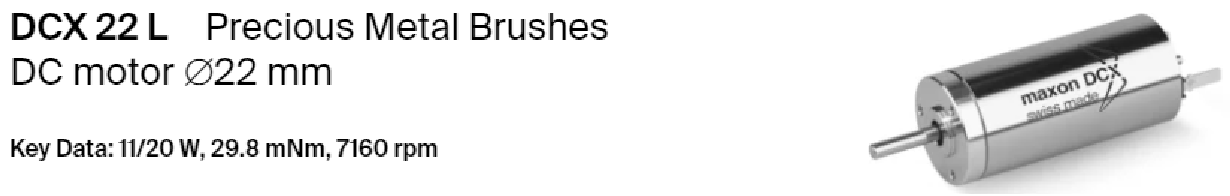


Figure 26: Maxon Motor DCX 22 L

3.2 Maxon DCX 12S

The motor has a length of 19.4 mm x 12 mm diameter with a 1.5 mm output shaft. Running this motor at 12 V draws a current of 159 mA and provides a maximum speed of 3620 rpm, a stall torque of 3.21 mNm and a nominal torque of 1.88 mNm [2]. The motor can be seen in Figure 27.

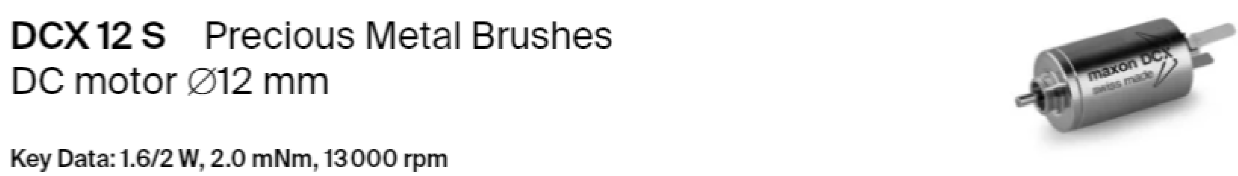


Figure 27: Maxon Motor DCX 12S

3.3 Encoder 16 EASY XT

The encoder draws a supply voltage of 5 V and 22 mA. It has three channels and has 1024 counts per turn. It's max operating frequency is 1600 kHz and it's max speed is 30,000 rpm [3]. The encoder and it's schematic can be seen in Figure 28 and Figure 29.

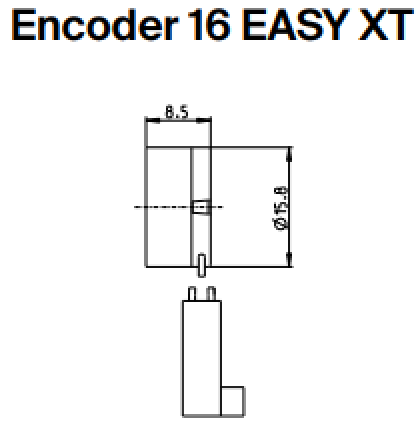


Figure 28: (left) ENC 16 EASY XT encoder Figure 29: (right) ENC 16 EASY XT schematic

3.4 Plastic Bevel Pinion

The nylon plastic bevel pinion has 20 teeth, a 25 mm pitch Φ, a face width of 8 mm and a bore Φ of 8 mm. The hub has a Φ of 32 mm and a width of 10 mm. Further details can be found on the McMaster-Carr website [4]. The pinion can be seen in Figure 30.

Figure 30: Plastic Bevel Pinion

3.5 Plastic Bevel Gear

The nylon plastic bevel gear has 40 teeth, a 50 mm pitch Φ, a face width of 8 mm and a bore Φ of 10 mm. The hub has a Φ of 32 mm and a width of 10 mm. Further details can be found on the McMaster-Carr website [5]. The gear can be seen in Figure 31.

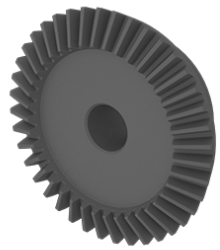


Figure 31: Plastic Bevel Gear

3.6 Ball bearing

The acetal plastic bearing has a shaft Φ of 10 mm and an outer Φ of 28 mm. It also includes an upper lip with a Φ of 30 mm and the total height of the bear is 9 mm. Further details can be found on the McMaster-Carr website [6]. The ball bearing can be seen in Figure 32.

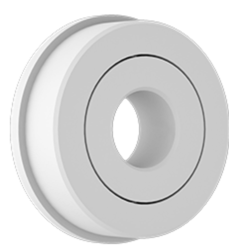
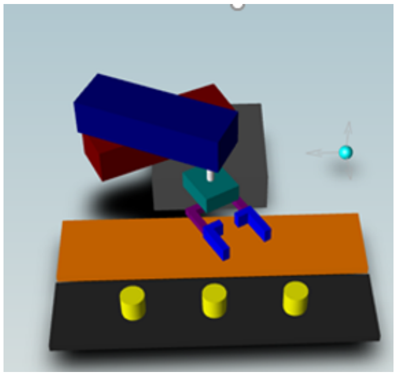


Figure 32: Ball Bearing

4. SimulationX Model



A SimulationX model was developed in order to test our control system. Our 3D model can be seen in Figures 33 and 34. An overview of the parts and components used can be seen in Figure 35.

