Transmission Contest PDR

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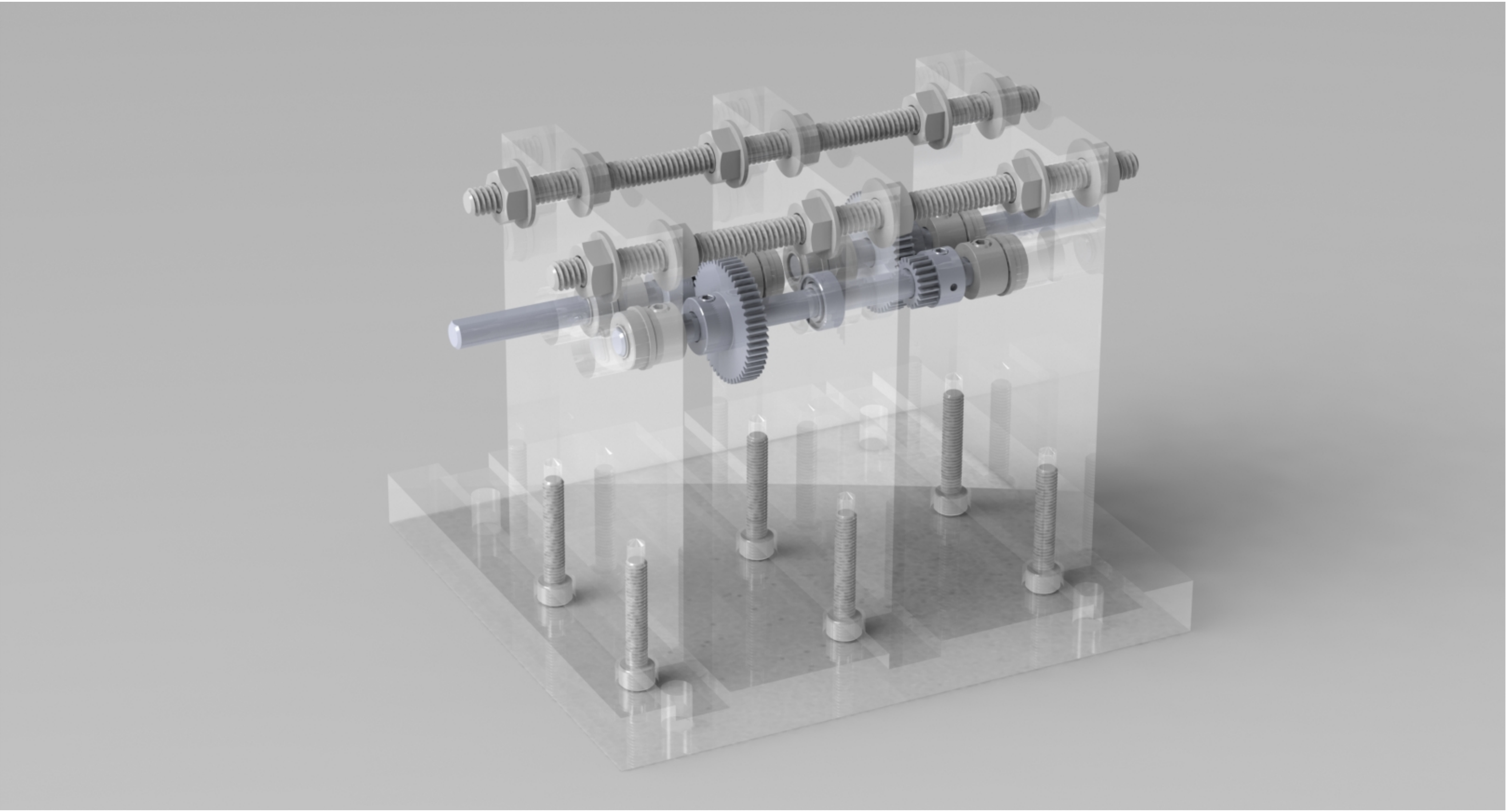
Team Oh

