GANTRY LOADER TURNING MACHINE (GLTM)

PROJECT REPORT

Submitted By,

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1. Problem Statement

It is required to design a gantry loader system for CNC turning machine/lathe for picking the workpiece from a specified location and place it in position for the chuck or collet to grip it. The weight carrying capacity of the loader should be minimum 3 kg. A vertical lift of 1500 mm, horizontal travel of 1000 mm is essential in the working envelope. The pick up position is in vertical orientation and the chuck/collet is horizontal orientation. The loader is required to be equipped with provision to orient the workpiece appropriately.

It is required to design the mechanism for picking the workpiece from the pick up location and transfer it to the chuck/collet. The design should clearly provide the mechanism implemented, design calculations for strength/dimensions for each link/component and justify selection of any off-the-shelf component like bolts, bearings, bushes, motors, couplings etc. You can select the gripper/end effector of your choice but you need to clearly specify its features and limitations.

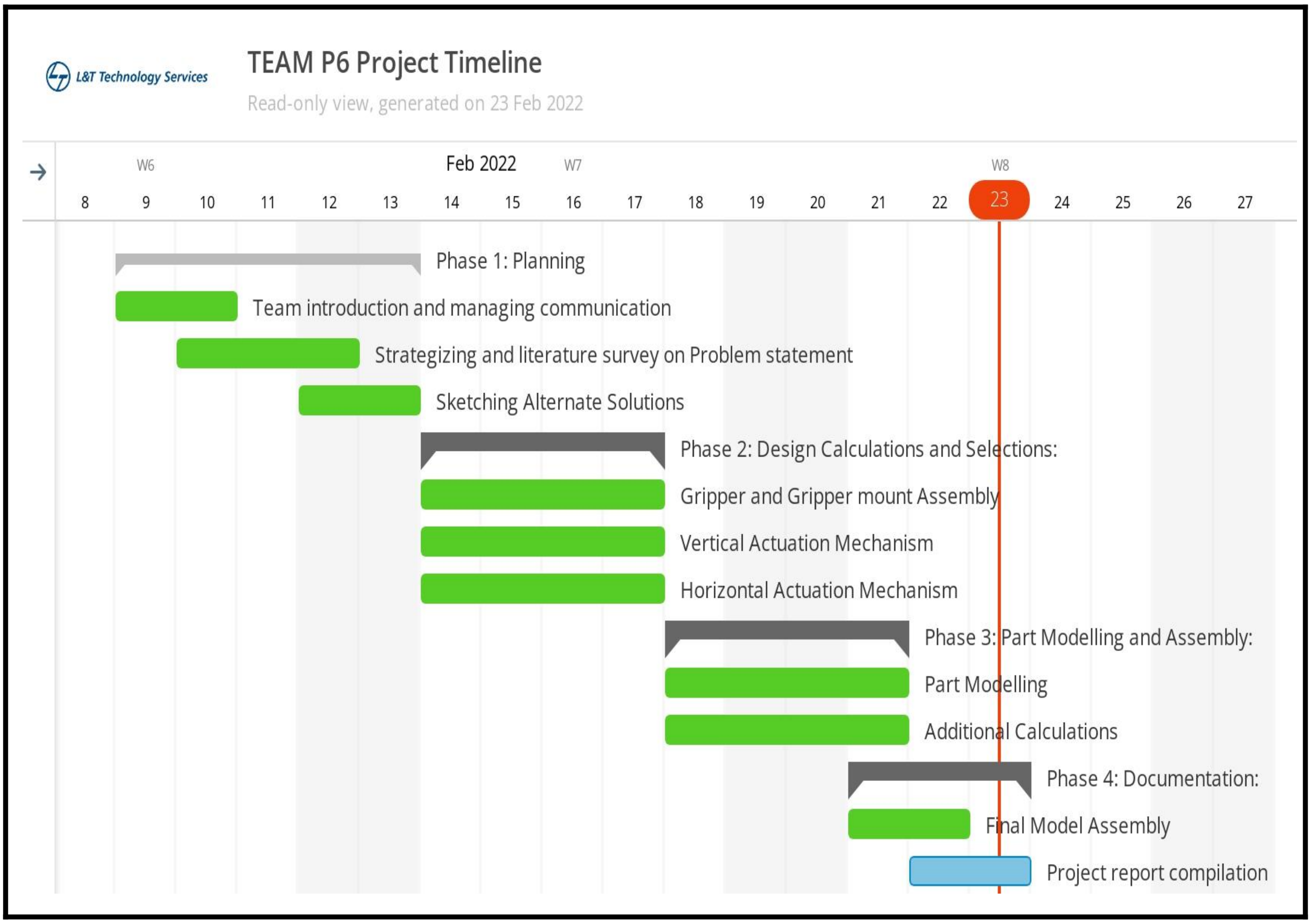
2. Abstract

The Gantry Loader for Turning machine to pick two workpieces from the workpiece station and load them on the turning machine, while collecting and carrying the finished parts from the machines to the respective station is designed based on the given dimension constraints, and clearly provide the mechanisms implemented, design calculations for justifying the design choices made for each component/mechanism.

3. Software Used

Creo parametric 7.0 is used to design the CAD model for parts and assembly.

4. Timeline


L&T Technology Services
TEAM P6 Project Timeline
Read-only view, generated on 23 Feb 2022
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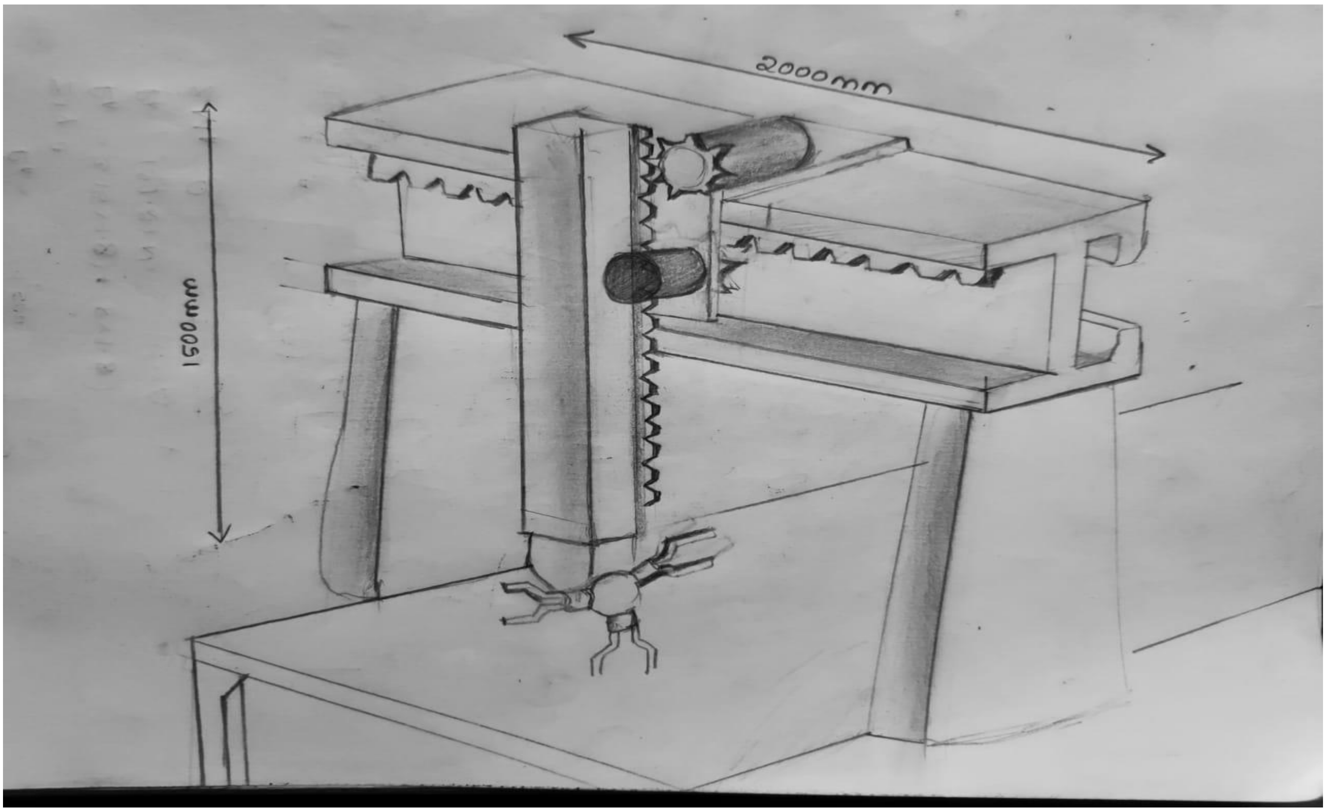
Phase 1: Planning
Team introduction and managing communication
Strategizing and literature survey on Problem statement
Sketching Alternate Solutions
Phase 2: Design Calculations and Selections:
Gripper and Gripper mount Assembly
Vertical Actuation Mechanism
Horizontal Actuation Mechanism
Phase 3: Part Modelling and Assembly:
Part Modelling
Additional Calculations
Phase 4: Documentation:
Final Model Assembly
Project report compilation

5. Design Alternatives

Two Design alternatives were selected after conducting literature surveys and brainstorming ideas. The main goal was to design for two consecutive turning machines, while being compliant to the problem statement.

