Claw Machine

ENME401 Strength of Materials Project

Team 36: **SPARKIH**

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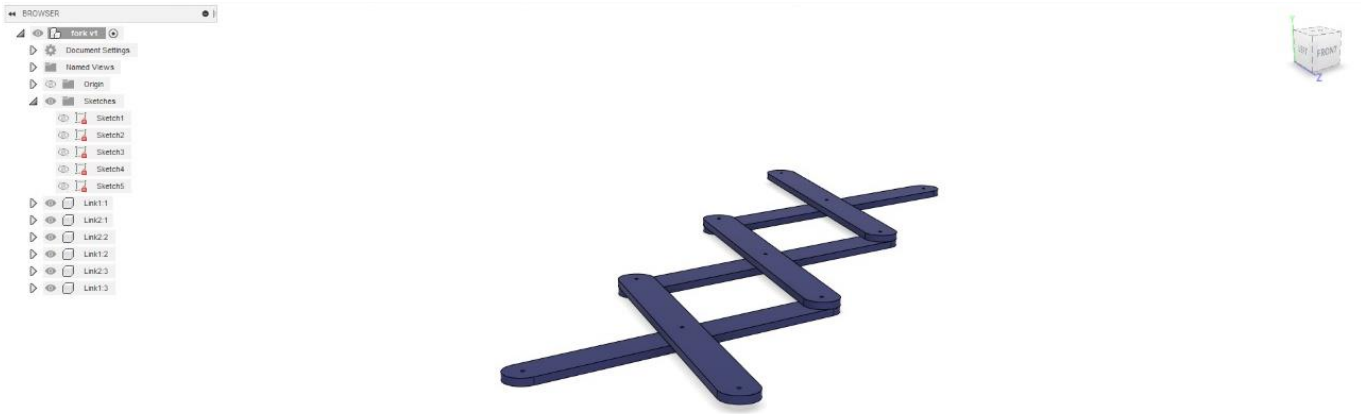
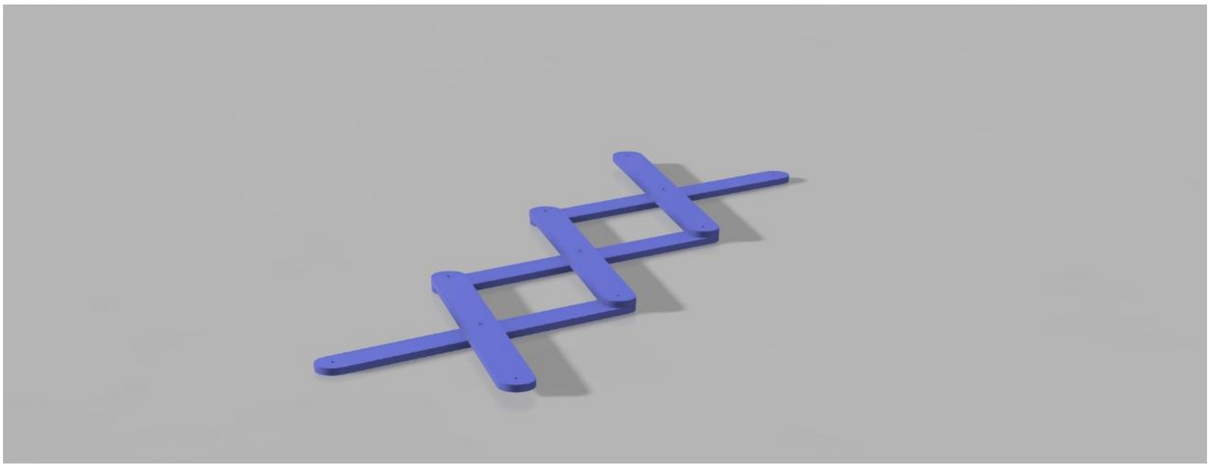
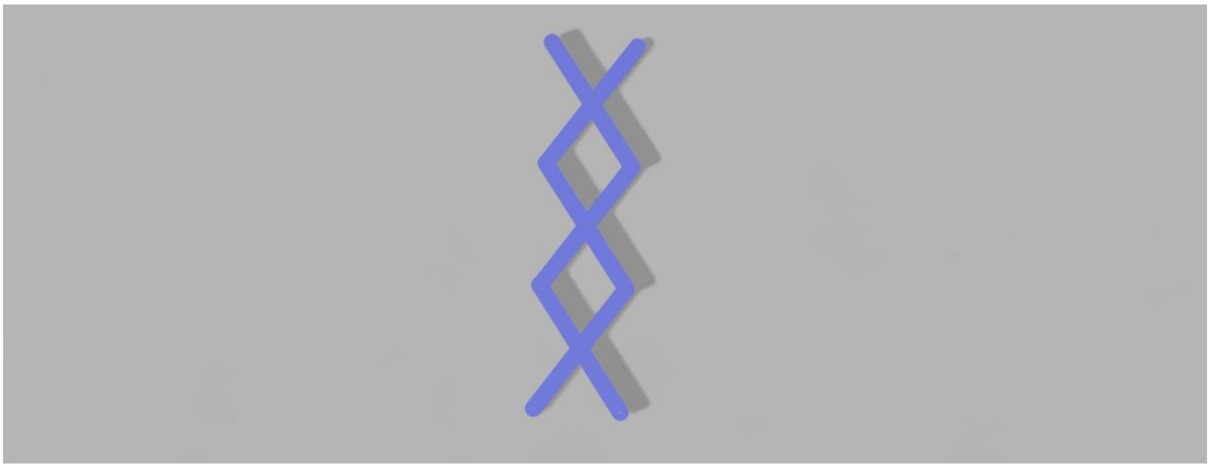
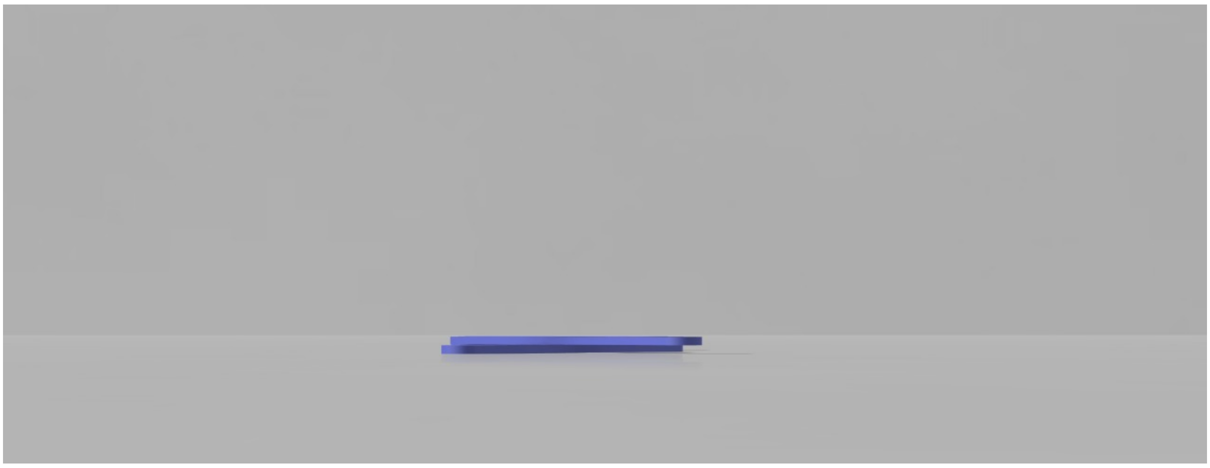
3D MODEL (FUSION 360)









The study report can be found at the end of this document starting page 36.

ANALYSIS

❖ Gripper:

Assume:

- Weight of the load: P = 5 N (m = ~500g)
- Thickness of links: t = 5 mm
- Width of links: w = 10 mm
- σ_{ult} = 33 MPa (The material chosen to make the grip is PLA)
- $\tau_{ult, PLA}$ = 37.5 MPa (The material chosen to make the grip is PLA)
- $\tau_{ult, steel}$ = 280 MPa (The material chosen for the pin is steel)
- diameter hole: d = 2 mm
- Angle of the fingers with the horizontal: θ = 40°

NORMAL STRESS (Tension):

$$\sigma = F/A = \frac{\frac{5}{3}}{5*(10-2)} = 0.04167\ MPa < \sigma_{ult}$$

BEARING STRESS:

$$T * cos(\theta) = \frac{P}{3}$$

$$T = \frac{5}{3 * cos(40)} = 2.17\ N$$

$$\sigma_b = \frac{2.17}{5*2} = 0.217\ MPa < \sigma_{ult}$$

SHEAR STRESS:

$$\tau_{finger} = \frac{\frac{5}{3}}{5*10} = 0.0333\ MPa < \tau_{ult, PLA}$$

(Assuming that there is pin connecting the wire and the grip)

$$\tau_{pin} = \frac{T}{\pi r^2} = \frac{2.17}{\pi * \left(\frac{2}{2}\right)^2} = 0.6907\ MPa < \tau_{ult, steel}$$

❖ Z-axis Fork:

- Angle of the link w.r.t horizontal:

    θ (open state) = 60°

    θ (collapsed state) = 15°

Considering the results of the force analysis at θ = 15° and θ = 60°, we can conclude that at 15° we have higher forces, hence we will analyse the stresses at that angle. (Pages 15-18)

COLLAPSED (θ = 15°):

After force analysis (please refer to the document attached at the end of this report for further details and the forces analysis at 60°):

- P = 2* F sin theta
- F = 9.66 N
- A_x = -37.65 N
- A_y = 0 N
- B_x = 27.99 N
- B_y = 2.5 N
- C_x = 27.99 N
- C_y = 2.5 N
- D_x = 74.64 N
- D_y = 0 N
- R_y = 2.5 N
- S = 46.65 N

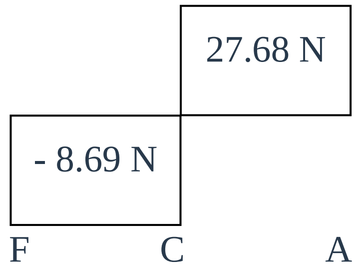
➢ LINK AC (and by symmetry link AB)

Taking into consideration new coordinate axis parallel and normal to the link we get the new values below (for further details please refer to the attached document, Page 19):