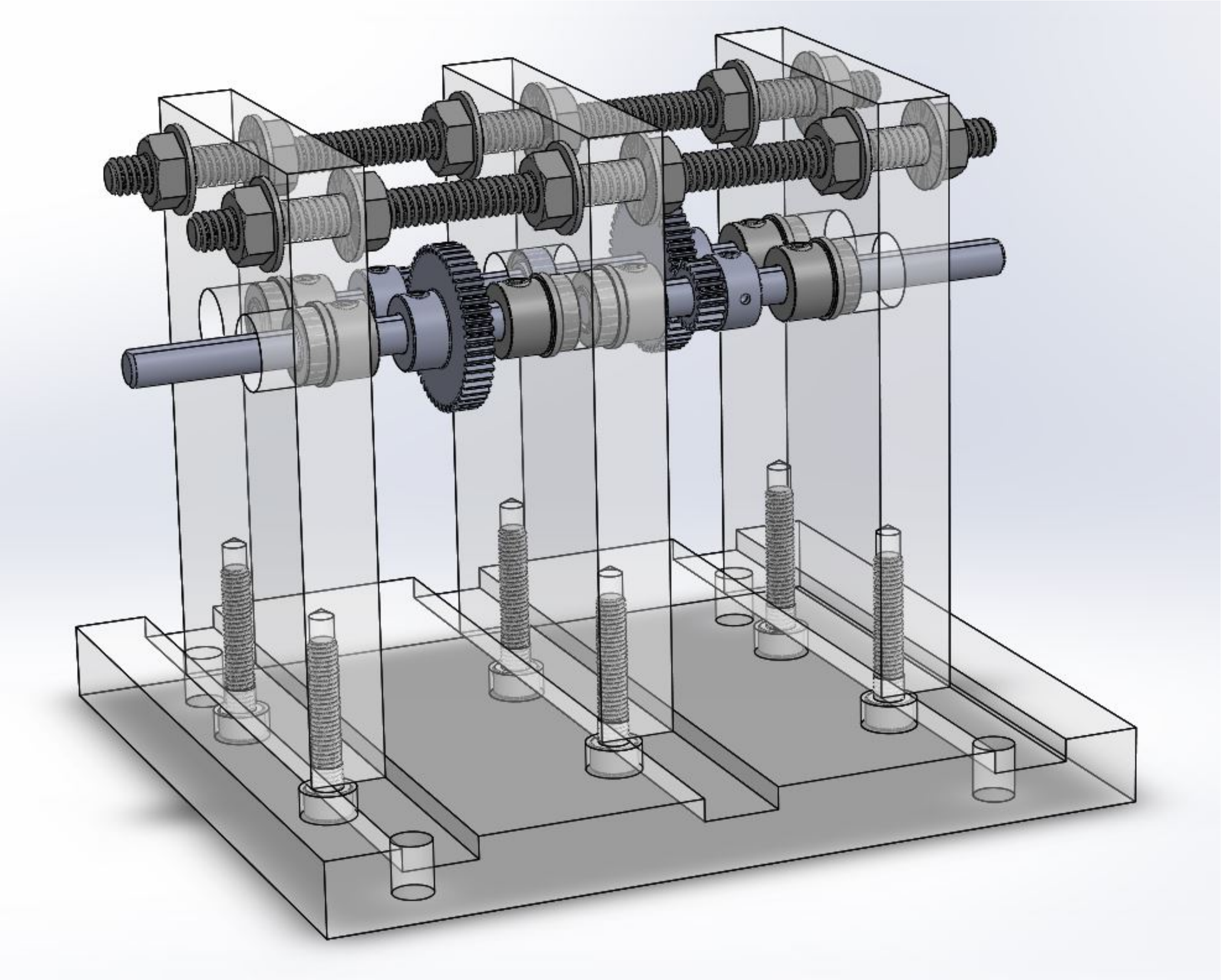
Drawings and Decisions

SolidWorks



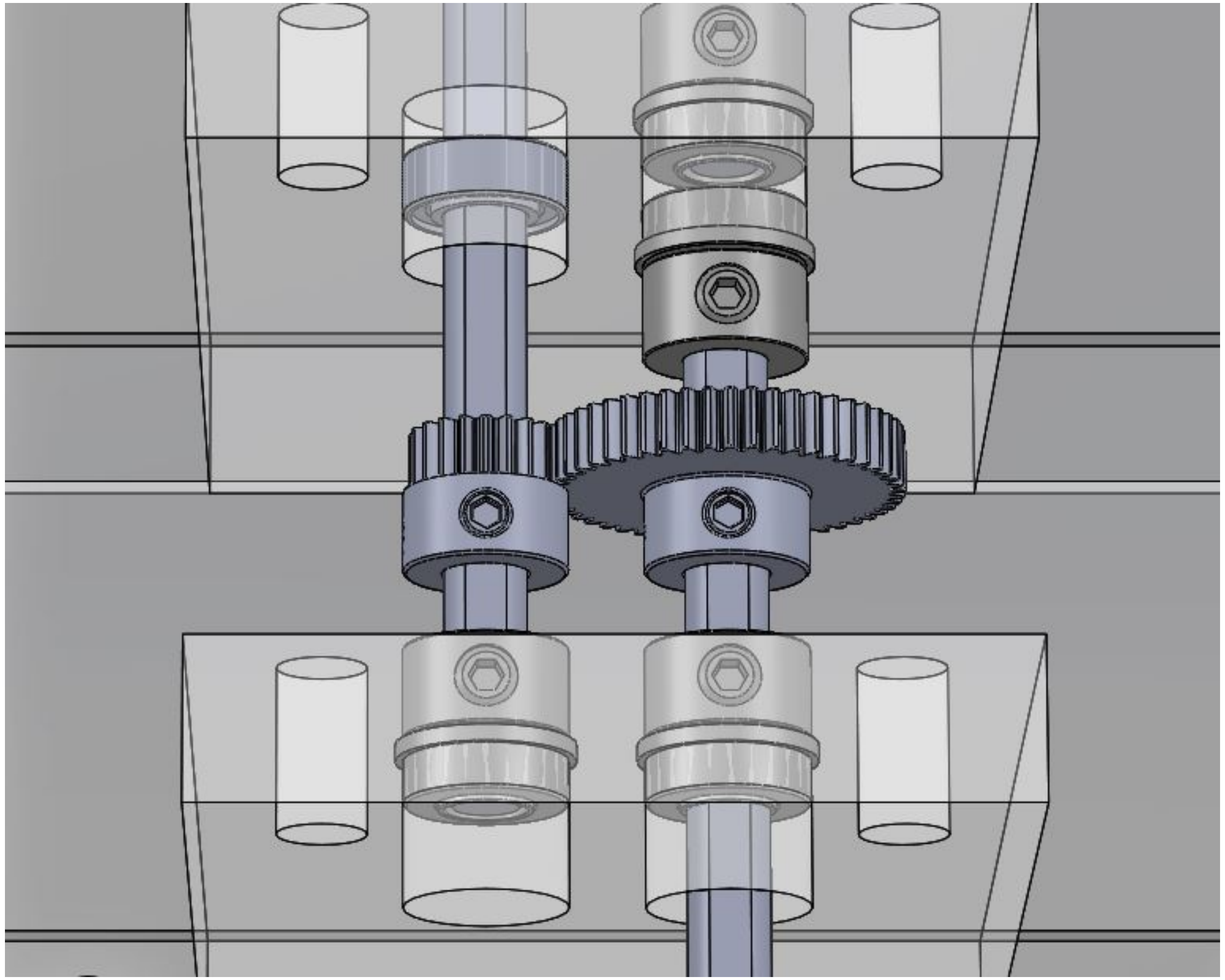
Overall design

- Two stage inline drive
- Three axles using spur gears – most simple, cheap design, allows higher quality parts
- 2.5 reduction at each gear interface = 6.25 overall gear ratio
- Minimise size