Design Alternative 1



Three gripper GLTM with simply supported horizontal beam

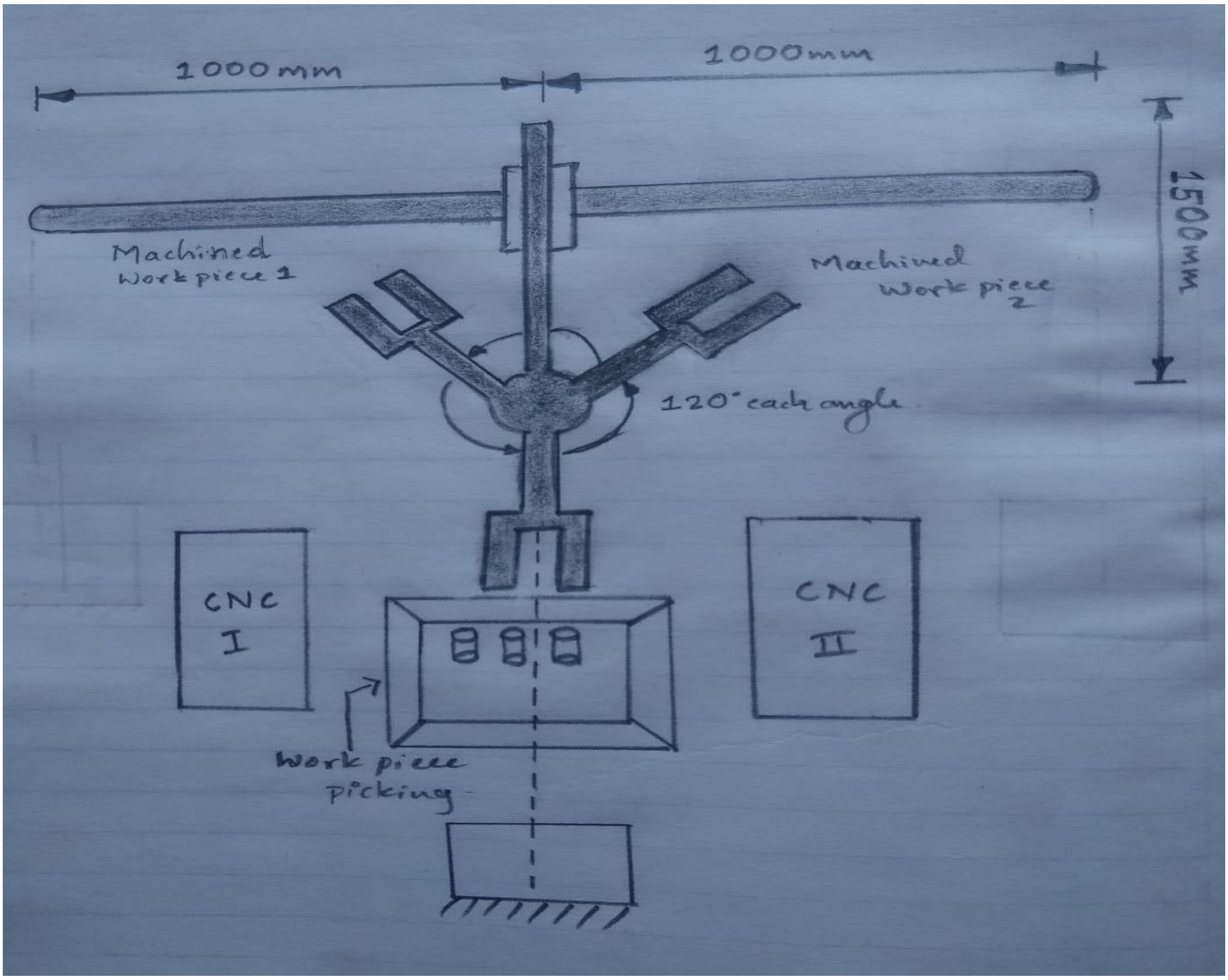
Advantages:

- Can Handle two workpieces in a single cycle.
- Maximum Bending Moment generated is less as compared to cantilever structure, so that it can take up heavy loads.
- Less Design complexity.
- Since the system is assembled with positive drives, No slip during transmission occurs.

Disadvantages:

- Need two mounting places
- Deflection will be more at the center of Horizontal beam

Design Alternative 2



Three gripper GLTM with cantilever beam for horizontal translation

Advantages:

- Capable of sensing load, mainly by resistance against bending
- Only one ground support is required.

Disadvantages:

- More design complexity.
- Less accurate movements with heavy workpieces, due to bending.

PUGH CHART

Requirements	Weightage	Design 1	Design 2	Reference
Design	9	+	0	0
Machinability	8	0	+	0
Supporting member	7	+	-	0
Position Accuracy	9	+	0	0
Height Adjustment	8	0	+	0
Failure of beam	9	0	0	0
Weighted Total		25	9	
Yes/No		Yes	No	

SELECTED BEST DESIGN: DESIGN ALTERNATIVE 1

6.Material Selection

For Side Support Columns

Material selection for Side support columns was carried out by conducting compressive load calculations while assuming the load as 45 kg. Consequently, Structural steel A36 was finalized for the application.

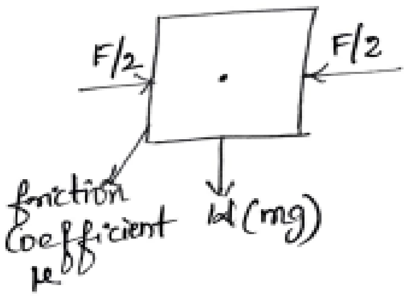
For Gripper Station Shaft

Material selection for the gripper station actuator shaft was carried out by conducting cantilever shaft calculations with torsional and bending combined loading. As a result, Aluminum Al 6061 T6 was selected for the application.

7.Design Calculation

Gripping force

Gripping Force & Transportable Work Part Weight



F : Gripping force (N)... sum of Push forces
μ : Coefficient of static friction between the finger attachment & the work part
m : Work part weight (Kg)
g : Gravitational acceleration ($9.8\ m/s^2$)

$$F\mu > W$$

$$F > \frac{mg}{\mu}$$

Necessary gripping force as the recommended safety factor of 2 for normal transportation

$$F > \frac{mg}{\mu} \times 2 \text{(safety factor)}$$

When the friction Coefficient μ is between 0.1 & 0.2

$$F > \frac{mg}{0.1 \text{ to } 0.2} \times 2 = (10 \text{ to } 20)\, mg.$$

When remarkable acceleration, deceleration & /or impact occur at work part transportation

Necessary gripping force ⟶ 30 to 50 times the work part weight or more.

$$\text{Gripping force} = 30 \times mg. \qquad [m = 3kg]$$

$$= 30 \times 3 \times 9.81$$

$$\boxed{F = 882.9\ N}$$

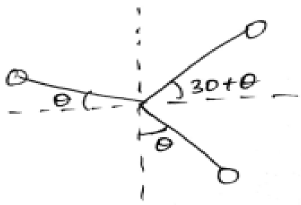
For this Gripping we have choosen Standard Pneumatic OEM Gripper UPG 100 Gripper holding force is 900 N. where it can suits the application.

Gripper mount Torque

The idea was to design a system for replacing and loading workpieces for 2 turning machines consecutively. Hence, a mechanism was developed to do the same. The Mechanism involves 3 grippers assembled in the same plane on the gripper station at 120 degrees separation. The working algorithm goes as follows:

- The gripper station initially above the workpiece tray, Picks up two workpieces at two of its grippers.
- The gripper station is taken near the first turning chuck, the free gripper picks the finished part from the chuck, one of the grippers loads the chuck with a workpiece after rotating the station by 120 degrees.
- Then the station is taken to the second turning station, where the recently freed gripper picks the finished part, and the second workpiece is loaded after rotating the station by 120 degrees.
- Then, the station carrying two finished parts delivers them to the finished tray.

Mounting 3 Gripper in a Plane. Calculating Torque Required.



$$T = mgl\cos\theta + mgl\cos(30+\theta) + mgl\sin\theta$$

$$T = mgl\cos\theta + mgl\left[\cos 30\cos\theta - \sin\theta\sin 30\right] + mgl\sin\theta$$

for max Torque w.r.t θ

$$\frac{dT}{d\theta} = 0$$

$$0 = mgl\left[-\sin\theta - \cos 30\sin\theta - \cos\theta\sin 30 + \cos\theta\right]$$

$$\cos\theta - \sin\theta - \frac{\sqrt{3}}{2}\sin\theta - \frac{1}{2}\cos\theta = 0$$

$$\frac{1}{2}\cos\theta = -\frac{\sqrt{3}}{2}\sin\theta$$

$$\theta = -75^\circ$$

Substituting $\theta = -75^\circ$ in T

$$T = mgl(-\cos(-75^\circ)) + \cos(30-75^\circ) + \sin(-75^\circ))$$

$$T = mgl\,(-0.5176)$$

$$\boxed{T_{max} = 7.321\,Nm}$$

$m = 18$ Kg
$l = 0.24$ m

For this Torque we have choosen Standard Servo motor MH3 140 27, 8Nm torque Servo motor. this suits the application

Shaft design calculations

Gripper Assembly Actuation shaft

Shaft length breakdown:

Gripper mount plate = 15 mm

Fastner clearance = 15 mm

Clearance from support = 70 mm

Load on shaft:

Bending = 20 kg = 200 N × 100 × 10^{-3} = 20 Nm

Torsion = 8.124 Nm

Equivalent Torque for Combined Load

$\Rightarrow T_e = \sqrt{M^2+T^2} = 21.58$ Nm

Equivalent bending moment for Combined Load

$\Rightarrow M_e = \frac{1}{2}\left[M+\sqrt{M^2+T^2}\right] = 20.79$ Nm

Material used for shaft

Aluminium AL 6061T6

Dencity = 2.7 gcc

Yield strength = 276 MPa

Rigedity modulus = G = 26.0 GPa

Elastic modulus E = 68.9 GPa

Shear strength = 207 MPa

The shaft dimensions are selected by considering availability & machinability.

$D_o = 25.4$ mm = 1 inch

$D_i = 12.7$ mm = 0.5 inch

Choosing hollow shaft since it helps with packing of connecting channels for grippers & better weight characterstics

$J = \frac{\pi}{32}(d_o^4 - d_i^4)$

$= \frac{\pi}{32}\left((25.4)^4 - (12.7)^4\right)$

$J = 0.383 \times 10^5$ mm^4

$R = \frac{D_o}{2} = \frac{25.4}{2} = 12.7$ mm

$I = \frac{\pi}{64}(d_o^4 - d_i^4) = 0.1915 \times 10^5$ mm^4

$y = \frac{d_o}{2} = 12.7$ mm

Torsional Equation

$$\frac{T}{J} = \frac{\tau}{R} = \frac{G\theta}{l}$$

Considering negligible length of shaft $l = 100mm$

We design the shaft with focus on strength

$$\frac{T_e}{J} = \frac{\tau}{R}$$

$$\frac{21.58 \times 10^3}{0.383 \times 10^5} = \frac{\tau}{12.7}$$

$$\tau = 7.15409 \, Nmm^{-2}$$

$$\tau = 7.154 \, MPa$$

Shear strength of AL6061 T6 = 207 MPa

Bending equation

$$\sigma = \frac{My}{I}$$

$$= \frac{20.79 \times 12.7 \times 10^3}{0.1915 \times 10^5}$$

$$\sigma = 13.78 \, MPa$$

Allowable stress for the material is 276 MPa

∴ Since the stresses developed in the shaft are less than allowable & fall into the asymptote region of SN Curve for the material, it has infinite life.