- $F_{x'}$ = 9.66 cos 30 = 8.36 N
- $A_{x'}$ = -37.65 cos 15 = -36.37 N
- $C_{x'}$ = 28.1 cos (15-5.1) = 27.68 N ($C_{resultant}$ = 28.1 ∠5.1°)

Normal Stress (Tension):

$$\sigma = \frac{27.68}{5*(10-2)} = 0.692\ MPa < \sigma_{ult}$$



Shear Stress:

$$\tau_{pin\ A} = \frac{37.65}{\pi*(1)^2} = 11.98\ MPa < \tau_{ult,\ steel}$$

Bearing Stress:

$$\sigma_{b,\ A} = \frac{37.65}{5*2} = 3.765\ MPa < \sigma_{ult}$$

$$\sigma_{b,\ B} = \frac{28.1}{5*2} = 2.81\ MPa < \sigma_{ult}$$

$$\sigma_{b,\ C} = \frac{9.66}{5*2} = 0.966\ MPa < \sigma_{ult}$$

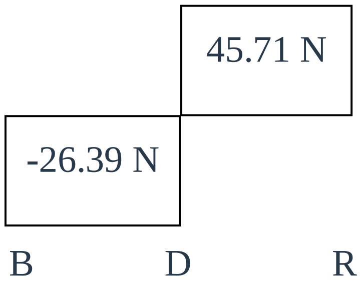
➢ LINK BD (and by symmetry link DC)

Taking into consideration new coordinate axis parallel and normal to the link we get the new values below (for further details please refer to the attached document, Page 20):

- $B_{x'}$ = 28.1 cos (15+5.1) = 26.39 N ($B_{resultant}$ = 28.1 ∠5.1°)
- $R_{x'}$ = 46.72 cos (15-3.07) = 45.71 N ($R_{resultant}$ = 46.72 ∠3.07°)
- $D_{x'}$ = -74.64 cos 15 = -72.10 N

Normal Stress (Tension):

$$\sigma = \frac{45.71}{5*(10-2)} = 1.14\ MPa < \sigma_{ult}$$



Shear Stress:

$$\tau_{pin\ D} = \frac{74.64}{\pi*(1)^2} = 23.76\ MPa < \tau_{ult,\ steel}$$

Bearing Stress:

$$\sigma_{b,\ D} = \frac{74.64}{5*2} = 7.464\ MPa < \sigma_{ult}$$

$$\sigma_{b,\ B} = \frac{28.1}{5*2} = 2.81\ MPa < \sigma_{ult}$$

$$\sigma_{b,\ R} = \frac{46.72}{5*2} = 4.672\ MPa < \sigma_{ult}$$

❖ Column:

The columns are made of cardboard (σ_{ult} = 1.48 MPa).

Assuming the weight of the structure's roof as 20 N and the width of the column 20 mm and its thickness 10 mm.

The weight of the roof will be divided on the 4 columns, therefore:

$$F = \frac{P}{4} = \frac{20}{4} = 5\ N$$

The normal stress in the columns is:

$$\sigma = \frac{-5}{20*10} = -0.025\ MPa < \sigma_{ult}\ \text{(Compression)}$$

MAXIMUM LOAD

Assume for the whole structure:

- Thickness of links: t = 5 mm
- Width of links: w = 10 mm
- σ_{ult} = 33 MPa (The material chosen to make the grip is PLA)
- $\tau_{ult,\ PLA}$ = 37.5 MPa (The material chosen to make the grip is PLA)
- $\sigma_{ult\ ,\ steel}$ = 420 MPa
- $\tau_{ult,\ steel}$ = 280 MPa (The material chosen for the pin is steel)
- diameter hole: d = 2 mm
- Factor of safety n = 2

Using factor of safety = 2 we calculated the following:

- $\sigma_{all\ ,\ PLA}$= 16.5 MPa
- $\tau_{all,\ PLA}$ = 18.75 MPa
- $\tau_{all,\ steel}$ = 140 MPa
- $\sigma_{all\ ,\ steel}$ = 210 MPa

❖ Gripper:

Assume:

- angle of the fingers with the horizontal: θ = 40°
- Diameter of wire = 0.5 mm

$$F = \frac{P}{3}$$

$$T * cos(\theta) = \frac{P}{3}$$

$$T = \frac{P}{3 * cos(40)}$$

NORMAL STRESS (Tension):

σ_{finger} = F/A → 16.5 MPa = $\frac{\frac{P}{3}}{5*(10-2)} \rightarrow P = 1980\ N$

σ_{wire} = T/A → 210 MPa = $\frac{\frac{P}{3*\cos(40)}}{\frac{\pi}{4}*(0.5)^2} \rightarrow P = 94.75\ N$

BEARING STRESS:

$\sigma_b = \frac{P}{3*\cos 40*5*2} = 16.5\ MPa\ \rightarrow P = 379.17\ N$

SHEAR STRESS:

$\tau_{finger} = \frac{\frac{P}{3}}{5*10} = 18.75\ MPa \rightarrow P = 2812.5\ N$

(Assuming that there is a pin connecting the wire and the grip)

$\tau_{pin} = \frac{T}{\pi r^2} = \frac{P}{3*\cos 40*\pi*\left(\frac{2}{2}\right)^2} = 140\ MPa \rightarrow P = 1010.7\ N$

❖ Z-axis Fork:

- Angle of the link w.r.t horizontal:

  θ (open state) = 60°

  θ (collapsed state) = 15°

Considering the results of the force analysis at θ = 15° and θ = 60°, we can conclude that at 15° we have higher forces, hence we will analyse the stresses at that angle. (Same as what happened in the analysis part)

COLLAPSED (θ = 15°):

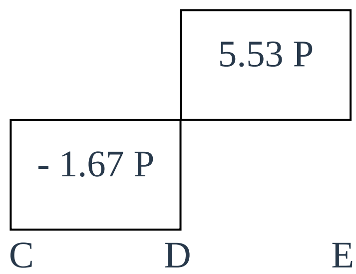
After force analysis (please refer to the document attached at the end of this report for further details, Pages 21-24):

- P = to be found
- F =1.93 P (At point B, C)
- D_x = 7.46 P
- D_y = 0 N
- E_x = 5.6 P
- E_y = 0.5 P
- F_x = 5.6 P
- F_y = 0.5 P
- G_x = 14.93 P
- G_y = 0 N
- R_y = P/2 (At point I and H)
- R_x = S = -9.33 P

➢ LINK EC (and by symmetry link FB)

Taking into consideration new coordinate axis parallel and normal to the link we get the new values below (for further details please refer to the attached document):

- $E_{x'}$ = 5.53 P ($E_{resultant}$ = 5.62 P)
- $D_{x'}$ = -7.2 P ($D_{resultant}$ = 7.46 P)
- $C_{x'}$ = 1.67 P ($C_{resultant}$ = 1.93 P)



Normal Stress (Tension):

$$\sigma = \frac{5.53\,P}{5*(10-2)} = 16.5\ MPa \rightarrow P = 119.35\ N$$

Shear Stress:

$$\tau_{\text{pin D}} = \frac{7.46\,P}{\pi*(1)^2} = 140\ MPa \rightarrow P = 58.96\ N$$

Bearing Stress:

$$\sigma_{b,\,D} = \frac{7.46\,P}{5*2} = 16.5\,MPa \rightarrow P = 22.12\,N$$

$$\sigma_{b,\,E} = \frac{5.62\,P}{5*2} = 16.5\,MPa \rightarrow P = 29.36\,N$$

$$\sigma_{b,\,C} = \frac{1.93\,P}{5*2} = 16.5\,MPa \rightarrow P = 85.49\,N$$

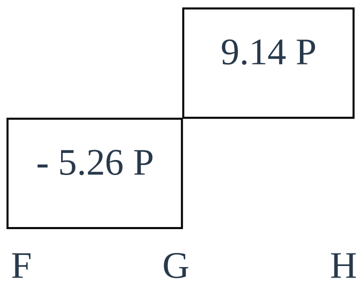
➢ LINK FH (and by symmetry link IE)

Taking into consideration new coordinate axis parallel and normal to the link we get the new values below (for further details please refer to the attached document):

- $H_{x'}$ = 9.14 P ($H_{resultant}$ = 9.34 P)
- $G_{x'}$ = -14.4 P ($G_{resultant}$ = 14.93 P)
- $F_{x'}$ = 5.26 P ($F_{resultant}$ = 5.62 P)

Normal Stress (Tension):

$$\sigma = \frac{9.14\,P}{5*(10-2)} = 16.5\,MPa \rightarrow P = 72.2\,N$$



Shear Stress:

$$\tau_{pin\ G} = \frac{14.93\,P}{\pi*(1)^2} = 140\,MPa \rightarrow P = 29.5\,N$$

Bearing Stress:

$$\sigma_{b,\,G} = \frac{14.93\,P}{5*2} = 16.5\,MPa \rightarrow P = 11.05\,N$$

$$\sigma_{b,\,F} = \frac{5.62\,P}{5*2} = 16.5\,MPa \rightarrow P = 29.36\,N$$

$$\sigma_{b,\,H} = \frac{9.34\,P}{5*2} = 16.5\,MPa \rightarrow P = 17.66\,N$$

Therefore, the maximum load that will satisfy the factor of safety of 2 is the minimum P obtained which is 11.05 N (m = 11.05/9.8 = 1.127 Kg)

❖ Column:

The columns are made of cardboard (σ_{ult} = 1.48 MPa).

Assuming the width of the column as 20 mm and its thickness 10 mm.

The weight of the roof will be divided on the 4 columns, therefore:

$$F = \frac{P}{4}$$

With a factor of safety of n = 2:

$n = \sigma_{ult} / \sigma_{all} \rightarrow \sigma_{all} = 0.74$ MPa

The normal stress in the columns is:

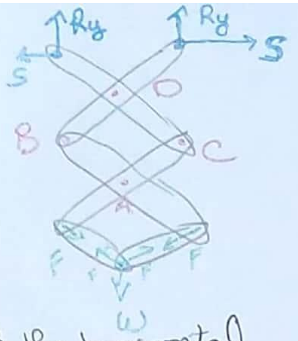
$$\sigma = \frac{-\frac{P}{4}}{20*10} = -0.74\ MPa \text{ (Compression)}$$

$$\rightarrow P = 592\ N$$

Therefore, the columns can withstand up to 60.34 Kg as the weight of the roof including the components.