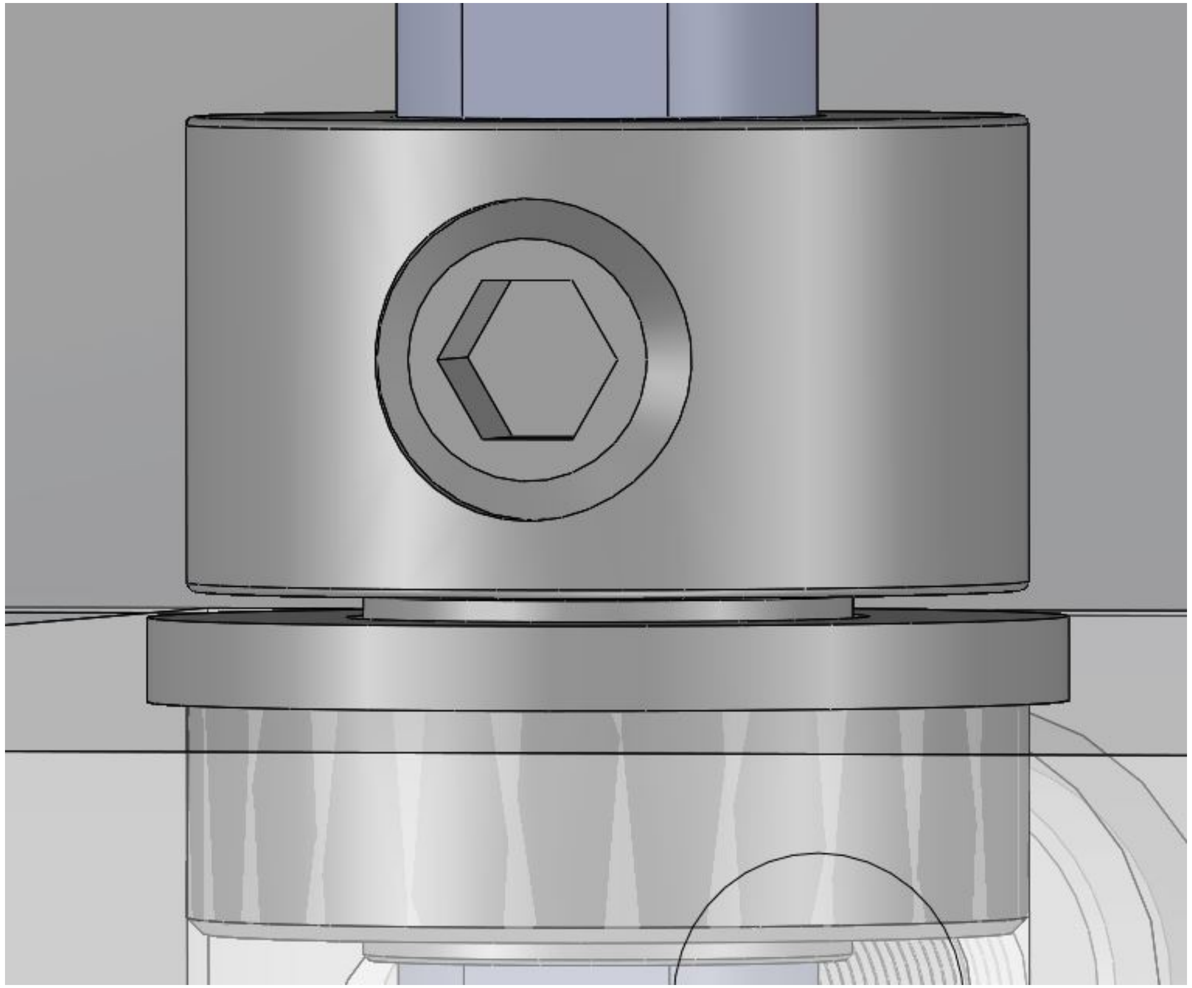
Gears

- Gears: 20 teeth to 50 teeth for 2.5 ratio
- Small gears instead of big – less inertia
- 48 diametral pitch instead of lower values – more teeth for better meshing
- Aluminium instead of plastic/steel – stronger than plastic, able to machine if needed
- Set screw hub cap for D shaft – easily adjustable, strong
- 20 degree pressure angle – only size available. Would have preferred 14.5 for better meshing.
- Wide face width (0.1875) – more contact area



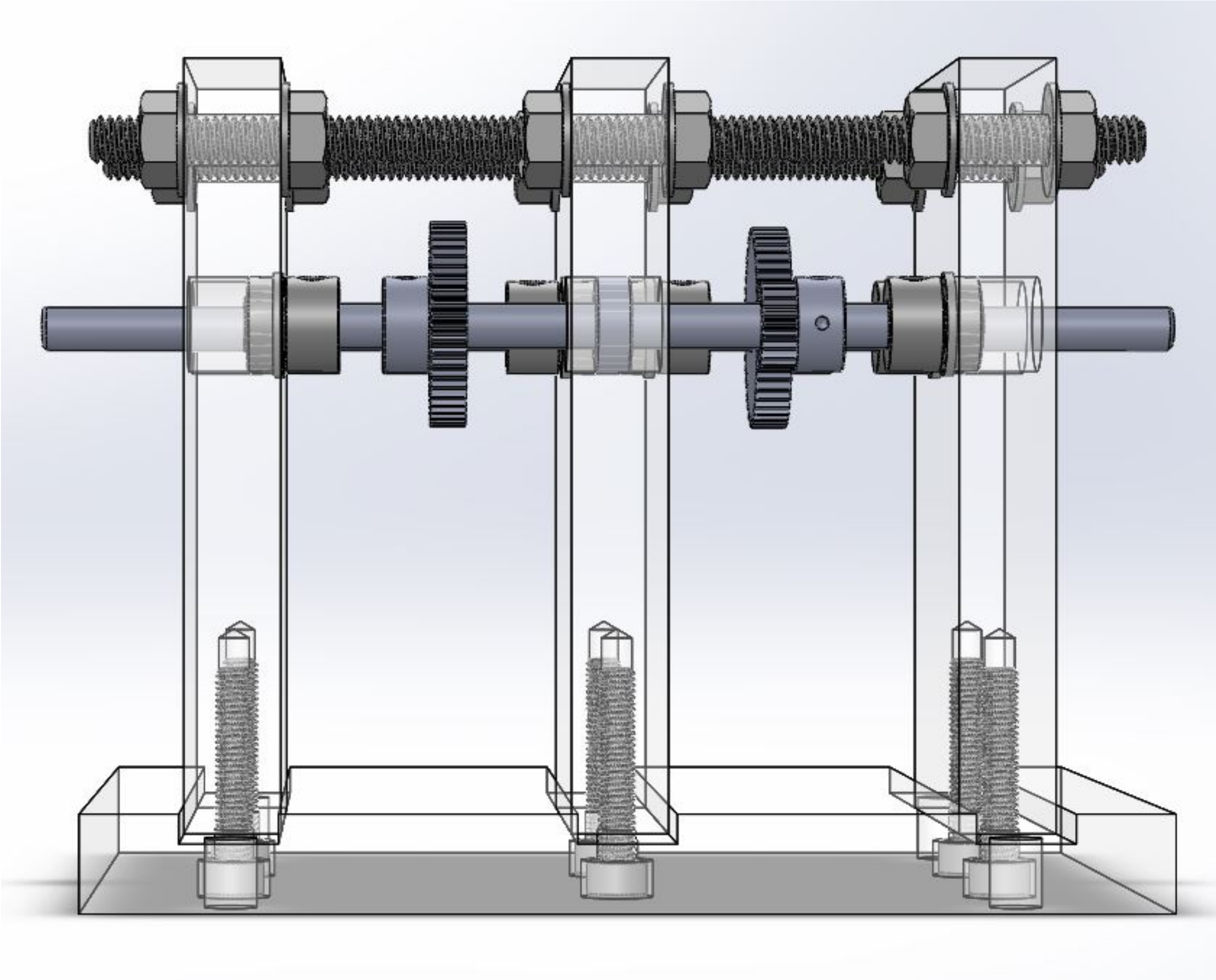
Bearings / Collars

- Steel Ball Bearings for better efficiency / lower friction than bushings
- Flanged instead of unflanged - so shaft/bearings are constrained
- Set screw collars instead of – easy adjustment on D shaft, cheap
- Smallest OD of ½ inch – fits press fit reamer in shop
- Extended inner race – collars only contact inner rotating part of bearing. Minimizes friction.
- Initially wanted bearings with set screw collars – too expensive