Vertical Rack and Pinion Calculations

Rack + Pinion for Vertical Motion

Mass = 28 Kg. $d = 35.15$

Linear Speed $V_a = 0.5$ m/s

$T_a = 0.5$ sec

Acceleration $a = V/t_a = \frac{0.5}{0.5} = 1 m/s^2$

Application force at rack $F_r = \mu Mg + M.a + F$

$F_r = 0.5 \times 28 \times 9.81^{\times 2} + 28 \times 1$

$F_r = 165 \times 2$ N $= 302.68$ N

Application Torque at Pinion $T_p = (F_r \times d)/2000$ Nm

$= \frac{165 \times 35.15 \times 2}{2000} = 2.9 \times 2$ Nm $= 5.8$ N

design torque $t_d = T_p \times S.F$

$= 2.9 \times 1.5 = 4.35 \times 2$ Nm $= 8.7$ Nm

Max rotational speed of Pinion, N_p $N_p = (v \times 19{,}100)/d$ rpm

$= 271.6$ rpm

Pinion Properties

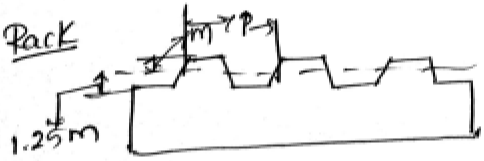
$M = \phi d/z = \frac{35.15}{16} = 2.19$ mm

* theoretical pitch dia $= \phi d_{th} = \frac{Z \times M}{\cos\beta} = 37.28$ mm

* working pitch dia $= \frac{Z \times M}{\cos\beta} + 2 \times Z \times M$

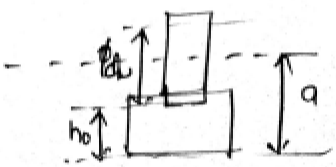
$= 37.727$ mm

Rack



$a = (\phi d_w/2) + h_o$

$a = 36.674$ mm



Horizontal Pinion Calculations

Horizontal Motion

Power = Force x Velocity

$= 350 \times 0.5 = 175\,W$

$V = 0.5\,m/s$ force $= 350\,N$

Pinion $m = 1.5\,mm$ $m = D/T$

$T = 26$ teeth

$D_p = 39\,mm$

$$P = \frac{2\pi N T}{60}$$

$$T = F \cdot r$$

$$T = \frac{350 \times 39}{2000}$$

$$T = 6.825\,Nm$$

$$175 = \frac{2\pi \times 6.82 \times N}{60}$$

$$\boxed{N = 245\,rpm}$$

Ftransmitted

$$F_t = \frac{P}{r} = \frac{175}{0.5} = 350\,N$$

$$F_{t\,effective} = F_t \times N_{cf} \times C_v$$

$N_{cf} = 61.95$ (Data Hand Book)

$$C_v = \frac{6+V_m}{6} = \frac{6+0.5}{6} = 1.08$$

$$F_{t\,effective} = 492.916\,N$$

$$FOS = 2$$

$$F_{t\,pinion} = 985.832\,N$$

$$F_v = S_n \times r \times b \times m$$

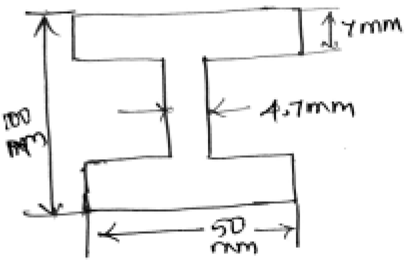
$$= 350 \times 0.346 \times 15 \times 1.5$$

$$F_v = 2724.75\,N$$

$F_{t\,pinion} < F_v$ (Pinion safe)

Horizontal Beam Calculations

Horizontal Beam Calculation



Area moment of Inertia

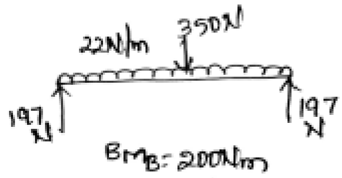
$$I_1 = \frac{50\times7^3}{12} + (7\times50\times46.5^2)$$

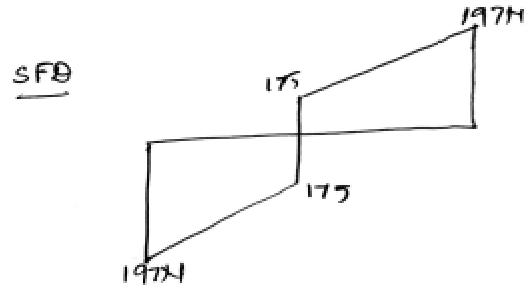
$$I_1 = 758216.66\,mm^4$$

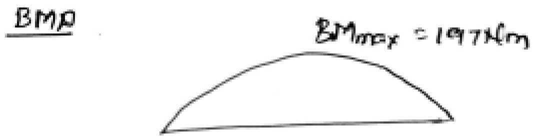
$$I_2 = \frac{4.7\times86^3}{12} = 249121.933\,mm^4$$