DETAILED CALCULATIONS

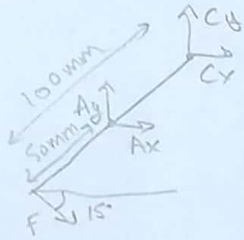
❖ Force analysis for the z-axis fork at 15°:



We will assume $\theta = 15°$ with the horizontal

$\Rightarrow W = 2F \sin 15 \Rightarrow F \approx 9.66N$

* Member AC:

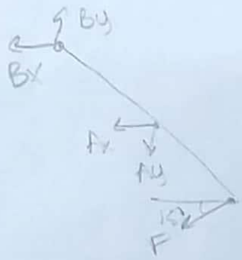


$$* \sum M_A = F\cos 15 \times 50 \sin 15 + F \sin 15 \times 50 \cos 15 + C_y \times 50 \cos 15 - C_x \times 50 \sin 15 = 0 \quad (1)$$

$$* \sum F_x = 0 \Rightarrow F\cos 15 - A_x + C_x = 0 \quad (2)$$

$$* \sum F_y = 0 \Rightarrow C_y + A_y - F \sin 15 = 0 \quad (3)$$

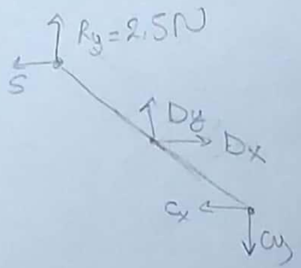
* Member AB:



$$* \sum F_x \Rightarrow -F\cos 15 - A_x - B_x = 0 \quad (4)$$

$$* \sum F_y \Rightarrow -A_y + B_y - F \sin 15 = 0 \quad (5)$$

* Member CD:

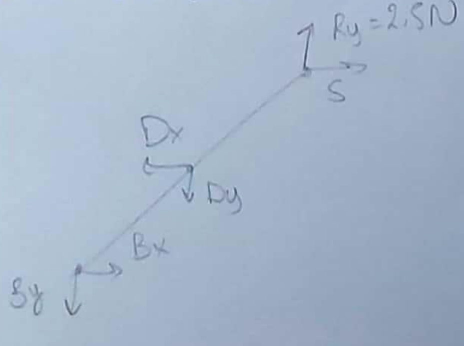


$$* \sum M_D = S \times 50 \sin 15 - R_y \times 50 \cos 15 - C_x \, 50 \sin 15 - C_y \, 50 \cos 15 = 0 \quad (6)$$

$$* \sum F_x \Rightarrow D_x - C_x - S = 0 \quad (7)$$

$$* \sum F_y \Rightarrow D_y - C_y + R_y = 0 \quad (8)$$

* Member BD:



$$* \sum F_x \Rightarrow B_x + S - D_x = 0 \quad (9)$$

$$* \sum F_y \Rightarrow B_y + D_y - R_y = 0 \quad (10)$$

Due to symmetry w.r.t the (AD) axis
we can conclude that :

$B_x = C_x$; $B_y = C_y$

$eq(3-5) \Rightarrow 2A_y = 0 \Rightarrow A_y = 0N$

$eq(8+10) \Rightarrow 2D_y = 0 \Rightarrow D_y = 0N$

$③ \Rightarrow C_y = B_y = F\sin 15 \approx 2.5N$

$$① \Rightarrow C_x = \frac{2 \times 50\, F \cos 15 \sin 15 + C_y \times 50 \times \cos 15}{50 \sin 15} \approx 27.99N$$

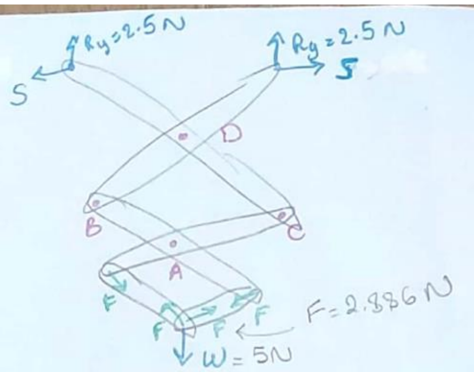
$$⑥ \Rightarrow S = \frac{B_y \times 50 \cos 15 + C_y \times 50 \cos 15 + C_x\, 50 \sin 15}{50 \sin 15} \approx 46.65N$$

$④ \Rightarrow A_x = -C_x - F\cos 15 \approx -37.32\,N$

$⑦ \Rightarrow D_x = S + C_x \approx 74.64\,N$

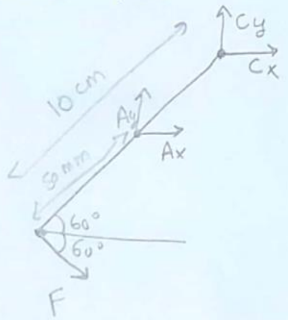
$$\Rightarrow \boxed{\begin{array}{l} A_x \approx -37.32N \\ A_y = 0N \\ B_x \approx 27.99N \\ B_y = 2.5N \\ C_x \approx 27.99N \\ C_y = 2.5N \\ D_x \approx 74.64N \\ D_y = 0N \\ S \approx 46.65N \end{array}}$$

❖ Force analysis for the z-axis fork at 60°:



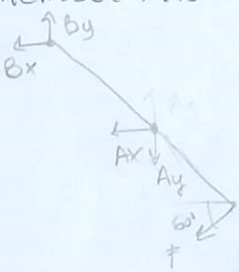
($W = 2 \times F \sin 60$
$\Rightarrow F = \dfrac{W}{2 \sin 60}$ 2.886N)

Member AC:



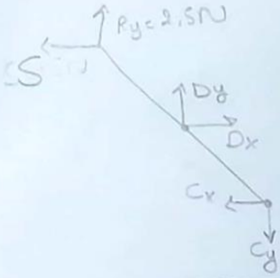
* $\sum M_A = F\cos 60 \times 50 \sin 60 + F\sin 60 \times 50 \cos 60 + C_y \times 50 \cos 60 - C_x \times 50 \sin 60 = 0$ (1)
* $\sum F_x = 0 \Rightarrow F\cos 60 + A_x + C_x = 0$ (2)
* $\sum F_y = 0 \Rightarrow C_y + A_y - F\sin 60 = 0$ (3)

Member AB:



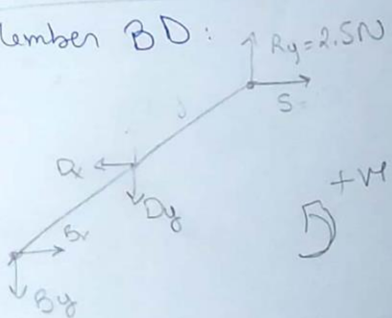
* $\sum M_A = -F\cos 60 \times 50 \sin 60 - F\sin 60 \times 50 \cos 60 + B_x \; 50 \sin 60 - B_y \; 50 \cos 60 = 0$ (4)
* $\sum F_x \Rightarrow -F\cos 60 - A_x - B_x = 0$ (5)
* $\sum F_y \Rightarrow -A_y + B_y - F\sin 60 = 0$ (6)

Member CD:



* $\sum M_D = S \times 50 \sin 60 - R_y \times 50 \cos 60 - C_x \; 50 \sin 60 - C_y \; 50 \cos 60 = 0$ (7)
* $\sum F_x \Rightarrow D_x - C_x - S = 0$ (8)
* $\sum F_y \Rightarrow D_y - C_y + R_y = 0$ (9)

Member BD:



* $\sum M_D = -S \times 50 \sin 60 + R_y \times 50 \cos 60 + B_x \times 50 \sin 60 + B_y \; 50 \cos 60 = 0$ (10)

+ve

* $\sum F_x \Rightarrow B_x + S - D_x = 0$ (11)
* $\sum F_y \Rightarrow B_y + D_y - R_y = 0$ (12)

Due to Symmetry in the (AD) axis
we can conclude that:

$B_x = C_x$; $B_y = C_y$

eq (3-6) $\Rightarrow 2A_y = 0 \Rightarrow A_y = 0\,N$

eq (9+12) $\Rightarrow 2D_y = 0 \Rightarrow D_y = 0\,N$

(3) $\Rightarrow C_y = B_y = F \sin 60 \approx 2.5\,N$

(1) $\Rightarrow C_x = \dfrac{2 \times 50 \times F \cos 60 \sin 60 + C_y \times 50 \times \cos 60}{50 \sin 60} \approx 4.33\,N$

(7) $\Rightarrow S = \dfrac{R_y \times 50 \cos 60 + C_y \times 50 \cos 60 + C_x\, 50 \sin 60}{50 \sin 60} \approx 7.216\,N$

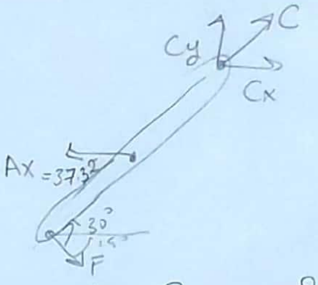
(5) $\Rightarrow A_x = -C_x - F \cos 60 \approx -5.77\,N$

(8) $\Rightarrow D_x = S + C_x \approx 11.55\,N$

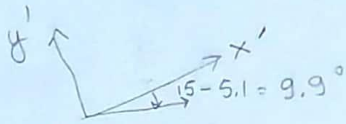
$$\Rightarrow \boxed{\begin{aligned} A_x &= -5.77\,N \\ A_y &= 0\,N \\ B_x &= 4.33\,N \\ B_y &= 2.5\,N \\ C_x &= 4.33\,N \\ C_y &= 2.5\,N \\ D_x &= 11.55\,N \\ D_y &= 0\,N \\ S &= 7.22\,N \end{aligned}}$$

Another way of calculating the force analysis can be found at Page 27 where we fixed the force represented by the letter S at a value of 15 N.