Supports

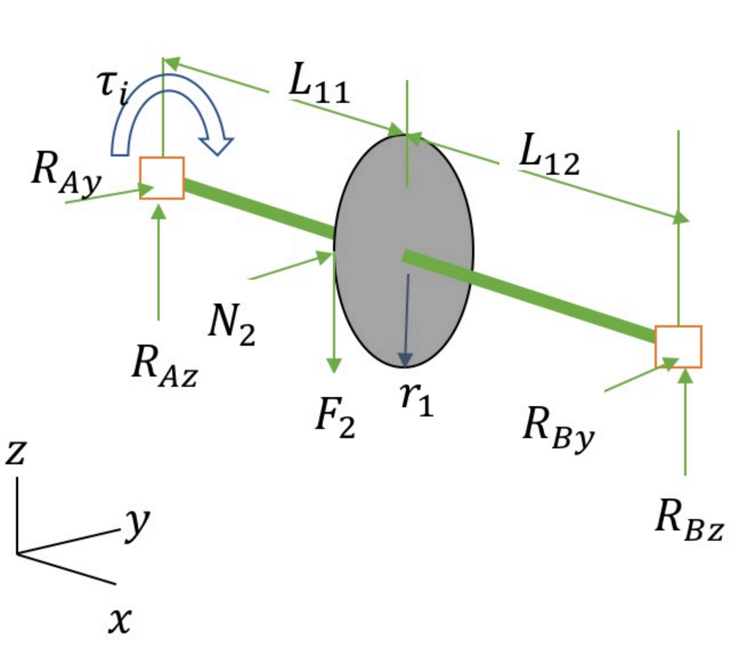
- Machined slots at bottom for close, flat fit
- 10-32 set screws
- Using threaded rod and nuts for top support – allows for tighter shaft constraining
- Flange nut to spread out pressure more
- Shaft steel – more rigid than other materials. ¼ inch as most popular bore size for gears.

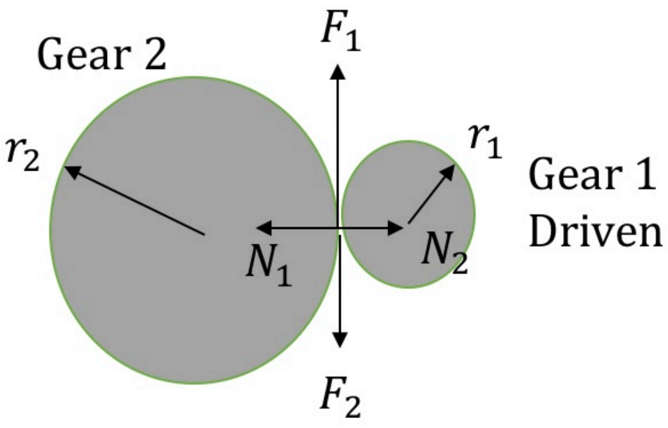


Calculations

Forces, Normal Stresses, Deflections, Torques (done with maximum input torque)

Shaft I: Gear 1, Driven





Force Considerations:

<u>x:</u>

$\Sigma \mathrm{M_x} = 0 = -\tau_i + F_2 \mathrm{r}_1$

<u>y:</u>

$\Sigma F_y = 0 = N_2 + R_{By} + R_{Ay}$

$\Sigma \mathrm{M}_{\mathrm{y_A}} = 0 = -\mathrm{F_2(L_{11}) + R_{Bz}(L_{11} + L_{12})}$

<u>z:</u>

$\Sigma F_z = 0 = R_{Az} + R_{Bz} - F_2$

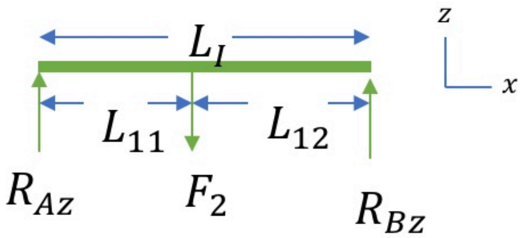
$\Sigma \mathrm{M}_{\mathrm{z_A}} = 0 = \mathrm{R_{By}(L_{11} + L_{12}) + N_2(L_{11})}$

$$F_2 = \frac{\tau_i}{r_1} \qquad N_2 = \frac{\tau_i}{r_1}\tan\phi$$

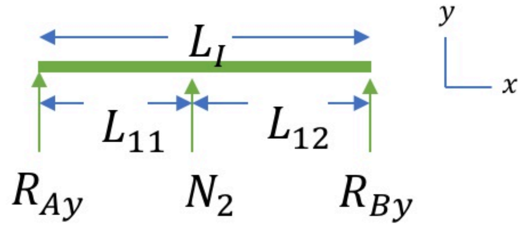
$$R_{Bz} = \frac{F_2 L_{11}}{L_{11} + L_{12}} \qquad R_{By} = \frac{-N_2 L_{11}}{L_{11} + L_{12}}$$

$$R_{Az} = \frac{F_2 L_{12}}{L_{11} + L_{12}} \qquad R_{Ay} = \frac{-N_2 L_{12}}{L_{11} + L_{12}}$$

Moments and Deflections (Magnitudes):



$$M = \frac{F_2 L_{12} x}{L_I} \qquad y = \frac{F_2 L_{12} x}{6EIL_I}(x^2 + L_{12}^2 - L_I^2)$$



$$M = \frac{N_2 L_{12} x}{L_I} \qquad y = \frac{N_2 L_{12} x}{6EIL_I}(x^2 + L_{12}^2 - L_I^2)$$

Shaft I: Continued

Specs:

- Gear 1: 20 tooth gear
  - $r_1 = \frac{0.4167}{2}\ in$
  - $\phi = 20^o$
- Motor:
  - $\tau_{stall} = 0.133\ Nm$
  - $\omega_o = 5500\ rpm$
  - $\tau_{in} = \tau_{stall} = 0.133 Nm$
- Shaft I:
  - Diameter ¼ in.
  - L_I =1.5in
    - We assume that the portion sticking out of the other side of the wall is negligible

Moments:

z:

$$M = \frac{F_2 L_{12} x}{L_I} \rightarrow M_{max} = \frac{F_2 L_{12} L_{11}}{L_I}$$

y:

$$M = \frac{N_2 L_{12} x}{L_I} \rightarrow M_{max} = \frac{N_2 L_{12} L_{11}}{L_I}$$

Force Calculations:

$$F_2 = \frac{\tau_i}{r_1} = \frac{0.133 Nm}{\frac{0.4167}{2} in} * \frac{39.3701\ in}{1m} = \mathbf{25.1\ N}$$

$$N_2 = \frac{\tau_i}{r_1} \tan\phi = 25.1\ N\ * \tan 20^o = \mathbf{9.15\ N}$$

Let $L_{11} = L_{12}$, we assume that because the shaft is so short, gear placement along the length of the shaft will not cause too much of a difference in our resulting forces and moments; especially since the forces acting on the shaft, as we can see, is fairly small.