$$I_{total} = I_1 + I_2 + I_1 = 1765555\,mm^4$$

$$I_{total} = 1.7655\times10^{-6}\,mm^4$$







$$\frac{\sigma}{y} = \frac{M}{I}$$

$$\frac{\sigma}{50\times10^{-3}} = \frac{200}{1.7655\times10^{-6}}$$

$$\sigma_{max} = 5.664\,MPa$$

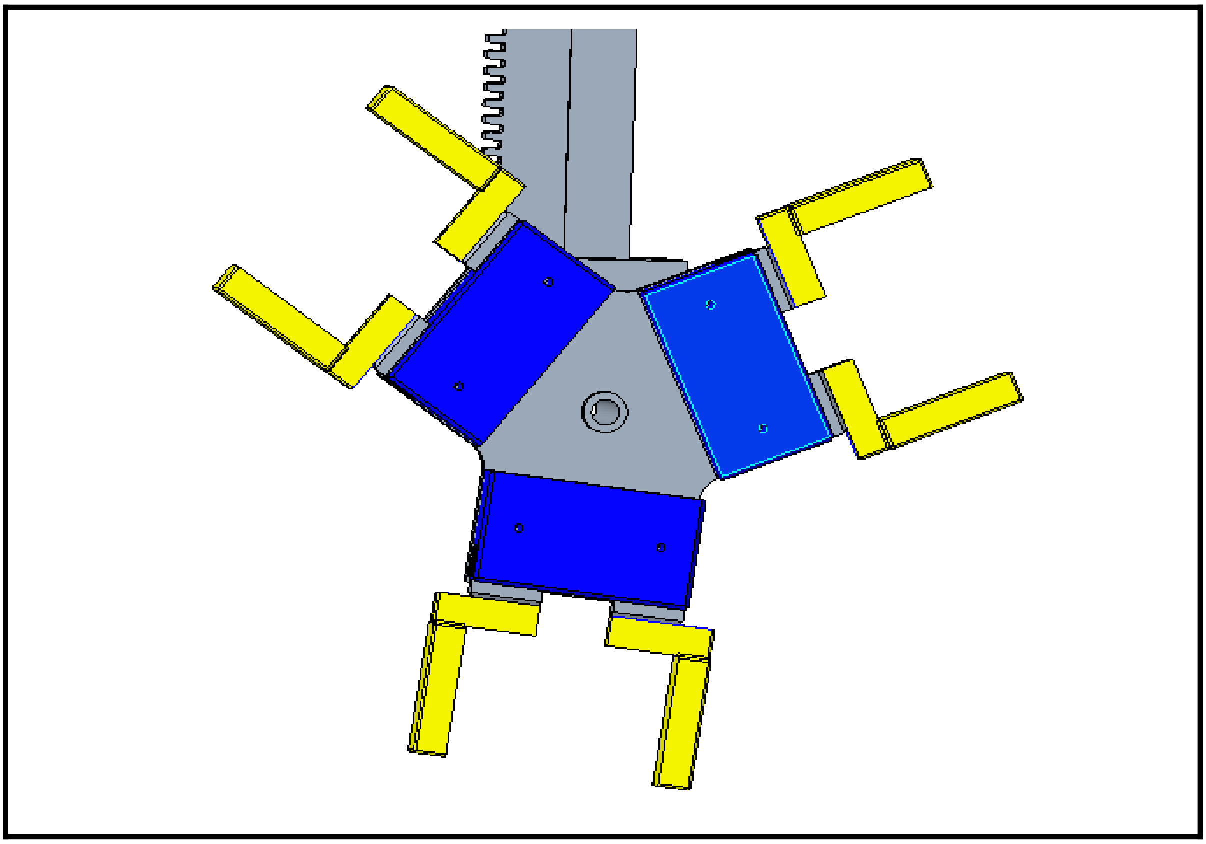
$$\sigma_{max} < \sigma_{yt}$$

$\Rightarrow$ Horizontal Beam is safe

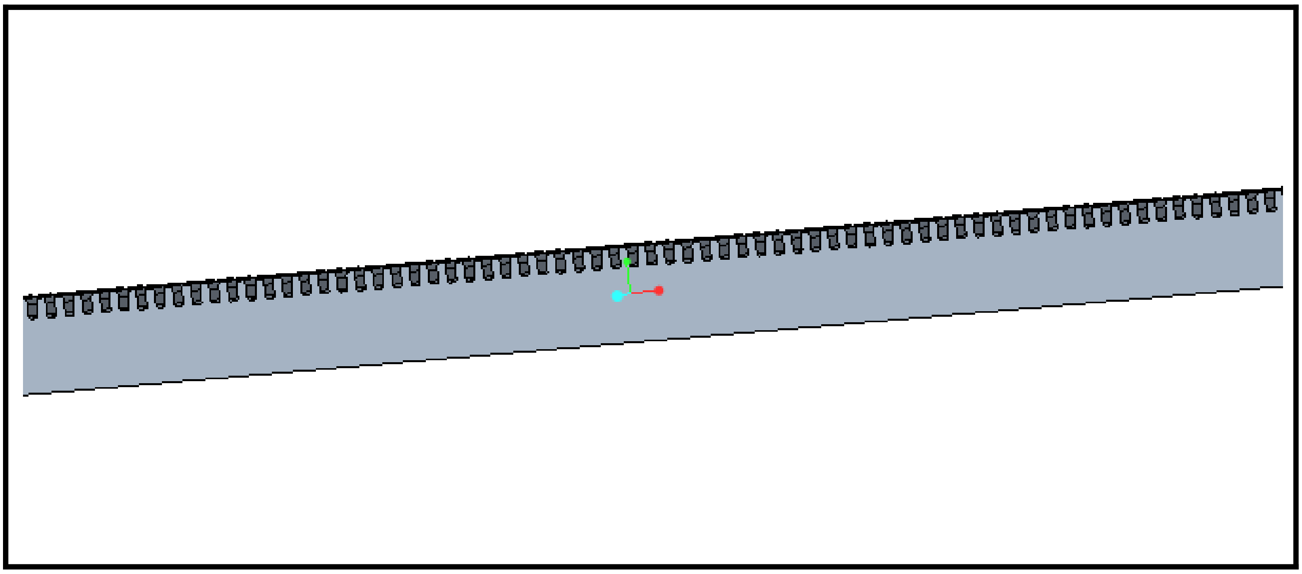
6. CAD Design

Part Models of Subsystems

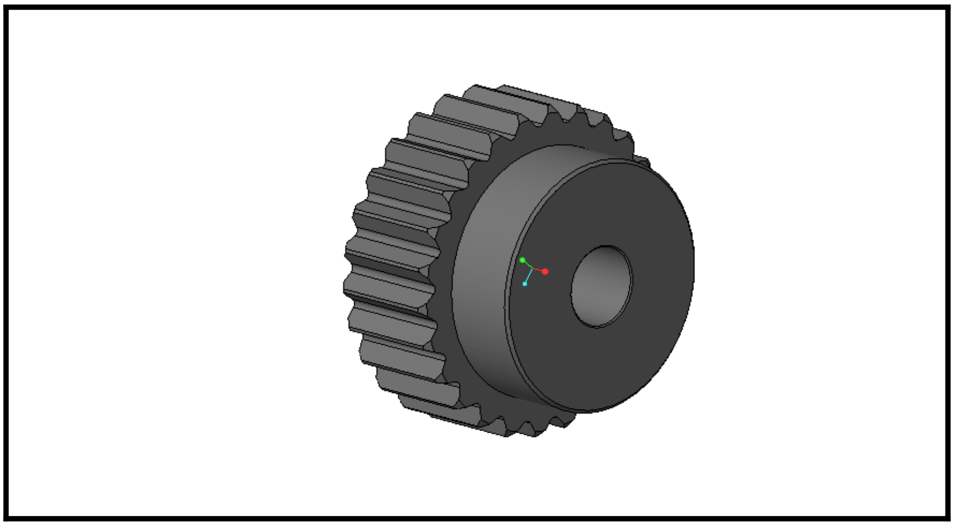
1.Gripper Station



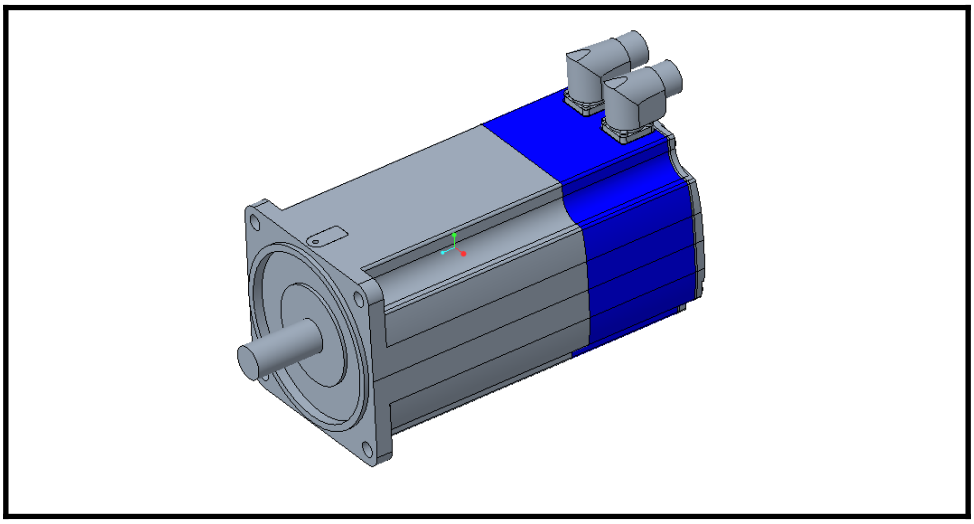
2.Vertical Rack



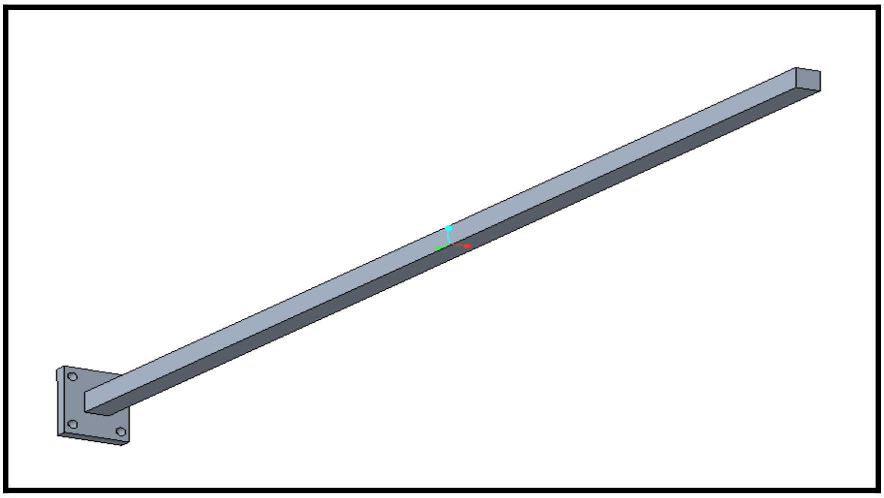
3.Pinion



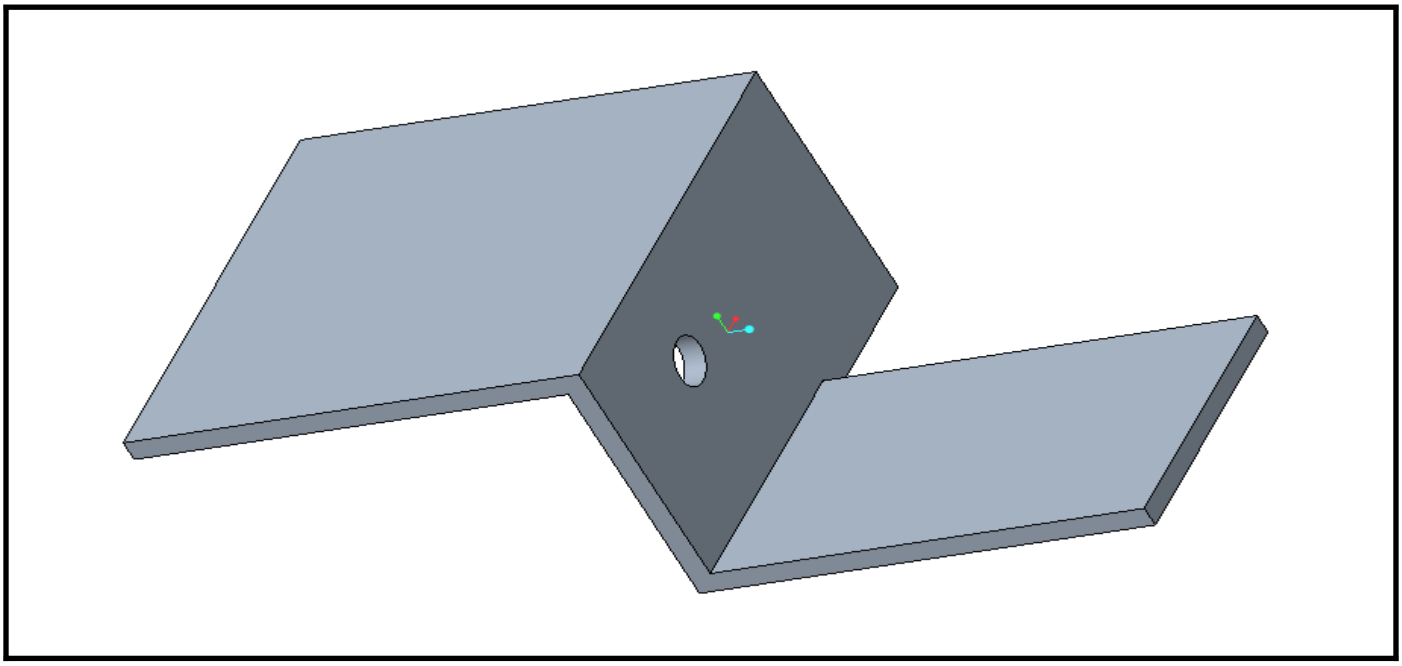
4.Motor



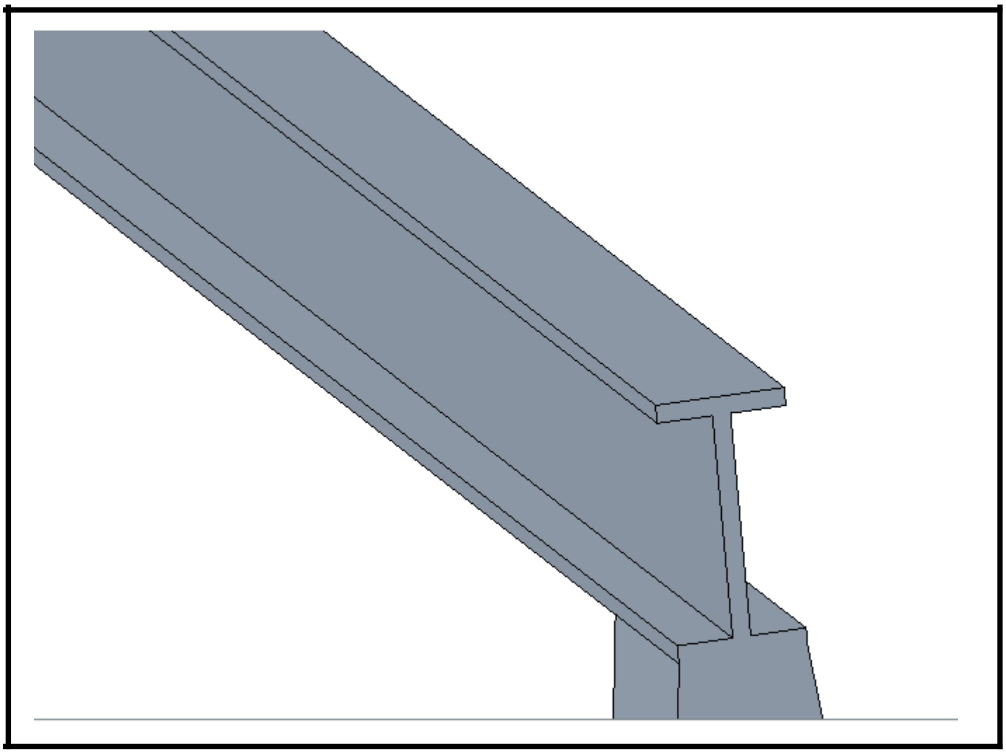
5.Extension



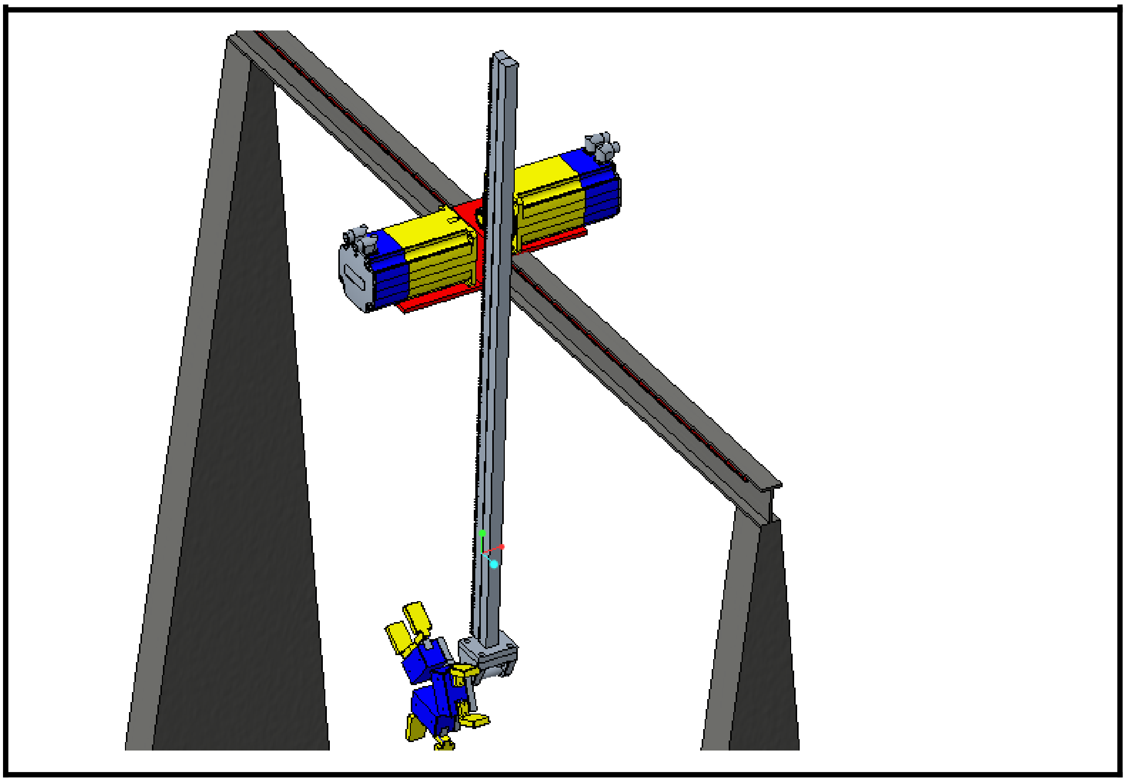
6.Motor Mount



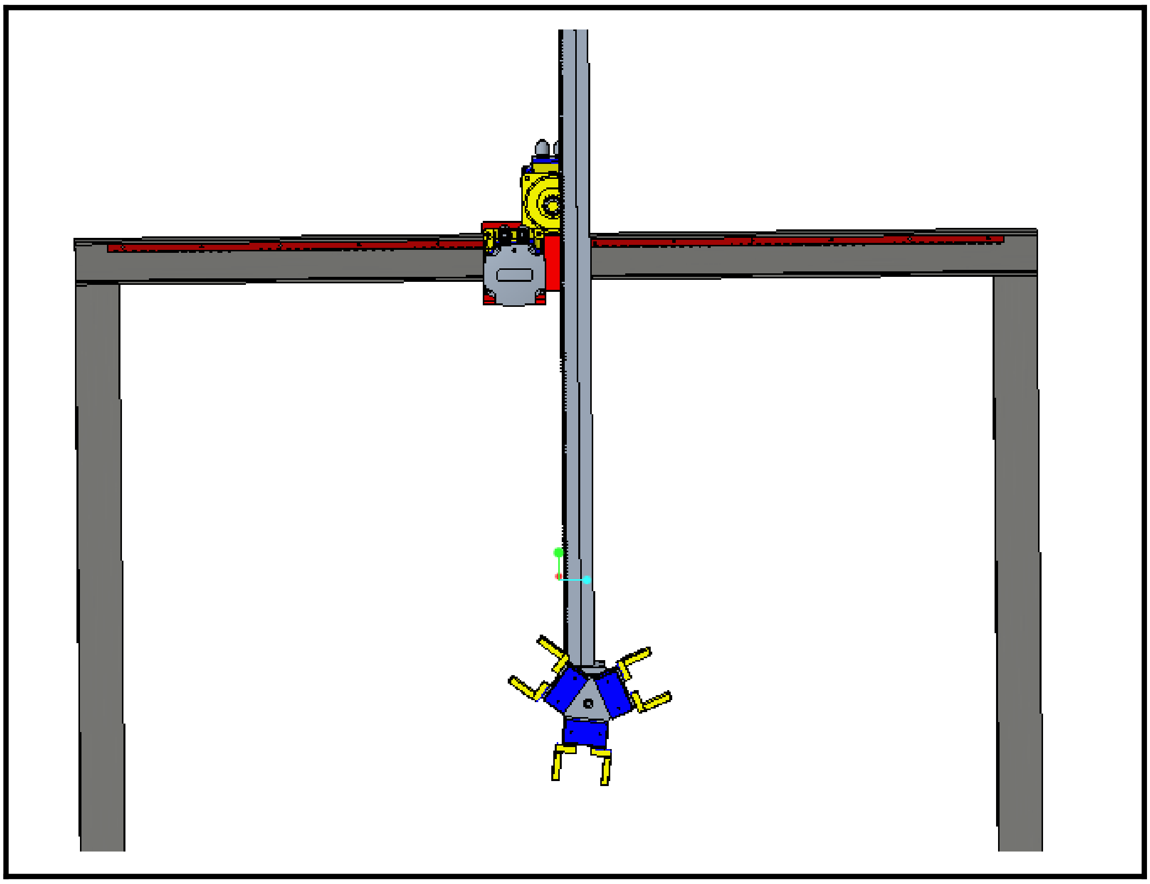
7.Simply Supported Beam



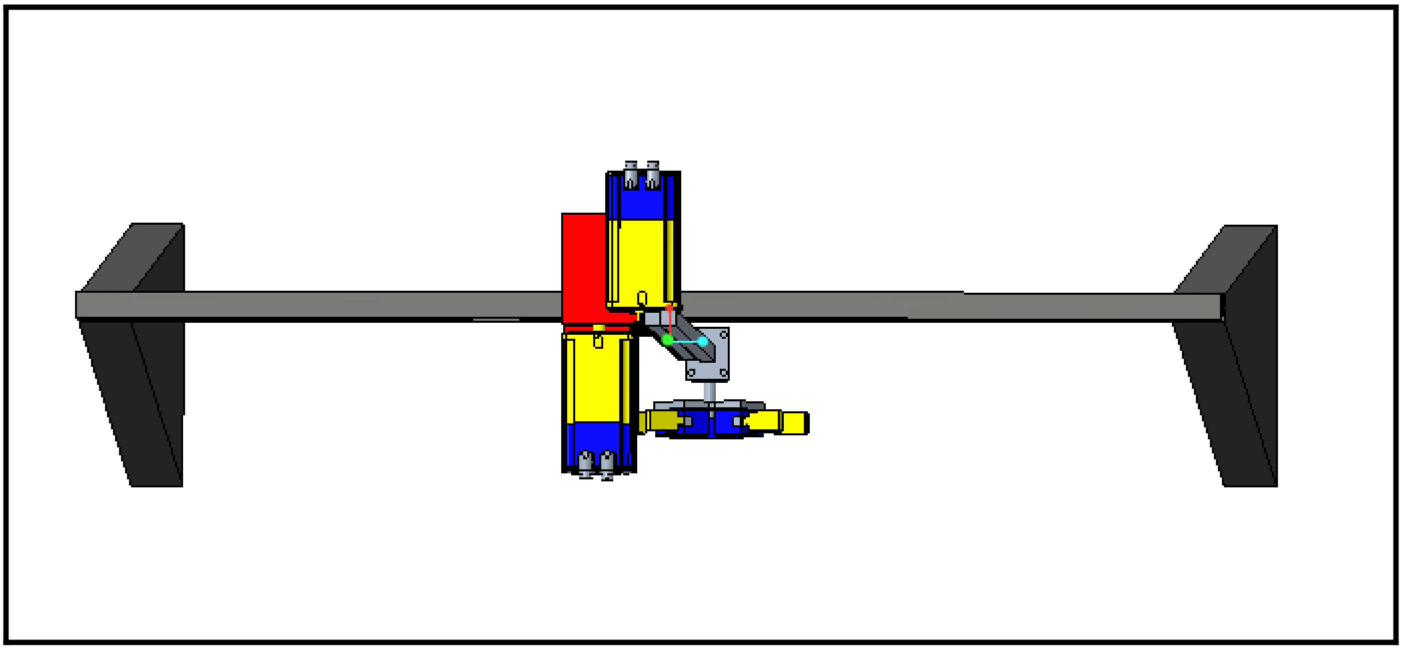
9. CAD Design of Assembly



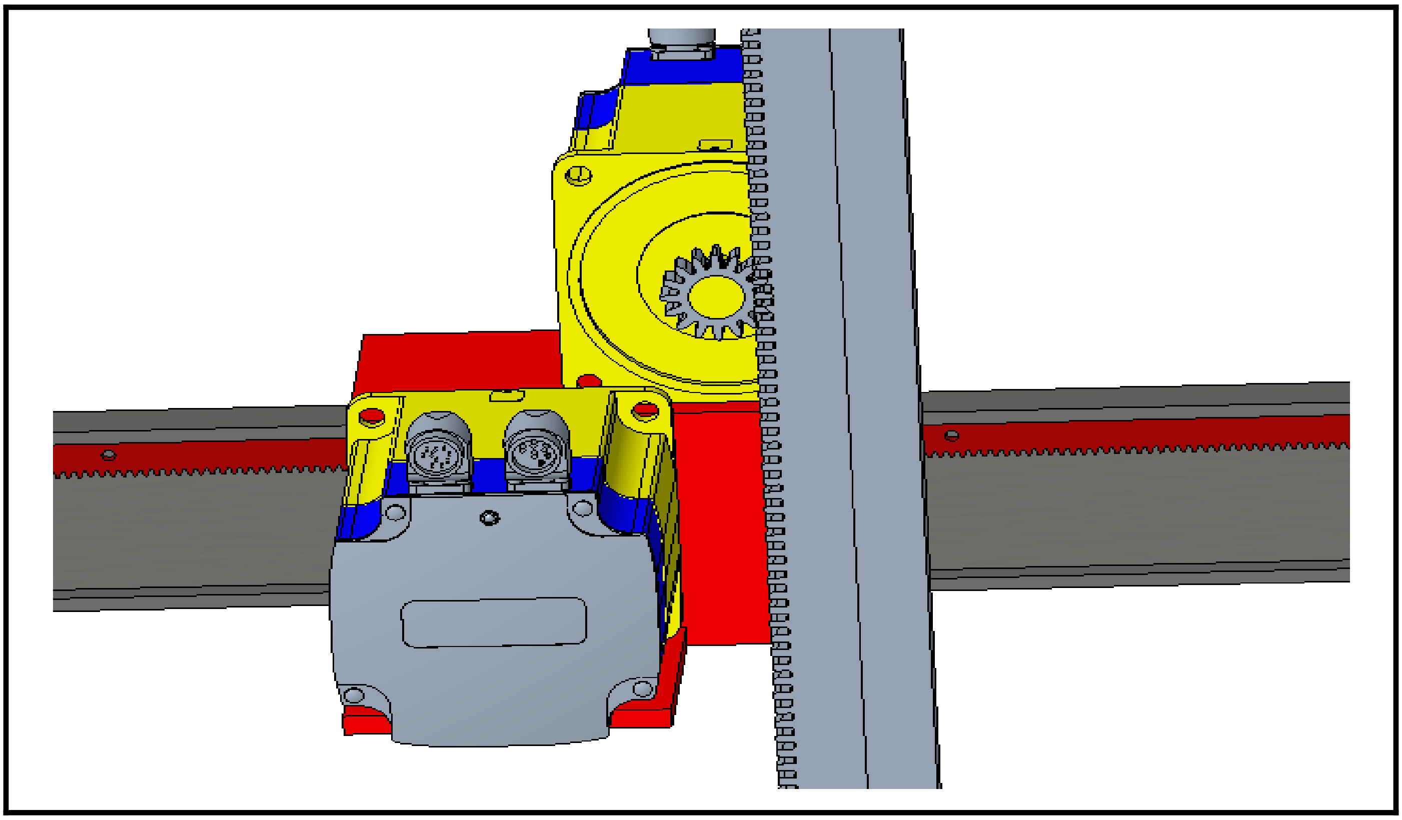
(Isometric view)



(Front view)



(Top view)



SYSTEM DESIGN PROJECT

1. **Problem Statement:** **Select suitable sensors to control the degrees of freedom you have designed. Generate the operational sequence and fault detection logic. Also suggest a suitable controller for the system. Locate the sensors on your assembly.**