❖ Stress analysis at link AC:



$C = 28.1 \angle 5.1^\circ$



$\Rightarrow C_{x'} = 28.1 \cos 9.9 \simeq 27.68\ N$ (Normal)

$C_{y'} = 28.1 \sin 9.9 \simeq -4.83\ N$ (Shear)

$A_{x'} = -37.32 \cos 15 = -36.04\ N$

$A_{y'} = 9.66\ N$

$F_{x'} = 9.66 \cos 30 = 8.36\ N$

$F_{y'} = 4.83\ N$

Normal stress: (In tension)

$\sigma_{AC} = \dfrac{27.68}{5 \times (10 - 2)} \approx 0.692\ MPa$

27.68

−8.36 N

Shear stress:

$\tau_{pin\ A} = \dfrac{37.32}{\pi (1)^2} \simeq 11.88\ MPa$

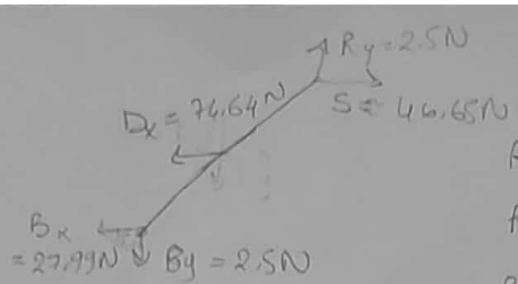
Bearing stress:

$\sigma_b\ (pin\ A) = \dfrac{37.32}{2 \times 5} = 3.732\ MPa$

$\sigma_b\ (pin\ C) = \dfrac{28.1}{2 \times 5} = 2.81\ MPa$

$\sigma_b\ (pin\ F) = \dfrac{9.66}{2 \times 5} = 0.966\ MPa$

❖ Stress analysis at link BD:



$R = 46.72 \angle 3.07^\circ$

$B = 28.10 \angle 5.10^\circ$

$R_x' = 46.72 \cos 11.93 \approx 45.71$ N (angle 15 − 3.07)

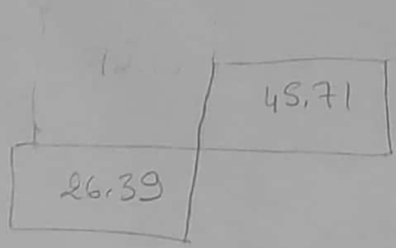
$R_y' = -9.66$ N

$B_x' = +26.39$ N (angle 5.1 + 15)

$B_y' = +9.66$ N

$D_x' = -72.10$ N (angle 0 + 15)

$D_y' = 19.32$ N



Normal Stress (tension)

$$\sigma = \frac{45.76}{5 \times (10-2)} = 1.1445 \text{ MPa}$$

Shear stress

$$\tau_D = \frac{74.64}{\pi \cdot (1)^2} = 23.76 \text{ MPa}$$

Bearing stress:

$$\sigma_b \text{ (pin B)} = \frac{28.1}{5 \times 2} = 2.81 \text{ MPa}$$

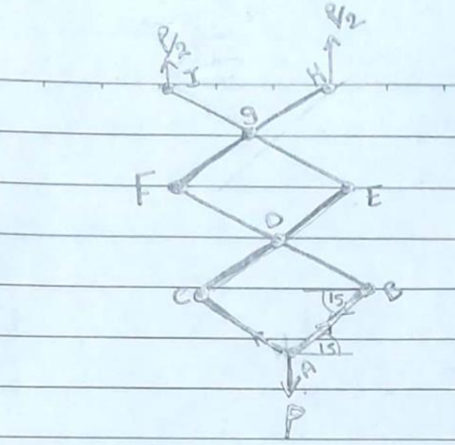
$$\sigma_b \text{ (pin D)} = \frac{74.64}{5 \times 2} = 7.464 \text{ MPa}$$

$$\sigma_b \text{ (pin R)} = \frac{46.72}{5 \times 2} = 4.672 \text{ MPa}$$

❖ Max load at the z-fork and gripper:

SUB

DATE



thickness = 5mm
width = 10mm
length = 100 mm
SF = 2
d_{pin} = 2mm

σ_{max} = 33 Mpa

τ_{max} = 37.5 Mpa

$\tau_{max\ for\ steel}$ = 280 Mpa

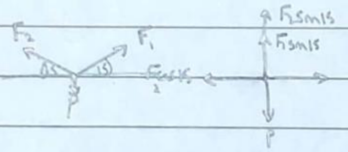
$\sigma_{allowable} = \frac{33}{2} = 16.5$ Mpa

$\tau_{allowable} = \frac{37.5}{2} = 18.75$ Mpa

$\tau_{allowable} = \frac{280}{2} = 140$ Mpa

$\sigma_{max\ for\ steel}$ = 420 Mpa

$\sigma_{allowable} = \frac{420}{2} = 210$ Mpa



$F_1 \cos 15$ $\quad \Sigma F_x = 0,\ F_1 = F_2$

$\Sigma F_y = 0$

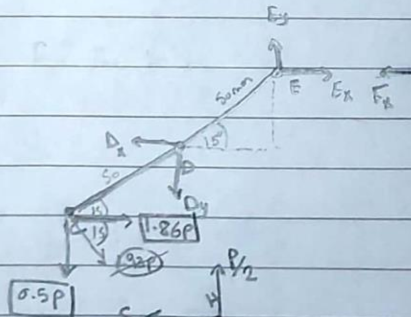
$2F \sin 15 = P$

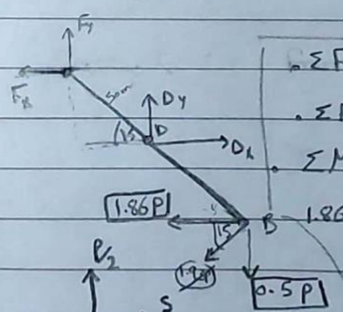
$F = 1.93\,P$

in link AB (link under tension) and CB:

$$\sigma_{normal} = \frac{F}{A} = \frac{1.93\,P}{5\times10\times10^{-6}} = 16.5\ \text{Mpa}$$

$\boxed{P = 427.5\ N}$



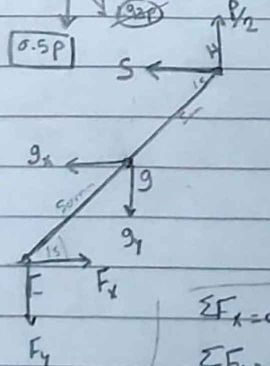


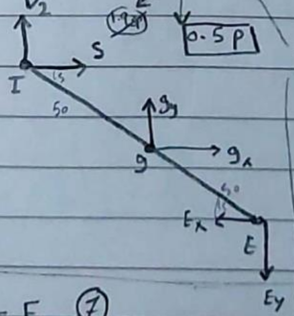
$\Sigma F_x = 0,\ E_x - D_x = -1.86\,P$ (1)

$\Sigma F_y = 0,\ E_y - D_y = 0.5\,P$ (2)

$\Sigma M_D = 0,$

$1.86\times50\sin15\,P + 0.5\times50\cos15\,P + 50\cos15\,E_y - 50\sin15\,E_x = 0$ (3)





$\Sigma F_x = 0,\ -F_x + D_x = 1.86\,P$ (4)

$\Sigma F_y = 0,\ F_y + D_y = 0.5\,P$ (5)

$\Sigma M_D = 0,$ (6)

$-1.86\times50\sin15\,P - 0.5\times50\cos15\,P + 50\sin15\,F_x - 50\cos15\,F_y = 0$

$\Sigma F_x = 0,\ S + g_x = F_x$ (7)

$\Sigma F_y = 0,\ \frac{P}{2} - g_y = F_y$ (8)

$\Sigma M_g = 0,$ (9)

$50\sin15\,F_x + 50\cos15\,F_y + 50\cos15\,\frac{P}{2} + 50\sin15\,S = 0$

$\Sigma F_x = 0,\ S + g_x = E_x$ (10)

$\Sigma F_y = 0,\ \frac{P}{2} + g_y = E_y$ (11)

$\Sigma M_g = 0,\ -50\cos15\,\frac{P}{2} - 50\sin15\,S - E_x\,50\sin15 - 50\cos15\,E_y = 0$ (12)

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from the symmetry, it's obvious that $E_x = F_x$ and $E_y = F_y$

eq (5-2): $\cancel{F_y} + D_y - \cancel{E_y} + D_y = 0$

$2D_y = 0 \qquad \boxed{D_y = 0}$

eq (~~1~~1-8): $\cancel{\frac{P}{2}} + g_y - \cancel{\frac{P}{2}} + g_y = \cancel{E_y - F_y} = 0$

$2g_y = 0 \qquad \boxed{g_y = 0}$

from eq 2 $\qquad \boxed{F_y = E_y = 0.5P}$

from eq 3

$1.86 \times 50 \sin 15 P + \overset{0.5\times 50 \times \cos 15 P}{P} + 50\cos 15 \times 0.5P - 50 \sin 15 E_x = 0$

$\boxed{E_x = 5.6\ P} \qquad \boxed{E_x = F_x = 5.6\ P}$

from eq 1 $\qquad E_x - D_x = -1.86P$

$\boxed{D_x = 7.46\ P}$

from eq 4 $\qquad 50 \sin 15 \times 5.6P + 50 \cos 15 \times 0.5P + 50 \cos 15 \frac{P}{2} + 50 \sin 15 (S) = 0$

$\boxed{S = -9.33P}$

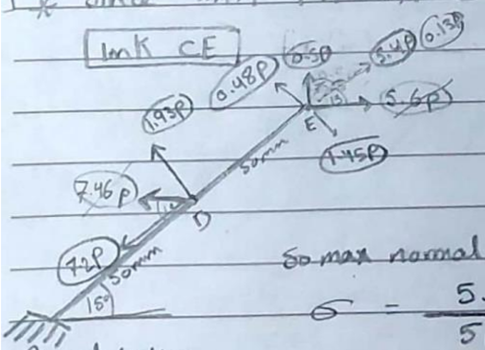
from eq 7 $\qquad S + g_x = F_x$

$\boxed{g_x = 5.6P + 9.33P = 14.93P}$

* since link CE and FG are the same we will study only link CE

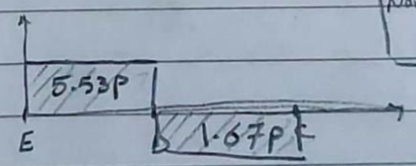
* since link FH and EI are the same we will study only link FH

link CE



fix at link C

Normal force diagram



so max normal will be in ED at E

$$\sigma = \frac{5.53P}{5(10-2)\times 10^{-6}} = 16.5\ Mpa \qquad \boxed{P = 119.35\ N}$$

$$E = \sqrt{E_x^2 + E_y^2} = 5.62P$$

$$D = 7.46P$$

max shear is at D (single shear)

$$\tau = \frac{7.46P}{\frac{\pi}{4} \times 2^2 \times 10^{-6}} = 140\ Mpa \qquad \boxed{P = 58.96\ N}$$