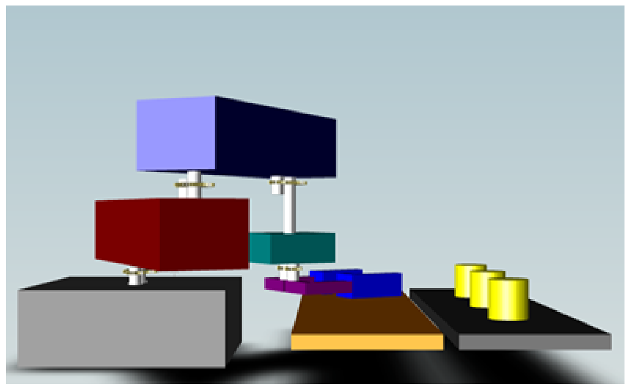


Figure 33: (left) 3D Overview of the robot in SimulationX and Figure 34: Side view of the robot(right)

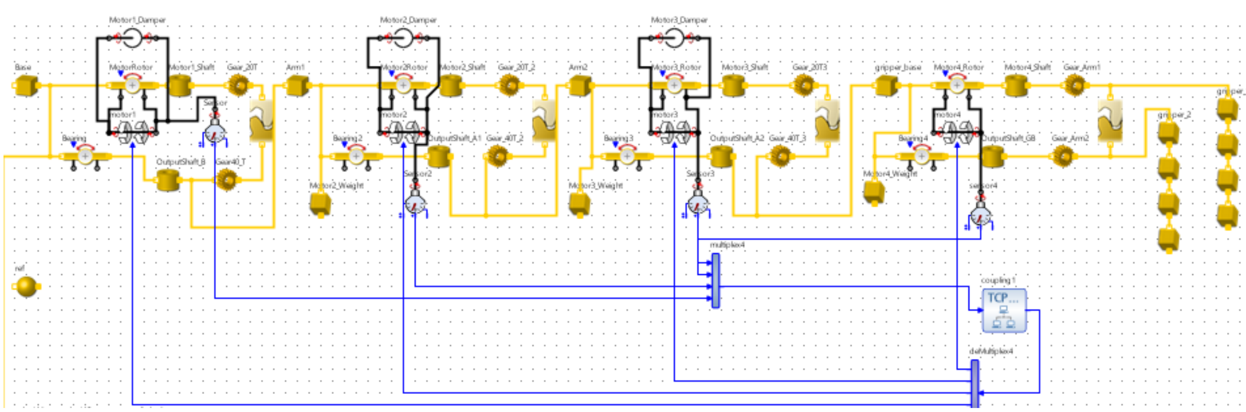


Figure 35: Overview of the SimulationX diagram

4.1 The Base

To model the base a cuboid was used with the same dimensions and mass as in the SolidWorks model. Connected to it is ‘MotorRotor’ which takes external torque from ‘motor1’. Motor1 takes an input from our coupling block which is connected to our Simulink model. A block named ‘Motor1_Damper’ is in parallel to the motor to represent the damping coefficient. MotorShaft_A1 represents the motor shaft and it connects to ‘Gear_20T’. ‘OutputShaft_B’ is the output shaft which is connected to gear2. The block in between gear1 and gear2 is a gear tooth contact block that turns the gears as intended. A difference between the SimulationX model and SolidWorks model is that both the gears in SimulationX are rotating about the z-axis while in SolidWorks the gears rotate on the x and z axis. This doesn’t affect the performance of the model and is simpler and easier to model. Arm1 can be seen connected to the output shaft. The sensor connected to ‘motor1’ represents the encoder by feeding the angular velocity of the motor back into Simulink. The diagram can be seen in Figure 36.