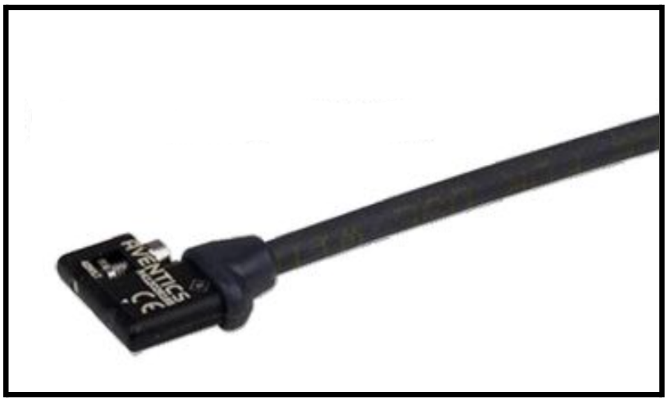
   To automate the mechanical design project we found out some sensors which can be used in the project to automate and we listed how many sensors to use and where to use.

1)**GRIPPER SENSOR FOR UPG 100**

SC4 sensor is used for UPG 100 Gripper

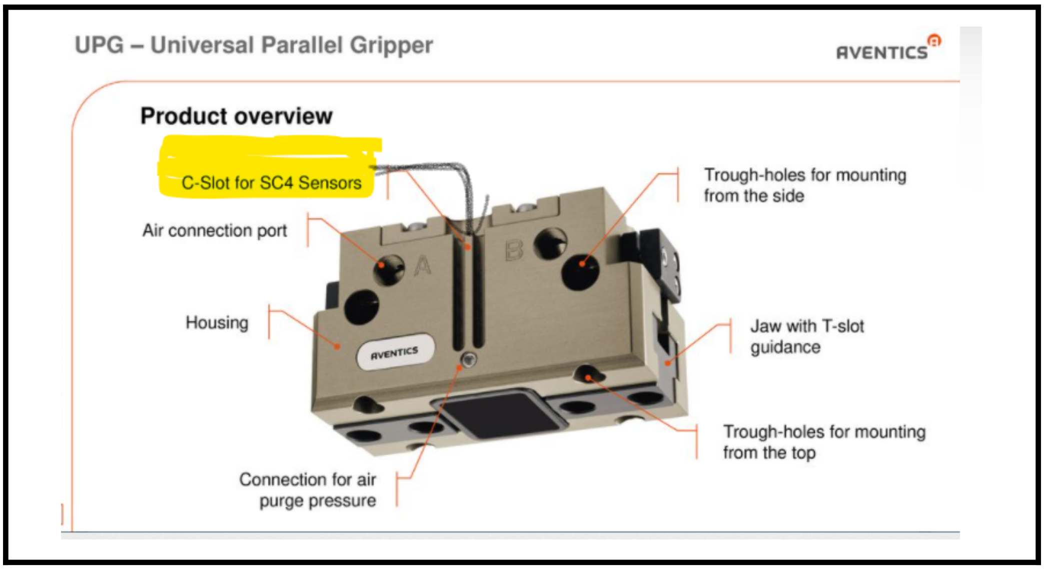
Specifications:

- Extremely small housing(12.2 mm) with LED for indicating the state.
- Output type:PNP or NPN
- Protecting class :IP67



Mounting:

SC4 sensor is directly going to mount on the UPG 100 gripper in the C slot of the gripper like shown in below diagram.



2)VERTICAL SENSOR:

We identified some sensor which helps in measurement of vertical distance

- SU series ultrasonic sensor
- Long range inductive proximity sensor

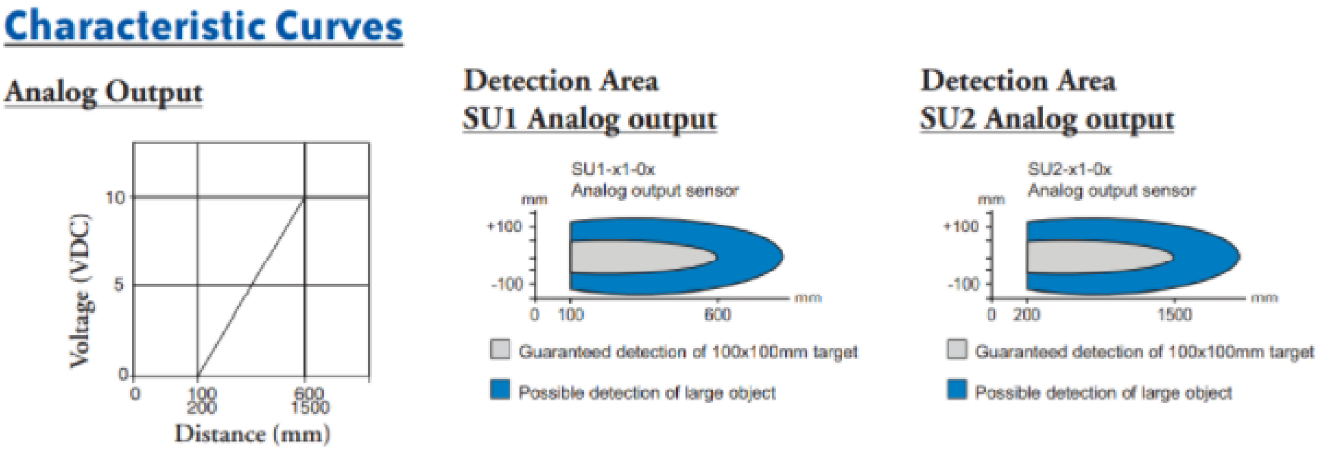
By comparing the above two sensors we find the SU series ultrasonic sensor which best suits our application because of its high resolution and long range detection capacity..

SU series ultrasonic sensor:

M18 (18mm) plastic –DC or analog output

Specifications:

- High resolution
- 2 DC models available with adjustable sensitivity
- 3 analog models available
- Complete overload protection
- IP67 rated
- LED status indicator on DC models



SU Series Ultrasonic DC Output Sensor Selection Chart