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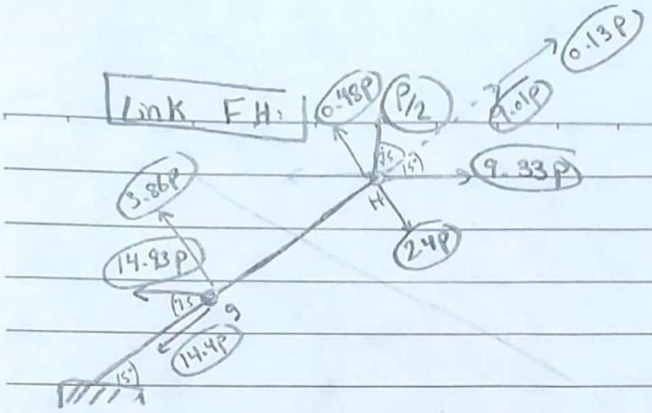
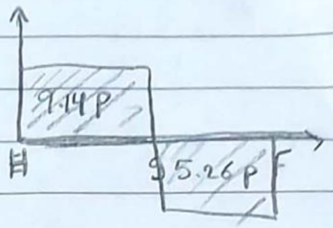
Link FH:





~~fix at F~~ So max normal will be at Hg at H

$$\sigma = \frac{9.14P}{5\times(10-2)\times10^{-6}} = 16.5\,Mpa \qquad \boxed{P = 72.2\,N}$$

$$H = \sqrt{(P/2)^2 + 5^2} = 9.34P$$

$$g = 14.93P$$

$$\tau = \frac{14.93P}{\frac{\pi}{4}\times2^2\times10^{-6}} = 1140\,Mpa \qquad \boxed{P = 29.5\,N}$$

bearing stress:

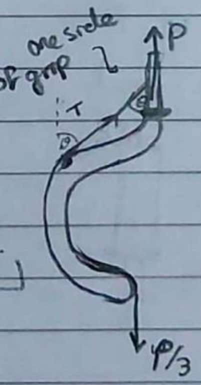
since force is max at g & H

$$\sigma_{bg} = \frac{14.93P}{2\times5\times10^{-6}} = 16.5\,M \qquad \boxed{P = 11.05\,N}$$

~~for the shear force max at B~~

$$\sigma_{bD} = \frac{7.46P}{2\times5\times10^{-6}} = 16.5\,M \qquad \boxed{P = 22.12\,N}$$

for the grip: assumption $\theta = 40$



for equilibrium:

$$T\cos\theta = P/3 \;,\; T = \frac{P}{3\cos\theta} = \frac{P}{3\cos40}$$

$$\sigma = \frac{P/3}{5\times(10-2)\times10^{-6}} = 16.5\,Mpa \qquad \boxed{P = 1980\,N}$$

$$\tau = \frac{P/3}{5\times(10)\times10^{-6}} = 18.75\,M \;,\; \boxed{P = 2812.5\,N}$$

wire is made of steel   diameter of wire is 0.5mm

so σ in wire

$$\sigma = \frac{T}{A} = \frac{P}{3\times\cos40\times\frac{\pi}{4}\times(0.5)^2\times10^{-6}} = 210\,Mpa \qquad \boxed{P = 94.75\,N}$$

$$\tau = \frac{T}{A} = \frac{P}{3\times\cos40\times\frac{\pi}{4}\times2^2\times10^{-6}} = 140\,Mpa \qquad \boxed{P = 1010.7\,N}$$

$$\sigma_b = \frac{T}{A} = \frac{P}{3\times\cos40\times2\times5} = 16.5\,Mpa \qquad \boxed{P = 379.17\,N}$$

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So max load that will satisfy the safety factor of 2 is 11.05 N

$$P = mg$$

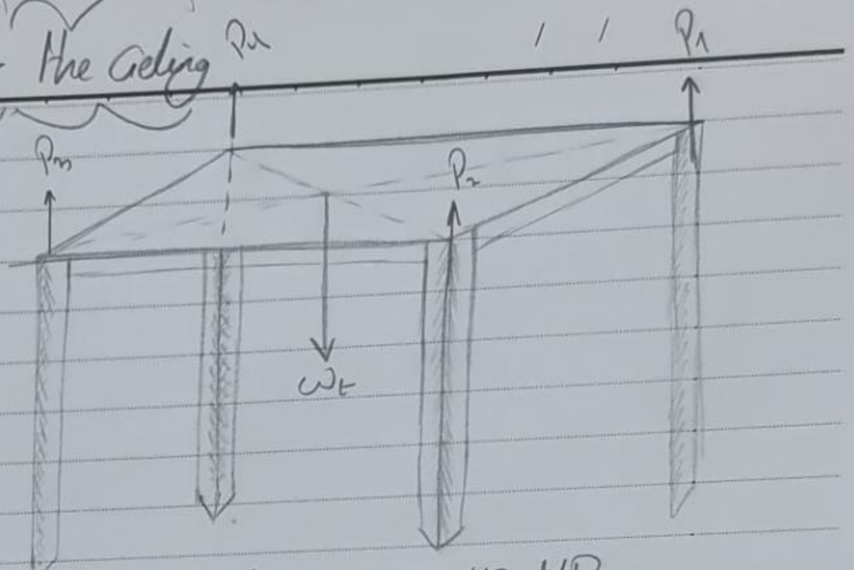
$$11.05 = m \times 9.8$$

$$\boxed{m = 1.127\ Kg}$$

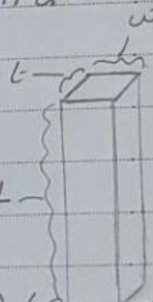
Another design was done with a safety factor of 3. This can be found at Page 29.

❖ Max load at the columns:

Max Load for the ceiling



using Cardboard know that $\sigma_{ult} = 1.48$ MPa



assuming: $L = 700$ mm, $t = 10$ mm, $\omega = 20$ mm

using factor of safety $n = 2$

$$n = \frac{\sigma_{ult}}{\sigma_{all}} \qquad \sigma_{all} = \frac{1.48}{2} = 0.74 \text{ MPa (Compression)}$$

$$\sigma_{all} = \frac{F}{A} = \frac{F}{4*10*20} \longrightarrow \boxed{F = 592 \text{ N}}$$

analysing the structure $\Sigma F_y = 0$ assuming $P_1 = P_2 = P_3 = P_4 = P$

$$4P = \omega \quad , \quad \text{where } \omega = F$$

$$P \text{ (for one column)} = \frac{F}{4} = \frac{592}{4} = 148 \text{ N}$$

So, it can withstand force equal to 592 N

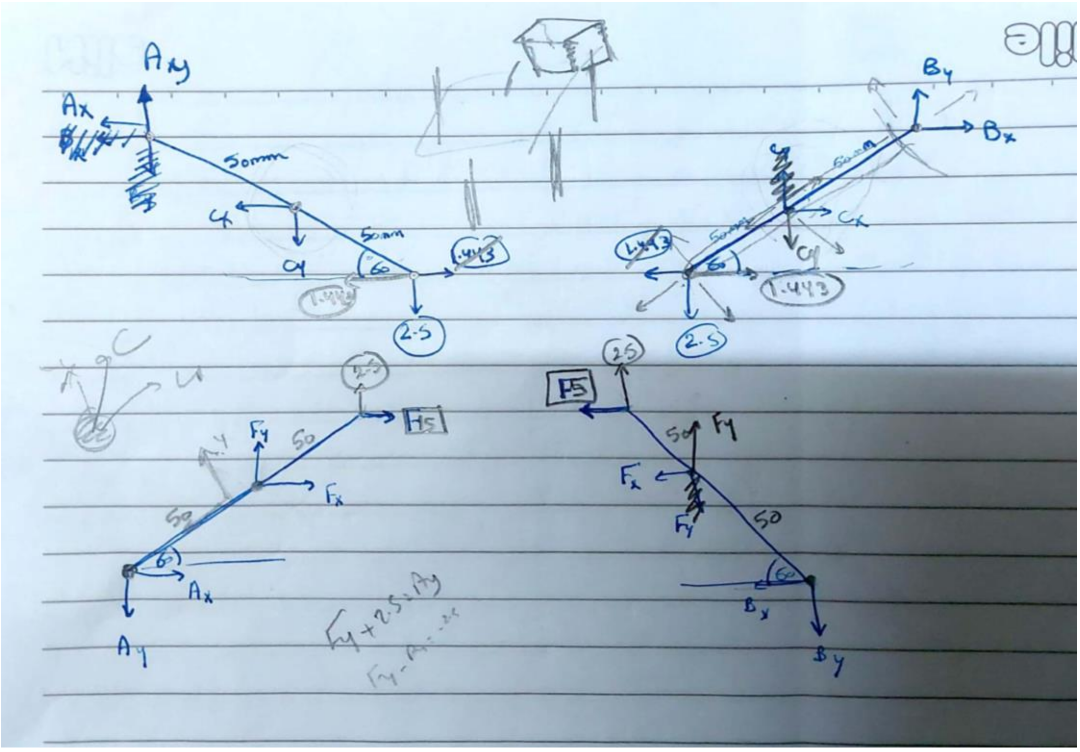
(each coulum will be subjected to force equal to 148N)

meaning the mass of the max wieght $= \frac{592}{9.81} = \boxed{60.37 \text{ kg}}$

(including the load and the mass of the rest of the components.