$$R_{Bz} = \frac{25.1N\ * \frac{1.5}{2} in\ * \frac{m}{39.3701\ in}}{1.5\ in\ * \frac{m}{39.3701\ in}} = 12.57\ N$$

$$R_{By} = \frac{-9.15\ N}{2} = -4.57\ N$$

$$R_{Az} = \frac{25.1\ N}{2} = 12.57\ N$$

$$R_{Ay} = \frac{-9.15\ N}{2} = -4.57\ N$$

Normal Stresses:

$$M_{max-z} = \frac{F_2 L_{12} L_{11}}{L_I} = \frac{25.1\ N\ * \left(\frac{1.5}{2} in\ * \frac{m}{39.3701\ in}\right)^2}{1.5\ in\ * \frac{m}{39.3701\ in}}$$

$$= 0.239\ Nm$$

$$M_{max-y} = \frac{N_2 L_{12} L_{11}}{L_I} = 0.0871\ Nm$$

We get that the maximum moment in both cases is at the location of the gear.

$$M_{max1} = \left((0.220)^2 + (0.0802)^2\right)^{\frac{1}{2}} = \boxed{\mathbf{0.255 Nm}}$$

$$\sigma_{max} = \frac{M_{max1} * \frac{0.25}{2}\ in\ * \frac{1\ m}{39.3701 in}}{\frac{1}{4}\pi\left(\frac{0.25\ in}{2} * \frac{1\ m}{39.3701 in}\right)^4} = \boxed{\mathbf{10.1\ MPa}}$$

We are well under the yield stress of steel.

Shaft I: Continued

Deflections: From Appendix A

$$y_{z-max} = -\frac{FL_I^3}{48EI}$$

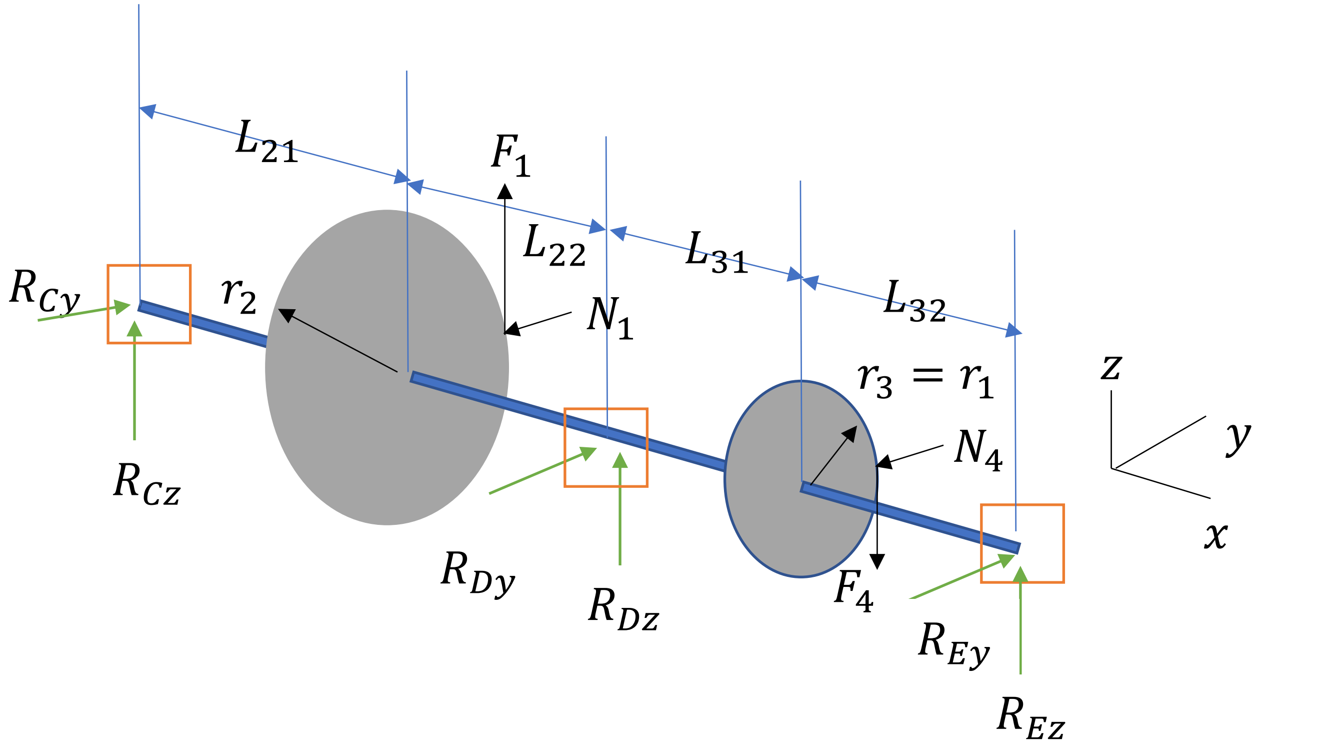
$$= -\frac{25.1\ N\ *\left(1.5in * \frac{1m}{39.3701\ in}\right)^3}{48 * 200 * 10^9\ Pa\ * \frac{1}{4} * \pi\left(\frac{0.25in}{2} * \frac{1m}{39.3701\ in}\right)^4}$$

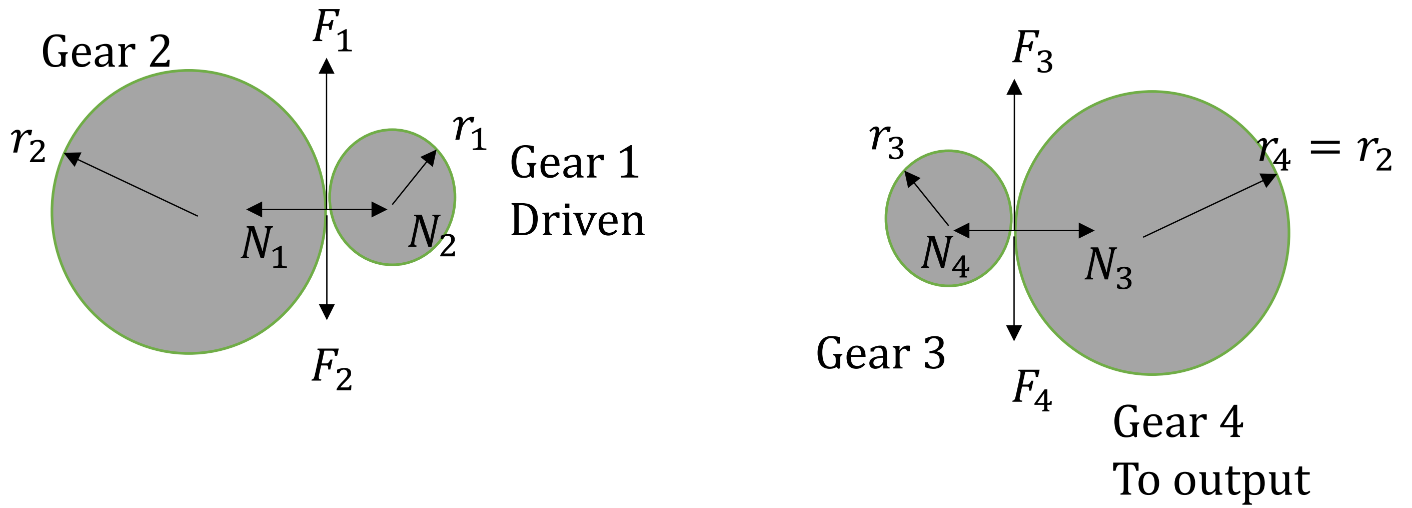
$$= \boxed{\mathbf{1.814 * 10^{-6}\ m.}}\ (\boldsymbol{down})$$

$$y_{y-max} = \frac{N_2 L_I^3}{48EI} = \boxed{\mathbf{6.60 * 10^{-7} m}}\ (\boldsymbol{positive\ y})$$

We can see that at the maximum input torque, the deflection is very small.