Specifications				
Type	*SU1-B0-0A*	*SU2-A0-0A*	*SU1-B1-0**	*SU2-A1-0E*
Differential Travel	±2.5%	±2.0%		
Repeatability	0.20%		±2mm	
Operating Voltage	15-30VDC		18-30VDC	
Linear Error			≤0.3%	
No load supply current	≤35mA			
load current	≤500mA		≤5mA	
leakage current	≤10µA			
voltage drop	≤2.5 volts			
output voltage	PNP / N.O.		0-10VDC	
Ultrasonic Frequency	300KHz	180KHz	300KHz	180KHz
Ultrasonic Beam Angle	8°			
Switching Frequency	25Hz	8Hz		
Max. Response Time			50ms	150ms
(tv) Time Delay Before Availability	≤200ms		≤500ms	
Control Input	Hold / Sync			
Sensitivity Adjustment	Yes			
Input Voltage Transient Production	Yes, only if transient peak does not exceed 30VDC			
Input power polarity reversal protection	Yes			
Output power short circuit protection	Yes (Switch auto resets after overload is removed)			
Temperature range	25° to +70° C (-13° to 158° F)			
Temperature compensation	Yes			
Protection degree	IEC IP67			
LED Indicators	Yellow (Output energized)			
Housing Materials	PBT			
Tightening Torque	3Nm (2.21lb./ft.)			
weight (cable/connector)	54g (1.90oz) / 38g (1.34oz)			

Mounting:

SU Series Ultrasonic Sensor is going to mount on rack because as rack moves from horizontal support below distance varies for detection we mounted sensor on rack.