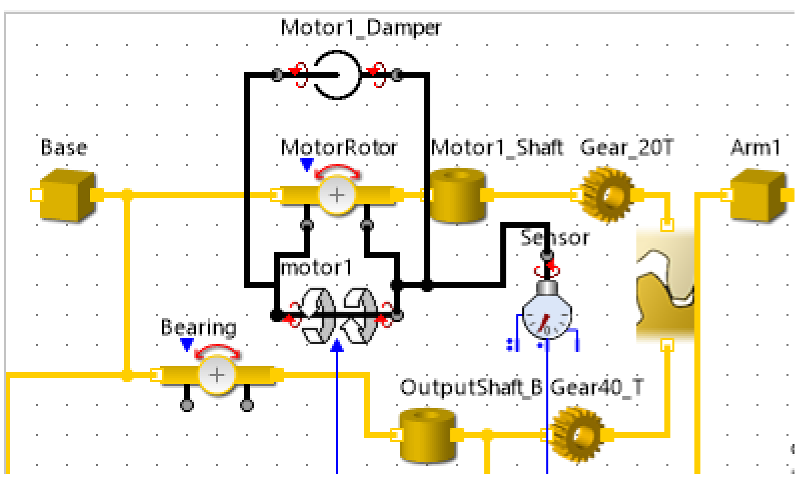


Figure 36: The diagram view of the Base

To model the arm a cuboid was used with roughly the same dimensions and mass as in the SolidWorks model. One difference between the SolidWorks model and the SimulationX model is that the SolidWorks model has rounded ends and windows on the side while the SimulationX model does not. These features don't make an impact on the performance of the model so they were not included. The block 'Motor2_Weight' is placed in position of our motor to represent the weight of our motor. The models for Arm 1 and Arm 2 are set up the exact same way. They can be seen in Figure 37 and 38.

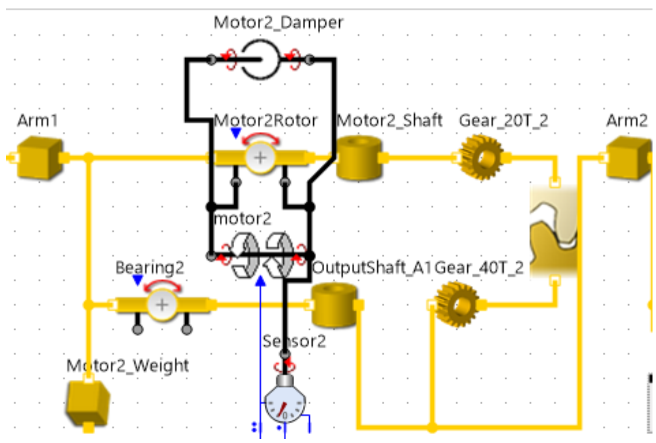


Figure 37: Diagram view of Arm 1

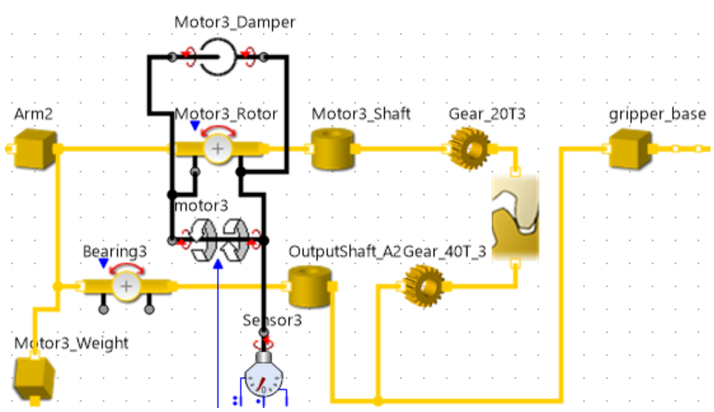


Figure 38: Diagram view of Arm 2

To model the gear arm, two gears, Gear_Arm1 and Gear_Arm2, with 23 teeth each were used in conjunction with the tooth contact block. To model the arm and the arm and the gripper, cuboids were used and dimensioned to the model in SolidWorks. They can be seen under ‘gripper_1’ and ‘gripper_2’. The diagram can be seen in Figure 39.

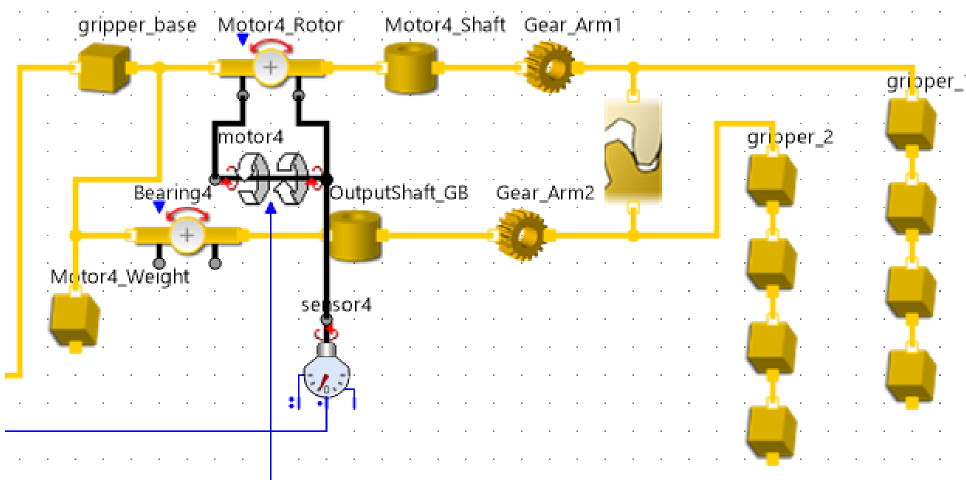


Figure 39: Diagram view of the gripper system

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[1] DCX 22 L datasheet,

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