BEHIND THE SCENES

❖ Force analysis for the z-axis fork at



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$$\Sigma M_C = 0$$

$$-1.443 \times 50 \times \sin 60 + 2.5 \times 50 \times \cos 60$$
$$+ B_y \times 50 \times \cos 60 - B_x \times 50 \times \sin 60 = 0$$

$$\boxed{25\, B_y - 43.3\, B_x = 0.0163}$$

$$\boxed{B_x = 1.443}$$

$$\Sigma M_C = 0$$

$$-50 \cos 60\, B_y + 50 \sin 60\, B_x$$
$$+ 1.443 \times 50 \times \sin 60$$

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$\Sigma F_y = 0$, $\boxed{A_y - C_y = 2.5}$ $\Sigma F_y = 0$, $\boxed{-C_y + B_y = 2.5}$

$\Sigma F_x = 0$, $\boxed{A_x + C_x = -1.443}$ $\Sigma F_x = 0$, $\boxed{B_x + C_x = -1.443}$

$\Sigma M_c = 0$,

$+ 1.443 \times 50 \times \sin 60 - 2.5 \times 50 \times \cos 60$

$- 50 \cos 60 \, A_y + 50 \sin 60 \, A_x = 0$

$\boxed{43.3 A_x - 25 A_y = 125}$

$\Sigma M_c = 0$

$+1.443 \times 50 \times \sin 60 + 2.5 \times 50 \times \cos 60$

$+ 50 \times \cos 60 \, B_y - 50 \sin 60 \, B_x = 0$

$\boxed{25 B_y - 43.3 B_x = -125}$

$\Sigma F_y = 0$, $\boxed{F_y - A_y = +2.5}$

$\Sigma F_x = 0$, $\boxed{F_x + A_x = -15}$

$\Sigma F_x = 0$, $\boxed{F_x + B_x = +15}$

$\Sigma F_y = 0$, $\boxed{-F_y + B_y = 2.5}$

$\Sigma M_F = 0$

$A_y \, 50 \cos 60 + A_x \, 50 \sin 60$

$- 15 \times 50 \sin 60 + 2.5 \times 50 \times \cos 60$

$\boxed{25 A_y + 43.3 A_x = 587}$

$\Sigma M_F = 0$

$- B_x \, 50 \sin 60 - B_y \, 50 \cos 60$

$+ 15 \times 50 \sin 60 - 2.5 \times 50 \times \cos 60 = 0$

$\boxed{43.3 B_x + 25 B_y = 587}$

$A_x = 8.22$	$B_x = -8.22$	$F_x = -23.22$	$C_x = -9.663$
$A_y = 9.24$	$B_y = 9.24$	$F_y = 6.74$	$C_y = -6.74$

Nile

❖ Maximum load with safety factor 3:

However, there is still a second part where we find the forces F with respect to the weight P to get the maximum load P possible.

Max load using PLA

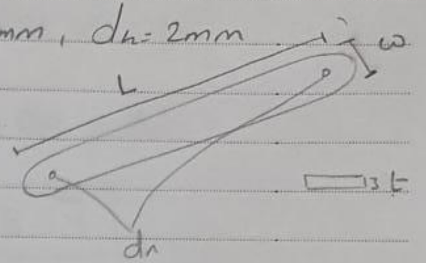
assume:

$t = 5mm$, $\omega = 10mm$, $L = 100\,mm$, $d_h = 2mm$

knowing that:

$E = 4.707$ GPA , $\sigma_{ult} = 32.938$ MPa

$\tau_{ult} = 37.5$ MPA



(n) with factor of safty = 3

→ link:

Z-fork:

$$n = \frac{\sigma_{ult}}{\sigma_{all}} \quad , \quad 3 = \frac{32.938}{\sigma_{all}}$$

$$\sigma_{all} = 10.979 \text{ MPa} \quad , \quad \sigma_{all} = \frac{F}{A} = \frac{F}{5*10}$$

$$\boxed{F = 5*10*10.979 = 548.9667 \text{ N}}$$

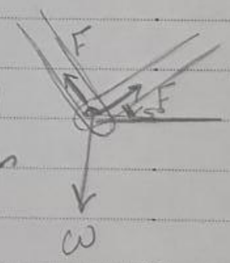
max load for max normal stress

$\Sigma F_y = 0$

$2F \sin 15 = \omega$

$\omega = 2*548.9667*\sin 15 = 284.166\,N$

↳ max weight the claw machine can withstand

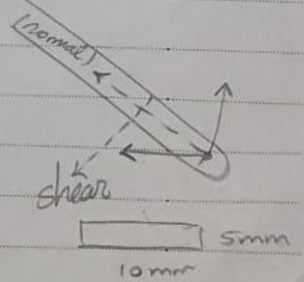


$$* \quad n = \frac{\tau_{ult}}{\tau_{all}} \quad , \quad 3 = \frac{37.5}{\tau_{all}}$$

$$\tau_{all} = 12.5 \text{ MPa} \qquad \tau_{all} = \frac{F}{A}$$

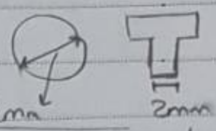
$F = 12.5*10*5 = 625\,N$

max force for max shear stress



→ Pin shear stress (Pins from PIA)

$n = \frac{\tau_{ult}}{\tau_{all}}$ $\tau_{all} = \frac{37.5}{3} = 12.5$

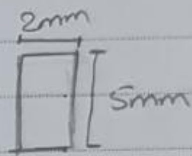


$\tau_{all} = \frac{F}{2A} = \frac{F}{2\times\frac{\pi}{4}d^2} = \frac{F}{2\times\frac{\pi}{4}\times 2^2}$, $\boxed{F = 78.539\ N}$ double shear

max Load for max shear

* Bearing stress $(\sigma_b)_{ult} =$

$n = \frac{\sigma_{b\,ult}}{\sigma_{b\,all}}$, $(\sigma_b)_{all} =$



$\sigma_b = \frac{F}{A} = \frac{F}{2\times 5}$, $F =$

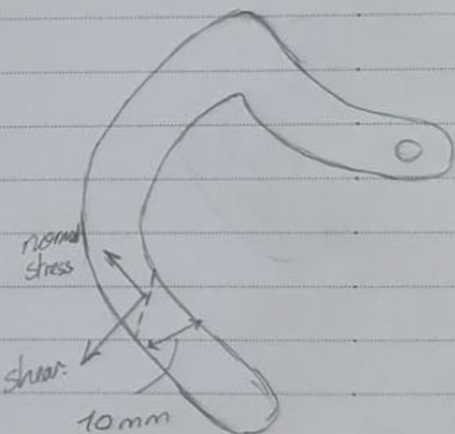
The Gripper

assume: $w = 10$ mm, $t = 10$mm

$d_h = 2$mm

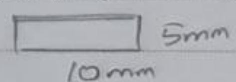
knowing that $\sigma_{ult} = 32.938$ MPa

$\tau_{ult} = 37.5$ MPa, $n = 3$



$n = \frac{\sigma_{ult}}{\sigma_{all}}$, $\sigma_{all} = 10.979$ MPa

$\sigma_{all} = \frac{F}{A} \longrightarrow F = 548.9667\ N$



$n = \frac{\tau_{ult}}{\tau_{all}} \longrightarrow F = 625N$

at the bin, max force for shear stress $F = 39.2699\ N$ single shear

these all as calculated in the Z fork assume same dimensions

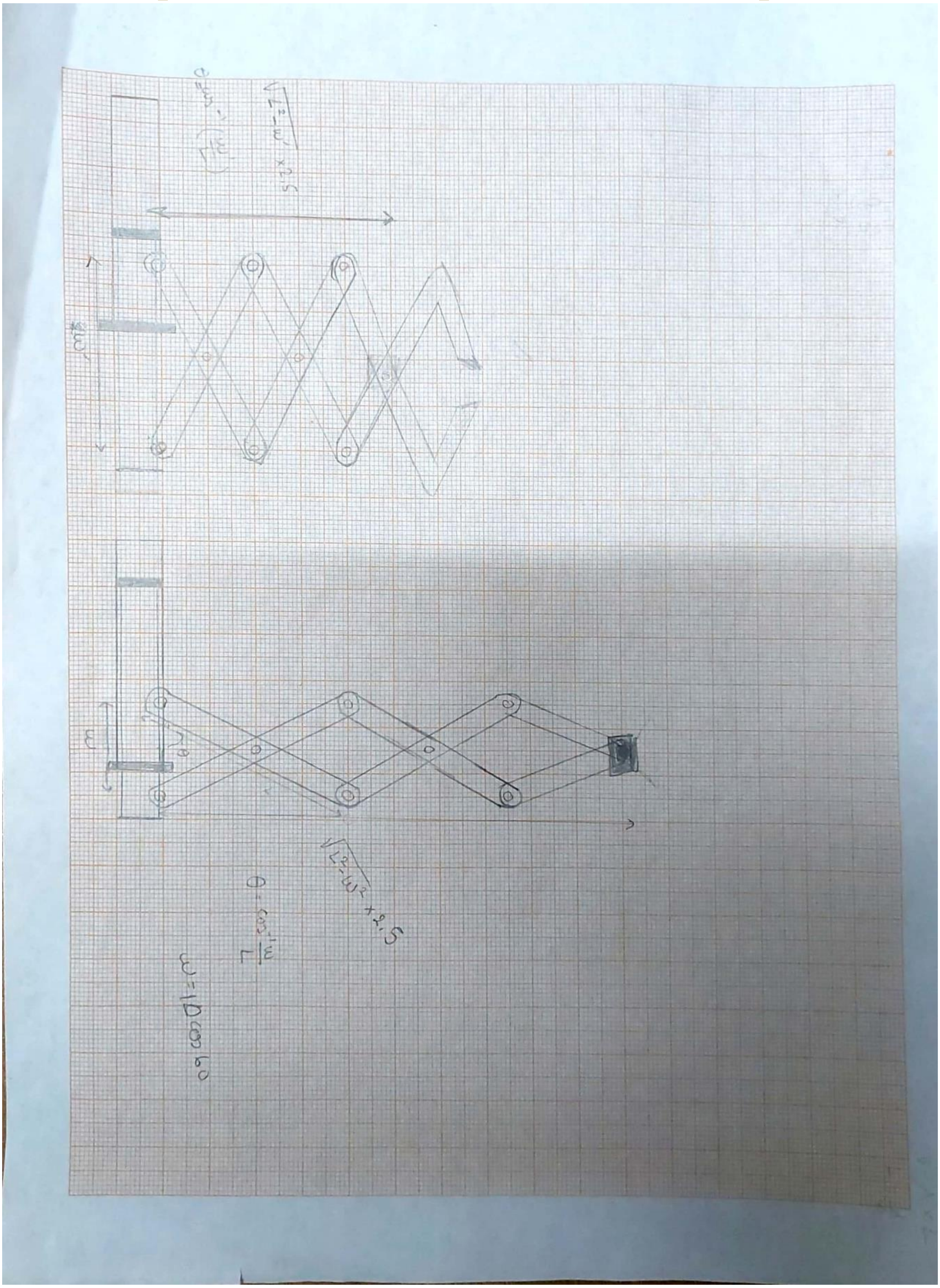
Pin shear stress (Pins from steel)