3)HORIZONTAL SENSOR

We identified some sensor which helps in measurement of horizontal distance

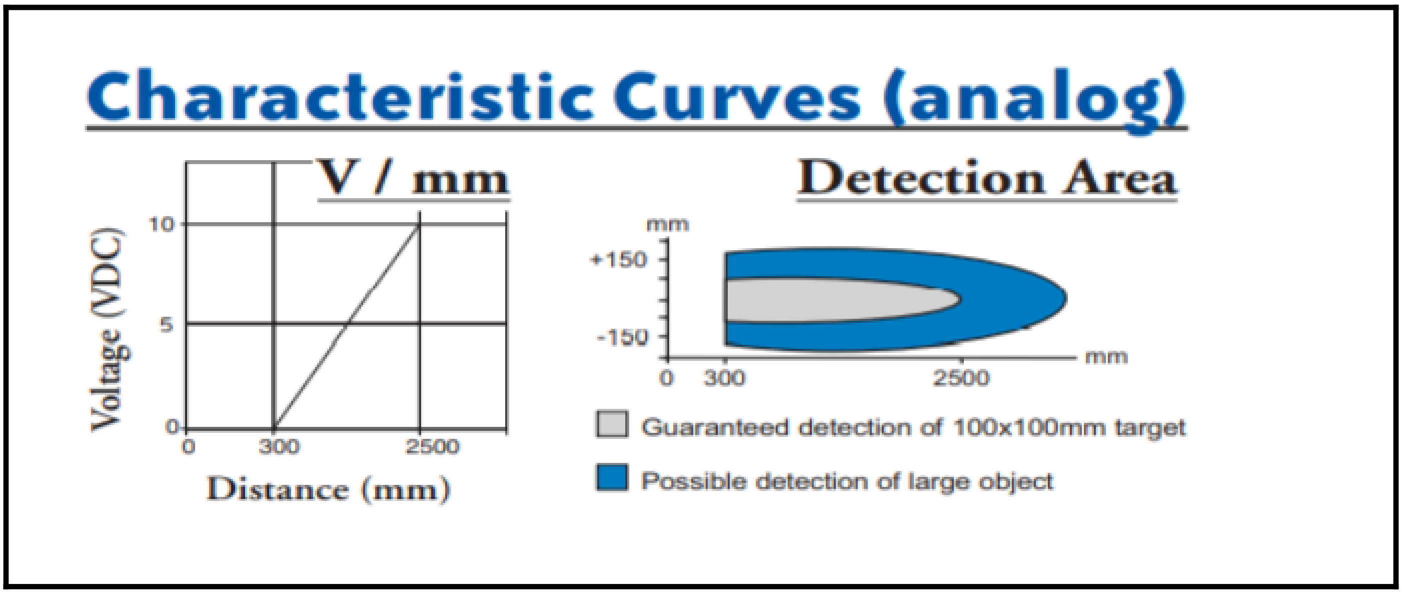
- TU series ultrasonic sensor.
- Long range inductive proximity sensor
- Banner 2000 mm Mid range Photoelectric Sensor

By comparing the above sensors we find the TU series ultrasonic sensor which best suits our application because of its high resolution and long range detection capacity.

TU Series Ultrasonic Sensor:

M30 (30mm) Plastic - DC or Analog Output

- High Resolution
- DC output available
- Complete Overload protection
- IP67 rated
- LED status indicator on DC models



TU Series Ultrasonic DC Output Sensor Selection Chart

Sensor Type	TU1-C0-OE
Accuracy	0.2%
Operating Voltage	19-30 V DC
Load Current	<=500mA
No load supply current	<=35mA
Ultrasonic Frequency	130KHz
Ultrasonic Beam angle	8 degree
Switch frequency	1Hz
Response time	100ms
Protection degree	IP67
Weight	124g

Mounting:

TU Series Ultrasonic Sensor is going to mount on the I section towards the direction of motor mounting to detect varying horizontal distance.

4)Rotation Sensor:

Gyroscope: CRS07 Gyroscope

Specifications:

Typical Data	CRS07-02S	CRS07-11S	CRS07-13S
Angular Rate Range	±100°/s	±573°/s	±100°/s
Output	Analogue voltage (ratiometric)		
Scale Factor			
Nominal	20mV/°/s	3.49mV/°/s	20mV/°/s
Variation over temperature range	< ±5%		
Non-linearity	< ±0.5% of full scale		
Bias			
Setting tolerance	< ±3°/s	< ±30°/s	< ±3°/s
Variation over temperature range	< ±3/s	< ±30°/s	< ±3°/s
Ratiometric error	< ±1°/s		
Drift vs time	< ±55°/s in any 30s period (after start-up time)		
g sensitivity	< ±0.1°/s/g on any axis		
Bandwidth	10Hz (-3dB)	> 30Hz (-3dB)	> 10Hz (-3dB)
Quiescent Noise	< 1mV rms		
Environment			
Temperature	-40°C to +85°C	-20°C to +60°C	-40°C to +85°C
Linear acceleration	< 100g		
Shock	200g (1ms, ½ sine)		
Vibration	2g rms (20Hz to 2kHz, random)		
Cross-axis sensitivity	< 5%		
Mass	< 10 gram		
Electrical			
Supply voltage	+4.75V to +5.25V		
Supply current	< 35mA (steady state)		
Noise and ripple	< 15mV rms (DC to 100Hz)		
Start-up time	< 0.2s		
RoHS Compliant	Yes		

Mounting:

CRS07 Gyroscope is directly mounted on the gripper assembly because the gripper assembly is a rotating member to detect the angular position of the gripper assembly. We use gyroscopes.

5)Workpiece pick and place sensor:

We use two ultrasonic sensors each on a workpiece picking conveyor and workpiece placing(machined component) conveyor.

Total number of sensor used are:

- 3 for gripper
- 1 for vertical
- 1 for horizontal
- 1 for angular position
- 2 for work piece and place

Therefore there are 7 sensors used in the project.

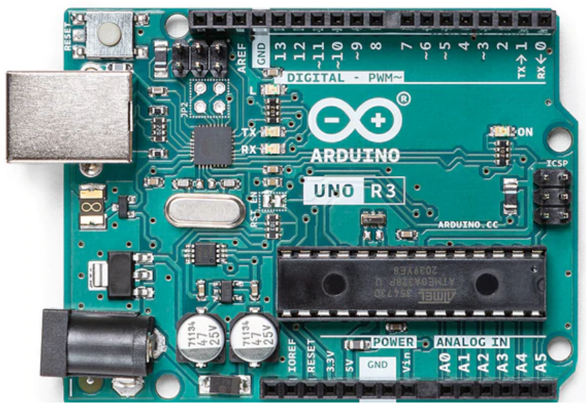
CONTROLLER:

Sensor:

1.Gripper sensor-SC4 Sensor(3 numbers for each gripper)
2.For vertical motion distance measurement-Ultrasonic sensor
3.For Horizontal motion distance measurement-Ultrasonic sensor
4.For rotation angle sensing-Gyroscope
5.For component picked and placed detection - proximity sensor

For 7 Sensors we require 10 input/output pins. For that we chose ARDUINO UNO which has 14 input/output pins which suits our requirements and its ease of use.

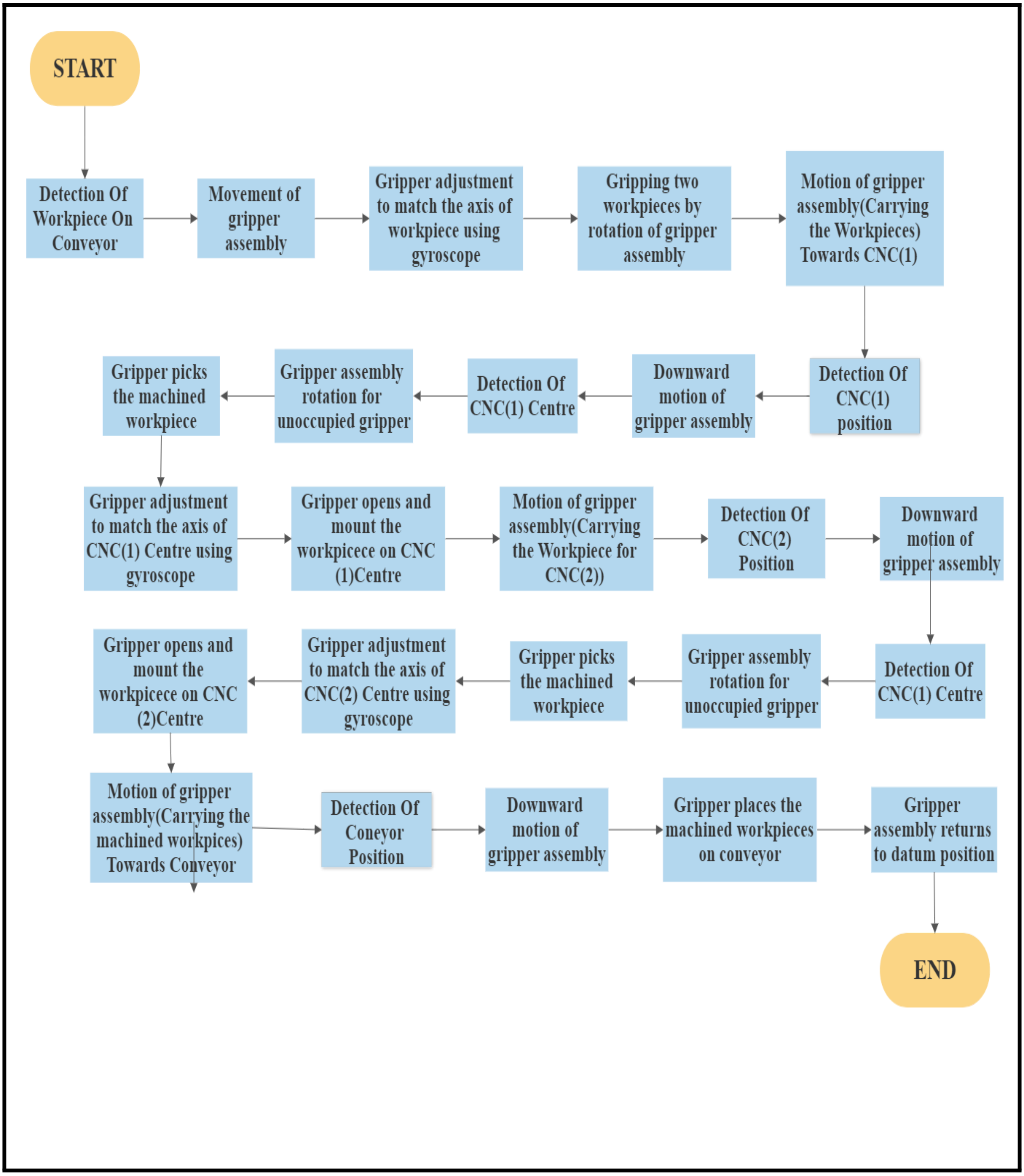
ARDUINO UNO:



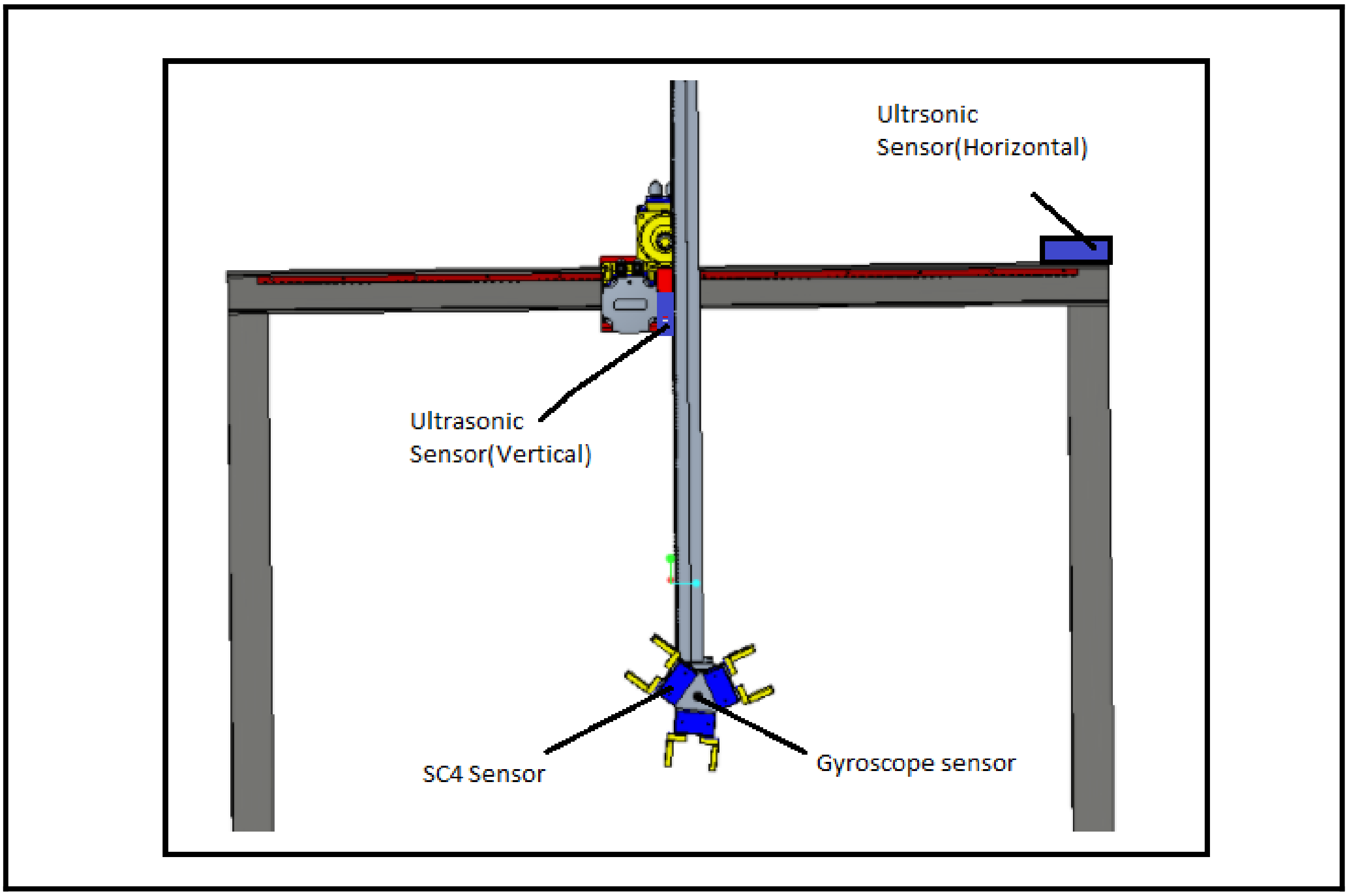
Specifications:

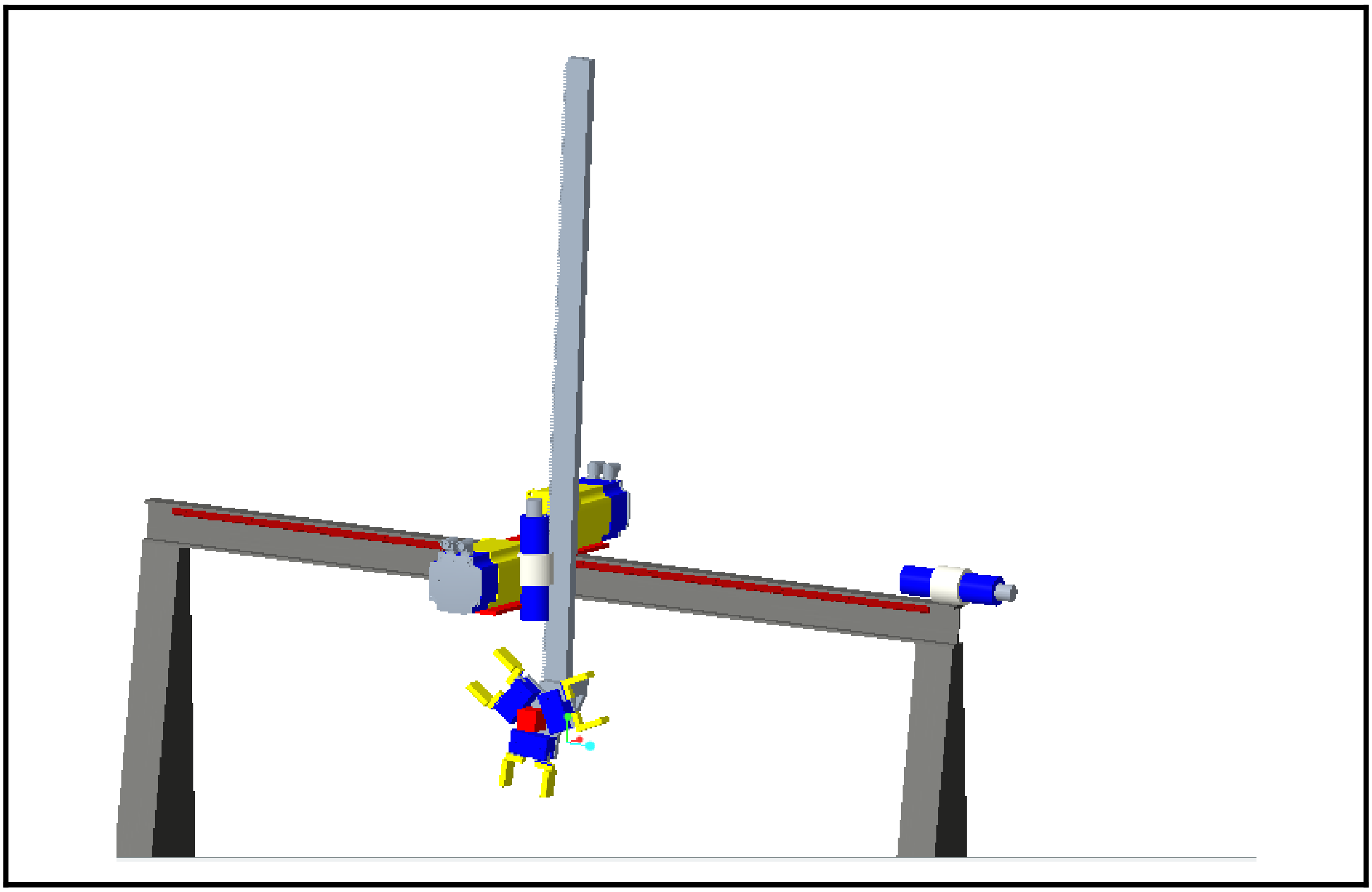
MICROCONTROLLER	ATmega328P
OPERATING VOLTAGE	5V
INPUT VOLTAGE (RECOMMENDED)	7-12V
INPUT VOLTAGE (LIMIT)	6-20V
DIGITAL I/O PINS	14 (of which 6 provide PWM output)
PWM DIGITAL I/O PINS	6
ANALOG INPUT PINS	6
DC CURRENT PER I/O PIN	20 mA
DC CURRENT FOR 3.3V PIN	50 mA
FLASH MEMORY	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
CLOCK SPEED	16 MHz
LED_BUILTIN	13
LENGTH	68.6 mm
WIDTH	53.4 mm
WEIGHT	25 g

FLOW CHART:


START
Detection Of Workpiece On Conveyor
Movement of gripper assembly
Gripper adjustment to match the axis of workpiece using gyroscope
Gripping two workpieces by rotation of gripper assembly
Motion of gripper assembly(Carrying the Workpieces) Towards CNC(1)
Detection Of CNC(1) position
Downward motion of gripper assembly
Detection Of CNC(1) Centre
Gripper assembly rotation for unoccupied gripper
Gripper picks the machined workpiece
Gripper adjustment to match the axis of CNC(1) Centre using gyroscope
Gripper opens and mount the workpicece on CNC (1)Centre
Motion of gripper assembly(Carrying the Workpiece for CNC(2))
Detection Of CNC(2) Position
Downward motion of gripper assembly
Detection Of CNC(1) Centre
Gripper assembly rotation for unoccupied gripper
Gripper picks the machined workpiece
Gripper adjustment to match the axis of CNC(2) Centre using gyroscope
Gripper opens and mount the workpicece on CNC (2)Centre
Motion of gripper assembly(Carrying the machined workpices) Towards Conveyor
Detection Of Coneyor Position
Downward motion of gripper assembly
Gripper places the machined workpieces on conveyor
Gripper assembly returns to datum position
END

SENSOR MOUNTING:





10. Conclusion

We designed the Gantry loader for a turning machine for 3kg weight which can pick and place vertical movement of 1500 mm and horizontal movement of 2000 mm deriving the design calculation of various parts like rack,pinion,motor etc and bending movements. Some standards selected from the catalogs. From these calculations we designed GLTM in Cre0 7.0.

11. References

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[9] https://www.indiamart.com/proddetail/long-range-inductive-proximity-sensor-23335199891.html

12. Annexure

Gripper

Gripper Name	Emerson Aventics UPG 100
Actuation type	pneumatic
Workpiece weight capacity	3.3 Kg
Gripper stroke	20mm
Gripper weight	1 kg

Servo Motor

Motor Name	Power HD Storm 2 servo
Working Torque	3 Nm
Operating voltage	6.4-8.4 V
Speed	430 rpm
Motor type	Brushless
Gear type	Titanium and steel

Servo motor MH3 140

Maximum speed	4000rpm
Tarque	24nm
Shaft Dia	24mm
Shaft length	50mm
Net weight	18.5kg
Maximum radial force (Fr)	2420 N at 1000 rpm 1920 N at 2000 rpm 1670 N at 3000 rpm
Rated supply voltage	115...480 V