Shaft II: Gear 2 and 3





Force Considerations:

We note that as with last time, $L_{21} = 0.75in, L_{22} = 1in$, $L_{31} = 1in$, $L_{32} = 0.75in$

x:

$\Sigma M_x = 0 = F_1 r_2 - F_4 r_3$

y:

$\Sigma F_y = 0 = R_{C_y} + R_{D_Y} + R_{E_y} - N_1 - N_4$

$\Sigma M_{y_c} = 0$

$= F_1(0.75in) + R_{D_z}(1.75in) - F_4(2.75in) + R_{E_z}(3.5in)$

z:

$\Sigma F_z = 0 = R_{C_z} + R_{D_z} + R_{E_z} + F1 - F2$

$\Sigma M_{z_c} = 0$

$= -N1(0.75) + R_{D_y}(1.75) - N_4(2.75) + R_{E_y}(3.5)$

Specs:

- Gear 2: 50 tooth gear
  - We are going for a gear reduction of 2.5 per contact
  - $r_2 = \frac{1.0417}{2}\ in$
  - $\phi = 20^o$
- Gear 3: 20 tooth gear
- Shaft I:
  - Diameter ¼ in.
  - $L_{II} = 3.5$ in

Note that from Shaft I and Balance:

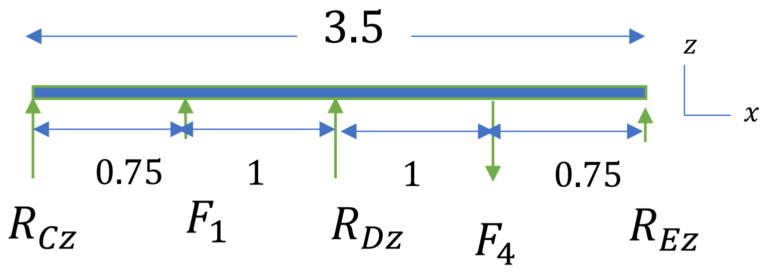
$F_1 = F_2 = \frac{\tau_i}{r_1} = 25.1N$

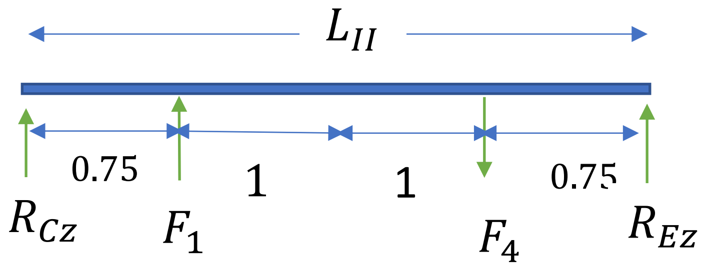
$N_1 = N_2 = F_2 * tan\,\phi = -9.15N$

$F_4 = F_1\frac{r_2}{r_3} = 25.1\ N\ * \frac{1.0417\ in}{0.4167\ in} = -62.8\ N$

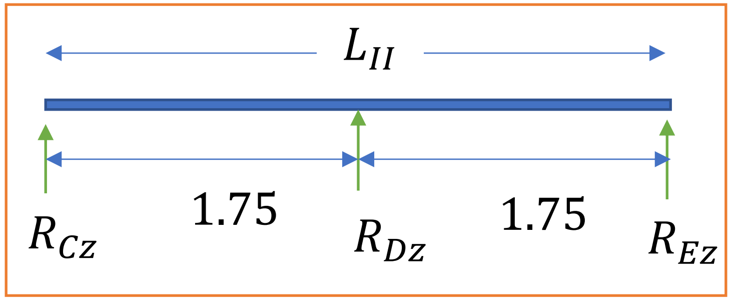
$N_4 = F_4 \tan\phi = -22.9N$

Superposition z direction:





1



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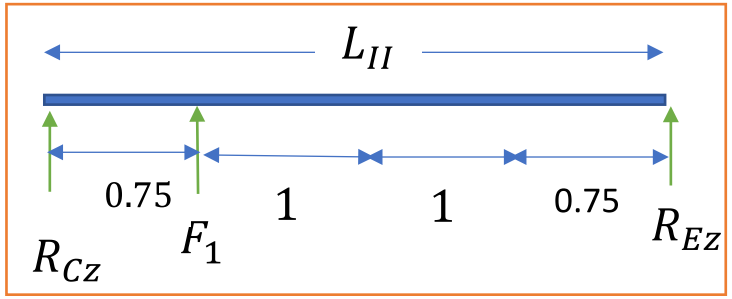
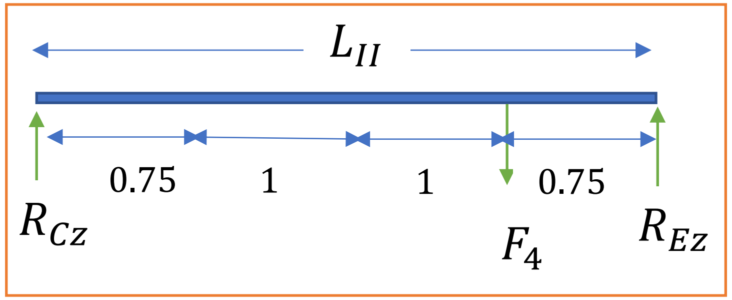