$\tau_{ult} = 280 \text{ MPa}$ $\qquad 2 = \frac{280}{\tau_{all}}$

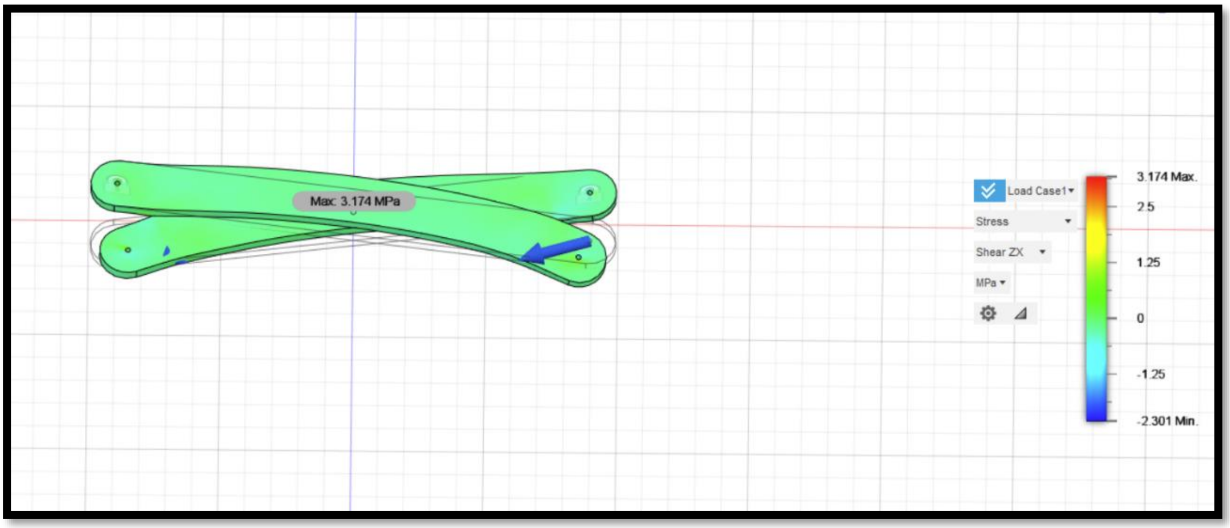
$\tau_{all} = 140 \text{ MPa}$ $\qquad \tau_{all} = \frac{F}{2A} = \frac{F}{2 \frac{\pi}{4} * 2^2}$

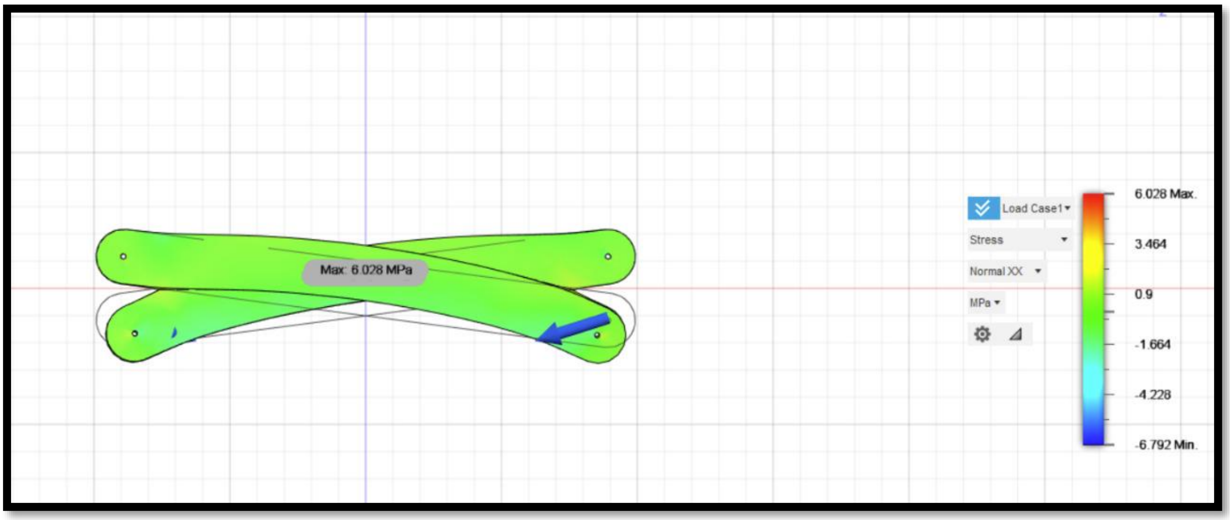
$$\boxed{F = 879.645 N}$$

❖ A simplified look at the fork extended and collapsed

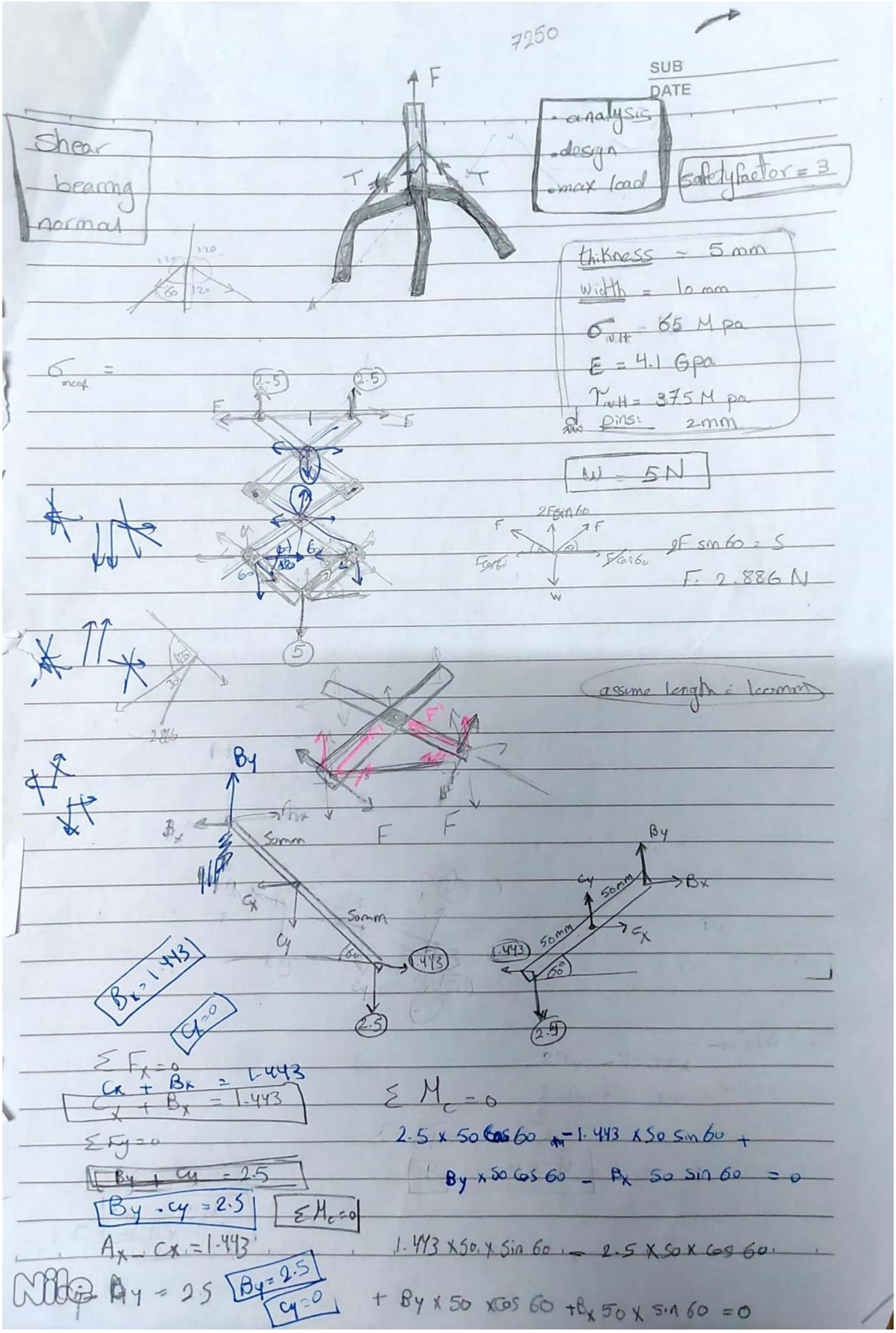


❖ Stress analysis with fusion 360

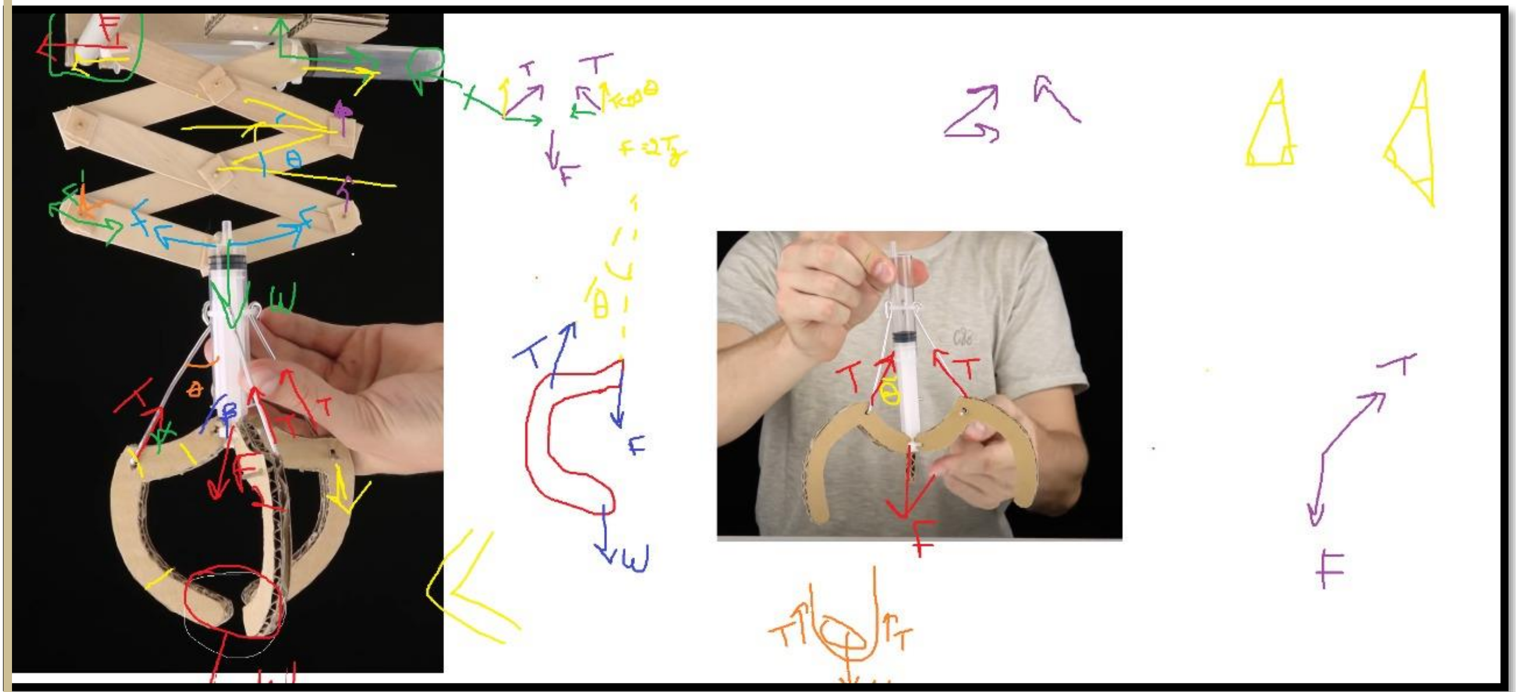


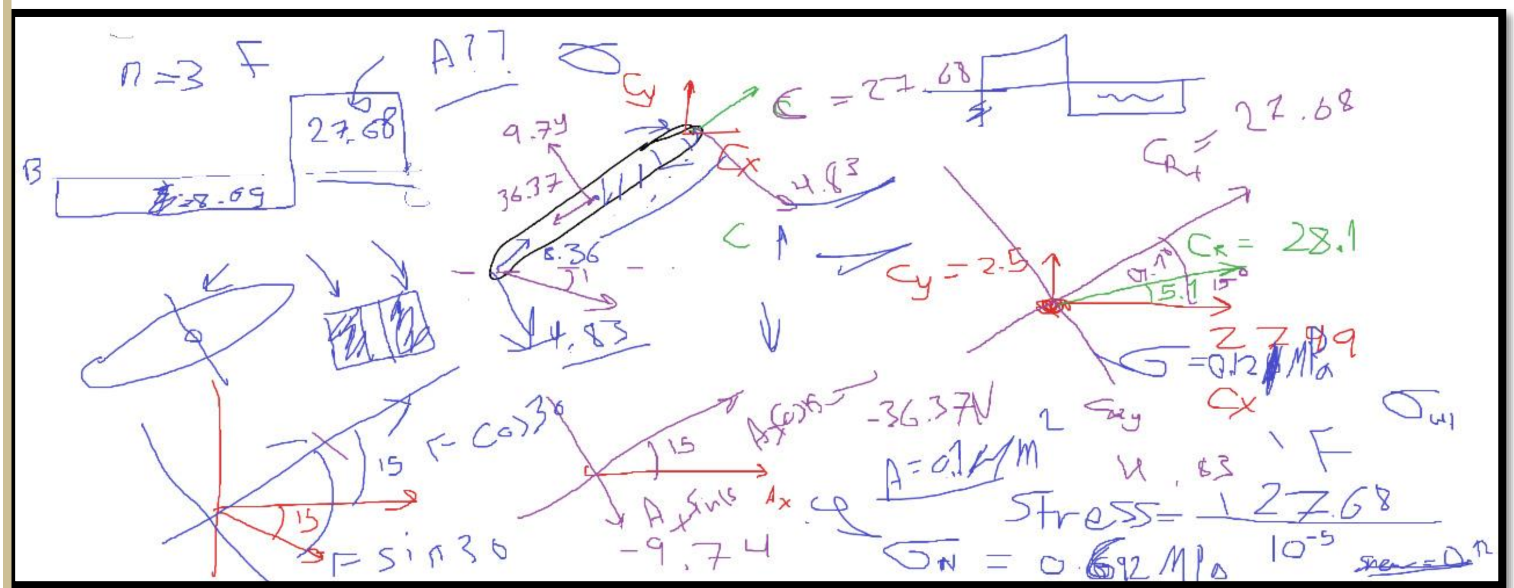


❖ An example of the thinking process behind the force analysis



❖ Finally, masterpieces called: "Starting this project on a google meet was so easy… or not"





Study Report

Analyzed File	fork v3
Version	Autodesk Fusion 360 (2.0.12670)
Creation Date	2022-04-07, 23:32:31
Author	i_sal

Project Properties

Title	Studies
Author	i_sal

Simulation Model 1:1

Study 1 - Static Stress

Study Properties

Study Type	Static Stress
Last Modification Date	2022-04-07, 23:00:28

Settings

General

Contact Tolerance	0.1 mm
Remove Rigid Body Modes	No

Damping

Mesh

Average Element Size (% of model size)	
Solids	10
Scale Mesh Size Per Part	No
Average Element Size (absolute value)	-
Element Order	Parabolic
Create Curved Mesh Elements	Yes
Max. Turn Angle on Curves (Deg.)	60
Max. Adjacent Mesh Size Ratio	1.5
Max. Aspect Ratio	10
Minimum Element Size (% of average size)	20

Adaptive Mesh Refinement

Number of Refinement Steps	0
Results Convergence Tolerance (%)	20
Portion of Elements to Refine (%)	10
Results for Baseline Accuracy	Von Mises Stress

Materials

Component	Material	Safety Factor
stick1:1	PLA	Yield Strength
stick2:1	PLA	Yield Strength
pin1:1	Steel	Yield Strength

PLA

Density	1.25E-06 kg / mm^3
Young's Modulus	3500 MPa
Poisson's Ratio	0.39
Yield Strength	49.5 MPa
Ultimate Tensile Strength	65 MPa
Thermal Conductivity	1.6E-04 W / (mm C)
Thermal Expansion Coefficient	8.57E-05 / C
Specific Heat	1500 J / (kg C)

Steel

Density	7.85E-06 kg / mm^3
Young's Modulus	210000 MPa

Poisson's Ratio	0.3
Yield Strength	207 MPa
Ultimate Tensile Strength	345 MPa
Thermal Conductivity	0.056 W / (mm C)
Thermal Expansion Coefficient	1.2E-05 / C
Specific Heat	480 J / (kg C)

Contacts

Bonded

Name
[S] Bonded7 [stick2:1||pin1:1]
[S] Bonded8 [stick1:1||pin1:1]
[S] Bonded9 [stick1:1||stick2:1]

Mesh

Type	Nodes	Elements
Solids	3566	1771

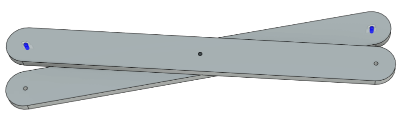
Load Case1

Constraints

Fixed1

Type	Fixed
Ux	Fixed
Uy	Fixed
Uz	Fixed

Selected Entities

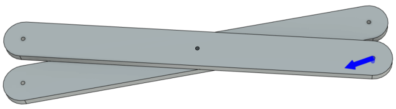


Loads

Force1

Type	Force
Magnitude	9.66 N
X Value	-9.213 N
Y Value	0 N
Z Value	2.905 N
X Angle	-115 deg
Y Angle	0 deg
Z Angle	0 deg
Force Per Entity	No

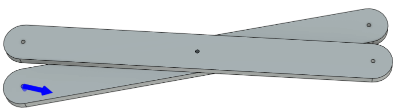
Selected Entities



Force2

Type	Force
Magnitude	9.66 N
X Value	9.213 N
Y Value	0 N
Z Value	2.905 N
X Angle	115 deg
Y Angle	0 deg
Z Angle	0 deg
Force Per Entity	No

Selected Entities



Results

Result Summary

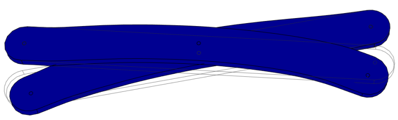
Name	Minimum	Maximum
Safety Factor		
Safety Factor (Per Body)	15	15
Stress		
Von Mises	0.008634 MPa	8.963 MPa
1st Principal	-1.301 MPa	16.16 MPa
3rd Principal	-7.321 MPa	5.823 MPa
Normal XX	-6.792 MPa	6.028 MPa
Normal YY	-5.705 MPa	11.44 MPa
Normal ZZ	-2.898 MPa	15.07 MPa
Shear XY	-1.643 MPa	1.237 MPa

Shear YZ	-1.633 MPa	2.802 MPa
Shear ZX	-2.301 MPa	3.174 MPa
Displacement		
Total	0 mm	0.02117 mm
X	-0.0136 mm	0.01345 mm
Y	-0.009247 mm	0.007381 mm
Z	-0.01195 mm	0.01687 mm
Reaction Force		
Total	0 N	0.216 N
X	-0.1691 N	0.1997 N
Y	-0.1228 N	0.08964 N
Z	-0.1765 N	0.09863 N
Strain		
Equivalent	2.056E-06	0.001659
1st Principal	-5.979E-07	0.001318
3rd Principal	-0.001544	-2.051E-06
Normal XX	-6.652E-04	5.68E-04
Normal YY	-2.478E-04	1.763E-04
Normal ZZ	-4.53E-04	4.21E-04
Shear XY	-3.024E-04	3.156E-04
Shear YZ	-4.4E-04	5.876E-04
Shear ZX	-0.001264	0.001431
Contact Pressure		
Total	0 MPa	9.596 MPa
X	-1.673 MPa	2.086 MPa
Y	-1.044 MPa	0.7549 MPa
Z	-9.493 MPa	1.511 MPa

Safety Factor

Safety Factor (Per Body)

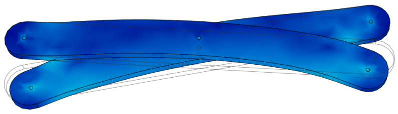
0 8



Stress

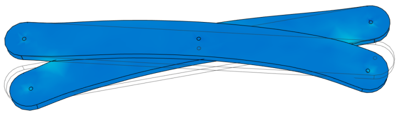
Von Mises

[MPa] 0.009 8.963



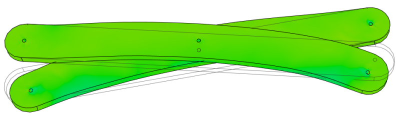
1st Principal

[MPa] -1.3 16.16



3rd Principal

[MPa] -7.321 5.823



Displacement

Total

[mm] 0 0.02117