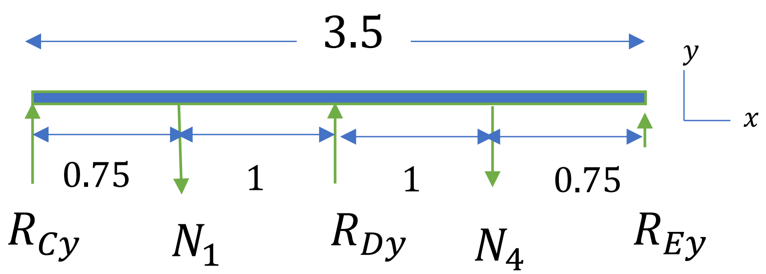


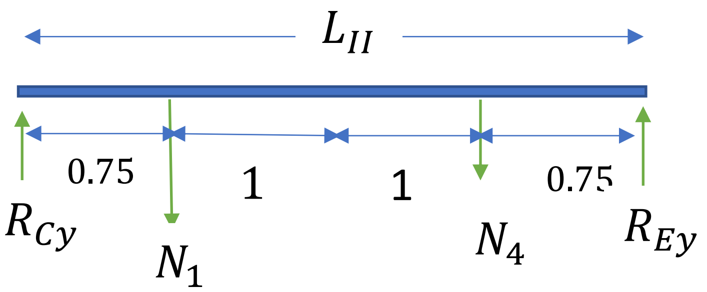
3

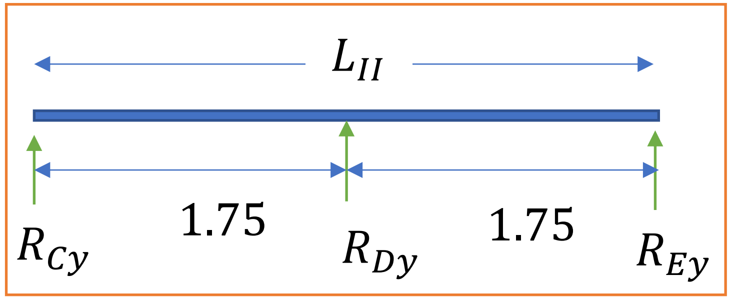
Solving the Superposition z:

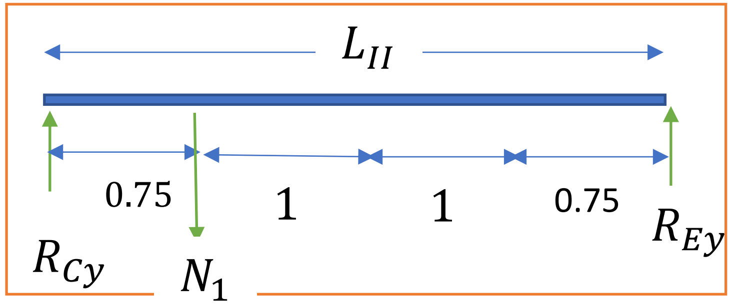
$R_{D_z} = -1.049\ N$

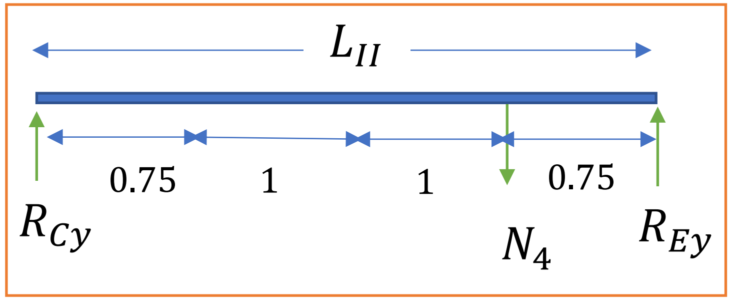
Superposition y direction:











Solution to the y superposition:

$$R_{D_y} = 0.599N$$

Solution:

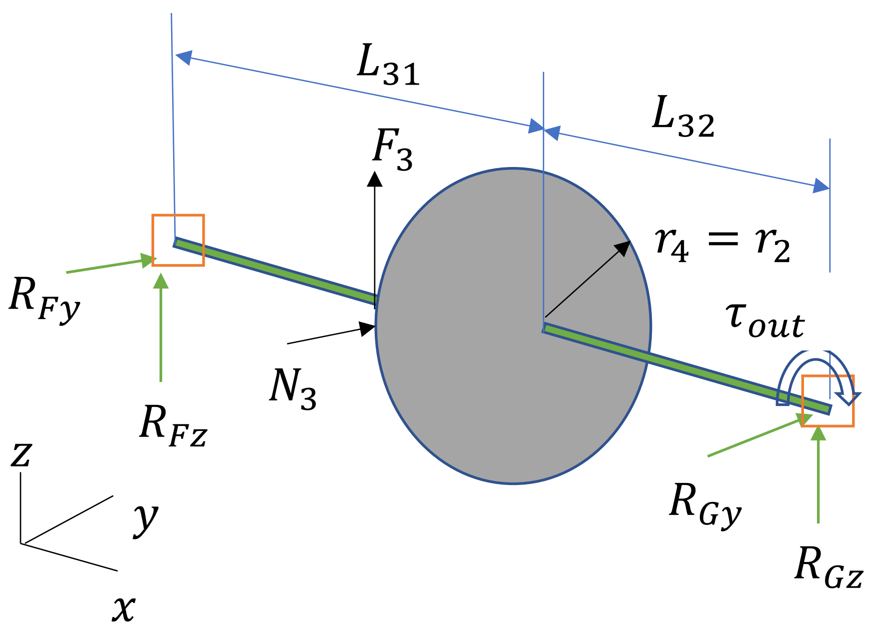
$$R_{C_y} = 12.77\ N$$
$$R_{C_z} = -43.5\ N$$
$$R_{E_y} = 19.6\ N$$
$$R_{E_z} = 44.5\ N$$

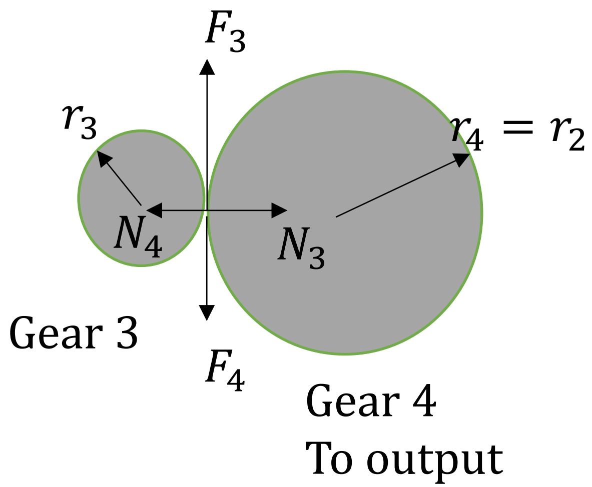
$$M_{maxy} = 12.77 * 0.75 + (12.77 - 9.15) * 1 + (12.77 - 9.15 + 0.599) * 1 = 0.417\ \text{Nm}$$

$$M_{maxz} = -5.76 * 0.75 + (-5.76 + 25.1)(1) + (-5.76 + 25.1 + 1)(1) = 0.878\ Nm$$

$$\boldsymbol{M_{max} = 0.945\ Nm}$$
$$\boldsymbol{\sigma_{max} = 37.4\ MPa}$$

Shaft III: Gear 4





Force Considerations:

x:

$$\Sigma M_x = 0 = -F_3(r_4) - \tau_{out}$$

y:

$$\Sigma F_y = 0 = R_{F_y} + N_3 + R_{G_y}$$

$$\Sigma M_{y_f} = 0 = F_3(L_{31}) + R_{G_z}(L_{III})$$

z:

$$\Sigma F_z = 0 = R_{F_z} + F_3 + R_{G_z}$$

$$\Sigma M_{z_f} = 0 = N_3(L_{31}) + R_{G_y}(L_{III})$$

$$\tau_{out} = -F_3 r_4$$

$$R_{G_y} = -\frac{N_3 L_{31}}{L_{III}}$$

$$R_{G_z} = -\frac{F_3 L_{31}}{L_{III}}$$

$$R_{F_y} = -\frac{N_3 L_{32}}{L_{III}}$$

$$R_{F_z} = \frac{-F_3 L_{32}}{L_{III}}$$

Specs:

- Gear 4: 50 tooth gear
  - $r_4 = \frac{1.0417}{2}\ in$
- Shaft III: 1.5in

$$\tau_{out} = -F_3 r_4 = \boxed{\mathbf{-0.831\ Nm}}$$

$$R_{G_y} = -\frac{N_3 L_{31}}{L_{III}} = -\frac{N_3}{2} = -11.43\ N$$

$$R_{G_z} = -\frac{F_3 L_{31}}{L_{III}} = -\frac{F_3}{2} = -31.4\ N$$

$$R_{F_y} = -\frac{N_3 L_{32}}{L_{III}} = -\frac{N_3}{2} = -11.43\ N$$

$$R_{F_z} = \frac{-F_3 L_{32}}{L_{III}} = -\frac{F_3}{2} = -31.4\ N$$

Deflections and Moments:

$$y_z = \frac{-F_3 * (L_{III})^3}{48EI} = \boxed{\mathbf{-4.54 * 10^{-6} m}}$$

$$M_{max-z} = \frac{-F_3 L_{III}}{4} - 0.598\ Nm$$

$$y_y = \frac{-N_3 * (L_{III})^3}{48EI} = \boxed{\mathbf{-1.651 * 10^{-6} m}}$$

$$M_{max-z} = \frac{-N_3 L_{III}}{4} = -0.218\ Nm$$

$$M_{max} = \boxed{\mathbf{0.637\ Nm}}$$

$$\sigma_{max} = \frac{M_{max1} * c}{I} = \boxed{\mathbf{25.3\ MPa}}$$

Peek at the Budget

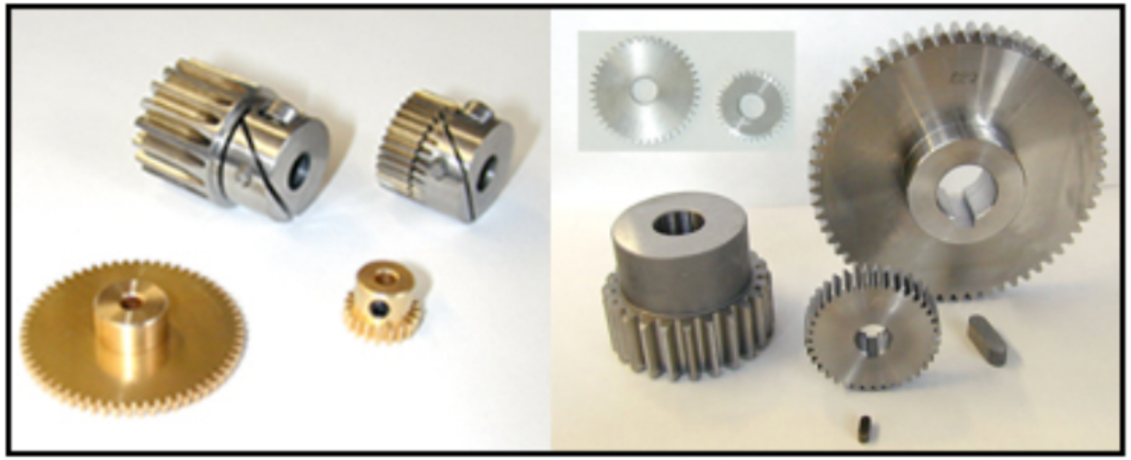
Pricing for the Parts

Bill of Materials

Item	Stock	Price Per Unit	Total Price
20 Tooth Gear	2	$16.04	$32.08
50 Tooth Gear	2	$21.99	$43.98
Stainless Steel Ball Bearing	6	$7.00	$42.00
Ball Bearing	1	$5.79	$5.79
Set Screw Shaft Collar	6	$0.99	$5.94
High Strength Steel Threaded Rod	1	$6.88	$6.88
High Strength Steel Flange Nuts	1(100)	$6.52	$6.52

Total Price of Materials for Project comes out to $143.19

The Gears



20 Tooth Gear

- 48 Pitch Diameter
- 20 Degree Pressure Angle
- 20 Teeth

50 Tooth Gear

- 48 Pitch Diameter
- 20 Degree Pressure Angle
- 50 Teeth

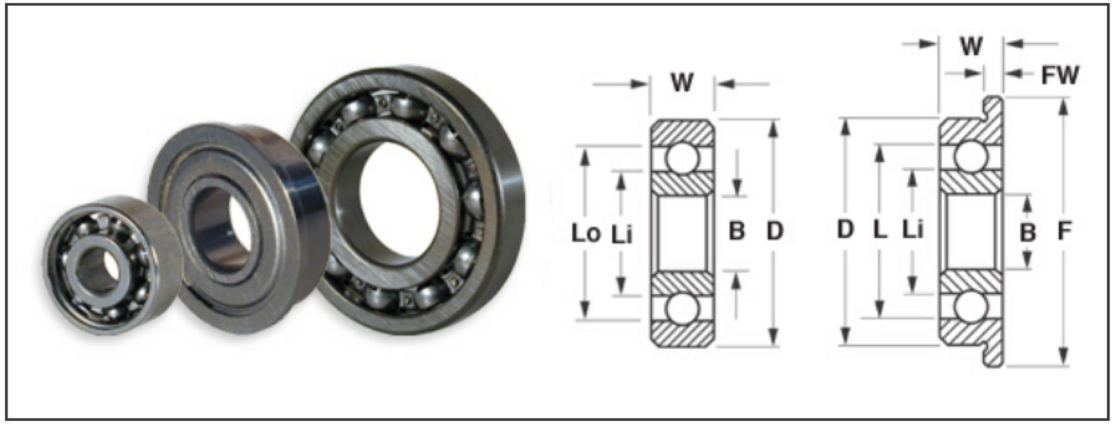
The Bearings

Stainless Ball Bearing

- For a 0.25” shaft & a 0.5” housing
- 0.1875” width
- 240lb dynamic load and 90lb static load
- Flanged
    - 0.547” diameter, 0.05” width

Ball Bearing

- For a 0.25” shaft and a 0.5” housing
- 0.188” width
- 123lb dynamic load and 54lb static load
- Not Flanged



Rods and Nuts

- High Strength Steel Flanged Nuts
  - Come in Pack of 100
  - 0.4375” width
  - 0.59375” flange diameter
  - 0.04” flange width

- High Strength Steel Threaded Rod
  - Tensile Strength of 115 lbs
  - 0.25”-20 Thread Size
  - 1 ft long